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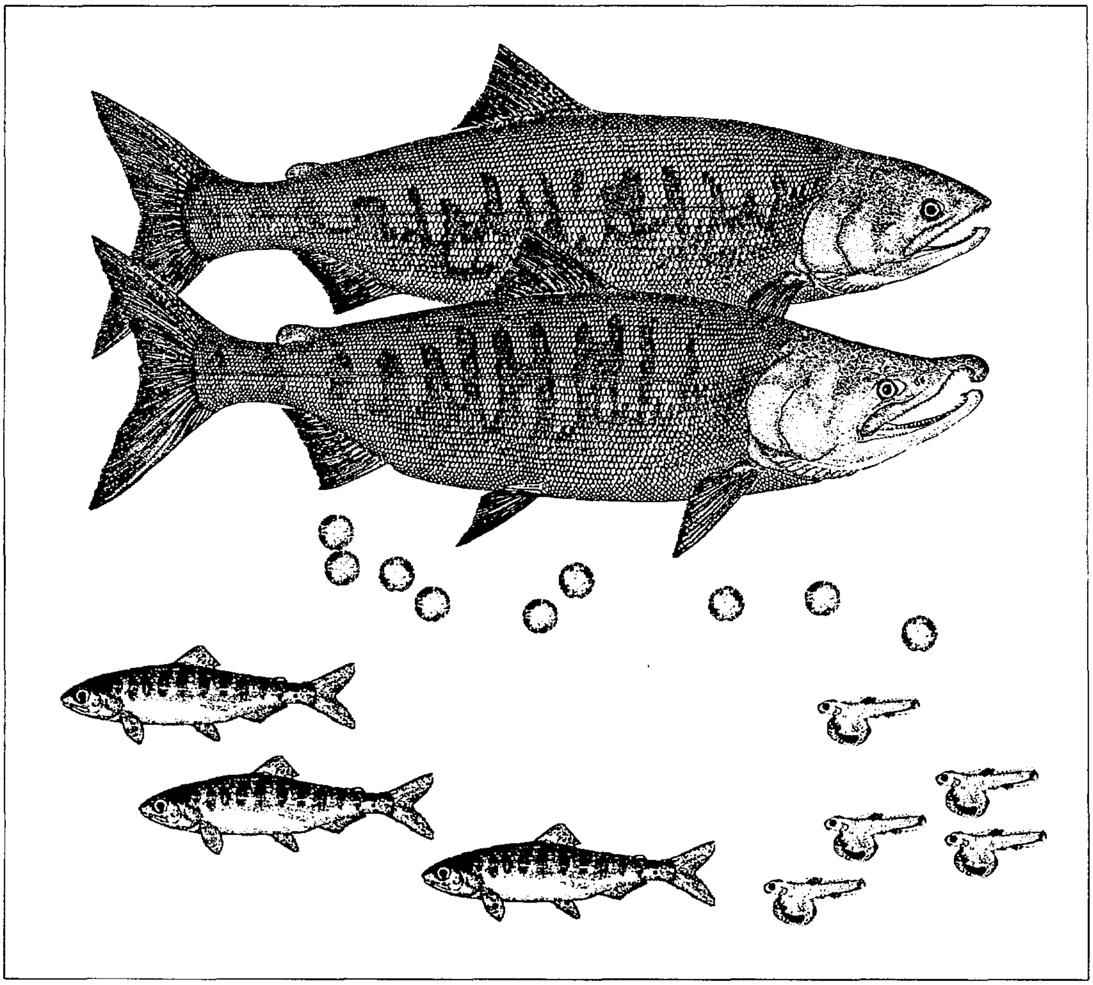
NOAA'S Estuarine Living Marine Resources Program

Distribution and Abundance of Fishes and Invertebrates in West Coast Estuaries

Volume II: Species Life History Summaries



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Distribution and Abundance of Fishes and Invertebrates in West Coast Estuaries
Volume II: Species Life History Summaries

Project Team

Robert L. Emmett* and Susan A. Hinton
Point Adams Biological Field Station
Coastal Zone and Estuarine Studies Division
Northwest Fisheries Center
National Marine Fisheries Service
Hammond, OR 97121

Steven L. Stone* and Mark E. Monaco
Strategic Environmental Assessments Division**
Office of Ocean Resources Conservation and Assessment
National Ocean Service
Rockville, MD 20852

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* Contact for copies of this report.
** Formerly Strategic Asessment Branch

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Distribution and Abundance of Fishes and Invertebrates in West Coast Estuaries
Volume II: Species Life History Summaries

Introduction

This is the second of two volumes that present information on the spatial and temporal distribution, relative abundance, and life history characteristics of 47 fish and invertebrate species in 32 estuaries along the contiguous west coast of the U.S. Information presented in this volume focuses on species life history summaries which were written to identify the critical life history characteristics that help define a species' occurrence in estuaries. These summaries were developed to complement data presented in *Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume I: Data summaries* (Monaco et al. 1990), hereafter referred to as *Volume I*. The life history summaries are not a complete treatise on each species; however, they provide a concise account of the most important physical and biological factors known to influence a species' occurrence.

This report is a product of the National Oceanic and Atmospheric Administration's (NOAA) *Estuarine Living Marine Resources* (ELMR) program (inside back cover), a joint study by the National Ocean Service and the National Marine Fisheries Service (NMFS). The objective of the ELMR program is to develop a consistent data base on the distribution, abundance, and life history characteristics of important fishes and invertebrates in the Nation's estuaries. The nationwide data base is divided into four study regions (Figure 1). This data base contains the relative abundance and monthly occurrence of each species' life stage by estuary for three salinity zones (seawater, mixing, and tidal fresh zones) identified in NOAA's *National Estuarine Inventory (NEI) Data Atlas - Volume I* (NOAA 1985). When completed, the entire data base will contain information for approximately 150 fish and invertebrate species found in approximately 120 U.S. estuaries.

Rationale

Estuaries are among the most productive natural systems and are important nursery areas that provide food, refuge from predation, and valuable habitat for many species (Gunter 1967, Joseph 1973, Weinstein 1979, Mann 1982). Estuarine organisms that support important commercial and recreational fisheries include salmonids, crabs, and shrimp. In spite of the well-documented importance of estuaries to fishes and invertebrates, few consistent and comprehensive data bases exist which allow examinations of the relationships between estuarine species found in or among groups of estuaries. Furthermore, much of the distribution and abundance information for estuarine-dependent species (i.e., species that require estuaries during their life cycle) is for offshore life stages and does not adequately describe estuarine distributions (Darnell et al. 1983, NOAA 1988).

Only a few comprehensive sampling programs collect fishes and invertebrates with identical methods across groups of estuaries within a region (Hammerschmidt and McEachron 1986). Therefore, most existing

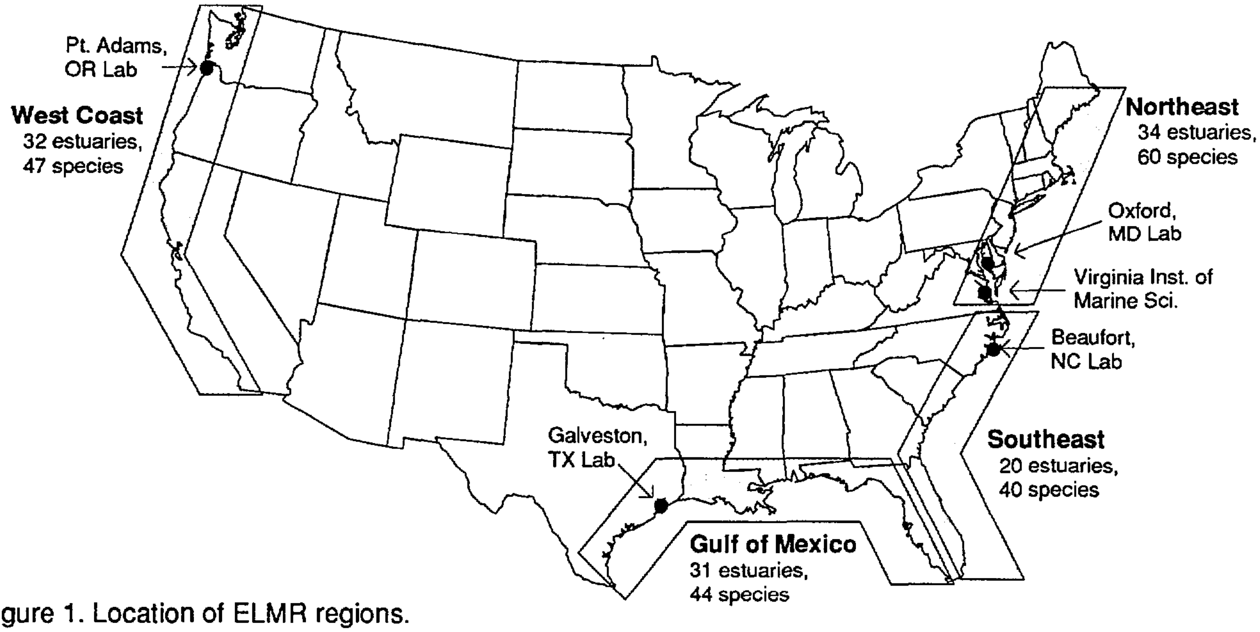


Figure 1. Location of ELMR regions.

estuarine fisheries data cannot be compared among estuaries because of the variable sampling strategies. In addition, existing research programs do not focus on how groups of estuaries may be important for regional fishery management, and few compile information for species having little or no economic value.

Because life stages of many species use both estuarine and marine habitats, information on distribution, abundance, temporal utilization, and life history characteristics are needed to understand the coupling of estuarine, nearshore, and offshore areas. To date, a national, comprehensive, and consistent data base of this type does not exist. Consequently, there is a need to develop a program which integrates fragments of information on marine and estuarine species and their associated habitats into a useful, comprehensive, and consistent format. The ELMR program was designed to help fulfill this need by developing a uniform nationwide data base on selected estuarine species. Results will complement NOAA efforts to develop a national estuarine assessment capability (NOAA 1985), identify information gaps, and assess the content and quality of existing estuarine fisheries data.

Data Collection and Organization

Volume I contains detailed distribution and abundance data for 47 fish and invertebrate species in 32 west coast estuaries, and a complete discussion of the methods used to compile these data. However, a brief description of methods from *Volume I* are presented here to aid interpretation of distribution and relative abundance tables included in the species life history summaries presented in this report. The following sections provide an overview of the estuary/species selection process, and development of the ELMR data base.

Selection of Estuaries. Nineteen estuaries and marine embayments of the west coast (Figure 2) were initially selected from the *National Estuarine Inventory Data Atlas: Volume I* (NOAA 1985). However, 13 additional

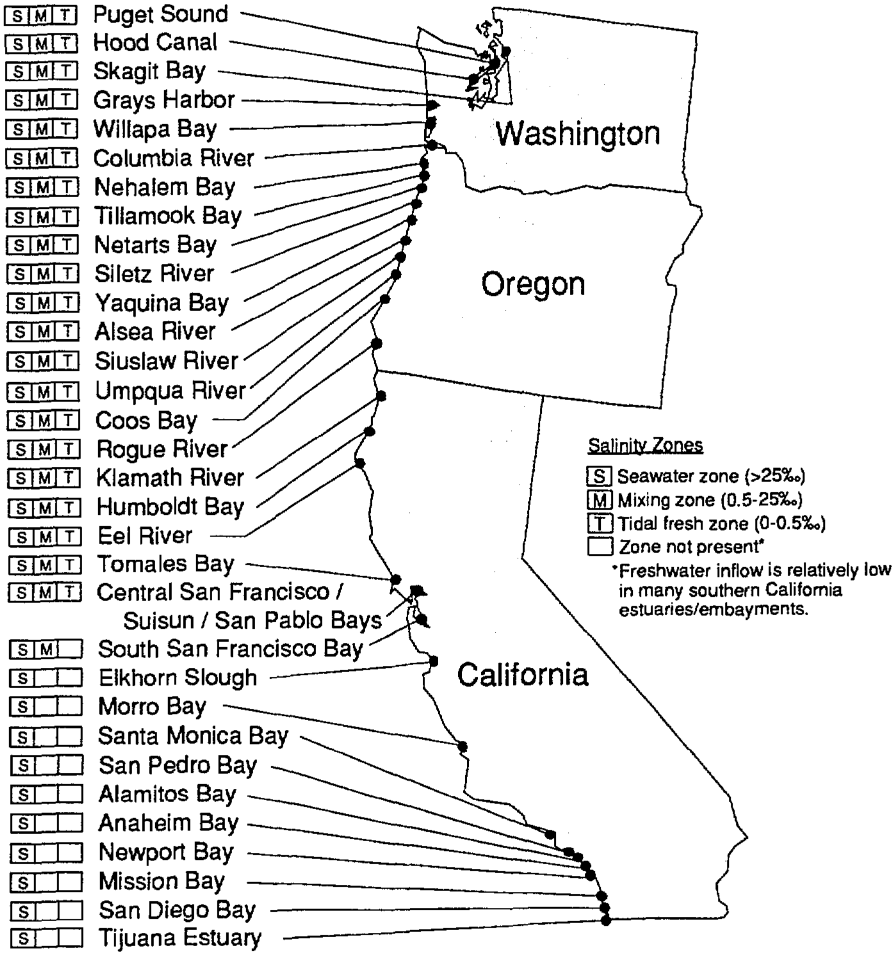


Figure 2. Location of the 32 west coast estuaries included in the ELMR program, and their salinity zones as identified by the National Estuarine Inventory (NOAA 1985).

west coast estuaries were added to the NEI (and ELMR program) due to their importance as habitat for west coast fishes and invertebrates. Data on the spatial and temporal distributions of species were compiled and organized based on three salinity zones delineated for each estuary in the NEI; tidal fresh (0.0 to 0.5‰), mixing (0.5 to 25.0‰), and seawater (>25.0‰). While some west coast estuaries do not contain all three salinity zones (e.g., southern California embayments), they were included because they provide important habitat for many euryhaline species.

Selection of Species. To ensure that important west coast estuarine species were included in the ELMR study, a species list was developed and reviewed by regional experts (Table 1). Four criteria were used to identify the 47 species entered into the data base:

1) Commercial value - a species that commercial fishermen specifically try to catch (e.g., Pacific herring and Dungeness crab), as determined from catch and value statistics of the NMFS and state agencies.

2) Recreational value - a species that recreational fishermen specifically try to catch that may or may not be of commercial importance. Recreational species (e.g., steelhead and California halibut) were determined by consulting regional experts and NMFS reports.

3) Indicator species of environmental stress - identified from the literature, discussions with fisheries experts, and from monitoring programs such as NOAA's National Status and Trends Program (NOAA 1984). These species (e.g., Pacific oyster and white croaker) are molluscs or bottom fishes that consume benthic invertebrates or have a strong association with bottom sediments. Their physiological disorders, morphological abnormalities, and ability to bioaccumulate contaminants indicate environmental pollution or stress.

4) Ecological value - based on several species attributes, including trophic level, relative abundance, and importance of species as a key predator or prey organism (e.g., bay shrimp and topsmelt).

Data Sheets. A data sheet was developed for each species in each estuary to enable quick compilation and data presentation. For example, Figure 3 shows the data sheet for threespine stickleback in central San Francisco, San Pablo, and Suisun bays. Data sheets were developed by project staff and reviewed by local experts. Data compiled for each species' life stage included: 1) the salinity zones it occupies, 2) its monthly occurrence in the zones, and 3) its relative abundance in the zones.

Table 1. ELMR species list.

Scientific Name	Common Name
Mytilis edulis	blue mussel
Crassostrea gigas	Pacific oyster
Tresus capax	horseneck gaper[1]
Tresus nuttallii	Pacific gaper
Tagelus californianus	California jackknife clam[2]
Protothaca staminea	Pacific littleneck clam
Venerupis japonica	Manila clam[3]
Mya arenaria	softshell
Panopea abrupta	geoduck[4]
Crangon franciscorum	bay shrimp[5]
Cancer magister	Dungeness crab
Triakis semifasciata	leopard shark
Acipenser medirostris	green sturgeon
Acipenser transmontanus	white sturgeon
Alosa sapidissima	American shad
Clupea pallasi	Pacific herring
Anchoa compressa	deepbody anchovy
Anchoa delicatissima	slough anchovy
Engraulis mordax	northern anchovy
Oncorhynchus clarki	cutthroat trout
Oncorhynchus gorbuscha	pink salmon
Oncorhynchus keta	chum salmon
Oncorhynchus kisutch	coho salmon
Oncorhynchus mykiss	steelhead[6] (3 races)
Oncorhynchus nerka	sockeye salmon
Oncorhynchus tshawytscha	chinook salmon (5 races)
Hypomesus pretiosus	surf smelt
Spirinchus thaleichthys	longfin smelt
Thaleichthys pacificus	eulachon
Microgadus proximus	Pacific tomcod
Atherinops affinis	topsmelt
Atherinopsis californiensis	jacksmelt
Gasterosteus aculeatus	threespine stickleback
Morone saxatilis	striped bass
Paralabrax clathratus	kelp bass
Paralabrax nebulifer	barred sand bass
Genyonemus lineatus	white croaker
Atractoscion nobilis	white seabass
Cymatogaster aggregata	shiner perch
Ammodytes hexapterus	Pacific sand lance
Clevelandia ios	arrow goby
Ophiodon elongatus	lingcod
Leptocottus armatus	Pacific staghorn sculpin
Paralichthys californicus	California halibut
Hypsopsetta guttulata	diamond turbot
Pleuronectes vetulus	English sole
Platichthys stellatus	starry flounder

[1] Also known as fat gaper (Turgeon et al. 1988).

[2] Also known as California tagelus (Turgeon et al. 1988).

[3] Also known as Japanese littleneck, *Tapes phillippinarum* (Turgeon et al. 1988).

[4] Also known as Pacific geoduck (Turgeon et al. 1988).

[5] Also known as California bay shrimp (Williams et al. 1989).

[6] The name steelhead refers to sea-run rainbow trout (Robins et al. 1980).

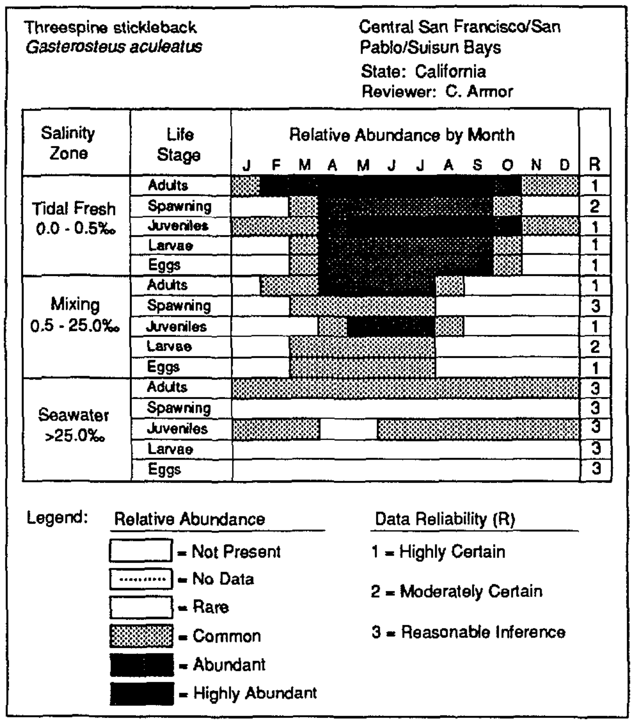


Figure 3. Example of a species/estuary data sheet: threespine stickleback in Central San Francisco, San Pablo, and Suisun Bays.

The relative abundance of a species was defined using one of the following categories:

- *Highly abundant* - species is numerically dominant relative to other species.
- *Abundant* - species is often encountered in substantial numbers relative to other species.
- *Common* - species is generally encountered but not in large numbers; does not imply an even distribution over a specific salinity zone.
- *Rare* - species is present but not frequently encountered.
- *Not present* - species or life stage not found, questionable data as to identification of the species, or recent loss of habitat or environmental degradation suggests absence.
- *No information available* - no data available, and after expert review it was determined that even an educated guess would not be appropriate.

Information was compiled for each of five life stages. Adults were defined as sexually mature individuals, juveniles as immature but otherwise similar to adults, and spawning adults as those releasing eggs or sperm. A few exceptions existed to these defined life stages, such as mating of Dungeness crab, and parturition (live birth) of the viviparous leopard shark and shiner perch. In addition, the following unique life history information is provided to interpret the data: 1) for the Pacific oyster, spawning adults, larvae, and eggs are not shown because spawning is sporadic (most spat is hatchery produced and placed on beds), 2) for the pink, chum, coho, and chinook salmon, the onset of sexual maturation (accompanied by morphological changes, homing behavior, and a reduction in feeding/growth) was used to define the beginning of the adult life stage, and 3) because migrating juveniles of different races of chinook salmon are difficult to separate in the field, the data for juveniles of the different races of chinook salmon include all races. However, yearling juveniles (spring and winter races) usually migrate to the ocean earlier than subyearling juveniles (fall race).

For well-studied species such as salmon, quantitative data were used to estimate abundance levels. For many species, however, reliable quantitative data were limited. Therefore, regional and local experts were consulted to estimate relative abundances based on the above criteria. Several reference or "guide" species with abundance levels corresponding to the above criteria were identified for each estuary. These guide species typified fishes and invertebrates belonging to a particular life mode (e.g., pelagic, demersal) or occupying similar habitats. Once guide species were selected, other species were then placed into the appropriate abundance categories relative to them. These data represent relative abundance levels within a specific estuary only; relative abundance levels across west coast estuaries **could not** be determined.

Information in *Volume I* was compiled for each species and estuary combination, and organized into four data summaries:

- Spatial distribution and relative abundance
- Temporal distribution
- Data reliability
- Presence/absence data

When compiled in this manner, the data can be easily translated into various tables, such as the overall occurrence of ELMR west coast species depicted in Table 2. Appendix tables 1-3 are examples of how the data were summarized and presented in *Volume I*. Due to post-publication revisions of the presence/absence information in *Volume I*, Appendix table 4 provides the revised west coast ELMR presence/absence data.

Data Verification. Approximately three years were required to develop the 1,760 data sheets and consult with regional and local experts. Each data sheet was carefully reviewed during consultations or by mail. These important consultations complemented the published and unpublished literature and data sets compiled by NOAA. Ninety-one scientists at 26 institutions or agencies were consulted. Local experts were particularly helpful in providing estuary/species-specific information. They also provided additional references and contacts and identified additional species to be included in the ELMR data base.

Data Content and Quality

An important aspect of the ELMR program, especially since it was based primarily on published and unpublished literature and consultations, was to determine the quality of the data used. For many species, gear selectivity, difficulty in identifying larval stages to species, and difficulty of sampling various habitats has limited the amount of reliable information. Therefore, a deliberate effort was made to assess the overall reliability of the data base so it could be used appropriately. Estimates of the reliability of distribution

Table 2. Occurrence (•) of 47 species (adults or juveniles rated as "common" to "highly abundant") in 32 west coast estuaries.

	Estuary																														
Species	Puget Sound	Hood Canal	Skagit Bay	Grays Harbor	Willapa Bay	Columbia River	Nehalem Bay	Tillamook Bay	Netarts Bay	Siletz River	Yaquina Bay	Alsea River	Siuslaw River	Umpqua River	Coos Bay	Rogue River	Klamath River	Humboldt Bay	Eel River	Tomales Bay	C. San Francisco Bay*	S. San Francisco Bay	Elkhorn Slough	Morro Bay	Santa Monica Bay	San Pedro Bay	Alamitos Bay	Anaheim Bay	Newport Bay	Mission Bay	San Diego Bay	Tijuana Estuary
blue mussel	●	●	●	●	●	●	●	●	●		●		●	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Pacific oyster	●	●	●	●	●			●	●		●			●	●			●		●				●								
horseneck gaper	●	●	●	●	●			●	●		●	●	●		●			●														
Pacific gaper	●	●	●						●									●		●			●	●		●						
California jackknife clam																								●	●	●	●	●	●	●	●	●
Pacific littleneck clam	●	●	●	●	●		●	●	●		●				●			●		●			●	●	●	●	●	●	●			●
Manila clam	●	●	●	●	●			●	●						●			●		●	●	●										
Eastern softshell clam	●	●	●	●	●	●	●	●	●		●	●	●	●	●			●	●	●	●	●	●									
geoduck	●	●	●																					●								
bay shrimp	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			●	●	●	●	●										
Dungeness crab	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●										
leopard shark																		●		●	●	●	●	●	●	●						
green sturgeon				●	●	●					●			●	●	●	●	●	●		●	●										
white sturgeon				●	●	●	●	●			●			●	●	●	●				●	●										
American shad			●	●	●	●					●	●	●	●	●	●	●		●		●	●										
Pacific herring	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●								
deepbody anchovy																										●	●	●	●	●	●	
slough anchovy																											●		●	●	●	
northern anchovy	●	●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●	
cutthroat trout	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●													
pink salmon	●	●	●																													
chum salmon	●	●	●	●	●	●	●	●	●	●	●	●	●		●																	
coho salmon	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●												
steelhead	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●	●											
sockeye salmon	●					●																										
chinook salmon	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●		●	●										
surf smelt	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●												
longfin smelt	●		●	●	●	●					●				●		●	●	●		●	●										
eulachon				●	●	●								●			●															
Pacific tomcod	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		●		●												
topsmelt								●	●		●	●	●	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
jacksmelt															●			●		●	●	●	●	●	●	●				●	●	
threespine stickleback	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●								
striped bass													●	●	●					●	●	●										
kelp bass																									●	●				●		
barred sand bass																									●	●	●	●	●	●	●	
white seabass																									●	●						
white croaker																		●		●	●	●			●	●	●	●	●		●	
shiner perch	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	
Pacific sand lance	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			●		●												
arrow goby	●	●	●	●	●						●				●			●		●	●	●	●	●		●	●	●	●	●	●	●
lingcod	●	●	●	●	●		●	●	●		●			●	●			●		●	●											
Pacific staghorn sculpin	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			●	●		●	●	●
California halibut																				●	●	●	●	●	●	●	●	●	●	●	●	●
diamond turbot																						●	●	●	●	●	●	●	●	●	●	●
English sole	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			●	●	●	●	●	●	●	●	●						
starry flounder	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●								

* Includes Central San Francisco, Suisun, and San Pablo Bays.

and abundance information organized by species, life stage, and estuary are presented in *Volume I* (p. 149-184). Data reliability was rated numerically as:

1= *Highly certain.* Considerable sampling data available. Distribution, ecology, and preferred habitats well-documented within an estuary.

2= *Moderately certain.* Some sampling data available for an estuary. Distribution, preferred habitats, and ecology well-documented in similar estuaries.

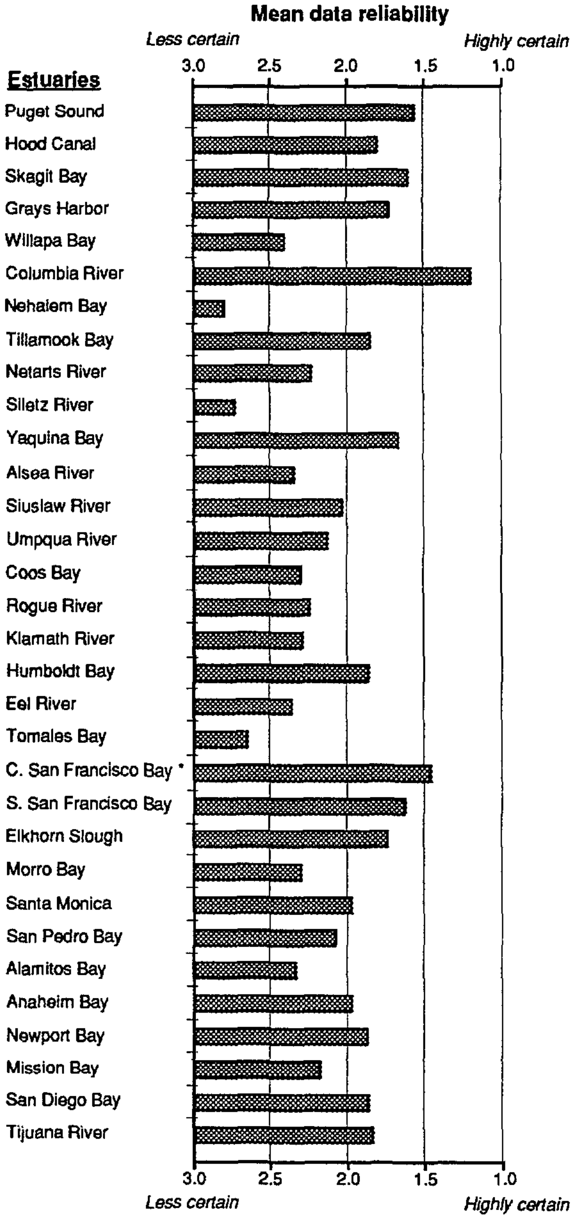
3= *Reasonable inference.* Little or no sampling data available. Information on species distributions, ecology, and preferred habitats documented in similar estuaries.

Appendix table 3 is an example of how data reliability estimates were summarized in *Volume I*, and the following section presents an analysis of that volume's data reliability estimates.

Analysis of Data Content and Quality. To assess the overall certainty of the ELMR west coast data, mean data reliability was calculated by estuary, species, and life stage. Mean data reliability was calculated using data reliability values for only those species and life stages that were known to occur within an estuary. This allowed accurate comparisons between estuaries and species since species and life stages known to be absent were always recorded as highly certain.

This analysis identified estuaries, species, and life stages that have the most reliable information and those with the poorest. This information, combined with the data in *Volume I*, clearly defines the ELMR species, life stages, and estuaries which should be the focus of research efforts. Future research should include a comprehensive and consistent sampling program to quantify species distributions and abundances within and across estuaries. In addition, life history data (like the information in this report) should be compiled, especially for those species that may not have economic value, but are ecologically important.

Mean data reliability of fish and invertebrate data for west coast estuaries ranged from 2.8 (poorly-studied Nehalem Bay) to almost 1.2 (highly-studied Columbia River) (Figure 4), with an overall average of 2.0 (moderately certain). In general, the reliability estimates reflect the amount of fisheries research that has been conducted within an estuary. These data reveal that large estuaries (Puget Sound, Hood Canal, Skagit Bay, Columbia River, and San Francisco Bay) have been relatively well-studied, while most small bays and estuaries have not. Developed estuaries (i.e., those subjected to dredging and filling, jetty and port construction, and nearby urbanization) and their drainages typically have been the focus of numerous research studies. In contrast, some of the least-developed estuaries (Willapa Bay, Nehalem Bay, Siletz River, and Tomales Bay) appear to be the least-studied. Hence, there appears to be a need to collect baseline fish and invertebrate distribution and abundance data from relatively undeveloped and unpolluted estuaries.



* Includes Central San Francisco, Suisun, and San Pablo Bays.

Figure 4. Mean data reliability of fish and invertebrate data collected for 32 west coast estuaries.

When analyzed by species (Figure 5), the data show that salmonids and Pacific oyster have the best data reliability (<1.6). This reflects the economic value of these species and consequently the large number of research studies that have focused on them. Poorly-studied species (data reliability ≥2.0) include California

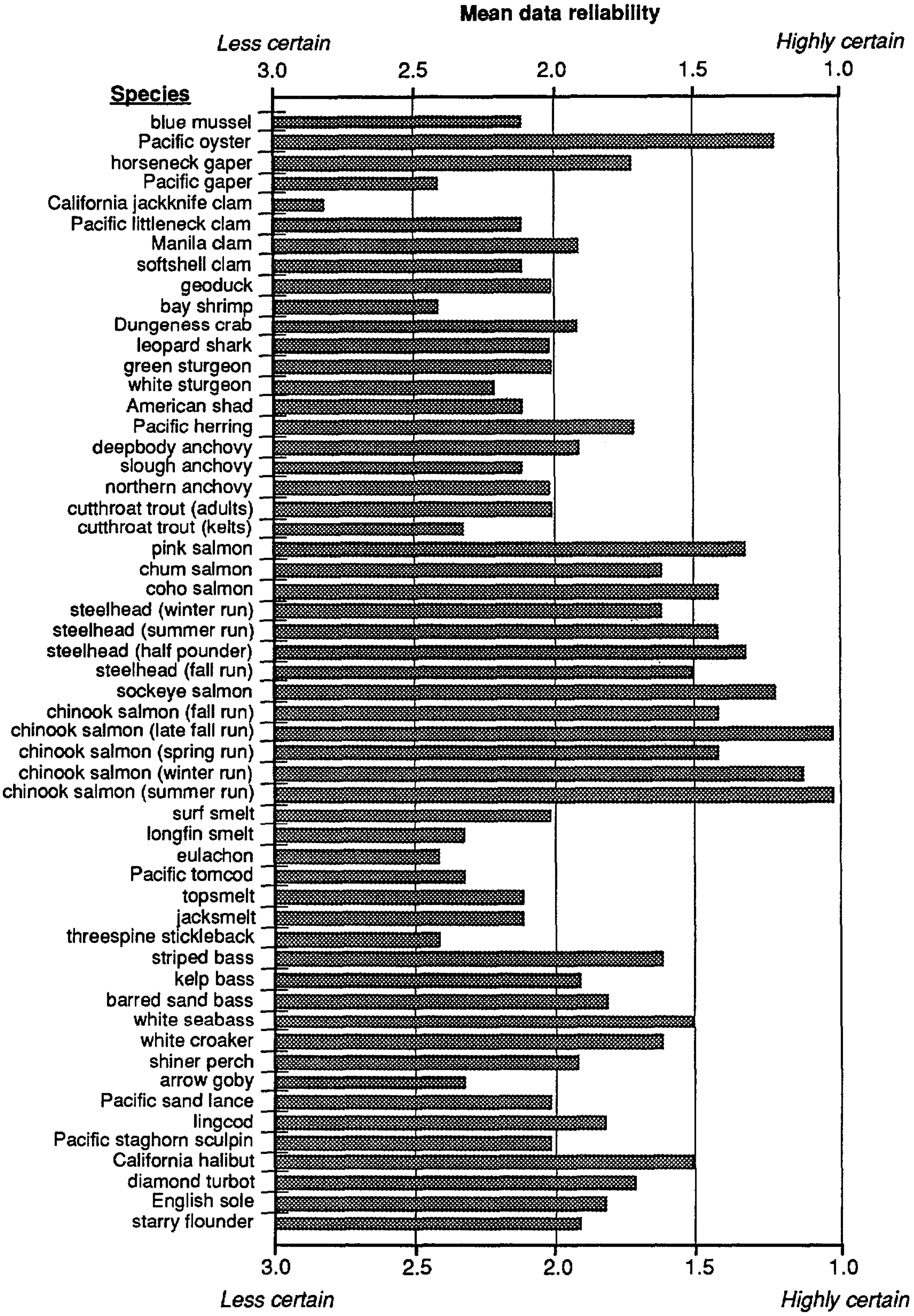


Figure 5. Mean data reliability of species data collected for 32 west coast estuaries.

jackknife clam, Pacific gaper, bay shrimp, cutthroat trout, three smelt species, Pacific tomcod, topsmelt, jacksmelt, threespine stickleback, arrow goby, Pacific sand lance, and Pacific staghorn sculpin. Most of these species have not been studied because they are not commercially important. However, some (e.g., Pacific sand lance) have potential for increased commercial harvest or as indicators of environmental health, and should be the focus of future research.

When analyzed by life stage, data for juvenile and adult life stages were most reliable (1.8 and 1.7, respectively), while data pertaining to spawning adults, larvae, and eggs were less certain (average >2.3). This reflects the number of research studies which have concentrated on adult and juvenile life stages. Species-specific studies of spawning adults, larvae, and eggs, have not been conducted in most estuaries. Thus, some of the information for these life stages was inferred from life history studies and data from similar estuaries.

Species Summaries

A concise life history summary was written for each species to provide an overview of how and when a species uses estuaries and what specific habitats it uses. The summaries highlight species-specific life history characteristics that relate directly to estuarine spatial and temporal distribution and abundance (e.g., many molluscs have particular salinity and substrate preferences). Information for the species life history summaries was gathered primarily from published and unpublished literature; individuals who had species-specific knowledge were also consulted. Summaries were written using the format shown in Table 3. A glossary of scientific terms used in the species summaries is provided after the last summary (p. 273).

Included with each summary is a relative abundance table based on ELMR data from *Volume I*. This table provides a synopsis of the species' occurrence in 32 west coast estuaries. Information for each table was obtained by summarizing the ELMR data for each month of the year and across all salinity zones to obtain the highest level of abundance for each life stage. Hence, these tables depict a species' highest abundance within an estuary, but lack the temporal and spatial definition provided in *Volume I*.

Life History Tables. While the species life history summaries provide brief accounts of important life history attributes, they do not permit a direct and simple assessment of characteristics that a species shares with others (or lacks altogether). Furthermore, many life history attributes are categorical (e.g., feeding

Table 3. Format of species life history summaries.

Common Name: the most often used common name.
Scientific Name: the most recent taxonomic genus and species name.
Other Common Names: other names that are sometimes used for a species.
Classification: the most recent taxonomic classification (Phylum to Family).

Value
Commercial: information on the commercial catches.
Recreational: information on recreational catches.
Indicator of Environmental Stress: identifies if a species is an indicator of environmental degradation.
Ecological: the role (e.g., key predator or prey) a species plays in a marine/estuarine ecosystem.

Range
Overall: the complete range of a species.
Within Study Area: the range of a species within west coast estuaries. In addition, each summary contains a relative abundance table (from *Volume I*) for the 32 ELMR west coast estuaries.

Life Mode: the life history strategy of a species and its life stages (e.g., anadromous, estuarine resident).

Habitat
Type: the habitats used by specific life stages (e.g., riverine, neritic, epipelagic).
Substrate: the substrate preferences of specific life stages.
Physical/Chemical Characteristics: the physical and water chemistry preferences of specific life stages (e.g., temperature, salinity, stream flows).
Migrations and Movements: the movements and migratory behavior of a species/life stage between or within habitats.

Reproduction
Mode: type of reproductive strategy (e.g., oviparous, viviparous) and fertilization (e.g., external, internal).
Mating/Spawning: timing of spawning and description of mating or spawning behavior.
Fecundity: the number of eggs or young produced by an individual.

Growth and Development
Egg Size and Embryonic Development: the size of an egg and length of time for embryonic development.
Age and Size of Larvae: the age and size range of larvae.
Juveniles Size Range: the size range of juveniles.
Age and Size of Adults: the age and size range of adults.

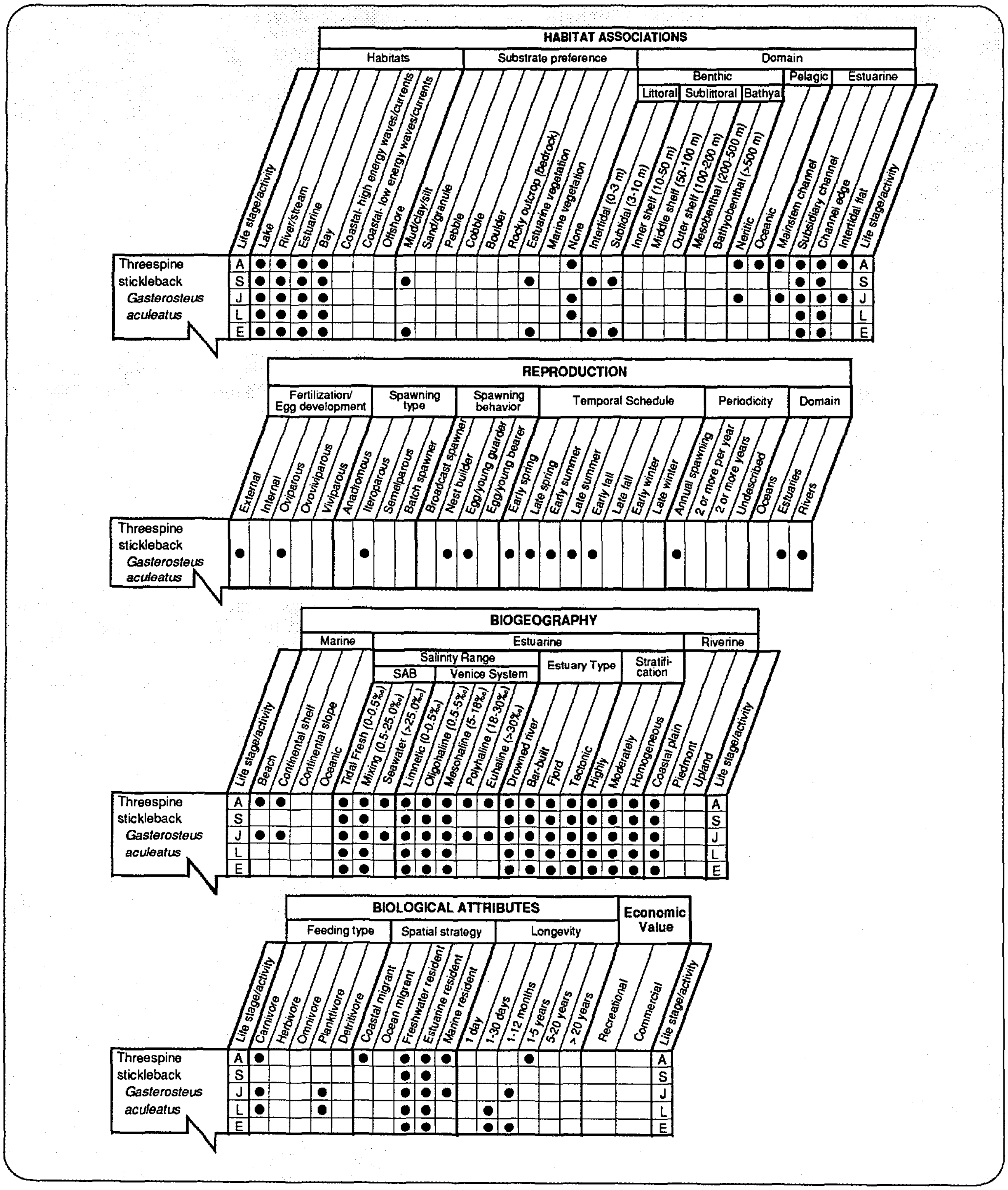
Food and Feeding
Trophic mode: type of feeder (e.g., carnivorous, herbivorous).
Food Items: the types of prey eaten (e.g., copepods, amphipods, larval fish).

Biological Interactions
Predation: the predators which consume a species.
Factors Influencing Populations: biological and physical parameters that are known to influence a species' population abundance (e.g., overfishing, ocean productivity, spawning habitat).

References: alphabetical listing of literature cited.

types can be classified as carnivore, herbivore, detritivore, etc.) and more easily viewed in a tabular format. Therefore, information found in the species life history summaries was augmented with additional physical and biological criteria and condensed into four life history tables (Appendix tables 5A-5D). Major table headings are: *Biogeography, Habitat Associations, Biological Attributes and Economic Value,* and

Figure 6. Life history table headings used to develop the information in Appendix 5.



		HABITAT ASSOCIATIONS																													
		Habitats							Substrate preference									Domain													
																		Benthic							Pelagic		Estuarine				
																		Littoral		Sublittoral			Bathya								
	Life stage/activity	Lake	River/stream	Estuarine	Bay	Coastal- high energy waves/currents	Coastal- low energy waves/currents	Offshore	Mud/clay/silt	Sand/granule	Pebble	Cobble	Boulder	Rocky outcrop (bedrock)	Estuarine vegetation	Marine vegetation	None	Intertidal (0-3 m)	Subtidal (3-10 m)	Inner shelf (10-50 m)	Middle shelf (50-100 m)	Outer shelf (100-200 m)	Mesobenthal (200-500 m)	Bathyobenthal (>500 m)	Neritic	Oceanic	Mainstem channel	Subsidiary channel	Channel edge	Intertidal flat	Life stage/activity
Threespine stickleback *Gasterosteus aculeatus*	A	●	●	●	●												●								●	●	●	●	●	●	A
	S	●	●	●	●				●						●			●	●									●	●			S
	J	●	●	●	●												●								●		●	●	●	●	J
	L	●	●	●	●												●											●	●			L
	E	●	●	●	●				●						●			●	●									●	●			E

	REPRODUCTION																											
	Fertilization/ Egg development					Spawning type				Spawning behavior				Temporal Schedule								Periodicity				Domain		
	External	Internal	Oviparous	Ovoviviparous	Viviparous	Anadromous	Iteroparous	Semelparous	Batch spawner	Broadcast spawner	Nest builder	Egg/young guarder	Egg/young bearer	Early spring	Late spring	Early summer	Late summer	Early fall	Late fall	Early winter	Late winter	Annual spawning	2 or more per year	2 or more years	Undescribed	Oceans	Estuaries	Rivers
Threespine stickleback *Gasterosteus aculeatus*	●		●				●				●	●		●	●	●	●	●				●					●	●

		BIOGEOGRAPHY																						
		Marine				Estuarine															Riverine			
						Salinity Range								Estuary Type				Stratification						
						SAB			Venice System															
	Life stage/activity	Beach	Continental shelf	Continental slope	Oceanic	Tidal Fresh (0-0.5‰)	Mixing (0.5-25.0‰)	Seawater (>25.0‰)	Limnetic (0-0.5‰)	Oligohaline (0.5-5‰)	Mesohaline (5-18‰)	Polyhaline (18-30‰)	Euhaline (>30‰)	Drowned river	Bar-built	Fjord	Tectonic	Highly	Moderately	Homogeneous	Coastal plain	Piedmont	Upland	Life stage/activity
Threespine stickleback *Gasterosteus aculeatus*	A	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			A
	S					●	●		●	●	●			●	●	●	●	●	●	●	●			S
	J	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			J
	L					●	●		●	●	●			●	●	●	●	●	●	●	●			L
	E					●	●		●	●	●			●	●	●	●	●	●	●	●			E

		BIOLOGICAL ATTRIBUTES																Economic Value		
		Feeding type					Spatial strategy					Longevity								
	Life stage/activity	Carnivore	Herbivore	Omnivore	Planktivore	Detritivore	Coastal migrant	Ocean migrant	Freshwater resident	Estuarine resident	Marine resident	1 day	1-30 days	1-12 months	1-5 years	5-20 years	> 20 years	Recreational	Commercial	Life stage/activity
Threespine stickleback *Gasterosteus aculeatus*	A	●					●		●	●	●				●					A
	S								●	●										S
	J	●			●				●	●	●			●						J
	L	●			●				●	●			●							L
	E								●	●			●	●						E

Reproduction (Figure 6). These tables present life history characteristics for each species along with behavior traits and preferred habitats. They reflect the most current information about a species as gathered from published and unpublished literature and can be used to quickly identify species with similar traits. For example, a reader interested only in pelagic (as opposed to benthic) species can use Appendix table 5B, *Habitat Associations*, to identify relevant species. In addition, terms used in the life history tables are defined in Appendix 6.

Concluding Comments

As it becomes apparent that the cumulative effects of small alterations in many estuaries have a total systemic impact on coastal ocean resources, it is more important than ever to compile consistent information on the Nation's estuarine fishes and invertebrates. Although the knowledge available to effectively preserve and manage estuarine resources is limited, the ELMR data base provides an important tool for assessing the status of estuarine fauna and examining their relationships with other species and their environment. These life history summaries and life history tables highlight many of the biological and environmental factors that play a role in determining each species' distribution and abundance. Together, the ELMR data base and life history information will provide valuable baseline information on the biogeography and ecology of estuarine fishes and invertebrates, and identify gaps in our knowledge of these valuable national resources.

The ELMR program is continuing to compile and assess estuarine biological and physical data to improve the Nation's ability to manage coastal ocean resources. Forthcoming reports will help further define the importance of west coast estuaries to fishes and invertebrates. One of these reports will present information on salmonid hatchery production and escapement for several west coast estuarine basins. Another will present results of multivariate analyses of the ELMR west coast fish data to identify the coupling of species distributions and estuarine physical and hydrological characteristics.

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Literature Cited

Darnell, R. M., R. E. Defenbaugh, and D. Moore. 1983. Northwestern Gulf shelf bio-atlas. Open File Rep. No. 82-04. Min. Manag. Serv., Gulf of Mexico OCS Regional Office, Metairie, LA, 438 p.

Gunter, G. 1967. Some relationships of estuaries to the fisheries of the Gulf of Mexico. *In* G. H. Lauff (editor), Estuaries, p. 621-638. Am. Assoc. Adv. Sci. Special Publ. No. 83, Washington, D.C.

Hammerschmidt, P. C., and L. W. McEachron. 1986. Trends in relative abundance of selected shellfishes along the Texas coast: January 1977 - March 1986. Texas Parks Wildl. Dept., Coast. Fish. Branch, Mgmt. Data Ser., No. 108, 149 p.

Joseph, E. B. 1973. Analysis of a nursery ground. *In* A. L. Pacheco (editor), Proceedings of a workshop on egg, larval, and juvenile stages of fish in Atlantic Coast estuaries. p. 118-121. Mid. Atlantic coast. Fish. Cent., Tech. Publ. No. 1, Beaufort, NC.

Mann, K. H. 1982. Ecology of coastal waters. Univ. Calif. Press, Los Angeles, CA, 322 p.

Monaco, M. E. 1986. National estuarine inventory: Living marine resources component, preliminary west coast study. Ocean Assessments Division, NOS/NOAA, Rockville, MD, 33 p.

Monaco, M. E., T. E. Czapla, D. M. Nelson, and M. E. Pattillo. 1989. Distribution and abundance of fishes and invertebrates in Texas estuaries. Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 107 p.

Monaco, M. E., R. L. Emmett, D. M. Nelson, and S. A. Hinton. 1990. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume I: Data summaries. Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 240 p.

NOAA (National Oceanic and Atmospheric Administration). 1984. The national status and trends program for marine environmental quality: Program description (memo). Ocean Assessments Division, NOS/NOAA, Rockville, MD, 28 p.

NOAA (National Oceanic and Atmospheric Administration). 1985. National estuarine inventory: Data atlas. Volume 1. Physical and hydrologic characteristics. Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 103 p.

NOAA (National Oceanic and Atmospheric Administration). 1988. Bering, Chukchi, and Beaufort Seas strategic assessment: Data atlas. Volume 1. Physical and hydrologic characteristics. Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 135 p.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc., Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Turgeon, D. D., A. E. Bogan, E. V. Coan, W. K. Emerson, W. G. Lyons, W. L. Pratt, C. F. E. Roper, A. Scheltema, F. G. Thompson, and J. D. Williams. 1988. Common and scientific names of aquatic invertebrates from the United States and Canada: mollusks. Am. Fish. Soc. Spec. Publ. No. 16, Am. Fish. Soc., Bethesda, MD, 277 p.

Weinstein, M. P. 1979. Shallow marsh habitats as primary nurseries for fishes and shellfish, Cape Fear River, North Carolina. Fish. Bull., U.S. 77:339-357.

Williams, A. B., L. G. Abele, D. L. Felder, H. H. Hobbs, Jr., R. B. Manning, P. A. McLaughlin, and I. Pérez Farfante. 1988. Common and scientific names of aquatic invertebrates from the United States and Canada: decapod crustaceans. Am. Fish. Soc. Spec. Publ. No. 17, Am. Fish. Soc., Bethesda, MD, 77 p.

Williams, C. W., D. M. Nelson, M. E. Monaco, S. L. Stone, C. Iancu, L. C. Clements, L. R. Settle, and E. A. Irlandi. 1990. Distribution and abundance of fishes and invertebrates in eastern Gulf of Mexico estuaries. Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 240 p.

For additional copies or information contact:

Robert L. Emmett
Point Adams Biological Field Station
Coastal Zone & Estuarine Studies Division
Northwest Fisheries Center
National Marine Fisheries Service
Hammond, OR 97121
FTS/Comm. (503) 861-1818

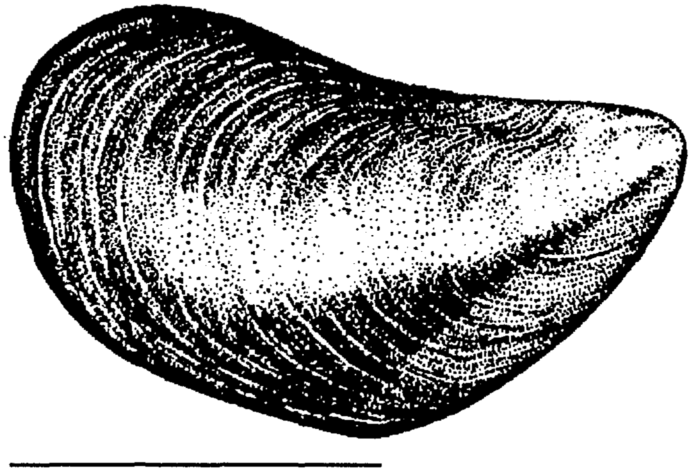
or

Steven L. Stone
Strategic Environmental Assessments Division
Office of Ocean Resources Conservation & Assessment
National Ocean Service
Rockville, MD 20852
FTS/Comm. (301) 443-0453

Index to Species Life History Summaries

Blue mussel

Mytilus edulis
Adult



Common Name: blue mussel
Scientific Name: *Mytilus edulis*
Other Common Names: bay mussel, edible mussel, black mussel, pile mussel (Gates and Frey 1974)
Classification (Bernard 1983)
Phylum: Mollusca
Class: Bivalvia
Order: Mytiloida
Family: Mytilidae

Recent research has shown that Pacific coast "*Mytilus edulis*" populations may actually be composed of two distinct species: *M. trossulus* Gould, 1850, distributed from northern California through Alaska and the Soviet Union, and *M. galloprovincialis* Lamarck, 1819, distributed in Japan, Hong Kong, South Africa, the Mediterranean Sea, the Atlantic coasts of Europe and the British Isles, and southern California. In central California, both species are present along with hybrids (McDonald and Koehn 1988). However, this species summary presents information using the previous nomenclature of *M. edulis*.

Value

Commercial: Between 1942 and 1947, up to 1,350 t were harvested annually in the United States (Cheney and Mumford 1986), but the harvest declined dramatically after that period. Since the 1960s, cultivation and harvesting increased; in 1981, 7,500 t were landed with most cultivation and harvesting occurring on the east coast, primarily in New England (Cheney and Mumford 1986). Cultivation of blue mussels has recently been initiated in Oregon and California coastal waters, and in Puget Sound, Washington. Presently, mussels are commercially harvested from California offshore oil platforms. However, California inland waters are closed to harvesting from May 1 to October 31 (both sport and commercial) because of potential for paralytic shellfish poisoning. Six culture methods are currently employed: raft, post, bottom, pole and line, long line, and rack. Spain is currently the world's largest producer of cultured blue mussels (Oceanographic Institute of Washington 1981). There appears to be an excellent opportunity for more U.S. aquaculture of this species (Lutz 1980).

Recreational: Estimates of blue mussels harvested by sportsmen are presently unknown. However, this species is regularly used as bait and human food throughout its range.

Indicator of Environmental Stress: Since it readily takes up and concentrates contaminants in the marine environment, this species has been used as a "sentinel" of environmental quality (National Research Council 1980, Broman and Ganning 1986). Increased temperatures can interact with zinc and salinity to accelerate toxic effects (Cotter et al. 1982). Even low concentrations of tributyltin oxide (a paint additive) reduce mussel growth hyperbolically (Strømgren and Bongard 1987). A decline in the scope for growth of *M. edulis* has been correlated with increasing body burdens of chromium, copper, mercury, silver, aluminum, zinc, total chlordanes, and dieldrin (Martin et al. 1984). Heavy metals, particularly mercury and copper, inhibit byssal-thread formation. Lead is incorporated at a rate that is linear with seawater concentration, thus making this an ideal animal for monitoring lead pollution in marine environments (Haderlie and Abbott 1980). Mussel embryos are highly sensitive to trace metals (Martin et al. 1981). Crude oil is not highly toxic to adult and juvenile blue mussels (Roberts 1976).

Table 1. Relative abundance of blue mussel in 32 U.S. Pacific coast estuaries.

	Life Stage				
Estuary	A	S	J	L	E
Puget Sound	●	●	●	●	●
Hood Canal	◉	◉	◉	◉	◉
Skagit Bay	●	●	●	●	●
Grays Harbor	○	○	○	○	○
Willapa Bay	○	○	○	○	○
Columbia River	○	○	○	○	○
Nehalem Bay	◉	◉	◉	◉	◉
Tillamook Bay	◉	◉	◉	◉	◉
Netarts Bay	◉	◉	◉	◉	◉
Siletz River	√	√	√	√	√
Yaquina Bay	◉	◉	◉	◉	◉
Alsea River	√	√	√	√	√
Siuslaw River	◉	◉	◉	◉	◉
Umpqua River	●	●	●	●	●
Coos Bay	◉	◉	◉	◉	◉
Rogue River	√		√		
Klamath River					
Humboldt Bay	●	●	●	●	●
Eel River	○	○	○	○	○
Tomales Bay	◉	◉	◉	◉	◉
Cent. San Fran. Bay*	●	●	●	●	●
South San Fran. Bay	●	●	●	●	●
Elkhorn Slough	◉	◉	◉	◉	◉
Morro Bay	◉	◉	◉	◉	◉
Santa Monica Bay	◉	◉	◉	◉	◉
San Pedro Bay	●	◉	●	◉	◉
Alamitos Bay	◉	◉	◉	◉	◉
Anaheim Bay	◉	◉	◉	◉	◉
Newport Bay	○	○	○	○	○
Mission Bay	◉	◉	◉	◉	◉
San Diego Bay	◉	◉	◉	◉	◉
Tijuana Estuary	○	○	○	○	○
	A	S	J	L	E

Relative Abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life Stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo Bays.

Ecological: Aggregations of this species often form a distinct "band" on substrates (pilings, rocks, etc.) where environmental conditions are suitable. These bands have a characteristic animal assemblage (i.e., mussel shells also provide substrates for barnacles, hydroids, bryozoans, and ascidians) (Kozloff 1976, Ricketts et al. 1985). This species is a common fouling organism. Larvae are important prey for carnivorous zooplanktivores (Bayne 1976). Blue mussel populations appear to be important in cycling nitrogen, phosphorus, and amino-nitrogen in some marine environments (Kautsky and Wallentinus 1980, Kautsky 1981, Kautsky and Evans 1987). Genetic differences between populations may enable them to invade suboptimal habitats (Koehn et al. 1984, Mallet et al. 1987).

Range

Overall: The blue mussel, cosmopolitan in temperate and cold seas (Bernard 1983), is very abundant in quiet-water locations from Puget Sound to Alaska (Ricketts et al. 1985). In the Pacific Ocean, it ranges from Alaska to Cedros Island, Mexico (Morris 1966). It is also found on the west coast of South America, and in Japan, Australia, and the North Atlantic (Haderlie and Abbott 1980). On the east coast of North America, the blue mussel ranges from Cape Hatteras, North Carolina to Labrador (Newell 1989). In the western Atlantic, it is found in Great Britain, Ireland, Scandinavia, and the Baltic Sea.

Within Study Area: This species is found in nearly all Pacific coast estuaries, but is most abundant in the northern part of its range (Table 1). In many southern California estuaries, this species is restricted to wharf pilings and the undersides of floating docks (Ricketts et al. 1985).

Life Mode

Eggs and larvae are pelagic. Juveniles and adults are sessile and epibenthic, living on hard or rocky bottoms or any relatively stable habitats (pilings, wharfs, hanging ropes, etc.). Juveniles and adults do not need light and are often found underneath floating objects. They attach themselves to these substrates by byssal threads. All life stages can be found in estuaries and in nearshore marine environments. Juveniles and adults do not dominate exposed nearshore rocky marine habitats; the California mussel *M. californianus* appears to have a competitive advantage in these areas.

Habitat

Type: All life stages inhabit marine and estuarine environments. They are most often found in estuaries or protected bays, since they prefer quiet water. Blue mussels occur primarily intertidally to 5 m depth, but have been found to 36 m (Cheney and Mumford 1986). In many northern locations, they are found only sublittorally (Seed 1976). The upper tidal limit of blue mussels is related to physical factors (e.g., exposure to air and desiccation), while the lower limit is probably determined by predation (Seed 1976).

Substrate: Plantigrades (late larval stages) appear to use algae-covered substrates initially before finding final attachment sites (Seed 1976). Juveniles and adults can be found on a variety of substrates, ranging from coarse unconsolidated substrates to rocky outcrops. Almost any fairly stable substrate can be used for settlement; including many man-made objects such as pilings, ropes, wharfs, boat bottoms, buoys, etc. (Shaw et al. 1988).

Physical/Chemical Characteristics: This species is found in waters that range in temperature from -4 to 30°C (Bernard 1983). It can withstand temperatures of 1.7-26.7°C (Cheney and Mumford 1986), but temperatures above 20°C appear to be stressful (Hines 1979). Trochophore development occurs best within a salinity range of 30 to 40‰ and temperatures of 8-18°C (Bayne 1965). Larval survival at salinities from 15-40‰ and temperatures of 5-20°C is good, but drops drastically at 25°C. Optimum larval growth occurs at 20°C in salinities of 25-30‰ (Brenko and Calabrese 1969). Juveniles and adults tolerate salinities of 5-37‰ and can withstand 0‰ for a short period. Optimum temperature for juvenile and adult growth is 10-20°C (Haderlie and Abbott 1980) and optimum salinity is 10-30‰; it can tolerate low oxygen for several days. The blue mussel prefers areas with slow to medium water currents and areas protected from surf. Limited data suggest that environmental requirements may limit embryonic development, especially in estuarine populations (Bayne 1976). It appears that when water conditions become adverse, adult and juvenile mussels will isolate themselves from these conditions (close shell and reduce pumping activity) and rely on anaerobic metabolism (Aunaas et al. 1988). Bay mussels are often infected with the parasitic copepod *Mytilicola orientalis* (Bradley and Siebert 1978).

Migrations and Movements: Larvae swim freely for approximately 4 weeks, settling mainly in the summer in southern California (Haderlie and Abbott 1980). In Puget Sound, peak settlement varies widely but usually occurs from late April through early July. The period of settlement appears to depend primarily on temperature (Skidmore and Chew 1985). Post-larval mussels secrete long, single, unattached byssal threads, which increase drag and allow young mussels to be carried by weak currents (Haderlie and Abbott 1980). Plantigrades often attach and detach themselves many times before finally settling (Seed 1976). Larvae may undergo diurnal vertical migrations and "selective swimming" (swimming at different tide stages), thus aiding retention in estuaries (Bayne 1976). Juvenile and adult blue mussels appear to be more mobile than *M. californianus*. Blue mussels apparently can crawl to the edge of mixed colonies. This ability also permits them to move when sedimentation threatens to bury them (Haderlie and Abbott 1980).

Reproduction

Mode: The blue mussel is gonochoristic (but some hermaphroditism has been reported), oviparous, and iteroparous. It is a broadcast spawner; eggs are fertilized externally.

Mating/Spawning: In Willapa Bay, Washington, spawning occurs when water temperatures warm to 18°C (late spring or summer) (D. Tufts, Willapa Bay Shellfish Lab., Washington Department of Fisheries, P.O. Box 190, Ocean Park, WA, pers. comm.). Mussels in British waters spawn when water temperatures rise from 9.5°C to 11-12.5°C (Chipperfield 1953). In Puget Sound, Washington spawning occurs from late spring through midsummer, with the spawning duration being a few weeks in any location (Cheney and Mumford 1986). Spawning begins in May in northern California, with partially spent mussels found until November (Edwards 1984). In southern California, some males may be ripe all year-round, but females have mature ova from November-May (Moore and Reish 1969, Haderlie and Abbott 1980). In British Columbia, most blue mussels appear to spawn in spring, but some may also spawn again in fall (Emmett et al. 1987). Mussels are stimulated to spawn by increasing water temperature, mechanical action, strong wave action, lunar cycle, and various chemicals (Cheney and Mumford 1986).

Fecundity: Fecundities range from 3 million to 6 million eggs per female (Skidmore and Chew 1985).

Growth and Development

Egg Size and Embryonic Development: Eggs are ovoid and 0.068-0.070 mm in diameter (Bayne 1976). Embryonic development is indirect and external, and takes about 48 hours.

Age and Size of Larvae: Fertilized eggs first form trochophore and then veliger larvae; these larval stages do not have a shell. Once secretion of the shells has started, the larva is called a veliconcha. In this form, locomotion is provided by the velum. As the larva nears metamorphosis, a pedal organ develops; when this is functional, the larva is called a pediveliger. After secretion of the adult shell (dissochonch) begins, the larva is called a plantigrade (Bayne 1976) and is ready to settle out of the water column. The length of the larval stages depends on food availability, temperature, salinity, and other variables (Bayne 1976). Larvae mature into spat in 3-4 weeks, but may remain planktonic for up to 10 weeks (Cheney and Mumford 1986). Veliger larvae are about 0.110-0.260 mm wide; plantigrades are approximately 0.26-1.50 mm wide (Bayne 1976).

Juvenile Size Range: The blue mussel is 1.0-1.5 mm long at settlement (Newell 1989). Growth rates are highly variable depending on area, temperature, food availability, and other factors.

Age and Size of Adults: Most appear to mature in about a year, depending on food availability and other physical factors. The smallest adults may be 10 mm long and they rarely grow more than 5 cm long. However, specimens up to 10 cm long have been found (Ricketts et al. 1985). Cultured mussels can reach 50 mm long (marketable size) in 12-13 months in Puget Sound (Skidmore and Chew 1985). This size is reached in 2-3 years in natural California populations. The oldest recorded specimens (18-24 years old) were from cool northern climates (Seed 1976). Growth may be limited by immersion time which in turn may be a result of vertical distribution (Suchanek 1978).

Food and Feeding

Trophic Mode: Larvae, juveniles, and adults are planktivorous filter feeders; pelagic detritus and planktonic organisms are trapped by mucus sheets that move over the gills. They can select food items and reject non-food items.

Food Items: Larvae feed on phytoplankton. Juveniles and adults feed on detritus, phytoplankton (such as dinoflagellates) and organisms as small as 4-5 µm in diameter (Incze et al. 1980). Organic detritus can be a major food source, and they also absorb dissolved and particulate organic compounds (Haderlie and Abbott 1980).

Biological Interactions

Predation: Predation has at times resulted in the loss of 50% of the harvestable blue mussels in an area. Important predators include perch (*Embiotoca lateralis* and *Rhacochilus vacca*), crabs (*Cancer* spp., and *Pachygrapsus crassipes*), starfish (*Pisaster ochracea*), snails (*Nucella* spp.), and scoter ducks (*Melanitta* spp. and *Oidemia nigra*) (Waterstrat et al. 1980, Oceanographic Institute of Washington 1981). Planktivorous fishes and invertebrates are important predators of blue mussel larvae.

Factors Influencing Populations: Paralytic shellfish poisoning can reduce mussel abundances (Reish 1963) and may result in unharvestable products. Diseases such as hemocytic neoplasia may also cause substantial mortality (Elston et al. 1988). Pollution (both industrial and residential) is a major problem for mussel growers (Oceanographic Institute of Washington 1981). Other factors which reduce this species' abundance are diseases, fouling, and storms. The mortality rate during the pelagic larval stage is probably as high as 99% (Bayne 1976). Causes of larval mortality include predation, excessive dispersal, and unsuitable physical parameters. Adult mortality may also be caused by spawning-related stress (Emmett et al. 1987). The blue mussel's upper intertidal distribution appears to be related to the survival of settling spat (Ross and Goodman 1974). Lower distribution is most often related to predation. Above mean tide level, the blue mussel competes with *Balanus glandula* (Ross and Goodman 1974).

References

Aunaas, T., J. P. Denstad, and K. E. Zachariassen. 1988. Ecophysiological importance of the isolation response of hibernating blue mussels (*Mytilus edulis*). Mar. Biol. 98:415-419.

Bayne, B. L. 1965. Growth and delay of metamorphosis of the larvae of *Mytilus edulis* (L.). Ophelia 2:1-47.

Bayne, B. L. 1976. The biology of mussel larvae. *In* B. L. Bayne (editor), Marine mussels: their ecology and physiology, p. 81-410. Cambridge Univ. Press, Cambridge, U.K.

Bernard, F. R. 1983. Catalogue of the living Bivalvia of the eastern Pacific Ocean: Bering Strait to Cape Horn. Can. Spec. Publ. Fish. Aquat. Sci. 61, 102 p.

Bradley, W., and A. E. Siebert, Jr. 1978. Infection of *Ostrea lurida* and *Mytilus edulis* by the parasitic copepod *Mytilicola orientalis* in San Francisco Bay, California. Veliger 21(1):131-134.

Brenko, M. H., and A. Calabrese. 1969. The combined effects of salinity and temperature on larvae of the mussel *Mytilus edulis*. Mar. Biol 4(3):224-226.

Broman, D., and B. Ganning. 1986. Uptake and release of petroleum hydrocarbons by two brackish water bivalves, *Mytilus edulis* (L.) and *Macoma balthica* (L.). Ophelia 25(1):49-57.

Cheney, D. P., and T. F. Mumford, Jr. 1986. Shellfish and seaweed harvests of Puget Sound. Wash. Sea Grant, Univ. Wash. Press, Seattle, WA, 164 p.

Chipperfield, P. N. J. 1953. Observations of the breeding and settlement of *Mytilus edulis* (L.) in British waters. J. Mar. Biol. Ass. U.K. 32:449-476.

Cotter, L. J. R., D. J. H. Phillips, and M. Ahsanullah. 1982. The significance of temperature, salinity, and zinc as lethal factors for the mussel *Mytilus edulis* in a polluted estuary. Mar. Biol. 68:135-141.

Edwards, R. L. 1984. The reproductive percentage solids cycles of *Mytilus edulis* and *Mytilus californianus* in Humboldt County, California. M.S. Thesis, Humboldt State Univ., Arcata, CA, 57 p.

Elston, R. A., M. L. Kent, and A. S. Drum. 1988. Progression, lethality and remission of hemic neoplasia in the bay mussel *Mytilus edulis.* Diseases Aquat. Organ. 4:135-142.

Emmett, B., K. Thompson, and J. D. Popham. 1987. The reproductive and energy storage cycles of two populations of *Mytilus edulis* (L.) from British Columbia. J. Shellfish Res. 6(1):29-36.

Gates, D. E., and H. W. Frey. 1974. Designated common names of certain marine organisms of California. Calif. Fish Game, Fish Bull. 161:55-90.

Haderlie, E. C., and D. P. Abbott. 1980. Bivalvia: the clams and allies. *In* R. H. Morris, D. P. Abbott, and E. C. Haderlie (editors), Intertidal invertebrates of California, p. 355-411. Stanford Univ. Press, Stanford, CA.

Hines, A. H. 1979. Effects of a thermal discharge on reproductive cycles in *Mytilus edulis* and *Mytilus californianus* (Mollusca, Bivalvia). Fish. Bull., U.S. 77(2):498-503.

Incze, L. S., R. A. Lutz, and L. Watling. 1980. Relationships between effects of environmental temperature and seston on growth and mortality of *Mytilus edulis* in a temperate northern estuary. Mar. Biol. 57:147-156.

Kautsky, N. 1981. On the trophic role of the blue mussel (*Mytilus edulis* L.) in a Baltic coastal ecosystem and the fate of the organic matter produced by the mussels. Kieler Meeresforsch., Sonderh. 5:454-461.

Kautsky, N., and S. Evans. 1987. Role of biodeposition by *Mytilus edulis* in the circulation of matter and nutrients in a Baltic coastal ecosystem. Mar. Ecol. Prog. Ser. 38:201-212.

Kautsky, N., and I. Wallentinus. 1980. Nutrient release from a Baltic *Mytilus*-red algal community and its role in benthic and pelagic productivity. Ophelia (suppl). 1:17-30.

Koehn, R. K., J. G. Hall, D. J. Innes, and A. J. Zera. 1984. Genetic differentiation of *Mytilus edulis* in eastern North America. Mar. Biol. 79:117-126.

Kozloff, E. N. 1976. Seashore life of Puget Sound, the Strait of Georgia, and the San Juan Archipelago. Univ. Wash. Press, Seattle, WA, 282 p.

Lutz, R. A. 1980. Introduction: mussel culture and harvest in North America. *In* R. A. Lutz (editor), Mussels culture and harvest: a North American perspective, p. 1-17. Elsevier Scientific Publ. Co., Amsterdam, Holland.

Mallet, A. L., C. E. A. Carver, S. S. Coffen, and K. R. Freeman. 1987. Mortality variations in natural populations of the blue mussel, *Mytilus edulis.* Can. J. Fish. Aquat. Sci. 44:1589-1594.

Martin, M., G. Ichikawa, J. Goetzl, M. de los Reyes, and M. D. Stephenson. 1984. Relationships between physiological stress and trace toxic substances in the bay mussel, *Mytilus edulis*, from San Francisco Bay, California. Mar. Envir. Res. 11:91-110.

Martin, M., K. E. Osborn, P. Billing, and N. Glickstein. 1981. Toxicities of ten metals to *Crassostrea gigas* and *Mytilus edulis* embryos and *Cancer magister* larvae. Mar. Poll. Bull. 12(9):305-308.

McDonald, J. H., and R. K. Koehn. 1988. The mussels *Mytilus galloprovincialis* and *M. trossulus* on the Pacific coast of North America. Mar. Biol. 99:111-118.

Moore, D. R., and D. J. Reish. 1969. Studies on the *Mytilus edulis* community in Alamitos Bay, California.-IV. Seasonal variation in gametes from different regions in the bay. Veliger 11(3):250-255.

Morris, P. A. 1966. A field guide to Pacific coast shells. Houghton Mifflin Company, Boston, MA, 297 p.

National Research Council. 1980. The international mussel watch. Nat. Acad. Sci., Washington, D.C., 248 p.

Newell, R. I. E., 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North and Mid-Atlantic)—blue mussel. U.S. Fish. Wildl. Serv. Biol. Rep. 82(11.102). U.S. Army Corps Eng., TR EL-82-4, 25 p.

Oceanographic Institute of Washington. 1981. Clam and mussel harvesting industries in Washington State. Oceanogr. Comm. Wash., Seattle, WA, various pagination.

Reish, D. J. 1963. Mass mortality of marine organisms attributed to the "red tide" in southern California. Calif. Fish Game 49:265-270.

Ricketts, E. F., J. Calvin, J. W. Hedgpeth, and D. W. Phillips. 1985. Between Pacific tides. Stanford Univ. Press, Stanford, CA, 652 p.

Roberts, D. 1976. Mussels and pollution. In B. L. Bayne (editor), Marine mussels: their ecology and physiology, p. 67-80, Cambridge Univ. Press, Cambridge, U.K.

Ross, J. R. P., and D. Goodman. 1974. Vertical intertidal distribution of *Mytilus edulis*. Veliger 16(4):388-395.

Seed, R. 1976. Ecology. *In* B. L. Bayne (editor), Marine mussels: their ecology and physiology, p. 13-65, Cambridge Univ. Press, Cambridge, U.K.

Shaw, W. N., T. J. Hassler, and D. P. Moran. 1988. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest)—California sea mussel and bay mussel. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.84), U.S. Army Corps Eng., TR EL-82-4, 16 p.

Skidmore, D., and K. K. Chew. 1985. Mussel aquaculture in Puget Sound. Wash. Sea Grant, Univ. Wash., Seattle, WA, 57 p.

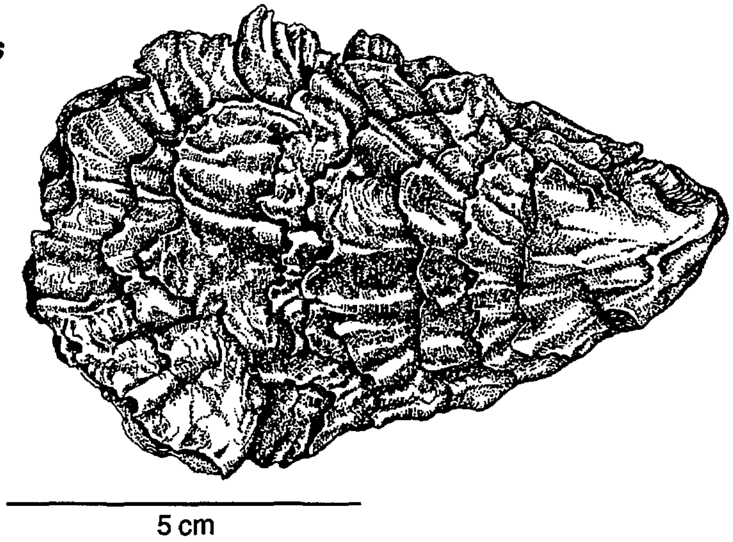
Strømgren, T., and T. Bongard. 1987. The effect of tributyltin oxide on growth of *Mytilus edulis*. Mar. Poll. Bull. 18(1):30-31.

Suchanek, T. H. 1978. The ecology of *Mytilus edulis* L. in exposed rocky intertidal communities. J. Exp. Mar. Biol. Ecol. 31:105-120.

Waterstrat, P., K. Chew, K. Johnson, and J. H. Beattie. 1980. Mussel culture: a west coast perspective. *In* R. A. Lutz (editor), Mussel culture and harvest: a North American perspective, p. 141-165, Elsevier Scientific Publ. Co., Amsterdam, Holland.

Pacific oyster

Crassostrea gigas
Adult



Common Name: Pacific oyster
Scientific Name: *Crassostrea gigas*
Other Common Names: Japanese oyster, Miyagi oyster, giant oyster, immigrant oyster, giant Pacific oyster (Fitch 1953, Gates and Frey 1974, Wolotira et al. 1989)
Classification (Bernard 1983a)
Phylum: Mollusca
Class: Bivalvia
Order: Pterioida
Family: Ostreidae

Value

Commercial: The Pacific oyster is a highly valuable estuarine species that is cultured in appropriate habitats all over the world, including Australia, Japan, Hawaii, Palau, southwest Europe, and the Pacific coast of North America (Haro et al. 1981, Lee et al. 1981, Menzel 1974, Quayle 1988). It was introduced to the United States from Japan in the early 1900s and has been cultured ever since (Quayle 1988). In North America, they are harvested from southeast Alaska to northern Baja California, with most produced in Washington and southwest British Columbia waters (Wolotira et al. 1989). It is Washington's most valuable shellfish resource (Pauley et al. 1988). In 1982, Washington alone harvested over 2,700 t of meat, worth $20.4 million, and representing over 70% of all Pacific coast harvests (Cheney and Mumford 1986). About half of Washington's landings come from Willapa Bay (Hedgpeth and Obrebski 1981, Washington Department of Fisheries and Washington Department of Ecology 1985). Other important western U.S. areas include the southern waters of Puget Sound, Hood Canal, Grays Harbor, Tillamook Bay, Yaquina Bay, Coos Bay, Humboldt Bay, Tomales Bay, Drakes Estero, Bolinas Lagoon, and Morro Bay (Barrett 1963, Pauley et al. 1988, Wolotira et al. 1989). Nearly all Pacific oysters are cultivated on "oyster farms" in protected coastal estuaries. Since successful spawning in many estuaries is erratic, Pacific coast hatcheries have been developed to produce spat, which is then sold to oyster growers who use this to "seed" their oyster beds. Prior to the development of these hatcheries, all seed was imported from Japan (Conte and Dupuy 1981, Ricketts et al. 1985, Pauley et al. 1988). The seed is allowed to grow, but clusters may have to be broken up and the oysters moved to fattening grounds before harvest (Beattie et al. 1981). Pacific oysters are harvested primarily by hydraulic dredge, tongs, and hand-picking (Frey 1971, Cheney and Mumford 1986). Most oysters are sold fresh-shucked and frozen, while some are canned or sold fresh in the shell. The Japanese have cultured Pacific oysters for over 300 years, and have developed numerous raft, line, and pole mariculture methods instead of on-bottom methods used primarily in the U.S. and British Columbia (Bardach et al. 1972, Haderlie and Abbott 1980, Gunn and Saxby 1981, Pauley et al. 1988).

Recreational: Although most oysters are cultivated, some wild beds do exist in Washington and British Columbia. In Puget Sound and Hood Canal, the daily limit is 18/person, with the season open from September 16 to July 14, except for a couple of state parks (Washington Department of Fisheries 1986, Wolotira et al. 1989). Oysters are primarily taken in intertidal regions to depths of <1.6 m (Wolotira et al. 1989).

Indicator of Environmental Stress: Because of its relative hardiness and ability to concentrate contaminates, the Pacific oyster has been used to indicate water quality

Table 1. Relative abundance of Pacific oyster in 32 U.S. Pacific coast estuaries.

Estuary	A	S	J	L	E
Puget Sound	●		●		
Hood Canal	●		●		
Skagit Bay	○		○		
Grays Harbor	●		●		
Willapa Bay	●		●		
Columbia River					
Nehalem Bay					
Tillamook Bay	●		●		
Netarts Bay	◉		◉		
Siletz River					
Yaquina Bay	●		●		
Alsea River					
Siuslaw River					
Umpqua River	○		○		
Coos Bay	●		●		
Rogue River					
Klamath River					
Humboldt Bay	●		●		
Eel River					
Tomales Bay	●		●		
Cent. San Fran. Bay *	√		√		
South San Fran. Bay	√		√		
Elkhorn Slough	√		√		
Morro Bay	●		●		
Santa Monica Bay					
San Pedro Bay					
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Life Stage

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

problems in many estuaries. For example, antifouling paints containing copper and tri-n-butyltin cause oyster shell thickening, alter growth rates, increase oxygen consumption, and may affect larvae viability (Paul and Davies 1986, His and Robert 1987, Lawler and Aldrich 1987, Quayle 1988). Presently, many estuarine areas are closed to oyster culture and harvest because of bacterial contamination commonly associated with urban centers, marinas, and sewage outfalls (Cheney and Mumford 1986).

Ecological: The Pacific oyster is the dominant bivalve species in many estuarine areas where it is cultured. Many other "exotic" organisms were introduced in Pacific coast estuaries along with Pacific and Virginia oysters (*C. virginica*). These exotics include sponges, cnidarians, polychaetes, molluscs, crustaceans, and bryozoans; many of these introduced species are predators or competitors with native species or are mariculture pests (Smith and Carlton 1975, Ricketts et al. 1985, Quayle 1988). Pacific oysters appear to successfully compete with the native oyster (*Ostrea lurida*), which is now restricted to typically deep low salinity areas (Sayce 1976).

Range

Overall: The Pacific oyster is a temperate species that is now found in southern Australia to New Zealand, Hawaii, Palau, along the Asian coast from China to the southern Kuril Islands, and the North American coast from southeast Alaska to northern Mexico (Morris 1966, Young 1966, Haro et al. 1981, Lee et al. 1981, Quayle 1988, Wolotira et al. 1989). The Portuguese oyster (*C. angulatus*), which ranges from Portugal, England, and southwest Europe, may be the same species (Menzel 1974, Wolotira et al. 1989).

Within Study Area: The Pacific oyster is found in most Pacific coast estuaries from Morro Bay, California, to Skagit Bay, Washington, where estuarine physical conditions are appropriate and water pollution is not a problem (Table 1). Pacific oysters were once cultured in San Francisco Bay and Elkhorn Slough, California, but high pollution levels now make oysters from these areas unhealthy to consume (Frey 1971). The Columbia, Rogue, Klamath, and Eel River estuaries do not have oysters because salinities are not appropriate.

Life Mode

Eggs and early larval stages are pelagic. Late larval stages are sedentary. Juveniles and adults are sedentary and benthic/epibenthic (Quayle 1988).

Habitat

Type: Eggs and larvae are estuarine/neritic, occurring in the upper warmer waters of the water column (Quayle 1988). Juveniles and adults are found in bays and estuaries in lower intertidal areas to depths of 7 m below mean lower low water (Haderlie and Abbott 1980).

Substrate: Firm bottoms appear to be preferred; however, this species can be found on mud or mud-sand bottoms. Pacific oysters are usually found attached to rocks, debris, or other oyster shells (Barrett 1963, Quayle 1988).

Physical/Chemical Characteristics: The Pacific oyster is found in mesohaline-euhaline waters (usually 10-35‰) (Barrett 1963, Berg 1971, Quayle 1988). It tolerates air temperatures to -4°C during low tides and water temperatures of 4-36°C (Quayle 1988, Wolotira et al. 1989), and spawns at water temperatures of 14-30°C, but only rarely below 18°C (Haderlie and Abbott 1980). Optimum spawning temperatures are probably 21-23°C (Quayle 1988). Larvae can survive water temperatures of 17.5-35.0°C (Berg 1971), and 15°C for a short time (Pauley et al. 1988). Larval setting is best at temperatures of 25 to 30°C, salinities of 19 to 27‰, and on oyster shells that were first dipped in an aqueous extract of oyster tissue (Carlson 1981, Nell and Holliday 1988). Adults will continue to feed down to 3°C, but growth stops when temperatures drop below 10°C (Barrett 1963, Quayle 1988). Best conditions for somatic growth are 17°C (ranges 15-18°C), salinities >24‰ (ranges 10-35‰), food suspensions of 120 mg/l (ranges 24-550 mg/l), oxygen levels above 70%, suspended sediments between 0.0 and 8.0 mg/l, and pH levels above 7.8 (Bernard 1983b, Brown and Hartwick 1988a). Growth rates correlate primarily with suspended particulate organic material levels and secondarily with temperature, but are mediated by salinity (Malouf and Bresse 1977, Brown 1988, Brown and Hartwick 1988b). Paralytic shellfish poisoning can be a problem when oysters feed on the dinoflagellate *Protogonyaulax acatanella*, but they quickly lose their toxicity when the dinoflagellate bloom is gone. (Haderlie and Abbott 1980, Quayle 1988). Embryos are very sensitive to zinc and other metals (Boyden et al. 1975).

Migrations and Movements: Planktonic eggs and larvae are moved by water currents. Late-stage larvae settle out of the water column and crawl on the bottom searching for suitable substrates before finally setting (Quayle 1988). Juveniles and adults are sedentary and usually become firmly attached to materials on the bottom (Quayle 1988).

Reproduction

Mode: The Pacific oyster is gonochoristic (some hermaphroditism occurs) and a batch spawner, broadcasting its gametes and relying on external fertilization (Berg 1969, Haderlie and Abbott 1980). This species is a protandric hermaphrodite, developing first as a male and later changing to a female (Quayle 1988). Sex appears to be influenced by environmental conditions, with some females becoming males when the food supply is low and males becoming females when food is abundant (Quayle 1988).

Mating/Spawning: Spawning is initiated by a rise in water temperatures (usually above 18°C) or by hormones released from the sperm of other oysters (Quayle 1988, Wolotira et al. 1989). This species spawns from June to September (primarily July to August) during high tide (Quayle 1988). Minimum threshold spawning temperatures are not often reached in many Pacific coast estuaries, or if they are, they do not occur annually. Therefore, spawning is sporadic or nonexistent in most estuaries (Span 1978, Ricketts et al. 1985, Quayle 1988). In California and other areas, Pacific oysters may spawn but the larvae may not survive (Berg 1971, Haderlie and Abbott 1980, Ricketts et al. 1985). Areas where successful reproduction does occur include: Pendrell Sound and the Strait of Georgia to Tofino Inlet on the west coast of Vancouver Island, Dabob Bay in Hood Canal, Washington, and occasionally in Willapa Bay, Washington (Quayle 1988, Wolotira et al. 1989). Eggs are not released into the exhalant siphon like many other bivalves, but discharged into the suprabranchial chambers, passed through the gills into the mantle chamber, and then expelled by contraction of the adductor mussel. Eggs may travel 30 cm or more when discharged. Females release eggs 5-10 times/minute, while the males release a continuous stream of sperm through their exhalant siphons (Quayle 1988).

Fecundity: Fecundity ranges from 10 million to 200 million eggs per female, with fecundity increasing with age (Frey 1971, Wolotira et al. 1989). The average market-sized oyster produces 50-100 million eggs/year (Quayle 1988). Individuals may spawn repeatedly during a spawning season (Haderlie and Abbott 1980, Quayle 1988).

Growth and Development

Egg Size and Embryonic Development: Eggs are spherical and 0.05 mm in diameter (Quayle 1988). Embryonic development is indirect and external.

Age and Size of Larvae: Fertilized eggs develop into veliger larvae in 24-48 hours depending on temperature (Cahn 1950, Quayle 1988). Larvae are free-swimming for 2-4 weeks depending on temperature (Haderlie and Abbott 1980, Strathmann et al. 1987). Then they settle on to substrates and metamorphose into spat (Quayle 1988). Larvae range in size from 0.06 to 1.32 mm (Wolotira et al. 1989); they are 0.27-0.31 mm long at settlement (Strathmann et al. 1987). They will grow from 0.075 mm to about 0.3 mm in about a month at 18 to 24°C (Quayle 1988).

Juvenile Size Range: Juvenile sizes range from about 0.30 mm to 40.0 mm. Size depends on tidal height, area of settlement, and other factors (Quayle 1988).

Age and Size of Adults: The Pacific oyster may mature in 1 year and may be as small as 30 mm shell length (Wolotira et al. 1989). Adults grow to 10-12 cm (market size) in 2 to 3 years in California's waters, but may grow for 20 years or more (Haderlie and Abbott 1980). In Oregon and southern Washington, 2-4 years are required to grow to market size; 4-6 years' growth is required in northern Washington, British Columbia, and Alaska (Pauley et al. 1988). This species may grow to 25.4 cm in shell length, but most are 10.2-12.7 cm (Pauley et al. 1988). Shell growth and shape are highly variable, depending on temperature, food supply, culture method, and other factors (Cahn 1950, Quayle 1988).

Food and Feeding

Trophic Mode: Juveniles and adults are detritivores, nannoplanktivores, and suspension feeders (Haderlie and Abbott 1980, Quayle 1988). Food is taken in the inhalant siphon, filtered and collected by mucus on the gills, sorted on the palps, and transferred to the mouth.

Food Items: Larvae feed on naked flagellates (Berg 1971). Juveniles and adults eat primarily nannoplankton, such as bacteria, dinoflagellates, flagellates, diatoms, and algal and invertebrate gametes (Barrett 1963, Quayle 1988). They also consume plant and animal detritus, but the importance of this material to their diet is unknown (Barrett 1963, Quayle 1988).

Biological Interactions

Predation: Larvae are eaten by numerous predators including: Tintinnidae and other ciliates, ctenophores, jellyfish (*Aurelia aurita* and *Chrysaora melanaster*), oysters, barnacles, Pacific herring (*Clupea pallasi*), and smelt (Berg 1971). The introduced flatworm (*Pseudostylochus ostreophagus*) can be a major predator of oyster spat (Quayle 1988). Predators of juveniles and adults include crabs (*C. magister, C productus,* and *C. gracilis*), oyster drills (*Ceratostoma inornatum* and *Urosalpinx cinerea*), starfish (*Pisaster ochraceus, P. brevispinus, Evasterias troschelii,* and *Pycnopodia helianthoides*), and ducks (*Aythya affinis*), and surf and white winged scoters (*Mellanita* spp.). Important fish predators of juvenile and adult oysters in California include the bat ray (*Myliobatis californica*) and angel shark (*Squatina californica*) (Haderlie and Abbott 1980, Ricketts et al. 1985).

Factors Influencing Populations: Probably the most important factor limiting Pacific oyster populations on the Pacific coast is low water temperatures which inhibit spawning. In areas where they do spawn, Pacific oyster larvae often do not survive and set, except in a few warm bays when conditions are optimal. Mortality of larvae may be due to low temperatures, excessive turbidity, lack of food, toxins from dinoflagellate blooms, predation, and bacterial or fungal diseases (Berg 1971). Juveniles may be killed by abrupt changes in salinity and temperature. Adults and juvenile populations are affected by storms and associated waves that can displace individuals and bury them in sediments (Cheney and Mumford 1986). Siltation and increased turbidities of oyster beds resulting from logging, upland alterations, and natural causes can result in high mortalities (Pauley et al. 1988, Quayle 1988). In northern latitudes, ice can push them into sediments. In areas of high population densities, food may be a limiting factor (Pauley et al. 1988). Diseases, algal blooms that inhibit feeding, bay ghost shrimp (*Callianassa californiensis*), and blue mud shrimp (*Upogebia pugettensis*) can also reduce population sizes. In the 1960s and 1970s, mass mortalities of older (>2 years old) Pacific oysters occurred in Washington and California during late summer when water temperatures approached or exceeded 20°C. The cause of this mortality was never positively identified, but infection by *Vibrio* spp. and variability in the oyster's carbohydrate cycle were implicated (Beattie et al. 1981, Elston et al. 1987, Pauley et al. 1988). However, environmental stresses such as prolonged air exposure times, warm temperatures, and dinoflagellate blooms may have promoted mortality of already stressed oysters (Pauley et al. 1988). Other estuarine species reduce Pacific oyster growth or indirectly affect oyster viability. Mud and ghost shrimp cause serious damage to oyster beds by making grounds too soft for culture or by smothering them. This has required the controversial use of the insecticide SEVIN (carbaryl) to reduce shrimp populations (Washington Department of Fisheries and Washington Department of Ecology 1985, Quayle 1988). Other harmful organisms include protozoa, bacterial diseases, sponges, flatworms, polychaetes, and a parasitic copepod (*Mytilicola orientalis*) (Dungan and Elston 1988, Quayle 1988). Fouling organisms such as mussels, tunicates, algae, sponges, anemones, hydroids, and bryozoans may compete with oysters for food, reduce oyster growth rates, and affect spat settlement (Quayle 1988). The Pacific oyster's chief enemy is man, who by dredging activities and pollution, reduces areas where viable oyster production can occur (Wallace 1966, Ricketts et al. 1985). For example, sulfite liquor effluent from pulp mills in the Pacific Northwest appears to affect survival and growth of all oyster life stages (Cheney and Mumford 1986). Because of pollution, many bays and estuaries once used for oystering are now closed or restricted (Gunn and Saxby 1981, Qualman 1981, Cheney and Mumford 1986).

References

Bardach, J. E., J. H. Ryther, and W. O. McLarney. 1972. Aquaculture: The farming and husbandry of freshwater and marine organisms. John Wiley and Sons, Inc., New York, NY, 868 p.

Barrett, E. M. 1963. The California oyster industry. Calif. Fish Game, Fish Bull. 123, 103 p.

Beattie, J. H., D. McMillin, and L. Wiegardt. 1981. The Washington State oyster industry: a brief overview. *In* K. K. Chew (editor), Proceedings of the North American oyster workshop, p. 28-38. Louisiana State Univ., Baton Rouge, LA.

Berg, C. J., Jr. 1969. Seasonal gonadal changes of adult oviparous oysters in Tomales Bay, California. Veliger 12:27-36.

Berg, C. J., Jr. 1971. A review of possible causes of mortality of oyster larvae of the genus *Crassostrea* in Tomales Bay, California. Calif. Fish Game 57(1):69-75.

Bernard, F. R. 1983a. Catalogue of the living Bivalvia of the eastern Pacific Ocean: Bering Strait to Cape Horn. Can. Spec. Publ. Fish. Aquat. Sci. 61, 102 p.

Bernard, F. R. 1983b. Physiology and the mariculture of some northeastern Pacific bivalve molluscs. Can. Spec. Publ. Fish. Aquat. Sci. 63, 24 p.

Boyden, C. R., H. Watling, and I. Thorton. 1975. Effect of zinc on the settlement of the oyster *Crassostrea gigas*. Mar. Biol. 31:227-234.

Brown, J. R. 1988. Multivariate analyses of the role of environmental factors in seasonal and site-related growth variation in the Pacific oyster *Crassostrea gigas*. Mar. Ecol. Prog. Ser. 45:225-236.

Brown, J. R., and E. B. Hartwick. 1988a. A habitat suitability index model for suspended tray culture of the Pacific oyster, *Crassostrea gigas* Thunberg. Aquacul. Fish. Manag. 19:109-126.

Brown, J. R., and E. B. Hartwick. 1988b. Influence of temperature, salinity and available food upon suspended culture of the Pacific oyster, *Crassostrea gigas* : I. Absolute and allometric growth. Aquacul. 70:231-251.

Cahn, A. R. 1950. Oyster culture in Japan. Fish. Wildl. Serv., Fish. Leaflt. 383, 80 p.

Carlson, B. L. K. 1981 Effects of temperature, salinity, feeding, substrate, and storage on the setting and survival of commercially-reared eyed larvae of the Pacific oyster, *Crassostrea gigas*. M.S. Thesis, Oregon State Univ., Corvallis, OR, 90 p.

Cheney, D. P., and T. F. Mumford, Jr. 1986. Shellfish and seaweed harvests of Puget Sound. Wash. Sea Grant, Univ. Wash. Press, Seattle, WA, 164 p.

Conte, F. S., and J. L. Dupuy. 1981. The California oyster industry. *In* K. K. Chew (editor), Proceedings of the North American oyster workshop, p. 43-63. Louisiana State Univ., Baton Rouge, LA.

Dungan, C. R., and R. A. Elston. 1988. Histopathological and ultrastructural characteristics of bacterial destruction of the hinge ligaments of cultured juvenile Pacific oysters, *Crassostrea gigas*. Aquacul. 72:1-14.

Elston, R. A., J. H. Beattie, C. Friedman, R. Hedrick, and M. L. Kent. 1987. Pathology and significance of fatal inflammatory bacteraemia in the Pacific oyster, *Crassostrea gigas* Thunberg. J. Fish. Diseases 10:121-132.

Fitch, J. E. 1953. Common marine bivalves of California. Calif. Fish Game, Fish Bull. 90, 102 p.

Frey, H. W. 1971. California living marine resources and their utilization. Calif. Dept. Fish Game, Sacramento, CA, 148 p.

Gates, D. E., and H. W. Frey. 1974. Designated common names of certain marine organisms of California. Calif. Fish Game, Fish Bull. 161:55-90.

Gunn, C. R., and D. J. Saxby. 1981. A brief history of the oyster industry in British Columbia. *In* K. K. Chew (editor), Proceedings of the North American oyster workshop, p. 17-27. Louisiana State Univ., Baton Rouge, LA.

Haderlie, E. C., and D. P. Abbott. 1980. Bivalvia: The clams and allies. *In* R. H. Morris, D. P. Abbott, and E. C. Haderlie (editors), Intertidal invertebrates of California, p. 355-411. Stanford Univ. Press, Stanford, CA.

Haro, B. H., E. P. Nunez, A. F. Mattus, and M. A. Landin. 1981. The development and perspective of oyster culture in Mexico. *In* K. K. Chew (editor), Proceedings of the North American oyster workshop, p. 64-69. Louisiana State Univ., Baton Rouge, LA.

Hedgpeth, J. W., and S. Obrebski. 1981. Willapa Bay: a historical perspective and a rationale for research. U.S. Fish Wildl. Serv., FWS/OBS-81/03, 52 p.

His, E., and R. Robert. 1987. Comparative effects of two antifouling paints on the oyster *Crassostrea gigas*. Mar. Biol. 95:(1):83-86.

Lawler, I. F., and J. C. Aldrich. 1987. Sublethal effects of Bis (tri-n-butyltin) Oxide on *Crassostrea gigas* spat. Mar. Poll. Bull. 18(6):274-278.

Lee, K. W. F., J. S. Corbin, and W. A. Brewer. 1981. Overview of oyster culture in Hawaii and various U.S. Pacific island territories. *In* K. K. Chew (editor), Proceedings of the North American oyster workshop, p. 70-85. Louisiana State Univ., Baton Rouge, LA.

Malouf, R. E., and W. P. Breese. 1977. Food consumption and growth of larvae of the Pacific oyster, *Crassostrea gigas* (Thunberg), in a constant flow rearing system. Proc. Natl. Shellfish. Assoc. 67:7-16.

Menzel, R. W. 1974. Portuguese and Japanese oysters are the same species. J. Fish. Res. Board Can. 31:453-456.

Morris, P. A. 1966. A field guide to Pacific coast shells. Houghton-Mifflin Co., Boston, MA, 297 p.

Nell, J. A., and J. E. Holliday. 1988. Effects of salinity and the growth and survival of Sydney rock oyster (*Saccostrea commercialis*) and Pacific oyster (*Crassostrea gigas*) larvae and spat. Aquacul. 68:39-44.

Paul, J. D., and I. M. Davies. 1986. Effects of copper and tin-based anti-fouling compounds on the growth of scallops (*Pecten maximus*) and oysters (*Crassostrea gigas*). Aquacult. 54:191-203.

Pauley, G. B., B. Van Der Raay, and D. Troutt. 1988. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest)—Pacific oyster. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.85), U.S. Army Corps Eng., TR EL-82.4, 28 p.

Qualman, J. L. 1981. Oregon's oyster industry. *In* K. K. Chew (editor), Proceedings of the North American oyster workshop, p. 39-42. Louisiana State Univ., Baton Rouge, LA.

Quayle, D. B. 1988. Pacific oyster culture in British Columbia. Can. Bull. Fish. Aquat. Sci. 218, 214 p.

Ricketts, E. F., J. Calvin, J. W. Hedgpeth, and D. W. Phillips. 1985. Between Pacific tides. Stanford Univ. Press, Stanford, CA, 652 p.

Sayce, C. S. 1976. The oyster industry of Willapa Bay. *In* Proceedings of the symposium on terrestrial and aquatic ecological studies of the Northwest, p. 347-356. Eastern Wash. State College, Cheney, WA.

Smith, R. I., and J. T. Carlton (editors). 1975. Light's manual: Intertidal invertebrates of the central California coast. Univ. Calif. Press, Berkeley, CA, 716 p.

Span, J. A. 1978. Successful reproduction of giant Pacific oysters in Humboldt Bay and Tomales Bay, California. Calif. Fish Game 64(2):123-124.

Strathmann, M. F., A. R. Kabat, and D. O'Foighil. 1987. Phylum Mollusca, class Bivalvia. *In* M. F. Strathmann (editor), Reproduction and development of marine invertebrates of the northern Pacific coast, p. 309-353. Univ. Wash. Press, Seattle, WA.

Wallace, D. H. 1966. Oysters in the estuarine environment. *In* Symposium on estuarine fisheries, p. 68-73. Am. Fish. Soc. Spec. Publ. No. 3., Am. Fish. Soc., Bethesda, MD.

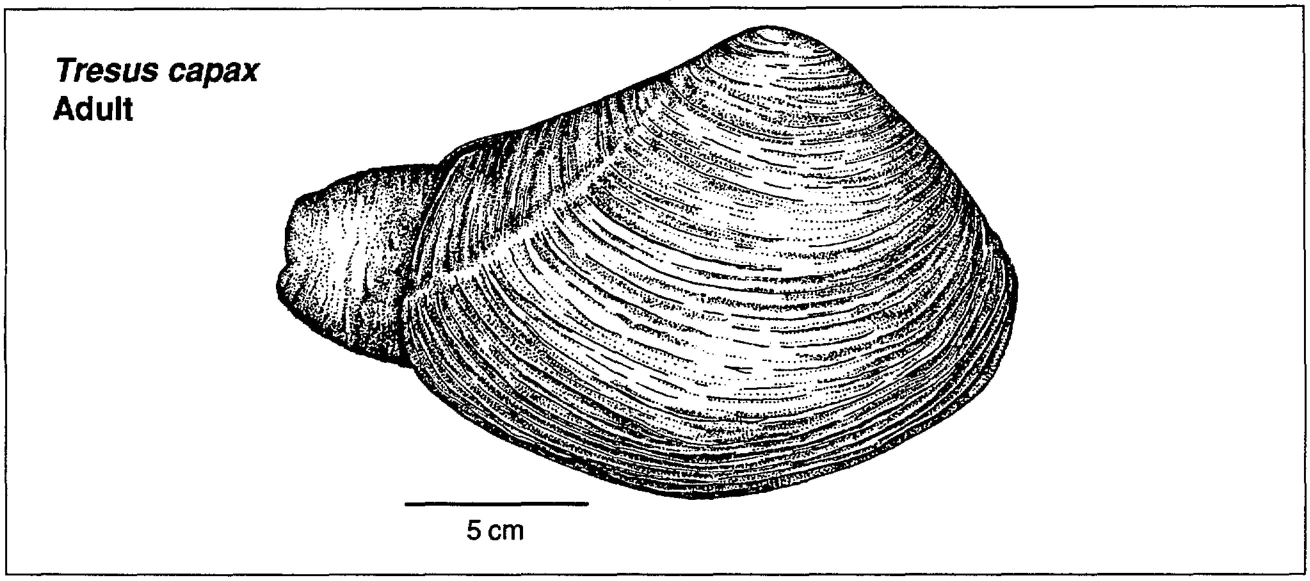
Washington Department of Fisheries. 1986. 1986-1987 salmon, shellfish, bottom fish sport fishing guide. Wash. Dept. Fish., Olympia, WA, 20 p.

Washington Department of Fisheries and Washington Department of Ecology. 1985. Use of the insecticide SEVIN to control ghost and mud shrimp in oyster beds of Willapa Bay and Grays Harbor. Final Env. Impact Statament, Wash. Dept. Fish. and Wash. Dept. Ecol., Olympia, WA, 64 p plus appendices

Wolotira, R. J., Jr., M. J. Allen, T. M. Sample, C. R. Iten, S. F. Noel, and R. L. Henry. 1989. Life history and harvest summaries for selected invertebrate species occurring off the west coast of North America. Volume 1: shelled molluscs. NOAA Tech. Memo, NMFS F/NWC-160, 177 p.

Younge, C. M. 1966. Oysters, 2nd edition. Collins, London, 209 p.

Horseneck gaper



Common Name: horseneck gaper
Scientific Name: *Tresus capax*
Other Common Names: Alaskan gaper, fat gaper, blue clam, empire clam, gaper, gaper clam, greyneck clam, horseneck clam, horse clam, bigneck clam, giant rockdweller, butter clam, money shell, giant saxidome (Morris 1966, Gates and Frey 1971, Haderlie and Abbott 1980, Wolotira et al. 1989)
Classification (Bernard 1983a)
Phylum: Mollusca
Class: Bivalvia
Order: Veneroida
Family: Mactridae

Value

Commercial: This species and the Pacific gaper (*Tresus nuttallii*) are harvested commercially from northern California to British Columbia (landings are not separated by species) (Wolotira et al. 1989). It is taken both subtidally and intertidally using hydraulic pumps, mechanical dredges, potato forks, shovels, and clam rakes (Frey 1971, Wolotira et al. 1989). Recent harvests have averaged about 225 t annually, placing them fifth in volume for the entire U.S. and Canada Pacific coast clam harvest (Wolotira et al. 1989). This species is taken year-round, but most are harvested from July to December in British Columbia and Oregon (Wolotira et al. 1989). Although the horseneck gaper is a large clam that provides excellent meat for chowder or clam steaks, it is not often sold fresh. Instead, it is usually canned because it has a fragile shell that breaks easily and its valves gape, reducing shelf life and allowing water loss. Also, a tough outer covering on its neck increases processing/packaging time and meat yield during processing is low (25-30% of total body weight) (Quayle and Bourne 1972, Ricketts et al. 1985, Wolotira et al. 1989).

Recreational: The horseneck gaper is harvested recreationally from Humboldt Bay, California, to Puget Sound, Washington (Machell and DeMartini 1971, Wolotira et al. 1989). No more than 10/day can be taken in California (Ricketts et al. 1985),12/day in Oregon (Oregon Department of Fish and Wildlife 1976), and 7/day in Washington (Washington Department of Fisheries 1986). It is harvested primarily by hand (using shovels, rakes, etc.) during low tides.

Indicator of Environmental Stress: Clam beds are sometimes closed to harvest because of paralytic shellfish poisoning or coliform bacterial contamination. As a result of pollution in Washington waters, over 25% of the potential areas for subtidal hardshell clam harvesting are closed (Schink et al. 1983).

Ecological: The horseneck gaper is often the largest subtidal and intertidal suspension/filter feeding bivalve in many Pacific coast estuaries (Hancock et al. 1979).

Range

Overall: This species' overall range is from Monterey, California, to Kodiak, Alaska and the mouth of Prince William Sound, Alaska. It is uncommon south of Humboldt Bay, where it is replaced by *T. nuttallii* (Bernard 1983a, Rudy and Rudy 1983, Wolotira et al. 1989).

Within Study Area: The horseneck gaper is found from Humboldt Bay to Puget Sound, reaching highest abundances in Coos and Siuslaw Bays, Oregon (Table 1). It is rare from Humboldt Bay south to San Francisco Bay, California, and is not found in any estuaries further

Table 1. Relative abundance of horseneck gaper in 32 U.S. Pacific coast estuaries.

	Life Stage				
Estuary	A	S	J	L	E
Puget Sound	◉	○	◉	○	○
Hood Canal	◉	◉	◉	◉	◉
Skagit Bay	◉	○	◉	○	○
Grays Harbor	○	○	○	○	○
Willapa Bay	○	○	○	○	○
Columbia River					
Nehalem Bay	√		√		
Tillamook Bay	◉	◉	◉	◉	◉
Netarts Bay	◉	◉	◉	◉	◉
Siletz River					
Yaquina Bay	◉	◉	◉	◉	◉
Alsea River	○	○	○	○	○
Siuslaw River	●	●	●	●	●
Umpqua River	√	√	√	√	√
Coos Bay	●	●	●	●	●
Rogue River					
Klamath River					
Humboldt Bay	◉	◉	◉	◉	◉
Eel River					
Tomales Bay					
Cent. San Fran. Bay *					
South San Fran. Bay					
Elkhorn Slough					
Morro Bay					
Santa Monica Bay					
San Pedro Bay					
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

south than San Francisco Bay. It is not found in many small estuaries or estuaries with relatively high river flows (e.g., Oregon's Columbia, Siletz, and Rogue Rivers, and California's Klamath and Eel Rivers).

Life Mode

Eggs and larvae are pelagic. Juveniles and adults are benthic infauna, burrowing into sediments to depths ≤1 m, but usually 25-50 cm (Cheney and Mumford 1986, Wolotira et al. 1989).

Habitat

Type: Eggs and larvae are neritic. Juveniles and adults are found primarily in bays and estuaries, occurring from mid-tide levels (+2 m) down to 30 m below mean lower low water (MLLW). In Puget Sound and Humboldt Bay, they are most abundant at depths 1-5 m below MLLW (Wendell et al. 1976, Goodwin and Shaul 1978, Cheney and Mumford 1986).

Substrate: The horseneck gaper is found primarily in substrates consisting of shell fragments and dense sand, as well as silty-sand and gravel (Bourne and Smith 1972b, Wendell et al. 1976, Cheney and Mumford 1986). In Humboldt Bay, clam densities are greatest in silty-sand substrates covered with eelgrass (*Zostera* spp.) (Wendell 1973). Sediment structure affects burrowing depth; clams burrow deeper in mud and sand substrates than in clay substrates (Oceanographic Institute of Washington 1981).

Physical/Chemical Characteristics: Juveniles and adults are found in polyhaline-euhaline waters, at temperatures of 2-20°C (Bernard 1983a). Larvae do not survive at 20°C (Bourne and Smith 1972a). Optimum conditions for somatic growth are 13°C water temperatures (range 11-18°C), 28‰ salinities (range 26-31‰), and food suspension density of 95 mg/l (range 15-200 mg/l) (Bernard 1983b).

Migrations and Movements: Eggs and larvae are dispersed by currents. Juveniles and adults do not move laterally once they become established. Clams older than two years (77 mm shell length) lose the ability to reburrow (Wendell et al. 1976).

Reproduction

Mode: The horseneck gaper is gonochoristic, oviparous, and iteroparous. It is a broadcast spawner, hence eggs are fertilized externally (Bourne and Smith 1972b).

Mating/Spawning: Spawning begins when waters warm after the seasonal minimum (Bourne and Smith 1972b, Cheney and Mumford 1986), usually late winter to early spring. In British Columbia and Puget Sound, spawning occurs from February-May, peaking primarily in March (Bourne and Smith 1972b). In California and Oregon, spawning occurs from January-March, peaking in February (Machell 1968, Machell and DeMartini 1971, Breed-Willeke and Hancock 1980, Robinson and Breese 1982). The horseneck gaper may spawn more than once during the spawning season (Bourne and Smith 1972b)

Fecundity: Unknown.

Growth and Development

Egg Size and Embryonic Development: Eggs are spherical and 0.06-0.07 mm in diameter (Bourne and Smith 1972a). Embryonic development is indirect and external; after fertilization, polar bodies form within 40 minutes, trochophores form within 24 hours, and veligers by 48 hours.

Age and Size of Larvae: Larvae range from 0.06-0.07 mm to 0.26-0.27 mm in diameter (Bourne and Smith 1972a). Metamorphosis to spat takes 24 days at 15°C, 26 days at 10°C, and 34 days at 5°C (Bourne and Smith 1972a). Larval settlement occurs primarily between early spring and summer.

Juvenile Size Range: Juveniles range in size from 0.26-0.28 mm to about 70 mm shell length (Bourne and Smith 1972a, 1972b). They may grow to 2.54 cm after 1 winter (Quayle and Bourne 1972). Most growth occurs during the spring and summer when phytoplankton is abundant (Wendell et al. 1976, Haderlie and Abbott 1980).

Age and Size of Adults: Size appears to determine maturity; most horseneck gapers mature at about 70 mm shell length (SL) (Bourne and Smith 1972b). In British Columbia, this takes four years, but only three years in California and Oregon (Bourne and Smith 1972b, Wendell et al. 1976, Hancock et al. 1979). In Oregon, subtidal clams between the ages of four and seven years grow faster than intertidal clams of similar ages (Hancock et al. 1979). The horseneck gaper can live to 16 years and can reach 254 mm SL (Morris 1966, Bourne and Smith 1972b). The oldest clams found in Oregon were 10-12 years old (Hancock et al. 1979).

Food and Feeding

Trophic Mode: Juveniles and adults are suspension/filter feeders (Haderlie and Abbott 1980). Food particles travel in water through the inhalant siphon and are collected on the gills, sorted by the palps, and passed to the mouth. Energy reserves are stored as glycogen in the gonads and as fat (Reid 1969).

Food Items: Juveniles and adults feed on suspended diatoms, flagellates, dinoflagellates, and fine detritus, including small eelgrass (*Z. marina*) particles (Stout 1967, Haderlie and Abbott 1980).

Biological Interactions

Predation: Eggs and larvae are probably preyed on by many planktivorous organisms. Predators of juveniles include: worms, snails, crustaceans, and copper rockfish (*Sebastes caurinus*) (Wolotira et al. 1989). Common predators of juveniles and adults include moon snails (*Polinices* spp.), Dungeness crab (*Cancer magister*), bat ray (*Myliobatis californica*), and sea stars (*Pisaster* spp.) (Haderlie and Abbott 1980).

Factors Influencing Populations: Predation can cause very high mortalities on some clam beds (Haderlie and Abbott 1980). High mortality of small juveniles is probably due to low salinities, temperature stress and predation (Wendell et al. 1976). As they grow, horseneck gapers burrow deeper, escaping many physical and biological stresses. Recruitment may be highly variable on some clam beds, resulting in beds dominated by only one or two age classes (Wendell et al. 1976, T. Gaumer, Oregon Department of Fisheries, Newport, OR, pers. comm.). In general, intertidal populations of this species are affected by numerous alterations and disturbances, including: siltation, storms, freshwater runoff, floods, erosion, dredging, and marina development (Schink et al. 1983). Diseases may also affect horseneck gaper populations (Wendell 1973, Armstrong and Armstrong 1974); it is often infected with a haplosporidan parasite (43% in Yaquina Bay, Oregon) (Armstrong and Armstrong 1974). Two species of pinnotherid crabs (*Pinnixa faba* and *P. littoralis*) are known to inhabit the mantle cavity of horseneck gapers (Pearce 1965, Stout 1967), but apparently cause little harm to the clam (Haderlie and Abbott 1980).

References

Armstrong, D. A., and J. L. Armstrong. 1974. A haplosporidan infection in gaper clams, *Tresus capax* (Gould), from Yaquina Bay, Oregon. Proc. Natl. Shellfish. Assoc. 64:68-72.

Bernard, F. R. 1983a. Catalogue of the living Bivalvia of the eastern Pacific Ocean: Bering Strait to Cape Horn. Can. Spec. Fish. Aquat. Sci. 61,102 p.

Bernard, F. R. 1983b. Physiology and the mariculture of some northeastern Pacific bivalve molluscs. Can. Spec. Publ. Fish. Aquat. Sci. 63, 24 p.

Bourne, N., and D. W. Smith. 1972a. The effect of temperature on the larval development of the horse clam, *Tresus capax* (Gould). Proc. Natl. Shellfish. Assoc. 62:35-37.

Bourne, N., and D. W. Smith. 1972b. Breeding and growth of the horse clam, *Tresus capax* (Gould), in southern British Columbia. Proc. Natl. Shellfish. Assoc. 62:38-46.

Breed-Willeke, G. M., and D. R. Hancock. 1980. Growth and reproduction of subtidal population of the gaper clam *Tresus capax* (Gould) from Yaquina Bay, Oregon. Proc. Natl. Shellfish. Assoc. 70:1-13.

Cheney, D. P., and T. F. Mumford, Jr. 1986. Shellfish and seaweed harvests of Puget Sound. Wash. Sea Grant, Univ. Wash. Press, Seattle, WA, 164 p.

Frey, H. W. 1971. California's living marine resources and their utilization. Calif. Fish Game, Sacramento, CA, 148 p.

Gates, D. E., and H. W. Frey. 1971. Designated common names of certain marine organisms of California. Calif. Fish Game, Fish Bull. 161:55-90.

Goodwin, L., and W. Shaul. 1978. Puget Sound subtidal hardshell clam survey data. Prog. Rep. 44, Wash. Dept. Fish., Olympia, WA, 92 p.

Haderlie, E. C., and D. P. Abbott. 1980. Bivalvia: The clams and allies. *In* R. H. Morris, D. P. Abbott, and E. C. Haderlie (editors), Intertidal invertebrates of California, p. 355-411. Stanford Univ. Press, Stanford, CA.

Hancock, D. R., T. F. Gaumer, G. B. Willeke, G. P. Robart, and J. Flynn. 1979. Subtidal clam populations: distribution, abundance, and ecology. Oregon Sea Grant Publ. No. ORESU-T-79-002. Oregon State Univ., Corvallis, OR, 243 p.

Machell, J. R. 1968. The reproductive cycle of the clam *Tresus capax* (Gould, 1850), Family Mactridae, in south Humboldt Bay, California. M.A. Thesis, Humboldt State Univ., Arcata, CA, 28 p.

Machell, J. R., and J. D. DeMartini. 1971. An annual reproductive cycle of the gaper clam, *Tresus capax* (Gould), in southern Humboldt Bay, California. Calif. Fish Game 57(4):274-282.

Morris, P. A. 1966. A field guide to Pacific coast shells. Houghton-Mifflin Co., Boston, MA, 297 p.

Oceanographic Institute of Washington. 1981. Clam and mussel harvesting industries in Washington State. Oceanog. Comm. Wash., Seattle, WA, various pagination.

Oregon Department of Fish and Wildlife. 1976. Oregon's captivating clams. Corvallis, OR.

Pearce, J. B. 1965. On the distribution of *Tresus nuttallii* and *Tresus capax* in the waters of Puget Sound and the San Juan Archipelago. Veliger 7(3):166-170.

Quayle, D. B., and N. Bourne. 1972. The clam fisheries in British Columbia. Fish. Res. Board Can., Bull. No. 179, 70 p.

Reid, R. G. B. 1969. Seasonal observations on diet, and stored glycogen and lipids in the horse clam, *Tresus capax* (Gould, 1850). Veliger 11(4):378-381.

Ricketts, E. F., J. Calvin, J. W. Hedgpeth, and D. W. Phillips. 1985. Between Pacific tides. Stanford Univ. Press, Stanford, CA, 652 p.

Robinson, A. M., and W. P. Breese. 1982. The spawning season of four species of clams in Oregon. J. Shellfish Res. 2(1):55-57.

Rudy, P., Jr., and L. H. Rudy. 1983. Oregon estuarine invertebrates - An illustrated guide to the common and important invertebrate animals. U.S. Fish Wildl. Serv., Biol. Serv. Prog., FWS/OBS-83/16, Portland, OR, 225 p.

Schink, T. D., K. A. McGraw, and K. K. Chew. 1983. Pacific coast clam fisheries. Wash. Sea Grant, Univ. Wash., Seattle, WA, 72 p.

Stout, W. E. 1967. A study of the autecology of the horse neck clams *Tresus capax* and *Tresus nuttallii* in South Humboldt Bay, California. M.A. Thesis, Humboldt State Univ., Arcata, CA, 51 p.

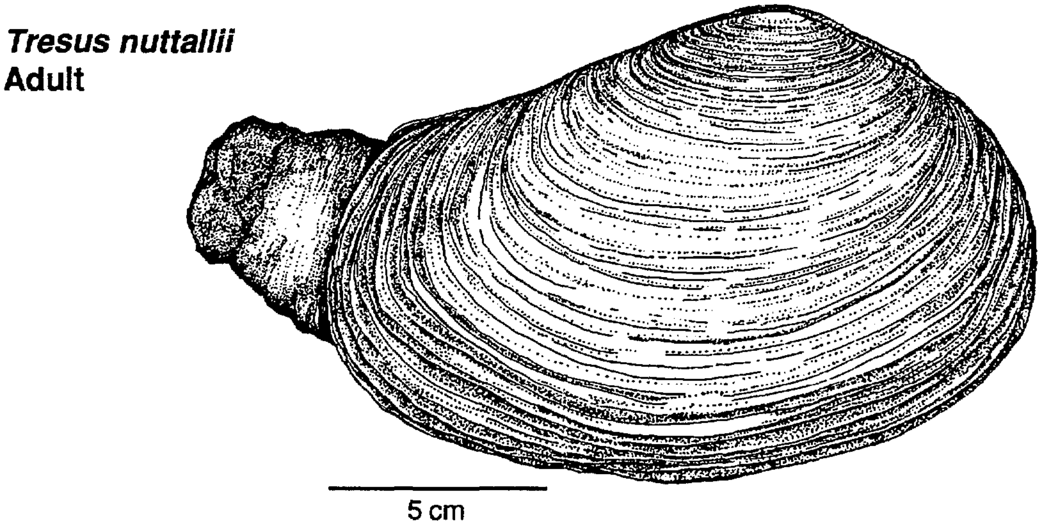
Washington Department of Fisheries. 1986. 1986-1987 (April 1 thru March 31) salmon, shellfish, bottom fish sport fishing guide. Wash. Dept. Fish., Olympia, WA, 20 p.

Wendell, F. E. 1973. Ecology of the gaper clam, *Tresus capax* (Gould, 1850) in Humboldt Bay, California. M.S. Thesis, Humboldt State Univ., Arcata, CA, 37 p.

Wendell, F., J. D. DeMartini, P. Dinnel, and J. Siecke. 1976. The ecology of the gaper or horse clam, *Tresus capax* (Gould 1850) (Bivalvia: Mactridae) in Humboldt Bay, California. Calif. Fish Game 62(1):41-64.

Wolotira, R. J., Jr., M. J. Allen, T. M. Sample, C. R. Iten, S. F. Noel, and R. L. Henry. 1989. Life history and harvest summaries for selected invertebrate species occurring off the west coast of North America. Volume 1: Shelled molluscs. NOAA Tech. Memo. NMFS F/NWC-160, 177 p.

Pacific gaper



Common Name: Pacific gaper
Scientific Name: *Tresus nuttallii*
Other Common Names: Washington clam, big-neck clam, blue clam, empire clam, gaper clam, great horseneck clam, otter-shell clam, rubberneck clam, summer clam (Wolotira et al. 1989)
Classification (Bernard 1983)
Phylum: Mollusca
Class: Bivalvia
Order: Veneroida
Family: Mactridae

Value

Commercial: The Pacific gaper is harvested with the similar horseneck clam, *Tresus capax*. Landings are not identified to species, but instead reported together as "horse clams". From 1981-1983, horse clam landings from the U.S. and Canadian Pacific coast averaged about 225 t annually, and ranked fifth in volume of all clams harvested (Wolotira et al. 1989). Much of the commercial harvest in British Columbia has been by geoduck (*Panopea abrupta*) divers after they have reached their geoduck quota (Wolotira et al. 1989). The Pacific gaper is relatively large and has many biological characteristics which discourage commercialization. It burrows deep into soft sediments, making hand harvest difficult. The shells are relatively fragile and tend to break; once harvested, the shells gape, causing water loss and reducing shelf life. Meat yield per clam is relatively low, usually <30%, and the large siphon (often 60% of its shucked weight) has a tough, leathery skin that requires extra effort to remove (Quayle and Bourne 1972, Ricketts et al. 1985, Wolotira et al. 1989). This species is harvested both subtidally and intertidally using hydraulic pumps, mechanical dredges, potato forks, shovels, and clam rakes (Frey 1971, Wolotira et al. 1989). It is taken year-round, but most are harvested from July to December in British Columbia (Wolotira et al. 1989).

Recreational: The Pacific gaper is an important recreational species in Puget Sound, Washington, and in California estuaries, including Humboldt Bay, Tomales Bay, Bodega Bay, Drakes Estero, Bolinas Lagoon, Elkhorn Slough, and Morro Bay. It is rarely found in the estuaries of coastal Washington and Oregon except for Netarts Bay, Oregon, where >50% of the gapers are *T. nuttallii* (T. Gaumer, Oregon Department of Fish and Wildllife, Newport, OR, pers. comm.). It is particularly abundant in Tomales Bay where up to 35,000 have been taken annually at one location (Frey 1971). This species is dug at low tide by hand or with hand tools (Frey 1971). It is one of the most common bay clams along the California coast. Not more than ten Pacific gapers per person per day can be taken in most areas of California (Schultze 1986). This species is often made into chowder (Frey 1971).

Indicator of Environmental Stress: Clam beds are sometimes closed to harvest because of paralytic shellfish poisoning. Other beds are permanently closed to harvesting because of contamination by coliform bacteria. As a result of pollution in Washington waters, over 25% of the potential areas for subtidal clam harvesting are closed (Schink et al. 1983). In California, clams in estuaries such as San Francisco Bay are not commonly harvested because of pollution. Embryos are good bioassay organisms (Woelke et al. 1971).

Ecological: This species is a large, subtidal and lower intertidal suspension/filter feeding bivalve and is

Table 1. Relative abundance of Pacific gaper in 32 U.S. Pacific coast estuaries.

Estuary	*Life Stage* A	S	J	L	E
Puget Sound	◉	◉	◉	◉	◉
Hood Canal	◉	◉	◉	◉	◉
Skagit Bay	○	○	○	○	○
Grays Harbor	√		√		
Willapa Bay	√		√		
Columbia River					
Nehalem Bay					
Tillamook Bay					
Netarts Bay	◉	◉	◉	◉	◉
Siletz River					
Yaquina Bay	√	√	√	√	√
Alsea River					
Siuslaw River					
Umpqua River					
Coos Bay					
Rogue River					
Klamath River					
Humboldt Bay	○	○	○	○	○
Eel River					
Tomales Bay	◉	◉	◉	◉	◉
Cent. San Fran. Bay *	√	√	√	√	√
South San Fran. Bay	√		√		
Elkhorn Slough	◉	◉	◉	◉	◉
Morro Bay	◉	◉	◉	◉	◉
Santa Monica Bay	√	√	√	√	√
San Pedro Bay	◉	◉	◉	◉	◉
Alamitos Bay	√	√	√	√	√
Anaheim Bay	√	√	√	√	√
Newport Bay	√	√	√	√	√
Mission Bay	√	√	√	√	√
San Diego Bay	√	√	√	√	√
Tijuana Estuary	√	√	√	√	√
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

important in Puget Sound and many California estuaries, bays, and lagoons (Frey 1971). Pea crabs (*Pinnixa faba* and occasionally *P. littoralis*) can be found in the Pacific gaper's mantle cavity (Ricketts et al. 1985). The hard, leathery tips are often covered with many different species of plants and animals (Haderlie and Abbott 1980). The Pacific gaper appears to harbor pea crabs only in the southern part of its range (Pearce 1965). This species is an intermediate host for the tapeworm, *Echeneibothrium* sp., whose definitive host is the bat ray (*Myliobatis californica*) (Haderlie and Abbott 1980).

Range

Overall: The Pacific gaper is a temperate, amphi-North Pacific species (Bernard 1983, Wolotira et al. 1989). In North America, it is found from Scammons Lagoon, Baja California, to British Columbia (Fitch 1953).

Within Study Area: The Pacific gaper is found in Pacific coast estuaries from Puget Sound, Washington, to Tomales Bay (Table 1). However, it is rarely found in the coastal estuaries of Washington and Oregon (except Netarts Bay), and is not common in most bays and lagoons south of Pt. Conception, California.

Life Mode

Eggs and larvae are pelagic. Juveniles and adults are benthic infauna; adults may burrow to depths of 1 m (usually found 25-50 cm deep) (Cheney and Mumford 1986, Wolotira et al. 1989).

Habitat

Type: Eggs and larvae are neritic. Juveniles and adults are found primarily in bays and estuaries, but may also occur in protected coastal waters (Frey 1971, Wolotira et al. 1989). Juveniles and adults occur from the lower intertidal zone to 30 m below mean lower low water (MLLW). In Puget Sound, they are most abundant from 1-5 m below MLLW (Goodwin and Shaul 1978, Cheney and Mumford 1986).

Substrate: The Pacific gaper is most abundant in sediments consisting of fine sand or firm sandy mud. But, it is also found in relatively firm sediments consisting of sand, silty-sand, sandy-clay, and gravel (Swan and Finucane 1951, Bourne and Smith 1972, Cheney and Mumford 1986, Wolotira et al. 1989). Sediment structure affects burrowing depth; clams burrow deeper in mud and sand substrates than clay substrates (Oceanographic Institute of Washington 1981).

Physical/Chemical Characteristics: It occurs in polyhaline-euhaline waters, and temperatures of 1-21°C (Bernard 1983). Freezing temperatures on mud flats may limit this species' northern distribution (Pearce 1965).

Migrations and Movements: Eggs and larvae are dispersed by currents. Juveniles and adults do not move laterally once they become established. Small Pacific gapers have the ability to reburrow after being disturbed, but like *T. capax*, older, larger clams (>60 mm shell length) lose the ability to reburrow (Pholo 1964, Wendell et al. 1976). However, since most larger clams live deep within the sediment (up to 1 m) they are protected from most natural disturbances. Peak settlement for spat occurs in May in central California and probably July in Puget Sound (Woelke et al. 1971, Clark et al. 1975).

Reproduction

Mode: The Pacific gaper is gonochoristic, oviparous, and iteroparous. It is a broadcast spawner; eggs are fertilized externally (Quayle and Bourne 1972).

Mating/Spawning: Spawning occurs year-round, depending on geographical location. Spawning occurs during summer in northern regions such as British Columbia and Puget Sound (Quayle and Bourne 1972, Cheney and Mumford 1986). Spawning occurs from spring to fall for much of California (Frey 1971), and year-round in central California, with a peak from February to April when temperatures are lowest (Laurent 1971, Clark et al. 1975, Haderlie and Abbott 1980, Ricketts et al. 1985). The wide daily water temperature fluctuations in central California may explain the occurrence of year-round spawning (Clark et al. 1975).

Fecundity: Unknown.

Growth and Development

Egg Size and Embryonic Development: Egg size is unknown, however, embryonic development is indirect and external (Wolotira et al. 1989).

Age and Size of Larvae: Larvae are probably 0.06-0.28 mm in diameter (Bourne and Smith 1972). In Elkhorn Slough, California, the duration of the larval stage is estimated to be 21-30 days (Clark et al. 1975). Spat require ten days to grow to 2 mm, and 25 days to grow to 5 mm (Clark et al. 1975).

Juvenile Size Range: Juveniles are 0.26 mm to 51.0-71.0 mm in diameter; small clams (4 mm) grow 0.25 mm/day (Frey 1971, Bourne and Smith 1972, Haderlie and Abbott 1980). One-year-old clams average 50 mm in shell length (Clark et al. 1975, Haderlie and Abbott 1980).

Age and Size of Adults: This species matures in about two years and between 51.0-70.0 mm shell length (Frey 1971, Clark et al. 1975, Haderlie and Abbott 1980). The Pacific gaper may live to 17 years, with a shell length as great as 200 mm (Frey 1971, Wolotira et al. 1989).

Food and Feeding

Trophic Mode: This species is a suspension/filter feeder. Food particles are transported via the inhalant siphon and are filtered from the water by the gills, sorted by the palps, and passed to the mouth.

Food Items: Food items include suspended diatoms, flagellates, dinoflagellates, and detritus. Detritus may include particles of eelgrass (*Zostera marina*) (Stout 1967, Haderlie and Abbott 1980).

Biological Interactions

Predation: Predators include those that prey on *T. capax*, especially worms, snails, crustaceans, fish, and mammals. Common predators include moon snails (*Polinices* spp.), Dungeness crab (*Cancer magister*), bat ray (Myliobatus cali*fornica*), leopard shark (*Triakis semifasciata*), starry flounder (*Platichthys stellatus*), sea stars (*Pisaster* spp.), and sea otters (*Enhydra lutris*) (Talent 1976, Haderlie and Abbott 1980, Kvitek et al. 1988). Many planktivorous organisms prey on Pacific gaper eggs and larvae.

Factors Influencing Populations: Sea otters prefer to feed in areas where Pacific gaper densities are high and composed of small individuals unable to burrow deeply because of sediment characteristics (Kvitek et al. 1988); large Pacific gapers in soft sediments are resistant to sea otter predation. The Pacific gaper may compete with *T. capax*, however *T. capax* is more common in gravel-shell soils whereas *T. nuttallii* is more common in pure sand substrates (Swan and Finucane 1951, Quayle and Bourne 1972, Wolotira et al. 1989). The Pacific gaper also burrows deeper than *T. capax* and thus avoids temporary freezing conditions (Quayle and Bourne 1972, Haderlie and Abbott 1980). No information is available concerning mortality rates, but very high mortality rates probably occur during larval and early juvenile stages, becoming lower as clams mature (Wolotira et al. 1989). Annual juvenile recruitment varies widely and probably has a major effect on the population structure (Clark et al. 1975).

References

Bernard, F. R. 1983. Catalogue of the living Bivalvia of the eastern Pacific Ocean: Bering Strait to Cape Horn. Can. Spec. Fish. Aquat. Sci. 61, 102 p.

Bourne, N., and D. W. Smith. 1972. The effect of temperature on the larval development of the horse clam, *Tresus capax* (Gould). Proc. Natl. Shellfish. Assoc. 62:35-46.

Cheney, D. P., and T. F. Mumford, Jr. 1986. Shellfish and seaweed harvests of Puget Sound. Wash. Sea Grant, Univ. Wash. Press, Seattle, WA, 164 p.

Clark, P., J. Nybakken, and L. Laurent. 1975. Aspects of the life history of *Tresus nuttallii* in Elkhorn Slough. Calif. Fish Game 6(4):215-227.

Fitch, J. E. 1953. Common marine bivalves of California. Calif. Fish Game, Fish Bull. 90, 102 p.

Frey, H. W. 1971. California's living marine resources and their utilization. Calif. Dept. Fish Game, Sacramento, CA, 148 p.

Goodwin, L., and W. Shaul. 1978. Puget Sound subtidal hardshell clam survey data. Prog. Rep. 44, Wash. Dept. Fish., Olympia, WA, 92 p.

Haderlie, E. C., and D. P. Abbott. 1980. Bivalvia: The clams and allies. *In* R. H. Morris, D. P. Abbott, and E. C. Haderlie (editors), Intertidal invertebrates of California, p. 355-411. Stanford Univ. Press, Stanford, CA.

Kvitek, R. G., A. K. Fukayama, B. S. Anderson, and B. K. Grimm. 1988. Sea otter foraging on deep-burrowing bivalves in a California coastal lagoon. Mar. Biol. 98:157-167.

Laurent, L. L. 1971. The spawning cycle and juvenile growth rate of the gaper clam, *Tresus nuttallii*, of Elkhorn Slough, California. M.A. Thesis, San Francisco State College, San Francisco, CA, 55 p.

Oceanographic Institute of Washington. 1981. Clam and mussel harvesting industries in Washington State. Oceanog. Comm. Wash., Seattle, WA, various pagination.

Pearce, J. B. 1965. On the distribution of *Tresus nuttallii* and *Tresus capax* in the waters of Puget Sound and the San Juan Archipelago. Veliger 7(3):166-170.

Pohlo, R. H. 1964. Ontogenetic changes of form and mode of life in *Tresus nuttallii* (Bivalvia: Mactridae). Malacologia 1(3):321-330.

Quayle, D. B., and N. Bourne. 1972. The clam fisheries in British Columbia. Fish. Res. Board Can., Bull. No. 179, 70 p.

Ricketts, E. F., J. Calvin, J. W. Hedgpeth, and D. W. Phillips. 1985. Between Pacific tides. Stanford Univ. Press, Stanford, CA, 652 p.

Schink, T. D., K. A. McGraw, and K. K. Chew. 1983. Pacific coast clam fisheries. Wash. Sea Grant, Univ. Wash., Seattle, WA, 72 p.

Schultze, D. L. 1986. Digest of California commercial fish laws, January 1, 1986. Calif. Dept. Fish Game, Sacramento, CA, 40 p.

Stout, W. E. 1967. A study of the autecology of the horse neck clams *Tresus capax* and *Tresus nuttallii* in South Humboldt Bay, California. M.A. Thesis, Humboldt State Univ., Arcata, CA, 51 p.

Swan, E. F., and J. H. Finucane. 1951. Observations on the genus *Schizothaerus*. Nautilus 66(1):19-26.

Talent, L. G. 1976. Food habits of the leopard shark, *Triakis semifasciata*, in Elkhorn Slough, Monterey Bay, California. Calif. Fish Game 62(4):286-298.

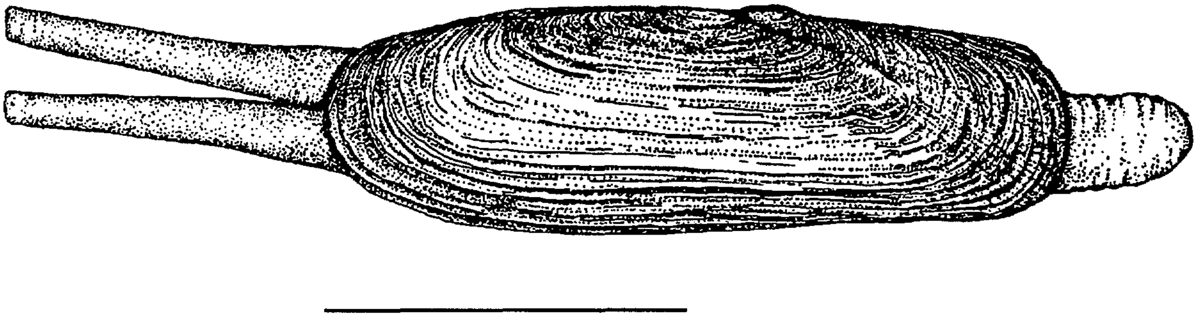
Wendell, F., J. D. DeMartini, P. Dinnel, and J. Siecke. 1976. The ecology of the gaper or horse clam, *Tresus capax* (Gould 1850) (Bivalvia: Mactridae) in Humboldt Bay, California. Calif. Fish Game 62(1):41-64.

Woelke, C., T. Schink, E. Sanborn, and W. Hoffman. 1971. Bivalve embryo bioassays of marine waters from Drayton Harbor to Hale Passage. Wash. Dept. Fish., Unpubl. Rep. to Atlantic Richfield Co., Olympia, WA, 18 p.

Wolotira, R. J., Jr., M. J. Allen, T. M. Sample, C. R. Iten, S. F. Noel, and R. L. Henry. 1989. Life history and harvest summaries for selected invertebrate species occurring off the west coast of North America. Volume 1: Shelled molluscs. NOAA Tech. Memo. NMFS F/NWC-160, 177 p.

California jackknife clam

Tagelus californianus
Adult



Common Name: California jackknife clam
Scientific Name: *Tagelus californianus*
Other Common Names: California short razor, short razor clam, jackknife clam, razor clam (Gates and Frey 1974)
Classification (Bernard 1983)
Phylum: Mollusca
Class: Bivalvia
Order: Veneroida
Family: Psammobiidae

Value

Commercial: This species is commercially dug for use as fish bait (Fitch 1953). Harvest began in 1962 and during the mid-1970s harvests averaged about 6 t/year (Wolotira et al. 1989).

Recreational: Although edible, it is most often used as fish bait (Fitch 1953, Meinkoth 1981).

Indicator of Environmental Stress: High temperatures (e.g., thermal effluent from power plants) can adversely affect populations (Merino 1981).

Ecological: The California jackknife clam is a numerically important bivalve species in southern California bays and lagoons.

Range

Overall: This species' overall range is from Cape San Lucas, Baja California to Cape Blanco, Oregon (Fitch 1953, Meinkoth 1981, Wolotira et al. 1989). Its recorded presence off Panama is probably not accurate (Wolotira et al. 1989).

Within Study Area: It is common to abundant from Tijuana estuary to Morro Bay, California; it is not common north of Monterey Bay, California (Table 1) (Fitch 1953, Haderlie and Abbott 1980, Seapy 1981).

Life Mode

Eggs and larvae are planktonic. Juveniles and adults are benthic infauna of bays, estuaries, or lagoons. Juveniles and adults live in a permanent, nonmucous-lined, vertical burrow 10-50 cm deep in which they can readily move up and down (Fitch 1953, Meinkoth 1981).

Habitat

Type: Eggs and larvae are estuarine-neritic. Adults and juveniles are common near mean low tide where sediments are appropriate (Seapy and Kitting 1978, Merino 1981). Adults and juveniles inhabit sand, mud, or muddy sand flats near the low tide level in bays, sloughs, and estuaries (Fitch 1953, Smith and Carlton 1975, Meinkoth 1981). This species reportedly occurs from +0.2 to -0.5 m mean tide level (Wolotira et al. 1989), but does not occur above mean sea level in San Diego Bay (Merino 1981). The bays and lagoons this species inhabits are euhaline on an annual basis. In low intertidal substrates, it is commonly associated with the rosy jackknife (*Solen rosaceus*) (Merino 1981).

Substrate: The California jackknife clam prefers sediments having some silts and clays (2-15%), and cannot burrow into sediments that are composed primarily of sand (Merino 1981).

Physical/Chemical Characteristics: This species is found in mesohaline-euhaline waters where water temperatures range from 9 to 30°C (Bernard 1983). Temperatures ≥35°C cause adult mortality. In San

Table 1. Relative abundance of California jackknife clam in 32 U.S. Pacific coast estuaries.

	Life Stage				
Estuary	A	S	J	L	E
Puget Sound					
Hood Canal					
Skagit Bay					
Grays Harbor					
Willapa Bay					
Columbia River					
Nehalem Bay					
Tillamook Bay					
Netarts Bay					
Siletz River					
Yaquina Bay					
Alsea River					
Siuslaw River					
Umpqua River					
Coos Bay					
Rogue River					
Klamath River					
Humboldt Bay					
Eel River					
Tomales Bay	√	√	√	√	√
Cent. San Fran. Bay *	√	√	√	√	√
South San Fran. Bay					
Elkhorn Slough	√	√	√	√	√
Morro Bay	○	○	○	○	○
Santa Monica Bay	◉	◉	◉	◉	◉
San Pedro Bay	◉	◉	◉	◉	◉
Alamitos Bay	○	○	○	○	○
Anaheim Bay	○	○	○	○	○
Newport Bay	○	○	○	○	○
Mission Bay	◉	◉	◉	◉	◉
San Diego Bay	◉	◉	◉	◉	◉
Tijuana Estuary	◉	◉	◉	◉	◉
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	*Rare*
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

Diego Bay, the clam's upper lethal tolerance limit (LT50) was 35.5°C in December and 37.6°C in May (Merino 1981). Smaller sizes (23-46 mm) are more resistant to elevated temperatures (Merino 1981).

Migrations and Movements: Eggs and larvae are dispersed by currents. Juveniles and adults migrate up and down in their burrow as the tide rises and falls (Meinkoth 1981) and will rapidly descend in their burrows when disturbed.

Reproduction

Mode: This species is gonochoristic, oviparous, and iteroparous. It is a broadcast spawner; eggs are fertilized externally.

Mating/Spawning: The exact spawning time for this species is unknown, however, spawning occurs intertidally during high tide. Eggs and sperm are released through the exhalant siphon. Based on the settlement of young, a peak spawning probably occurs in early spring (May-June recruitment), with some spawning occurring year-round (Merino 1981).

Fecundity: Unknown.

Growth and Development

Egg Size and Embryonic Development: Unknown, but embryonic development is probably indirect and external.

Age and Size of Larvae: Unknown.

Juvenile Size Range: The stout tagelus (*Tagelus plebius*) is a congener, and has spat that settle out of the water column at 155-175 µm in shell length (SL) (Merino 1981). Clams average about 46 mm SL at 2.5 years (Merino 1981).

Age and Size of Adults: The California jackknife reaches maturity between 60 and 120 mm SL (Merino 1981). Age and growth of this species has not been determined, but it appears to reach reproductive size in 2-3 years (Merino 1981). Ultimate age is unknown. Clams in San Diego Bay average 72 mm SL and appear to be 5 years old (Merino 1981).

Food and Feeding

Trophic Mode: This species is a suspension feeder, although originally it was thought to be a deposit feeder (Pohlo 1966, Haderlie and Abbott 1980). When feeding, it is located about 10 cm below the substratum surface and extends its two siphons into the water through separate openings (Haderlie and Abbott 1980). The siphon openings lay at the sediment-water interface.

Food Items: The California jackknife clam feeds on phytoplankton, probably including diatoms, dinoflagellates, and other types of phytoplankton. Its diet may include suspended detrital particles and their associated epifauna (Wolotira et al. 1989).

Biological Interactions

Predation: Larvae probably are eaten by planktivorous fishes and invertebrates. Newly-settled individuals and juveniles are eaten by numerous fishes, including diamond turbot (*Hypsopsetta guttulata*) (Lane 1975), stingrays (*Dasyatis* spp.), and other rays. Birds such as stilts (*Himantopus* spp.), godwits (*Limosa* spp.), curlews (*Numenius* spp.), and dowitchers (*Limnodromus* spp.), also prey on the California jackknife clam (Merino 1981).

Factors Influencing Populations: Population densities are influenced by tidal elevation, water temperature, sediment characteristics, recruitment, and mortality. There are no indications that populations are controlled by density-dependent interactions (Merino 1981).

References

Bernard, F. R. 1983. Catalogue of the living Bivalvia of the eastern Pacific Ocean: Bering Strait to Cape Horn. Can. Spec. Publ. Fish. Aquat. Sci. 61, 102 p.

Fitch, J. E. 1953. Common marine bivalves of California. Calif. Fish Game, Fish Bull. 90, 102 p.

Gates, D. E., and H. W. Frey. 1974. Designated common names of certain marine organisms of California. Calif. Fish Game, Fish Bull. 161:55-90.

Haderlie, E. C., and D. P. Abbott. 1980. Bivalvia: The clams and allies. *In* R. H. Morris, D. P. Abbott, and E. C. Haderlie, Intertidal invertebrates of California, p. 355-411. Stanford Univ. Press, Stanford, CA.

Lane, E. D. 1975. Quantitative aspects of the life history of the diamond turbot, *Hypsopsetta guttulata* (Girard), in Anaheim Bay. *In* E. D. Lane and C. W. Hill (editors), The marine resources of Anaheim Bay. Calif. Fish Game, Fish Bull. 165:153-173.

Meinkoth, N. A. 1981. The Audubon Society field guide to North American seashore creatures. Alfred A. Knopf, Inc., New York, NY, 799 p.

Merino, J.-M. 1981. A study of the temperature tolerances of adult *Solen rosaceus* and *Tagelus californianus* in south San Diego Bay: the effects of power plant cooling water discharge. Ph.D. Diss., San Diego State Univ., San Diego, CA, 140 p.

Pohlo, R. 1966. A note on the feeding behavior in *Tagelus californianus*. Veliger 8(4):225.

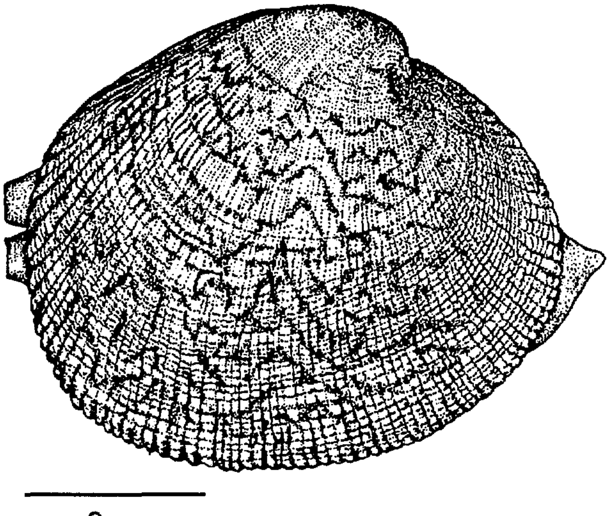
Seapy, R. R. 1981. Structure, distribution, and seasonal dynamics of the benthic community in the upper Newport Bay, California. Mar. Res. Tech. Rep. 46, Calif. Dept. Fish Game, Sacramento, CA, 74 p.

Seapy, R. R., and C. L. Kitting. 1978. Spatial structure of an intertidal molluscan assemblage on a sheltered sandy beach. Mar. Biol. 46:137-145.

Smith, R. I, and J. T. Carlton (editors). 1975. Lights manual: Intertidal invertebrates of the central California coast. Univ. Calif. Press, Berkeley, CA, 716 p.

Wolotira, R. J., Jr., M. J. Allen, T. M. Sample, C. R. Iten, S. F. Noel, and R. L. Henry. 1989. Life history and harvest summaries for selected invertebrate species occurring off the west coast of North America. Volume 1: shelled molluscs. NOAA Tech. Memo. NMFS F/NWC-160, 177 p.

Protothaca staminea
Adult



2 cm

Common Name: Pacific littleneck clam
Scientific Name: *Protothaca staminea*
Other Common Names: Tomales Bay cockle, common littleneck, littleneck clam, ribbed carpet shell, common Pacific littleneck, native littleneck, rock cockle, hardshell, rock clam, steamer, butter clam (Fitch 1953, Gates and Frey 1974, Hancock et al. 1979)
Classification (Bernard 1983a)
Phylum: Mollusca
Class: Bivalvia
Order: Veneroida
Family: Veneridae

Value

Commercial: The Pacific littleneck clam is usually sold fresh in the shell (Wolotira et al. 1989), but it is also sold frozen and canned (Paul and Feder 1976). It is harvested using rakes, shovels, and by mechanical and hydraulic devices (Frey 1971, Schink et al. 1983, Cheney and Mumford 1986). Harvested from Prince William Sound, Alaska to southern California, this species constitutes about 8% of the entire clam harvest along the Pacific coast of the United States and Canada (Wolotira et al. 1989). Most of this harvest comes from Washington and British Columbia. Most Pacific coast waters are open year-round, but California waters are closed to littleneck harvest from April to August in Marin County and from May to August for much of northern California (Schultze 1986). Because California commercial clammers are allowed only 50 clams/day over 3.8 cm diameter, the California commercial harvest is limited. New aquaculture programs may increase the production and harvest of this species.

Recreational: The Pacific littleneck clam is highly esteemed for its good taste and ease of capture (Fitch 1953). In California, up to 50 clams/day over 3.8 cm in diameter are allowed (California Department of Fish and Game 1987), while Oregon limits recreational harvest to only 36/day. The Washington limit varies depending on the area (60/day or 10 lb, 40/day or 7 lb, 5 lb/day) (Washington Department of Fisheries 1986). Clam diggers usually harvest this species at low tide during daylight using rakes, trowels, and shovels (Frey 1971).

Indicator of Environmental Stress: Habitat alterations (water pollution, marina construction, loss of habitat, etc.) directly affect the abundance of this species. Paralytic shellfish poisoning often closes clam beds to harvest for temporary periods and contamination by coliform bacteria has permanently closed many areas (Cheney and Mumford 1986). Commercial landings from the U.S. Pacific Northwest (excluding Alaska) have decreased in recent years, while effort has increased (Chew and Ma 1987). This species is highly sensitive to copper and tri-n-butyltin (a paint additive) (Roesijadi 1980). Crude oil reduces this species' growth rate, but does not appear to be highly toxic. However, the addition of oil dispersants can alter clam behavior deleteriously (Chew and Ma 1987).

Ecological: This species is common to highly abundant in many Pacific coast estuaries (Table 1). It is an important suspension feeder along protected gravel-mud beaches (Wolotira et al. 1989) and the most important lower intertidal clam in Puget Sound (Kozloff 1983).

Range

Overall: This species may be distributed from Socorro Island, Mexico, around the North Pacific rim to the

Table 1. Relative abundance of Pacific littleneck clam in 32 U.S. Pacific coast estuaries.

Life Stage

Estuary	A	S	J	L	E
Puget Sound	●	●	●	●	●
Hood Canal	●	●	●	●	●
Skagit Bay	●	●	●	●	●
Grays Harbor	○	○	○	○	○
Willapa Bay	○	○	○	○	○
Columbia River					
Nehalem Bay	●	●	●	●	●
Tillamook Bay	◉	◉	◉	◉	◉
Netarts Bay	◉	◉	◉	◉	◉
Siletz River					
Yaquina Bay	○	○	○	○	○
Alsea River	√	√	√	√	√
Siuslaw River	√	√	√	√	√
Umpqua River					
Coos Bay	●	●	●	●	●
Rogue River					
Klamath River					
Humboldt Bay	◉	◉	◉	◉	◉
Eel River					
Tomales Bay	◉	◉	◉	◉	◉
Cent. San Fran. Bay *	√	√	√	√	√
South San Fran. Bay	√	√	√	√	√
Elkhorn Slough	○	○	○	○	○
Morro Bay	○	○	○	○	○
Santa Monica Bay	○	○	○	○	○
San Pedro Bay	○	○	○	○	○
Alamitos Bay	◉	◉	◉	◉	◉
Anaheim Bay	◉	◉	◉	◉	◉
Newport Bay	○	○	○	○	○
Mission Bay	√	√	√	√	√
San Diego Bay	√	√	√	√	√
Tijuana Estuary	◉	◉	◉	◉	◉
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

northern Sea of Japan (Wolotira et al. 1989). However, most authors show it distributed from Cape San Lucas, Baja California, to the Aleutian Islands, Alaska (Fitch 1953, Schink et al. 1983, Cheney and Mumford 1986).

Within Study Area: It is found in most Pacific coast estuaries where appropriate substrates and salinities exist. It is not found in the Columbia, Siletz, Umpqua, and Rogue River estuaries of Oregon, or the Klamath, and Eel River estuaries in California (Table 1) (Monaco et al. 1990).

Life Mode

Eggs and larvae are pelagic, while very small clams are epifaunal (Paul and Feder 1973). Juveniles and adults are benthic infauna and found in the upper 15-20 cm of sediments (rarely deeper than 5-7 cm). Larger individuals are often found deeper than smaller ones (Fitch 1953, Quayle and Bourne 1972, Paul and Feder 1973, Abbott 1974, Meinkoth 1981, Wolotira et al. 1989).

Habitat

Type: Eggs and larvae are estuarine-neritic. Adults and juveniles are found in coarse, sandy-rocky muds of bays, sloughs, and estuaries, and on the open coast where there is appropriate substrate and protection (Fitch 1953). It is often associated with butter clams (*Saxidomus giganteus*) (Paul and Feder 1976). The Pacific littleneck clam is found intertidally down to 37 m (usually <10 m), but normally from -1.0 to 1.3 m mean lower low water (MLLW) (Chew and Ma 1987). It is most abundant from the lower intertidal zone to 0.4 m above MLLW (Goodwin and Shaul 1978, Bernard 1983a, Wolotira et al. 1989).

Substrate: The Pacific littleneck clam prefers firm, gravel or clay-gravel sediments, but occurs in sediments ranging from mud to cobble (Quayle and Bourne 1972, Goodwin and Shaul 1978). Along the open coast it is found in coarse sand, gravel, and cobble near rock points and reefs or under large rocks (Fitch 1953).

Physical/Chemical Characteristics: It is found in mesohaline to euhaline waters and temperatures of just below freezing to 25°C (Glude 1978, Bernard 1983a). Water temperatures above 25°C are lethal to larvae, and they can withstand 20°C only when salinity is near 32‰ (Strathmann et al. 1987). This species may tolerate salinities as low as 20‰ for extended periods (Quayle and Bourne 1972); however, it closes its shell at very low salinities. Optimum conditions for growth appear to be 12-18°C, 24-31‰ salinity, and 15-150 mg/l suspended food particles (Bernard 1983b). Also, areas near strong tidal currents may enhance growth (Chew and Ma 1987). Burial by decomposing bark has been shown to reduce survival (likely due to elevated levels of hydrogen sulfide and ammonia along with decreases in dissolved oxygen) (Freese and O'Clair 1987). High turbidities (>2 g/l) may reduce larval survival (Glude 1978).

Migration and Movements: Eggs and larvae are pelagic and dispersed by water currents. Veliger larvae move to the bottom after developing a foot. Here they search for an appropriate surface on which to settle, then undergo metamorphosis, and attach themselves to the sediment surface by secreting byssal threads (Chew and Ma 1987). Very young clams probably first attach in deeper waters and then move to shallow waters as they grow (Chew and Ma 1987). Adults are sedentary and remain in the same area for life, but a small juvenile clam can use its foot to crawl to new areas (Shaw

1986). Adults and juveniles can reburrow if they have been disturbed (Quayle and Bourne 1972).

Reproduction

Mode: The Pacific littleneck clam is gonochoristic (although some hermaphroditism occurs), oviparous, iteroparous, and a broadcast spawner; eggs are fertilized externally (Fraser and Smith 1928, Frey 1971). Females may spawn several times during a season (Quayle and Bourne 1972).

Mating/Spawning: Spawning occurs during spring and summer depending on the region: from March to August and sometimes later in Oregon estuaries (Robinson and Breese 1982); April to September in British Columbia; late spring to summer (April-July) in Puget Sound; late May to mid-June in Prince William Sound, Alaska (Fraser and Smith 1928, Haderlie and Abbott 1980, Cheney and Mumford 1986, Strathmann et al. 1987, Wolotira et al. 1989). It spawns at temperatures of 5.6-13.6°C in Prince William Sound (Wolotira et al. 1989), and begins spawning in south-central Alaska when water temperatures are about 8°C (Chew and Ma 1987). Dense algal suspensions may stimulate spawning (Robinson and Breese 1982). Optimum temperatures for rearing are 15-20°C (Strathmann et al. 1987).

Fecundity: Unknown.

Growth and Development

Egg Size and Embryonic Development: Eggs are spherical and 0.06 mm in diameter (Wolotira et al. 1989). Embryonic development is indirect and external. Fertilized eggs hatch to become free-swimming trochophore larvae in 10-12 hours; these transform into veliger larvae approximately 24 hours later (Quayle and Bourne 1972, Schink et al. 1983, Chew and Ma 1987).

Age and Size of Larvae: Larvae range from 0.06-0.25 mm long (Quayle and Bourne 1972, Wolotira et al. 1989). The larval period lasts about three weeks, but may be longer depending on water temperatures (Quayle and Bourne 1972, Cheney and Mumford 1986).

Juvenile Size Range: At settlement, juveniles are 0.26-0.28 mm in shell length (SL) (Quayle and Bourne 1972) and grow to 15-35 mm SL before maturity. Growth varies depending on the region. In Prince William Sound, clams are 2 mm SL at the end of the first growing season (Paul and Feder 1973).

Age and Size of Adults: This species is usually sexually mature after 1.5 years (and at 15-35 mm SL), but this depends upon location (Paul and Feder 1976, Ricketts et al. 1985, Cheney and Mumford 1986). British Columbia and Alaska clams are often not mature until their second or third year (Fraser and Smith 1928, Quayle 1943, Nickerson 1977). This species may live 13-16 years (Fraser and Smith 1928, Abbott 1974, Chew and Ma 1987). In California, many die before reaching sexual maturity and rarely do they reach 7 years old (Schmidt and Warme 1969). Maximum size is about 8 cm SL (Quayle and Bourne 1972, Oceanographic Institute of Washington 1981). Growth rates vary widely, depending on substrate, clam densities, tidal level, and geographic location (Chew and Ma 1987). For example, they may grow to 37 mm SL in 3.5-4 years in the Strait of Georgia (Cheney and Mumford 1986), and 6-8 years to reach 32 mm SL in Alaska (Paul and Feder 1973, 1976, Ricketts et al. 1985).

Food and Feeding

Trophic Mode: The Pacific littleneck clam is a nonselective suspension/filter feeder. It gathers food by sucking in water and food particles through the inhalant siphon. Particles are then filtered through the gills (ctenidia), and sorted by the palps before being brought to the mouth (Wolotira et al. 1989).

Food Items: Larvae, juveniles, and adults feed on phytoplankton, benthic diatoms, and detritus. The role of detritus in its diet is not well understood, but thought to be important (Peterson 1982, Chew and Ma 1987, Wolotira et al. 1989).

Biological Interactions

Predation: Important predators of the Pacific littleneck clam include: oyster drills (*Ceratostoma* spp. and *Urosalpinx* spp.), moon snails (*Polinices spp.*), and other gastropods, sea stars (*Pycnopodia helianthoides*, *Evasterias troschelli*, and *Pisaster brevispinis*), two-spotted octopus (*Octopus bimaculatus*), rock crabs (*Cancer* spp.), and fishes (Chew and Ma 1987, Wolotira et al. 1989). Rock crabs have the ability to identify foraging areas with high littleneck clam densities (Boulding and Hay 1984). In California lagoons, siphons are nipped off by Pacific staghorn sculpin (*Leptocottus armatus*), diamond turbot (*Hypsopsetta guttulata*), and California halibut (*Paralichthys californicus*) (Peterson and Quammen 1982). Sea otters (*Enhydra lutris*) are major predators in Prince William Sound, Alaska (Chew and Ma 1987), and the Pacific littleneck clam is also eaten by ducks and other birds (Schink et al. 1983, Cheney and Mumford 1986).

Factors Influencing Populations: Recruitment (i.e., survival of the settling spat) is highly variable and is a dominant factor determining population size (Paul and Feder 1973, 1976). Many environmental conditions affect successful settlement, such as temperature, adequate food supply, predation, currents, beach topography, and appropriate substrate (Paul and Feder 1973, Peterson 1982). High siltation caused by upland development and construction of marinas can cause problems (Schink et al. 1983). Dredging has been shown to affect subtidal populations. For example, mechanical clam harvesters may adversely affect populations by suspending and depositing fine sediments that can smother clams (Schink et al. 1983). Similarly, severe weather often affects intertidal populations by producing high freshwater run-off that kills clams by covering them with sediment or washing away sediments and exposing them (Cheney and Mumford 1986). "Winter kills" caused by low salinities, low temperatures, and microbial diseases may occur in northern latitudes (Schink et al. 1983, Cheney and Mumford 1986).

References

Abbott, R. T. 1974. American seashells: The marine mollusca of the Atlantic and Pacific coasts of North America, 2nd edition. Van Nostrand Reinhold Co., NY, 663 p.

Bernard, F. R. 1983a. Catalogue of the living bivalvia of the eastern Pacific Ocean: Bering Strait to Cape Horn. Can. Spec. Publ. Fish. Aquat. Sci. No. 61, 102 p.

Bernard, F. R. 1983b. Physiology and the mariculture of some northeastern Pacific bivalve molluscs. Can. Spec. Publ. Fish. Aquat. Sci. No. 63, 24 p.

Boulding, E. G., and T.K. Hay. 1984. Crab response to prey density can result in density-dependent mortality of clams. Can. J. Fish. Aquat. Sci. 41:521-525.

California Department of Fish and Game. 1987. 1987 California sport fishing regulations. Calif. Dept. Fish Game, Sacramento, CA, 12 p.

Cheney, D. P., and T. F. Mumford, Jr. 1986. Shellfish and seaweed harvests of Puget Sound. Wash. Sea Grant, Univ. Wash. Press, Seattle, WA, 164 p.

Chew, K. K., and A. P. Ma. 1987. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest)—common littleneck clam. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.78). U.S. Army Corps Eng., TR EL-82-4, 22 p.

Fitch, J. E. 1953. Common marine bivalves of California. Calif. Fish Game, Fish Bull. 90, 102 p.

Fraser, C. M., and G. M. Smith. 1928. Notes on the ecology of the littleneck clam, *Paphia staminea* Conrad. Trans. Roy. Soc. Can. 3(22):249-269.

Freese, J. L., and C. E. O'Clair. 1987. Reduced survival and condition of the bivalves *Protothaca staminea* and *Mytilus edulis* buried by decomposing bark. Mar. Env. Res. 23:49-64.

Frey, H. W. 1971. California living marine resources and their utilization. Calif. Dept. Fish Game, Sacramento, CA, 148 p.

Gates, D. E., and H. W. Frey. 1974. Designated common names of certain marine organisms of California. Calif. Fish Game, Fish Bull. 161:55-90.

Glude, J. B. 1978. The clams genera *Mercenaria, Saxidomus, Protothaca, Tapes, Mya, Panopea,* and *Spisula*: A literature review and analysis of the use of thermal effluent in the culture of clams. Unpubl. Rep. to Tenn. Valley Authority, J. B. Glude, Seattle, WA, 74 p.

Goodwin, L., and W. Shaul. 1978. Puget Sound subtidal hardshell clam survey data. Prog. Rep. 44, Wash. Dept. Fish., Olympia, WA, 92 p.

Haderlie, E. C., and D. P. Abbott. 1980. Bivalvia: The clams and allies. *In* R. H. Morris, D. P. Abbott, and E. C. Haderlie (editors), Intertidal invertebrates of California, p. 355-411. Stanford Univ. Press, Stanford, CA.

Hancock, D. R., T. F. Gaumer, G. B. Willeke, G. P. Robart, and J. Flynn. 1979. Subtidal clam populations: distribution, abundance, and ecology. Sea Grant Coll. Prog. Publ. No. ORESU-T-79-002, Oregon State Univ., Corvallis, OR, 243 p.

Kozloff, E. N. 1983. Seashore life of the northern Pacific coast. Univ. Wash. Press, Seattle, WA, 370 p.

Meinkoth, N. A. 1981. The Audubon Society field guide to North American seashore creatures. Alfred A. Knopf, New York, NY, 799 p.

Monaco, M. E., R. L. Emmett, S. A. Hinton, and D. M. Nelson. 1990. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume I: data summaries. ELMR Rep. No. 4. Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 240 p.

Nickerson, R. B. 1977. A study of the littleneck clam (*Protothaca staminea* Conrad) and the butter clam

(*Saxidomus giganteus* Deshayes) in a habitat permitting coexistence, Prince William Sound, Alaska. Proc. Natl. Shellfish Assoc. 67:85-102.

Oceanographic Institute of Washington. 1981. Clam and mussel harvesting industries of Washington State. Oceanog. Comm. Wash., Seattle, WA, various pagination.

Paul, A. J., and H. M. Feder. 1973. Growth, recruitment, and distribution of the littleneck clam, *Protothaca staminea*, in Galena Bay, Prince William Sound, Alaska. Fish. Bull., U.S. 71(3):665-677.

Paul, A. J., and H. M. Feder. 1976. Clam, mussel, and oyster resources of Alaska. Sea Grant Rep. 76-6, Univ. Alaska, Fairbanks, AK, 41 p.

Peterson, C. H. 1982. The importance of predation and intra- and interspecific competition in the population biology of two infaunal suspension-feeding bivalves, *Protothaca staminea* and *Chione undatella*. Ecol. Monog. 52(4):437-475.

Peterson, C. H., and M. L. Quammen. 1982. Siphon nipping: its importance to small fishes and its impact on growth of the bivalve *Protothaca staminea* (Conrad). J. Exp. Mar. Biol. Ecol. 63:249-268.

Quayle, D. B. 1943. Sex, gonad development and seasonal gonad changes in *Paphia staminea* Conrad. J. Fish. Res. Board Can. 6(2):140-151.

Quayle, D. B., and N. Bourne. 1972. The clam fisheries in British Columbia. Fish. Res. Board Can., Bull. No. 179, 71 p.

Ricketts, E. F., J. Calvin, J. W. Hedgpeth, and D. W. Phillips. 1985. Between Pacific tides. Stanford Univ. Press, Stanford, CA, 652 p.

Robinson, A. M., and W. P. Breese. 1982. The spawning season of four species of clams in Oregon. J. Shellfish Res. 2(1):55-57.

Roesijadi, G. 1980. Influence of copper on the clam *Protothaca staminea*: Effects on gills and occurrence of copper-binding proteins. Biol. Bull. 158:233-247.

Schink, T. D., K. A. McGraw, and K. K. Chew. 1983. Pacific coast clam fisheries. Wash. Sea Grant Prog., Tech. Rep. WSG 83-1, Univ. Wash., Seattle, WA, 72 p.

Schmidt, R. R., and J. E. Warme. 1969. Population characteristics of *Protothaca staminea* (Conrad) from Magu Lagoon, California. Veliger 12(2):193-199.

Schultze, D. L. 1986. Digest of California commercial fish laws. Calif. Dept. Fish Game, Sacramento, CA, 40 p.

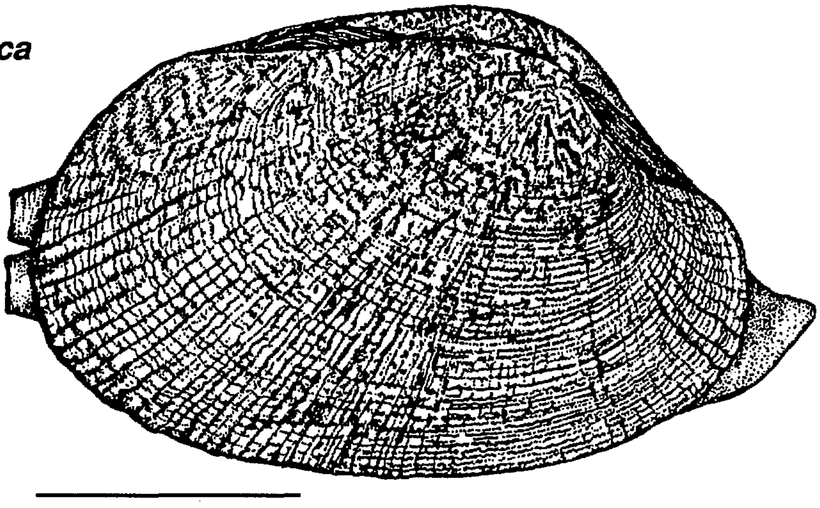
Shaw, W. N. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates. (Pacific Southwest)—common littleneck clam. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.46), U.S. Army Corps Eng., TR EL-82-4, 11 p.

Strathmann, M. F., A. R. Kabat, and D. O'Foighil. 1987. Phylum Mollusca, class Bivalvia. *In* M. F. Strathmann (editor), Reproduction and development of marine invertebrates of the northern Pacific coast, p. 309-353. Univ. Wash. Press, Seattle, WA.

Washington Department of Fisheries. 1986. 1986-1987 salmon, shellfish, bottomfish sport fishing guide. Wash. Dept. Fish., Olympia, WA, 20 p.

Wolotira, R. J., Jr., M. J. Allen, T. M. Sample, C. R. Iten, S. F. Noel, and R. L. Henry. 1989. Life history and harvest summaries for selected invertebrate species occurring off the west coast of North America. Volume 1: shelled molluscs. NOAA Tech. Memo. NMFS F/NWC-160, 177 p.

Venerupis japonica
Adult



Common Name: Manila clam
Scientific Name: *Venerupis japonica*
Other Common Names: Japanese cockle, Japanese littleneck, Manila cockle, Manila littleneck, Philippine cockle, steamer, asari (in Japan) (Cahn 1951, Chew 1989)
Classification (Bernard 1983a)
Phylum: Mollusca
Class: Bivalvia
Order: Veneroida
Family: Veneridae

Value

Commercial: The Manila clam is the second-most important commercial clam species on the Pacific coast of North America. It is primarily sold as a fresh product. About 500 t have been landed annually in Washington since 1975 (Schink et al. 1983, Chew 1989). Presently, only a limited commercial Manila clam harvest exists in California or Oregon. Nearly all Pacific coast commercial harvest of this species comes from Washington and British Columbia. In Washington, it is harvested year-round by diggers using forks, rakes, clam hacks, and hydraulic dredges (Wolotira et al. 1989). This harvest occurs on private and state tide lands, for which diggers pay a royalty or "stumpage fee" according to the weight landed (Chew 1989). Harvest of this species is often aligned with oyster growers, who also participate in a Manila clam fishery (Chew 1989). Minimum commercial size is 38 mm shell length (SL) (Frey 1971, Wolotira et al. 1989). Because of strong market demands and good biological attributes, aquaculture of this species has been initiated (Anderson et al. 1982).

Recreational: This species is highly prized by recreational diggers because of its good taste and ease of capture (Chew 1989). It is one of the most important recreationally dug clams on the Pacific coast (Wolotira et al. 1989). Clammers harvest Manila clams year-round during low tide periods by hand or using a fork, pick, rake, shovel, or garden trowel (Frey 1971, Wolotira et al. 1989). It is so heavily harvested in some areas of Puget Sound, Washington, that it has been almost eliminated (Williams 1980a). Sport harvesting of this species does occur in San Francisco Bay, California, despite the possibility of harvesting clams contaminated by urban wastes and the lack of official authorization (Nichols and Pamatmat 1988).

Indicator of Environmental Stress: The Manila clam is highly tolerant of pollution (Fitch 1953) and it may accumulate large amounts of pollutants that are harmful to humans. Hence, many waters are closed to the harvest of this species due to urban waste water and industrial contamination (primarily coliform bacteria). Only recently have limited areas in San Francisco Bay been open for Manila clam harvest.

Ecological: The Manila clam was introduced accidentally to the Pacific coast of North America probably around the 1930s with Pacific oysters (*Crassostrea gigas*) imported from Japan. It was first reported from British Columbia in 1936 (Quayle 1938). It is often one of the most abundant bivalves in estuarine intertidal habitats, and the dominant intertidal bivalve in San Francisco Bay (Frey 1971). Because its preferred distribution is in the upper tidal zone, it is not believed to have displaced any native species (Bourne 1982). The Manila clam often occurs with Pacific littleneck clam (*Protothaca staminea*), butter clam (*Saxidomus giganteus*), softshell (*Mya arenaria*), *Macoma* spp.

Table 1. Relative abundance of Manila clam in 32 U.S. Pacific coast estuaries.

Estuary	A	S	J	L	E
	Life Stage				
Puget Sound	●	●	●	●	●
Hood Canal	◉	◉	◉	◉	◉
Skagit Bay	○	○	○	○	○
Grays Harbor	◉	◉	◉	◉	◉
Willapa Bay	●	●	●	●	●
Columbia River					
Nehalem Bay					
Tillamook Bay	○	○	○	○	○
Netarts Bay	○	○	○	○	○
Siletz River					
Yaquina Bay	√		√		
Alsea River					
Siuslaw River					
Umpqua River					
Coos Bay	○	○	○	○	○
Rogue River					
Klamath River					
Humboldt Bay	◉	◉	◉	◉	○
Eel River					
Tomales Bay	○	○	○	○	○
Cent. San Fran. Bay *	●	●	●	●	●
South San Fran. Bay	●	●	●	●	●
Elkhorn Slough	√		√		
Morro Bay					
Santa Monica Bay					
San Pedro Bay					
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

clams, and other estuarine infauna (Wolotira et al. 1989). Pinnotherid crabs (*Pinnixa faba* and *P. littoralis*) are common commensals within the mantle cavity of Manila clams (Haderlie and Abbott 1980).

Range

Overall: The Manila clam is a tropical-temperate western Pacific species, originally found from the Philippines and China north along Japan to the southern Sea of Okhotsk (Wolotira et al. 1989). It now occurs on eastern Pacific shores from Elkhorn Slough, California to British Columbia (Fitch 1953), and is also found in Hawaii (Morris 1966).

Within Study Area: The Manila clam is abundant in Washington estuaries, but is not commonly found in many Oregon estuaries (Table 1). It is highly abundant in some areas of San Francisco Bay, but not in other California estuaries. Oregon has had little success with establishing and increasing Manila clam populations in the state's estuaries. Aquaculture of this species is presently being conducted in Humboldt Bay, California, Puget Sound, and other estuaries.

Life Mode

Eggs and larvae are pelagic. Juveniles and adults are benthic infauna, occurring just below the sediment surface down to about 5 cm (sometimes to 10 cm) (Bourne 1982, Wolotira et al. 1989).

Habitat

Type: It is found from the intertidal zone to depths of about 10 m (Wolotira et al. 1989), but is primarily found at 0.9-2.4 m above mean lower low water (MLLW) (Quayle and Bourne 1972). It is not found subtidally in British Columbia (Bourne 1982).

Substrate: An ideal substrate appears to consist of gravel (much of which is <25 mm in diameter), sand, some mud (4-5%), and shell (Anderson et al. 1982). Beaches having this type of substrate are often relatively stable, and occur in many protected areas of Pacific Northwest inlets and bays (Chew 1989). However, Manila clams can inhabit a wide range of substrates. Dense concentrations of Manila clams have been found in substrates ranging from primarily sand (Cahn 1951, Ohba 1959) to mud. Additions of pea gravel and small rock on Manila clam beds can enhance settlement (Chew 1989).

Physical/Chemical Characteristics: The Manila clam is found in mesohaline-euhaline waters (Haderlie and Abbott 1980). Optimum salinities for larval development are 20-30‰ (Robinson and Breese 1984). Optimum temperatures for larval development are 23-25°C, but they can withstand temperatures of 0-36°C (Cahn 1951, Robinson and Breese 1984). Optimum conditions for adult and juvenile growth are 28‰ salinity (range of 24-31‰), 16°C temperature (range of 13-21°C), and a food suspension density of 55 mg/l (ranges 10-135 mg/l) (Bernard 1983b). Prolonged salinities below 10‰ are lethal (Bardach et al. 1972). Optimum tidal level appears to be 1.5-2.5 m above MLLW (Quayle and Bourne 1972, Glock and Chew 1979). Small clams do not appear to grow during the winter when temperatures are <10°C (Bardach et al. 1972, Glock 1978, Williams 1980a). The Manila clam requires temperatures >14-15°C for maturation, spawning, and larval development (Holland and Chew 1974, Mann 1979, Bourne 1982). Juvenile and adult clams require maximum summer temperatures greater than about 12°C to survive (Bourne 1982). Steeply-sloped beaches are not good Manila clam habitat (Miller 1982, Chew 1989). Waves and water currents play a major role in regulating clam productivity. Currents remove waste, supply food and oxygen, distribute spat, and may redistribute young clams (Miller 1982, Chew 1989).

Migrations and Movements: Larvae are carried by currents into appropriate areas for settlement. Convergences and eddies often concentrate larvae. Larvae attach a byssus thread to a pebble or shell during settlement (Cahn 1951, Nosho 1971, Quayle and Bourne 1972).

Reproduction

Mode: The Manila clam is gonochoristic, oviparous, and iteroparous. It is a broadcast spawner, expelling gametes from the exhalant siphon; eggs are fertilized externally.

Mating/Spawning: In Japan, spawning occurs both in the spring and autumn (Chew 1989). In Kasaoka, Japan the Manila clam spawns from early May to July and then again between early November and late December (Chew 1989). Other Japanese studies reveal spawning times from early March to mid-May and from late October to early November (Yasuda et al. 1945, Ko 1957). In Washington's waters, the Manila clam spawns once per year, usually between May and September (typically peaking during June and July) (Nosho and Chew 1972, Holland and Chew 1974). Spawning apparently does not take place at water temperatures below 15°C (Mann 1979).

Fecundity: Unknown.

Growth and Development

Egg Size and Embryonic Development: Eggs are spherical and 0.06 mm in diameter (Wolotira et al. 1989). Embryonic development is indirect and external.

Age and Size of Larvae: Larvae range from 0.06 mm to 0.19-0.24 mm in length (Wolotira et al. 1989). A ciliated, motile, trochophore larvae forms within 24-48 hours after fertilization at 13-16°C. The veliger needs about 3-4 weeks before metamorphosing to spat (setting juveniles) (Cahn 1951, Quayle and Bourne 1972, Bourne 1982). The duration of larval stages is dependent on temperature and food availability (Chew 1989).

Juvenile Size Range: At settlement, clams range from 0.190-0.235 mm SL (Williams 1978, 1980a), and reach 15 mm SL (range: 12-20 mm) before becoming sexually mature (Ko 1957, Nosho and Chew 1972, Holland and Chew 1974, Wolotira et al. 1989).

Age and Size of Adults: Some Manila clams may mature at 15 mm SL (Ko 1957, Holland and Chew 1974). Growth rates vary considerably among geographic locations. One-year-old clams are reported to be 8 mm SL in Hokkaido, 18 mm SL in the Inland Sea (Ohba 1959), 27 mm SL in southern Japan (Tanaka 1954), 24 mm SL in Hood Canal, Washington (Nosho and Chew 1972), and 10-15 mm SL in the Strait of Georgia, British Columbia (Quayle and Bourne 1972). Growth is also dependent upon the tidal level clams inhabit, with growth often lower at higher tidal levels (Chew 1989). Clams take 16-22 months to reach market size in Washington (Glock 1978), and about 24 months in California (Frey 1971). However, they may need 3-4 years before reaching legal size in British Columbia (Bourne 1982). Manila clams also grow more slowly in overcrowded conditions (Haderlie and Abbott 1980). The maximum age is probably 7-10 years (Frey 1971).

Food and Feeding

Trophic Mode: The Manila clam is a nonselective suspension/filter feeder. Food particles are inhaled with water through the inhalant siphon, trapped by the gill, sorted by the palps, and passed to the mouth (Wolotira et al. 1989).

Food Items: Food consists of suspended detritus and phytoplankton.

Biological Interactions

Predation: Important predators include: the moonsnails (*Polinices* spp.), rock crabs (*Cancer spp.)*, shore crabs, rock sole (*Lepidopsetta bilineata*), English sole (*Pleuronectes vetulus*), starry flounder (*Platichthys stellatus*), pile perch (*Rhacochilus vacca*), shiner perch (*Cymatogaster aggregata*), starfish (*Pisaster* spp.), ducks, and scoters (Cahn 1951, Glude 1964, Bardach et al. 1972, Quayle and Bourne 1972, Anderson et al. 1982, Chew 1989). Nematodes and other meiofaunal predators may prey heavily on newly-setting spat (Williams 1980a).

Factors Influencing Populations: Spat settlement areas are dependent on currents and substrates (Chew 1989). Wave damage, extreme temperatures, and siltation can adversely affect population sizes (Bardach et al. 1972, Chew 1989). Extreme substrate temperatures during winter and summer are potentially lethal (Chew 1989). High densities of adult clams may decrease the ability of spat to settle (Williams 1980a, 1980b). Most mortality appears to occur within the first two months after settlement (Williams 1980a, 1980b). Losses of newly settled spat are probably a result of predation, starvation, and climatic conditions. Because of good market conditions, numerous aquaculture ventures are being established or considered (Anderson et al.

1982). This species' northern distribution is probably limited by cold water temperatures (Bourne 1982). Its southern distribution may be limited by the high salinities and substrate structure of southern California bays and estuaries. Plastic netting placed on beaches improves settlement and growth (Glock 1978, Glock and Chew 1979).

References

Anderson, G. J., M. B. Miller, and K. K. Chew. 1982. A guide to Manila clam aquaculture in Puget Sound. Wash. Sea Grant, Univ. Wash., Seattle, WA, 45 p.

Bardach, J. E., J. H. Ryther, and W. O. McLarney. 1972. Aquaculture - the farming and husbandry of freshwater and marine organisms. John Wiley and Sons, New York, NY, 868 p.

Bernard, F. R. 1983a. Catalogue of the living Bivalvia of the eastern Pacific Ocean: Bering Strait to Cape Horn. Can. Spec. Publ. Fish. Aquat. Sci. 61, 102 p.

Bernard, F. R. 1983b. Physiology and the mariculture of some northeastern Pacific bivalve molluscs. Can. Spec. Publ. Fish. Aquat. Sci. 63, 24 p.

Bourne, N. 1982. Distribution, reproduction, and growth of Manila clam, *Tapes philippinarum* (Adams and Reeves) in British Columbia. J. Shellfish Res. 2(1):47-54.

Cahn, A. R. 1951. Clam culture in Japan. U.S. Fish Wildl. Serv., Fish Leafl. No. 299, 103 p.

Chew, K. K. 1989. Manila clam biology and fishery development in western North America. *In* J. J. Manzi and M. Castagna (editors), Clam mariculture in North America, p. 243-261. Dev. Aquat. Fish. Sci., Vol. 19. Elsevier Press, New York, NY.

Fitch, J. E. 1953. Common marine bivalves of California. Calif. Fish Game, Fish Bull. 90, 102 p.

Frey, H. W. 1971. California's living marine resources and their utilization. Calif. Dept. Fish Game, Sacramento, CA, 48 p.

Glock, J. W. 1978. Growth, recovery, and movement of Manila clams, *Venerupis japonica* planted under protective devices and on open beaches at Squaxin Island, Washington. M.S. Thesis, Univ. Wash., Seattle, WA, 66 p.

Glock, J. W., and K. K. Chew. 1979. Growth, recovery, and movement of Manila clams, *Venerupis japonica* (Deshayes) at Squaxin Island, Washington. Proc. Natl. Shellfish. Assoc. 69:15-20.

Glude, J. B. 1964. The effect of scoter duck predation on a clam population in Dabob Bay, Washington. Proc. Natl. Shellfish. Assoc. 55:73-86.

Haderlie, E. C., and D. P. Abbott. 1980. Bivalvia: The clams and allies. *In* R. H. Morris, D. P. Abbott, and E. C. Haderlie (editors), Intertidal invertebrates of California, p. 355-411. Stanford Univ. Press, Stanford, CA.

Holland, D. A., and K. K. Chew. 1974. Reproductive cycle of the Manila clam (*Venerupis japonica*) from Hood Canal, Washington. Proc. Natl. Shellfish. Assoc. 64:53-58.

Ko, Y. 1957. Some histological notes on the gonads of *Tapes japonica* Deshayes. [in Japanese, English summary]. Bull. Jap. Soc. Sci. Fish. 23(7/8):394-399.

Mann, R. 1979. The effect of temperature on growth, physiology and gametogenesis in the manila clam, *Tapes philippinarum* Adams and Reeve 1850. J. Exp. Mar. Biol. Ecol. 38:122-133.

Miller, M. B. 1982. Recovery and growth of hatchery-produced juvenile Manila clams, *Venerupis japonica* (Deshayes) planted on several beaches in Puget Sound. Ph.D. Thesis, Univ. Wash, Seattle, WA, 250 p.

Morris, P. A. 1966. A field guide to Pacific coast shells. Houghton-Mifflin Co., Boston, MA, 297 p.

Nichols, F. H., and M. M. Pamatmat. 1988. The ecology of the soft-bottom benthos of San Francisco Bay: a community profile. U.S. Fish Wildl. Serv. Biol. Rep. 85(7.19), 73 p.

Nosho, T. Y. 1971. The setting and growth of the Manila clam, *Venerupis japonica* (Deshayes) in Hood Canal, Washington. M.S. Thesis, Univ. Wash., Seattle, WA, 67 p.

Nosho, T. Y., and K. K. Chew. 1972. The setting and growth of the Manila clam, *Venerupis japonica* (Deshayes) in Hood Canal, Washington. Proc. Natl. Shellfish. Assoc. 62:50-58.

Ohba, S. 1959. Ecological studies in the natural population of a clam, *Tapes japonica*, with special reference to seasonal variations in the size and structure of the population and individual growth. Biol. J. Okayama Univ. 5(1/2):13-42.

Quayle, D. B. 1938. *Paphia bifurcata*, a new molluscan species from Ladysmith Harbor, B.C. J. Fish. Res. Board Can. 4:53-54.

Quayle, D. B., and N. Bourne. 1972. The clam fisheries in British Columbia. Fish. Res. Board Can. Bull. No. 179, 70 p.

Robinson, A. M., and W. P. Breese. 1984. Gonadal development and hatchery rearing techniques for the Manila clam *Tapes philippinarum* (Adams and Reeve). J. Shellfish Res. 4(2):161-163.

Schink, T. D., K. A. McGraw, and K. K. Chew. 1983. Pacific coast clam fisheries. Wash. Sea Grant, Univ. Wash., Seattle, WA, 72 p.

Tanaka, Y. 1954. Spawning season of important bivalves in Ariake Bay — *Venerupis semidecussata* (Reeve). [In Japanese, English summary]. Bull. Jap. Soc. Sci. Fish 19(12):1165-1167.

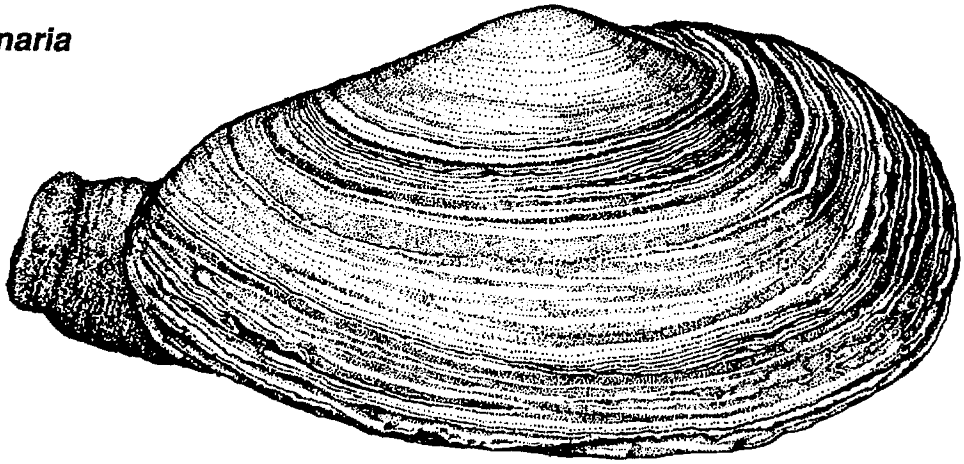
Williams, J. G. 1978. The influence of adults on the settlement, growth, and survivals of spat in the commercially important clam, *Tapes japonica* Deshayes. Ph.D. Thesis, Univ. Wash., Seattle, WA, 60 p.

Williams, J. G. 1980a. Growth and survival in newly settled spat of the Manila clam, *Tapes japonica*. Fish. Bull., U.S. 891-900.

Williams, J. G. 1980b. The influence of adults on the settlement of spat of the clam, *Tapes japonica*. J. Mar. Res. 38(4):729-741.

Wolotira, R. J., Jr., M. J. Allen, T. M. Sample, C. R. Iten, S. F. Noel, and R. L. Henry. 1989. Life history and harvest summaries for selected invertebrate species occurring off the west coast of North America. Volume 1: shelled molluscs. NOAA Tech. Memo. NMFS F/NWC-160, 177 p.

Yasuda, J., I. Hamai, and H. Hotta. 1945. A note on the spawning season in *Venerupis philippinarum*. Bull. Jap. Soc. Sci. Fish. 290(4):277-279.



Common Name: softshell
Scientific Name: *Mya arenaria*
Other Common Names: soft clam, long clam, mud clam, sand clam, common mya, nanninose, eastern softshell clam, softshell clam, steamer clam, long-necked clam, sand gaper (Fitch 1953, Gates and Frey 1974, Newell and Hidu 1986)
Classification (Bernard 1983)
Phylum: Mollusca
Class: Bivalvia
Order: Myoida
Family: Myidae

Value

Commercial: The softshell is not as valuable as some other bivalves along the Pacific coast, but may be underutilized in Washington. Over 181 t were commercially harvested in Washington in 1985 (Washington Department of Fisheries 1985). It has been estimated that 900 t could be harvested annually in Skagit Bay and Port Susan, Washington (Cheney and Mumford 1986). About 34 t were harvested in Oregon in 1980, but in California this species has not been harvested since about 1948 (Skinner 1962, Schink et al. 1983). The limited commercial harvest of this species in Oregon and California occurs because of small population sizes (Oregon) and pollution (California) (Schink et al. 1983). This species is harvested primarily by hydraulic escalator dredge (Kyte and Chew 1975).

Recreational: This is an important clam for sport diggers. In some areas of Washington over 9.1 kg/day are allowed to be dug per person (Washington Department of Fisheries 1986). Oregon permits sport diggers to harvest 36 clams/day (Oregon State University Extension Service et al. 1976). In general, this species is underutilized by sport diggers because of the abundance of more desirable species.

Indicator of Environmental Stress: The softshell often occurs in estuarine areas where industrial and domestic pollution problems first occur and the clams then become unsafe to consume. Many areas (e.g., San Francisco Bay, California) that have harvestable numbers of *M. arenaria* are presently closed to harvesting due to pollution. However, this species is relatively tolerant of pollution. The softshell accumulates crude oil into its lipid-containing tissues when oil is in low concentrations (90-380 µg oil/liter) (Fong 1976). It also concentrates heavy metals in its tissues. However, at water temperatures of 22.0°C and salinities of 30.0‰, the following concentrations caused death in 50% of the test clams within 96 hours: copper, 0.039 mg/l; cadmium, 0.850 mg/l; zinc, 5.2 mg/l; lead, 27.0 mg/l; manganese, >300.0 mg/l; and nickel, >50.0 mg/l (Eisler 1977).

Ecological: The softshell was probably introduced to the Pacific coast before 1874, perhaps in 1869 when the first eastern oysters were introduced. However, there is some evidence that softshell clams were once native to the Pacific coast (Porter 1974). This species is common in estuaries from Elkhorn Slough, California, to Alaska (Ricketts et al. 1985), and may have crowded out the native *Macoma* species in some areas of the Pacific coast (Rudy and Rudy 1983).

Range

Overall: In the Atlantic, it is found along the coast of North America from Labrador to Cape Hatteras, North Carolina, and less commonly to South Carolina. In Europe, it occurs from northern Norway to the Bay of

Table 1. Relative abundance of softshell in 32 U.S. Pacific coast estuaries.

Estuary	Life Stage A	S	J	L	E
Puget Sound	◉	◉	◉	◉	◉
Hood Canal	○	○	○	○	○
Skagit Bay	●	●	●	●	●
Grays Harbor	◉	◉	◉	◉	◉
Willapa Bay	◉	◉	◉	◉	◉
Columbia River	○	○	○	○	○
Nehalem Bay	●	●	●	●	●
Tillamook Bay	◉	◉	◉	◉	◉
Netarts Bay	○	○	○	○	○
Siletz River	√	√	√	√	√
Yaquina Bay	●	●	●	●	●
Alsea River	◉	◉	◉	◉	◉
Siuslaw River	●	●	●	●	●
Umpqua River	●	●	●	●	●
Coos Bay	●	●	●	●	●
Rogue River					
Klamath River					
Humboldt Bay	◉	◉	◉	◉	◉
Eel River	○	○	○	○	○
Tomales Bay	○	○	○	○	○
Cent. San Fran. Bay*	○	◉	◉	◉	◉
South San Fran. Bay	◉	◉	◉	◉	◉
Elkhorn Slough	○	○	○	○	○
Morro Bay	√	√	√	√	√
Santa Monica Bay					
San Pedro Bay					
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

Biscay, France. In the eastern Pacific, it occurs from Monterey Bay (maybe San Diego), California, through Alaska (Gross 1967, Paul and Feder 1976, Rudy and Rudy 1983, Abraham and Dillon 1986), and is also found along the western Pacific coast from the Kamchatka Peninsula to the southern Japanese islands (Hanks 1963). It is apparently still extending its range as seen by its expansion into the Black Sea (Ivanov 1969, Porter 1974).

Within Study Area: The softshell is commonly found from Elkhorn Slough, California, north through Washington's estuaries (Table 1) (Haderlie and Abbott 1980, Kozloff 1983, Ricketts et al. 1985).

Life Mode
Eggs and larval stages are planktonic; juveniles and adults are benthic infauna.

Habitat
Type: The softshell is a true estuarine organism, with all life stages occurring there. A euryhaline species, it is found primarily in mesohaline and polyhaline water. Eggs and larvae are found in the estuarine and nearshore marine plankton, while juveniles and adults occur primarily in quiet estuarine mud flats that are near river mouths where low salinity occurs (Oceanographic Institute of Washington 1981, Newell and Hidu 1986). Adults and juveniles are often most abundant in the upper mid-tidal zone [+1.8 to 0.6 feet mean lower low water (MLLW)] (Cheney and Mumford 1986), but they can occur down to approximately -5.5 to -9 m MLLW (Filice 1958, Meinkoth 1981). Adults may be found buried in sediments down to 25-30 cm (Haderlie and Abbott 1980, Abraham and Dillon 1986).

Substrate: Adults and juveniles prefer medium to soft substrates, consisting primarily of sand, compact clays, coarse gravel, a mixture of sand and mud, and gravel and mud (Cheney and Mumford 1986, Newell and Hidu 1986). However, they are often found in thick, dark mud (Haderlie and Abbott 1980) that may consist of up to 50% silt (Abraham and Dillon 1986). Adults and juveniles cannot burrow or maintain themselves in shifting substrates (Ricketts et al. 1985). Growth rates and shell form are dependent on the substrate properties (Newell and Hidu 1982).

Physical/Chemical Characteristics: The softshell is a euryhaline species. Adults can tolerate salinities down to 5‰, but larvae are more sensitive to low salinities (Newell and Hidu 1986). Adult clams on the Atlantic coast have preferred salinities that decrease north to south (Newell and Hidu 1986); it is not known if this is true for Pacific coast populations. Juvenile clam salinity tolerances are related to size; larger juveniles can withstand lower salinities. The ability to withstand extremely low salinities is inversely related to temperature. Temperature also controls timing of spawning and influences distribution. The northern range of *M. arenaria* is limited by temperatures too low for spawning, while southern distribution is limited by high temperatures (Laursen 1966). Temperatures above 28°C can affect its distribution and abundance (Newell and Hidu 1986). However, it can withstand temperatures down to at least -1.7°C (Newell and Hidu 1986). The softshell clam can function as a facultative anaerobe at low tide (Collip 1920), surviving anaerobic conditions longer at lower temperatures (Newell and Hidu 1986). Spawning temperatures depend on latitude and location, ranging from about 4°C to 22°C. Spawning on the Pacific coast appears to occur at temperatures between 10 and 15°C (Simel 1980). This species prefers to orient its siphon perpendicular to the principal component of water currents (Vincent et al. 1988).

Migrations and Movements: Planktonic eggs and larvae are dispersed by waves and currents. Newly-metamorphosed spat may spend 2-5 weeks floating and crawling. During this time, the spat uses a byssal thread to hold on to various substrates, such as eelgrass (*Zostera* spp.), filamentous algae, and other objects. Eventually the spat finds a favorable location where it drops to the bottom and burrows into the sediment. Initially spat settle primarily in lower intertidal and subtidal areas, but as they grow they may move shoreward. This shoreward movement is believed to be caused primarily by shoaling wave sorting (Matthiessen 1961, Newell and Hidu 1986). Clams up to 12-13 mm in diameter will wander (Smith 1955), while larger clams are sedentary.

Reproduction

Mode: The softshell clam is gonochoristic (but some hermaphroditism has been reported), oviparous, and iteroparous. It is a broadcast spawner; eggs are fertilized externally (Porter 1974, Brousseau 1978, Brousseau 1987).

Mating/Spawning: There are only two published records of softshell spawning times on the Pacific coast; one from Skagit Bay, Washington (Porter 1974) and the other from Humboldt Bay, California (Simel 1980). Similar to northern Atlantic coast populations (Ropes and Stickney 1965, Brousseau 1987), *M. arenaria* in Skagit Bay spawns one time between May and September, peaking in June or July (Porter 1974). In Humboldt Bay, it appears to spawn at the peak of phytoplankton abundance from late March through April (Simel 1980). Males normally spawn first, producing both pheromones and sperm which stimulate females to spawn (Newell and Hidu 1986).

Fecundity: Fecundity has been reported to be 3 million eggs per female per year, but may actually be 120,000 to 1,000,000 (Brousseau 1978, Newell and Hidu 1986).

Growth and Development

Egg Size and Embryonic Development: When released into seawater, eggs are spherical and about 66 µm in diameter (Newell and Hidu 1986). Embryonic development is indirect and external. Fertilized eggs may take 12 hours to develop into the trocophore (a top-shaped ciliated larvae).

Age and Size of Larvae: The trochophore takes 24-36 hours to develop into a veliger, which has calcareous valves and stays in the water column by its ciliated velum. The veliger stage may last 2-6 weeks, depending on temperature before transforming into a spat, which has a muscular foot, byssal gland, no velum, and settles out of the water column (Abraham and Dillon 1986). Initially, veliger larvae are about 80 µm in diameter and most metamorphose to spat soon after reaching 200 µm (Loosanoff et al. 1966).

Juvenile Size Range: Juveniles grow from 0.2 mm shell length (SL) (newly-settled spat) up to 25.0-45.0 mm SL before maturing (Porter 1974).

Age and Size of Adults: The softshell may reach maturity at one year and 27-34 mm SL (Brosseau and Baglivo 1988); adults may reach commercial size (50-75 mm SL) in 2-3 years in Washington (Oceanographic Institute of Washington 1981, Cheney and Mumford 1986), but may reach this size earlier in Oregon and California. Growth is slower during winter and faster during early spring and summer, but is modified by sediment type, tidal level, population densities, and food abundance (Newell and Hidu 1986, Brousseau and Baglivo 1987). Softshells have been reported to live up to 28 years (MacDonald and Thomas 1980), but 10-12 years is more likely the maximum age (Brousseau 1978, Brousseau and Baglivo 1987).

Food and Feeding

Trophic Mode: Larvae, juveniles, and adults are planktivorous filter feeders, trapping and ingesting food particles via mucus on the gill tissues.

Food Items: Trochophores feed on various suspended particles, while veligers feed primarily on phytoplankton. Adults and juveniles prefer flagellates and diatoms, but bacteria, dissolved organic material, and organic detritus are also fed upon (Abraham and Dillon 1986, Newell and Hidu 1986).

Biological Interactions

Predation: Veligers are important prey for many species of larval fish. Jellyfish, combjellies (Holland et al. 1980), and fish are efficient predators of softshell larvae. Important predators of spat and juveniles include birds, fish, shrimp, polychaetes, crabs, snails, and flatworms. Important predators of adults include raccoons (*Procyon lotor*) and otters (*Enhydra lutris*).

Factors Influencing Populations: Less than 0.1% of the eggs produced during a spawning season successfully settle, but only 1% of the settled spat need to mature to maintain populations (Newell and Hidu 1986). Extremely high densities of spat settlement have been observed, but densities are quickly reduced, probably due to predation. First year survivorship rates ranged from 24 million to 420 million at two Atlantic coast sites (Brousseau and Baglivo 1988). Alterations of estuarine habitats adversely affect populations. Municipal sewage, industrial effluent, and estuarine development projects (e.g., dredging, pier and jetty construction) may all reduce softshell clam populations.

References

Abraham, B. J., and P. L. Dillon. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (mid-Atlantic)—softshell clam. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.68), U.S. Army Corps Eng., TR EL-82-4, 18 p.

Bernard, F. R. 1983. Catalogue of the living Bivalvia of the eastern Pacific Ocean: Bering Strait to Cape Horn. Can. Spec. Publ. Fish. Aquatic Sci. 61, 102 p.

Brousseau, D. J. 1978. Spawning cycle, fecundity and recruitment in a population of soft-shell clam, *Mya arenaria*, from Cape Ann, Massachusetts. Fish. Bull., U.S. 76:155-166.

Brousseau, D. J. 1987. A comparative study of the reproductive cycle of the soft-shell clam, *Mya arenaria* in Long Island Sound. J. Shellfish Res. 6:7-15.

Brousseau, D. J., and J. A. Baglivo. 1987. A comparative study of age and growth in *Mya arenaria* (soft-shell clam) from three populations in Long island Sound. J. Shellfish Res. 6:17-24.

Brosseau, D. J., and J. A. Baglivo. 1988. Life tables for two field populations of soft-shell clam, *Mya arenaria*, *(Mollusca: Pelecypoda) from Long Island Sound.* Fish. Bull., U.S. 86(3):567-579.

Cheney D. P., and T. F. Mumford. 1986. Shellfish and seaweed harvests of Puget Sound. Wash. Sea Grant, Univ. Wash. Press, Seattle, WA, 164 p.

Collip, J. B. 1920. Studies on molluscan celomic fluid. Effect of change in environment on the carbon dioxide content of the celomic fluid. Anaerobic respiration in *Mya arenaria*. J. Biol. Chem. 45:23-39.

Eisler, R. 1977. Acute toxicities of selected heavy metals to the softshell clam, *Mya arenaria*. Bull. Environm. Contam. Toxicol. 17(2):137-145.

Filice, F. P. 1958. Invertebrates from the estuarine portion of San Francisco Bay and some factors influencing their distributions. Wasmann J. Biol. 16:159-211.

Fitch, J. E. 1953. Common marine bivalves of California. *Calif.* Fish Game, Fish Bull. 90, 98 p.

Fong, W. C. 1976. Uptake and retention of Kuwait crude oil and its effects on oxygen uptake by the soft-shell clam, *Mya arenaria*. J. Fish. Res. Board Can. 33:2774-2780.

Gates, D. E., and H. W. Frey. 1974. Designated common names of certain marine organisms of California. Calif. Fish Game, Fish Bull. 161:55-90.

Gross, J. B. 1967. Note on the northward spreading of *Mya arenaria* Linnaeus in Alaska. Veliger 10:203.

Haderlie, E. C., and D. P. Abbott. 1980. Bivalvia: the clams and allies. *In* R. H. Morris, D. P. Abbott, and E. C. Haderlie (editors), Intertidal invertebrates of California, p. 355-411. Stanford Univ. Press, Stanford, CA.

Hanks, R. W. 1963. The soft-shell clam. U.S. Fish Wildl. Serv., Bureau Comm. Fish. Circular 162, 16 p.

Holland, A. F., N. K. Mountford, M. H. Hiegel, K. R. Kaumeyer, and J. A. Mihursky. 1980. Influence of predation on infaunal abundance in upper Chesapeake Bay, USA. Mar. Biol. 57:221-235.

Ivanov, A. I. 1969. Immigration of *Mya arenaria* L. to the Black Sea, its distribution and quantity. [In Russ. with Engl. summary], Okawnologiya 9:341-347.

Kozloff, E. N. 1983. Seashore life of the northern Pacific coast. Univ. Wash. Press, Seattle, WA, 370 p.

Kyte, M. A., and K. K. Chew. 1975. A review of the hydraulic escalator shellfish harvester and its known effects in relation to the soft-shell clam, *Mya arenaria*. Wash. Sea Grant, Univ. Wash., Seattle, WA, 32 p.

Laursen, D. 1966. The genus *Mya* in the Arctic region. Malacologia 3: 399-418.

Loosanoff, V. L., H. C. Davis, and P. E. Chanley. 1966. Dimensions and shapes of larvae of some marine bivalve mollusks. Malacologia 4:351-435.

MacDonald, B. A., and M. L. H. Thomas. 1980. Age determination of the soft-shell clam *Mya arenaria* using shell internal growth lines. Mar. Biol. 58:105-109.

Matthiessen, G. C. 1961. Intertidal zonation in populations of *Mya arenaria*. Limnol. Ocean.5:381-388.

Meinkoth, N. A. 1981. The Audubon Society field guide to North American seashore creatures. Alfred A. Knopf, New York, NY, 799 p.

Newell, C., and H. Hidu. 1982. The effects of sediment type on growth rate and shell allometry in the soft shelled clam *Mya arenaria* L. J. Exp. Mar. Biol. Ecol. 65:285-295.

Newell, C. R., and H. Hidu. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic)—softshell clam. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.53), U.S. Army Corps Eng. TR EL-82-4, 17 p.

Oceanographic Institute of Washington. 1981. Clam and mussel harvesting industries in Washington state. Oceanogr. Comm. Wash., Seattle, WA, various pagination.

Oregon State University Extension Service, Sea Grant Marine Advisory Program, and Oregon Department of Fish and Wildlife. 1976. Oregon's captivating clams. Oregon State Univ. Ext. Serv. , Sea Grant Marine Advis. Prog., and Oregon Fish Wildl., Corvallis, OR, 2 p.

Paul, A. J., and H. M. Feder. 1976. Clam, mussel, and oyster resources of Alaska. Inst. Marine Res. Rep. 76-4, Sea Grant Rep. 76-6, Univ. Alaska, Fairbanks, AK, 40 p.

Porter, R. G. 1974. Reproductive cycle of the soft-shell clam, *Mya arenaria* at Skagit Bay, Washington. Fish. Bull., U.S. 72:648-656.

Ricketts, E. F., J. Calvin, J. W. Hedgpeth, and D. W. Phillips. 1985. Between Pacific tides. Stanford Univ. Press, Stanford, CA, 652 p.

Ropes, J. W., and A. P. Stickney. 1965. Reproductive cycle of *Mya arenaria* in New England. Biol. Bull. (Woods Hole) 128:315-327.

Rudy, P., Jr., and L. H. Rudy. 1983. Oregon estuarine invertebrates. An illustrated guide to the common and important invertebrate animals. U.S. Fish Wildl. Serv., Biol. Serv. Prog. FWS/OBS-83/16, Portland, OR, 225 p.

Schink, T. D., K. A. McGraw, and K. K. Chew. 1983. Pacific coast clam fisheries. Wash. Sea Grant, Univ. Wash., Seattle, WA, 72 p.

Simel, N. R. 1980. Aspects of the ecology of *Mya arenaria* L. in Humboldt Bay, California. M.A. Thesis, Humboldt State Univ., Arcata, CA, 90 p.

Skinner, J. E. 1962. An historical review of the fish and wildlife resources of the San Francisco Bay area. Water Proj. Branch Rep. No. 1, Calif. Dept. Fish Game, Sacramento, CA, 226 p.

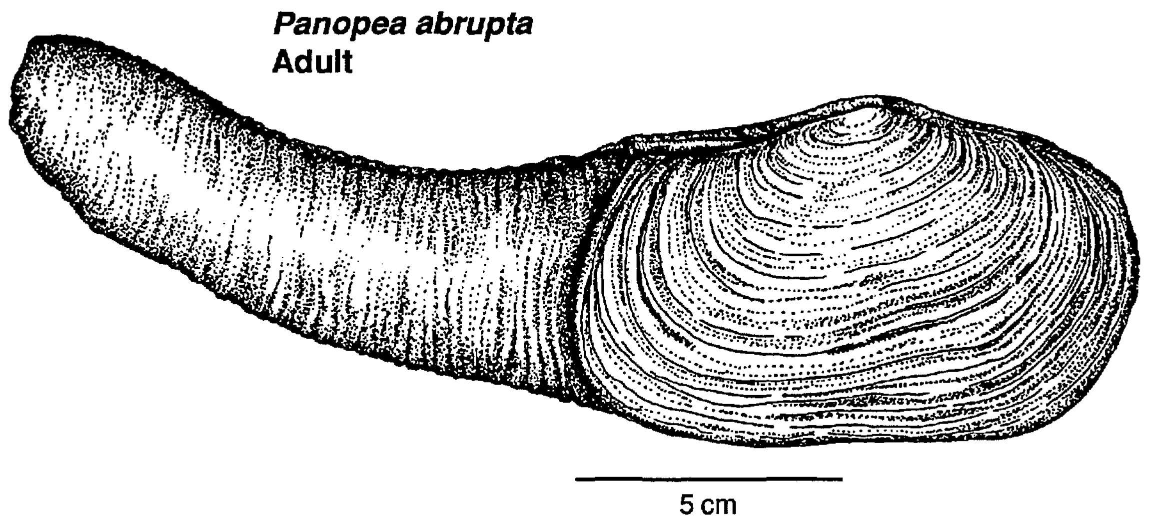
Smith, O. R. 1955. Movements of small soft-shell clams, (*Mya arenaria*). U.S. Fish Wildl. Serv., Special Sci. Rep. Fish. 159, 9 p.

Vincent, B., G. Desrosiers, and Yves Gratton. 1988. Orientation of the infaunal bivalve *Mya arenaria* L. in relation to local current direction on a tidal flat. J. Exp. Mar. Biol. Ecol. 124:205-214.

Washington Department of Fisheries. 1985. 1985 fisheries statistical report. Wash. Dept. Fish., Olympia, WA, 101 p.

Washington Department of Fisheries. 1986. 1986-1987 (April 1 thru March 31) salmon, shellfish, bottom fish sport fishing guide. Wash. Dept. Fish., Olympia, WA, 20 p.

Geoduck



Common Name: geoduck
Scientific Name: *Panopea abrupta*
Other Common Names: Pacific geoduck, giant panopaea, geoduc, gweduc, king clam, gooey-duck (Gates and Frey 1974, Wolotira et al. 1989)
Classification (Bernard 1983)
Phylum: Mollusca
Class: Bivalvia
Order: Myoida
Family: Hiatellidae

Value

Commercial: The geoduck was not commercially harvested until 1970 (Wolotira et al. 1989), but it now supports the largest clam fishery on the Pacific coast of North America (Schink et al. 1983). It is commercially harvested from Alaska to Washington, but primarily from southern British Columbia, Puget Sound, and Hood Canal, Washington. In 1977, 3,900 t were harvested from Washington State's subtidal areas. The industry is now limited to below the optimum sustained yield quota of about 2.25 t per year (Schink et al. 1983, Goodwin and Shaul 1984, Cheney and Mumford 1986). Geoduck neck meat is sold in Japan, Taiwan, and within the U.S.; body meat is sold primarily in California and on the U.S. Atlantic coast (Cheney and Mumford 1986). Geoduck harvests are worth about $2.4 million annually to U.S. fishermen (Wolotira et al. 1989). This species is harvested by divers during daylight using hand-held, high-pressure water jets. Most harvesting is in depths <18.3 m because diving time is limited in deeper water (Schink et al. 1983). In Washington, subtidal tracts are leased from the state. Tracts are required to be >182 m away from the mean high-water line and have depths >5.5 m below mean lower low water (MLLW) (Schink et al. 1983). Geoducks are harvested year-round, but primarily during spring and summer (Wolotira et al. 1989). Meat quality appears to be correlated with substrate type; geoducks growing in coarse substrates produce a better quality product (Goodwin and Pease 1987). The Washington commercial geoduck industry pays a royalty fee which supports a geoduck hatchery that raises cultured juveniles to seed harvested beds. Geoducks must be processed within 24 hours after harvesting or they gape, lose water and body fluids, die, and the meat dries out (Schink et al. 1983).

Recreational: This species is recreationally harvested from British Columbia to California, but is particularly important in Washington (Schink et al. 1983). Because the geoduck lives deep within the sediment, shovels and open-ended tubes are used to dig them. It is harvested year-round, usually during very low tides on intertidal flats. However, a small number are harvested by sport divers (Goodwin and Shaul 1984).

Indicator of Environmental Stress: Geoduck beds may be closed to harvesting because of coliform bacteria contamination. Beds may also be temporarily closed because of paralytic shellfish poisoning, however, this has not been a significant problem in Puget Sound. Many productive subtidal clam beds in Puget Sound are closed to shellfish harvesting because of industrial and municipal pollution (Schink et al. 1983). Little is known about this species' ability to concentrate heavy metals, pesticides, and other chemicals (Goodwin and Pease 1989).

Ecological: This is the largest burrowing bivalve on the Pacific coast of North America. The geoduck is very abundant in subtidal areas of Puget Sound and British

Table 1. Relative abundance of geoduck in 32 U.S. Pacific coast estuaries.

	Life Stage				
Estuary	A	S	J	L	E
Puget Sound	◉	◉	◉	◉	◉
Hood Canal	◉	◉	◉	◉	◉
Skagit Bay	○	○	○	○	○
Grays Harbor					
Willapa Bay					
Columbia River					
Nehalem Bay					
Tillamook Bay					
Netarts Bay	√	√	√	√	√
Siletz River					
Yaquina Bay					
Alsea River					
Siuslaw River					
Umpqua River					
Coos Bay					
Rogue River					
Klamath River					
Humboldt Bay	√	√	√	√	√
Eel River					
Tomales Bay					
Cent. San Fran. Bay *					
South San Fran. Bay					
Elkhorn Slough					
Morro Bay	○	○	○	○	○
Santa Monica Bay					
San Pedro Bay	√	√	√	√	√
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

Columbia and it often dominates the biomass of benthic infauna communities there (Cheney and Mumford 1986, Goodwin and Pease 1989). A conservative population estimate of 117.6 million geoducks was made for 33,799 acres of subtidal beds surveyed in Puget Sound in 1977 (Cheney and Mumford 1986).

Range

Overall: This is a temperate amphi-North Pacific species, found from Kyushu to Hokkaido Islands, Japan, and in the northeast Pacific from southeast Alaska to Baja California (Scammons Lagoon), and also in the northern Gulf of California (Fitch 1953, Haderlie and Abbott 1980, Bernard 1983, Wolotira et al. 1989).

Within Study Area: The geoduck is common to abundant in Skagit Bay, Puget Sound, and Hood Canal, Washington (Table 1). It is not found in coastal estuaries of Washington and Oregon except for Netarts Bay, Oregon, where some are harvested. It is not found or is rare in California's estuaries, except for Morro Bay where it is common (Marriage 1954, Haderlie and Abbott 1980, MacIntyre et al. 1986).

Life Mode

Eggs and larvae are pelagic. Juveniles and adults are benthic infauna, burrowing to depths of 100 cm (Goodwin et al. 1979, Haderlie and Abbott 1980).

Habitat

Type: The geoduck is found intertidally to depths of at least 110 m in bays, sloughs, and estuaries (Goodwin 1973a, Bernard 1983, Goodwin and Pease 1987, Wolotira et al. 1989). In Alaska, geoducks are found only subtidally at depths from 4.5-12.0 m (Wolotira et al. 1989). This species is most abundant between 9.1 and 18.2 m below MLLW (Goodwin 1973a). The length and weight of geoducks decreases with depths between 3 and 20 m (Goodwin and Pease 1987).

Substrate: The geoduck is found in a variety of substrates ranging from soft mud to pea gravel, but primarily in stable mud or sand bottoms (Goodwin 1973a, Goodwin and Pease 1987). It is often associated with the sea pen (*Ptilosarcus gurneyi*) and polychaete tubes (Cox 1979). Polychaete tubes of *Spiochaetopeterus costarum*, *Phyllochaetopeterus prolifica*, and *Diopatra ornata*, are preferred attachment areas for juveniles (Strathmann et al. 1987).

Physical/Chemical Characteristics: This species is found in areas where water temperatures range from 3-20°C (Bernard 1983). Eggs and larvae are found in polyhaline-euhaline waters ranging from 22.0-35.0‰; optimum is 27.5-32.5‰ (Goodwin 1973b). Juveniles and adults occur in mesohaline-euhaline waters (5.0-35.0‰), but prefer salinities above 25.0‰ (Andersen 1971, Goodwin 1976). Optimum spawning temperatures are 12-14°C, but spawning occurs in temperatures from 8-16°C (Goodwin 1976). The best temperature for larval survival is between 6 and 16°C (Goodwin 1973b). Although juveniles and adults withstand air temperatures of 0-25°C, they are only found in areas where water temperatures during the spawning period (April to July) are not above 16°C (Andersen 1971, Goodwin 1973b, 1976).

Migrations and Movements: Planktonic eggs and larvae are dispersed by water currents. Bottom-dwelling post-larvae are active crawlers (Goodwin et al. 1979). Newly-settled juveniles remain at or near the sediment surface until they grow to 15 mm shell length (SL), then their siphons begin to lengthen. Once siphons are elongated and well-developed, juveniles begin to burrow deeply (Strathmann et al. 1987). Juvenile and adults are sedentary infauna, remaining in the area where they initially burrowed.

Reproduction

Mode: The geoduck is gonochoristic, oviparous, and a broadcast spawner; eggs are fertilized externally. It is iteroparous and a batch spawner with one spawning period per year (Andersen 1971, Goodwin 1973a, Goodwin et al. 1979).

Mating/Spawning: In Hood Canal and Puget Sound, spawning occurs from April to July (primarily from May to June) (Goodwin 1973a, 1976, Strathmann et al. 1987). In British Columbia, the geoduck spawns primarily from June to July (Sloan and Robinson 1984). It is stimulated to spawn by increasing water temperatures, the presence of geoduck sperm in the water, and (at least in hatchery situations) by increased algae concentrations (Goodwin 1973b, Wolotira et al. 1989). When it spawns, both eggs and sperm are expelled from the exhalant siphon continuously for several minutes or up to an hour (Goodwin et al. 1979).

Fecundity: A female can release 7.5-20.0 million eggs during a single spawning; hatchery stock have been induced to spawn again if returned to cooler water. (Goodwin et al. 1979). Although reproductive output is high, recruitment (i.e., settlement of larvae and survival of young) is usually erratic or low (Goodwin et al. 1979).

Growth and Development

Egg Size and Embryonic Development: Eggs are spherical and 0.082 mm (Goodwin et al. 1979). Embryonic development is indirect and external.

Age and Size of Larvae: Larval size ranges are 0.11-0.40 mm (pelagic larvae) and 0.40-0.80 mm (epibenthic post-larvae) (Goodwin et al. 1979). At 14°C, larval growth is as follows: at 48 hr, straight-hinge larvae develops; at 6 days, veligers are 0.120 x 0.105 mm; at 10 days, veligers are 0.150 x 0.125 mm. Settlement occurs at 30 days at 17.6°C, and 47 days at 14-15°C (Goodwin 1973a, 1973b). The largest veligers (before metamorphosis to benthic juveniles) are 0.350-0.400 mm in diameter (Goodwin et al. 1979). Settlement is usually from April to August, peaking in mid-July (Andersen 1971).

Juvenile Size Range: Juveniles range in size from 0.8-100.0 mm SL (Andersen 1971). When 1.5-2.0 mm SL, they start to burrow into the substrate (Goodwin and Pease 1989). Juveniles <5 mm SL still have the ability to move, while larger juveniles simply bury themselves as they grow (Goodwin and Shaul 1984).

Age and Size of Adults: In Puget Sound, most males mature in three years at 60-100 mm SL; females mature in four years at 100-120 mm SL (Andersen 1971). In British Columbia, maturity may be reached in 5-7 years (Sloan and Robinson 1984, Wolotira et al. 1989). During the first four years they grow rapidly, but older, large clams (>100 mm SL) grow little if at all (Andersen 1971, Goodwin 1973a, 1976, Shaul and Goodwin 1982, Breen and Shields 1983). In general, this is a very long-lived and slow-growing species, but growth can be highly variable. Depending on geographic area, geoducks may reach 75 mm SL in 2-8 years (Goodwin and Shaul 1984). In most areas in Puget Sound and British Columbia, it reaches 0.9 kg (market size) in 8 to 10 years (Cheney and Mumford 1986, Wolotira et al. 1989). The oldest individuals are about 146 years old. Maximum size and weight is 230 mm SL and 9.1 kg, but most weigh <4.5 kg (Oceanographic Institute of Washington 1981, Kozloff 1983, Wolotira et al. 1989).

Food and Feeding

Trophic Mode: This species is a suspension/filter-feeding planktivore. Larvae, juveniles, and adults feed by filtering food particles from seawater with their gills. Post-larval geoducks may also feed on substrate deposits (Goodwin and Pease 1989).

Food Items: Larvae have been successfully reared on the following algae species: *Pavlova lutheri, Isochrysis galbana, Pseudoisochrysis paradoxa, Phaeodactylum tricornutum, Monochrysis lutheri, Chaetoceros calcitrans*, and *Thalassiosira pseudonona* (Goodwin 1973a, Goodwin et al. 1979, Strathmann et al. 1987). Larvae, juveniles, and adults feed on various phytoplankton and suspended detritus.

Biological Interactions

Predation: Important predators of small juveniles include northern moon snail (*Polinices lewisii*), coonstriped shrimp (*Pandalus danae*), rock crabs (*Cancer* spp.), English sole (*Parophrys vetulus*), rock sole (*Lepidopsetta bilineata*), sand sole (*Psettichthys melanostictus*), pile perch (*Rhacochilus vacca*), spiny dogfish (*Squalus acanthias*), starry flounder (*Platichthys stellatus*), and other flatfish. Seastars (*Pisaster* spp.) and sunstar (*Pycnopodia helianthoides*) feed on juveniles and adults (Sloan and Robinson 1983, Wolotira et al. 1989). Rock crabs will feed on any dislodged individuals (Wolotira et al. 1989). The tips of geoduck siphons are eaten by the Pacific staghorn sculpin (*Leptocottus armatus*) (Andersen 1971). Adults are also excavated and eaten by sea otters (*Enhydra lutris*). Geoducks reduce predation rates by burrowing deeply into sediments as they grow. Siphons are protected by retracting them when inactive and allowing the siphon hole to be buried (Wolotira et al. 1989). Predation is probably highest in areas where a hard layer of rock or clay does not permit geoducks to burrow deeply.

Factors Influencing Populations: Larvae and small juveniles appear to suffer extremely high mortality which results in low recruitment (Goodwin et al. 1979). However, mortality rates for older juveniles (2+ years) and adults are very low (Andersen 1971, Goodwin et al. 1979). Recruitment of juveniles appears to be highest in areas containing adults, indicating that commercial harvest may adversely affect recruitment (Goodwin and Shaul 1984). To assist reestablishment of geoducks in areas where they have recently been harvested, the Washington Department of Fisheries has developed a geoduck hatchery and "seeds" these areas (Goodwin and Shaul 1984). Some adult mortalities result from anoxic conditions arising from vegetation accumulation and decomposition, dredging operations, sediment slumping and earthquakes (which may crack their shells) (Andersen 1971, Wolotira et al. 1989). Other factors possibly affecting populations include disease, siltation (especially intertidal and shallow water subtidal beds), and illegal harvest (Andersen 1971, Schink et al. 1983). Some geoduck beds in Puget Sound are closed to harvest because of industrial and municipal pollution. Other beds have been lost because of pier, jetty, marina, and pipeline development projects. Aquaculture of other species (primarily salmonid net pens) has altered and reduced geoduck harvest in some areas (Goodwin and Pease 1989).

References

Andersen, A. M., Jr. 1971. Spawning, growth, and spatial distribution of the geoduck clam, *Panopea generosa* Gould, in Hood Canal, Washington. Ph.D. Thesis, Univ. Wash., Seattle, WA, 118 p.

Bernard, F. R. 1983. Catalogue of the living Bivalvia of the eastern Pacific Ocean: Bering Strait to Cape Horn. Can. Spec. Publ. Fish. Aquat. Sci. 61, 102 p.

Breen, P. A., and T. L. Shields. 1983. Age and size structure in five populations of geoduc clams (*Panopea generosa*) in British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. No. 1169, 62 p.

Cheney, D. P., and T. F. Mumford, Jr. 1986. Shellfish and seaweed harvests of Puget Sound. Wash. Sea Grant, Univ. Wash. Press, Seattle, WA, 164 p.

Cox, R. K. 1979. The geoduck, *Panopea generosa*: some general information on distribution, life history, harvesting, marketing and management in British Columbia. British Columbia Ministry Env., Mar. Res. Branch, Fish. Man. Rep. No. 15, 25 p.

Fitch, J. E. 1953. Common marine bivalves of California. Calif. Fish Game, Fish Bull. 90, 102 p.

Gates, D. E., and H. W. Frey. 1974. Designated common names of certain marine organisms of California. Calif. Fish Game, Fish Bull. 161:55-90.

Goodwin, C. L. 1973a. Subtidal geoducks of Puget Sound, Washington. Tech. Rep. 14, Wash. Dept. Fish., Olympia, WA, 81 p.

Goodwin, C. L. 1973b. Effects of salinity and temperature on the embryos of the geoduck clam (*Panopea generosa* Gould). Proc. Natl. Shellfish. Assoc. 63:93-95.

Goodwin, C. L. 1976. Observations on spawning and growth of subtidal geoducks (*Panopea generosa* Gould). Proc. Natl. Shellfish. Assoc. 65:49-58.

Goodwin, C. L., and B. Pease. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest)—Pacific geoduck clam. U.S. Fish. Wildl. Serv. Biol. Rep. 82(11.120), U.S. Army Corps Eng., TR EL-82-4, 14 p.

Goodwin, L., and B. Pease. 1987. The distribution of geoduck (*Panopea abrupta*) size, density, and quality in relation to habitat characteristics such as geographic area, water depth, sediment type, and associated flora and fauna in Puget Sound, Washington. Tech. Rep. 102, Wash. Dept. Fish., Olympia, WA, 44 p.

Goodwin, L., and W. Shaul. 1984. Age recruitment and growth of the geoduck clam (*Panopea generosa*, Gould) in Puget Sound Washington. Prog. Rep. 215, Wash. Dept. Fish., Olympia, WA, 30 p.

Goodwin, L., W. Shaul, and C. Budd. 1979. Larval development of the geoduck clam (*Panopea generosa*, Gould). Proc. Natl. Shellfish. Assoc. 69:73-76.

Haderlie, E. C., and D. P. Abbott. 1980. Bivalvia: The clams and allies. *In* R. H. Morris, D. P. Abbott, and E. C. Haderlie (editors), Intertidal invertebrates of California, p. 355-411. Stanford Univ. Press, Stanford, CA.

Kozloff, E. N. 1983. Seashore life of the northern Pacific coast. Univ. Wash. Press, Seattle, WA, 370 p.

MacIntyre, J., S. R. Sparling, M. Faustini, T. L. Richards, R. Nakamura, and B. F. Putman. 1986. Resource inventory: Marine life: Cayucos State Beach, Morrow Strand State Beach, Atascadero State Beach, Morro Bay State Park, Montana De Oro State Park. Calif. Polytech. State Univ., San Luis Obispo, CA, various pagination.

Marriage, L. D. 1954. The bay clams of Oregon: their economic importance, relative abundance, and general distribution. Cont. No. 20, Fish Comm. Oregon, Portland, OR, 47 p.

Oceanographic Institute of Washington. 1981. Clam and mussel harvesting industries in Washington state. Oceanog. Comm. Wash., Seattle, WA, various pagination.

Schink, T. D., K. A. McGraw, and K. K. Chew. 1983. Pacific coast clam fisheries. Wash. Sea Grant Prog., Univ. Wash., Seattle, WA, 72 p.

Shaul, W., and L. Goodwin. 1982. Geoduck (*Panopea generosa*: Bivalvia) age as determined by internal growth lines in the shell. Can. J. Fish. Aquat. Sci. 39:632-636.

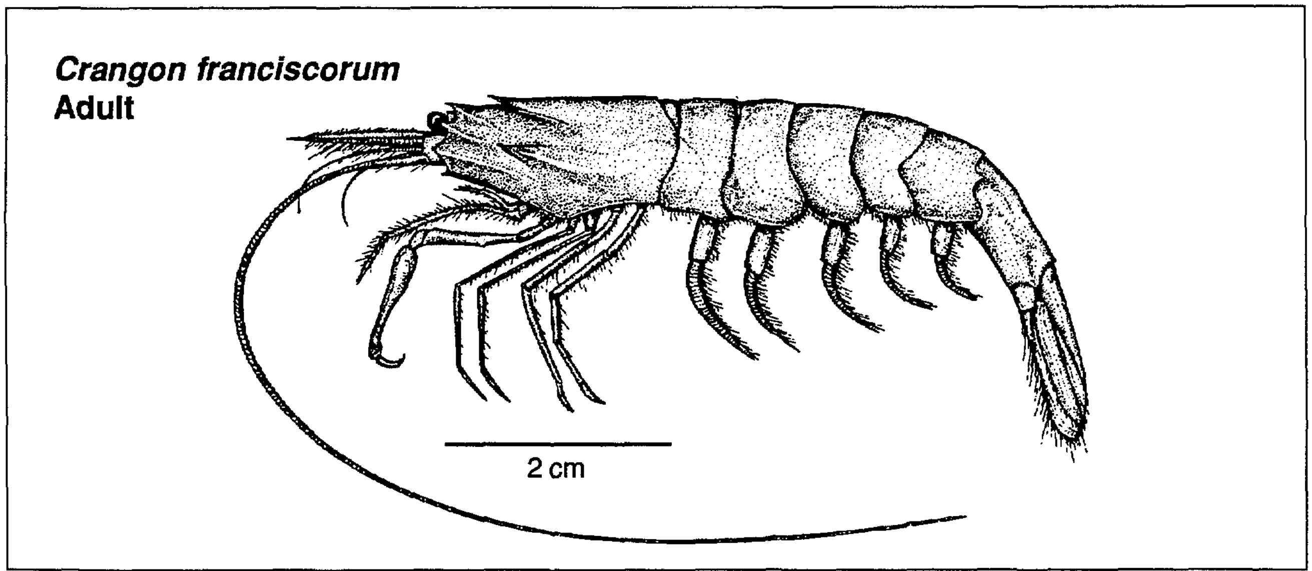
Sloan, N.A., and S. M. C. Robinson. 1983. Winter feeding by asteroids on a subtidal sandbed in British Columbia. Ophelia 22(2):125-140.

Sloan, N. A., and S. M. C. Robinson. 1984. Age and gonad development in the geoduck clam, *Panopea abrupta* (Conrad) from southern British Columbia, Canada. J. Shellfish Res. 4(2):131-137.

Strathmann, M. F., A. R. Kabat, and D. O'Foighil. 1987. Phylum Mollusca, class Bivalvia. *In* M. F. Strathmann (editor), Reproduction and development of marine invertebrates of the northern Pacific coast, p. 309-353. Univ. Wash. Press, Seattle, WA.

Wolotira, R. J., Jr., M. J. Allen, T. M. Sample, C. R. Iten, S. F. Noel, and R. L. Henry. 1989. Life history and harvest summaries for selected invertebrate species occurring off the west coast of North America. Volume 1: shelled molluscs. NOAA Tech. Memo. NMFS F/NWC-160, 177 p.

Bay shrimp



Common Name: bay shrimp
Scientific Name: *Crangon franciscorum*
Other Common Names: Franciscan bay shrimp, California shrimp, grass shrimp (Gates and Frey 1974, Khorram and Knight 1977)
Classification (Bowman and Abele 1982)
Phylum: Crustacea
Class: Malacostraca
Order: Decapoda
Family: Crangonidae

Two subspecies are defined, *C. franciscorum franciscorum* and *C. franciscorum angustimana*. The latter differs from *C. f. franciscorum* by having a long chela, with tip of dactylus crossing under basal part of fixed finger (Butler 1980).

Value

Commercial: The bay shrimp is commercially fished (primarily with trawls) only in San Francisco Bay, California (Smith and Kato 1979, Chace and Abbott 1980). It once supported a larger fishery that utilized trawls, fyke nets, and seines (Butler 1980). It is fished mainly for use as bait, but some is used for human consumption. Recently, annual landings for three *Crangon* species (*C. franciscorum, C. nigricauda*, and *C. nigromaculata*) captured in San Francisco Bay have ranged from 2.3 to 25.0 t (Chace and Abbott 1980).

Recreational: This species is used as bait for striped bass (*Morone saxatilis*) and sturgeon (*Acipenser* spp.).

Indicator of Environmental Stress: Because estuaries play a critical role in the bay shrimp's life history, alterations of these habitats directly affect its populations (Frey 1971). This species is a good indicator of changes in estuarine temperature and salinity regimes (Khorram and Knight 1977). River discharge and subsequent changes to estuarine salinity regimes appear to determine distribution, recruitment levels, survival, and growth (Hatfield 1985, California Department of Fish and Game 1987). Alicyclic hexanes at concentrations ranging of 1.5-10.9 ppm are acutely toxic to bay shrimp; these chemicals can be bioaccumulated by a factor of 13 (Benville et al. 1985).

Ecological: The bay shrimp is the dominant decapod shrimp in most Pacific coast estuaries (Krygier and Horton 1975, Hoeman 1982, Rudy and Rudy 1983, Hatfield 1985). It is an important prey for many Pacific coast fish and crab species (Haertel and Osterberg 1966, Stevens et al. 1982), and an important estuarine benthic and epibenthic predator (Sitts and Knight 1979, Siegfried 1980, Hatfield 1985). The agitation of bottom sediments (caused by this species as it searches for food) may contribute to nutrient cycling (Krygier and Horton 1975). Estuaries are used as nursery areas by this species, with lower salinity areas particularly important to young shrimp (Krygier and Horton 1975).

Range

Overall: The bay shrimp's overall range is from San Diego, California, to Alaska (Butler 1980, Chace and Abbott 1980). *C. f. angustimana* is apparently only found in deeper waters (18-183 m) from Tillamook Rock, Oregon to Kachemak Bay, Alaska (Butler 1980).

Within Study Area: This species is abundant to common in all Pacific coast estuaries from San Francisco Bay to Puget Sound, Washington, but it is not normally found in estuaries south of San Francisco Bay (Table 1) (Monaco et al. 1990).

Table 1. Relative abundance of bay shrimp in 32 U.S. Pacific coast estuaries.

Estuary	A	S	J	L	E
Puget Sound	◉	◉	◉	◉	◉
Hood Canal	○	○	○	○	○
Skagit Bay	◉	◉	●	◉	◉
Grays Harbor	◉	◉	●	◉	◉
Willapa Bay	◉	◉	●	◉	◉
Columbia River	◉	◉	●	◉	◉
Nehalem Bay	◉	◉	●	◉	◉
Tillamook Bay	◉	◉	●	◉	◉
Netarts Bay	○	○	○	○	○
Siletz River	◉	◉	●	◉	◉
Yaquina Bay	◉	◉	●	◉	◉
Alsea River	◉	◉	●	◉	◉
Siuslaw River	◉	◉	●	◉	◉
Umpqua River	◉	◉	●	◉	◉
Coos Bay	◉	◉	●	◉	◉
Rogue River					
Klamath River					
Humboldt Bay	√		◉	○	
Eel River	◉	◉	●	◉	◉
Tomales Bay	○	○	◉	◉	○
Cent. San Fran. Bay *	◉	◉	●	●	◉
South San Fran. Bay	◉	○	◉	○	○
Elkhorn Slough					
Morro Bay					
Santa Monica Bay					
San Pedro Bay					
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Life Stage

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

Life Mode

Eggs are brooded on the female's body, carried under the abdomen, attached to and between the basal joints and inner rami of the pleopods or abdominal legs (Israel 1936). The larvae are epipelagic, and juveniles and adults are epibenthic.

Habitat

Type: Adults are found in estuaries and offshore, intertidally down to 183 m (Butler 1980). Ovigerous females are found in the lower portions of estuaries and adjacent offshore waters (Krygier and Horton 1975). Juveniles primarily inhabit channels and flats in the low salinity areas of estuaries.

Substrate: Larvae are found over a variety of substrates. Juveniles and adults occur primarily over sandy to muddy substrates (Kuris and Carlton 1977).

Physical/Chemical Characteristics: The bay shrimp is a euryhaline species. Juveniles and adults are found in euhaline to oligohaline waters in Prince William Sound, Alaska (2.2-28.3‰) (Butler 1980). In San Francisco Bay and Delta, highest densities are found at salinities of 1-7‰ (Siegfried 1980). Juveniles appear to prefer lower salinities (<32.0‰), while ovigerous females prefer salinities >14.6‰ (Krygier and Horton 1975). Juveniles and nonovigerous adults tolerate temperatures of 5.2-21.3°C; ovigerous females prefer temperatures of 6.8-19.2°C (Krygier and Horton 1975). Salinity and temperature influence this species' distribution significantly. High salinities retard the movements of juveniles to lower estuarine areas, while high temperatures in the summer increase movements to upper estuarine areas (Krygier and Horton 1975). Low salinities probably retard egg development (Krygier and Horton 1975), and salinities <12‰ may reduce larval survival (Siegfried 1980). Optimum conditions for adults are salinities of 18-20‰ and temperatures of 4.5-17.0°C (Khorram and Knight 1977, Siegfried 1980).

Migrations and Movements: A "spawning migration" occurs during the reproductive periods; adult females and males move to lower, more saline areas of estuaries (primarily March to July) (Krygier and Horton 1975). Juveniles move up estuaries during the summer to rear in lower salinity, higher temperature areas (Israel 1936, Armstrong et al. 1981, Hatfield 1985). As they grow and mature, bay shrimp move to lower, more saline areas (Krygier and Horton 1975). In the fall and winter, many adults move to near the mouth of estuaries and nearshore areas outside estuaries (Hatfield 1985). Juveniles and adults undergo nocturnal vertical migrations to feed (Sitts and Knight 1979). Larvae appear to be advected seaward by river flow (Hatfield 1985).

Reproduction

Mode: The bay shrimp is gonochoristic and oviparous. Sperm is stored internally in the female; eggs are fertilized when extruded and brooded externally on the female's body.

Mating/Spawning: Although gravid females may be found year-round, usually only two spawning periods exist (sometimes only one depending on the estuary) (Israel 1936, Krygier and Horton 1975). In Yaquina Bay, Oregon, spawning occurs from December to March (older females), and from April to August (first-time and repeat spawners). The second spawning is usually larger (more spawners present for a longer period) than the first (Krygier and Horton 1975). In San Francisco Bay, only a single extended spawning period was thought to exist, with a peak from March to September (Israel 1936). However, a bimodal reproductive schedule appears to occur here also; during the first period, gravid females reside primarily off the mouth of San Francisco Bay (Hatfield 1985). A "spawning migration" occurs, with females and males moving to deeper, higher salinity areas (usually >21‰, depending on water temperature) when they become reproductively active (Krygier and Horton 1975, Siegfried 1980). Nearshore areas outside of estuaries are often used by spawning adults during the winter and spring (Durkin and Lipovsky 1977, Hatfield 1985).

Fecundity: Females from 47.8-67.4 mm total length (TL) carried 1,923-4,764 eggs per female, with a mean of 3,528 (Krygier and Horton 1975). Fecundity of bay shrimp ranged from 1,977-3,103 in Grays Harbor, Washington (Hoeman 1982), and from 2,499-8,840 in south San Francisco Bay (Stevenson et al. 1987). Fecundity (Y) was calculated to be Y=-5338.7+156.1(TL) for shrimp in Yaquina Bay (Krygier and Horton 1975), and log Y=-3.66+4.09log(TL) for shrimp in San Francisco Bay (Siegfried 1980).

Growth and Development

Egg Size and Embryonic Development: Eggs are spherical and 0.60 mm in diameter (Mondo 1980). Embryonic development is indirect and external; eggs remain in the female's brood pouch until hatching. Eggs appear to take 8-12 weeks to mature, depending on temperature. Larvae hatched in early spring develop into juveniles by May to July (Krygier and Horton 1975).

Age and Size of Larvae: Larvae range from 6.0-7.4 mm TL (Israel 1936, Krygier and Horton 1975). Larvae undergo seven larval stages in 21 days at 17.5°C (Mondo 1980).

Juvenile Size Range: Juvenile bay shrimp range from 6.0-7.4 mm to about 34 mm TL for males, 48 mm TL for females (Israel 1936, Krygier and Horton 1975), however, this may differ between estuaries (Israel 1936). After reaching 30 mm TL, growth is estimated to be 2.0 mm/month (Stevenson et al. 1987).

Age and Size of Adults: Both sexes mature in about 1-1.5 years, with most males reaching maturity at 34 mm TL and females at 48 mm TL (Krygier and Horton 1975, Butler 1980, Stevenson et al. 1987) or 55-60 mm TL in San Francisco Bay (Hatfield 1985, Stevenson et al. 1987). Males appear to spawn only once, while females may produce two broods (Butler 1980). Females are 60 mm TL in 1.5 years, males 50-52 mm TL after 1 year; females >62 mm TL are rare in Yaquina Bay, but are common off the Columbia River (Krygier and Horton 1975, Durkin and Lipovsky 1977). The largest size reported is 110 mm TL off the Columbia River (Durkin and Lipovsky 1977). Females may live 2-2.5 years, and males about 1.5 years (Stevenson et al. 1987).

Food and Feeding

Trophic Mode: Larvae, juveniles, and adults are primarily carnivorous (occasionally detritivorous), feeding on benthic and epibenthic prey. Food habits depend on the shrimp's size, temperature-salinity preferences, and prey availability (Wahle 1985).

Food Items: The bay shrimp feeds on mysids (*Neomysis mercedis*), amphipods (primarily *Corophium* spp., *Ampelisca abdita*, and *Grandidierella japonica*), bivalves (primarily *Mya arenaria*, *Gemma gemma*, and *Venerupis japonica*), foraminiferans, isopods, copepods, ostracods, gastropods, and plant material (Wahle 1985).

Biological Interactions

Predation: The bay shrimp is an important prey for the striped bass (*Morone saxatilis*), brown smoothhound (*Mustelus henlei*), green sturgeon (*A. medirostris*), white sturgeon (*A. transmontanus*), Pacific staghorn sculpin (*Leptocottus armatus*), Pacific tomcod (*Microgadus proximus*), prickly sculpin (*Cottus asper*), sand sole (*Psettichthys melanostictus*), waterfowl, harbor seal (*Phoca vitulina*), and the Dungeness crab (*Cancer magister*) (Ganssle 1966, Hoeman 1982, Stevens et al. 1982). The bay shrimp is also susceptible to cannibalism (Mondo 1980).

Factors Influencing Populations: This species may compete with the introduced oriental shrimp (*Palaemon macrodactylus*) for food and resources, especially during drought years (Sitts and Knight 1979, Siegfried 1980). The bay shrimp is one of the most abundant organisms entrained during dredging operations in Pacific Northwest estuaries (Armstrong et al. 1981, Hoeman 1982). Its distribution is also influenced by the availability and abundance of the mysid *Neomysis mercedis* (Siegfried 1980). Freshwater inflow into estuaries strongly influences this species' distribution and abundance (Hatfield 1985, California Department of Fish and Game 1987). Abiotic conditions during winter and spring off the mouths of estuaries may also influence populations (Hatfield 1985). The bay shrimp is a short-lived species that shows large annual fluctuations in abundance and may be highly sensitive to effects of short-term estuarine pollution (Frey 1971). Parasitism by the branchial isopod *Argeia pugettensis* inhibits female reproduction (Butler 1980, Hoeman 1982). Necrotic shell lesions may affect populations, but little information is available (Stevenson et al. 1987). Predation may also significantly control year class strength (Stevenson et al. 1987).

References

Armstrong, D. A., B. G. Stevens, and J. C. Hoeman. 1981. Distribution and abundance of Dungeness crab and *Crangon* shrimp, and dredging-related mortality of invertebrates and fish in Gray's Harbor, Washington. Tech. Rep. to Wash. Dept. Fish. and U.S. Army Corps Eng., School Fish., Univ. Wash., Seattle, WA, 349 p.

Benville, P. E., J. A. Whipple, and M. B. Eldridge. 1985. Acute toxicity of seven alicyclic hexanes to striped bass, *Morone saxatilis*, and bay shrimp, *Crangon franciscorum*, in seawater. Calif. Fish Game 71(3):132-140.

Bowman, T. E., and L. G. Abele. 1982. Classification of the recent crustacea. *In* L. G. Abele (editor), D. E. Bliss (editor-in-chief), The biology of Crustacea, Volume 1. Systematics, the fossil record, and biogeography, p. 1-25. Academic Press, New York, NY.

Butler, T. H. 1980. Shrimps of the Pacific coast of Canada. Can. Bull. Fish Aquat. Sci., Bull. No. 202, 280 p.

California Department of Fish and Game. 1987. Delta outflow effects on the abundance and distribution of San Francisco Bay fish and invertebrates, 1980-1985. Exhibit 60, entered by the California Department of Fish and Game for the State Water Resources Control Board 1987 Water Quality/Water Rights Proceeding on the San Francisco Bay/Sacramento-San Joaquin Delta. Calif. Dept. Fish Game, Stockton, CA, 345 p.

Chace, F. A., Jr., and D. P. Abbott. 1980. Caridea: the shrimps. *In* R. H. Morris, D. P. Abbott, and E. C. Haderlie (editors), Intertidal invertebrates of California, p. 567-593. Stanford Univ. Press, Stanford, CA.

Durkin, J. T., and S. J. Lipovsky. 1977. Aquatic disposal field investigations Columbia River disposal site, Oregon. Appendix E: Demersal fish and decapod shellfish studies. Tech. Rep. D-77-30, U.S. Army Corps Eng., Waterways Exper. Sta., Vicksburg, MI, 184 p.

Frey, H. W. 1971. California's living marine resources and their utilization. Calif. Dept. Fish Game, Sacramento, CA, 148 p.

Ganssle, D. 1966. Fishes and decapods of San Pablo and Suisun Bays. *In* D. W. Kelley (compiler), Ecological studies of the Sacramento-San Joaquin estuary. Calif. Fish Game, Fish Bull. 133:64-94.

Gates, D. E., and H. W. Frey. 1974. Designated common names of certain marine organisms of California. Calif. Fish Game, Fish Bull. 161:55-90.

Haertel, L., and C. Osterberg. 1966. Ecology of zooplankton, benthos and fishes in the Columbia River estuary. Ecology 48(3):459-472.

Hatfield, S. E. 1985. Seasonal and interannual variation in distribution and population abundance of the shrimp *Crangon franciscorum* in San Francisco Bay. Hydrobiol. 129:199-210.

Hoeman, J. C. 1982. The distribution and ecology of three species of crangonid shrimp in Grays Harbor, Washington, and their susceptibility to entrainment by dredges. M.S. Thesis, Univ. Wash., Seattle, WA, 135 p.

Israel, H. R. 1936. A contribution toward the life histories of two California shrimps, *Crago franciscorum* (Stimpson) and *Crago nigricauda* (Stimpson). Calif. Fish Game, Fish Bull. 46, 28 p.

Khorram, S., and A. W. Knight. 1977. Combined temperature-salinity effects on grass shrimp. J. Environ. Engin. Div., Am. Soc. Civil Engin. 103:381-388.

Krygier, E. E., and H. Horton. 1975. Distribution, reproduction, and growth of *Crangon nigricauda* and *Crangon franciscorum* in Yaquina Bay, Oregon. Northw. Sci. 49(4):216-240.

Kuris, A. M., and J. T. Carlton. 1977. Description of a new species, *Crangon handi*, and new genus, *Lissocrangon*, of crangonid shrimps (Crustacea: Caridea) from the California coast, with notes on adaptation in body shape and coloration. Biol. Bull. 153:540-559.

Mondo, G. S. 1980. The larval development of the bay shrimp *Crangon franciscorum*. M.A. Thesis, San Francisco State Univ., San Francisco, CA, 120 p.

Monaco, M. E., R. L. Emmett, S. A. Hinton, and D. M. Nelson. 1990. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume I: data summaries. ELMR Rep. No. 4. Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 240 p.

Rudy, P., Jr., and L. H. Rudy. 1983. Oregon estuarine invertebrates. An illustrated guide to the common and important invertebrate animals. U.S. Fish Wildl. Serv. Biol. Serv. Prog., FWS/OBS-83/16, Portland, OR, 225 p.

Siegfried, C. A. 1980. Seasonal abundance and distribution of *Crangon franciscorum* and *Palaemon macrodactylus* (Decapod, Caridea) in the San Francisco Bay-Delta. Biol. Bull. 159:177-192.

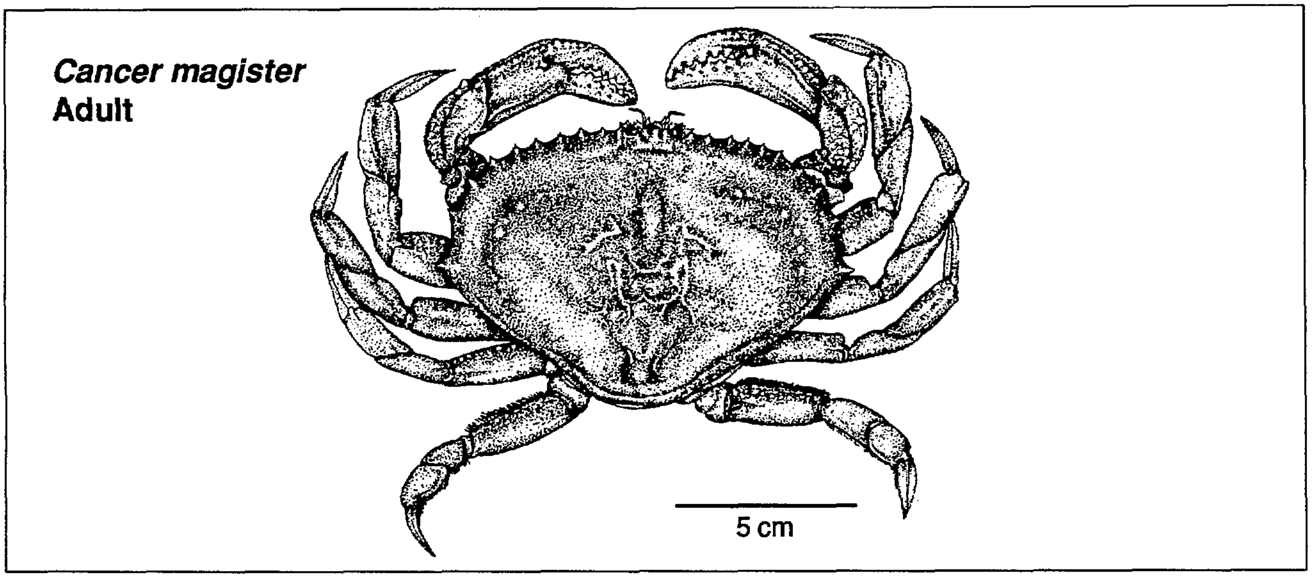
Sitts, R. M., and A. W. Knight. 1979. Predation by the estuarine shrimps *Crangon franciscorum* Stimpson and *Palaemon macrodactylus* Rathbun. Biol. Bull. 156:356-368.

Smith, S. E., and S. Kato. 1979. The fisheries of San Francisco Bay: past, present and future. *In* T. J. Conomos (editor), San Francisco Bay: the urbanized estuary, p. 445-468. Pac. Div. Am. Assoc. Adv. Sci., and Calif. Acad. Sci., San Francisco, CA.

Stevens, B. G., D. A. Armstrong, and R. Cusimano. 1982. Feeding habits of the Dungeness crab *Cancer magister* as determined by the index of relative importance. Mar. Biol. (Berl.) 72(1):135-145.

Stevenson, M. L., T. C. Goddard, L. M. Kiguchi, and P. J. Kinney. 1987. South Bay Discharges Authority water quality monitoring program. Final Report to South Bay Discharges Authority, San Jose, CA. Kennetic Lab. Inc., Santa Cruz, CA, and Larry Walker Assoc., Inc., Davis, CA, 467 p.

Wahle, R. A. 1985. The feeding ecology of *Crangon franciscorum* and *Crangon nigricauda* in San Francisco Bay, California. J. Crust. Biol. 5(2):311-326.



Common Name: Dungeness crab
Scientific Name: *Cancer magister*
Other Common Names: Pacific edible crab, edible crab, market crab, commercial crab (Hart 1982, Pauley et al. 1986)
Classification (Bowman and Abele 1982)
Phylum: Crustacea
Class: Malacostraca
Order: Decapoda
Family: Cancridae

Value

Commercial: The Dungeness crab is an important commercial shellfish that is harvested from the waters of Alaska to California. In 1985, more than 12,700 t worth over $39 million were landed (National Marine Fisheries Service 1986). The abundance of this species fluctuates considerably, but long-term average annual landings are near 17,000 t (Pacific Marine Fisheries Commission 1987). Baited crab pots are used to catch this species in nearshore marine waters normally <120 m deep (Dahlstrom and Wild 1983, Barry 1985). In the study area, major commercial landings occur north from Fort Bragg, California (Garth and Abbott 1980). The commercial season occurs primarily when males are hard-shelled. Off northern California, Oregon, and Washington the season usually opens December 1 and only male crabs ≥159 mm carapace width (CW) are legal (Barry 1985, Demory 1985, Warner 1985). In Alaska, the commercial season in the Southeast opens July 1, Yakutat opens May 1, and Kodiak opens May 1. In Washington, the season in Prince William Sound opens April 1. Only male crabs ≥165 mm CW are legal in these areas (Eaton 1985, Kimker 1985a, Koeneman 1985). The commercial season may last 9 months, but most crabs are captured within the first 2 months. The Dungeness crab is sold as cooked whole or shelled (and frozen or vacuum-packed) in cans.

Recreational: Limited data are available on the numbers of Dungeness crab captured by sport fishermen. It is primarily caught in bays and estuaries, captured either intertidally by hand or subtidally by baited crab pots, ring nets, dip nets, and hook and line (Pauley et al. 1986). Legal crabs for recreational fishermen must be male and ≥146 mm CW in Oregon, ≥152 mm CW in Washington, and ≥165 mm CW in California (where males and females can be taken) (Dahlstrom and Wild 1983).

Indicator of Environmental Stress: The effects of urban pollution including chlorine residuals, heavy metals, chlorinated pesticides, polychlorinated biphenyls, and hydrocarbons, on Dungeness crab are not clear. However, sublethal effects are indicated for some pollutants at concentrations presently occurring in San Francisco Bay, California (Guard et al. 1983, Haugen 1983a, 1983b, Horne et al. 1983, Cheney and Mumford 1986). Exposure to oiled sediments lowers this species' reproductive activity and larval survival (Karinen et al. 1985). Crabs are intolerant of low dissolved oxygen (optimal is > 5 ppm), and low concentrations of ammonia are toxic (Cheney and Mumford 1986). The insecticide SEVIN (carbaryl) is sometimes used to control ghost shrimp (*Callianassa* spp.) in Pacific oyster (*Crassostrea gigas*) beds, but is also very toxic to Dungeness crabs (Buchanan et al. 1985). Zoeae of *C. magister* are among the most sensitive life stages to insecticides and fungicides (Buchanan et al. 1970, Armstrong et al. 1976, Caldwell et al. 1979).

Table 1. Relative abundance of Dungeness crab in 32 U.S. Pacific coast estuaries.

Estuary	A	M	J	L	E
Puget Sound	◉	○	●	○	○
Hood Canal	○	○	●	○	○
Skagit Bay	◉	○	●	○	○
Grays Harbor	○		●	○	
Willapa Bay	○		●	○	
Columbia River	○		●	○	
Nehalem Bay	◉		●	●	
Tillamook Bay	◉		●	●	
Netarts Bay	○		●	●	
Siletz River	○		◉	◉	
Yaquina Bay	◉		●	●	
Alsea River	◉		●	●	
Siuslaw River	◉		●	●	
Umpqua River	○		●	●	
Coos Bay	◉	○	●	●	○
Rogue River	○		◉		
Klamath River	○		○		
Humboldt Bay	○		●	◉	
Eel River	○		●	○	
Tomales Bay	○		●	○	
Cent. San Fran. Bay *	√		●	√	
South San Fran. Bay	√		○	√	
Elkhorn Slough	√		√	√	
Morro Bay	√		√		
Santa Monica Bay					
San Pedro Bay					
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	M	J	L	E

Life Stage

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
M- Mating
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

Ecological: The Dungeness crab is important as both a predator (on *Crangon* spp. shrimp and bivalves) and prey species in nearshore and estuarine habitats. Estuaries are very important to early life stages (Tasto 1983, Armstrong and Gunderson 1985, Emmett and Durkin 1985).

Range

Overall: This species occurs from Santa Barbara, California in the south, to the Pribilof Islands (southeastern Bering Sea) in the north (Schmitt 1921, MacKay 1942, Pauley et al. 1986). It does not occur off Baja California (Garth and Abbott 1980). It is found along the Pacific coast in intertidal waters down to 420 m, but is not abundant at depths below 90 m.

Within Study Area: The Dungeness crab occurs in coastal waters and probably all bays and estuaries from Morro Bay, California (Soule and Tasto 1983), to Puget Sound, Washington (Table 1).

Life Mode

Eggs adhere to pleopods of the epibenthic-living adult female. Larvae (zoeae) are planktonic. Post-larvae (megalopae) are primarily planktonic, but become mostly benthic when close to molting (Reilly 1983a). Megalopae can actively swim and sometimes form "swarms" near the surface (Lough 1976, Hatfield 1983). Megalopae are often found on the hydrozoan *Velella velella* (Wickham 1979, Stevens and Armstrong 1985). Juveniles and adults are epibenthic.

Habitat

Type: Eggs adhere to pleopods of female crabs in euhaline (30-40‰) waters. Females with eggs can be found intertidally and in deeper nearshore waters (MacKay 1942). Larvae initially occur in nearshore euhaline waters (5-16 km from shore) (Lough 1976, Orcutt 1977, Reilly 1983a), with offshore movement and distribution influenced by depth, latitude, temperature, salinity, and currents (Reilly 1983a, 1985). Larvae are found near the surface at night and 15-25 m deep during daylight (Reilly 1983a, 1985). Megalopae are primarily found in shallow nearshore areas (Lough 1976, Hatfield 1983, Reilly 1983a). Megalopae occupy the upper 15 m both day and night (Reilly 1983a, 1985), but they also have diel migrations (Booth et al. 1985). Juveniles occur primarily in shallow coastal waters and estuaries (Butler 1956, Orcutt et al. 1975, Stevens and Armstrong 1984, 1985). Adults are found primarily intertidally to 90 m depths in marine (euhaline) waters, but sizable numbers occur in the lower reaches of estuaries.

Substrate: The Dungeness crab is found over various substrates. Juveniles are often found intertidally in estuarine areas of soft substrate containing eelgrass (*Zostera* spp.) and bivalve shells (Armstrong and Gunderson 1985). Adults can be found on mud, rock, and gravel bottoms, but they prefer sand (Frey 1971, Karpov 1983, Rudy and Rudy 1983).

Physical/Chemical Characteristics: Salinity tolerance varies with life stage (Pauley et al. 1986), but small juveniles do not appear to be more tolerant than adults (Stevens and Armstrong 1985). Eggs hatch over a wide range of salinities, but survival is best in euhaline waters (Pauley et al. 1986). Larvae are highly sensitive to salinity variations and are found primarily in euhaline waters (Buchanan and Milleman 1969, Lough 1976, Reilly 1983a). The interaction between salinity and temperature can significantly affect larval survival. At lower temperatures (≤10°C) eggs take longer to hatch and have lower hatching mortality rates (Mayer 1973, Wild 1983). Larval survival is best when temperatures are 10.0-14.0°C and salinities are 25-30‰ (Reed 1969, Pauley et al. 1986); larvae will not successfully develop to megalopae at 20°C (Sulkin and McKeen 1989). Juvenile and adult crabs in estuaries are exposed to rapidly changing salinities which they respond to by pulsing, closure (Surgarman et al. 1983), and movement (Stevens et al. 1984). Mating takes place at temperatures of 8.0-17.0°C (Pauley et al 1986). Water temperatures >20.0-25.0°C may cause juvenile and adult mortalities, depending on other environmental factors (Wild 1983, Pauley et al. 1986).

<u>Migrations and Movements</u>: Before spreading offshore, larvae initially appear in nearshore waters 5-16 km from shore in December (off California) and late January (off Oregon). Megalopae appear in early March to mid-April in California and April off Oregon and Washington (Lough 1976, Reilly 1983a, Pauley et al. 1986). Both larvae and megalopae undertake daily vertical migrations, being at the surface at night (Reilly 1983a, Booth et al. 1985, Shenker 1988). Tidal currents and self-propulsion bring megalopae within 1 km of shore and into estuaries in Oregon (Lough 1976). Megalopae may also "ride" the hydrozoan *Velella velella* to inshore waters (Wickham 1979). Early juveniles settle out in shallow water estuarine areas or adjacent marine waters (Tasto 1983, Stevens and Armstrong 1985), and also settle on tidal flats at high tide (Stevens and Armstrong 1984, Armstrong and Gunderson 1985). Adult crabs move out of estuaries to mate, but there are always some adults in estuaries. While tagging studies have shown that adult Dungeness crabs can move over a wide area, most exhibit limited random movements (Waldron 1958, Diamond and Hankin 1985). However, there is some evidence that male crabs move northward and into shallow waters during winter and southward and deeper during summer (Gotshall 1978). Diel movements to intertidal habitats may be a result of food availability (Stevens et al. 1984).

Reproduction

<u>Mode</u>: The Dungeness crab is gonochoristic, oviparous, and iteroparous. Eggs are fertilized while being extruded by the female.

<u>Mating/Spawning</u>: Mating occurs from April to September in British Columbia (MacKay 1942, Butler 1956), primarily from March to April (but sometimes to June) in Washington (Cleaver 1949, Pauley et al. 1986), and from March to July in California (Pauley et al. 1986). Mating takes place in non-estuarine locations, with males finding females via the possible aid of pheromones (Knudsen 1964, Pauley et al. 1986). Mating usually occurs when the female is soft-shelled. To accomplish this, the male may hold the female in a premating embrace for up to 7 days before she molts (Snow and Neilsen 1966). After she molts, the male inserts his gonopods into the spermathecae of the female and deposits spermatophores. The male may remain with the female for two days to insure her protection (Snow and Neilsen 1966). The spermatophores remain viable in the female for many months and fertilize the eggs when they are extruded (MacKay 1942, Wild 1983). Males can mate with more than one female.

<u>Fecundity</u>: Eggs are extruded in the fall and winter; from September to February in British Columbia (MacKay 1942, Butler 1956), October to December in Washington (Cleaver 1949), October to March in Oregon (Waldron 1958), and September to November in California (Orcutt et al. 1975, Wild 1983). A female may have 3 or 4 broods in a lifetime (MacKay 1942) and can carry up to 2.5 million eggs (Wickham 1980), but the actual number that hatch is much less (Wild 1980, 1983). Females have to be buried in sand for eggs to adhere properly to pleopods (Wild 1983). Eggs form an orange "sponge" that gets darker as the eggs mature.

Growth and Development

<u>Egg size and Embryonic Development</u>: Eggs are 0.4-0.6 mm in diameter, and smaller at higher incubation temperatures (Wild 1983). Embryonic development is indirect and external. Egg incubation takes 64-128 days depending on temperature (Cleaver 1949, Orcutt 1978, Wild 1983). Upon hatching, crabs emerge as prezoeae and molt to zoeae within one hour. (Buchanan and Milleman 1969).

<u>Age and Size of Larvae</u>: Larvae are 2.5-11.0 mm in length (Poole 1966). The larvae molt through five zoeal stages before metamorphosing into megalopae (Poole 1966, Lough 1976). The megalopa is the final planktonic stage; it molts to become the initial juvenile instar (Reilly 1983a, 1985).

<u>Juvenile Size Range</u>: Juveniles range in size from 5.0 mm CW to about 100 mm CW (larger for males) (Cleaver 1949, Waldron 1958, Butler 1960, 1961, Poole 1967). Crabs may molt 11 or 12 times before reaching sexual maturity (Butler 1961). Juveniles in estuaries grow faster than juveniles residing in coastal waters. Subyearling crabs in Grays Harbor and Willapa Bay, Washington, grew to 40 mm CW by September of their first year (Gunderson et al. 1990).

<u>Age and Size of Adults</u>: The Dungeness crab matures after approximately two years when 116 mm CW (males) or 100 mm CW (females) (Butler 1960, 1961).

Some male crabs reach harvestable size three years after settlement, and most males reach this size after four years (Warner 1987, Smith and Jamieson 1989). This species can live up to 8-10 years and reach a size of 218 mm CW (males), and 160 mm CW (females) (MacKay 1942, Butler 1961).

Food and Feeding

Trophic Mode: Larvae are planktivorous. Juveniles and adults are carnivorous.

Food Items: Larvae and megalopae eat phytoplankton and zooplankton, but primarily zooplankton (Lough 1976, Ebert et al. 1983). Juvenile crabs eat fish, molluscs, and crustaceans (Butler 1954, Gotshall 1977, Stevens et al. 1982). Shrimp (*Crangon* spp.) appear to be a preferred prey for juveniles that are 61-100 mm CW in Grays Harbor (Stevens et al. 1982). Larger juveniles often cannibalize smaller crabs (MacKay 1942, Butler 1954, Gotshall 1977, Stevens et al. 1982). Adults also eat fish, molluscs, and crustaceans, and are nonspecific feeders that alter their food habits as prey abundances fluctuate (Gotshall 1977). In general, crabs eat bivalves their first year, *Crangon* spp. their second year, and fish their third year (Stevens et al. 1982).

Biological Interactions

Predation: Dungeness crab eggs are consumed by a nemertean (*Carcinonemertes errans*) which can cause large losses in egg production (Wickham 1980). Larvae are eaten by planktivorous fishes such as Pacific herring (*Clupea pallasi*), Pacific sardine (*Sardinops sagax*), and others (Garth and Abbott 1980, Pauley et al. 1986). Megalopae are eaten by rockfish (*Sebastes* spp.), coho salmon (*Oncorhynchus kisutch*), and chinook salmon (*Oncorhynchus tshawytscha*), and probably other fishes (Prince and Gotshall 1976, Emmett et al. 1986). Juveniles are eaten by many species of fish, including starry flounder (*Platichthys stellatus*), English sole (*Pleuronectes vetulus*), rock sole (*Lepidopsetta bilineata*), lingcod (*Ophiodon elongatus*), cabezon (*Scorpaenichthys marmoratus*), wolf-eel (*Anarrhichthys ocellatus*), rockfish, sturgeon (*Acipenser* spp.), sharks, skates, Pacific halibut (*Hippoglossus stenolepis*), and others (Waldron 1958, Orcutt 1977, Reilly 1983b). Other important predators include *Octopus* spp. and sea otters (*Enhydra lutris*) (Kimker 1985b). Adults are consumed by humans, harbor seal (*Phoca vitulina*), sea lions, and gulls.

Factors Influencing Populations: Upwelling (Peterson 1973), cannibalism (Botsford and Wickham 1978), sea surface temperature (Wild 1980), sunspot number (Love and Westphal 1981), and wind stress (Johnson et al. 1986) have been proposed as causes for the cyclic nature of crab abundance. The success of a year class is probably determined by larval survival to metamorphosis, thus factors which influence egg, larvae, and megalopae survival are very important (Peterson 1973, Lough 1976, Pauley et al. 1986). Factors which affect larval survival include predation, extreme water temperatures, currents, and food availability (Lough 1976). Other causes of mortality which may influence population abundance include egg predation by *C. errans* (Wickham 1980), megalopae predation by salmon (Reilly 1983b), and diseases (Stevens and Armstrong 1981). Commercial trawling kills approximately 53 crabs per trawling hour (males) in California (Reilly 1983c). Finally, estuaries play a vital role in Dungeness crab abundance. Estimates of juvenile crab populations in Willapa Bay and Grays Harbor showed that these two systems contribute substantially to future crab catches (Stevens and Armstrong 1984, 1985). Estuaries are important nursery habitats for subyearling and yearling crabs (Gunderson et al. 1990). Hence, dredging and habitat modification projects in estuaries should consider the potential impacts on crab populations (Armstrong and Gunderson 1985, Emmett and Durkin 1985, Pauley et al. 1986, McGraw et al. 1988).

References

Armstrong, D. A., and D. R. Gunderson. 1985. The role of estuaries in Dungeness crab early life history: a case study in Grays Harbor, Washington. *In* B. R. Melteff (coordinator), Proceedings of the symposium on Dungeness crab biology and management, p. 145-170. Lowell Wakefield Fisheries Symposia Series, Univ. Alaska, Alaska Sea Grant Rep. No. 85-3, Fairbanks, AK.

Armstrong, D. A., D. V. Buchanan, and R. S. Caldwell. 1976. A mycosis caused by *Lagenidium* sp. in laboratory-reared larvae of the Dungeness crab, *Cancer magister*, and possible chemical treatments. J. Invert. Pathol. 28: 329-336.

Barry, S. 1985. Overview of the Washington coastal Dungeness crab fishery. *In* B. R. Melteff (coordinator). Proceedings of the symposium on Dungeness crab biology and management, p. 33-36. Lowell Wakefield Fisheries Symposia Series, Univ. Alaska, Alaska Sea Grant Rep. No. 85-3, Fairbanks, AK.

Booth, J., A. Phillips, and G. S. Jamieson. 1985. Fine scale spatial distribution of *Cancer magister* megalopae and its relevance to sampling methodology. *In* B. R. Melteff (coordinator), Proceedings of the symposium on Dungeness crab biology and management, p. 273-286 Lowell Wakefield Fisheries Symposia Series, Univ. Alaska, Alaska Sea Grant Rep. No. 85-3, Fairbanks, AK.

Botsford, L. W., and D. E. Wickham. 1978. Behavior of age-specific, density-dependent models and the northern California Dungeness crab (*Cancer magister*) fishery. J. Fish. Res. Board Can. 35(6):833-843.

Bowman, T. E., and L. G. Abele. 1982. Classification of the recent crustacea. *In* L. G. Abele (editor), D. E. Bliss (editor-in-chief), The biology of Crustacea, Volume 1. Systematics, the fossil record, and biogeography, p. 1-25. Academic Press, NY.

Buchanan, D. W., and R. E. Milleman. 1969. The prezoeal stage of the Dungeness crab, *Cancer magister* Dana. Biol. Bull. (Woods Hole) 137(2):250-255.

Buchanan, D. V., R. E. Millemann, and N. E. Stewart. 1970. Effects of the insecticide Sevin on various stages of Dungeness crab, *Cancer magister*. J. Fish. Res. Board Can. 27:93-104.

Buchanan, D. V., D. L. Bottom, and D. A. Armstrong. 1985. The controversial use of the insecticide Sevin in Pacific Northwest estuaries: its effects on Dungeness crab, Pacific oyster, and other species. *In* B. R. Melteff (coordinator), Proceedings of the symposium on Dungeness crab biology and management, p. 401-417. Lowell Wakefield Fisheries Symposia Series, Univ. Alaska, Alaska Sea Grant Rep. No. 85-3, Fairbanks, AK.

Butler, T. H. 1954. Food of the commercial crab in the Queen Charlotte Islands region. Fish. Res. Board Can. Prog. Rep. 99:3-5.

Butler, T. H. 1956. The distribution and abundance of early larval stages of the British Columbia commercial crab. Fish. Res. Board Can. Prog. Rep. 107:22-23.

Butler, T. H. 1960. Maturity and breeding of the Pacific edible crab, *Cancer magister* Dana. J. Fish. Res. Board Can. 17(5):641-646.

Butler, T. H. 1961. Growth and age determination of the Pacific edible crab, *Cancer magister* Dana. J. Fish. Res. Board Can. 18(5):873-889.

Caldwell, R. S., D. V. Buchanan, D. A. Armstrong, M. H. Mallon, and R. E. Millemann. 1979. Toxicity of the herbicides 2,4-D, DEF, Propanil and Trifluralin to the Dungeness crab, *Cancer magister*. Arch. Environ. Contam. Toxicol. 8:383-396.

Cheney, D. P., and T. F. Mumford, Jr. 1986. Shellfish and seaweed harvests of Puget Sound. Wash. Sea Grant, Univ. Wash. Press, Seattle, WA, 164 p.

Cleaver, F. C. 1949. Preliminary results of the coastal crab (*Cancer magister*) investigation. Biol. Rep. 49A:74-82, Wash. Dept. Fish., Olympia, WA.

Dahlstrom, W. A., and P. W. Wild. 1983. A history of Dungeness crab fisheries in California. *In* P. W. Wild and R. N. Tasto (editors), Life history, environment, and mariculture studies of the Dungeness crab, *Cancer magister*, with emphasis on the central California fishery resource. Calif. Fish Game, Fish Bull. 172:7-24.

Demory, D. 1985. An overview of Oregon Dungeness crab fishery with management concepts for the future. *In* B. R. Melteff (coordinator), Proceedings of the symposium on Dungeness crab biology and management, p. 27-32. Lowell Wakefield Fisheries Symposia Series, Univ. Alaska, Alaska Sea Grant Rep. No. 85-3, Fairbanks, AK.

Diamond, N., and D. G. Hankin. 1985. Movements of adult female Dungeness crabs (*Cancer magister*) in northern California based on tag recoveries. Can. J. Fish. Aquat. Sci. 42(5):919-926.

Eaton, M. F. 1985. Kodiak Island commercial Dungeness, *Cancer magister*, fishery. *In* B. R. Melteff (coordinator), Proceedings of the symposium on Dungeness crab biology and management, p. 97-116. Lowell Wakefield Fisheries Symposia Series, Univ. Alaska, Alaska Sea Grant Rep. No. 85-3, Fairbanks, AK.

Ebert, E. E., A. W. Hazeltine, J. L. Houk, and R. O. Kelly. 1983. Laboratory cultivation of the Dungeness crab, *Cancer magister*. *In* P. W. Wild and R. N. Tasto (editors), Life history, environment, and mariculture studies of the Dungeness crab, *Cancer magister*, with emphasis on the central California fishery resource. Calif. Fish Game, Fish Bull. 172:259-309.

Emmett, R. L., and J. T. Durkin. 1985. The Columbia River estuary: an important nursery for Dungeness crabs, *Cancer magister*. Mar. Fish. Rev. 47(3):21-25.

Emmett, R. L., D. R. Miller, and T. H. Blahm. 1986. Food of juvenile chinook, *Oncorhynchus tshawytscha*, and coho, *O. kisutch*, salmon off the northern Oregon and southern Washington coasts, May-September 1980. Calif. Fish Game 72(1):38-46.

Frey, H. W. 1971. California's living marine resources and their utilization. Calif. Dept. Fish Game, Sacramento, CA, 148 p.

Garth, J. S., and D. P. Abbott. 1980. Brachyura: the true crabs. *In* R. H. Morris, D. P. Abbott, and E. C. Haderlie (editors). Intertidal invertebrates of California, p. 594-630. Stanford Univ. Press. Stanford, CA.

Gotshall, D. W. 1977. Stomach contents of northern California Dungeness crabs (*Cancer magister*). Calif. Fish Game 63(1):43-51.

Gotshall, D. W. 1978. Northern California Dungeness crab, *Cancer magister*, movements as shown by tagging. Calif. Fish Game 64(4):234-254.

Guard, H. E., L. H. DiSalvo, J. Ng, and P. W. Wild. 1983. Hydrocarbons in Dungeness crabs, *Cancer magister*, and estuarine sediments. *In* P. W. Wild and R. N. Tasto (editors), Life history, environment, and mariculture studies of the Dungeness crab, *Cancer magister*, with emphasis on the central California fishery resource. Calif. Fish Game, Fish Bull. 172:243-257.

Gunderson, D. R., D. A. Armstrong, Y.-B. Shi., and R. A. McConnaughey. 1990. Patterns of estuarine use by juvenile English sole (*Parophrys vetulus*) and Dungeness crab (*Cancer magister*). Estuaries 13(1):59-71.

Hart, J. F. L. 1982. Crabs and their relatives of British Columbia. British Columbia Provincial Museum Handbook No. 40. British Columbia Provincial Museum, Victoria, B.C., 267 p.

Hatfield, S. E. 1983. Intermolt staging and distribution of Dungeness crab, *Cancer magister*, megalopae. *In* P. W. Wild and R. N. Tasto (editors), Life history, environment, and mariculture studies of the Dungeness crab, *Cancer magister*, with emphasis on the central California fishery resource. Calif. Fish. Game, Fish Bull. 172:85-96.

Haugen, C. W. 1983a. Field and laboratory studies of toxic trace elements in Dungeness crabs. *In* P. W. Wild and R. N. Tasto (editors), Life history, environment, and mariculture studies of the Dungeness crab, *Cancer magister*, with emphasis on the central California fishery resource. Calif. Fish Game, Fish Bull. 172:227-238.

Haugen, C. W. 1983b. Chlorinated hydrocarbon pesticides and polychlorinated biphenyls in Dungeness crabs. *In* P. W. Wild and R. N. Tasto (editors), Life history, environment, and mariculture studies of the Dungeness crab, *Cancer magister*, with emphasis on the central California fishery resource. Calif. Fish Game, Fish Bull. 172:239-241.

Horne, A. J., M. Bennett, R. Valentine, R. E. Selleck, P. P. Russell, and P. W. Wild. 1983. The effects of chlorination of wastewater on juvenile Dungeness crabs in San Francisco Bay waters. *In* P. W. Wild and R. N. Tasto (editors), Life history, environment, and mariculture studies of the Dungeness crab, *Cancer magister*, with emphasis on the central California fishery resource. Calif. Fish Game, Fish Bull. 172:215-225.

Johnson, D. F., L. W. Botsford, R. D. Methot, Jr., and T. C. Wainwright. 1986. Wind stress and cycles in Dungeness crab (*Cancer magister*) catch off California, Oregon and Washington. Can. J. Fish. Aquat. Sci. 43:838-845.

Karinen, J. F., S. D. Rice, and M. M. Babcock. 1985. Reproductive success in Dungeness crab (*Cancer magister*) during long-term exposures to oil-contaminateed sediments. *In* Final Reports of Principal Investigators, Vol. 67, p. 435-461. Outer Cont. Shelf Environ. Assm. Prog., U.S. Dept. Comm., Nat. Ocean. Atmos. Adm., Ocean Asses. Div., U.S. Dept. Int., Min. Man. Serv., MMS 90-0044.

Karpov, K. A. 1983. Effect of substrate type on survival and growth in high density communal cultures of juvenile Dungeness crabs, *Cancer magister*. *In* P. W. Wild and R. N. Tasto (editors), Life history, environment, and mariculture studies of the Dungeness crab, *Cancer magister*, with emphasis on the central California fishery resource. Calif. Fish Game, Fish Bull. 172:311-318.

Kimker, A. 1985a. Overview of the Prince William Sound management area Dungeness crab fishery. *In* B. R. Melteff (coordinator), Proceedings of the symposium on Dungeness crab biology and management, p. 77-83. Lowell Wakefield Fisheries Symposia Series, Univ. Alaska, Alaska Sea Grant Rep. No. 85-3, Fairbanks, AK.

Kimker, A. 1985b. A recent history of the Orca Inlet, Prince William Sound Dungeness crab fishery with specific reference to sea otter predation. *In* B. R. Melteff (coordinator), Proceedings of the symposium on Dungeness crab biology and management, p. 231-241. Lowell Wakefield Fisheries Symposia Series, Univ. Alaska, Alaska Sea Grant Rep. No. 85-3, Fairbanks, AK.

Knudsen, J. W. 1964. Observations of the reproductive cycles and ecology of the common Brachyura and crablike Anomura of Puget Sound, Washington. Pac. Sci. 18(1):3-33.

Koeneman, T. M. 1985. A brief review of the commercial fisheries for *Cancer magister* in southeast Alaska and Yakutat waters, with emphasis on recent seasons. *In*

B. R. Melteff (coordinator), Proceedings of the symposium on Dungeness crab biology and management, p. 61-76. Lowell Wakefield Fisheries Symposia Series, Univ. Alaska, Alaska Sea Grant Rep. No. 85-3, Fairbanks, AK.

Lough, R. G. 1976. Larval dynamics of the Dungeness crab, *Cancer magister*, off the central Oregon coast, 1970-71. Fish. Bull., U.S. 74(2):353-375.

Love, M. S., and M. V. Westphal. 1981. A correlation between annual catches of Dungeness crab, *Cancer magister*, along the west coast of North America and mean annual sunspot number. Fish. Bull., U.S. 79:794-796.

MacKay, D. C. G. 1942. The Pacific edible crab, *Cancer magister*. Fish. Res. Board Can., Bull. 621:1-32.

Mayer, D. L. 1973. The ecology and thermal sensitivity of the Dungeness crab, *Cancer magister*, and related species of its benthic community in Similk Bay, Washington. Ph.D. Thesis. Univ. Wash., Seattle, WA, 188 p.

McGraw, K. A., L. L. Conquiest, J. O. Waller, P. A. Dinnel, and D. A. Armstrong. 1988. Entrainment of Dungeness crabs, *Cancer magister*, by hopper dredge in Grays Harbor, Washington. J. Shellfish Res. 7(2):219-231.

National Marine Fisheries Service. 1986. Fisheries of the United States, 1985. Current Fishery Statistics No. 8368. U.S. Dept. Comm., NOAA, Nat. Mar. Fish Serv., Nat. Fish. Stat. Prog., Washington, D.C., 122 p.

Orcutt, H. G. 1977. Dungeness crab research program. Marine Res. Rep. No. 76-16. Calif. Dept. Fish Game, Sacramento, CA, 55 p.

Orcutt, H. G., R. N. Tasto, P. W. Wild, C. W. Haugen, and P. C. Collier. 1975. Dungeness crab research program. Marine Res. Rep. No. 75-16. Calif. Dept. Fish Game, Sacramento, CA, 77 p.

Pacific Marine Fisheries Commission. 1987. 39'th annual report of the Pacific Marine Fisheries Commission for the year 1986. Pac. Mar. Fish. Comm., Portland, OR, 29 p.

Pauley, G. B., D. A. Armstrong, and T. W. Heun. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest)—Dungeness crab. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.63). U.S. Army Corps Eng., TR EL-82-4, Washington, D.C, 20 p.

Peterson, W. T. 1973. Upwelling indices and annual catches of Dungeness crab, *Cancer magister*, along the west coast of the United States. Fish. Bull., U.S. 22(3):902-910.

Poole, R. L. 1966. A description of the laboratory-reared zoeae of *Cancer magister* Dana, and megalopae taken under natural conditions (Decapoda, Brachyura). Crustac. 11(1):83-97.

Poole, R. L. 1967. Preliminary results of the age and growth study of the market crab, *Cancer magister*, in California: the age and growth of *Cancer magister* in Bodega Bay. *In* Proceedings of the symposium on crustacea. Mar. Biol. Assoc. India, Ernakulam, Part II:553-567.

Prince, E. D., and D. W. Gotshall. 1976. Food of the copper rockfish, *Sebastes caurinus* Richardson, associated with an artificial reef in south Humboldt Bay, California. Calif. Fish Game 64(4):274-285.

Reed, P. H. 1969. Culture methods and effect of temperature and salinity on survival and growth of Dungeness crab (*Cancer magister*) larvae in the laboratory. J. Fish. Res. Board Can. 26(2):389-397.

Reilly, P. N. 1983a. Dynamics of the Dungeness crab, *Cancer magister*, larvae off central and northern California. *In* P. W. Wild and R. N. Tasto (editors), Life history, environment, and mariculture studies of Dungeness crab, *Cancer magister*, with emphasis on the central California fishery resource. Calif. Fish Game, Fish Bull. 172:57-84.

Reilly, P. N. 1983b. Predation on Dungeness crabs, *Cancer magister*, in central California. *In* P. W. Wild and R. N. Tasto (editors), Life history, environment, and mariculture studies of Dungeness crab, *Cancer magister*, with emphasis on the central California fishery resource. Calif. Fish Game, Fish Bull. 172:155-164.

Reilly, P. N. 1983c. Effects of commercial trawling on Dungeness crab survival. *In* P. W. Wild and R. N. Tasto (editors), Life history, environment, and mariculture studies of Dungeness crab, *Cancer magister*, with emphasis on the central California fishery resource. Calif. Fish Game, Fish Bull. 172:165-169.

Reilly, P. N. 1985. Dynamics of the Dungeness crab, *Cancer magister*, larvae off central and northern California. *In* B. R. Melteff (coordinator), Proceedings of the symposium on Dungeness crab biology and management, p. 245-272. Lowell Wakefield Fisheries

Symposia Series, Univ. Alaska, Alaska Sea Grant Rep. No. 85-3, Fairbanks, AK.

Rudy, P., Jr., and L. H. Rudy. 1983. Oregon estuarine invertebrates - an illustrated guide to the common and important invertebrate animals. U.S. Fish Wildl. Serv., Biol. Serv. Prog. FWS/OBS-83/16, Portland, OR, 225 p.

Schmitt, W. L. 1921. The marine decapod crustacea of California. Univ. Calif. Publ. Zool., No. 23, 470 p.

Shenker, J. M. 1988. Oceanic associations of neustonic larval and juvenile fishes and Dungeness crab megalopae off Oregon. Fish. Bull., U.S. 86(2):299-317.

Smith, B. D., and G. S. Jamieson. 1989. Growth of male and female Dungeness crabs near Tofino, British Columbia. Trans. Am. Fish. Soc. 118:556-563.

Snow, C. D., and J. R. Neilsen. 1966. Premating and mating behavior of the Dungeness crab (*Cancer magister* Dana). J. Fish. Res. Board Can. 23(9):1319-1323.

Soule, M., and R. N. Tasto. 1983. Stock identification studies on the Dungeness crab, *Cancer magister*. *In* P. W. Wild and R. N. Tasto (editors), Life history, environment, and mariculture studies of the Dungeness crab, *Cancer magister*, with emphasis on the central California fishery resource. Calif. Fish Game, Fish Bull. 172:39-42.

Stevens, B. G., and D. A. Armstrong. 1981. Mass mortality of female Dungeness crab, *Cancer magister*, on the southern Washington coast. Fish. Bull., U.S. 79(2):349-352.

Stevens, B. G., and D. A. Armstrong. 1984. Distribution, abundance and growth of juvenile Dungeness crabs, *Cancer magister*, in Grays Harbor estuary, Washington. Fish. Bull., U.S. 82(3):469-483.

Stevens, B. G., and D. A. Armstrong. 1985. Ecology, growth, and population dynamics of juvenile Dungeness crab, *Cancer magister* Dana, in Grays Harbor, Washington 1980-1981. *In* B. R. Melteff (coordinator), Proceedings of the symposium on Dungeness crab biology and management, p. 119-134. Lowell Wakefield Fisheries Symposia Series, Univ. Alaska, Alaska Sea Grant Rep. No. 85-3, Fairbanks, AK.

Stevens, B. G., D. A. Armstrong, and R. Cusimano. 1982. Feeding habits of the Dungeness crab *Cancer magister* as determined by the index of relative importance. Mar. Biol. (Berlin) 72(1):135-145.

Stevens, B. G., D. A. Armstrong, and J. C. Hoeman. 1984. Diel activity of an estuarine population of Dungeness crabs, *Cancer magister*, in relation to feeding and environmental factors. J. Crust. Biol. 4(3):390-403.

Sulkin, S. D., and G. L. McKeen. 1989. Laboratory study of survival and duration of individual zoeal stages as a function of temperature in the brachyuran crab *Cancer magister*. Mar. Biol. 103:31-37.

Sugarman, P. C., W. H. Pearson, and D. L. Woodruff. 1983. Salinity detection and associated behavior in the Dungeness crab, *Cancer magister*. Estuaries 6(4):380-386.

Tasto, R. N. 1983. Juvenile Dungeness crab, *Cancer magister*, studies in the San Francisco Bay area. *In* P. W. Wild and R. N. Tasto (editors), Life history, environment, and mariculture studies of the Dungeness crab, *Cancer magister*, with emphasis on the central California fishery resource. Calif. Fish Game, Fish Bull. 172:135-154.

Waldron, K. D. 1958. The fishery and biology of the Dungeness crab (*Cancer magister* Dana) in Oregon waters. Oregon Fish Comm., Contrib. No. 24:1-43.

Warner, R. W. 1985. Overview of the California Dungeness crab, *Cancer magister*, fisheries. *In* B. R. Melteff (coordinator), Proceedings of the symposium on Dungeness crab biology and management, p. 11-26. Lowell Wakefield Fisheries Symposia Series, Univ. Alaska, Alaska Sea Grant Rep. No. 85-3, Fairbanks, AK.

Warner, R. W. 1987. Age and growth of male Dungeness crabs, *Cancer magister*, in northern California. Calif. Fish Game 73:4-20.

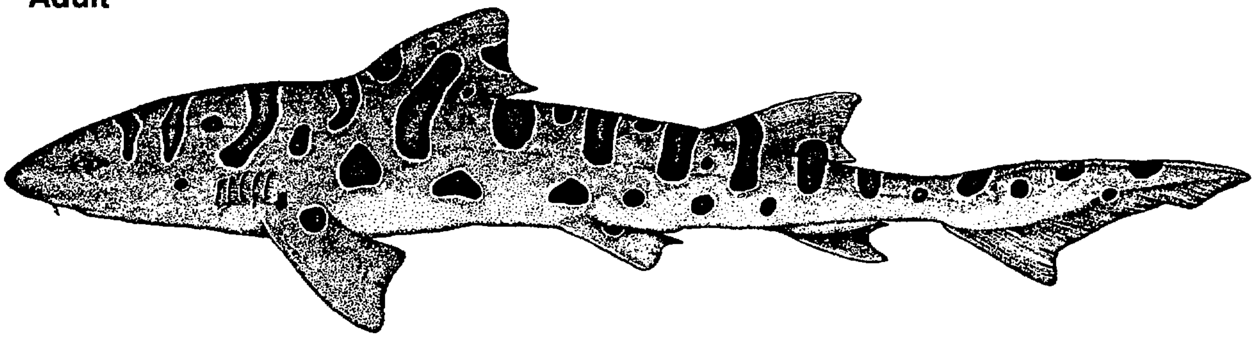
Wickham, D. E. 1979. The relationship between megalopae of the Dungeness crab, *Cancer magister*, and the hydroid, *Velella velella*, and its influence on abundance estimates of *C. magister* megalopae. Calif. Fish Game 65(3):184-186.

Wickham, D. E. 1980. Aspects of the life history of *Carcinonemertes errans* (Nemertea: Carcinonemertidae), an egg predator of the crab *Cancer magister*. Biol. Bull. (Woods Hole) 159:247-257.

Wild, P. W. 1980. Effects of seawater temperature on spawning, egg development, hatching success, and population fluctuations of the Dungeness crab, *Cancer* *magister.* Calif. Coop. Ocean. Fish. Invest. Rep. 21:115-120.

Wild, P. W. 1983. The influence of seawater temperature on spawning, egg development, and hatching success of the Dungeness crab, *Cancer magister. In* P. W. Wild and R. N. Tasto (editors), Life history, environment, and mariculture studies of the Dungeness crab, *Cancer magister*, with emphasis on the central California fishery resource. Calif. Fish Game, Fish Bull. 172:197-214.

Leopard shark



Common Name: leopard shark
Scientific Name: *Triakis semifasciata*
Other Common Names: cat shark, sand tiger
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Carcharhiniformes
Family: Triakidae

Value

Commercial: The leopard shark is caught and sold commercially year-round, but it is not normally targeted by commercial fishermen. However, a limited longline fishery exists in San Francisco Bay, California (S. Smith, National Marine Fisheries Service, La Jolla, California, unpubl. manuscr.). The meat is considered excellent and is sold fresh and fresh-frozen (Compagno 1984). This species was not sought during early shark fisheries because its liver does not contain high concentrations of vitamin A (Roedel and Ripley 1950).

Recreational: This species is a valuable sport fish in nearshore shallow waters of central and southern California. Important sport fisheries exist in San Francisco Bay and Elkhorn Slough, California (Herald and Ripley 1951, Smith and Kato 1979).

Indicator of Environmental Stress: Concentrations of polychlorinated biphenyls of 46.9 ppm have been found in leopard sharks in San Francisco Bay (Russo 1975). However, it is not known how or at what levels contaminants affect leopard shark biology.

Ecological: The leopard shark is one of the most common sharks in California bays and estuaries (Talent 1973, de Wit 1975, Ebert 1986) and along southern California beaches (Miller and Lea 1972). It is the most abundant shark in San Francisco Bay (Ebert 1986) and is common near jetties and piers (Talent 1976).

Range

Overall: Overall range of this species is from Baja Mexico, to southern Oregon. It is also found in the northern Gulf of California (Miller and Lea 1972, Eschmeyer et al. 1983).

Within Study Area: The leopard shark inhabits most California estuaries and bays, but is primarily found south of Tomales Bay (Table 1) (Monaco et al. 1990).

Life Mode

The leopard shark is a live-bearer; eggs are fertilized internally and embryogenesis occurs within the female. Juveniles and adults are demersal, sometimes resting on the bottom (Feder et al. 1974).

Habitat

Type: This shark is a neritic species found primarily in polyhaline to euhaline waters. It is most common in waters <3.7 m deep, but may occur down to 91 m (Eschmeyer et al. 1983, Compagno 1984). Estuaries appear to be used as pupping and feeding/rearing areas (Ackerman 1971, Talent 1973, Barry and Cailliet 1981).

Substrate: Juveniles and adults prefer sandy or muddy flats, but they may also be found over cobble bottoms, and near rocky reefs and kelp beds (Feder et al. 1974)

Physical/Chemical Characteristics: The leopard shark is a marine species, but no information is available concerning salinity tolerances. However, sharks

Table 1. Relative abundance of leopard shark in 32 U.S. Pacific coast estuaries.

Estuary	*Life Stage* A	P	J	M
Puget Sound				
Hood Canal				
Skagit Bay				
Grays Harbor				
Willapa Bay				
Columbia River				
Nehalem Bay				
Tillamook Bay				
Netarts Bay				
Siletz River				
Yaquina Bay				
Alsea River				
Siuslaw River				
Umpqua River				
Coos Bay	√			
Rogue River				
Klamath River				
Humboldt Bay	◉	◉	◉	
Eel River				
Tomales Bay	○	○	◉	
Cent. San Fran. Bay *	◉	○	○	○
South San Fran. Bay	●	◉	○	○
Elkhorn Slough	○	○	◉	
Morro Bay	○	○	○	
Santa Monica Bay	○	○	○	○
San Pedro Bay	○	○	○	○
Alamitos Bay	√		√	
Anaheim Bay	√		√	
Newport Bay	√		√	
Mission Bay	√		√	
San Diego Bay	√		√	
Tijuana Estuary				
	A	P	J	M

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
P- Parturition
J - Juveniles
M- Mating

* Includes Central San Francisco, Suisun, and San Pablo bays.

disperse in fall and winter in San Francisco Bay during months of high freshwater outflows (S. Smith, unpubl. manuscr.).

Migrations and Movements: Most adult leopard sharks leave Elkhorn Slough by June, but begin to return by October (Talent 1973); juveniles have their highest abundance in Elkhorn Slough in the summer. Tagging studies in San Francisco Bay showed that most sharks resided in the Bay from March to September, but dispersed both inside and outside the Bay from October through February. One tagged shark was recovered in Elkhorn Slough, 140 km south of San Francisco Bay (S. Smith unpubl. manuscr.). Leopard sharks may form large schools mixed with gray or brown smoothhound sharks (*Mustelus californicus* and *M. henlei*) (Compagno 1984). Schools appear to be nomadic, spending a few hours in one location and then moving to another area (Compagno 1984). Leopard sharks often enter shallow bays and onto intertidal flats during high tide, retreating during ebb tide (Compagno 1984). Unlike many sharks which are nocturnal, leopard sharks appear to be active during daylight (Dubsky 1974).

Reproduction

Mode: The leopard shark is gonochoristic, ovoviviparous, and iteroparous. Fertilization is internal and there is no yolk-sac placenta.

Mating/Spawning: Mating appears to occur soon after females give birth, primarily during April and May. Mating (as observed in the Steinhart Aquarium in San Francisco, California) is preceded by the male and female swimming rapidly together and the male holding the female's left pectoral fin in his mouth. By twisting his body under hers, the male is able to insert his left clasper into the female's cloaca. Hence, coitus occurs while swimming, with the male retaining the female's pectoral fin in his mouth the entire time (Ackerman 1971). Females give birth from March through August, with an April or May peak (Ackerman 1971, Talent 1973, S. Smith unpubl. manuscr.).

Fecundity: Litter size is 4-29 pups (Compagno 1984).

Growth and Development

Egg Size and Embryonic Development: Eggs develop within the female, but do not receive nourishment from the female (Jones and Stokes Associates, Inc. 1981). Embryonic development is direct and internal. The required developmental period for embryos appears to be 10-12 months (Ackerman 1971).

Age and Size of Larvae: There is no larval stage; embryonic development is direct and internal.

Juvenile Size Range: Young are 18-20 cm long at birth (S. Smith unpubl. manuscr.).

Age and Size of Adults: Females may take 12-14 years and be 110-129 cm long before reaching maturity. Males mature earlier and at smaller sizes than females (Ackerman 1971, Compagno 1984). The maximum recorded length is 1.8 m. Growth is apparently slow, tagged fish grew only 1.4 cm/yr (S. Smith unpubl. manuscr.). Calcified rings (useful for aging a fish) are laid down in vertebral centra sometime between May and September each year (Smith 1984).

Food and Feeding

Trophic Mode: Juveniles and adults are carnivorous, feeding primarily on benthic and epibenthic crustacea.

However, large adults also feed on pelagic fishes such as northern anchovy (*Engraulis mordax*) (Russo 1975).

Food Items: Young, smaller leopard sharks feed heavily on crabs (e.g., yellow shore crab, *Hemigrapsus oregonensis*) and other crustacea. As leopard sharks grow (80-130 cm long), echinuroid worms (*Urechis caupo*), fish eggs, and clam siphons become important prey. Larger adults (>130 cm in length) feed primarily on fish (Ackerman 1971, Russo 1975, Talent 1976). Common prey include ghost shrimp (*Callianassa* spp.), rock crabs (*Cancer* spp.), octopus (*Octopus* spp.), shiner perch (*Cymatogaster aggregata*), arrow goby (*Clevelandia ios*), Pacific herring (*Clupea pallasi*), topsmelt (*Atherinops affinis*), and northern anchovy (Talent 1973, Russo 1975, Talent 1976).

Biological Interactions

Predation: The leopard shark probably has no major predators except man.

Factors Influencing Populations: Recent reductions in shark numbers in San Francisco Bay may be due to reduced salinity, warm water, or over-harvesting (Ebert 1986). Populations may also be adversely affected by pollutants (Russo 1975). High pesticide concentrations in the livers of leopard sharks may relate to its benthic feeding habits and preference for nearshore habitat. A large shark die-off of unknown origin occurred in San Francisco Bay in 1967 (Russo and Herald 1968). However, a connection between pollutant loads and die-offs has not been established.

References

Ackerman, L. T. 1971. Contributions to the biology of the leopard shark, *Triakis semifasciata* (Girard) in Elkhorn Slough, Monterey Bay, California. M.A. Thesis, Sacramento State Coll., Sacramento, CA, 54 p.

Barry, J. P., and G. M. Cailliet. 1981. The utilization of shallow marsh habitats by commercially important fishes in Elkhorn Slough, California. Cal.-Nev. Wildl. Trans. 1981:38-47.

Compagno, L. J. V. 1984. FAO species catalogue. Vol. 4. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Part 2. Carcharhiniformes. FAO Fish. Synop. 125(4):433-434

de Wit, L. A. 1975. Change in the species composition of sharks in south San Francisco Bay. Calif. Fish Game 61(2):106-111.

Dubsky, P. A. 1974. Movement patterns and activity levels of fishes in Morro Bay, California as determined by ultrasonic tagging. M.S. Thesis, Calif. Polytech. State Univ., San Luis Obispo, CA, 51 p.

Ebert, D. A. 1986. Observations on the elasmobranch assemblage of San Francisco Bay. Calif. Fish Game 72(4):244-249.

Eschmeyer, W. N., W. S. Herald, and H. Hammann. 1983. A field guide to Pacific coast fishes of North America. Houghton Mifflin Co., Boston, MA, 336 p.

Feder, H. M., C. H. Turner, and C. Limbaugh. 1974. Observations on fishes associated with kelp beds in southern California. Calif. Fish Game, Fish Bull. 160, 144 p.

Herald, E. S., and W. E. Ripley. 1951. The relative abundance of sharks and bat stingrays in San Francisco Bay. Calif. Fish Game 37(3):315-329.

Jones and Stokes Associates, Inc. 1981. Ecological characterization of the central and northern California coastal region. Volume II, Part 2, Species. U.S. Fish Wildl. Serv., Off. Biol. Serv., and Bureau Land Manag., Pacific Outer Contin. Shelf Off., Washington, D.C., FWS/OBS-80/46.2, various pagination.

Miller, D. J., and R. N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Fish Game, Fish Bull. 157, 235 p.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Roedel, P. M., and W. E. Ripley. 1950. California sharks and rays. Calif. Fish Game, Fish Bull. 75:1-85.

Russo, R. A. 1975. Observations on the food habits of leopard sharks (*Triakis semifasciata*) and brown smoothhounds (*Mustelus henlei*). Calif. Fish Game 61(2):95-103.

Russo, R. A., and E. S. Herald. 1968. The 1967 shark kill in San Francisco Bay. Calif. Fish Game 54(3):215-216.

Smith, S. E. 1984. Timing of vertebral-band deposition in tetracycline-injected leopard sharks. Trans. Am. Fish. Soc. 113:308-313.

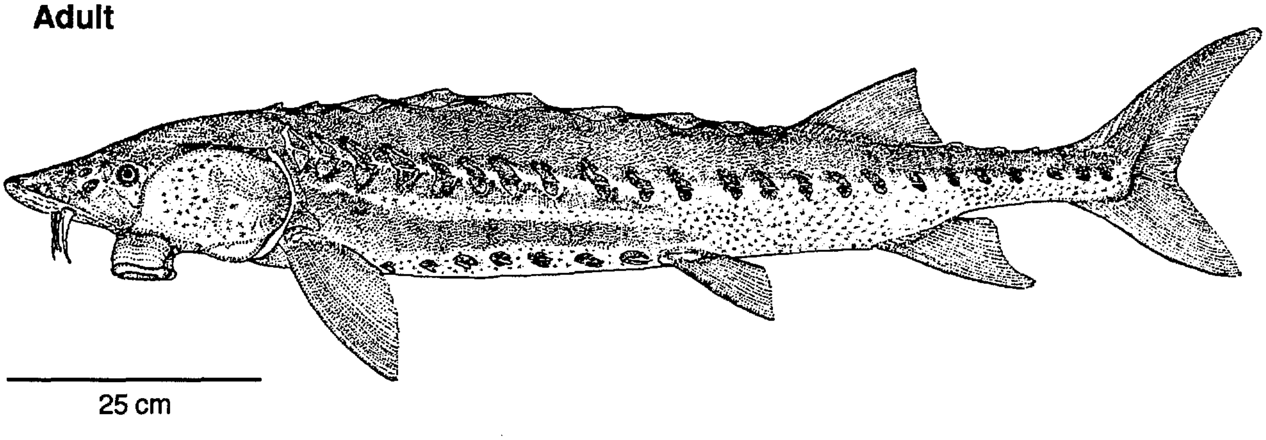
Smith, S. E., and S. Kato. 1979. The fisheries of San Francisco Bay: past, present and future. *In* San

Francisco Bay: the urbanized estuary, p. 445-468. Pac. Div. Am. Adv. Sci. and Calif. Acad. Sci., San Francisco, CA.

Talent, L. G. 1973. The seasonal abundance and food of elasmobranchs occurring in Elkhorn Slough, Monterey Bay, California. M.A. Thesis, Calif. State Univ., Fresno, CA, 58 p.

Talent, L. G. 1976. Food habits of the leopard shark, *Triakis semifasciata,* in Elkhorn slough, Monterey Bay, California. Calif. Fish Game 62(4):286-298.

Acipenser medirostris
Adult



Common Name: green sturgeon
Scientific Name: *Acipenser medirostris*
Other Common Names: Sakhalin sturgeon or sterlyad in USSR (Scott and Crossman 1973)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Acipenseriformes
Family: Acipenseridae

Value

Commercial: The green sturgeon is commercially targeted with white sturgeon (*A. transmontanus*) in the Columbia River estuary, Grays Harbor, and Willapa Bay, Washington. It is not as valuable as the white sturgeon because its meat is considered inferior. The green sturgeon is often captured while gillnetting for salmon (*Oncorhynchus spp.*) in estuaries. The green sturgeon is rarely captured in the trawl fishery. In Washington, an average of 4.7 and 15.9 t are annually landed in Grays Harbor and Willapa Bay, respectively (G. Kreitman, Washington Department of Fisheries, Battle Ground, WA, pers. comm.). It is the primary bottomfish landed in Willapa Bay. In 1986, during a 4-day commercial sturgeon season in the Columbia River estuary, 5,000 green sturgeon were captured (S. King, Oregon Department of Fish and Wildlife, Clackamas, OR, pers. comm.). The green sturgeon is also gillnetted by Native Americans in Grays Harbor and the Klamath River, California.

Recreational: The green sturgeon is incidentally captured during the white sturgeon sport fishery in many estuaries. However, this species does not appear to take a hook as readily as the white sturgeon.

Indicator of Environmental Stress: Since the green sturgeon is long-lived, it may concentrate contaminants. However, no chemical body burden information is presently available.

Ecological: This species is not highly abundant in any Pacific coast estuary, and very little is known about its life history (spawning areas, marine distributions, migrations, etc.). The green sturgeon is more marine-oriented than white sturgeon and spends limited time in fresh water (except perhaps early juveniles and spawning adults).

Range:

Overall: The green sturgeon's overall range is along the Pacific coast from Ensenada, Mexico (Moyle 1976) to southeast Alaska. It is also found in Asia (north Japan, Korea, and Sakhalin) (Wydoski and Whitney 1979).

Within Study Area: This species occurs in lower reaches of larger rivers. It appears to be the most common sturgeon in the Klamath River (Fry 1973, Tuss et al. 1987) and Willapa Bay (Table 1).

Life Mode

Eggs, juveniles, and adults are all demersal. Eggs are probably similar to the white sturgeon's, being slightly adhesive to substrates after fertilization. Larvae, juveniles, and adults are benthic feeders.

Habitat

Type: Green sturgeon larvae have not been positively identified, but they probably inhabit similar benthic freshwater areas as do white sturgeon larvae (Stevens and Miller 1970). Juveniles may occur in shallow water

Table 1. Relative abundance of green sturgeon in 32 U.S. Pacific coast estuaries.

	Life Stage				
Estuary	A	S	J	L	E
Puget Sound	√				
Hood Canal					
Skagit Bay					
Grays Harbor	○				
Willapa Bay	○				
Columbia River	○				
Nehalem Bay					
Tillamook Bay			√		
Netarts Bay					
Siletz River					
Yaquina Bay	○		○		
Alsea River	√		√		
Siuslaw River	√		√		
Umpqua River	○		√		
Coos Bay	○		○		
Rogue River	○		○		
Klamath River	○		○		
Humboldt Bay	○		○		
Eel River	○		○		
Tomales Bay					
Cent. San Fran. Bay *	○		○	○	
South San Fran. Bay	○		○		
Elkhorn Slough					
Morro Bay					
Santa Monica Bay					
San Pedro Bay					
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

(Radtke 1966), and probably move to deeper and more saline areas as they grow. Adults are euryhaline and reside in subtidal areas.

Substrate: Spawning substrate is probably similar to that preferred by other sturgeon, (i.e., large cobble). Adults and juveniles are found primarily on clean sand.

Physical/Chemical Characteristics: Juveniles are found in marine, estuarine, and freshwater habitats (Radtke 1966). Adults are primarily marine.

Migrations and Movements: Juveniles are common in freshwater areas of the San Joaquin Delta, California, in summer (Radtke 1966), and also in the lower Klamath River (Tuss et al. 1987). Juveniles migrate out to sea before they are two years old and primarily during summer and fall. Juvenile emigration through the lower Klamath River may peak in September (CH2M Hill 1985). Juveniles appear to remain near estuaries at first, but as they grow, they can become highly migratory and move out to nearshore waters. Adults appear to move into estuaries and rivers to feed and spawn (riverine areas) in spring and early summer. The green sturgeon seldom migrates far up rivers or estuaries in Oregon or Washington, but may migrate extensively up the Klamath and Trinity Rivers, California. Some travel long distances in the ocean; fish tagged in the Sacramento-San Joaquin estuary have been collected from the Columbia River and in Grays Harbor 1-3 years later (Miller 1972). Adult immigration to the Klamath River occurs between late February and late July (CH2M Hill 1985). Adults appear to migrate back to the ocean during summer and fall.

Reproduction

Mode: The green sturgeon is gonochoristic, oviparous, and iteroparous. It is a broadcast spawner; eggs are fertilized externally.

Mating/Spawning: Spawning occurs in the Klamath River and perhaps in the lower reaches of other rivers. The only known spawning site in the U.S.S.R. is the Tumnin River (Artyukhin and Andronov 1990). Adults spawn in spring and early summer in California, and between March and July (with a peak from mid-April to mid-June) in the Klamath River (CH2M Hill 1985). However, three gravid females were captured during fall in the Columbia River estuary (G. Kreitman, Washington Department of Fisheries, Battle Ground, WA, Pers. commun.). Females broadcast spawn near appropriate substrate (believed to range from clean sand to bedrock) and at relatively fast water flows. Water depths in spawning areas are probably greater than 3 m.

Fecundity: Fecundity ranges from 60,000 to 140,000 eggs per female (Artyukhin and Andronov 1990).

Growth and Development

Because eggs and larvae have not been described, the following information is inferred from what is known for white sturgeon, a very similar species.

Egg Size and Embryonic Development: Eggs are probably 4 mm in diameter and darkly pigmented (Wang et. al. 1985). Embryonic development is indirect and external. Time to hatching is 196 hours at 12.7°C (Artyukhin and Andronov 1990).

Age and Size of Larvae: Larval development has not been described, but larvae in the U.S. may be 8 to 19 mm (Kohlhorst 1976). Larvae in the U.S.S.R. are about

12.3 mm long at hatching (Artyukhin and Andronov 1990).

Juvenile Size Range: Minimum juvenile size is unknown, but is probably 2.0 cm; maximum juvenile size is probably about 1.5 m.

Age and Size of Adults: Adults can reach a length of 2.1 m and weigh 136 kg (Hart 1973). Very little age data exists, but the estimated maximum age for Klamath River green sturgeon is 60 years (CH2M Hill 1985).

Food and Feeding

Trophic Mode: Larvae initially feed on their yolk sac. Juveniles and adults are primarily carnivorous benthic feeders.

Food items: Young feed on benthic invertebrates. Adults and larger juveniles feed on benthic invertebrates, epibenthic invertebrates, and small fish (Radtke 1966).

Biological Interactions

Predation: Eggs, larvae, and small juveniles are probably preyed upon by numerous fish species. Large green sturgeon have few known predators except for man and some large marine mammals.

Factors Influencing Populations: River flow (Khoroshko 1972, Kohlhorst 1980), water temperature, and salinity may affect survival of larvae and juveniles. Bioaccumulation of polychlorinated biphenyls or other contaminants may reduce sturgeon survival. The overall number of adult females in the population may be important because they mature late in life and probably not all females spawn every year. Very little is known about this species and there is need for more research into all aspects of its biology and ecology.

References

Artyukhin, E. N., and A. E. Andronov. 1990. A morphological study of the green sturgeon, *Acipenser medirostris* (Chondrostei, Acipenseridae), from the Tumnin (Datta) River and some aspects of the ecology and zoogeography of the Acipenseridae. J. Ichthyol. 30(7):11-22.

CH2M Hill. 1985. Klamath River basin fisheries resource plan. U.S. Dept. Inter., various pagination.

Fry, D. H., Jr. 1973. Anadromous fishes of California. Calif. Dept. Fish Game, Sacramento, CA, 41 p.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. No. 180, 740 p.

Khoroshko, P. N. 1972. The amount of water in the Volga Basin and its effect on the reproduction of sturgeon (Acipenseridae) under conditions of normal and regulated discharge. J. Ichthyol. 12: 608-615.

Kohlhorst , D. W. 1976. Sturgeon spawning in the Sacramento River in 1973, as determined by distribution of larvae. Calif. Fish Game 62(1):32-40.

Kohlhorst, D. W. 1980. Recent trends in the white sturgeon population in California's Sacramento-San Joaquin estuary. Calif. Fish Game 66(4):210-219.

Miller, L. W. 1972. Migrations of sturgeon tagged in the Sacramento-San Joaquin estuary. Calif. Fish Game 58(2):102-106.

Moyle, P. B. 1976. Inland fishes of California. Univ. Calif. Press, Berkeley, CA, 405 p.

Radtke, L. D. 1966. Distribution of smelt, juvenile sturgeon, and starry flounder in the Sacramento-San Joaquin delta with observations on food of sturgeon. *In* J. L. Turner and D. W. Kelley (compilers), Ecological studies of the Sacramento-San Joaquin delta, Part II, Fishes of the delta. Calif. Fish Game, Fish Bull. 136:115-129, .

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12. Am. Fish. Soc., Bethesda, MD, 174 p.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can., Bull. No. 184, 966 p.

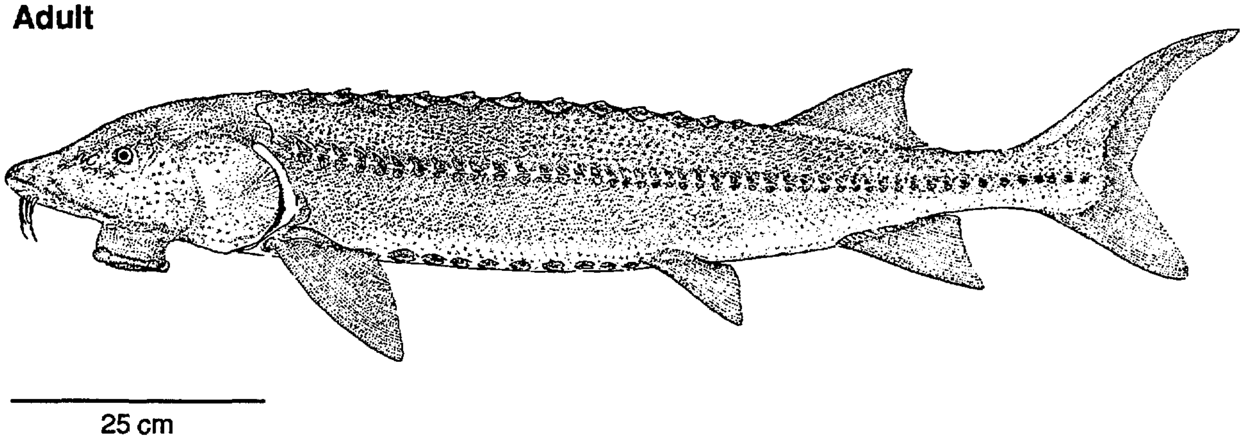
Stevens, D. E., and L. W. Miller. 1970. Distribution of sturgeon larvae in the Sacramento-San Joaquin River system. Calif. Fish Game 56 (2):80-86.

Tuss, D., T. Kisanuki, J. Larson, J. Polos, and T. Frazer. 1987. Klamath River fisheries investigation program. Annual Rep. 1986. U.S. Fish Wildl. Serv., Arcata, CA, 93 p.

Wang, Y. L., E. P. Binkowski, and S. I. Doroshov. 1985. Effect of temperature on early development of white sturgeon and lake sturgeon, *Acipenser transmontanus* and *A. fulvescens*. Env. Biol. Fish. 14 (1) 43-51.

Wydoski, R. S., and R. R. Whitney. 1979. Inland fishes of Washington. Univ. Wash. Press, Seattle, WA, 220 p.

White sturgeon



Acipenser transmontanus
Adult

Common name: white sturgeon
Scientific Name: *Acipenser transmontanus*
Other Common Names: Pacific sturgeon, Oregon sturgeon, Columbia sturgeon, Sacramento sturgeon
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Acipensiformes
Family: Acipenseridae

Value

Commercial: The white sturgeon is primarily captured incidentally while gillnetting for salmon (*Oncorhynchus* spp.), but has recently become a target fishery. In the Columbia River, 199 t were landed in 1985. Washington State total landings were nearly 46 t in 1985 (G. Kreitman, Washington Department of Fisheries, Battle Ground, WA, pers. comm.). Roe is valuable caviar. Columbia River sturgeon production is second only to the total Soviet Union production. This species is an important fish for Native American fishermen in the Columbia River and Klamath River, California. Private aquaculture operations in California are capable of producing a 4.5 kg fish in 30 months (Anderson 1988).

Recreational: The white sturgeon is the focus of an intense sport fishery in the lower Columbia River; 62,400 were landed in this fishery during 1987 (Bohn and McIsaac 1988). Sport fisheries also exist in the Sacramento-San Joaquin Delta of California, Willapa Bay, Washington, and other estuaries.

Indicator of Environmental Stress: River flow may affect larval dispersal and survival. Because of its long life span, the white sturgeon may concentrate pollutants in its flesh. Metabolites from aromatic hydrocarbons found in the bile of white sturgeon identified their exposure to petroleum hydrocarbons from an oil spill (Krahn et al. 1986).

Ecological: Although the white sturgeon is anadromous, it is capable of completing its entire life cycle in fresh water. It generally spawns in large rivers and spends time in both marine and fresh water. However, dams have created landlocked populations because the species does not normally use fish ladders.

Range

Overall: The white sturgeon's overall range is from Ensenada, Mexico (Moyle 1976) to Cook Inlet in northwestern Alaska (Wydoski and Whitney 1979).

Within Study Area: This species is found in most estuaries on the Pacific coast from San Francisco Bay, California, north to Grays Harbor, Washington, but is rare in Puget Sound and Hood Canal, Washington (Table 1). It is most common in estuaries of large rivers.

Life Mode

It is principally an anadromous species. Adults, juveniles, and eggs are demersal. Eggs are adhesive after fertilization.

Habitat

Type: Larvae and very young juveniles are riverine. Older juveniles and adults are found in riverine, estuarine, and marine waters. However, the older life stages are primarily found in riverine and estuarine areas. Young-of-the-year white sturgeon may be associated with structures such as pile jetties, rocks, and submerged logs (McCabe and McConnell 1988).

Table 1. Relative abundance of white sturgeon in 32 U.S. Pacific coast estuaries.

	Life Stage				
Estuary	A	S	J	L	E
Puget Sound	√				
Hood Canal	√				
Skagit Bay					
Grays Harbor	○		◉		
Willapa Bay	○		◉		
Columbia River	○		◉		
Nehalem Bay	○		○		
Tillamook Bay	○		○		
Netarts Bay					
Siletz River					
Yaquina Bay	○		○		
Alsea River	√		√		
Siuslaw River	√		√		
Umpqua River	○		√		
Coos Bay	○		○		
Rogue River	○		○		
Klamath River	√		○		
Humboldt Bay			√		
Eel River			√		
Tomales Bay					
Cent. San Fran. Bay *	◉		◉	○	
South San Fran. Bay	○		○		
Elkhorn Slough					
Morro Bay					
Santa Monica Bay					
San Pedro Bay					
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

The white sturgeon is not usually found in intertidal areas, although it may feed on intertidal flats at high tide. Water flow is important to the downstream movement of larvae. Subyearlings are common during the summer in shallow freshwater areas of the San Joaquin Delta in summer (Radtke 1966). In the Columbia River, small juveniles appear to prefer deep-water channel habitat.

Substrate: Adults and juveniles occur on a wide range of sediment types, ranging from sandy-mud and coarse sand to cobble. Spawning substrate is large smooth cobble.

Physical/Chemical Characteristics: Best egg development and survival is 14-16°C, although incubation is possible from 10-18°C (Wang et al. 1985). The white sturgeon is a euryhaline species, although younger and smaller fish do not osmoregulate as well as larger, older individuals (McEnroe and Cech 1985). Eggs, larvae, and small juveniles are found only in freshwater. Older juveniles are common in freshwater areas of the Columbia River estuary.

Migrations and Movements: Initially after hatching, fry are found throughout the water column. Within 5 to 6 days, fry become negatively phototaxic and primarily benthic (Conte et al. 1988). General movements for juveniles and adults exist, but no "migration" has been established. Large white sturgeon appear to move upstream to spawning grounds in late winter and spring and downstream in fall and winter (Miller 1972). Movement is probably related to both spawning and feeding conditions (Bajkov 1951). Some individuals move extensively (between California and Oregon or Washington), but most do not (Stockley 1981). The creation of dams/impoundments has created isolated populations. Estuarine residing sturgeon may move onto intertidal flats to feed during high tide.

Reproduction

Mode: The white sturgeon is gonochoristic, oviparous, and iteroparous. It is a broadcast spawner; eggs are fertilized externally.

Mating/Spawning: Spawning occurs during the spring in areas with swift currents and large cobble. Peak spawning in the Sacramento River occurs at 14.4°C (Kohlhorst 1976). In the Columbia River, spawning apparently occurs at temperatures of 13-20°C (end of May to early July) below John Day Dam (Palmer et al. 1988), and 10-16°C below Bonneville Dam (late April to early July) (McCabe and McConnell 1988). Females do not spawn annually, but every 3-5 years. They broadcast spawn near appropriate substrate and water flow; no nest is built.

Fecundity: The white sturgeon is very fecund; a 2.7 m long female in California contained 4.7 million eggs (Moyle 1976).

Growth and Development

Egg Size and Embryonic Development: White sturgeon eggs are 4.0 mm in diameter, and darkly pigmented (Wang et al. 1985). Eggs hatch in approximately seven days (depending on temperature) (Conte et al. 1988).

Age and Size of Larvae: Captured larvae ranged from 8-19 mm in total length (Kohlhorst 1976), while cultured larvae averaged 12.6 mm (Wang et al. 1985). Fry yolk sacs are depleted and active feeding begins approximately 12 days after hatching (Anderson 1988).

Juvenile Size Range: Newly-metamorphosed juveniles are about 20 cm long. Older juveniles may be 1.2 m or longer before maturing.

Age and Size of Adults: The white sturgeon is a very slow-growing, late-maturing fish. Growth and maturity are highly variable. In California, females mature at approximately 11 years and 1.2 m long (Moyle 1976). In Oregon, female white sturgeon mature at about 15 years and 1.7 m long (Stockley 1981). Males mature earlier and at a shorter length. The life span of white sturgeon is unknown, but probably exceeds 100 years. There are reports of some fish weighing more than 816 kg and almost 6 m long (Anderson 1988). White sturgeon are North America's largest freshwater fish.

Food and Feeding

Trophic Mode: Larvae feed on their yolk sac. Juveniles, and adults are primarily benthic carnivores.

Food items: Very small juveniles probably feed on benthic algae and small invertebrates. Juveniles consume benthic and epibenthic invertebrates, including amphipods, shrimp, mysids, bivalves, and insect larvae (Radtke 1966). Larger juveniles and adults feed on benthic invertebrates and fish such as eulachon (*Thaleichthys pacificus*) and northern anchovy (*Engraulis mordax*). They also feed on clams, amphipods, *Crangon* shrimp, ghost shrimp (*Callianasa* spp.), mud shrimp (*Upogebia* spp.), and other benthic invertebrates (Semakula and Larkin 1968, Muir et al. 1988). Optimum growth of hatchery juveniles occurs when fed a diet consisting of 40% crude protein (Moore et al. 1988). The optimal feeding rate for subyearlings at 18°C is between 1.5 and 2.0% of their body weight per day (Hung et al. 1989).

Biological Interactions

Predation: Eggs, larvae, and small juveniles are probably preyed upon by numerous fish species. Larger juveniles and adult white sturgeon are primarily taken by man, however, some may be eaten by marine mammals.

Factors Influencing Populations: Dams have created land-locked populations and destroyed spawning grounds. Bioaccumulation of contaminants such as polychlorinated biphenyls may inhibit growth and impair egg and larval survival (Parsley et al. 1989). High temperatures (>20°C) may reduce larval viability (Wang et al. 1985). Overfishing could reduce the adult spawning stock, although present regulations prohibit taking fish longer than 6 ft (1.8 m total length) in Oregon and Washington. Reduced river flows may also hinder sturgeon production (Khoroshko 1972).

References

Anderson, R. S. 1988. Columbia River sturgeon. Wash. Sea Grant, Seattle, WA, 19 p. (WSG-AS 88-14).

Bajkov. A. D. 1951. Migration of white sturgeon (*Acipenser transmontanus*) in the Columbia River. Fish Comm. Oreg. Res. Briefs 3(2):8-21.

Bohn, B. R., and D. McIsaac. 1988. Columbia River fish runs and fisheries 1960-1987. Oreg. Dept. Fish Wildl. and Wash. Dept. Fish., Clackamas, OR, 83 p.

Conte, F. S., S. I. Doroshov, P. B. Lutes, and E. M. Strange. 1988. Hatchery manual for the white sturgeon *Acipenser transmontanus* Richardson with application to other North American Acipenseridae. Publ. No. 3322, Coop. Extension, Div. Agricul. Nat. Res., Univ. Calif., Oakland, CA, 104 p.

Hung, S. S. O., P. B. Lutes, F. S. Conte, and T. Storebakken. 1989. Growth and feed efficiency of white sturgeon (*Acipenser transmontanus*) sub-yearlings at different feeding rates. Aquacult. 80:147-153.

Khoroshko, P. N. 1972. The amount of water in the Volga Basin and its effect on the reproduction of sturgeon (Acipenseridae) under conditions of normal and regulated discharge. J. Ichthy. 12:608-615.

Kohlhorst , D. W. 1976. Sturgeon spawning in the Sacramento River in 1973, as determined by distribution of larvae. Calif. Fish. Game 62(1):32-40.

Krahn, M. M., L. J. Kittle, Jr., and W. D. MacLeod, Jr. 1986. Evidence for exposure of fish to oil spilled into the Columbia River. Mar. Envir. Res. 20:291-298.

McCabe, G. T. , Jr., and R. J. McConnell. 1988. Appendix D. *In* A. A. Nigro (editor), Status and habitat requirements of white sturgeon populations in the Columbia River downstream from McNary Dam, p. 114-139. Annual Prog. Rep., July 1987 - March 1988. Bonneville Power Admin., Portland, OR.

McEnroe, M., and J. J. Cech, Jr. 1985. Osmoregulation in juvenile and adult white sturgeon, *Acipenser transmontanus*. Env. Biol. Fish. 14(1):23-30.

Miller, L. W. 1972. Migration of sturgeon tagged in the Sacramento-San Joaquin estuary. Calif. Fish Game 58(2):102-106.

Moore, B. J., S. S. O. Hung, and J. F. Medrano. 1988. Protein requirement of hatchery-produced juvenile white sturgeon (*Acipenser transmontanus*). Aquacult. 71:235-245.

Moyle, P. B. 1976. Inland fishes of California. Univ. Calif. Press, Berkeley, CA, 405 p.

Muir, W. D., R. L. Emmett, R. J. McConnell. 1988. Diet of juvenile white sturgeon in the lower Columbia River and its estuary. Calif. Fish Game. 74(1):49-54.

Palmer, D. E., M. J. Parsley, and L. G. Beckman. 1988. Appendix C. *In* A. A. Nigro (editor), Status and habitat requirements of white sturgeon populations in the Columbia River downstream from McNary Dam, p. 89-113. Annual Prog. Rep., July 1987 - March 1988, Bonneville Power Admin., Portland, OR.

Parsley, M. J., S. D. Duke, T. J. Underwood, and L. G. Beckman. 1989. Report C. *In* A. A. Nigro (editor), Status and habitat requirements of white sturgeon populations in the Columbia River downstream from McNary Dam, p. 101-166. Annual Prog. Rep., April 1988 - March 1989, Bonneville Power Admin., Portland, OR.

Radtke, L. D. 1966. Distribution of smelt, juvenile sturgeon, and starry flounder in the Sacramento-San Joaquin delta with observations on food of sturgeon. *In* J. L. Turner and D. W. Kelley (compilers), Ecological studies of the Sacramento-San Joaquin delta, Part II, Fishes of the delta. Calif. Fish Game, Fish. Bull, 136:115-129.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

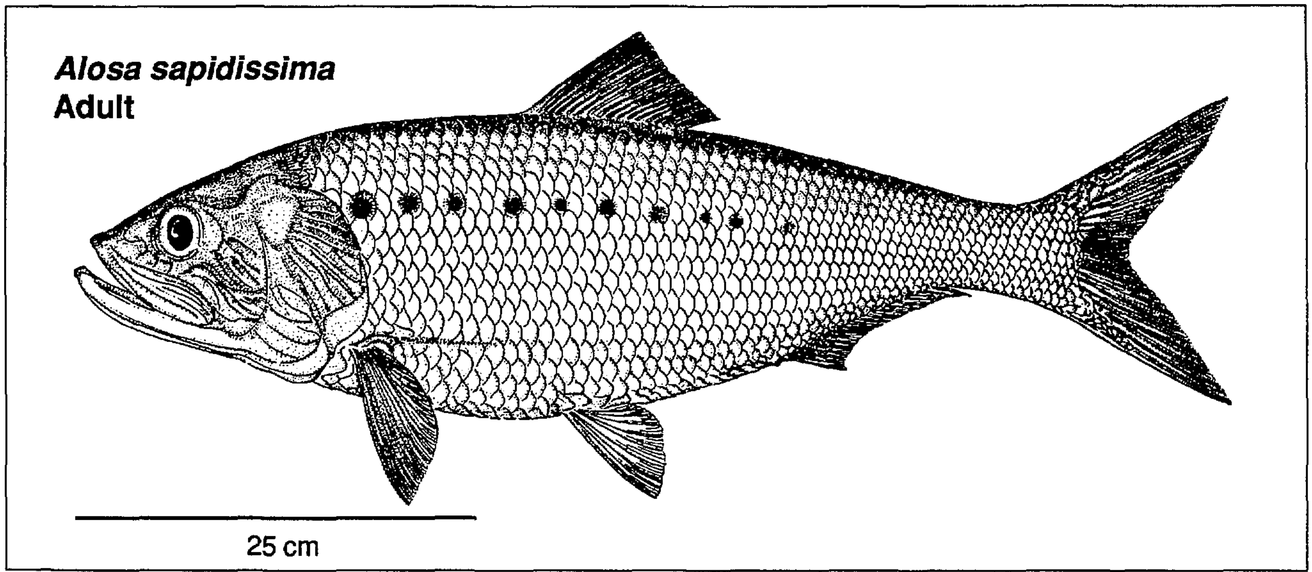
Semakula, S. N., and P. A. Larkin. 1968. Age, growth, food, and yield of white sturgeon (*Acipenser transmontanus*) of the Fraser River, British Columbia. J. Fish. Res. Board Can. 25:2589-2602.

Stockley, C. 1981. Columbia River sturgeon. Prog. Rep. No. 150, Wash. Dept. Fish., Olympia, WA, 28 p.

Wang, Y. L., E. P. Binkowski, and S. I. Doroshov. 1985. Effect of temperature on early development of white sturgeon and lake sturgeon, *Acipenser transmontanus* and *A. fulvescens*. Env. Biol. Fish. 14 (1):43-51.

Wydoski, R. S., and R. R. Whitney. 1979. Inland fishes of Washington, Univ. Wash. Press, Seattle, WA, 220 p.

American shad



Common Name: American shad
Scientific Name: *Alosa sapidissima*
Other Common Names: Atlantic shad, Potomac shad, shad, whiteshad, common shad, North River shad, Connecticut River shad, Alose (Scott and Crossman 1973)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Clupeiformes
Family: Clupeidae

Value

Commercial: The American shad was introduced to the Pacific coast in 1871, 1885, and 1886 (Craig and Hacker 1940). It has since proliferated and now is highly abundant in many western rivers and estuaries. Average minimum run size for the Columbia River is >1.4 million fish/year for the past five years (Bohn and McIsaac 1988). In the Sacramento-San Joaquin River, California, run sizes range from 0.7 to 4.0 million fish/year. Commercial fishermen primarily use gill nets for this species. The commercial harvest of shad in California rivers was terminated in 1957 (Stevens et al. 1987) due to conflicts with salmonid (*Oncorhynchus* spp.) resources and sport anglers. Large Pacific coast commercial catches were once common, but only small catches presently occur because of poor market demand and conflicts with the incidental catch of salmonids. In Oregon, it can only be commercially caught in the Columbia River. In 1987, 159 t (121,000 fish) were caught in the Columbia River (Bohn and McIsaac 1988).

Recreational: The American shad is considered a good sport fish for light tackle, but an intense Pacific coast sport fishery (such as for salmonids) has not developed. The Sacramento River harvest is all recreational (Moyle 1976).

Indicator of Environmental Stress: This species is very temperature-sensitive and many aspects of its life cycle are cued by specific temperatures.

Ecological: The introduction of American shad to the Pacific coast does not appear to have displaced native species, but competition may occur. Juvenile shad in fresh water and estuaries are prey for salmonids and many other fish and birds.

Range

Overall: The American shad is found along the east coast of North America from Florida to Newfoundland. It also ranges along the Pacific coast from San Pedro, California, to Cooks Inlet, Alaska, and the Kamchatka Peninsula on the Asiatic side of the North Pacific (Scott and Crossman 1973).

Within Study Area: This species is found in all estuaries that have rivers with appropriate spawning habitat, but primarily occurs from San Francisco Bay, California, to Puget Sound, Washington (Table 1).

Life Mode: Eggs are semibuoyant and float downstream near the bottom in slow currents. Larvae, juveniles, and adults are nektonic and pelagic.

Habitat

Type: Eggs are demersal. Larvae are pelagic, but are found in shallow water, primarily along river bank areas. Juveniles and adults are also pelagic. Juveniles rear in rivers and estuaries before moving offshore.

Table 1. Relative abundance of American shad in 32 U.S. Pacific coast estuaries.

	Life Stage				
Estuary	A	S	J	L	E
Puget Sound	√				
Hood Canal	√				
Skagit Bay	○		○		
Grays Harbor	◉		◉		
Willapa Bay	◉		◉		
Columbia River	◉	○	●		
Nehalem Bay	√		√		
Tillamook Bay			√		
Netarts Bay					
Siletz River					
Yaquina Bay	◉		◉		
Alsea River	◉		◉		
Siuslaw River	◉		◉		
Umpqua River	◉		◉		
Coos Bay	◉	◉	●	◉	◉
Rogue River	◉		◉		
Klamath River	○		◉		
Humboldt Bay			√		
Eel River	◉		◉		
Tomales Bay					
Cent. San Fran. Bay *	●		●		
South San Fran. Bay			○		
Elkhorn Slough					
Morro Bay					
Santa Monica Bay					
San Pedro Bay					
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

Reservoirs appear to be ideal rearing habitat for juveniles, therefore, the development of reservoirs on the Columbia and other rivers appears to have benefitted this species.

Substrate: Larvae, juveniles and adults are not substrate selective. Spawning occurs over various substrates, but primarily over clean sand and gravel.

Physical/Chemical Characteristics: The American shad is a euryhaline anadromous species. Eggs can tolerate moderate salinities (7.5-15‰), depending on water temperatures (Facey and Van Den Avyle 1986). Juveniles rear in both freshwater and estuarine habitats. Adults apparently need two or three days in estuaries to acclimate to fresh water (Weiss-Glanz et al. 1986). Adults reside within a temperature range of 3-15°C while in the ocean (Neves and Depres 1979), and their migration patterns are closely linked with water temperature. Optimum temperatures for egg survival are 15.5-26.6°C (Leggett and Whitney 1972). Dissolved oxygen (DO) levels above 4.0 mg/l are needed for spawning (Facey and Van Den Avyle 1986) and DO levels above 2.5-3.0 mg/l (perhaps 5.0 mg/l) are necessary for all life stages (Facey and Van Den Avyle 1986, Weiss-Glanz et al. 1986). Spawning occurs in water flows of 30.5 to 91.0 cm/sec.

Migrations and Movements: Juveniles begin their downstream migration in late summer and fall when water temperature approaches 15.5°C. Most juveniles will migrate out to sea before winter, but some may reside more than a year in rivers and estuaries (Stevens et al. 1987). A schooling species, adults return primarily to their natal river, but there is some straying. Adults begin entering estuaries when water temperatures are 10-15°C, and typically remain there for two or three days before moving upstream (Leggett and O'Boyle 1976). Adult upstream migration typically peaks in spring when water temperature is near 18.5°C, usually May to June on the Pacific coast (Leggett and Whitney 1972). In the ocean, adults appear to migrate vertically, following the diel movements of zooplankton (Neves and Depres 1979). Adults and ocean-dwelling juveniles may be found down to 340 m depth, but most reside within the 50-100 m isobath (Neves and Depres 1979). The American shad is highly migratory; for example, individuals have been caught 3,000 km from where they were tagged (Whitehead 1985).

Reproduction

Mode: The American shad is gonochoristic, oviparous, and iteroparous (although many die after spawning). It is a broadcast spawner; eggs are fertilized externally.

Mating/Spawning: This species returns to its natal river to spawn. Spawning usually occurs at temperatures of 14-21°C during spring and early summer in the mainstem of rivers. Many shad die soon after spawning, with post-spawning survival highest in northern estuaries. Spawners prefer shallow water in gently sloping areas with sand or gravel substrates. Most spawning probably occurs during late afternoon and evening (Facey and Van Den Avyle 1986). Before spawning, males may chase females into a tight circle and spawning is often indicated by splashing at the surface.

Fecundity: Spawning females release 30,000-300,000 eggs, depending on their body size (Moyle 1976). On the Atlantic coast, American shad fecundity is reported to range from 100,000-600,000 eggs per female (Facey and Van Den Avyle 1986).

Growth and Development

Egg Size and Embryonic Development: Egg diameters are 2.5-3.8 mm after fertilization (Walburg and Nichols 1967). Eggs are nonadhesive and slightly heavier than water. Eggs need adequate water circulation during incubation (Facey and Van Den Avyle 1986). Embryonic development is indirect, and eggs hatch in 4-5 days at 15-18°C (depending on temperature).

Age and Size of Larvae: Larvae are 7-10 mm long at hatching and develop into juveniles in 4-5 weeks at about 25 mm in length (Walburg and Nichols 1967).

Juvenile Size Range: The minimum size of juveniles is about 2.5 cm. Sexual maturity is reached when this species is about 30-40 cm long.

Age and Size of Adults: Mature shad range from 30-76 cm total length, with males typically being shorter and younger than females. Males are usually three years old and females four years old when they first mature (Moyle 1976). Shad may live for seven years (Clemens and Wilby 1961).

Food and Feeding

Trophic Mode: Larvae, juveniles and adults are planktivorous.

Food items: American shad larvae eat small zooplankton (copepods and cladocerans) and midge larvae and pupae (Facey and Van Den Avyle 1986). Riverine- and estuarine-dwelling juveniles consume primarily zooplankton, such as copepods, cladocerans (*Daphnia* spp.), amphipods (*Corophium* spp.), mysids (*Neomysis* spp.), and shrimp (*Crangon* spp.) (Stevens 1966, Hammann 1982). Juveniles also eat aquatic and terrestrial insects. The diet of American shad in Pacific coast marine waters is not well-studied, but likely consists of euphausiids, copepods, decapod larvae, cephalopod larvae, and probably small fishes (Hart 1973, Brodeur et al. 1987).

Biological Interactions

Predation: Young shad in rivers and estuaries are eaten by white sturgeon (*Acipenser transmontanus*), juvenile salmonids, walleye (*Stizostedian vitreum*), bass (*Micropterus* spp.), striped bass (*Morone saxatilis*), gulls, osprey (*Pandion haliaetus*), bald eagles (*Haliaetus leucocephalus*), harbor seals (*Phoca vitulina*), and other large predators. After moving offshore, they are probably prey for sharks, tuna, porpoises, sea lions, salmonids, and other piscivorous fishes.

Factors Influencing Populations: Alteration of temperature regimes can affect all life stages (Leggett and Whitney 1972, Facey and Van Den Avyle 1986). Shad year-class strength appears to be determined by river flow and water temperatures during and immediately after spawning (Leggett 1976). Larval survival ultimately determines year-class strength (Crecco and Savoy 1985). High river flows during spawning and early life stages positively affect population abundances in the Sacramento-San Joaquin river systems (Stevens et al. 1987). Probably the largest factor influencing populations on the Pacific coast has been the creation of dams and reservoirs, which has both created and destroyed habitat. Water irrigation projects can also have an adverse affect on shad populations (Stevens et al. 1987) and proper dam bypass systems for adults and juveniles are necessary. On the Pacific coast, commercial fishing is presently limited due to limited markets and the incidental catch of depressed salmonid stocks.

References

Bohn, B. R., and D. McIsaac. 1988. Columbia River fish runs and fisheries 1960-1987. Oregon Dept. Fish Wildl. and Wash. Dept. Fish., Clackamas, OR, 83 p.

Brodeur, R. D., H. V. Lorz, and W. G. Pearcy. 1987. Food habits and diet variations of pelagic nekton off Oregon and Washington, 1979-1984. U.S. Dept. Commer., NOAA, Tech. Rep. NMFS 57, 32 p.

Clemens, W. A., and G. V. Wilby. 1961. Fishes of the Pacific coast of Canada. Fish. Res. Board Can., Bull. No. 68. 443 p.

Craig, J. A., and R. L. Hacker. 1940. The history and development of the fisheries of the Columbia River. Fish. Bull., U.S. 32:133-216.

Crecco, V. A., and T. F. Savoy. 1985. Effects of biotic and abiotic factors on growth and relative survival of young American shad, *Alosa sapidissima*, in the Connecticut River. Can. J. Fish. Aquat. Sci. 42:1640-1648.

Facey, D. E., and M. J. Van Den Avyle. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (South Atlantic)—American shad. U.S. Fish Wildl. Serv. Biol. Rep. 82 (11.45). U.S. Army Corps Eng., TR EL-82-4, 18 p.

Hammann, M. G. 1982. Utilization of the Columbia River estuary by American shad, *Alosa sapidissima* (Wilson). M.S. Thesis, Oregon State Univ., Corvallis, OR, 48 p.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. No. 180, 740 p.

Leggett, W. C. 1976. The American shad (*Alosa sapidissima*), with special reference to its migration and population dynamics in the Connecticut River. *In* D. Merriman and L. M. Thorpe (editors), The Connecticut River ecological study, p. 169-225. Am. Fish. Soc. Monog. No. 1, Am. Fish. Soc., Bethesda, MD.

Leggett, W. L., and R. N. O'Boyle. 1976. Osmotic stress and mortality in adult American shad during transfer from saltwater to freshwater. J. Fish Biol. 8:459-469.

Leggett, W. C., and R. R. Whitney. 1972. Water temperature and the migrations of American shad. Fish. Bull., U.S. 79(3):659-670.

Moyle, P. B. 1976. Inland fishes of California. Univ. Calif. Press, Berkeley, CA, 405 p.

Neves, R. J., and L. Depres. 1979. The oceanic migration of American shad, *Alosa sapidissima*, along the Atlantic coast. Fish. Bull., U.S. 77(1):199-212.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No.12, Am. Fish. Soc., Bethesda, MD, 174 p.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can., Bull. No. 184, 966 p.

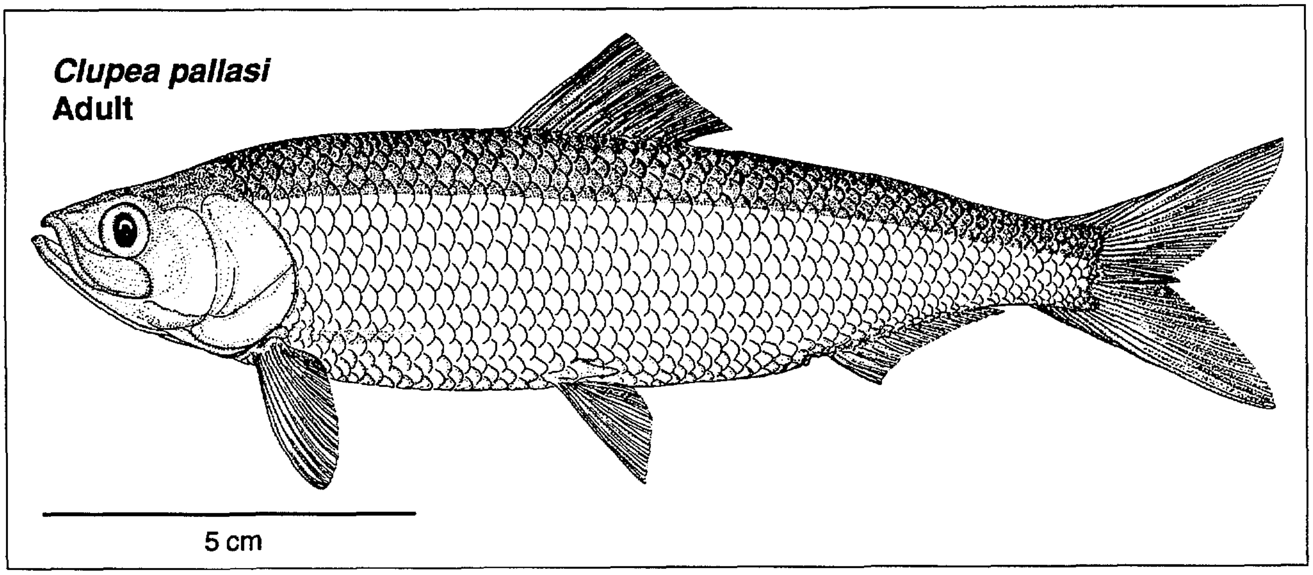
Stevens, D. E. 1966. Distribution and food habits of the American shad, *Alosa sapidissima*, in the Sacramento-San Joaquin delta. *In* J. L. Turner and D. W. Kelley (compilers), Ecological studies of the Sacramento-San Joaquin delta. Calif. Fish Game, Fish Bull. 136:97-114.

Stevens, D. E., H. K. Chadwick, and R. E. Painter. 1987. American shad and striped bass in California's Sacramento-San Joaquin River system. Am. Fish. Soc. Symp. 1:66-78.

Walburg, C. H., and P. R. Nichols. 1967. Biology and management of the American shad and status of the fisheries, Atlantic coast of the United States, 1960. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Fish. No. 550, 105 p.

Weiss-Glanz, L. S., J. G. Stanley, and J. R. Moring. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic)—American shad. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.59). U.S. Army Corps Eng., TR EL-82-4, 16 p.

Whitehead, P. J. P. 1985. Clupeoid fishes of the world. An annotated and illustrated catalogue of herrings, sardines, pilchards, sprats, shads, anchovies and wolf-herrings, Part 1-Chirocentridae, Clupeidae and Pristigasteridae. FAO Fish. Synop. 125(7):1-303.



Common Name: Pacific herring
Scientific Name: *Clupea pallasi*
Other Common Names: California herring, Ches-Pechora herring, eastern herring, herring, Kara herring, Pacific Ocean herring, seld, white sea herring
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Clupeiformes
Family: Clupeidae

Value

Commercial: The Pacific herring has a long history of exploitation. It has been sold fresh or salted and also used for fish meal. Since 1965, the fishery has concentrated on gravid females for roe (eggs), which are exported primarily to Japan. Presently, over 90% of the Pacific herring caught are in the roe fishery. Fishermen take advantage of the Pacific herring's natural spawning cycle by fishing in nearshore areas when it spawns. They are primarily caught by purse seine and gill net. Recent U.S. annual harvests have been 52,600 t, worth $47 million (National Marine Fisheries Service 1986). The San Francisco and Tomales Bay, California, fishery alone is worth $11 million (Suer 1987). Most U.S. harvest comes from Alaska, California, and Washington. Since spawning adults are highly vulnerable to overfishing, the fishery is strictly regulated (Grosse and Hay 1989). Commercial bait fisheries (which harvest juveniles) exist in Puget Sound, Washington, and other Pacific coast estuaries (Trumble 1983).

Recreational: The Pacific herring is used as bait for Pacific salmon (*Oncorhynchus* spp.) and other fishes. However, some are caught for human consumption.

Indicator of Environmental Stress: Herring larvae appear to have high mortality rates in oil-contaminated water (Nelson-Smith 1973). The water-soluble fraction of crude oil reduces larval feeding and growth at low concentrations and mortalities at high levels (Lassuy 1989). Populations show wide fluctuations in abundance, apparently related to environmental conditions (see "Factors Influencing Populations"), and are affected by alterations of bays and estuaries (spawning habitats).

Ecological: Seasonally, *C. pallasi* is one of the most abundant species in Pacific coast marine and estuarine neritic zones. Juveniles are highly abundant in many Pacific coast estuaries in summer. They are important prey for many marine species (e.g., Pacific salmon, seals, and gulls).

Range

Overall: The Pacific herring is Arctic-circumboreal. In the eastern Pacific it ranges from Ensenada, Baja California, to St. Michael Island and to Cape Bathurst in the Beaufort Sea (Hart 1973). It is also found in Arctic waters from Coronation Gulf, Canada, to the Chukchi Sea and the USSR arctic. In the western Pacific, it is found to Toyama Bay, Japan, west to Korea, and the Yellow Sea (Haegele and Schweigert 1985, Wang 1986).

Within Study Area: This species is found in most Pacific coast estuaries north of San Diego, California, but occurs primarily north of Point Conception, California (Table 1).

Life Mode

Eggs are adhesive after fertilization and attach to

Table 1. Relative abundance of Pacific herring in 32 U.S. Pacific coast estuaries.

	Life Stage				
Estuary	A	S	J	L	E
Puget Sound	●	●	●	●	●
Hood Canal	◉	●	●	●	●
Skagit Bay	●	●	●	●	●
Grays Harbor			◉	○	
Willapa Bay	○	○	◉	○	○
Columbia River	○	○	●	○	○
Nehalem Bay	◉	◉	◉	◉	◉
Tillamook Bay	◉	◉	◉	◉	◉
Netarts Bay	◉	◉	◉	◉	◉
Siletz River			○		
Yaquina Bay	◉	●	●	●	●
Alsea River	○	○	○	○	○
Siuslaw River	○	○	○	○	○
Umpqua River	◉	◉	●	◉	◉
Coos Bay	●	●	●	●	●
Rogue River	√		○		
Klamath River	√		○		
Humboldt Bay	●	●	●	●	●
Eel River	○	○	◉	◉	◉
Tomales Bay	●	●	●	◉	●
Cent. San Fran. Bay *	●	●	◉	◉	●
South San Fran. Bay	●	●	○	◉	●
Elkhorn Slough	◉	◉	◉	◉	◉
Morro Bay	○		○		
Santa Monica Bay	√		√		
San Pedro Bay	√		√		
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Relative abundan

●	Highly abun
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adul
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

benthic substrates. Larvae, juveniles, and adults are pelagic, schooling nekton.

Habitat

Type: Eggs are laid in intertidal (3.7 m above mean lower low water) and subtidal areas (to 20 m depth), but normally occur in +1 to -2 m depth. Larvae and juveniles are neritic and adults are neritic-oceanic (Eldridge and Kaill 1973, Suer 1987).

Substrate: Eggs are found on eelgrass (*Zostera* spp.), algae, tube worms, Pacific oysters (*Crassostrea gigas*), hydroids, driftwood, pilings, brush, rocks, and rocky-sandy bottoms (Garrison and Miller 1982). Larvae, juveniles, and adults occur throughout the water column.

Physical/Chemical Characteristics: Eggs can tolerate temperatures of 5-14°C and salinities of 3-33‰ (Haegele and Schweigert 1985). Larvae are tolerant of salinities ranging from 2-28‰ (Alderdice and Velsen 1971, Alderdice and Hourston 1985). Best spawning salinities in British Columbia are 27.0-28.7‰. (Alderdice and Hourston 1985). Optimum temperatures and salinities for egg and larval survival appear to be 5.5-8.7°C and 13-19‰ (Alderdice and Velsen 1971). However, spawning temperatures in California are normally above 9°C (Barnhart 1988). Salinity tolerances of larvae are affected by temperature and salinity during egg incubation (Alderdice and Hourston 1985). Turbidity in estuaries may increase larval survival (Boehlert and Morgan 1985).

Migrations and Movements: The Pacific herring does not make extensive coastal migrations, but moves onshore and offshore in schools as it spawns and feeds (Morrow 1980). Adults typically move onshore during winter and early spring, residing in "holding" areas before moving to adjacent spawning grounds. The Pacific herring population consists of many discrete stocks (Grosse and Hay 1989). However, offshore distributions of adults for many Pacific coast stocks are unknown (Barnhart 1988). Pacific herring return to natal spawning grounds to spawn. Larvae are easily dispersed by currents, but their behavior and local currents often retain them in specific areas. Juveniles usually stay in nearshore shallow-water areas until fall when they disperse to deeper offshore waters. However, they may reside year-round in some estuaries (San Francisco Bay) (Wang 1986). Adult Pacific herring are found down to 100-150 m, with vertical distribution apparently controlled by temperature (Grosse and Hay 1989). Larvae, juveniles, and adults move toward the surface to feed at dawn and dusk (Grosse and Hay 1989).

Reproduction

Mode: This species is gonochoristic, oviparous, and iteroparous; eggs are fertilized externally. It spawns annually after reaching maturity.

Mating/Spawning: Spawning occurs from November in the southern part of its range to August in the far north. Spawning peaks in December and January in California (Spratt 1981) and February and March in Puget Sound (Trumble 1983). Herring spawn in the same areas every year. These areas are high-energy areas, located in protected coastal habitats or bays and estuaries, and are usually influenced by fresh water. Spawning apparently does not occur until a tactile stimulus (e.g., a storm, contact with bottom or other fish) causes some males to extrude milt, which in turn stimulates the entire school to spawn. During spawning both sexes come in contact with the spawning substrate (Haegele and

Schweigert 1985). Most spawning occurs at night (Eldridge and Kaill 1973, Suer 1987).

Fecundity: Fecundity increases with female size and ranges from 4,000-134,000 eggs per female (Hart 1973). Fecundity is 227 and 220 eggs/gram of female weight in Tomales Bay and San Francisco Bay, respectively (Hardwick 1973, Rabin and Barnhart 1977). Size-specific fecundity is inversely related to latitude (Hay 1985).

Growth and Development

Egg Size and Embryonic Development: Unfertilized eggs are 1.0 mm in diameter (Outram 1955); 1.2-1.5 mm in diameter after fertilization (Hart 1973). Hatching occurs in 11-12 days at 10.7°C, 14-15 days at 8.5°C, and 28-40 days at 4.4°C (Outram 1955). Most eggs hatch at night (Alderdice and Velsen 1971).

Age and Size of Larvae: Larvae range from 5 mm to about 26 mm total length (TL). Metamorphosis to juvenile begins at about 26 mm TL and is completed by 35 mm TL (Fraser 1922, Stevenson 1962); metamorphosis takes about 2 to 3 months (Hay 1985).

Juvenile Size Range: Juveniles are 35-150 mm TL, depending on region. Growth of juveniles is dependent on population size and environmental conditions (Reilly 1988).

Age and Size of Adults: Adult lengths are from 13-26 cm TL, depending on region. The Pacific herring matures in 2 to 3 years in California and 3 to 4 years in Washington. It lives up to 19 years and grows to a maximum length of 38 cm TL (Hart 1973). Northern stocks live longer than southern stocks (Wang 1986, Grosse and Hay 1989).

Food and Feeding

Trophic Mode: Larvae, juveniles, and adults are selective pelagic plankton feeders, although filter feeding has been observed.

Food Items: Larvae consume diatoms, tintinnids, invertebrate and fish eggs, crustacean larvae, mollusc larvae, and copepods. Juveniles eat primarily crustaceans (copepods, cladocerans, euphausiids, mysids, amphipods, and decapod larvae). They also consume mollusc and fish larvae. Adults eat planktonic crustaceans (copepods, euphausiids, and amphipods) and fish larvae (Hart 1973, Simenstad et al. 1979, Miller et al. 1980, McCabe et al. 1983).

Biological Interactions

Predation: Eggs are eaten by many fish species, ducks, and gulls, while larvae are prey for ctenophores, jellyfish, amphipods, chaetognaths, and various fishes. Juveniles and adults are consumed by squid, sharks, salmonids, gadids, sculpins (*Cottus* spp.), lingcod (*Ophiodon elongatus*), sand sole (*Psettichthys melanostictus*), and other fishes. They are also eaten by many species of birds and marine mammals, such as seals and sperm whales (*Physeter catodon*) (Hart 1973, Simenstad et al. 1979, Grosse and Hay 1989).

Factors Influencing Populations: No relation exists between number of eggs spawned and adult population size (Pacific Fishery Management Council 1981). Egg and larval mortalities are thought to be the major events influencing population sizes. Eggs and larvae suffer natural mortalities due to tidal fluctuations, desiccation, freezing, low oxygen, wave action, and predation. Approximately 98-99% of all larvae are killed by predation, competition, and offshore transport. In general, a clupeoid year-class' strength appears to be determined within the first 6 months (Smith 1985). Other studies indicate that onshore transport, density-dependent mechanisms, upwelling, sea temperatures, predation, climate fluctuations, initial feeding period of larvae, and larval dispersal patterns may all be important in determining population abundances (Lasker 1985, Grosse and Hay 1989). Juveniles and adults are affected by competition, predation, disease, spawning stress, and fishing. Human and natural alterations of water quality, prey species, migration rates, spawning substrate and habitat can also impact populations (Alaska Department of Fish and Game 1985).

References

Alaska Department of Fish and Game. 1985. Alaska habitat management guide. South central region, Vol. 1: life histories and habitat requirements of fish and wildlife. Alaska Dept. Fish Game, Juneau, AK, 429 p.

Alderdice, D. F., and A. S. Hourston. 1985. Factors influencing development and survival of Pacific herring (*Clupea harengus pallasi*) eggs and larvae to beginning of exogenous feeding. Can. J. Fish. Aquat. Sci. 42 (Suppl. 1):56-68.

Alderdice, D. F., and F. P. J. Velsen. 1971. Some effects of salinity and temperature on early development of Pacific herring (*Clupea pallasi*). J. Fish. Res. Board Can. 28(10):1545-1562.

Barnhart, R. A. 1988. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest) — Pacific herring. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.79). U.S. Army Corps Eng., TR EL-82-4, 14 p.

Boehlert, G. W., and J. B. Morgan. 1985. Turbidity enhances feeding abilities of larval Pacific herring, *Clupea harengus pallasi.* Hydrobiol. 123(2):161-170.

Eldridge, M. B., and W. M. Kaill. 1973. San Francisco Bay area's herring resource - a colorful past and a controversial future. Mar. Fish. Rev. 25:25-31.

Fraser, C. M. 1922. The Pacific herring. Biol. Board Can., Contrib. Can. Biol. Fish. 1921(6):103-111.

Garrison, K. J. and B. S. Miller. 1982. Review of the early life history of Puget Sound fishes. Fish. Res. Inst., Univ. Wash., Seattle, WA, 729 p. (FRI-UW-8216).

Grosse, D. J., and D. E. Hay. 1989. Pacific herring, *Clupea harengus pallasi*, in the Northeast Pacific and Bering Sea. *In* N. J. Wilimovsky, L. S. Incze, and S. J. Westerheim (editors), Species synopses, life histories of selected fish and shellfish of the Northeast Pacific and Bering Sea, p. 34-54. Wash. Sea Grant Prog. and Fish. Res. Inst., Univ. Wash., Seattle, WA.

Haegele, C. W., and J. F. Schweigert. 1985. Distribution and characteristics of herring spawning grounds and description of spawning behavior. Can. J. Fish. Aquat. Sci. 42(Suppl. 1):39-55.

Hardwick, J. E. 1973. Biomass estimates of spawning herring, *Clupea harengus pallasi*, herring eggs, and associated vegetation in Tomales Bay. Calif. Fish Game 59(1):36-61.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. No. 180, 740 p.

Hay, D. E. 1985. Reproductive biology of Pacific herring (*Clupea harengus pallasi*). Can. J. Fish. Aquat. Sci. 42(Suppl. 1):111-126.

Lasker, R. 1985. What limits clupeoid production? Can. J. Fish. Aquat. Sci. 42(Suppl. 1):31-38.

Lassuy, D. R. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest)—Pacific herring. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.126), U.S. Army Corps Eng., TR EL-82-4. 18 p.

McCabe, G. T. Jr., W. D. Muir, R. L. Emmett, and J. T. Durkin. 1983. Interrelationships between juvenile salmonids and nonsalmonid fish in the Columbia River estuary. Fish. Bull., U.S. 81(4):815-826.

Miller, B. S., C. A. Simenstad, J. N. Cross, K. L. Fresh, and S. N. Steinfort. 1980. Nearshore fish and macroinvertebrate assemblages along the Strait of Juan de Fuca including food habits of the common nearshore fish. Interagency (NOAA, EPA) Energy/ Environ. Res. Dev. Prog. Rep., EPA-600/7-80-027, Washington, D.C., 211 p.

Morrow, J. E. 1980. The freshwater fishes of Alaska. Alaska Northw. Publ. Co., Anchorage, AK, 248 p.

National Marine Fisheries Service. 1986. Fisheries of the United States, 1985. Current Fishery Statistics No. 8368. U.S. Dept. Comm., NOAA, Nat. Mar. Fish Serv., Nat. Fish. Stat. Prog., Washington, D.C., 122 p.

Nelson-Smith, A. 1973. Oil pollution and marine ecology. Plenum Press, New York, NY, 260 p.

Outram, D. N. 1955. The development of the Pacific herring egg and its use in estimating age of spawn. Fish. Res. Board Can., Pac. Biol. Sta. Circ. 40, 9 p.

Pacific Fishery Management Council. 1981. Pacific herring fishery management plan. Pac. Fish. Manag. Council, Portland, OR, 127 p.

Rabin, D. J., and R. A. Barnhart. 1977. Fecundity of Pacific herring, *Clupea harengus pallasi*, in Humboldt Bay. Calif. Fish Game 63(3):193-196.

Reilly, P. N. 1988. Growth of young-of-the-year and juvenile Pacific herring from San Francisco Bay, California. Calif. Fish Game 74(1):38-48.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, Robert N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Simenstad, C. A., B. S. Miller, C. F. Nyblad, K. Thornburgh, and L. J. Bledsoe. 1979. Food web relationships of northern Puget Sound and the Strait of Juan de Fuca. Interagency (NOAA/EPA) Energy/ Environ. Res. Dev. Prog. Rep., EPA-600/7-79-259, Washington, D.C., 335 p.

Smith, P. E. 1985. Year-class strength and survival of 0-group clupeoids. Can. J. Fish. Aquat. Sci. 42(Suppl. 1):69-82.

Spratt, J. D. 1981. Status of the Pacific herring, *Clupea harengus pallasi*, in California to 1980. Calif. Fish Game, Fish Bull. 171:1-104.

Stevenson, J. C. 1962. Distribution and survival of herring larvae (*Clupea pallasi* Valenciennes) in British

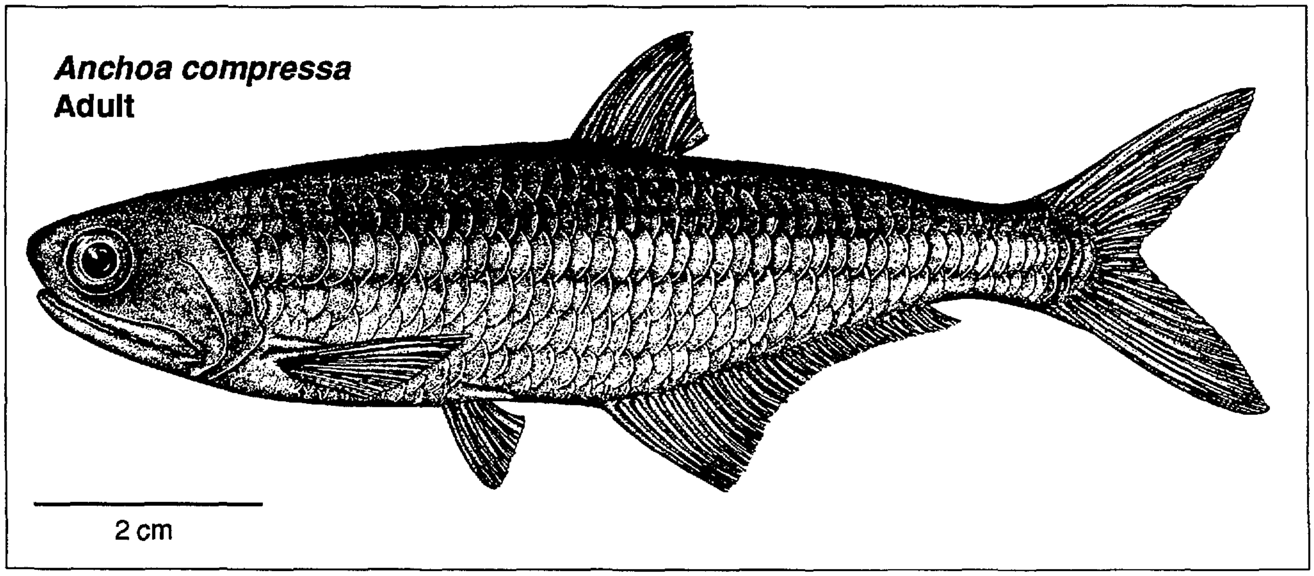
Columbia waters. J. Fish. Res. Board Can. 19(5):735-810.

Suer, A. L. 1987. The herring of San Francisco and Tomales Bays. The Ocean Res. Inst., San Francisco, CA, 64 p.

Trumble, R. J. 1983. Management plan for baitfish species in Washington State. Prog. Rep. No. 195, Wash. Dept. Fish., Olympia, WA, 106 p.

Wang, J. C. S. 1986. Fishes of the Sacramento-San Joaquin estuary and adjacent waters, California: A guide to the early life histories. Tech. Rep. 9. Interagency ecological study program for the Sacramento-San Joaquin estuary. Calif. Dept. Water Res., Calif. Dept. Fish Game, U.S. Bureau Reclam., and U.S. Fish Wildl. Serv., various pagination.

Deepbody anchovy



Common Name: deepbody anchovy
Scientific Name: *Anchoa compressa*
Other Common Names: California deepbody anchovy, sprat, deep-bodied anchovy, sardinus (Walford 1931, Gates and Frey 1974)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Clupeiformes
Family: Engraulidae

Value

Commercial: The deepbody anchovy is of little commercial value.

Recreational: This species is occasionally used as live bait for other fishes (Roedel 1953).

Indicator of Environmental Stress: The deepbody anchovy uses estuaries during all life stages and may be a good indicator of environmental stress. However, little ecological research has been done for this species.

Ecological: This is an abundant pelagic fish in many southern California estuaries (Klingbeil et al. 1975, Heath 1980, Horn and Allen 1985).

Range

Overall: The deepbody anchovy's overall range is from Todos Santos Bay, Baja California, to Morro Bay, California (Miller and Lea 1972, Eschmeyer et al. 1983).

Within Study Area: It is most common in California bays and estuaries south of Alamitos Bay (Table 1) (Horn and Allen 1976).

Life Mode

Eggs and larvae are planktonic, while juveniles and adults are pelagic.

Habitat

Type: All life stages live primarily in estuaries, bays, and lagoons, but schools of juveniles and adults are occasionally found along coastal shorelines (Miller and Lea 1972).

Substrate: Because this is a pelagic species, all life stages are found over various substrates.

Physical/Chemical Characteristics: Population abundances of this species were significantly correlated with temperature and dissolved oxygen (Allen 1982, Horn and Allen 1985). However, thermal and salinity tolerances have not been identified.

Migrations and Movements: Adults move from the lower portions of bays and estuaries to upper portions during the spawning season (spring and summer). Adults show post-spawning movements away from spawning areas, while juveniles reside in the upper portions of bays until late fall and winter (Heath 1980).

Reproduction

Mode: The deepbody anchovy is gonochoristic, oviparous, and iteroparous. It is a broadcast spawner; eggs are fertilized externally.

Mating/Spawning: Spawning occurs from March to August, with most spawning activity occurring at night from April to June (McGowan 1977, Heath 1980, Edmands 1983). The upper reaches of bays and estuaries are the usual spawning areas (Heath 1980,

Table 1. Relative abundance of deepbody anchovy in 32 U.S. Pacific coast estuaries.

	Life Stage				
Estuary	A	S	J	L	E
Puget Sound					
Hood Canal					
Skagit Bay					
Grays Harbor					
Willapa Bay					
Columbia River					
Nehalem Bay					
Tillamook Bay					
Netarts Bay					
Siletz River					
Yaquina Bay					
Alsea River					
Siuslaw River					
Umpqua River					
Coos Bay					
Rogue River					
Klamath River					
Humboldt Bay					
Eel River					
Tomales Bay					
Cent. San Fran. Bay *					
South San Fran. Bay					
Elkhorn Slough					
Morro Bay					
Santa Monica Bay	√		√		
San Pedro Bay	○		○		
Alamitos Bay	○	○	○	○	○
Anaheim Bay	◉	◉	◉	○	○
Newport Bay	◉	◉	◉	●	●
Mission Bay	○	○	◉	◉	○
San Diego Bay	◉	○	◉	○	○
Tijuana Estuary					
	A	S	J	L	E

Relative abundance:
● Highly abundant
◉ Abundant
○ Common
√ Rare
Blank Not present

Life stage:
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

Edmands 1983). This species reduces competition with the slough anchovy (*A. delicatissima*) by spawning in different areas of bays (Edmands 1983).

Fecundity: Average fecundity is about 15,000 eggs per female (Heath 1980). Fecundity is significantly related to size (1,268 eggs/g female weight) (Heath 1980). Large females may lay over 28,000 eggs (Heath 1980).

Growth and Development

Egg Size and Embryonic Development: Eggs are spherical and 0.8 mm in diameter (White 1977, Caddell 1988). Embryonic development is indirect and external. Time to hatching is probably less than 4 days.

Age and Size of Larvae: Larvae are 1.5-2.5 mm long at hatching and grow to about 20-25 mm before taking on juvenile characteristics (Caddell 1988), probably in about 30 days (Heath 1980).

Juvenile Size Range: Juveniles grow from 20-25 mm to approximately 70 mm standard length (minimum) before reaching maturity.

Age and Size of Adults: This species may live to 6 years, but most die before 5 years. One-year-olds range from 70 mm to about 90 mm in length (Heath 1980). The largest reported deepbody anchovy was 165 mm (Miller and Lea 1972).

Food and Feeding

Trophic Mode: All feeding life stages are planktivorous.

Food Items: Larvae probably feed on phytoplankton and small zooplankton. Primary prey for juveniles and adults are small crustaceans. Major prey taxa include calanoid, harpacticoid, and cyclopoid copepods, ostracods, cumaceans, amphipods, and *Callianassa* spp. larvae. Minor taxa eaten are polychaetes, oligochaetes, small gastropods, mysids, tanaidaceans, isopods, crab zoea, dipterans, small gobiids, and plant material (Klingbeil et al. 1975, Horn and Allen 1985). This species utilizes the entire water column when searching for prey (Klingbeil et al. 1975).

Biological Interactions

Predation: The deepbody anchovy is probably eaten by many species of birds and piscivorous fishes.

Factors Influencing Populations: The abundance of eggs and larvae (and probably juveniles and adults) of this species appears to cycle widely. The dominant *Anchoa* species in southern California estuaries appears to fluctuate year to year. Some years *A. compressa* may dominate in ichthyoplankton surveys, while in other years *A. delicatissima* prevails. Reasons for these wide fluctuations are unknown (Heath 1980). Since all life stages reside in estuaries, any estuarine modifications or pollution directly affects this species.

References

Allen, L. G. 1982. Seasonal abundance, composition, and productivity of the littoral fish assemblage in upper Newport Bay. Fish. Bull., U.S. 80(4):769-790.

Caddell, S. M. 1988. Early life history descriptions of the deepbody and slough anchovies with comparisons to the northern anchovy (family Engraulidae). Bull. Mar. Sci. 42(2):273-291.

Edmands, F. A., II. 1983. The diel distribution and transport of ichthyoplankton collected by stationary nets in Newport Bay, Calif., July 1979. M.A. Thesis, Calif. State Univ., Fullerton, CA, 112 p.

Eschmeyer, W. N., W. S. Herald, and H. Hammann. 1983. A field guide to Pacific coast fishes of North America. Houghton Mifflin Co., Boston, MA, 336 p.

Gates, D. E., and H. W. Frey. 1974. Designated common names of certain marine organisms of California. California Fish Game, Fish Bull. 161:55-88

Heath, K. L. 1980. Comparative life histories of two species of anchovies, *Anchoa delicatissima* and *A. compressa* (F. Engraulidae) from Newport Bay, California. M.A. Thesis, Calif. State Univ., Fullerton, CA, 71 p.

Horn, M. H., and L. G. Allen. 1976. Numbers of species and faunal resemblance of marine fishes in California bays and estuaries. Bull. South. Calif. Acad. Sci. 75(2):159-170.

Horn, M. H., and L. G. Allen. 1985. Fish community ecology in southern California bays and estuaries. Chapter 8. *In* A. Yanez-Arancibia (editor), Fish community ecology in estuaries and coastal lagoons: towards an ecosystem integration, p. 169-190. DR (R) UNAM Press, Mexico.

Klingbeil, R. A., R. D. Sandell, and A. W. Wells. 1975. An annotated checklist of the elasmobranchs and teleosts of Anaheim Bay. *In* E. D. Lane and C. W. Hill (editors), The marine resources of Anaheim Bay. Calif. Fish Game, Fish Bull. 165: 79-90.

McGowan, G. E. 1977. Ichthyoplankton populations in south San Diego Bay and related effects of an electricity generating station. M.S. Thesis, San Diego State Univ., San Diego, CA, 157 p.

Miller, D. J., and R. N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Fish Game, Fish Bull. No. 157, 235 p.

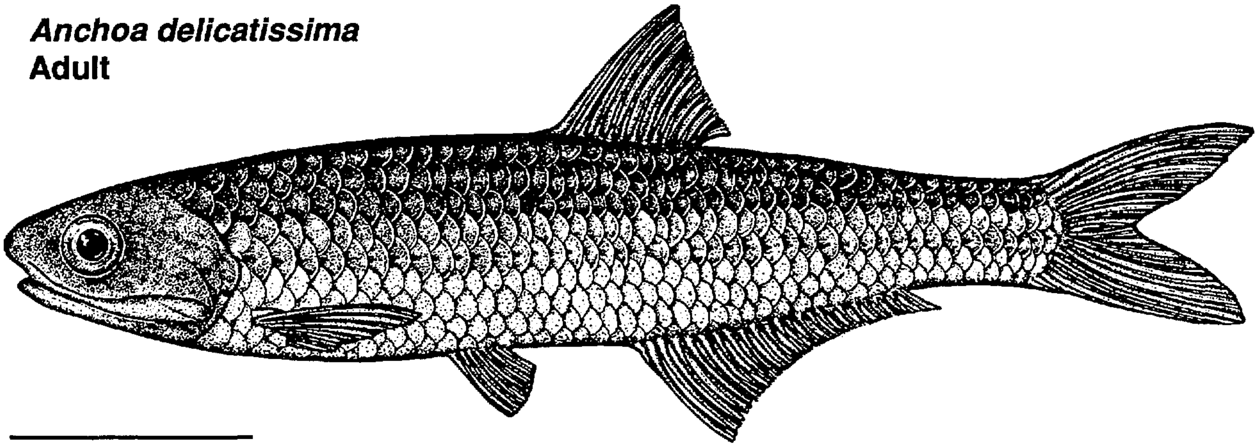
Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Roedel, P. M. 1953. Common ocean fishes of the California coast. Calif. Fish Game, Fish Bull. 91, 184 p.

Walford, L. A. 1931. Handbook of common commercial and game fishes of California. Calif. Fish Game, Fish Bull. 28, 183 p.

White, W. S. 1977. Taxonomic composition, abundance, distribution and seasonality of fish eggs and larvae in Newport Bay, California. M.A. Thesis. Calif. State Univ., Fullerton, CA, 107 p.

Slough anchovy



Common Name: slough anchovy
Scientific Name: *Anchoa delicatissima*
Other Common Names: southern anchovy (Gates and Frey 1974)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Clupeiformes
Family: Engraulidae

Value

Commercial: The slough anchovy is not of commercial value.

Recreational: It is occasionally used as live bait for other fishes (Roedel 1953).

Indicator of Environmental Stress: Since this species uses estuaries during all life stages it may be an good indicator of environmental stress, however, little ecological research has been done for this species.

Ecological: The slough anchovy is a highly abundant pelagic fish in many southern California estuaries (Allen and Horn 1975, Heath 1980, San Diego Gas and Electric 1980, Horn and Allen 1985).

Range

Overall: This species' overall range is from southern Baja California to Long Beach Harbor, California (Miller and Lea 1972, Eschmeyer et al. 1983).

Within Study Area: It is found in all estuaries and lagoons from Alamitos Bay, California, south through Tijuana Estuary (Table 1) (Horn and Allen 1976).

Life Mode

Eggs and larvae are planktonic, while juveniles and adults are pelagic.

Habitat

Type: All life stages reside primarily in estuaries, bays, and lagoons. Juveniles and adults are found occasionally in neritic environments (Miller and Lea 1972, Heath 1980).

Substrate: All life stages are pelagic and thus found over various substrates.

Physical/Chemical Characteristics: The slough anchovy will avoid temperatures >25°C (San Diego Gas and Electric 1980). Salinity tolerance and tolerance to other physical factors have not been identified. The estuaries, bays, and lagoons inhabited by this species are primarily euhaline with salinities rarely <25‰, except during the winter rainy period.

Migrations and Movements: During spring and early summer, adults move to spawning areas and then show post-spawning movements to other bay areas (Heath 1980). Schools are sometimes found along the coast (Eschmeyer et al. 1983, Love et al. 1986). Larvae undertake nocturnal vertical migrations (Edmands 1983).

Reproduction

Mode: The slough anchovy is gonochoristic, oviparous, and iteroparous. It is a broadcast spawner; eggs are fertilized externally.

Mating/Spawning: Spawning occurs from May to September, with most spawning probably occurring in

Table 1. Relative abundance of slough anchovy in 32 U.S. Pacific coast estuaries.

	Life Stage				
Estuary	A	S	J	L	E
Puget Sound					
Hood Canal					
Skagit Bay					
Grays Harbor					
Willapa Bay					
Columbia River					
Nehalem Bay					
Tillamook Bay					
Netarts Bay					
Siletz River					
Yaquina Bay					
Alsea River					
Siuslaw River					
Umpqua River					
Coos Bay					
Rogue River					
Klamath River					
Humboldt Bay					
Eel River					
Tomales Bay					
Cent. San Fran. Bay *					
South San Fran. Bay					
Elkhorn Slough					
Morro Bay					
Santa Monica Bay					
San Pedro Bay	√		√		
Alamitos Bay	●	●	◉	◉	●
Anaheim Bay	√		√		
Newport Bay	◉	◉	◉	●	●
Mission Bay	◉	◉	◉	●	◉
San Diego Bay	●	●	●	◉	●
Tijuana Estuary	√		√		
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
O	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

July (White 1977). Spawning takes place in bays and estuaries at night (Heath 1980, Edmands 1983). This species appears to spawn primarily in the lower reaches of bays and estuaries, whereas the deepbody anchovy (*A. compressa*) utilizes the upper reaches of bays for spawning (Edmands 1983).

Fecundity: Mean fecundity is approximately 7,000 eggs per female (or 1,418 eggs/g of female weight), with larger fish producing more eggs (Heath 1980).

Growth and Development

Egg Size and Embryonic Development: Eggs are ellipsoid, similar to northern anchovy (*Engraulis mordax*) eggs (Heath 1980), and are 0.94-1.10 mm maximum width (White 1977, Caddell 1988). Larval development is indirect and external. Time to hatching is unknown, but probably less than 4 days.

Age and Size of Larvae: Larvae are approximately 1.5-2.5 mm long at hatching (White 1977, Caddell 1988). Upper length limit of larval stage has not been identified, but is probably about 20-25 mm. Metamorphosis to juvenile probably begins after about 30 days (Heath 1980).

Juvenile Size Range: Juveniles range from about 25 to 50 mm in length.

Age and Size of Adults: The slough anchovy matures in one year at a minimum length of about 50 mm (standard length). Maximum age appears to be 3 years (Heath 1980), with maximum length about 94 mm (Miller and Lea 1972). Females tend to grow larger than males (Heath 1980).

Food and Feeding

Trophic Mode: Larvae, juveniles, and adults are planktivorous.

Food Items: Calanoid copepods appear to be the major prey for juveniles and adults. Other prey items include plant material, polychaetes, oligochaetes, gammarid amphipods, harpacticoid and cyclopoid copepods, cumaceans, ostracods, and cladocerans (Horn and Allen 1985).

Biological Interactions

Predation: The slough anchovy is probably preyed on by many piscivorous birds and fishes.

Factors Influencing Populations: This species is often impinged on power plant intake screens during July and August in San Diego Bay (San Diego Gas and Electric 1980). Modification and pollution of bays and estuaries can significantly affect this species because it spends its entire life within these habitats (Horn and Allen 1985). Abundance of this species appears to cycle widely; some years the slough anchovy is the dominant *Anchoa* species in California bays and other years *A. compressa* dominates (Heath 1980). Reasons for the wide fluctuations are unknown, however the slough anchovy may prefer cooler temperatures and more oceanic conditions for spawning than *A. compressa* (Edmands 1983).

References

Allen, L. G., and M. H. Horn. 1975. Abundance, diversity and seasonality of fishes in Colorado Lagoon, Alamitos Bay, California. Est. Coast. Mar. Sci. 3:371-380.

Caddell, S. M. 1988. Early life history descriptions of the deepbody and slough anchovies with comparisons to the northern anchovy (family Engraulidae). Bull. Mar. Sci. 42(2):273-291.

Edmands, F. A., II. 1983. The diel distribution and transport of ichthyoplankton collected by stationary nets in Newport Bay, California, July 1979. M.A. Thesis, Calif. State Univ., Fullerton, CA,112 p.

Eschmeyer, W. N., W. S. Herald, and H. Hammann. 1983. A field guide to Pacific coast fishes of North America. Houghton Mifflin Co., Boston, MA, 336 p.

Gates, D. E., and H. W. Frey. 1974. Designated common names of certain marine organisms of California. Calif. Fish Game, Fish Bull. 161:55-88.

Heath, K. L. 1980. Comparative life histories of two species of anchovies, *Anchoa delicatissima* and *A. compressa* (F. Engraulidae) from Newport Bay, California. M.A. Thesis, Calif. State Univ., Fullerton, CA, 71 p

Horn, M. H., and L. G. Allen. 1976. Numbers of species and faunal resemblance of marine fishes in California bays and estuaries. Bull. South. Calif. Acad. Sci. 75(2):159-170.

Horn, M. H., and L. G. Allen. 1985. Fish community ecology in southern California bays and estuaries. Chapter 8. *In* A. Yanez-Arancibia (editor), Fish community ecology in estuaries and coastal lagoons: towards an ecosystem integration, p. 169-190. DR (R) UNAM Press, Mexico.

Love, M. S., J. S. Stephens, Jr., P. A. Morris, M. M. Singer, M. Sandhu, and T. C. Sciarrotta. 1986. Inshore soft substrata fishes in the southern California bight: an overview. Calif. Coop. Ocean. Fish. Invest. Rep. 27:84-104.

Miller, D. J., and R. N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Fish Game, Fish Bull. 157, 235 p.

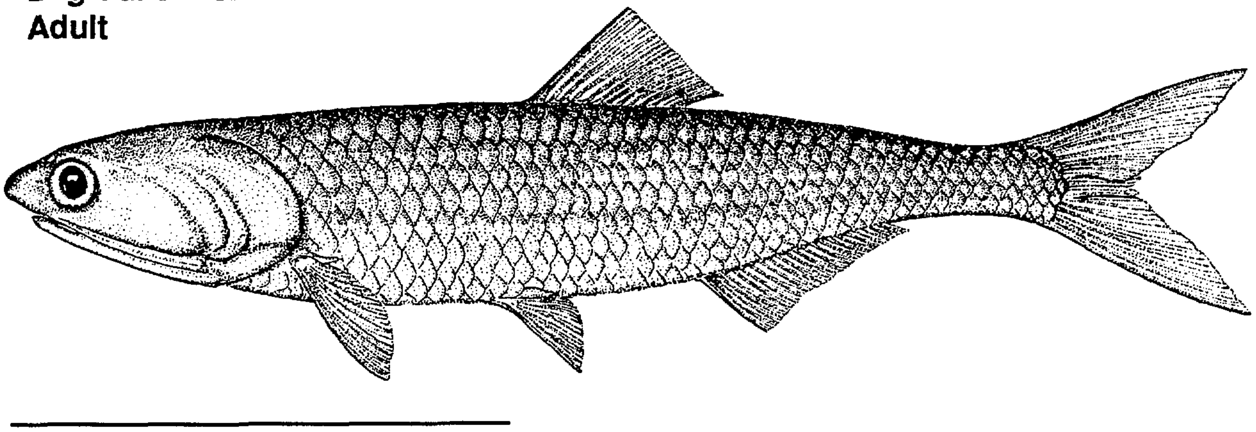
Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Roedel, P. M. 1953. Common ocean fishes of the California coast. Calif. Fish Game, Fish Bull. 91, 184 p.

San Diego Gas and Electric. 1980. Silvergate power plant cooling water intake system demonstration [in accordance with section 316(b) Federal Water Pollution Control Act Amendment of 1972]. Rep. to Calif. Reg. Water Qual. Control Board, San Diego Gas and Electric, San Diego, CA, various pagination.

White, W. S. 1977. Taxonomic composition, abundance, distribution and seasonality of fish eggs and larvae in Newport Bay, California. M.A. Thesis, Calif. State Univ., Fullerton, CA, 107 p.

Engraulis mordax
Adult



5 cm

Common Name: northern anchovy
Scientific Name: *Engraulis mordax*
Other Common Names: California anchovy, pinhead, anchoa, anchoveta, anchovy, bay anchovy, North American anchovy, plain anchovy
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Clupeiformes
Family: Engraulidae

Value

Commercial: The northern anchovy is commercially fished from British Columbia to northern Baja California, Mexico, but primarily from San Francisco, California, to Bahia San Ramon, Baja California. It was not commercially important until after the collapse of the Pacific sardine (*Sardinops sagax*) fishery in the 1940s. In 1981, over 400,000 t were landed, representing the 25th largest species catch in the world (Food and Agriculture Organization 1984). The California commercial catch in 1981 was estimated to be worth $3.2 million (Pacific Fishery Management Council 1983). This species is commercially fished for reduction (i.e., fish meal and paste) and live bait, however, the reduction fishery has declined dramatically since 1981.

Recreational: It is the most important bait fish for nearly all marine recreational fisheries off southern California. It is also used as bait in Oregon and Washington for sturgeon (*Acipenser* spp.), salmonids (*Oncorhynchus* spp.), and other fishes.

Indicator of Environmental Stress: Low dissolved oxygen can cause die-offs (Pacific Fishery Management Council 1983). Anchovy hatching success, larval survival, juvenile feeding, and growth are reduced when exposed to water-soluble fractions of crude oil (MBC Applied Environmental Sciences 1987).

Ecological: The northern anchovy is one of the most abundant fish in the California Current and is an important prey for many species of fishes, seabirds, and marine mammals (Frey 1971, Eschmeyer et al. 1983). It is highly abundant in many Pacific coast bays and estuaries during spring, summer, and fall. Elegant tern (*Thalasseus elegans*) and California brown pelican (*Pelecanus occidentalis*) production is strongly correlated with anchovy abundance (Anderson et al. 1980, Schaffner 1986). The northern anchovy occupies an ecological niche similar to the Pacific sardine's and may be inhibiting its comeback (Frey 1971).

Range

Overall: The northern anchovy was distributed from Cape San Lucas, Baja California, to Queen Charlotte Islands, Canada, but has recently moved into the Gulf of California, Mexico (Hammann and Cisneros-Mata 1989). Three genetically distinct subpopulations exist (Vrooman and Smith 1971). One ranges from northern California to British Columbia. The second is off southern California and the northern Baja California peninsula in Mexico. The third occurs off central and southern Baja California (Vrooman and Smith 1971).

Within Study Area: This species can be found in all estuaries within the study area (Table 1). A subspecies (*E. mordax nanus*) is restricted to San Francisco Bay (Hubbs 1925).

Life Mode

Eggs and larvae are planktonic, while juveniles and

Table 1. Relative abundance of northern anchovy in 32 U.S. Pacific coast estuaries.

Estuary	A	S	J	L	E
Puget Sound	○	○	○	○	○
Hood Canal	○	○	○	○	○
Skagit Bay	○	○	○	○	○
Grays Harbor	●		●	○	○
Willapa Bay	●		●	○	○
Columbia River	●		●	○	○
Nehalem Bay	○		●	○	
Tillamook Bay	○		●	○	
Netarts Bay	○		○		
Siletz River	○		○		
Yaquina Bay	○		◉	○	
Alsea River	○		○	○	
Siuslaw River	√		√		
Umpqua River	√		◉		
Coos Bay	◉		●	○	
Rogue River	○		●	√	
Klamath River	◉		●	√	
Humboldt Bay	●		●		
Eel River	○		○		
Tomales Bay	◉		◉	○	
Cent. San Fran. Bay *	●	●	●	●	●
South San Fran. Bay	●	●	●	●	●
Elkhorn Slough	●		●	◉	
Morro Bay	●		●	◉	
Santa Monica Bay	●	●	●	●	●
San Pedro Bay	●	●	●	●	●
Alamitos Bay	●		●	○	○
Anaheim Bay	○		○	○	○
Newport Bay	◉		◉	○	◉
Mission Bay				◉	
San Diego Bay	○		○	○	○
Tijuana Estuary				◉	◉
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

adults are pelagic nekton (Garrison and Miller 1982).

Habitat

Type: Eggs are neritic and epipelagic (from the surface to 50 m depth, but primarily in the upper 20 m). Larvae are also neritic and epipelagic, occurring from the surface to 75 m depth, but usually in the upper 50 m. Juveniles are epipelagic and often highly abundant in shallow nearshore areas and estuaries. Adults are oceanic-neritic, occurring from the surface to 300 m deep. Adults can also be abundant in shallow nearshore areas and estuaries. Eggs and larvae can be found out to 480 km offshore (Hart 1973, Garrison and Miller 1982), while adults occur out to 157 km offshore (Pacific Fishery Management Council 1983).

Substrate: Because this is a pelagic species, all life stages are found over various substrates.

Physical/Chemical Characteristics: Eggs are found in euhaline waters (32-35‰), while adults, juveniles, and larvae can be found in estuarine and marine waters (Simenstad 1983). Spawning occurs at water temperatures of 12-15°C and usually within 10 m of the surface (Ahlstrom 1959). Eggs are found in temperatures of 10.0-23.3°C, larvae at 10.0-19.7°C (mostly 14.0-17.4°C), and juveniles and adults at 5.0-25.0°C. The lower lethal temperature for juveniles appears to be 7°C, but at 10.0°C larvae do not develop properly. Temperatures above 25°C are actively avoided by juveniles and adults. (Brewer 1974).

Migrations and Movements: The northern anchovy does not make extensive migrations (Pacific Fishery Management Council 1983), but it does undertake inshore-offshore movements as well as movements along the shore. In the Pacific Northwest, juveniles and adults move into estuaries during spring and summer and then out during fall (Waldvogel 1977, National Marine Fisheries Service 1981, Simenstad and Eggers 1981). In southern California, young-of-the year and yearling anchovies utilize shallow inshore areas (Parrish et al. 1985). Adult and juvenile anchovies show some diel movements during the summer, staying at depths of 110-183 m during the day and coming to the surface at night (Hart 1973). Larvae swim to the surface at night to gulp air and inflate their swim bladder (Hunter and Sanchez 1976). Larvae, juveniles, and adults form small low density schools during the day and disperse into a thin surface scattering layer at night (Mais 1974). Juveniles and adults may also form dense schools or "balls" when being attacked by predatory fishes.

Reproduction

Mode: This species is gonochoristic, oviparous, and iteroparous; eggs are fertilized externally. It is a broadcast spawner that spawns in batches annually after reaching maturity.

Mating/Spawning: Spawning is reported from Barkley Sound and the Strait of Georgia, British Columbia, to south of Magdalena Bay, Baja California, and in the Gulf of California. Spawning can occur throughout the year depending on region (i.e., subpopulation). Times for spawning are July to August in British Columbia waters, June to August off Oregon, December to June in central California waters, May to September in San Francisco Bay, and January to May off southern California (McGowan 1986). Most spawning takes place within 100 km of the coast in the upper mixed layer (sometimes surface) at night (Baxter 1967, Hunter and Macewicz 1980). The majority of spawning in California waters occurs at depths less than 10 m and water temperatures between 12 and 15°C. However, spawning has been recorded up to 482 km offshore (Ahlstrom 1959). In the northern subpopulation, spawning appears to be associated with the Columbia River plume, which may provide a stable and productive environment for egg and larval survival (Richardson 1981). The timing of reproduction near San Pedro Bay, California, may be constrained by dietary requirements (Brewer 1978). This species is a batch spawner (Hunter and Goldberg 1980) and may spawn about 20 times per spawning season (Hunter and Leong 1981).

Fecundity: Females lay eggs in batches and can produce up to 130,000 eggs per year (20 spawnings) in southern California (Hunter and Macewicz 1980, Hunter and Leong 1981). Females in the northern subpopulation are apparently limited to only a few batches and a total fecundity of 35,000 eggs per female per year (Laroche and Richardson 1980). Batch fecundities are estimated to be 2,794-16,662 eggs per female (Hunter and Macewicz 1980).

Growth and Development

Egg Size and Embryonic Development: Eggs are ellipsoidal with dimensions of 1.23-1.55 mm x 0.65-0.82 mm (Garrison and Miller 1982). Embryonic development is indirect and external. Eggs hatch in 2-4 days, depending on temperature.

Age and Size of Larvae: The yolk sac is absorbed within 36 hours of hatching (Lasker et al. 1970). Larvae range from 2.5 mm to 25.0 mm in length (Hart 1973). Larvae begin schooling at 11-12 mm standard length (SL) (Hunter and Coyne 1982), and transform into juveniles in approximately 70 days (Hart 1973).

Juvenile Size Range: Juveniles range in size from 2.5-14.0 cm SL (Clark and Phillips 1952).

Age and Size of Adults: Some fish mature at less than one year of age (7.1-10.0 cm) and all are mature at 4 years, depending on location and population size (Clark and Phillips 1952, Hart 1973, Hunter and Macewicz 1980, Laroche and Richardson 1980). Larger fish mature earlier than smaller fish in the same age group (Huppert et al. 1980). The maximum age reported for this species is 7 years (Frey 1971).

Food and Feeding

Trophic Mode: Juveniles and adults are random filtering or particulate (i.e., biting) planktivores, depending on food concentrations (O'Connell 1972). Anchovies apparently feed primarily during the day (Kucas 1986). Females need to eat approximately 4-5% of their wet weight per day for growth and reproduction (Hunter and Leong 1981).

Food Items: Larvae consume copepods (primarily eggs and nauplii), naked dinoflagellates, rotifers, ciliates, and foraminiferans (Baxter 1967, Arthur 1976, Hunter 1977). Larvae, juveniles, and adults are often found in areas of plankton blooms. Adults and juveniles prey on phytoplankton, planktonic crustaceans, and fish larvae (Loukashkin 1970, Frey 1971, Hart 1973, Pacific Fishery Management Council 1983).

Biological Interactions

Predation: Northern anchovy eggs and larvae are eaten by adult anchovies (Hunter 1977) and probably many other fishes. In the California Current, juveniles and adults are consumed by most species of predatory fishes, including California halibut (*Paralichthys californicus*), chinook (*O. tshawytscha*) and coho salmon (*O. kisutch)*, rockfishes, yellowtail (*Seriola lalandei*), tunas, and sharks. Other predators include harbor seal (*Phoca vitulina*), northern fur seal (*Callorhinus ursinus*), California sea lions (*Zalophus californianus*), common murre (*Uria aalge*), sooty shearwater (*Puffinus griseus*), cormorant (*Phalacrocorax* spp.), gulls, and terns (Kucas 1986). The northern anchovy is the primary prey for the California brown pelican, an endangered species (Huppert et al. 1980).

Factors Influencing Populations: Egg and larval survival probably determines subsequent year-class strength (Smith 1985). However, egg and larval abundance are not correlated with age-1 recruits (Peterman et al. 1988). Anchovy spawning biomass is presently estimated from egg production (Lasker 1985). Good larval survival appears to depend on many factors, including the availability and density of appropriate phytoplankton species (Lasker 1975, Lasker and Smith 1976, Lasker 1981, Peterman and Bradford 1987). Larval food availability is reduced by storms and strong upwelling. Strong upwelling may also transport larvae out of the Southern California Bight (Power 1986), however, upwelling may benefit later life stages. El Niño events affect populations both positively and negatively, depending on subpopulation and life stage (Brodeur et al. 1985, Fiedler et al. 1986). High rates of predation and commercial harvest also impact populations. Northern anchovy populations increased dramatically during the collapse of the Pacific sardine populations, suggesting competition between these species (Smith 1972, Kucas 1986).

References

Ahlstrom, E. H. 1959. Vertical distribution of pelagic fish eggs and larvae off California and Baja California. Fish. Bull., U.S. 60:107-146.

Anderson, D. W., F. Gress, K. F. Mais, and P. R. Kelly. 1980. Brown pelicans as anchovy stock indicators and their relationship to commercial fishing. Calif. Coop. Ocean. Fish. Invest. Rep. 21:54-61.

Arthur, D. K. 1976. Food and feeding of larvae of three fishes occurring in the California Current, *Sardinops sagax*, *Engraulis mordax*, and *Trachurus symmetricus*. Fish. Bull., U.S. 74:517-530.

Baxter, L. L. 1967. Summary of biological information on the northern anchovy, *Engraulis mordax* Girard. Calif. Coop. Ocean. Fish. Invest. Rept. 11:110-116.

Brewer, G. 1974. Thermal tolerance and sediment toxicity studies. *In* D. F. Soule and M. Oguri (editors), Marine studies of San Pedro Bay, California, p. 21-43. Allan Hancock Found., Off. Sea Grant Publ., Univ. S. Calif., Los Angeles, CA.

Brewer, G. D. 1978. Reproduction and spawning of the northern anchovy, *Engraulis mordax* in San Pedro Bay, California. Calif. Fish Game 64(3):175-184.

Brodeur, R. D., D. M. Gadomski, W. G. Pearcy, G. P. Batchelder, and C. B. Miller. 1985. Abundance and distribution of ichthyoplankton in the upwelling zone off Oregon during anomalous El Niño conditions. Estuar. Coast. Shelf Sci. 21:365-378.

Clark, F. N., and J. B. Phillips. 1952. The northern anchovy (*Engraulis mordax*) in the California fishery. Calif. Fish Game 38(2):189-207.

Eschmeyer, W. N., W. S. Herald, and H. Hammann. 1983. A field guide to Pacific coast fishes of North America. Houghton Mifflin Co., Boston, MA, 336 p.

Fiedler, P. C., R. D. Methot, and R. P. Hewitt. 1986. Effects of California El Niño 1982-1984 on the northern anchovy. J. Mar. Res. 44:317-338.

Food and Agriculture Organization. 1984. Yearbook of fishery statistics, 1983: catches and landings. FAO, U.N., Rome, 393 p.

Frey, H. W. 1971. California's living marine resources and their utilization. Calif. Dept. Fish Game, Sacramento, CA, 148 p.

Garrison, K. J. and B. S. Miller. 1982. Review of the early life history of Puget Sound fishes. Fish. Res. Inst., Univ. Wash., Seattle, WA, 729 p. (FRI-UW-8216).

Hammann, M. G., and M. A. Cisneros-Mata. 1989. Range extension and commercial capture of the northern anchovy, *Engraulis mordax* Girard, in the Gulf of California, Mexico. Calif. Fish Game 75(1):49-53.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. No. 180, 740 p.

Hubbs, C. L. 1925. Racial and seasonal variation in the Pacific herring, California sardine, and California anchovy. Calif. Fish Game, Fish Bull. 8:1-23.

Hunter, J. R. 1977. Behavior and survival of northern anchovy, *Engraulis mordax*, larvae. Calif. Coop. Ocean. Fish. Invest. Rep. 19:138-146.

Hunter, J. R., and K. M. Coyne. 1982. The onset of schooling in northern anchovy larvae, *Engraulis mordax*. Calif. Coop. Ocean. Fish. Invest. Rep. 23:246-251.

Hunter, J. R., and S. R. Goldberg. 1980. Spawning incidence and batch fecundity in northern anchovy, *Engraulis mordax*. Fish. Bull., U.S. 77(3):641-652.

Hunter, J. R., and R. Leong. 1981. The spawning energetics of female northern anchovy, *Engraulis mordax*. Fish. Bull., U.S. 79(2):215-230.

Hunter, J. R., and B. J. Macewicz. 1980. Sexual maturity, batch fecundity, spawning frequency, and temporal pattern of spawning for the northern anchovy, *Engraulis mordax*, during the 1979 spawning season. Calif. Coop. Ocean. Fish. Invest. Rep. 21: 139-149.

Hunter, J. R., and C. Sanchez. 1976. Diel changes in swim bladder inflation of the larvae of the northern anchovy, *Engraulis mordax*. Fish. Bull., U.S. 74(4):847-855.

Huppert, D. D., A. D. MacCall, G. D. Stauffer, K. R. Parker, J. A. McMillan, and H. W. Frey. 1980. California's northern anchovy fishery: biological and economic basis for fishery management. NOAA Tech. Mem. NMFS, Nat. Mar. Fish. Serv., Southwest Fish. Cent., La Jolla, CA, 121 p. plus appendices.

Kucas, S. T., Jr. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest)—northern anchovy. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.50). U.S. Army Corps Eng., TR EL-82-4, 11 p.

Laroche, J. L. , and S. L. Richardson 1980. Reproduction of northern anchovy, *Engraulis mordax*, off Oregon and Washington. Fish. Bull., U.S. 78(3):603-618.

Lasker, R. 1975. Field criteria for survival of anchovy larvae: the relation between inshore chlorophyll maximum layers and successful first feeding. Fish. Bull., U.S. 73:453-462.

Lasker, R. 1981. Factors contributing to variable recruitment of the northern anchovy (*Engraulis mordax*) in the California current: contrasting years, 1975 through 1978. Rapp. P.-v. Reun. Cons. Int. Explor. Mer. 178:375-388.

Lasker, R. (editor). 1985. An egg production method for estimating spawning biomass of pelagic fish: application to the northern anchovy, *Engraulis mordax*. U.S. Dept. Commer., NOAA Tech. Rep. NMFS 36, 99 p.

Lasker, R., H. M. Feder, G. H. Theilacker, and R. C. May. 1970. Feeding, growth, and survival of *Engraulis mordax* reared in the laboratory. Mar. Biol. 5:345-353.

Lasker, R., and P. Smith. 1976. Estimation of the effects of environmental variations on the eggs and larvae of the northern anchovy. Calif. Coop. Ocean. Fish. Invest. Rep. 19:128-137.

Loukashkin, A. S. 1970. On the diet and feeding behavior of the northern anchovy, *Engraulis mordax* (Girard). Proc. Calif. Acad. Sci. 37:419-458.

Mais, K. F. 1974. Pelagic fish surveys in the California Current. Calif. Fish Game, Fish Bull. No. 162, 721 p.

MBC Applied Environmental Sciences. 1987. Ecology of important fisheries species offshore California. Miner. Manag. Serv. Study 86-0093, MBC Appl. Envir. Sci., Costa Mesa, CA , 251 p.

McGowan, M. F. 1986. Northern anchovy, *Engraulis mordax*, spawning in San Francisco Bay, California, 1978-79, relative to hydrography and zooplankton prey of adults and larvae. Fish. Bull., U.S. 84(4):879-894.

National Marine Fisheries Service. 1981. Salmonid and non-salmonid fishes. Annual Data Rep., Second Year, to Pacific NW River Basins Comm., CREDDP Tasks A-2.8 and A-2.9, 139 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA 98112.

O'Connell, C. P. 1972. The interrelation of biting and filtering in the feeding activity of the northern anchovy (*Engraulis mordax*). J. Fish. Res. Board. Can. 29:285-293.

Pacific Fishery Management Council. 1983. Northern anchovy fishery management plan, fourth draft revision. Pac. Fish. Manag. Council, Portland, OR, various pagination.

Parrish, R. H., D. L. Mallicoate, and K. F. Mais. 1985. Regional variations in the growth and age composition of northern anchovy, *Engraulis mordax*. Fish. Bull., U.S. 83(4):483-496.

Peterman, R. M., and M. J. Bradford. 1987. Wind speed and mortality rate of a marine fish, the northern anchovy (*Engraulis mordax*). Science 235:354-356.

Peterman, R. M., M. J. Bradford, N. C. H. Lo, and R. D. Methot. 1988. Contribution of early life stages to interannual variability in recruitment of northern anchovy (*Engraulis mordax*). Can. J. Fish. Aquat. Sci. 45(1):8-46.

Power, J. H. 1986. A model of the drift of northern anchovy, *Engraulis mordax* larvae in the California current. Fish. Bull., U.S. 84(3):585-603.

Richardson, S. L. 1981. Spawning biomass and early life of northern anchovy, *Engraulis mordax*, in the northern subpopulation off Oregon and Washington. Fish. Bull., U.S. 78(4):855-876.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, Robert N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Amer. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Schaffner, F. C. 1986. Trends in elegant tern and northern anchovy populations in California. Condor 88:347-354.

Simenstad, C. A. 1983. The ecology of estuarine channels of the Pacific Northwest coast: a community profile. U.S. Fish Wildl. Serv., FWS/OBS-83/05, 181 p.

Simenstad, C. A., and D. M. Eggers, (editors). 1981. Juvenile salmonid and baitfish distribution, abundance, and prey resources in selected areas of Grays Harbor, Washington. Final Rep. to Seattle Dist., U.S. Army Corps Eng., Fish. Res. Inst., Coll. Fish., Univ. Wash., Seattle, WA, 205 p. (FRI-UW-8116).

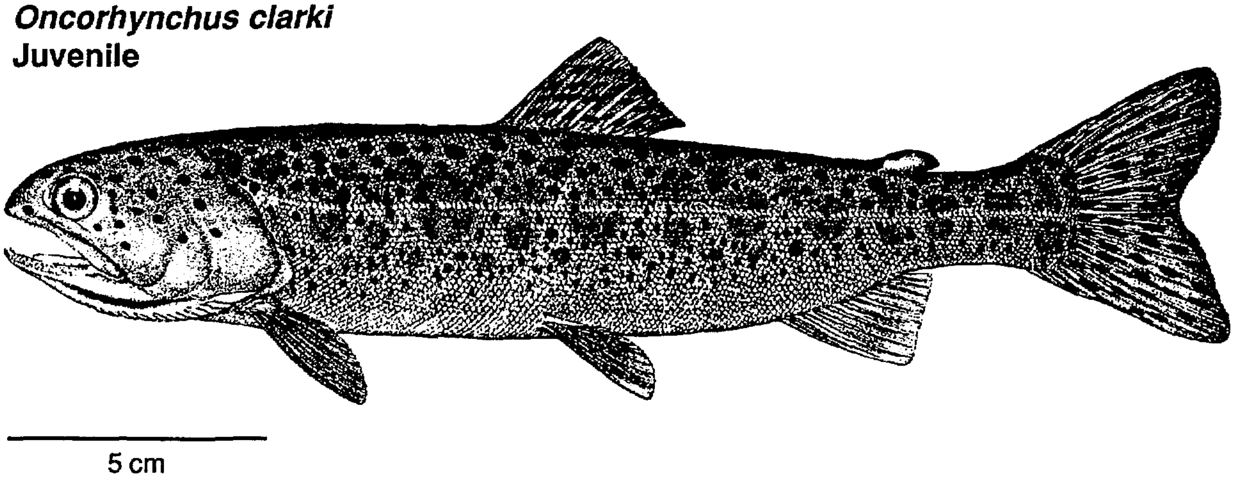
Smith, P. E. 1972. The increase in spawning biomass of northern anchovy, *Engraulis mordax.* Fish. Bull., U.S. 70:849-874.

Smith, P. E. 1985. Year-class strength and survival of 0-group clupeoids. Can. J. Fish. Aquat. Sci. 42 (Suppl. 1):69-82.

Vrooman, A. M., and P. E. Smith. 1971. Biomass of the subpopulations of the northern anchovy *Engraulis mordax* Girard. Calif. Coop. Ocean. Fish. Invest. Rep. 15:49-51.

Waldvogel, J. B. 1977. Age, maturity and distribution of northern anchovy, *Engraulis mordax*, in Humboldt Bay, California. M.S. Thesis, Humboldt State Univ., Arcata, CA, 36 p.

Cutthroat trout



Common Name: cutthroat trout
Scientific Name: *Oncorhynchus clarki*
Other Common Names: Clark's trout, coastal cutthroat, coastal cut-throat trout, sea-run cutthroat trout, red-throated trout, sea trout, short-tailed trout, harvest trout
Classification (Smith and Stearley 1989)
Phylum: Chordata
Class: Osteichthyes
Order: Salmoniformes
Family: Salmonidae

Value

Commercial: The cutthroat trout is not commercially fished, but is incidentally captured during gillnetting for Pacific salmon (*Oncorhynchus* spp.) (Tipping 1982).

Recreational: It is the third most popular gamefish in the Pacific Northwest (Washington 1977). In Washington, the Cowlitz River recreational fishery was estimated to be worth $290,000 recently (Tipping 1982). Hatcheries in Oregon and Washington stock this species into numerous streams.

Indicator of Environmental Stress: The sea-run cutthroat trout is sensitive to temperature changes and stream alterations resulting from logging practices (Moring and Lantz 1975). It has been compared to the "canary in the mine", being one of the first species to suffer from environmental degradation (Behnke 1987).

Ecological: The cutthroat trout is a minor predator in nearshore coastal waters (Loch and Miller 1988) and an important resident of many streams and rivers. It has been displaced by introduced salmonids and non-native fishes in many rivers and streams.

Range

Overall: The overall range of this species' anadromous form is from the Eel River, California, to Seward, southeastern Alaska (Scott and Crossman 1973).

Within Study Area: This species is common in nearly all estuaries along the Pacific coast from the Eel River to Puget Sound, Washington (Table 1) (Monaco et al. 1990).

Life Mode

The cutthroat trout has four life histories: 1) an anadromous form, 2) a form that migrates between lakes and small streams, 3) a form that migrates between small tributaries and main rivers, and 4) a form that lives its entire life in small streams (Trotter 1987). This life history summary focuses primarily on the anadromous variety, *O. clarki clarki*. Eggs and larvae (alevins) are benthic and infaunal. Young juveniles (fry and parr) are benthopelagic; parr become pelagic when they transform into smolts (juveniles that migrate to the ocean). Smolts, ocean-dwelling and maturing juveniles (subadults), and adults are primarily pelagic. Subadults and adults in rivers and streams are benthopelagic.

Habitat

Type: Eggs, alevins, fry, and parr are riverine. Smolts are riverine and estuarine. Young-of-the-year are often found only in small coastal streams; many of these streams will have low summer flows. Subadults and adults are found in coastal neritic waters during ocean residence (spring and summer), and in riverine habitats during the spawning migration. Smolts, subadults, adults, and "kelts" (spent adults) migrate through estuaries. Some individuals are permanent

Table 1. Relative abundance of cutthroat trout in 32 U.S. Pacific coast estuaries.

	Life Stage					
Estuary	A	S	K	J	L	E
Puget Sound	○		○	○		
Hood Canal	○		○	○		
Skagit Bay	○		○	○		
Grays Harbor	○		○	○		
Willapa Bay	○		○	○		
Columbia River	○		○	○		
Nehalem Bay	◉		○	◉		
Tillamook Bay	○		○	○		
Netarts Bay	○		○	○		
Siletz River	○		○	○		
Yaquina Bay	○		○	○		
Alsea River	◉		○	◉		
Siuslaw River	◉		○	◉		
Umpqua River	○		○	○		
Coos Bay	○		√	○		
Rogue River	○		○	○		
Klamath River	○		○	○		
Humboldt Bay	√		√	√		
Eel River	○		○	○		
Tomales Bay						
Cent. San Fran. Bay *						
South San Fran. Bay						
Elkhorn Slough						
Morro Bay						
Santa Monica Bay						
San Pedro Bay						
Alamitos Bay						
Anaheim Bay						
Newport Bay						
Mission Bay						
San Diego Bay						
Tijuana Estuary						
	A	S	K	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
K - Kelts
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

residents of estuaries (Levy and Levings 1978).

Substrate: Eggs are found beneath gravel (0.6-10.2 cm in diameter) in shallow riffle areas at the tail end of pools (Reiser and Bjornn 1979). Juveniles and adults occur over various substrates depending on life stage and habitat.

Physical/Chemical Characteristics: The cutthroat trout prefers water temperatures of 9-12°C (Bell 1984). It can tolerate 26°C, but is not usually found where stream temperatures are consistently greater than 22°C (Pauley et al. 1989). The best spawning temperature appears to be 10°C, but spawning occurs over a range from 6-17°C (Scott and Crossman 1973). Waters with dissolved oxygen concentrations less than 5 mg/l are avoided (Pauley et al. 1989). This species can be found in streams with flows as low as 0.01-0.03 m^3/s (DeWitt 1954). Spawning occurs in stream flows ranging from 0.11-0.90 m/s and depths of 10-100 cm (Pauley et al. 1989). While in fresh water, adults typically reside in pools, while fry reside in riffles.

Migrations and Movements: Parr in fresh water often move upstream and downstream (Moring and Lantz 1975). Parr remain in streams for at least 1 year, but may stay up to 9 years. Parr become smolts as they migrate to estuaries. In Oregon and Washington, most smolts migrate during spring in their third year (Wydoski and Whitney 1979). However, the juvenile's size appears to determine its year of migration; larger fish migrate to sea while smaller fish remain (Tipping 1986). In Oregon, immature fish moved downstream from February through May, with April being a peak month for outmigration. In Washington, outmigration occurs from March to July (peaking in May) (Michael 1989). Few juveniles remain in the ocean for more than one summer and most migrate back to natal streams in late summer and fall of the same year (Johnston 1982). Depending on the stock, a proportion of the fish returning to fresh water after their first summer in the ocean are still not reproductively mature (Johnston 1982). Prior to their spawning migration, adult cutthroat trout often reside in tidal freshwater areas of estuaries, awaiting increased stream flows and decreased water temperatures before proceeding upstream. In Oregon, adults move upstream from October to March, with most movement during November through January; kelts move downstream from January to April, with most moving in January and February (Lowry 1965). Some streams are used for overwintering only and others for spawning (Michael 1989). After overwintering (or spawning), sea-run cutthroat trout migrate to the ocean again in spring. Information concerning ocean movements and migrations are limited, but some fish do not migrate far from where they entered the ocean (Johnston 1982). However, some have been found out to 31 km offshore (Loch and Miller 1988). The cutthroat trout may school while in estuarine and marine environments (Giger 1972). When returning to their natal stream, wild fish rarely stray. However, straying of hatchery fish (from streams in which they were stocked) may be 30% (Pauley et al. 1989).

Reproduction

Mode: The cutthroat trout is gonochoristic and oviparous; eggs are fertilized externally. This species differs from all other members of the genus *Oncorhynchus* (except steelhead trout, *O. mykiss*) in being iteroparous.

Mating/Spawning: Sea-run cutthroat trout return to their natal streams to spawn from late fall to late winter

(Johnston 1982, Pauley et al. 1989), however, only 41-61% of a "run" may actually be sexually mature (Jones 1977). Spawning occurs primarily in gravel riffles of small tributary coastal streams at the tail of pools in water that is 10-15 cm deep (Jones 1977). Like other salmonids, the female digs a redd in the gravel and lays her eggs while the male fertilizes them with his milt. The female then covers the eggs with more gravel. Although this species is iteroparous, substantial post-spawning mortality can occur. The best spawning conditions include incubation temperatures from 6.1-17.2°C, depths ≥6 cm, water velocities from 11-72 cm/sec, and gravel that is 0.6-10.2 cm^2 in diameter (Reiser and Bjornn 1979).

Fecundity: Fecundity ranges from 226-4,420 eggs per female (depending on female size), averaging 1,000-1,700 (Scott and Crossman 1973).

Growth and Development

Egg Size and Embryonic Development: Eggs are 4.3-5.1 mm in diameter, orange-red in color, and demersal (Pauley et al. 1989). Embryonic development is indirect and external. Eggs usually hatch in 28-40 days (depending on temperature) (Scott and Crossman 1973).

Age and Size of Larvae: Alevins are 15 mm long at hatching and spend 1 to 2 weeks in the redd before emerging. Fry (small young juveniles) are approximately 35 mm in length.

Juvenile Size Range: Juveniles range from 35-200 mm in length.

Age and Size of Adults: Wild sea-run cutthroat mature after 2-10 years, ranging in length from 131 to 450 mm (Summer 1962, Scott and Crossman 1973, Jones 1977). However, hatchery fish grow quicker than wild fish and may return to spawn as one-year-old fish (Tipping 1982).

Food and Feeding

Trophic Mode: Larvae feed on their yolk. Juveniles and adults are carnivorous.

Food Items: Fry feed on insects, crustaceans, and some fish. Large cutthroat trout may prey on threespine stickleback (*Gasterosteus aculeatus*) and young sockeye (*O. nerka*) and coho (*O. kisutch*) salmon while in fresh water(Lowry 1966, Pauley et al. 1989). Large juveniles (migrants) and adults are highly piscivorous when in estuaries and marine waters (Behnke 1979, Loch 1982). In the ocean, cutthroat trout feed on northern anchovy (*Engraulis mordax*), kelp greenling (*Hexagrammos decagrammus*), scorpaenids, salmonids, euphausiids, mysids, and crab megalopae (Brodeur et al. 1987, Loch and Miller 1988).

Biological Interactions

Predation: Little is known about predation on this species, but 58% of the adults and subadults returning to the Alsea River, Oregon, had marks indicating predator attacks (Giger 1972). Marine mammals prey on this species at sea, while belted kingfishers (*Megaceryle alcyon*) and other piscivorous birds are probably major predators in streams and estuaries. Sculpins and salmonids may also be predators of alevins and fry in streams.

Factors Influencing Populations: This species is very sensitive to changes in its freshwater habitat. The amount of cover, water quality, and substrate characteristics determine stream population densities (Reiser and Bjornn 1979). Forestry practices influence stream carrying capacity and can affect spawning success. Increases in temperature and turbidity reduces cutthroat trout production (Behnke 1979) and predation, disease, residualism, and straying, affect the number of returning adults (Tipping 1982). The myxosporidean protozoan *Ceratomyxa shasta* can cause severe larval/juvenile mortalities in hatcheries (Tipping 1988). Natural production of the sea-run cutthroat appears to be severely depressed in many rivers and watersheds. In some areas, urbanization has adversely affected stream environments and subsequently cutthroat trout populations (Trotter 1987). Ocean survival of first-year smolts reportedly ranges from 1.8-21.7% in Washington (Michael 1989) and 20-40% in Oregon (Giger 1972). Survival of subadults and adults in fresh water ranges from 22.2-76.9% (Michael 1989). Because sea-run cutthroat trout are accessible to many anglers and relatively easy to catch, populations are easily overfished (Jones 1977, Tipping 1982). As a result, strict harvest restrictions have been implemented in British Columbia and Washington (Pauley et al. 1989). The genetic integrity of some stocks is threatened because there are very few adults in the spawning population (Michael 1989). By selecting the small tributaries of rivers and streams for spawning, sea-run cutthroat avoid competition with rainbow trout and coho salmon (Johnston 1982, Pauley et al. 1989). Although stream-dwelling juveniles eat similar foods as juvenile coho salmon, competition is reduced by habitat partitioning. Juvenile cutthroat trout are often forced to reside in riffle areas until falling water temperatures reduce the aggressive behavior of other salmonids (Glova 1986, 1987, Pauley et al. 1989).

References

Behnke, R. J. 1979. Monograph of the native trouts of the genus *Salmo* of western North America. U.S. Fish and Wildl. Serv., and U.S. Forest Serv., Lakewood, CO, 163 p.

Behnke, R. J. 1987. Forward. *In* P. C. Trotter, Cutthroat: native trout of the west. Colorado Assoc. Univ. Press, Boulder, CO.

Bell, M. C. 1984. Fisheries handbook of engineering requirements and biological criteria. Fish Passage Development and Evaluation Program, U.S. Army Corps Eng., North Pac. Div., Portland, OR, 290 p. (Contract No. DACW57-79-M-1594 and DACW57-80-M-0567).

Brodeur, R. D., H. V. Lorz, and W. G. Pearcy. 1987. Food habits and diet variations of pelagic nekton off Oregon and Washington, 1979-1984. NOAA, Tech. Rep. NMFS 57, 32 p.

DeWitt, J. W., Jr. 1954. A survey of the coast cutthroat trout, *Salmo clarki clarki* Richardson, in California. Calif. Fish Game 40:329-335.

Giger, R. D. 1972. Ecology and management of coastal cutthroat trout in Oregon. Fish. Res. Rep. No. 6, Oregon State Game Comm., Portland, OR, 61 p.

Glova, G. J. 1986. Interaction for food and space between experimental populations of juvenile coho salmon (*Oncorhynchus kisutch*) and coastal cutthroat trout (*Salmo clarki*) in a laboratory stream. Hydrobiol. 131:155-168.

Glova, G. J. 1987. Comparison of allopatric cutthroat trout stocks with those sympatric with coho salmon and sculpins in small streams. Env. Biol. Fish. 20(4):275-284.

Johnston, J. 1982. Life histories of anadromous cutthroat with emphasis on migratory behavior. *In* E. L. Brannon and E. O. Salo (editors), Salmon and trout migratory behavior symposium, p. 123-127. School Fish., Univ. Wash., Seattle, WA.

Jones, D. E. 1977. Life history of steelhead trout and life history of sea-run cutthroat trout. Alaska Dept. Fish Game, Compl. Rep. AFS-42, 18:52-105.

Levy, D. A., and C. D. Levings. 1978. A description of the fish community of the Squamish River estuary, British Columbia: relative abundance, seasonal changes and feeding habits of salmonids. Can. Fish. Mar. Serv. Manuscr. Rep. 1475, 63 p.

Loch, J. J. 1982. Juvenile and adult steelhead and sea-run cutthroat trout within the Columbia River estuary 1980. 1982 Ann. Rep., Wash. Dept. Game, Olympia, WA, 47 p. plus appendices.

Loch, J. J., and D. R. Miller. 1988. Distribution and diet of sea-run cutthroat trout captured in and adjacent to the Columbia River plume, May-July 1980. Northw. Sci. 62(1):41-48.

Lowry, G. R. 1965. Movement of cutthroat trout, *Salmo clarki clarki* (Richardson) in three Oregon coastal streams. Trans. Am. Fish. Soc. 94(4):334-338.

Lowry, G. R. 1966. Production and food of cutthroat trout in three Oregon coastal streams. J. Wildl. Manag. 30(4):754-767.

Michael, J. H., Jr. 1989. Life history of anadromous coastal cutthroat trout in Snow and Salmon Creeks, Jefferson County, Washington, with implications for management. Calif. Fish Game 75(4):188-203.

Monaco, M. E., R. L. Emmett, S. A. Hinton, and D. M. Nelson. 1990. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume I: data summaries. ELMR Rep. No. 4. Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 240 p.

Moring, J. R., and R. L. Lantz. 1975. Alsea watershed study: effects of logging on the aquatic resources of three headwater streams on the Alsea River, Oregon. Part I—Biological studies. Fish. Res. Rep. No. 9, Oregon Dept. Fish Wildl., Corvallis, OR, 66 p.

Pauley, G. B., K. Oshima, K. L. Bowers, and G. L. Thomas. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest)—sea-run cutthroat trout. U.S. Fish Wild. Serv. Biol. Rep. 82(11.86), U.S. Army Corps Eng. TR EL-82-4, 21 p.

Reiser, D. W., and T. C. Bjornn. 1979. 1. Habitat requirements of anadromous salmonids. *In* W. R. Meehan (editor), Influence of forest and rangeland management on anadromous fish habitat in the western United States and Canada, p. 1-54. USDA Forest Service, Gen. Tech. Rep. PNW-96, Pac. Northw. Forest Range Exp. Sta., Portland, OR.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can., Bull. No. 84, 966 p.

Smith, G. R., and R. F. Stearley. 1989. The classification and scientific names of rainbow and cutthroat trouts. Fisheries 14(1):4-10.

Summer, F. H. 1962. Migration and growth of coastal cutthroat trout in Tillamook County, Oregon. Trans. Am. Fish. Soc. 91:71-83.

Tipping, J. 1982. Cowlitz River sea-run cutthroat 1979-1981. Wash. Dept. Game, Olympia, WA, 24 p.

Tipping, J. 1986. Effect of release size on return rates of hatchery sea-run cutthroat trout. Prog. Fish-Cult. 48:195-197.

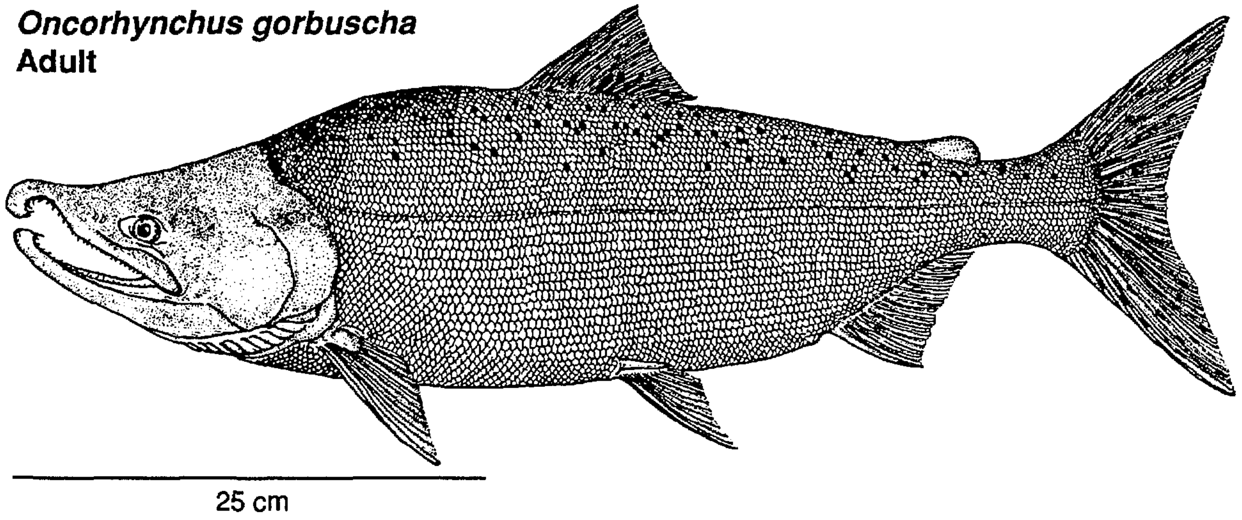
Tipping, J. 1988. Ozone control of ceratomyxosis: survival and growth benefits to steelhead and cutthroat trout. Prog. Fish-Cult. 50:202-210.

Trotter. P. C. 1987. Cutthroat: native trout of the west. Colorado Assoc. Univ. Press., Boulder, CO, 219 p.

Washington, P. 1977. The sea-run cutthroat trout resource and sport fishery. Mar. Fish. Rev. 39(12):20-22.

Wydoski, R. S., and R. R. Whitney. 1979. Inland fishes of Washington, Univ. Wash. Press, Seattle, WA, 220 p.

Pink salmon



Common Name: pink salmon
Scientific Name: *Oncorhynchus gorbuscha*
Other Common Names: humpy salmon, dog salmon, hone salmon, humpback salmon, lost salmon (Shiino 1976, Alaska Department of Fish and Game 1985)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Salmoniformes
Family: Salmonidae

Value

Commercial: The pink salmon is the smallest Pacific salmon and fishermen receive the lowest price/lb for it. However, it is the most abundant salmon species in the North Pacific. Annual harvest is over 84 million fish, with over 95% of the U.S. catch coming from Puget Sound, Washington, through Alaska (Forrester 1981a,1981b, Takehama 1983). In 1985, landings of pink salmon (144.7 t) were worth $75 million to U.S. fishermen. (National Marine Fisheries Service 1986). Since virtually all pink salmon mature in their second year, commercial catches in a particular area fluctuate markedly from one year to the next. In Puget Sound, odd-year runs predominate, but in the Gulf of Alaska and Bristol Bay, even-year runs are largest (Fredin et al. 1977). Most Puget Sound pink salmon are captured from July to September (Washington Department of Fisheries and Northwest Indian Fisheries Commission 1986). This species is harvested primarily by purse seines, but also by trolling, stationary and drift gill nets, and reef nets.

Recreational: The pink salmon is not as important as coho (*O. kisutch*) and chinook salmon (*O. tshawytscha*) to coastal sport fisheries. Most sport harvests of pink salmon occur in Alaska, although in odd years they are caught in Oregon and Washington (21,000 in 1983) (Pacific Marine Fisheries Commission 1985,1987). This species is primarily captured when fishing for other salmon species, although it is regionally abundant at times. The pink salmon is caught by trolling in nearshore marine waters and by spincasting in streams and along beaches (Squire and Smith 1977).

Indicator of Environmental Stress: As with other salmonids, destruction of spawning habitat reduces run sizes.

Ecological: The pink salmon is the most abundant epipelagic fish in the subarctic oceanic North Pacific (Fredin et al. 1977). See "Factors Influencing Populations".

Range

Overall: Overall, the pink salmon is found in oceanic and coastal areas of the North Pacific Ocean, north of about 40°N latitude, in the Bering Sea, and along the southern coastline of the Polar Sea (Neave 1962). In North America, occasional runs occur in the Russian River, California, and along the Oregon coast. Regular spawning runs occur from the Puyallup River, Washington, north to central Alaska, west to Attu Island, north to northern Alaska, and east to the Mackenzie River in Canada's Northwest Territories. In Asia, this species is distributed from the Tumen and North Nandai Rivers, North Korea, and Hokkaido, Japan, to the Yana and Lena Rivers that flow into the Arctic Ocean (Takagi et al. 1981). The pink salmon has also been successfully introduced into the Great Lakes (Scott and Crossman 1973).

Table 1. Relative abundance of pink salmon in 32 U.S. Pacific coast estuaries.

	Life Stage				
Estuary	A	S	J	L	E
Puget Sound	●		●		
Hood Canal	●		◉	○	
Skagit Bay	●		●		
Grays Harbor	√				
Willapa Bay					
Columbia River	√				
Nehalem Bay					
Tillamook Bay					
Netarts Bay					
Siletz River					
Yaquina Bay	√				
Alsea River	√				
Siuslaw River					
Umpqua River					
Coos Bay					
Rogue River	√				
Klamath River	√				
Humboldt Bay					
Eel River					
Tomales Bay	√				
Cent. San Fran. Bay *					
South San Fran. Bay					
Elkhorn Slough					
Morro Bay					
Santa Monica Bay					
San Pedro Bay					
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

Within Study Area: Although there are reports of pink salmon occurring in many California rivers (Hallock and Fry 1967), probably only the Russian River and possibly the Sacramento River have any spawning runs (Fry 1973). Only very limited spawning runs occur along the Oregon and Washington coasts, but strong spawning runs occur in Puget Sound (Atkinson et al. 1967) (Table 1).

Life Mode

The pink salmon is an anadromous species. Eggs and larvae (alevins) are benthic and infaunal. Young juveniles (fry) are benthopelagic and live in shallow waters. Ocean-dwelling and maturing juveniles (subadults) and adults are epipelagic, occurring possibly down to depths of 36 m, but usually within the top 10 m (Hart 1973, Scott and Crossman 1973, Wydoski and Whitney 1979, Takagi et al. 1981).

Habitat

Type: Eggs and alevins occur primarily in the lower reaches of rivers, but can also occur in intertidal estuarine areas (Helle et al. 1964, McNeil 1966). Fry are riverine initially, but soon move downstream and utilize estuaries and nearshore shallow water marine environments (Healey 1980, 1982, Simenstad et al. 1982). Juveniles are initially neritic, but become oceanic as they mature. Adults are primarily estuarine and riverine.

Substrate: Eggs and alevins are normally found in gravel that is 1.3-10.2 cm in diameter (Reiser and Bjornn 1979). Gravel cover protects eggs and alevins from predation, mechanical injury, and ultraviolet light (Raleigh and Nelson 1985). Fry, juveniles, and adults are found in the water column over various substrates.

Physical/Chemical Characteristics: Eggs and alevins are found primarily in fresh water, but can withstand constant salinities of 18‰ and brief periods of higher salinities (33‰) (McNeil 1966, Takagi et al. 1981). Fry adapt very quickly to high salinities (Takagi et al. 1981) and the species was originally thought to require marine waters for survival (Baggerman 1960). However, the successful introduction of pink salmon into the Great Lakes demonstrates that this species can complete its entire life cycle in fresh water. The pink salmon generally spawns at temperatures of 7.2-12.8°C, with incubation temperatures of 4.4-13.3°C providing the best hatching (Bell 1984). Optimum temperatures for pink salmon are 5.6-14.4°C, with 0.0°C and 25.6°C being lower and upper lethal limits, respectively (Bell 1984). Low pH impairs embryo and alevin development (Rombough 1983). Embryos and alevins need fast-flowing (21-101 cm/sec) and well-oxygenated (>6 mg/l) water for proper development and survival (Bailey et al. 1980). Spawning gravel must be permeable to water flow for proper egg and alevin development (Wickett 1962, McNeil 1969). Adults cannot migrate upstream in velocities greater than about 2.13 m/sec (Reiser and Bjornn 1979).

Migrations and Movements: The pink salmon is a highly-migratory anadromous species. Downstream movement begins immediately upon emergence from the gravel (Neave 1966), and normally at night (McDonald 1960, Neave 1966). Fry are about 30 mm long at emergence. Peak out-migration from rivers occurs between late March and mid-May in southern British Columbia, Washington, and Oregon (Healey 1982, Simenstad et al. 1982). Most pink salmon spend little time residing in estuaries (Levy et al. 1979, Healey 1982, Simenstad et al. 1982), but move and disperse rapidly into shallow marine waters and nearshore nursery areas (Healey 1980). However, they may be abundant in estuarine tidal channels for a short time (Levy and Northcote 1982). As juveniles grow to about 60-80 mm in length (May and June), they move to offshore waters (Healey 1980), with larger individuals moving first. During their first summer and fall, migrating pink salmon move north in coastal waters. By late fall/ early winter, many turn south, dispersing to the high seas (Takagi et al. 1981, Hartt and Dell 1986). Pink salmon return to their natal streams after about 18 months at sea. Some pink salmon apparently never leave Puget Sound (Wydoski and Whitney 1979). A combined map-compass-calendar system probably guides this species on the high seas, but olfaction dominates riverine orientation as adults return to their natal stream (Brannon 1982, Quinn 1982). Upstream (i.e., spawning) migration may be disrupted if adults encounter hydrocarbon concentrations above 1-10 ppb (Martin et al. 1990).

Reproduction

Mode: The pink salmon is gonochoristic, oviparous, and semelparous (all adults die soon after spawning). Eggs are fertilized externally.

Mating/Spawning: Spawning generally occurs from June (north) to October (south), and primarily August through October in Washington (Atkinson et al. 1967, Wydoski and Whitney 1979). Most spawning takes place in the lower reaches of coastal rivers and can include intertidal areas (Helle et al. 1964). However, pink salmon may spawn far upstream in large rivers such as the Skagit River, Washington (Wydoski and Whitney 1979). Spawning usually occurs in riffle areas ≥15 cm deep, with water velocities of 12-101 cm/s, in gravel that is 1.3-10.2 cm in diameter, and at temperatures of 7.2-12.8°C (Reiser and Bjornn 1979). In Alaska, preferred spawning velocities are 35-47 cm/s (Bonar et al. 1989). Females build the redd (nest) by digging up the substrate with the caudal fin. During spawning, the female and male move to the bottom of the redd and release eggs and sperm while vibrating, gaping their mouths, and erecting their fins. The female will then deposit gravel over the eggs by digging upstream of the redd. Males may spawn with more than one female, and females with more than one male. Females may dig more than one nest (Scott and Crossman 1973). Males develop enlarged teeth, a large hump on their back, a hooked snout, and when mature, are aggressive toward other males (Scott and Crossman 1973).

Fecundity: Fecundity ranges from 800-2,000 eggs per female, averaging 1500-1900 (depending on size of female) (Scott and Crossman 1973).

Growth and Development

Egg Size and Embryonic Development: Eggs are 6.0-7.0 mm and orange-red in color (Scott and Crossman 1973, Bell 1984). Embryonic development is indirect and external. Incubation time is affected by temperature, but hatching occurs primarily in December and January (McPhail and Lindsey 1970, Scott and Crossman 1973).

Age and Size of Larvae: Alevins are 6.0 mm to 30-45 mm in length (Morrow 1980) and remain in the gravel until most of the yolk is absorbed. Peak emergence is in April and May, but may begin as early as late February (Neave 1966).

Juvenile Size Range: Juveniles are approximately 3.0-45.0 cm long and weigh up to 1.8 kg (Bell 1984). Pink salmon move to the open ocean when they are 6.0-8.0 cm long (central British Columbia) or 9.0-10.0 cm long (Strait of Georgia) (Healey 1980).

Age and Size of Adults: Adults are two years old with rare reports of three-year-olds (Scott and Crossman 1973). Adults can reach 76.0 cm in length and weigh 5.5 kg, however most are 1.4-2.3 kg (Hart 1973).

Food and Feeding

Trophic Mode: Larvae feed on their yolk. Juvenile and adult pink salmon are carnivorous, opportunistic feeders.

Food Items: Fry will feed sparingly on nymphal and larval insects if their migration to the ocean is lengthy (Scott and Crossman 1973). In nearshore nursery areas, juvenile pink salmon eat mainly epibenthic prey, particularly harpacticoid copepods (Gerke 1972, Kaczynski et al. 1973, Godin 1981). However, juveniles will also eat pelagic zooplankton such as Cirripedae larvae, calanoid copepods, amphipods, crustacean larvae, and other invertebrate larvae (Kaczynski et al. 1973, Bailey et al. 1975, Fresh et al. 1979, Godin 1981). When juvenile pink salmon first enter offshore habitats, they feed on zooplankton, primarily copepods, amphipods, chaetognaths, larvaceans, decapod larvae, and larval and juvenile fishes (Healey 1980, Brodeur et al. 1987). Later in life, they feed on euphausiids, decapod larvae, fishes, amphipods, squids, copepods, pteropods, and other invertebrates (Allen and Aron 1958, Andrievskaya 1958, Ito 1964, LeBrasseur 1966, Hart 1973, Fresh et al. 1981, Takagi et al. 1981). Pink salmon are usually crepuscular feeders (Godin 1981, Takagi et al. 1981), however, they are known to feed on euphausiids at night (Pearcy et al. 1984).

Biological Interactions

Predation: Eggs, alevins, and fry are eaten by cutthroat trout (*O. clarki*), rainbow trout (*O. mykiss*), coho salmon, Dolly Varden (*Salvelinus malma*), northern squawfish (*Ptychocheilus oregonensis*), and various sculpins (*Cottus* spp.) (Hunter 1959, Scott and Crossman 1973). Belted kingfisher (*Megaceryle alcyon*), mergansers, other predatory birds and small mammals also eat fry (Scott and Crossman 1973). Mammals (e.g., bears) and large avian predators (e.g., bald eagles, *Haliaeetus leucocephalus*) feed on adult pink salmon in fresh water. Marine and estuarine fish predators include lamprey (*Lampetra* spp.), spiny dogfish (*Squalus acanthias*), coho salmon, chinook salmon, rainbow trout, cutthroat trout and Pacific staghorn sculpin (*Leptocottus armatus*). Predatory birds such as common murre (*Uria aalge*), common merganser (*Mergus merganser*), bald eagle, and Caspian tern(*Hydroprogne caspia*), and mammals such as harbor seal (*Phoca vitulina*), northern fur seal (*Callorhinus ursinus*), killer whale (*Orcinus orca*), and sea lions also prey on the pink salmon (Fresh 1984). Small juvenile pink salmon apparently alter their habitat preferences depending on predation risk (Magnhagen 1988).

Factors Influencing Populations: Chum (*O. keta*) and pink salmon have similar feeding habits during their early marine life; thus, competition may be occurring in the shallow marine habitats (Ames 1983, Fresh 1984). A chum escapement variable is used in the Washington Department of Fisheries' model for forecasting pink salmon abundance/returns (Washington Department of Fisheries 1983). One of the primary factors determining recruitment appears to be survival from egg to fry stage (McNeil 1966, 1969, 1980), which is typically around 10% (Merrell 1962, McNeil 1980). Mortality can result from low dissolved oxygen concentrations, high temperatures, high stream discharges, and unsuitable gravel structure (McNeil 1966). Average marine survival from fry to adult is about 4% (McNeil 1980), with much of the mortality believed to occur as a result of predation during early marine residency (Parker 1971). There also appears to be density-dependent marine mortality and growth (Peterman 1980). Suitable coastal water temperatures and salinities are also considered important to juvenile survival (Tabata 1983). Besides natural mortality, there is fishing and incidental fishing mortality (Ricker 1976). Although the U.S. harvest of pink salmon has declined since the 1930s, the Canadian harvest has not (Fredin 1980). Some pink salmon originating from North America are taken by the Japanese salmon fishery (Fredin et al. 1977). Man-made alterations to streams, estuaries, and shallow marine environments caused by improper road and rail construction, logging practices, dredging, bulkheading, dam and irrigation development, and pollution can adversely affect pink salmon populations. Hatcheries have been built to help maintain and rehabilitate pink salmon stocks and millions of pink salmon are released annually (Wahle and Smith 1979). However, increased fishing pressure due to hatchery runs can destroy wild populations (McNeil 1980).

References

Alaska Department of Fish and Game. 1985. Alaska habitat management guide. Southcentral Region, Vol. I: Life histories and habitat requirements of fish and wildlife. Alaska Dept. Fish Game, Juneau, AK, 429 p.

Allen, G. H., and W. Aron. 1958. Food of salmonid fishes of the western North Pacific Ocean. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 237, 11 p.

Ames, J. 1983. Salmon stock interactions in Puget Sound: a preliminary look. *In* M. A. Miller (editor), Southeast Alaska coho salmon research and management review and planning workshop, May 18-19, 1982, p. 84-95. Alaska Dept. Fish Game, Juneau, AK.

Andrievskaya, L. D. 1958. Pitanie tikhookeanskikh lososei v severo-zapadnoi chasti tikhovo okeana (The food of Pacific salmon in the northwestern Pacific Ocean). [In Russ.] From: Materialy po biologii morskovo perioda zhizni dalnevostochnykh lososei, p. 64-75. Publ. by: Vses Nauchno-Issled. Inst. Morsk. Rybn. Khoz. Okeanogr. (VNIRO), Moscow. [Fish. Res. Board Can., Trans. Ser. No. 182.]

Atkinson, C. E., J. H. Rose, and T. O. Duncan. 1967. Pacific salmon in the United States. Internat. North Pac. Fish. Comm., Bull. No. 23:43-223.

Baggerman, B. 1960. Salinity preference, thyroid activity and seaward migration of four species of Pacific salmon (*Oncorhynchus*). J. Fish. Res. Board Can. 17(3):295-322.

Bailey, J. E., B. L. Wing, and C. R. Mattson. 1975. Zooplankton abundance and feeding habits of fry of pink salmon, *Oncorhynchus gorbuscha*, and chum salmon, *Oncorhynchus keta* in Traitor's Cove, Alaska, with speculations on the carrying capacity of the area. Fish. Bull., U.S. 73:846-861.

Bailey, J. E., S. Rice, J. Pella, and S. Taylor. 1980. Effects of seeding density of pink salmon, *Oncorhynchus gorbuscha*, eggs on water chemistry, fry characteristics and fry survival in gravel incubators. Fish. Bull., U.S. 78(3):649-658.

Bell, M. C. 1984. Fisheries handbook of engineering requirements and biological criteria. Fish passage development and evaluation program, U. S. Army Corps Eng., North Pac. Div., Portland, OR, 290 p. (Contract No. DACW57-79-M-1594 AND DACW57-80-M-0567).

Bonar, S. A., G. B. Pauley, and G. L. Thomas. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest)—pink salmon. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.88). U.S. Army Corps Eng., TR EL-82-4, 18 p.

Brannon, E. L. 1982. Orientation mechanisms of homing salmonids. *In* E. L. Brannon and E. O. Salo (editors), Proceedings of the salmon and trout migratory behavior symposium, p. 219-227. School Fish., Univ. Wash., Seattle, WA.

Brodeur, R. D., H. V. Lorz, and W. G. Pearcy. 1987. Food habits and diet variations of pelagic nekton off Oregon and Washington, 1979-1984. U.S. Dept. Comm., NOAA, Tech. Rep. NMFS 57, 32 p.

Forrester, C. R. (compiler). 1981a. Statistical yearbook 1977. Internat. North Pac. Fish. Comm., Vancouver, B.C., Canada, 96 p.

Forrester, C. R. (compiler). 1981b. Statistical yearbook 1978. Internat. North Pac. Fish. Comm., Vancouver, B.C., Canada, 113 p.

Fredin, R. A. 1980. Trends in North Pacific salmon fisheries. *In* W. J. McNeil and D. C. Himsworth (editors), Salmonid ecosystems of the North Pacific, p. 59-119, Oregon State Univ. Press, Corvallis, OR.

Fredin, R. A., R. L. Major, R. G. Bakkala, and G. K. Tanonaka. 1977. Pacific salmon and the high seas salmon fisheries of Japan. NWAFC Proc. Rep., 324 p. Northwest and Alaska Fish. Cent., Nat. Mar. Fish. Serv., NOAA, Seattle, WA.

Fresh, K. L. 1984. Evaluation of potential species interaction effects in the planning and selection of salmonid enhancement projects. Report prepared by the species interaction workgroup of the enhancement planning team. NOAA, Nat. Mar. Fish. Serv., Seattle, WA, 80 p.

Fresh, K. L., R. D. Cardwell, and R. R. Koons. 1981. Food habits of Pacific salmon, baitfish, and their potential competitors and predators in marine waters of Washington, August 1978 to September 1979. Prog. Rep. No. 145, Wash. Dept. Fish., Olympia, WA, 58 p.

Fresh, K. L., D. Rabin, C. Simenstad, E. O. Salo, K. Garrison, and L. Matheson. 1979. Fish ecology studies in the Nisqually Reach area of southern Puget Sound, Washington. Fish. Res. Inst., Coll. Fish., Univ. Wash., Seattle, WA, 229 p.

Fry, D. H., Jr. 1973. Anadromous fishes of California. Calif. Dept. Fish. Game, Sacramento, CA, 112 p.

Gerke, R. J. 1972. Food of juvenile pink and chum salmon in Puget Sound, Washington. Tech. Rep. No. 10, Wash. Dept. Fish., Olympia, WA, 7 p.

Godin, J.-G. J. 1981. Daily patterns of feeding behavior, daily rations, and diets of juvenile pink salmon (*Oncorhynchus gorbuscha*) in two marine bays of British Columbia. Can. J. Fish. Aquat. Sci. 38:10-15.

Hallock, R. J., and D. H. Fry. 1967. Five species of salmon, *Oncorhynchus*, in the Sacramento River, California. Calif. Fish Game 53(1):5-22.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. No. 180, 740 p.

Hartt, A. C., and M. B. Dell. 1986. Early oceanic migrations and growth of juvenile Pacific salmon and steelhead trout. Internat. North Pac. Fish. Comm., Bull. No. 46:1-105.

Healey, M. C. 1980. The ecology of juvenile salmon in Georgia Strait, British Columbia. *In* W. J. McNeil and D. C. Himsworth (editors), Salmonid ecosystems of the North Pacific, p. 203-229, Oregon State Univ. Press, Corvallis, OR.

Healey, M. C. 1982. Juvenile Pacific salmon in estuaries: the life support system. *In* V. S. Kennedy (editor), Estuarine comparisons, p. 315-341, Academic Press, New York, NY.

Helle, J. H., R. S. Williamson, and J. E. Bailey. 1964. Intertidal ecology and life history of pink salmon at Olsen Creek, Prince William Sound, Alaska. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. No. 483, 26 p.

Hunter, J. G. 1959. Survival and production of pink and chum salmon in a coastal stream. J. Fish. Res. Board Can. 16(6):835-886.

Ito, J. 1964. Food and feeding habits of Pacific salmon (genus *Oncorhynchus*) in their oceanic life. Bull. Hokkaido Reg. Fish. Lab. 29:85-97. (Fish. Res. Board Can., Trans. Ser. No. 1309).

Kaczynski, V. W., R. J. Feller, J. Clayton, and R. J. Gerke. 1973. Trophic analysis of juvenile pink and chum salmon (*Oncorhynchus gorbuscha* and *O. keta*) in Puget Sound. J. Fish. Res. Board Can. 30:1003-1008.

LeBrasseur, R. J. 1966. Stomach contents of salmon and steelhead trout in the northeastern Pacific Ocean. J. Fish. Res. Board Can. 23(1):85-100.

Levy, D. A., and T. G. Northcote. 1982. Juvenile salmon residency in a marsh area of the Fraser River estuary. Can. J. Fish. Aquat. Sci. 39:270-276.

Levy, D. A., T. G. Northcote, and G. J. Birch. 1979. Juvenile salmon utilization of tidal channels in the Fraser River estuary, British Columbia. Tech. Rep. 23, Westwater Res. Cent., Univ. British Columbia, Vancouver, B.C., Canada, 70 p.

Magnhagen, C. 1988. Predation risk and foraging in juvenile pink (*Oncorhynchus gorbuscha*) and chum salmon (*O. keta*). Can. J. Fish. Aquat. Sci. 45(4):592-596.

Martin, D. J., C. J. Whitmus, L. A. Brocklehurst, A. E. Nevissi, J. M Cox, and K. Kurrus. 1990. Effects of petroleum contaminated waterways on migratory behavior of adult pink salmon. Outer Contin. Shelf Envir. Asses. Prog., Final Rep. Principal Invest. 66:281-529

McDonald, J. 1960. The behavior of Pacific salmon fry during their downstream migration to freshwater and saltwater nursery areas. J. Fish. Res. Board Can. 17(5):655-676.

McNeil, M. J. 1966. Effect of the spawning bed environment on reproduction of pink and chum salmon. Fish. Bull., U.S. 65(2):495-523.

McNeil, M. J. 1969. Survival of pink and chum salmon eggs and alevins. *In* T. G. Northcote (editor), Symposium on salmon and trout in streams. H. R. MacMillan lectures in fisheries, p. 101-117. Univ. British Columbia, Vancouver, B.C., Canada.

McNeil, M. J. 1980. Vulnerability of pink salmon populations to natural and fishing mortality. *In* W. J. McNeil and D. C. Himsworth (editors), Salmonid ecosystems of the North Pacific, p. 147-151. Oregon State Univ. Press, Corvallis, OR.

McPhail, J. D., and C. C. Lindsey. 1970. Freshwater fishes of northwestern Canada and Alaska. Fish. Res. Board Can., Bull. No. 73. 381 p.

Merrell, T. R., Jr. 1962. Freshwater survival of pink salmon at Sashin Creek, Alaska. *In* N. J. Wilimovsky (editor), Symposium on pink salmon. H. R. MacMillan lectures in fisheries, p. 59-72. Univ. British Columbia, Vancouver, B.C., Canada.

Morrow, J. E. 1980. The freshwater fishes of Alaska. Alaska Northw. Publ. Co., Anchorage, AK, 248 p.

National Marine Fisheries Service. 1986. Fisheries of the United States, 1985. Current Fishery Statistics No. 8368. U.S. Dept. Comm., NOAA, Nat. Mar. Fish Serv., Nat. Fish. Stat. Prog., Washington, D.C., 122 p.

Neave, F. 1962. The observed fluctuations of pink salmon in British Columbia. *In* N. J. Wilimovsky (editor), Symposium on pink salmon. H. R. MacMillan lectures in fisheries, p. 3-14. Univ. British Columbia, Vancouver, B.C., Canada.

Neave, F. 1966. Pink salmon in British Columbia. Internat. North Pac. Fish. Comm., Bull. No. 18:71-79.

Pacific Marine Fisheries Commission. 1985. 37th annual report of the Pacific Marine Fisheries Commission - for the year 1984. Pac. Mar. Fish. Comm., Portland, OR, 35 p.

Pacific Marine Fisheries Commission. 1987 39th annual report of the Pacific Marine Fisheries Commission - for the year 1986. Pac. Mar. Fish. Comm., Portland, OR, 29 p.

Parker, R. R. 1971. Size selective predation among juvenile salmonid fishes in a British Columbia inlet. J. Fish. Res. Board Can. 28:1503-1510.

Pearcy, W., T. Nishiyama, T. Fujii, and K. Masuda. 1984. Diel variations in the feeding habits of Pacific salmon caught in gill nets during a 24-hour period in the Gulf of Alaska. Fish. Bull., U.S. 82(2):391-399.

Peterman, R. M. 1980. Testing for density-dependent marine survival in Pacific salmonids. *In* W. J. McNeil and D. C. Himsworth (editors), Salmonid ecosystems of the North Pacific, p. 1-24. Oregon State Univ. Press, Corvallis, OR.

Quinn, T. P. 1982. A model for salmon navigation on the high seas. *In* E. L. Brannon and E. O. Salo (editors), Proceedings of the salmon and trout migratory behavior symposium, p. 229-237. School Fish., Univ. Wash., Seattle, WA.

Raleigh, R. F., and P. C. Nelson. 1985. Habitat suitability index models and instream flow suitability curves: Pink salmon. U.S. Fish Wildl. Serv. Biol. Rep. 82(10.109), 36 p.

Reiser, D. W., and T. C. Bjornn. 1979. 1. Habitat requirements of anadromous salmonids. *In* W. R. Meehan (editor), Influence of forest and rangeland management on anadromous fish habitat in the western United States and Canada, p. 1-54. USDA Forest Service, Gen. Tech. Rep. PNW-96, Pacific Northw. Forest Range Exp. Sta., Portland, OR.

Ricker, W. E. 1976. Review of the rate of growth and mortality of Pacific salmon in salt water, and noncatch mortality caused by fishing. J. Fish. Res. Board Can. 33:1483-1524.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD.

Rombough, R. J. 1983. Effects of low pH on eyed embryos and alevins of Pacific salmon. Can. J. Fish. Aquat. Sci. 40:1575-1582.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can., Bull. No. 184, 966 p.

Shiino, S. 1976. List of common names of fishes of the world, those prevailing among English-speaking nations. Sci. Rep. Shima Marineland No. 4, Kashikojima, Shima, Mie, Japan, 262 p.

Simenstad, C. A., K. L. Fresh, and E. O. Salo. 1982. The role of Puget Sound and Washington coastal estuaries in the life history of Pacific salmon: an unappreciated function. *In* V. S. Kennedy (editor), Estuarine comparisons, p. 343-364. Academic Press, New York, NY.

Squire, J. L., Jr., and S. E. Smith. 1977. Anglers' guide to the United States Pacific coast - marine fish, fishing grounds & facilities. Nat. Mar. Fish. Serv., NOAA, Seattle, WA, 139 p.

Tabata, S. 1983. Oceanographic factors influencing the distribution, migration and survival of salmonids in the northeast Pacific Ocean—a review. *In* W. J. McNeil and D. C. Himsworth (editors), Salmonid ecosystems of the North Pacific, p. 128-160. Oregon State Univ. Press, Corvallis, OR.

Takagi, K., K. V. Aro, A. C. Hartt, and M. B. Dell. 1981. Distribution and origin of pink salmon (*Oncorhynchus gorbuscha*) in offshore waters of the North Pacific Ocean. Internat. North Pac. Fish. Comm., Bull. No. 40, 195 p.

Takehama, S. (compiler). 1983. Statistical yearbook 1980. Internat. North Pac. Fish. Comm., Vancouver, B.C., Canada, 115 p.

Wahle, R. J., and R. Z. Smith. 1979. A historical and descriptive account of Pacific coast anadromous salmonid rearing facilities and summary of their releases by region, 1960-76. U.S. Dept. Comm., NOAA Tech. Rep. NMFS, Spec. Sci. Rep. Fish. No. 736, 35 p.

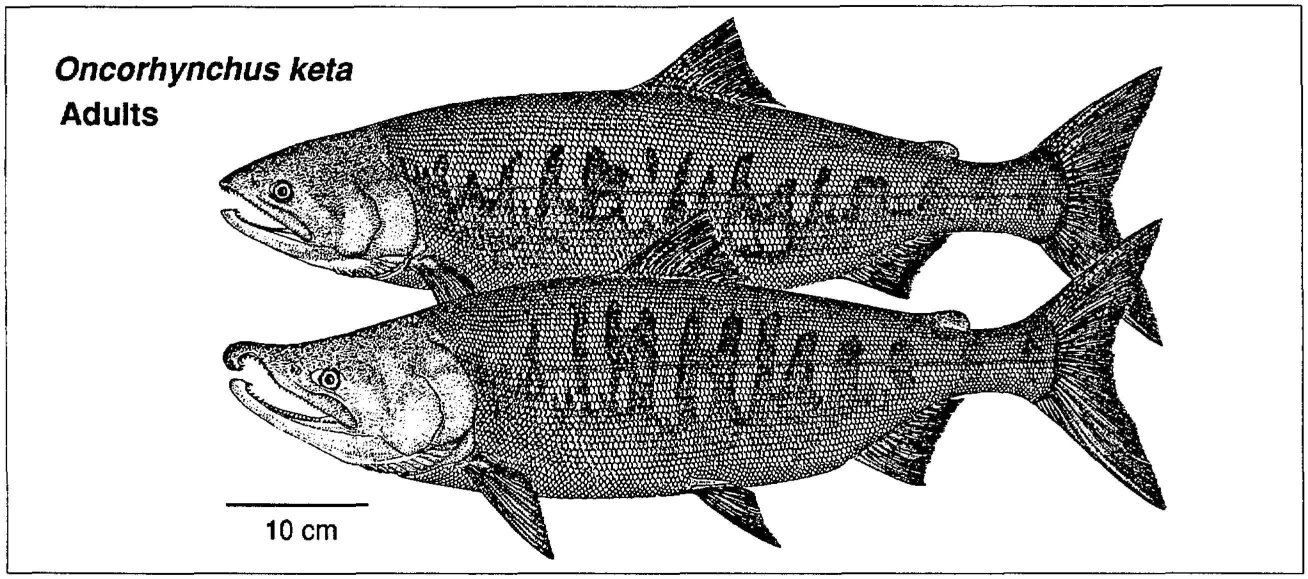
Washington Department of Fisheries. 1983. Prog. Rep. No. 184, Wash. Dept. Fish., Olympia, WA, 28 p.

Washington Department of Fisheries and Northwest Indian Fisheries Commission 1986. Puget Sound salmon management periods and their derivations. Wash. Dept. Fish, Olympia, WA, 6 p.

Wickett, W. P. 1962. Environmental variability and reproduction potentials of pink salmon in British Columbia. *In* N. J. Wilimovsky (editor.), Symposium on pink salmon. H. R. MacMillan lectures in fisheries, p. 73-86. Univ. British Columbia, Vancouver, B.C., Canada.

Wydoski, R. S., and R. R.Whitney. 1979. Inland fishes of Washington, Univ. Wash. Press, Seattle, WA, 220 p.

Chum salmon



Common Name: chum salmon
Scientific Name: *Oncorhynchus keta*
Other Common Names: dog salmon, calico salmon, chub, fall salmon, keta salmon, le kai salmon (Shiino 1976)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Salmoniformes
Family: Salmonidae

Value

Commercial: The chum salmon is the most important Pacific salmon to Japanese commercial fishermen (Forrester 1981), but third in importance to U.S. fishermen (National Marine Fisheries Service 1986). From 1980-84, nearly 43,000 t were landed by U.S. fishermen and the 1985 catch was worth over $36 million. This species is commercially fished in North American waters from Oregon to Alaska. However, most (75%) are landed in Alaskan waters, with only Puget Sound, Washington, producing any sizable landings outside of Alaska (Forrester 1981). The chum salmon is captured primarily by fixed or drift gill nets and purse seines. It is primarily caught from June to September in Alaska, and September to December in Washington (Forrester 1981).

Recreational: The chum salmon is not a target sport fish in marine waters (Scott and Crossman 1973), but it is sometimes fished in rivers that have large runs. The marine sport catch is low and is grouped with sockeye salmon in the reported marine sport catches (Pacific Marine Fisheries Commission 1985, 1986). This species does not strike lures or baits as readily as other salmonids and its flesh does not have the desired oil content of other salmon species.

Indicator of Environmental Stress: The freshwater, estuarine, and early marine life stages are the most sensitive to habitat alterations and pollution (Shepard 1981).

Ecological: The chum salmon is the second most abundant salmonid in the North Pacific region (Forrester 1981), and has the widest distribution of any Pacific salmon (Bakkala 1970).

Range

Overall: In North America, the chum salmon inhabits coastal streams from the Sacramento River, California [occasionally as far south as the San Lorenzo River (Moyle 1976)], northward to the Arctic shore of Alaska (Aro and Shepard 1967, Atkinson et al. 1967, Hallock and Fry 1967). It is found as far east as the Mackenzie River in Canada. In Asia, the chum salmon is found south to the Tone River of Chiba Prefecture on the Pacific side of Honshu, in Nagasaki Prefecture of Kyushu in the Sea of Japan, and in the Nakdong River of the Republic of Korea (Sano 1967, Bakkala 1970). In Asia most spawning occurs in the lower 100 km of coastal streams. However, some spawn 2,500 km from the sea in both the Amur River of the U.S.S.R. and the Yukon River of Alaska and Canada (Sano 1966, Bakkala 1970). This species' oceanic distribution ranges from the Bering Sea to about lat. 40°N in the western Pacific Ocean and approximately lat. 44°N in the eastern Pacific Ocean (Neave et al. 1976, Fredin et al. 1977).

Within Study Area: The chum salmon is primarily found in Oregon and Washington, north of the Rogue River,

Table 1. Relative abundance of chum salmon in 32 U.S. Pacific coast estuaries.

	Life Stage				
Estuary	A	S	J	L	E
Puget Sound	●		●		
Hood Canal	●		●		
Skagit Bay	●		●		
Grays Harbor	◉		◉		
Willapa Bay	●		●		
Columbia River	○		○		
Nehalem Bay	○		○		
Tillamook Bay	◉		◉		
Netarts Bay	◉		●		
Siletz River	○		○		
Yaquina Bay	○		○		
Alsea River	○		○		
Siuslaw River	○		○		
Umpqua River	√				
Coos Bay	○		○		
Rogue River	√				
Klamath River	√		√		
Humboldt Bay	√				
Eel River	√				
Tomales Bay					
Cent. San Fran. Bay *					
South San Fran. Bay					
Elkhorn Slough					
Morro Bay					
Santa Monica Bay					
San Pedro Bay					
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

Oregon (Table 1) (Atkinson et al. 1967, Ratti 1979). Occasionally some are found in the Sacramento River, California (Hallock and Fry 1967). In the ocean, this species can occasionally be found as far south as San Diego, California (Eschmeyer et al. 1983).

Life Mode

The chum salmon is an anadromous species. Eggs and larvae (alevins) are benthic and infaunal. Young juveniles (fry) are benthopelagic, while ocean-dwelling and maturing juveniles (subadults) and adults are epipelagic (Sano 1966, Bakkala 1970, Fredin et al. 1977). Subadults and adults in rivers and streams are bottom-oriented.

Habitat

Type: Eggs and alevins occur in rivers and streams, from intertidal areas to 2,500 km upriver in large river systems (Bakkala 1970), but they are normally found in riverine areas less than 200 km from the ocean (Sano 1966). Fry are found in rivers, estuaries, and marine waters. Fry prefer shallow waters (nearshore and intertidal areas <1.0 m deep) during their initial outmigration (Bakkala 1970, Healey 1980). Once at sea juveniles are primarily epipelagic (surface to 60 m depth) (Manzer 1964), but may be found to depths of 95 m (LeBrasseur and Barner 1964). Adults are estuarine and riverine (Bakkala 1970, Fredin et al. 1977).

Substrate: Eggs and alevins are found primarily in medium-sized gravel (about 2-4 cm in diameter) (Bakkala 1970, Alaska Department of Fish and Game 1985) and are buried down to 40 cm (Moyle 1976). Recommended spawning gravel diameters range from 1.3-10.2 cm (Reiser and Bjornn 1979). Burner (1951) found Columbia River redds were composed of 81% medium and small gravel (< 15 cm diameter), 13% large gravel (> 15 cm) and 6% mud-silt-sand. Juveniles and adults occur over a variety of substrates.

Physical/Chemical Characteristics: Best spawning temperatures range from 7.2-12.8°C, and incubation temperatures range from 4.4-13.3°C (Bell 1984). Eggs can survive lower temperatures provided initial development has progressed to a stage that is cold-water tolerant (Reiser and Bjornn 1979). Incubation temperatures affect alevin length at hatching (Beacham and Murray 1987). Optimum temperatures for fry to outmigrate from rivers range from 6.7-13.3°C (Bell 1984). Ocean-dwelling juveniles occur in waters of 1.0-15.0°C, but prefer 2.0-11.0°C. During the spawning migration, adults migrate upstream at temperatures from just above freezing to 21.1°C, but optimum temperatures are 8.3-15.6°C. The upper lethal temperature is 25.6°C, and the lower lethal temperature is 0.0°C (Bell 1984). Adults migrate upstream in velocities up to 2.44 m/sec and successfully spawn in velocities of 46-101 cm/sec (Reiser and Bjornn 1979). Dissolved oxygen levels below saturation can adversely affect swimming performance of adults. Oxygen levels above 80% saturation with temporary levels no lower than 5.0 mg/l are recommended for spawning (Reiser and Bjornn 1979). High concentrations of suspended sediments (15.8-54.9 g/l) can kill juvenile chum salmon (Hale et al. 1985). Eggs and alevins are found primarily in fresh water, but can tolerate euhaline conditions for short periods (McNeil 1966). Fry show a preference for salt water soon after their yolk sac is absorbed and cannot live for extended periods in fresh water (Baggerman 1960, Iwata et al. 1986). A limited residence in a mesohaline (10-15‰) estuarine environment may be needed for complete adaptation to sea water (Iwata and Komatsu 1984). Alevins with completely-absorbed yolk sacs show abnormal behavior in waters with a pH $\leq$6.0 (Rombough 1983).

Migrations and Movements: The chum salmon is highly migratory. Fry migrate seaward immediately after emerging from the redd, although some may reside in fresh water for several months (Simenstad et al. 1982). They migrate primarily at night in small rivers and sometimes during daylight in larger rivers (Bakkala 1970). Juveniles are typically 30-55 cm long when they enter estuaries (March to mid-May), however some may be larger if the migration is long (Moyle 1976). Once juveniles enter estuaries, their migration typically slows and many will rear for up to several months in the estuary (Healey 1982, Levy and Northcote 1982, Simenstad et al. 1982). Increasing salinities prompt schooling behavior (Shelboun 1966). Juveniles occur in Washington estuaries from January to July, peaking from late March to mid-May. Most chum salmon leave Oregon estuaries by mid-May (Myers 1980). Chum salmon juveniles move in and out of tidal creeks, sloughs, marsh habitats, and intertidal areas as the tide fluctuates (Mason 1974, Healey 1982). Besides this daily tidal movement, there is a general movement seaward as the juveniles grow (Healey 1982). Individuals may spend 4-32 days in estuaries; residency varies seasonally. In some stocks, early migrants may reside longer than later migrants while in other stocks, the opposite is true (Healey 1979, Simenstad et al. 1982, Kaeriyama 1986). Most chum salmon move offshore from April to June when they are 80-100 mm in fork length (Healey 1982). Once in the ocean, migrating chum salmon head north, but stay along the continental shelf until fall, when they disperse out into the Gulf of Alaska (Hartt and Dell 1986) and mix with other salmon species and other age groups of chum salmon. Some chum salmon do not appear to migrate out of Puget Sound (Hartt and Dell 1986). Immature fish move about 28 km/day, while maturing fish average 35 km/day (Neave et al. 1976). Immature fish are temperature sensitive and move south in winter and north in summer (Neave et al. 1976).

Reproduction

Mode: The chum salmon is gonochoristic, oviparous, and semelparous (all adults die soon after spawning) (Bakkala 1970). Eggs are fertilized externally.

Mating/Spawning: Two spawning populations exist; a northern stock that spawns from June to September, and a southern (late-run) stock that spawns from August to January (Sano 1966, Bakkala 1970). Washington, Oregon, and California stocks are all late-run fish. Chum salmon are sexually dimorphic when mature; males have a hooked snout, a slight hump, and more fang-like teeth, than females (Bakkala 1970). As with other salmonids, the female builds the nest by turning on her side and excavating the nest by fanning the streambed with her caudal fin (Bakkala 1970). During spawning, the male and female will settle into the nest and quiver with mouths agape as they release eggs and milt (Scott and Crossman 1973). After laying the eggs, the female covers them by digging upstream. This process continues until the female is spent. Males may spawn with more than one female; both sexes are aggressive on the spawning grounds. An average redd is 2.8 m^2 (Reiser and Bjornn 1979). A female will guard her redd as long as she is able before dying. Some adults may spend less than a week in fresh water if they arrive sexually mature (Scott and Crossman 1973).

Fecundity: Large females can release over 4,000 eggs, but on average 2,400-3,000 eggs are laid per female (Scott and Crossman 1973). Late-run southern stocks are more fecund than early-run stocks (Sano 1966, Bakkala 1970). This may be a function of different body sizes between the stocks.

Growth and Development

Egg Size and Embryonic Development: Eggs are reported to be 6.0-9.5 mm in diameter after fertilization (Bakkala 1970, Bell 1984). Embryonic development is indirect and external. Eggs require from 0.5 to 4.5 months to hatch (depending on temperature). Hatching usually occurs from December to February (McPhail and Lindsey 1970, Scott and Crossman 1973, Pauley et al. 1988).

Age and Size of Larvae: Alevins absorb their yolk-sac in 30-50 days, depending on temperatures (Wydoski and Whitney 1979). Alevins are 20.0-24.0 mm long at hatching (Bakkala 1970, Kaeriyama 1986, Beacham and Murray 1987) and grow to 30.0-35.0 mm before leaving the gravel (Moyle 1976, Wydoski and Whitney 1979).

Juvenile Size Range: Fry in fresh water are 30.0-70.0 mm long, depending on the distance between the estuary and spawning grounds (Scott and Crossman 1973). Growth in estuaries and the ocean is rapid; by the end of their first year at sea juveniles will average over 30.0 cm in length and after five years will be 50.0 cm long (Fredin et al. 1977).

Age and Size of Adults: Adults return to spawn at 2-7 years of age (primarily 3-5 years) (Scott and Crossman 1973). Bell (1984) determined that chum salmon average 63.5 cm in length and 4.0 kg at maturity, but Squire and Smith (1977) reported that they can grow up to 107 cm in length and their average weight is 4.5-5.3 kg at maturity.

Food and Feeding

Trophic Mode: Larvae feed on their yolk. Juveniles and adults are carnivores and "opportunistic" feeders.

Food Items: Fry may not feed in fresh water if their migration to estuaries is short. However, if freshwater residency is lengthy, fry will feed on aquatic and terrestrial insects and small crustaceans. Chironomid larvae appear to be particularly important to fry in fresh water (Sano 1966, Bakkala 1970, Scott and Crossman 1973). Feeding in nearshore marine areas and estuaries by fry and fingerlings appears to be an important component of chum salmon life history (Healey 1980, Simenstad 1983). Initially juveniles feed in shallow waters and concentrate on epibenthic prey such as harpacticoid copepods and gammarid amphipods, but they may also eat terrestrial insects and other small crustacea (Sibert et al. 1977, Healey 1979, Simenstad and Salo 1982, Kaeriyama 1986). Young chum salmon are size-selective feeders (Feller and Kaczynski 1975). Food limitation in shallow waters may induce movement to deeper waters (Healey 1980, Simenstad and Salo 1982) where juvenile chum salmon shift their diets to include more pelagic prey, such as calanoid copepods, hyperiid amphipods, crustacean larvae, and larvaceans (Fresh et al. 1981, Simenstad and Salo 1982, Kaeriyama 1986). In the ocean, juveniles and subadults feed on euphausiids, squids, pteropods, and fishes (Andrievskaya 1957, Allen and Aron 1958, LeBrasseur 1966, Peterson et al. 1982, Pearcy et al. 1984).

Biological Interactions

Predation: In freshwaterand estuarine environments, this species' primary predators are probably other salmonids. Chum salmon fry are reportedly eaten by juvenile coho (*O. kisutch*), sockeye (*O. nerka*), and chinook salmon (*O. tshawytscha*), cutthroat (*O. clarki*) and rainbow trout (*O. mykiss*), Dolly Varden (*Salvelinus malma*), sculpins, Pacific cod (*Gadus macrocephalus*), and birds [belted kingfisher (*Megaceryle alcyon*), merganser (Merginae), and others] (Bakkala 1970, Scott and Crossman 1973, Bax et al. 1980, Fresh 1984, Nagata and Miyamota 1986). Predation rates are variable, depending on such factors as predator and prey size, the alevin's amount of yolk, abundance of fry, and composition of other prey (Hunter 1959, Fresh and Schroeder 1987). At sea, juveniles are preyed on by lamprey, shark, and probably other large predatory fishes. Subadult and adult chum salmon are eaten by killer whales (*Orcinus orca*), harbor seals (*Phoca vitulina*), and other marine mammals (Fiscus 1980). Bears and large predatory birds such as osprey (*Pandion haliaetus*) and bald eagles (*Haliaeetus leucocephalus*) prey on spawning adults (Scott and Crossman 1973).

Factors Influencing Populations: To augment natural production, chum salmon are produced by hatcheries in Oregon, Washington, Alaska, Canada, U.S.S.R., and Japan (Atkinson et al. 1967, Sano 1967). Over 23.7 million juveniles were released from hatcheries along the Pacific coast in 1976 (Wahle and Smith 1979). However, in 1987, over 90 million chum fry were released just in Washington (Abrahamson 1988). In Japan, over 2 billion fry are released from hatcheries annually (Kaeriyama 1989). Most natural mortality occurs in fresh water during the embryonic stage as a result of poor environmental conditions such as siltation, low dissolved oxygen, spawning gravel disruptions, and freezing (McNeil 1966, Wydoski and Whitney 1979). Beacham and Starr (1982) concluded that freshwater survival in Canada's Fraser River was mostly a function of interactions among temperature, rainfall, and egg abundance. Human alterations of freshwater habitat caused by improper logging practices, hydroelectric and irrigation developments, channelization, chemical and pollutant introductions, and other factors, can lower chum salmon production (Bottom et al. 1985, Holtby and Scrivener 1989). High river temperatures affect chum salmon migrations, rate of maturation, cause direct mortality, and increase the incidence of diseases (Hale et al. 1985). Survival of chum salmon eggs is correlated with the permeabilty of the redd to water flow (Pauley et al. 1988). Besides their initial freshwater residency, early estuarine and marine residence appears to be a critical period for chum salmon and can affect the eventual number of returning adults (Bakkala 1970, Bax 1983). Bax (1983) showed that chum salmon in Puget Sound can have high early marine mortality. Parker (1971) suggested that chum salmon fry must "outgrow" their marine predators. Stream temperatures affect fry emergence and migration, and may prompt synchronized emigration during "windows of opportunity" (Holtby et al. 1989). There also appears to be adverse interactions between pink salmon (*O. gorbuscha*) and chum salmon, based on fewer chum salmon returning to spawn in years when pink salmon are abundant (Ames 1983, Fresh 1984). Beacham and Starr (1982) suggested that competition between chum and pink salmon in the Fraser River estuary or Strait of Georgia reduces eventual adult chum salmon abundance. Andrievskaya (1970) found that in years of low pink salmon abundance, chum and pink salmon in the ocean eat similar prey. But in years of high pink salmon abundance, chum salmon consume different prey. Fishing pressure also affects abundance. The Japanese high seas salmon fishing fleets and an unrestricted squid gillnet fishery take an unknown bycatch of chum salmon from North America.

References

Abrahamson, P. 1988. A detailed listing of the liberations of salmon into the open waters of the state of Washington during 1987. Prog. Rep. No. 267, Wash. Dept. Fish., Olympia, WA, 447 p.

Alaska Department of Fish and Game. 1985. Alaska habitat management guide. Southcentral Region, Vol. I: Life histories and habitat requirements of fish and wildlife. Alaska Dept. Fish Game, Juneau, AK, 429 p.

Allen, G. H., and W. Aron. 1958. Food of salmonid fishes of the western North Pacific Ocean. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. 237, 11 p.

Ames, J. 1983. Salmon stock interactions in Puget Sound: a preliminary look. *In* M. A. Miller (editor), Southeast Alaska coho salmon research and management review and planning workshop, May 18-19, 1982, p. 84-95. Alaska Dept. Fish Game, Juneau, AK.

Andrievskaya, L. D., 1957. Pitanie Tikhookeanskikh lososei v severo-zapadnoi chasti Tikhogo okeana (The food of Pacific salmon in the northwestern Pacific Ocean). [In Russ.] From: Materialy po biologii morskogo qperioda zhizni dal'nevostochnykh losoei, p. 64-75. Publ. by: Vses. Nauch.-issled. Inst. Morsk. Ryb. Khoz. Okeanogr., Moscow. (Fish. Res. Board Can., Transl. Ser. No 182).

Andrievskaya, L. D., 1970. Pitanie molodi tikhokeanskikh losoei v Okhotskom more. (Feeding of Pacific salmon juveniles in the Sea of Okhotsk). [In Russ.] From: Izvestiya Tikhookeanskogo Nauchno-Issledovatel'skogo. Instituta rybnogo Knozyaistva i Okeanografii (TINRO). (Proceedings of the Pacific Scientific Research Institute of Marine Fisheries and Oceanography) 78:105-115 (Fish. Res. Board Can., Transl. Ser. No. 2441).

Aro, K. V., and M. P. Shepard. 1967. Pacific salmon in Canada. Internat. North Pac. Fish. Comm., Bull. No. 23: 225-327.

Atkinson, C. E., J. H. Rose, and T. O. Duncan. 1967. Pacific salmon in the United States. Internat. North Pac. Fish. Comm., Bull. No. 23:43-223.

Baggerman, B. 1960. Salinity preference, thyroid activity and seaward migration of four species of Pacific salmon (*Oncorhynchus*). Fish. Res. Board Can. 17(3):295-322.

Bakkala, R. G. 1970. Synopsis of biological data on the chum salmon, *Oncorhynchus keta* (Walbaum) 1792. FAO Species Synopsis No. 41. U.S. Fish Wildl. Circ. No. 315, 89 p.

Bax, N. J. 1983. Early marine mortality of marked juvenile chum salmon (*Oncorhynchus keta*) released into Hood Canal, Puget Sound, Washington, in 1980. Can. J. Fish. Aquat. Sci. 40:426-435.

Bax, N. J., E. O. Salo, B. P. Snyder, C. A. Simenstad, and W. J. Kinney. 1980. Salmon outmigration studies in Hood Canal: a summary—1977. *In* W. J. McNeil and D. C. Himsworth (editors), Salmonid ecosystems of the North Pacific, p. 171-201 Oregon State Univ. Press, Corvallis, OR.

Beacham, T. D., and C. B. Murray. 1987. Adaptive variation in body size, age, morphology, egg size, and developmental biology of chum salmon (*Oncorhynchus keta*) in British Columbia. Can. J. Fish. Aquat. Sci. 44(2):244-261.

Beacham T. D., and P. Starr. 1982. Population biology of chum salmon, *Oncorhynchus keta*, from the Fraser River, British Columbia. Fish. Bull., U.S. 80(4):813-825.

Bell, M. C. 1984. Fisheries handbook of engineering requirements and biological criteria. Fish passage development and evaluation program, U.S. Army Corps Eng., North Pac. Div., Portland, OR, 290 p. (Contract No. DACW57-79-M-1594 AND DACW57-80-M-0567).

Bottom, D. L., P. J. Howell, and J. D. Rodgers. 1985. The effects of stream alterations on salmon and trout habitat in Oregon. Oregon Dept. Fish Wildl., Portland, OR, 70 p.

Burner, C. J. 1951. Characteristics of spawning nests of Columbia River salmon. Fish. Bull., U.S. 61(52):97-110.

Eschmeyer, W. N., W. S. Herald, and H. Hammann. 1983. A field guide to Pacific coast fishes of North America. Houghton Mifflin Co., Boston, MA, 336 p.

Feller, R. J., and V. W. Kaczynski. 1975. Size selective predation by juvenile chum salmon (*Oncorhynchus keta*) on epibenthic prey in Puget Sound. J. Fish. Res. Board Can. 32(8):1419-1429.

Fiscus, C. H. 1980. Marine mammal-salmonid interactions: a review. *In* W. J. McNeil and D. C. Himsworth (editors), Salmonid ecosystems of the North Pacific, p. 121-131. Oregon State Univ. Press, Corvallis, OR.

Forrester, C. R. 1981. Statistical yearbook 1978. Internat. North Pac. Fish. Comm., Vancouver, B.C., Canada, 123 p.

Fredin, R. A., R. L. Major, R. G. Bakkala, and G. K. Tanonaka. 1977. Pacific salmon and the high seas salmon fisheries of Japan. Proc. Rep., Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Seattle, WA, 324 p.

Fresh, K. L. 1984. Evaluation of potential species interaction effects in the planning and selection of salmonid enhancement projects. Report prepared by the species interaction work group of the enhancement planning team. NOAA, Nat. Mar. Fish. Serv., Seattle, WA, 80 p.

Fresh, K. L., R. D. Cardwell, and R. R. Koons. 1981. Food habits of Pacific salmon, baitfish, and their potential competitors and predators in marine waters of Washington, August 1978 to September 1979. Prog. Rep. No. 145, Wash. Dept. Fish., Olympia, WA, 58 p.

Fresh, K. L., and S. L. Schroeder. 1987. Influence of the abundance, size, and yolk reserves of juvenile chum salmon (*Oncorhynchus keta*) on predation by freshwater fishes in a small coastal stream. Can. J. Fish. Aquat. Sci. 44(22):236-243.

Hale, S. S., T. E. McMahon, and P. C. Nelson. 1985. Habitat suitability index models and instream flow suitability curves: chum salmon. U.S. Fish Wildl. Serv. Biol. Rep. 82(10.108), 48 p.

Hallock, R. J., and D. H. Fry, Jr. 1967. Five species of salmon, *Oncorhynchus*, in the Sacramento River, California. Calif. Fish Game 53:5-22.

Hartt, A. C., and M. B. Dell. 1986. Early oceanic migrations and growth of juvenile Pacific salmon and steelhead trout. Internat. North Pac. Fish. Comm. Bull., No. 46:1-105

Healey, M. C. 1979. Detritus and juvenile salmon production in the Nanaimo estuary: 1. Production and feeding rates of juvenile chum salmon (*Oncorhynchus keta*). J. Fish. Res. Board Can. 36(5):488-496.

Healey, M. C. 1980. The ecology of juvenile salmon in Georgia Strait, British Columbia. *In* W. J. McNeil and D. C. Himsworth (editors), Salmonid ecosystems of the North Pacific, p. 203-229, Oregon State Univ. Press, Corvallis, OR.

Healey, M. C. 1982. Juvenile Pacific salmon in estuaries: the life support system. *In* V. S. Kennedy (editor), Estuarine comparisons, p. 315-341. Academic Press, New York, NY.

Holtby, L. B., T. E. McMahon, and J. C. Scrivener. 1989. Stream temperatures and inter-annual variability in the emigration timing of coho salmon (*Oncorhynchus kisutch*) smolts and fry and chum salmon (*O. keta*) fry from Carnation Creek, British Columbia. Can. J. Fish. Aquat. Sci. 46:1396-1405.

Holtby, L. B., and J. C. Scrivener. 1989. Observed and simulated effects of climatic variability, clear-cut logging, and fishing on the numbers of chum salmon (*Oncorhynchus keta*) and (*O. kisutch*) returning to Carnation Creek, British Columbia. Can. Spec. Publ. Fish. Aquat. Sci. 105:62-81.

Hunter, J. G. 1959. Survival and production of pink and chum salmon in a coastal stream. J. Fish. Res. Board Can. 16(6):835-886.

Iwata, M., and S. Komatsu. 1984. Importance of estuarine residence for adaptation of chum salmon (*Oncorhynchus keta*) fry to seawater. Can. J. Fish. Aquat. Sci. 41:747-749.

Iwata, M., H. Ogura, S. Komatsu, and K. Suzuki. 1986. Loss of seawater preference in chum salmon (*Oncorhynchus keta*) fry retained in fresh water after migration season. J. Exp. Zool. 240:369-376.

Kaeriyama, M. 1986. Ecological study of the early life of the chum salmon, *Oncorhynchus keta* (Walbaum). Sci. Rep. Hokkaido Salmon Hatchery 40:31-92.

Kaeriyama, M. 1989. Aspects of salmon ranching in Japan. Physiol. Ecol. Japan 1:625-638.

LeBrasseur, R. J. 1966. Stomach contents of salmon and steelhead trout in the northeastern Pacific Ocean. J. Fish. Res. Board Can. 23(1):85-100.

LeBrasseur, R. J., and L. W. Barner. 1964. Midwater trawl salmon catches in northern Hecata Strait, November 1963. Fish. Res. Board Can., MS Rep. Ser. No. 176, 11 p.

Levy, D. A., and T. G. Northcote. 1982. Juvenile salmon residency in a marsh area of the Fraser River estuary. Can. J. Fish. Aquat. Sci. 39:270-276.

Manzer, J. I. 1964. Preliminary observations on the vertical distribution of Pacific salmon (genus *Oncorhynchus*) in the Gulf of Alaska. J. Fish. Res. Board Can. 21(5):891-903.

Mason, J. L. 1974. Behavior ecology of chum salmon fry (*Oncorhynchus keta*) in a small estuary. J. Fish. Res. Board Can. 31:83-92.

McNeil, W. J. 1966. Effect of the spawning bed environment on reproduction of pink and chum salmon. Fish. Bull., U.S. 65(2):495-523.

McPhail, J. D., and C. C. Lindsey. 1970. Freshwater fishes of northwestern Canada and Alaska. Fish. Res. Board Can., Bull. No. 173, 381 p.

Moyle, P. B. 1976. Inland fishes of California. Univ. Calif. Press, Berkeley, CA, 405 p.

Myers, K. W. W. 1980. An investigation of the utilization of four study areas in Yaquina Bay, Oregon, by hatchery and wild juvenile salmonids. MS. Thesis, Oregon State Univ., Corvallis, OR, 234 p.

Nagata, M., and M. Miyamoto. 1986. The downstream migration of chum salmon fry, *Oncorhynchus keta*, released into the Utabetsu River of eastern Hidaka in Hokkaido, and the estimation of predation amount of the fry by fresh water sculpin, *Cottus nozawae*, Synder. Sci. Rep. Hokkaido Fish Hatchery 41:13-22.

National Marine Fisheries Service. 1986. Fisheries of the United States, 1985. Current Fishery Statistics No. 8368. U.S. Dept. Comm., NOAA, Nat. Mar. Fish Serv., Nat. Fish. Stat. Prog., Washington, D.C., 122 p.

Neave, F., T. Yonemori, and R. G. Bakkala. 1976. Distribution and origin of chum salmon in offshore waters of the North Pacific Ocean. Internat. North Pac. Fish. Comm., Bull. No. 35, 79 p.

Pacific Marine Fisheries Commission. 1985. 37th annual report of the Pacific Marine Fisheries Commission for the year 1984. Pac. Mar. Fish. Comm., Portland, OR, 35 p.

Pacific Marine Fisheries Commission. 1986. 38th annual report of the Pacific Marine Fisheries Commission for the year 1985. Pac. Mar. Fish. Comm., Portland, OR, 36 p.

Parker, R. R. 1971. Size selective predation among juvenile salmonid fishes in a British Columbia inlet. J. Fish. Res. Board Can. 28(10):1503-1510.

Pauley, G. G., K. L. Bowers, and G. L. Thomas. 1988. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest) — chum salmon. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.81). U.S. Army Corps Engin., TR EL-82-4, 17 p.

Pearcy, W., T. Nishiyama, T. Fujii, and K. Masuda. 1984. Diel variations in the feeding habits of Pacific salmon caught in gill nets during a 24-hour period in the Gulf of Alaska. Fish. Bull., U.S. 82(2):391-399.

Peterson, W. T., R. D. Brodeur, and W. G. Pearcy. 1982. Food habits of juvenile salmon in the Oregon coastal zone, June 1979. Fish. Bull., U.S. 80(4):841-851.

Ratti, F. 1979. Natural resources of Rogue estuary. Oregon Dept. Fish Wildl., Portland, OR, 33 p.

Reiser, D. W., and T. C. Bjornn. 1979. 1. Habitat requirements of anadromous salmonids. *In* W. R. Meehan (editor), Influence of forest and rangeland management on anadromous fish habitat in the western United States and Canada, p. 1-54. USDA Forest Service, Gen. Tech. Rep. PNW-96, Pacific Northw. Forest Range Exp. Sta., Portland, Oregon.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Rombough, P. J. 1983. Effects of low pH on eyed embryos and alevins of Pacific salmon. Can. J. Fish. Aquat. Sci. 40(10):1575-1582.

Sano, S. 1966. Chum salmon in the Far East. Internat. North Pac. Fish. Comm., Bull. No. 18:41-57.

Sano, S. 1967. Spawning populations of North Pacific salmon, 3. Chum salmon in the Far East. Internat. North Pac. Fish. Comm. Bull. No. 23: 23-41.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can., Bull. No. 84, 966 p.

Shelboun, J. E. 1966. Influence of temperature, salinity, and photoperiod on the aggregations of chum salmon fry. J. Fish. Res. Board Can. 23:293-304.

Shepard, M. F. 1981. Status and review of the knowledge pertaining to the estuarine habitat requirements and life history of chum and chinook salmon juveniles in Puget Sound. Final Rep. to Wash. Coop. Fish. Res. Unit, College Fish., Univ. Wash., Seattle, WA, 113 p.

Shiino, S. 1976. List of common names of fishes of the world, those prevailing among English-speaking Nations. Sci. Rep. Shima Marineland No. 4, Kashikojima, Shima, Mie, Japan, 262 p.

Sibert, J., T. J. Brown, M. C. Healey, and B. A. Kask. 1977. Detritus-based food webs: exploitation by juvenile chum salmon (*Oncorhynchus keta*). Science 196(4290):649-650.

Simenstad, C. A. 1983. The ecology of estuarine channels of the Pacific Northwest coast: a community profile. U.S. Fish Wildl. Serv., FWS/OBS-83/05, 181 p.

Simenstad, C. A., and E. O. Salo. 1982. Foraging success as a determinant of estuarine and nearshore carrying capacity of juvenile chum salmon (*Oncorhynchus keta*) in Hood Canal, Washington. *In* B. R. Melteff and R. A. Neve (editors), Proceedings of the North Pacific aquaculture symposium, p. 21-37. Alaska Sea Grant Prog., Univ. Alaska, Fairbanks, AK.

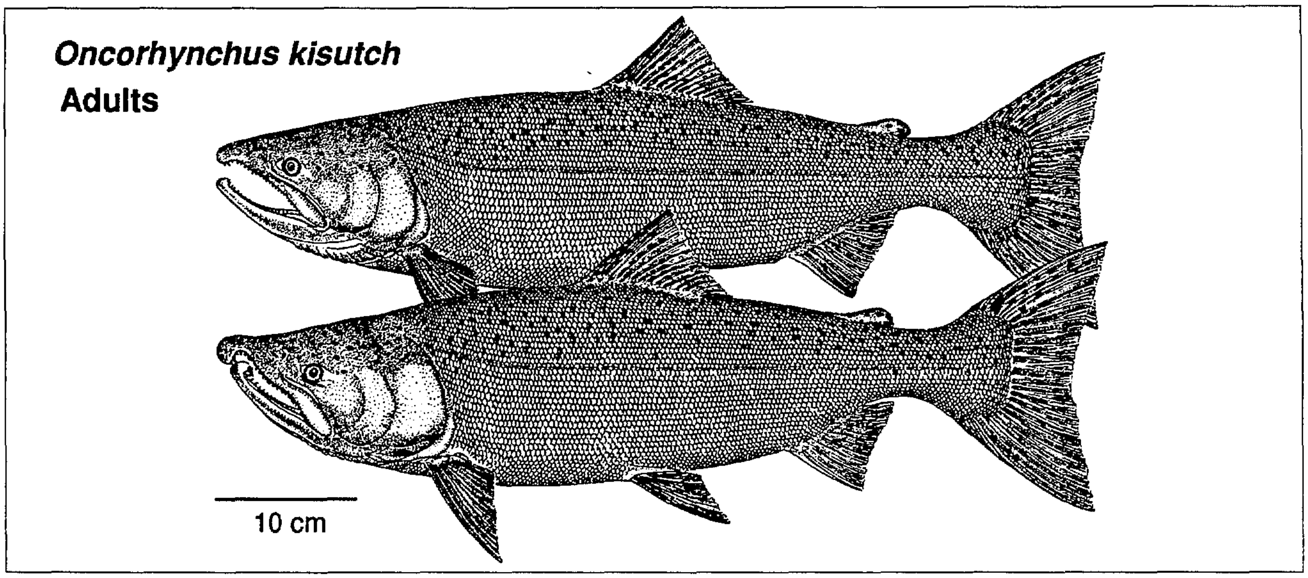
Simenstad, C. A., K. L. Fresh, and E. O. Salo. 1982. The role of Puget Sound and Washington coastal estuaries in the life history of Pacific salmon: an unappreciated function. *In* V. S. Kennedy (editor), Estuarine comparisons, p. 343-364. Academic Press, New York, NY.

Squire, J. L., Jr., and S. E. Smith. 1977. Anglers' guide to the United States Pacific coast - marine fish, fishing grounds and facilities. Nat. Mar. Fish. Serv., NOAA, Seattle, WA, 139 p.

Wahle, R. J., and R. Z. Smith. 1979. A historical and descriptive account of Pacific coast anadromous salmonid rearing facilities and summary of their releases by region, 1960-76. U.S. Dept. Comm., NOAA, Tech Rep. NMFS, Spec. Sci. Rep. Fish. No. 736, 35 p.

Wydoski, R. S. and R. R. Whitney. 1979. Inland fishes of Washington, Univ. Wash. Press, Seattle, WA, 220 p.

Coho salmon



Common Name: coho salmon
Scientific Name: *Oncorhynchus kisutch*
Other Common Names: silver salmon, blueback salmon, hookbill, hooknose salmon, hoopid salmon, jack salmon, medium red salmon, salmon trout, siverside salmon, white salmon (Scott and Crossman 1973, Shiino 1976, Laufle et al. 1986)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Salmoniformes
Family: Salmonidae

Value

Commercial: The coho salmon is fished commercially from Norton Sound, Alaska, south to northern Japan, and along western North America to northern California. It is also fished on the high seas (International North Pacific Fishery Mangement Council 1979). Coho salmon make up 8-11% of the total Pacific salmonid catch (Forrester 1982, Takehama 1983). This species is usually ranked fourth in commercial catches (numbers and weight) of salmonids [behind pink (*Oncorhynchus gorbuscha*), chum (*O. keta*), and sockeye salmon (*O. nerka*)]. An average of 19,500 t were landed in the United States from 1980-1984 (National Marine Fisheries Service 1986). The 1985 commercial catch was worth approximately $46 million (National Marine Fisheries Service 1986). It is commercially caught with gill nets (drift and set), purse seines, reef nets, and trolling (primary method). Some fish are canned, but most are sold fresh or fresh-frozen for human consumption. About 75% of the U.S. catch comes from Alaska and is harvested primarily during July and August. Native Americans are allocated 50% of the coho salmon harvest in Washington (Clark 1985).

Recreational: The coho salmon is the primary target for many marine and freshwater sport fishermen on the Pacific coast. A total of 674,000 fish (not including freshwater catch) were caught by sport anglers off California, Oregon, Washington, and Alaska in 1984 (Pacific Marine Fisheries Commission 1986). Sport caught coho salmon originating from the Columbia River were estimated to be worth over $30 million (Richards 1986). Most coho salmon are caught by trolling (in ocean and estuaries), but they are also taken by spin casting and fly-fishing. It is a highly-esteemed sport fish because of its abundance, availability, size, fighting ability, and excellent taste. This species was introduced into the Great Lakes and is now very abundant there (Morrow 1980).

Indicator of Environmental Stress: Reduced run sizes are often the result of adverse environmental and habitat changes. Coho salmon exposed to low concentrations of aromatic hydrocarbons decrease feeding, while fish exposed to high concentrations may stop feeding for days (Purdy 1989). See "Factors Influencing Populations".

Ecological: The coho salmon is a common species in many coastal streams (Atkinson et al. 1967). Stream-dwelling juveniles are territorial (Shapovalov and Taft 1954, Steine et al. 1972) and sometimes prey on other salmonids (Fresh and Schroeder 1987). Adults and juveniles are common in neritic waters off Oregon and Washington (Fisher et al. 1983, Fisher and Pearcy 1985).

Range

Overall: The coho salmon spawns in coastal streams from northern Japan to the Anadyr River in Siberia and

Table 1. Relative abundance of coho salmon in 32 U.S. Pacific coast estuaries.

	Life Stage				
Estuary	A	S	J	L	E
Puget Sound	◉		◉		
Hood Canal	◉		◉		
Skagit Bay	◉		◉		
Grays Harbor	◉		◉		
Willapa Bay	◉		◉		
Columbia River	◉		◉		
Nehalem Bay	◉		◉		
Tillamook Bay	◉		◉		
Netarts Bay	O		O		
Siletz River	◉		◉		
Yaquina Bay	◉		●		
Alsea River	◉		◉		
Siuslaw River	◉		◉		
Umpqua River	◉		◉		
Coos Bay	◉		◉		
Rogue River	◉		◉		
Klamath River	O		◉		
Humboldt Bay	O		O		
Eel River	O		O		
Tomales Bay	O		O		
Cent. San Fran. Bay *					
South San Fran. Bay					
Elkhorn Slough					
Morro Bay					
Santa Monica Bay					
San Pedro Bay					
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
O	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

from northern Monterey Bay, California, to Point Hope, Alaska (Moyle 1976). In the ocean, it occurs in coastal waters from Baja California to the Bering Sea (Hart 1973, Hartt and Dell 1986).

Within Study Area: This species occurs in all estuaries north of Monterey Bay, California, to Puget Sound, Washington (Table 1). It is very rare in San Francisco Bay (strays). Major U.S. spawning grounds (other than Alaska) are in Washington and Oregon (Atkinson et al. 1967).

Life Mode

The coho salmon is an anadromous species. Eggs and larvae (alevins) are benthic and infaunal. Young juveniles (fry and parr) are benthopelagic. Parr become pelagic and acquire a silver color when they transform into smolts (juveniles that migrate to the ocean). Smolts and ocean-dwelling and maturing juveniles (subadults) and adults are primarily pelagic (Shapovalov and Taft 1954). Subadults and adults in rivers and streams are bottom-oriented.

Habitat

Type: Eggs, alevins, fry, and parr are riverine. Eggs and alevins occur primarily in riffle areas of streams. Fry inhabit shallow stream areas adjacent to pools, but move into deeper waters as they grow (Shapovalov and Taft 1954, Moyle 1976). Smolts are found in rivers, estuaries, and nearshore coastal waters. In estuaries, smolts occur in intertidal and pelagic habitats (Simenstad and Eggers 1981, Durkin 1982, Myers and Horton 1982), with deep, marine-influenced habitats often preferred (Macdonald et al. 1987). Smolts are epipelagic in offshore marine waters (Miller et al. 1983). Subadults range from neritic to oceanic (Hartt and Dell 1986). Adults are estuarine and riverine.

Substrate: Eggs are buried in areas that are composed of gravel ranging from 1.3-10.2 cm in diameter (Reiser and Bjornn 1979, Bell 1984). Coho salmon are the only salmon whose redd can contain up to 10% mud (Burner 1951). Juveniles in streams are not substrate selective, but prefer areas with good cover and food availability. Smolts, subadults, and adults can be found migrating over a wide range of substrates (mudflats to rocks).

Physical/Chemical Characteristics: The coho salmon is found in fresh water to euhaline waters. Eggs, alevins, fry, and parr occur in fresh water. Smolts and adults are euryhaline. Eggs and alevins are found in waters ranging from 4.4-21.0°C (Bell 1984), but 4.4-13.3°C is best for egg incubation (Reiser and Bjornn 1979). Juveniles prefer stream temperatures of 11.8-14.6°C, with 25.1°C the upper lethal limit (Brett 1952). Growth ceases above 20.3°C because of increased metabolic rate (Bell 1984). However, other water quality parameters can lower this upper thermal limit (Ebel et al. 1971). Water temperature can also affect juvenile osmoregulatory ability (Zaugg and McLain 1976). At sea, most coho salmon are found in waters that are 4.0-15.2°C. (Godfrey et al. 1975, Fredin et al. 1977). Adults can migrate upstream in velocities up to 2.44 m/sec; juveniles prefer stream velocities of 0.09-0.46 m/sec depending on the habitat (Reiser and Bjornn 1979). Adequate stream cover is important to freshwater life stages. Juveniles and eggs require well-oxygenated waters. Dissolved oxygen (DO) levels below 8 mg/l sharply reduce embryo survival (Phillips and Campbell 1968) and DO levels below 4 mg/l reduce juvenile food consumption, food conversion, and growth (Herrmann et al. 1962). Low pH (below 5.01) can be lethal to newly-hatched alevins (Rombough

1983). Adults need a minimum depth of 18 cm to migrate and spawn (Thompson 1972). Short-term pulses of suspended sediment in streams can cause a breakdown of social organization, a change in aggressive behavior, an increase in activity, and a decrease in feeding ability (Berg 1982). High turbidity can affect emergence and growth of young coho salmon (Sigler et al. 1984) and also alters feeding habits (Reiser and Bjornn 1979).

Migrations and Movements: Over their range, adult coho salmon can be found to migrate into their natal streams from June to February and spawn from September through March (Washington 1982). Fry initially live and school in shallow gravel areas, but soon disperse upstream and downstream and to deeper waters as they grow. Fry may be displaced downstream by fall freshets. Fry may enter tributaries, sloughs, and side channels to overwinter, and return to the mainstream in spring (Tschaplinski and Hartman 1982). After residing approximately one year in fresh water (two or more in northern streams) most juveniles will migrate to the ocean (outmigration) (Gribanov 1948, Godfrey 1965). Most juveniles outmigrate from April to August, peaking in May (Shapovalov and Taft 1954, Deschamps et al. 1971, Simenstad and Eggers 1981, Myers and Horton 1982, Dawley et al. 1986). Outmigration has been reported to occur at night (McDonald 1960) and day (Durkin 1982, Dawley et al. 1986). Migrating smolts are approximately 8.8-13.8 cm long (Salo and Bayliff 1958, Durkin 1982), with larger smolts migrating sooner than smaller smolts (Durkin 1982). Limited estuarine rearing occurs in the Columbia River estuary (Dawley et al. 1986). However, in Puget Sound, residency for coho salmon smolts was estimated to be 6-40 days, with 3-5% of the naturally-produced yearling coho salmon residing inside the Strait of Juan de Fuca until maturity (Simenstad et al. 1982). In Yaquina Bay, Oregon, a few overwinter within and near the bay, but most juveniles migrate out of the bay in 2-9 days (Myers and Horton 1982). Some coho salmon fry in Canada may rear in estuaries from March to October or November (Tschaplinski 1982). Once in the ocean, smolts from Oregon and coastal Washington rivers appear to initially head south, but later head north (Pearcy 1984). Most Oregon coho salmon probably remain in coastal waters off California, Oregon, and Washington (Parmenter and Bailey 1985, Pearcy and Fisher 1988). However, during the first summer some may make extensive migrations to the Gulf of Alaska (Hartt and Dell 1986), but by their second summer, many will be captured by sport and commercial fisheries near their river of origin (Wright 1968). Both juveniles and adults stay near the surface (within 10 m), except when the sea is covered by a layer of warm water (Fredin et al. 1977). Maturing coho salmon can migrate up to 30 km/day (Godfrey et al. 1975). Ocean migration appears to involve the use of magnetic information, celestial cues, and polarized light. Olfaction appears to be the dominant guidance mechanism during the riverine (spawning) migration (Brannon 1982, Quinn 1982, Hasler and Scholz 1983).

Reproduction

Mode: The coho salmon is gonochoristic, oviparous, and semelparous (all adults die after spawning). Eggs are fertilized externally.

Mating/Spawning: Spawning occurs from September to March (depending on location). Peak spawning occurs from September to February in the Columbia River (Netboy 1980) and November to January in California (Moyle 1976). This species typically spawns in small streams (sometimes in large rivers) within 240 km of the river mouth (Laufle et al. 1986). Although coho salmon may spawn in the same habitats as chinook salmon (Burner 1951), it normally spawns in areas that have lower stream velocities, shallower depths, and smaller gravel (Fraser et al. 1982). The coho salmon typically spawns in riffle areas where water velocities are 0.08-0.70 m/sec, stream depths are 0.05-0.66 m, substrate gravel ranges from 2-15 cm in diameter, and water temperatures are 4-14°C (Schmidt et al. 1979). Spawning adults are dimorphic. Males have a thick, hooked snout, exposed teeth, and change color, while females change little (Scott and Crossman 1973). Females select and build the redds and both sexes are territorial. A dominant (larger) male moves into the nest and spawns with the female when ready. At this time subdominant males may dart in and release sperm (Scott and Crossman 1973). Females will spawn in up to four different nests and with different males. Eggs are covered by the digging and displacement of gravel upstream (Scott and Crossman 1973). Redds average 2.9 m^2 (Burner 1951), with eggs buried an average of 22.0 cm deep (Gribanov 1948).

Fecundity: In North America, a coho salmon female can lay 1,000-5,700 eggs (depending on size) (Scott and Crossman 1973, Moyle 1976). Average fecundity is about 2,500-3,500 eggs per female (Rounsefell 1957, Crone and Bond 1976, Wydoski and Whitney 1979). In Kamchatka, U.S.S.R., the average is about 5,000 eggs per female (Gribanov 1948).

Growth and Development

Egg Size and Embryonic Development: This species' egg is relatively large and second only to the chinook salmon's in size (Rounsefell 1957). In Canada, coho salmon eggs have a diameter of 4.5-6.0 mm (McPhail and Lindsey 1970), but are reported to be 6.6-7.9 mm in diameter in the U.S. (Bell 1984). Embryonic development is indirect and external. Eggs hatch in 38 days at 11°C, 48 days at 9°C, and 86-101 days at 4.5°C (Laufle et al. 1986).

Age and Size of Larvae: Larvae (alevins) are 17-19 mm long at hatching and grow to 27-30 mm in length before the yolk sac is absorbed (Gribanov 1948). It takes about 2-5 weeks (depending on temperature) before larvae absorb the yolk sac and leave the gravel (Gribanov 1948, Laufle et al. 1986).

Juvenile Size Range: Juveniles range from 3 cm to at least 40 cm long (Gribanov 1948).

Age and Size of Adults: Most coho salmon mature and spawn during their 3rd year, but some mature as 2-5 year-olds (Scott and Crossman 1973, Moyle 1976). Two-year-old mature males that have spent only one year in the ocean are call "jacks". Off Oregon and Washington, "jack" abundance is a good predictor of next year's three-year-old coho salmon abundance. In the Fraser River, Canada, the coho salmon run is usually composed of 92% three-year-olds, 4% four-year-olds, and 4% "jacks" (Fraser et al. 1982). Adults range from 40-99 cm in length (Gribanov 1948, Kessler 1985).

Food and Feeding

Trophic Mode: Larvae feed on their yolk. Juveniles and subadults are carnivorous, "opportunistic" feeders.

Food Items: Once fry emerge they begin feeding on a variety of terrestrial and aquatic invertebrates (spiders, mites, insects, snails, etc.) (Shapovalov and Taft 1954, Scott and Crossman 1973). Parr may eat invertebrates and other salmon (Roos 1960, Fresh and Schroeder 1987). In reservoirs, parr feed on zooplankton (e.g., *Daphnia*), insects, and amphipods (Wydoski and Whitney 1979, Muir and Emmett 1988). In estuaries, they feed primarily on large planktonic or small nektonic animals, such as amphipods (*Corophium* spp., *Eogammarus* spp.), insects, mysids, decapod larvae, and larval and juvenile fishes (including other salmonids) (Levy and Levings 1978, Fresh et al. 1979, Simenstad and Eggers 1981, Durkin 1982, Pearce et al. 1982). Initially, ocean-dwelling coho salmon eat decapod larvae, gammarid and hyperid amphipods, euphausiids, terrestrial insects, copepods, cephalopods, Cnideria, gastropods (*Limacina helicina*), planktonic annelids, and larval and juvenile fishes (Peterson et al. 1983, Emmett et al. 1986, Brodeur et al. 1987, Brodeur 1989). As they grow, juveniles become more piscivorous, eating northern anchovy (*Engraulis mordax*), Pacific herring (*Clupea pallasi*), Pacific sardine (*Sardinops sagax*), juvenile scorpaenids, capelin (*Mallotus villosus*), and other fish species (Silliman 1941, Ito 1964, Scott and Crossman 1973, Fresh et al. 1981). An opportunistic feeder, the coho salmon's diet differs spatially and temporally, and probably reflects relative prey availability (Prakash 1962, Brodeur et al. 1987).

Biological Interactions

Predation: In fresh water, juveniles are eaten by other fishes, including coho salmon smolts, cutthroat trout (*O. clarki*), rainbow trout (*O. mykiss*), Dolly Varden (*Salvelinus malma*), squawfish (*Ptychocheilus oregonensis*), and sculpins (Scott and Crossman 1973). Marine fish predators include spiny dogfish (*Squalus acanthias*) and other sharks. Juveniles are also eaten by birds such as mergansers, belted kingfishers (*Megaceryle alcyon*), loons (*Gavia* spp.), gulls, and common murres (*Uria aalge*) (Scott and Crossman 1973, Varoujean and Matthews 1983). Marine mammals such as harbor seals (*Phoca vitulina*), northern and California sea lions (*Eumetropias tubata* and *Zalophus californianus*, respectively), and killer whales (*Orcus orcinus*) will also eat coho salmon. Most marine mammal predation occurs in nearshore, estuarine and river areas (Fiscus 1980, Beach et al. 1981). On their spawning run, coho salmon are taken by bears and other mammals, bald eagles (*Haliaeetus leucocephalus*), and osprey (*Pandion haliaetus*).

Factors Influencing Populations: Freshwater mortality is high, with only 0.13-12.0% survival from egg to age 1 smolt expected (Fredin et al. 1977). This mortality is related to habitat suitability and alteration, disease, predation, disruption of eggs and larvae, siltation, food abundance, and competition with other fishes (Chapman 1966, Steine et al. 1972, Fredin et al. 1977, Reiser and Bjornn 1979). Man-induced changes to streams by improper logging, road construction, irrigation, pollutants, dams and reservoir construction, channelization, residential development, and agricultural practices can cause physical and chemical alterations which may be detrimental to coho salmon production (Reiser and Bjornn 1979, Laufle et al. 1986, Scrivener and Brownlee 1989). Summer streamflow affects survival and is an important determinant of Puget Sound coho salmon runs (Mathews and Olson 1980). Valley tributaries and sloughs may be important for winter survival for many coho salmon juveniles (Tschaplinski and Hartman 1982). Marine mortality can also be high; Lander and Henry (1973) estimated that only 5-6% of Columbia River smolts survived after 13.5 months at sea. Year-class strength appears to be determined very early in ocean residence and may be related to predation rates (Fisher and Pearcy 1988). Ricker (1976) estimated that the offshore troll fishery kills one coho salmon (below legal size) for every two landed. Coho salmon abundance has been correlated with ocean "upwelling" one year earlier (Gonsolus 1978). The Oregon Production Area coho salmon population has gone from predominantly high-survival wild fish to predominantly low-survival hatchery fish (Nickelson 1986). Over 62 million hatchery smolts were released in the Oregon Production Area (Monterey Bay, California to Leadbetter Point, Washington) in 1981, including 24 million from private hatcheries (Nickelson 1986). Hatcheries (private and public) play a dominant role in the abundance of this species in the Pacific Northwest. However, the introduction of hatchery coho salmon presmolts into streams appears to reduce wild coho salmon populations (Nickelson et al. 1986). Hatcheries may also precipitate overharvest of wild stocks and cause density-dependent mortality in both freshwater and marine environments (Lichatowich and McIntyre 1987). Coho salmon smolts may need to reach a "critical size" for proper smoltification and marine survival. Hence, growth and time of release are important attributes for hatchery fish (Bilton et al. 1982, Mahnken et al. 1982). Thomas (1985) found a correlation between coho salmon hatchery production and a decline in central California Dungeness crab (*Cancer magister*) abundance, probably related to coho salmon feeding on crab megalopae. El Niño also affects coho salmon abundance (Hayes and Henry 1985). Finally, Japanese high-seas fishing fleets take unknown numbers of coho salmon and the squid gillnet fisheries may also take coho salmon incidentally.

References

Atkinson, C. E., J. H. Rose, and T. O. Duncan. 1967. Pacific salmon in the United States. Internat. North Pac. Fish. Comm., Bull. No. 23:43-223.

Bell, M. C. 1984. Fisheries handbook of engineering requirements and biological criteria. Fish Passage Development and Evaluation Program, U.S. Army Corps Eng., North Pac. Div., Portland, OR, 290 p. (Contract No. DACW57-79-M-1594 and DACW57-80-M-0567).

Beach, R. J., A. C. Geiger, S. J. Jeffries, and S. D. Tracy. 1981. Marine mammal - fishery interactions on the Columbia River and adjacent waters, 1981. Second Annual Rep. to NOAA, NMFS, 186 p. Wash. Dept. Game, Olympia, WA.

Berg, L. 1982. The effect of exposure to short-term pulses of suspended sediment on the behavior of juvenile salmonids. *In* G. Hartman (editor), Proceedings of the Carnation Creek workshop, a 10 year review, p. 177-196. Dept. Fish. Oceans, Pacific Biol. Sta., Nanaimo, B.C., Canada.

Bilton, H. T., D. F. Alderdice, and J. T. Schnute. 1982. Influence of time and size at release of juvenile coho salmon (*Oncorhynchus kisutch*) on returns at maturity. Can. J. Fish. Aquat. Sci. 39:426-447.

Brannon, E. L. 1982. Orientation mechanisms of homing salmonids. *In* E. L. Brannon and E. O. Salo (editors), Proceedings of the salmon and trout migratory behavior symposium, p. 219-227. School Fish., Univ. Wash, Seattle, WA.

Brett. J. R. 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus*. J. Fish. Res. Board Can. 9(6):265-323.

Brodeur, R. D. 1989. Neustonic feeding by juvenile salmonids in coastal waters of the northeast Pacific. Can. J. Zool. 67:1995-2007.

Brodeur, R. D., H. V. Lorz, and W. G. Pearcy. 1987. Food habits and diet variations of pelagic nekton off Oregon and Washington, 1979-1984. NOAA Tech. Rep. NMFS 57, 32 p.

Burner, C. J. 1951. Characteristics of spawning nests of Columbia River salmon. Fish. Bull., U.S. 61(52):97-110.

Chapman, D. W. 1966. Food and space as regulators of salmonid populations in streams. Am. Nat. 100:345-357.

Clark, W. G. 1985. Fishing in a sea of court order: Puget Sound salmon management 10 years after the Boldt decision. N. Am. J. Fish. Mang. 5(3b):417-434.

Crone, R. A., and C. E. Bond. 1976. Life history of coho salmon, *Oncorhynchus kisutch*, in Sashin Creek, southeastern Alaska. Fish. Bull., U.S. 74(4):897-923.

Dawley, E. M., R. D. Ledgerwood, T. H. Blahm, C. W. Sims, J. T. Durkin, R. A. Kirn, A. E. Rankis, G. E. Monan, and F. J. Ossiander. 1986. Migrational characteristics, biological observations, and relative survival of juvenile salmonids entering the Columbia River estuary, 1966-1983. Final Rep. to Bonneville Power Adm., Contract DE-A179-84BP39652, 256 p. Available Northwest and Alaska Fish. Center, 2725 Montlake Blvd. E., Seattle, WA.

Deschamps, G., S. G. Wright, and R. E. Watson. 1971. Fish migration and distribution in the lower Chehalis River and Upper Grays Harbor. *In* Grays Harbor cooperative water quality study 1964-1966, p. 1-58. Tech. Rep. No. 7, Wash. Dept. Fish., Olympia, WA.

Durkin, J. T. 1982. Migration characteristics of coho salmon (*Oncorhynchus kisutch*) smolts in the Columbia River and its estuary. *In* V. S. Kennedy (editor), Estuarine comparisons, p. 365-376. Academic Press, New York, NY.

Ebel, W. J., E. M. Dawley, and B. H. Monk. 1971. Thermal tolerance of juvenile Pacific salmon and steelhead trout in relation to supersaturation of nitrogen gas. Fish. Bull., U.S. 69(4):833-843.

Emmett, R. L., D. R. Miller, T. H. Blahm. 1986. Food of juvenile chinook, *Oncorhynchus tshawytscha*, and coho, *O. kisutch*, salmon off the northern Oregon and southern Washington coasts, May-September 1980. Calif. Fish Game 72(1):38-46.

Fiscus. C. H. 1980. Marine mammal-salmonid interactions: a review. *In* W. J. McNeil and D. C. Himsworth (editors), Salmonid ecosystems of the North Pacific, p. 121-132. Oregon State Univ. Press, Corvallis, OR.

Fisher, J. P., W. G. Pearcy. 1985. Studies of juvenile salmonids off the Oregon and Washington coast, 1985. Cruise Rep. Ref. 85-14, Sea Grant College Prog., Oregon State Univ., 31 p. (ORESU-T-85-004).

Fisher, J. P., and W. G. Pearcy. 1988. Growth of juvenile coho salmon (*Oncorhynchus kisutch*) off Oregon and Washington, USA, in years of differing coastal upwelling. Can. J. Fish. Aquat. Sci. 45:1036-1044.

Fisher, J. P., W. G. Pearcy, and A. W. Chung. 1983. Studies of juvenile salmonids off the Oregon and Washington coast, 1982. Cruise Rep. Ref. 83-2, Sea Grant College Prog., Oregon State Univ., 41 p. (ORESU-T-83-003).

Forrester, C. R. (compiler). 1982. Statistical yearbook 1978. Internat. North Pac. Fish. Comm., Vancouver, B.C., Canada, 143 p.

Fraser, F. J., P. J. Starr, and A. Y. Fedorenko. 1982. A review of the chinook and coho salmon of the Fraser River. Can. Tech. Rep. Fish. Aquat. Sci. No. 1126, 92 p. plus appendices.

Fredin, R. A., R. L. Major, R. G. Bakkala, and G. K. Tanonaka. 1977. Pacific salmon and the high seas salmon fisheries of Japan. NWAFC Proc. Rep., Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Seattle, WA, 324 p.

Fresh, K. L., D. Rabin, C. Simenstad, E. O. Salo, K. Garrison, and L. Matheson. 1979. Fish ecology studies in the Nisqually reach area of southern Puget Sound, Washington. Fish. Res. Inst., Coll. Fish., Univ. Wash, Seattle, WA, 229 p.

Fresh, K. L., R. D. Cardwell, R. R. Koons. 1981. Food habits of Pacific salmon, baitfish, and their potential competitors and predators in marine waters of Washington, August 1978 to September 1979. Prog. Rep. No. 145, Wash. Dept. Fish., Olympia, WA, 58 p.

Fresh, K. L., and S. L. Schroeder. 1987. Influence of the abundance, size, and yolk reserves of juvenile chum salmon (*Oncorhynchus keta*) on predation by freshwater fishes in a small coastal stream. Can. J. Fish. Aquat. Sci. 44:236-243.

Godfrey, H. 1965. Coho salmon in offshore waters. Internat. North Pac. Fish. Comm., Bull. No. 16, 40 p.

Godfrey, H., K. Henry, and S. Machidori. 1975. Distribution and abundance of coho salmon in offshore waters of the North Pacific Ocean. Internat. North Pac. Fish. Comm., Vancouver, B.C., Canada, 80 p.

Gonsolus, R. T. 1978. The status of Oregon coho and recommendations for managing the production, harvest, and escapement of wild and hatchery-reared stocks. Oregon Dept. Fish Wildl., Clackamas, OR. 59 p.

Gribanov. V. I. 1948. Coho (*Oncorhynchus kisutch* Walbaum) (General Biology). Izvestiia TINRO, Vol. 28. (Translation by W. E. Ricker, Fish. Res. Board Can., Transl. Ser. 370), 84 p.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. No. 180, 740 p.

Hartt, A. C., and M. B. Dell. 1986. Early oceanic migrations and growth of juvenile Pacific salmon and steelhead trout. Internat. North Pac. Fish Comm., Bull. No. 46, 105 p.

Hasler, A. D., and A. T. Scholz. 1983. Olfactory imprinting and homing in salmon. Springer-Verlag, Berlin, 134 p.

Hayes, M. L., and K. A. Henry. 1985. Salmon management in response to the 1982-83 El Niño event. *In* W. S. Wooster and D. L. Fluharty (editors), El Niño North, Niño effects in the eastern subarctic Pacific Ocean, p. 226-236. Wash. Sea Grant Prog., Univ. Wash., Seattle, WA.

Herrmann, R. B., C. E. Warren, and P. Doudoroff. 1962. Influence of oxygen concentration on the growth of juvenile coho salmon. Trans. Am. Fish. Soc. 91(2):155-167.

International North Pacific Fishery Mangement Council. 1979. Historical catch statistics for salmon of the North Pacific Ocean. Internat. North Pac. Fish. Comm., Bull No. 39, 166 p.

Ito, J. 1964. Food and feeding habits of Pacific salmon (Genus *Oncorhynchus*) in their ocean life. Bull. Hokkaido Reg. Fish. Res. Lab. 29:85-97. (Fish. Res. Board Can., Transl. Ser. 1309).

Kessler , D. W. 1985. Alaska's saltwater fishes and other sea life. Alaska Northw. Publ. Co., Anchorage, AK, 258 p.

Lander, R. H., and K. A. Henry. 1973. Survival, maturity, abundance and marine distribution of 1965-66 brood coho salmon, *Oncorhynchus kisutch*, from the Columbia River hatcheries. Fish. Bull., U.S. 71:679-695.

Laufle, J. C., G. B. Pauley, and M. F. Shepard. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest) —coho salmon. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.48), U.S. Army Corps Eng., TR EL-82-4, 18 p.

Levy, D. A., and C. D. Levings. 1978. A description of the fish community of the Squamish River estuary, British Columbia: relative abundance, seasonal changes, and feeding habits of salmonids. Fish. Env. Canada, Fish. Mar. Serv. Manusc. Rep. No. 1475, 63 p.

Lichatowich, J. A., and J. D. McIntyre. 1987. Use of hatcheries in the management of Pacific anadromous salmonids. Am. Fish. Soc. Sympos. 1:131-136.

Macdonald, J. S., I. K. Birtwell, and G. M. Kruzynski. 1987. Food and habitat utilization by juvenile salmonids in the Campbell River estuary. Can J. Fish. Aquat. Sci. 44:1233-1246.

Mahnken, C., E. Prentice, W. Waknitz, G. Monan, C. Sims, and J. Williams. 1982. The application of recent smoltification research to public hatchery releases: an assessment of size/time requirements for Columbia River hatchery coho salmon (*Oncorhynchus kisutch*). Aquaculture 28:251-268.

Mathews, S. B., and F. W. Olson. 1980. Factors affecting Puget Sound coho salmon (*Oncorhynchus kisutch*) runs. Can. J. Fish. Aquat. Sci. 37:1373-1378.

McDonald, J. 1960. The behavior of Pacific salmon fry during their downstream migration to freshwater and saltwater nursery areas. J. Fish. Res. Board Can. 17(5):655-676.

McPhail, J. D., and C. C. Lindsey. 1970. Freshwater fishes of Northwestern Canada and Alaska. Fish. Res. Board Can., Bull. No. 173. 381 p.

Miller, D. R., J. G. Williams, and C. W. Sims. 1983. Distribution, abundance and growth of juvenile salmonids off the Oregon coast and Washington, summer 1980. Fish. Res. (Amsterdam) 2:1-17.

Morrow, J. E. 1980. The freshwater fishes of Alaska. Alaska Northwest Publ. Co., Anchorage, AK, 248 p.

Moyle, P. B. 1976. Inland fishes of California. Univ. Calif. Press, Berkeley, CA, 405 p.

Muir, W. D., and R. L. Emmett. 1988. Food habits of migration salmonid smolts passing Bonneville Dam in the Columbia River, 1984. Reg. Riv. Res. Man. 2:1-10.

Myers, K. W., and H. F. Horton. 1982. Temporal use of an Oregon estuary by hatchery and wild juvenile salmon. *In* V.S. Kennedy (editor), Estuarine comparisons, p. 377-392. Academic Press, New York, NY.

National Marine Fisheries Service. 1986. Fisheries of the United States, 1985. Current Fishery Statistics No. 8368. U.S. Dept. Comm., NOAA, Nat. Mar. Fish Serv., Nat. Fish. Stat. Prog., Washington, D.C., 122 p.

Netboy, A. 1980. The Columbia River salmon and steelhead trout, their fight for survival. Univ. Wash. Press, Seattle, WA, 180 p.

Nickelson, T. E. 1986. Influences of upwelling, ocean temperature, and smolt abundance on marine survival of coho salmon (*Oncorhynchus kisutch*) in the Oregon Production Area. Can. J. Fish. Aquat. Sci. 43:527-535.

Nickelson, T. E., M. F. Solazzi, and S. L. Johnson. 1986. Use of hatchery coho salmon (*Oncorhynchus kisutch*) presmolts to rebuild wild populations in Oregon coastal streams. Can. J. Fish. Aquat. Sci. 43:2443-2449.

Pacific Marine Fisheries Commission. 1986. 38th annual report of the Pacific Marine Fisheries Commission for the year 1985. Pac. Mar. Fish. Comm., Portland, OR, 36 p.

Parmenter, T., and R. Bailey. 1985. The Oregon oceanbook - an introduction to the Pacific Ocean off Oregon including its physical setting and living marine resources. Oregon Dept. Land Consv. Dev., Salem, OR, 85 p.

Pearce, T. A., J. H. Meyer, and R. S. Boomer. 1982. Distribution and food habits of juvenile salmon in the Nisqually estuary, Washington, 1979-1980. U.S. Dept. Int., Fish. Assis. Off., U.S. Fish. Wildl. Serv., Olympia, WA, 77 p.

Pearcy, W. G. 1984. Where do all the coho go? The biology of juvenile coho salmon off the coasts of Oregon and Washington. *In* W. G. Pearcy (editor), The influence of ocean conditions on the production of salmonids in the North Pacific, a workshop, p. 50-60. Sea Grant Coll. Prog., Oregon State Univ., Corvallis, OR (ORESU-W-83-001).

Pearcy, W. G., and J. P. Fisher. 1988. Migrations of coho salmon, *Oncorhynchus kisutch*, during their first summer in the ocean. Fish. Bull., U.S. 86(2):173-195.

Peterson, W. T., R. D. Brodeur, and W. A. Pearcy. 1983. Feeding habits of juvenile salmonids in the Oregon coastal zone in June 1979. Fish. Bull., U.S. 80(4):841-851.

Phillips, R. W., and H. J. Cambell. 1968. The embryonic survival of coho salmon and steelhead trout as influenced by some environmental conditions in gravel beds. *In* 14th Annual Report of the Pacific Marine Fisheries Commission, p. 60-73. Pac. Mar. Fish. Comm., Portland, OR.

Prakash, A. 1962. Seasonal changes in feeding of coho and chinook (spring) salmon in southern British Columbia waters. J. Fish. Res. Board Can. 19(5):851-866.

Purdy, J. E. 1989. The effects of brief exposure to aromatic hydrocarbons on feeding and avoidance behavior in coho salmon, *Oncorhynchus kisutch*. J. Fish Biol. 34:621-629.

Quinn, T. P. 1982. A model for salmon navigation on the high seas. *In* E. L. Brannon and E. O. Salo (editors), Proceedings of the salmon and trout migratory behavior symposium, p. 229-237. School Fish., Univ. Wash., Seattle, WA.

Reiser, D. W., and T. C. Bjornn. 1979. Habitat requirements of anadromous salmonids. *In* W. R. Meehan (editor), Influence of forest and rangeland management on anadromous fish habitat in western North America, p. 1-54. U.S. Forest Serv. Gen. Tech. Rep. PNW-96, Pac. Northw. Forest Range Exp. Sta., Portland, OR.

Richards, J. 1986. Estimated contribution and value of Columbia River salmon and steelhead during 1985. Unpubl. manuscr., NOAA, NMFS, Env. Tech. Ser. Div., Portland, OR.

Ricker, W. E. 1976. Review of the rate of growth and mortality of Pacific salmon in salt water, and noncatch mortality caused by fishing. J. Fish. Res. Board Can. 33:1483-1524.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Rombough, P. J. 1983. Effects of low pH on eyed embryos and alevins of Pacific salmon. Can. J. Fish. Aquat. Sci. 40:1575-1582.

Roos, J. F. 1960. Predation of young coho salmon on sockeye salmon fry at Chignik, Alaska. Tran. Am. Fish. Soc. 89(4):377-379.

Rounsefell, G. A. 1957. Fecundity of North American salmonidae. Fish. Bull., U.S. 57:451-468.

Salo, E. O., and W. H. Bayliff. 1958. Artificial and natural reproduction of silver salmon, *Oncorhynchus kisutch*, a Minter Creek, Washington. Wash. Dept. Fish., Res. Bull. No. 4, 75 p.

Schmidt, A. H., C. C. Grahm, and J. E. McDonald. 1979. Summary of literature on four factors associated with salmon and trout fresh water life history. Can. Fish Mar. Serv., MS Rep. 1487, 128 p.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can., Bull. No. 184, 966 p.

Scrivener, J. C., and M. J. Brownlee. 1989. Effects of forest harvesting on spawning gravel and incubation survival of chum (*Oncorhynchus keta*) and coho salmon (*O. kisutch*) in Carnation Creek, British Columbia. Can. J. Fish. Aquat. Sci. 46:681-696.

Shapovalov, L., and A. C. Taft. 1954. The life histories of the steelhead rainbow trout (*Salmo gairdneri gairdneri*) and silver salmon (*Oncorhynchus kisutch*) with special reference to Waddel Creek, California, and recommendations regarding their management. Cal. Fish Game, Fish Bull. No. 98, 375 p.

Shiino, S. M. 1976. List of common names of fishes of the world, those prevailing among English-speaking nations. Sci. Rep., Shima Marineland No. 4., Kashikojima, Japan, 262 p.

Sigler, J. W., T. C. Bjornn, and F. H. Everest. 1984. Effects of chronic turbidity on density and growth of steelheads and coho salmon. Trans. Am. Fish. Soc. 113(2):142-150.

Silliman, R. P. 1941. Fluctuations in the diet of chinook and silver salmon (*Oncorhynchus tshawytscha* and *O. kisutch*) off Washington, as related to the troll catch of salmon. Copeia 2:80-87.

Simenstad, C. A., and D. M. Eggers. 1981. Juvenile salmonid and baitfish distribution, abundance, and prey resources in selected areas of Grays Harbor, Washington. Fish. Res. Inst., Univ. Wash., Seattle, WA, 205 p. (FRI-UW-8816).

Simenstad, C. A., K. L. Fresh, and E. O. Salo. 1982. The role of Puget Sound and Washington coastal estuaries in the life history of Pacific salmon: an unappreciated function. *In* V. S. Kennedy (editor), Estuarine comparisons, p. 343-364. Academic Press, New York, NY.

Steine, R. A., P. A. Reimers, and J. D. Hall. 1972. Social interaction between juvenile coho (*Oncorhynchus kisutch*) and fall chinook salmon (*O. tshawytscha*) in Sixes River, Oregon. J. Fish. Res. Board Can. 29:1737-1748.

Takehama, S. (compiler). 1983. Statistical yearbook 1980. Internat. North Pac. Fish. Comm., Vancouver, B.C., Canada, 115 p.

Thomas, D. H. 1985. A possible link between coho (silver) salmon enhancement and a decline in central California Dungeness crab abundance. Fish. Bull., U.S. 83(4):682-691.

Thompson, K. 1972. Determining stream flows for fish life. *In* Instream flow requirement workshop, a transcript of proceedings, p. 31-46. Pacific Northw. River Basins Comm., Vancouver, WA.

Tschaplinski, P. J. 1982. Aspects of the population biology of estuary-reared and stream-reared juvenile coho salmon in Carnation Creek: a summary of current research. *In* G. Hartman (editor), Proceedings of the Carnation Creek workshop, a 10 year review, p. 289-305. Dept. Fish. Oceans, Pacific Biol. Sta., Nanaimo, B.C., Canada.

Tschaplinski, P. J., and G. F. Hartman. 1982. Winter distribution of juvenile coho salmon (*Oncorhynchus kisutch*) in Carnation Creek and some implications to overwinter survival. *In* G. Hartman (editor), Proceedings of the Carnation Creek workshop, a 10 year review, p. 273-286. Dept. Fish. Oceans, Pacific Biol. Sta., Nanaimo, B.C., Canada.

Varoujean, D. H., and D. R. Matthews. 1983. Distribution, abundance, and feeding habits of seabirds off the Columbia River, May-June, 1982. Rep. No. OIMB 83-1, Oregon Inst. Mar. Biol., Univ. Oregon, Charleston, OR, 25 p.

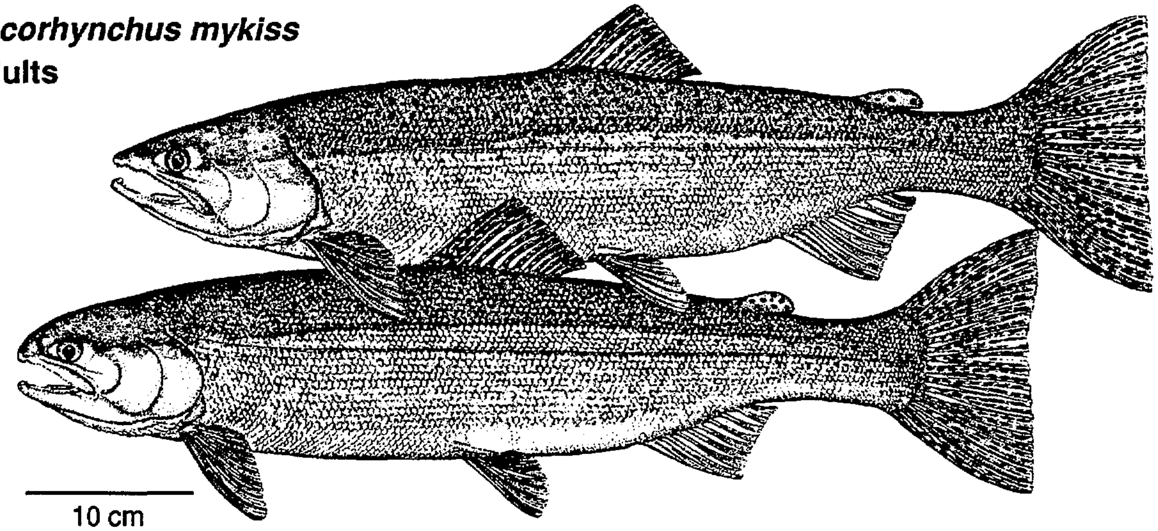
Washington, P. M. 1982. An analysis of factors affecting the production of coho salmon (*Oncorhynchus kisutch*) in the Columbia River. Ph.D. Thesis, Univ. Wash., Seattle, WA, 227 p.

Wright, S. G. 1968. The origin and migration of Washington's chinook and coho salmon. Info. Bookl. No. 1., Wash. Dept. Fish., Res. Div., Olympia, WA, 25 p.

Wydoski, R. S., and R. R.Whitney. 1979. Inland fishes of Washington, Univ. Wash. Press, Seattle, WA, 220 p.

Zaugg, W. S., and L. R. McLain. 1976. Influence of water temperature on gill sodium, potassium-stimulated ATPase activity in juvenile coho salmon (*Oncorhynchus kisutch*). Comp. Biochem. Physiol. 54A:419-421.

Steelhead



Oncorhynchus mykiss
Adults

Common Name: steelhead (rainbow trout)
Scientific Name: *Oncorhynchus mykiss*, previously known as *Salmo gairdneri* (Smith and Stearley 1989)
Other Common Names: Kamchatka salmon-trout, coastal rainbow trout, silver trout, salmon trout, ironhead, chromer, hardhead, steelie, sea-run rainbow trout, seatrout, silversides, or summer salmon (Pauley et al. 1986)
Classification
Phylum: Chordata
Class: Osteichthyes
Order: Salmoniformes
Family: Salmonidae

Value
Commercial: The peak commercial catch (3,900 t) of steelhead occurred in 1945 (Sheppard 1972). Presently, only Native Americans are allowed to fish commercially for steelhead in Oregon and Washington. In 1985, 342 t were landed in the Columbia River, caught primarily with gillnets (Bohn and McIsaac 1986).

Recreational: The steelhead is a highly-prized sport fish because of its size, fighting abilities, and excellent taste. Nearly all recreational fishing occurs in streams and rivers. In Washington, steelhead allocation is divided 50:50 between Native American and non-treaty fishermen (Clark 1985). Although much natural reproduction occurs, steelhead abundance has been augmented by hatchery production (Larson and Ward 1954); approximately 17 million steelhead smolts were planted in the Columbia River basin in 1987.

Indicator of Environmental Stress: This species is susceptible to changes in temperature, dissolved oxygen, substrate, water depth, water velocities, and suspended sediment (Reiser and Bjornn 1979, Bell 1984).

Ecological: The steelhead is a dominant fish in many coastal and inland streams/rivers.

Range
Overall: This species was originally found from northwestern Mexico to Kuskokwim River, Alaska. Now it is rarely found south of the Ventura River, California (Wydoski and Whitney 1979, Barnhart 1986). It is also found in Kamchatka and Okhotsk Sea drainages (McPhail and Lindsey 1970).

Within Study Area: The steelhead is found in all Pacific coast estuaries north of San Francisco Bay, California (Table 1) (Monaco et al. 1990). A small run occurs in Morro Bay, California (Horn 1980).

Life Mode
The steelhead is the anadromous form of the rainbow trout. Eggs and larvae (alevins) are benthic and infaunal. Young juveniles (fry and parr) are benthopelagic. Parr become pelagic and acquire a silver color when they transform into smolts (juveniles that migrate to the ocean). Steelhead parr are territorial and reside in streams and rivers from 1 to 4 years before transforming into smolts (Pauley et al. 1986). Smolts and ocean-dwelling and maturing juveniles (subadults), and adults are epipelagic (to depths of 23 m) (Okazaki 1983, Alaska Department of Fish and Game 1985). Subadults and adults in rivers and streams are bottom-oriented.

Habitat
Type: Eggs, alevins, fry, and parr are riverine. Smolts

Table 1. Relative abundance of steelhead in 32 U.S. Pacific coast estuaries.

	Winter					**Summer**					**Half-pounder**					**Fall**				
	Life Stage					*Life Stage*					*Life Stage*					*Life Stage*				
Estuary	A	S	J	L	E	A	S	J	L	E	A	S	J	L	E	A	S	J	L	E
Puget Sound	○		○			○		○												
Hood Canal	○		○			○		○												
Skagit Bay	○		○			○		○												
Grays Harbor	◉		◉																	
Willapa Bay	◉		◉																	
Columbia River	◉		◉			◉		◉												
Nehalem Bay	◉		◉																	
Tillamook Bay	○		○			○		○												
Netarts Bay	√		√																	
Siletz River	○		○			○		○												
Yaquina Bay	○		○																	
Alsea River	◉		○			○		○												
Siuslaw River	○		○																	
Umpqua River	○		○			○		○												
Coos Bay	◉		◉																	
Rogue River	◉		◉			◉		◉					◉							
Klamath River	○		◉			○		◉					○			○		◉		
Humboldt Bay	○		○																	
Eel River	○		◉			○		◉					○							
Tomales Bay	○		○																	
Cent. San Fran. Bay *	○		○																	
South San Fran. Bay																				
Elkhorn Slough																				
Morro Bay	√		√																	
Santa Monica Bay																				
San Pedro Bay																				
Alamitos Bay																				
Anaheim Bay																				
Newport Bay																				
Mission Bay																				
San Diego Bay																				
Tijuana Estuary																				
	A	S	J	L	E	A	S	J	L	E	A	S	J	L	E	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo Bays.

are riverine and estuarine. Fry and parr reside in areas that have cover and move to deeper water (such as pools) as they grow. Subadults and adults are found in coastal neritic waters during ocean residence and in riverine habitats during the spawning migration. Smolts, subadults, and "kelts" (spent adults) migrate through estuaries, but this species does not spend much time rearing in estuaries (Dawley et al. 1986).

Substrate: Eggs are found in redds made in areas containing medium and small gravel (<85 mm in diameter) (Shapovalov and Taft 1954, Alaska Department of Fish and Game 1985). Fry overwinter in stream areas where rubble is present. Sport-caught adults are often captured below spawning tributaries in swift-flowing water containing boulders (Scott and Crossman 1973). Oceanic juveniles and adults are probably not substrate-dependent.

Physical/Chemical Characteristics: The steelhead survives temperatures from 0-28°C, but at the upper limit water must be saturated with dissolved oxygen. The best temperatures for growth and development are 13-21°C (Moyle 1976). Freshwater life stages prefer temperatures of 10.0-12.8°C (Bell 1984); spawning occurs at 8.0-15.5°C (Wang 1986). The steelhead appears to grow best in slightly alkaline (pH = 7.0-8.0) waters (Moyle 1976). Eggs, alevins, fry, and parr are only found in fresh water. Juvenile salinity tolerance is determined by fish size and water temperature (Johnsson and Clarke 1988). Successful smoltification appears to be temperature-dependent (Zaugg et al. 1972, Adams et al. 1975). Smolts, subadults, and adults are found in fresh to marine waters. This species' ocean distribution is influenced by sea surface temperatures (Sutherland 1973).

Migrations and Movements: The steelhead has excellent homing abilities, so unique stocks or races have developed in specific drainage areas or streams (Moyle 1976). At least two races exist, as defined by when adult fish enter fresh water to spawn (Smith 1960). The winter run migrates upstream during fall, winter and early spring, while the summer run migrates during spring, summer, and early fall (Bell 1984). In the Columbia River and other large rivers with many tributaries, there are probably some steelhead entering year round. Adults appear to enter spawning streams during freshets (Pautzke and Meigs 1940). Juvenile steelhead normally rear in fresh water for 1-4 years (usually 2 or 3). They then migrate to the ocean (during spring-early summer) where they spend 1-5 years (usually 2 or 3) before returning to their natal river. In some northern California and southern Oregon Rivers (e.g., Klamath, Eel, and Rogue rivers), a "half-pounder" run exists. These are immature fish (weighing approximately one-half pound) that return to rivers and streams after just a few months in the ocean. They overwinter in streams and then migrate back to sea in the spring (Kesner and Barnhart 1972). Virtually all summer steelhead from these rivers make half-pounder migrations, but only a small percentage of winter steelhead do (Satterthwaite 1988). Half-pounders appear to stray significantly more than adults (Satterthwaite 1988). Smolts and adults spend little time in estuaries (Dawley et al. 1986). In the ocean, the steelhead is most abundant in the Gulf of Alaska and the eastern North Pacific (Sutherland 1973). In some California coastal streams, it may return only in the fall because river mouths are not open (i.e., of sufficient depth) until after heavy rains (Fry 1973).

Reproduction

Mode: The steelhead is gonochoristic and oviparous; eggs are fertilized externally. This species differs from all other members of the genus *Oncorhynchus* (except cutthroat trout, *O. clarki*) in that it is iteroparous.

Mating/Spawning: Winter-run steelhead typically spawn from December to June (Bell 1984), while summer steelhead (which return to fresh water in spring and summer) do not spawn until the following spring (Everest 1973). Spawning periods vary from north to south and by river system (Leider et al. 1984). Females build redds (up to 5.5 m^2)in areas with appropriate gravel and water flows. The mating male defends the female and redd from intruders and fertilizes the eggs as the female extrudes them (Shapovalov and Taft 1954). Spawning occurs day and night. Spent adults (kelts) may not die after spawning, but instead move back to the ocean and return a year or more later to their natal stream as "repeat spawners". The percentage of repeat spawners appears to vary according to stock, habitat quality, fishing intensity, and management practices (Shapovalov and Taft 1954, Withler 1966, Jones 1977, Barnhart 1986). Females survive spawning more often than males (Withler 1966); up to five times has been documented (Jones 1984).

Fecundity: Fecundity varies with female size and geographic origin (Buckley 1967). Most females produce an average of 1,500-5,000 eggs (Bell 1984), although large females may produce over 12,000 eggs (Moyle 1976).

Growth and Development

Egg Size and Embryonic Development: Eggs are spherical, non-adhesive, and 3.0-6.2 mm in diameter (Scott and Crossman 1973, Wang 1986). Embryonic development is indirect, external, and has an alevin (prolarval) stage. Eggs hatch in 18-101 days, depending on water temperature and oxygen concentrations (Silver et al. 1963, Carlander 1969).

Age and Size of Larvae: Alevins are 14.0 mm long at hatching, and grow to a length of 28.0 mm before becoming juveniles (Wang 1986).

Juvenile Size Range: Juvenile lengths are extremely variable (2.8-40.6 cm), depending on age and environmental conditions (Scott and Crossman 1973).

Age and Size of Adults: Wild fish usually spend 2-4 years in fresh water and 1-5 years at sea. Most hatchery fish spend only one year in fresh water. Most returning wild fish are 2/2, 2/3, 3/2, and 3/3 (years in freshwater/years in ocean), while hatchery fish are 1/1, 1/2, or 1/3 (Pauley et al. 1986). The more time spent in the ocean (during the initial ocean residency), usually the larger the fish is at maturity (Maher and Larkin 1954). Mature steelhead range from 45-70 cm in length and usually 2-5 kg (Shapovalov and Taft 1954, Wydoski and Whitney 1979, Jones 1984). However, steelhead can reach nine years (Washington 1970), 122 cm in length (Scott and Crossman 1973), and 19.5 kg (Hart 1973). Fish in the southern part of the range are smaller and spend less time at sea than those to the north (Withler 1966). Adults averaged 58.1 cm in length in California, 66.7 cm in Oregon, and 71.0 cm in southern British Columbia (Withler 1966).

Food and Feeding

Trophic Mode: Larvae feed on their yolk. Juveniles and adults are carnivorous.

Food Items: In freshwater and estuarine areas, primary food items include gammarid amphipods, small crustaceans, insects, and small fishes (Moyle 1976, Wydoski and Whitney 1979, Loch 1982, Dawley et al. 1986). In the ocean, juveniles and adults eat crustaceans, insects, squid, and fishes (LeBrasseur 1966, Wydoski and Whitney 1979).

Biological Interactions

Predation: In fresh water, this species is eaten by coho salmon (*O. kisutch*), char (*Salvelinus* spp.), mergansers, gulls, belted kingfisher (*Megaceryle alcyon*), bears, marten (*Martes americana*), otter (*Loutra canadensis*), and other steelhead. In the ocean, Pacific lamprey (*Lampetra tridentata*), seals, sea lions, and killer whale (*Orcinus orca*) prey upon this species (Scott and Crossman 1973, Simenstad et al. 1979).

Factors Influencing Populations: Freshwater life stages are often adversely affected by natural and human-induced habitat alterations. Most natural mortality occurs in the egg and larval stages (97%) (Shapovalov and Taft 1954). Factors which influence freshwater mortality include the number of eggs deposited, siltation, dissolved oxygen, water velocity, temperature, turbidity, depth, barriers, pollution, and competition with other fishes (Pauley et al. 1986). Survival of migrating smolts is size-dependent, with larger and older fish having higher survival rates (Pauley et al. 1986, Ward et al. 1989). "El Nino" (i.e., abnormally warm ocean conditions) also affects survival and growth (Pearcy et al. 1985). Overfishing has reduced some populations and the proliferation of hatchery smolts can adversely affect wild fish populations (Pauley et al. 1986). Hatchery fish do not have survival rates as high as wild fish nor are they as successful in producing smolted offspring (Chilcote et al. 1986). Many wild stocks in Washington appear to have reduced genetic diversity because of interbreeding with hatchery-produced fish (Reisenbichler and Phelps 1989). Some stocks are more resistant to disease than others (Wade 1986). Hence, interbreeding between wild and hatchery fish may produce fish with lower resistance to disease.

References

Adams, B. L., W. S. Zaugg, and L. R. McLain. 1975. Inhibition of salt water survival and Na-K-ATPase elevation in steelhead trout (*Salmo gairdneri*) by moderate water temperatures. Trans. Am. Fish. Soc. 104(4):766-769.

Alaska Department of Fish and Game. 1985. Alaska habitat management guide, southcentral region, Vol. I: Life histories and habitat requirements of fish and wildlife. Alaska Dept. Fish Game, Juneau, AK, 429 p.

Barnhart, R. A. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest) — steelhead. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.60), U.S. Army Corps Eng., TR EL-82-4, 21 p.

Bell, M. C. 1984. Fisheries handbook of engineering requirements and biological criteria. Fish Passage Development and Evaluation Program, Corps Eng., North Pac. Div., Portland, OR, 290 p. (Contract No. DACW57-79-M-1594 and DACW57-80-M-0567).

Bohn, B. R., and D. McIsaac. 1986. Columbia River fish runs and fisheries 1960-1985. Oreg. Dept. Fish Wildl. and Wash. Dep. Fish., Clackamas, OR, 77 p.

Buckley, R. V. 1967. Fecundity of steelhead trout, *Salmo gairdneri* from Alsea River, Oregon. J. Fish. Res. Board Can. 24(4):917-926.

Carlander, K. D. 1969. Handbook of freshwater fishery biology, Vol. 1. Iowa State Univ. Press, Ames, IA, 752 p.

Chilcote, M. W., S. A. Leider, and J. J. Loch. 1986. Differential reproductive success of hatchery and wild summer-run steelhead under natural conditions. Trans. Am. Fish. Soc. 115:726-735.

Clark, W. G. 1985. Fishing in a sea of court orders: Puget Sound salmon management ten years after the Boldt decision. N. Am. J. Fish. Manag. 5(3B):417-434.

Dawley, E. M., R. D. Ledgerwood, T. H. Blahm, C. W. Sims, J. T. Durkin, R. A. Kirn, A. E. Rankis, G. E. Monan, and F. J. Ossiander. 1986. Migrational characteristics, biological observations, and relative survival of juvenile salmonids entering the Columbia River estuary, 1966-1983. Final Rep. to Bonneville Power Adm., Contract DE-A179-84BP39652, 256 p. Available Northwest and Alaska Fish. Center, 2725 Montlake Blvd. E., Seattle, WA.

Everest, F. H. 1973. Ecology and management of summer steelhead in the Rogue River. Fish Res. Rep. 7, Oreg. State Game Comm., Portland, OR, 48 p.

Fry, D. H., Jr. 1973. Anadromous fishes of California. Calif. Dept. Fish Game, Sacramento, CA, 111 p.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. No. 180, 740 p.

Horn, M. H. 1980. Diel and seasonal variation in abundance and diversity of shallow-water fish populations in Morro Bay, California. Fish. Bull., U.S. 78(3):759-770.

Johnsson, J., and W. C. Clarke. 1988. Development of seawater adaptation in juvenile steelhead trout (*Salmo gairdneri*) and domesticated rainbow trout (*Salmo gairdneri*)-effects of size, temperature and photoperiod. Aquacult. 71:247-263.

Jones, D. E. 1977. Life history of steelhead trout and life history of sea-run cutthroat trout. Alaska Dept. Fish Game, Compl. Rep. AFS-42, 18:52-105.

Jones, D. E. 1984. A study of cutthroat-steelhead in Alaska. Alaska Dept. Fish Game, Anad. Fish Studies. Annual Performance Rep. 1983-84. Project AFS-42-11, 25:73-87..

Kesner W. D., and R. A. Barnhart. 1972. Characteristics of the fall-run steelhead trout (*Salmo gairdneri gairdneri*) of the Klamath River system with emphasis on the half-pounder. Calif. Fish Game 58(3):204-220.

Larson, R. W., and J. M. Ward. 1954. Management of steelhead trout in the state of Washington. Trans. Am. Fish. Soc. 84:261-274.

LeBrasseur, R. J. 1966. Stomach contents of salmon and steelhead trout in the northeastern Pacific Ocean. J. Fish. Res. Board Can. 23(1):85-100.

Leider, S. A., M. W. Chilcote, and J. J. Loch. 1984. Spawning characteristics of sympatric populations of steelhead trout (*Salmo gairdneri*): evidence for partial reproductive isolation. Can. J. Fish. Aquat. Sci. 41(10):1454-1462.

Loch, J. J. 1982. Juvenile and adult steelhead and sea-run cutthroat trout within the Columbia River estuary, 1980. 1982 Ann. Rep., Wash. Dept. Game, Olympia, WA, 47 p. plus appendices.

Maher, F. P., and P. A. Larkin 1954. Life history of steelhead trout of the Cilliwack River, British Columbia. Trans. Am. Fish. Soc. 84:27-38

McPhail, J. D., and C. C. Lindsey. 1970. Freshwater fishes of northwestern Canada and Alaska. Fish. Res. Board Can., Bull. No. 173, 381 p.

Monaco, M. E., R. L. Emmett, S. A. Hinton, and D. M. Nelson. 1990. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume I: data summaries. ELMR Rep. No. 4. Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 240 p.

Moyle, P. B. 1976. Inland fishes of California. Univ. Calif. Press, Berkeley, CA, 405 p.

Okazaki, T. 1983. Distribution and seasonal abundance of *Salmo gairdneri* and *Salmo mykiss* in the North Pacific Ocean. Japan. J. Ichthyol. 30(3):235-246.

Pauley, G. B., B. M. Bortz, and M. F. Shepard. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest) — steelhead trout. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.62). U.S. Army Corps Eng., TR EL-82-4, 24 p.

Pautzke, C. F., and R. C. Meigs. 1940. Studies on the life history of the Puget Sound steelhead trout (*Salmo gairdnerii*). Trans. Am. Fish. Soc. 70:209-220.

Pearcy, W., J. Fisher, R. Brodeur, and S. Johnson. 1985. Effects of El Nino on coastal nekton off Oregon and Washington, *In* W. S. Wooster and D. L. Fluharty (editors), El Nino North — El Nino effects in the subartic Pacific Ocean, p. 186-204. Wash. Sea Grant Publ. WSG-WO 85-3, Univ. Wash., Seattle, WA.

Reisenbichler, R. R., and S. R. Phelps. 1989. Genetic variation in steelhead (*Salmo gairdneri*) from the north coast of Washington. Can. J. Fish. Aquat. Sci. 46:66-73.

Reiser, D. W., and T. C. Bjornn. 1979. 1. Habitat requirements of anadromous salmonids. *In* W. R. Meehan (editor), Influence of forest and rangeland management on anadromous fish habitat in the western United States and Canada, p. 1-54. U.S. Forest Serv. Gen. Tech. Rep. PNW-96, Pac. Northw. Forest Range Exp. Sta., Portland, OR.

Satterthwaite, T. D. 1988. Influence of maturity on straying rates of summer steelhead into the Rogue River, Oregon. Calif. Fish Game 74(4):203-207.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can., Bull. No. 184, 966 p.

Shapovalov, L., and A. C. Taft. 1954. The life histories of the steelhead rainbow trout (*Salmo gairdneri gairdneri*) and silver salmon (*Oncorhynchus kisutch*) with special reference to Waddell Creek, California, and recommendations regarding their management. Calif. Fish. Game, Fish Bull. 98, 375 p.

Sheppard, D. 1972. The present status of the steelhead trout stocks along the Pacific coast. *In* D. H. Rosenberg (editor). A review of the oceanography and renewable resources of the northern Gulf of Alaska, p. 519-556. Univ. Alaska Inst. Mar. Sci. Rep. R72-73, Sea Grant Rep. 73-3, Fairbanks, AK.

Silver, S. J., C. E. Warren, and P. Doudoroff. 1963. Dissolved oxygen requirements of developing steelhead trout and chinook salmon embryos at different water velocities. Trans. Am. Fish. Soc. 92(4):327-341.

Simenstad, C. A., B. S. Miller, C. F. Nyblade, K. Thornburgh, and L. J. Bledsoe. 1979. Food web relationships of northern Puget Sound and the Strait of Juan de Fuca. U.S. Interagency (NOAA, EPA) Energy/Environ. Res. Dev. Prog. Rep., EPA-600/7-79-259, Wash., D.C., 335 p.

Smith, G. R., and R. F. Stearley. 1989. The classification and scientific names of rainbow and cutthroat trouts. Fisheries 14(1):4-10.

Smith, S. B. 1960. A note on two stocks of steelhead trout (*Salmo gairdneri*) in Capilano River, British Columbia. J. Fish. Res. Board Can. 17:739-742.

Sutherland, D. F. 1973. Distribution, seasonal abundance, and some biological features of steelhead trout, *Salmo gairdneri*, in the North Pacific Ocean. Fish. Bull., U.S. 73(3):787-826.

Wade, M. 1986. The relative effects of *Ceratomyxa shasta* on crosses of resistant and susceptible stocks of summer steelhead. Info. Rep. 86-6, Oreg. Dept. Fish Wildl., Corvallis, OR, 16 p.

Wang, J. C. S. 1986. Fishes of the Sacramento-San Joaquin estuary and adjacent waters, California: A guide to the early life histories. Tech. Rep. No. 9. Interagency ecological study program for the Sacramento-San Joaquin estuary. Calif. Dept. Water Res., Calif. Dept. Fish Game, U.S. Bureau Reclam., and U.S. Fish Wildl. Serv., various pagination.

Ward, B. R., P. A. Slaney, A. R. Facchin, and R. W. Land. 1989. Size-biased survival in steelhead trout (*Oncorhynchus mykiss*): back-calculated lengths from adults' scales compared to migrating smolts at the Keogh River, British Columbia. Can. J. Fish. Aquat. Sci. 46(11):1853-1858.

Washington, P. 1970. Occurrence on the high seas of a steelhead trout in its ninth year. Calif. Fish Game 56(4):312-314.

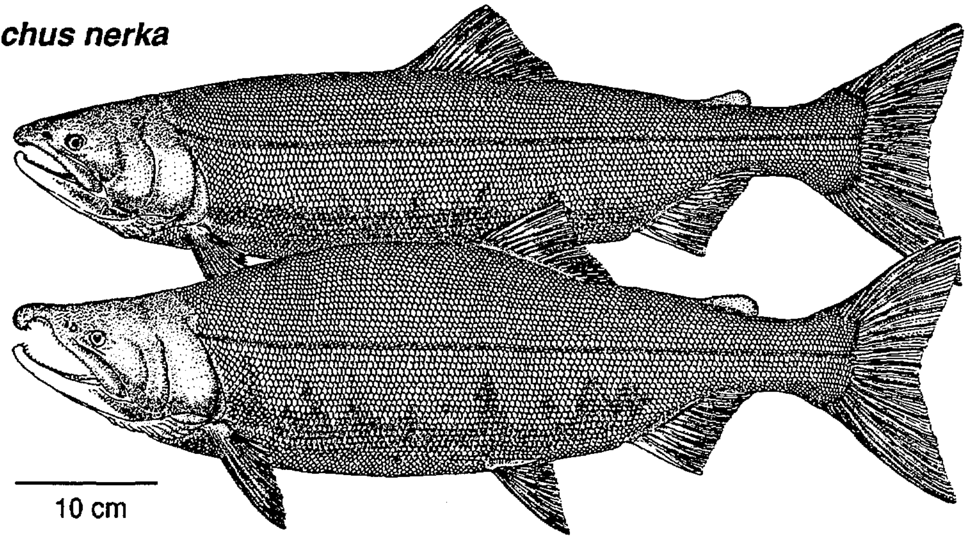
Withler, I. L. 1966. Variability in life history characteristics of steelhead trout (*Salmo gairdneri*) along the Pacific coast of North America. J. Fish. Res. Board Can. 23(3):365-393.

Wydoski, R. S., and R. R. Whitney. 1979. Inland fishes of Washington. Univ. Wash. Press, Seattle, WA, 220 p.

Zaugg, W. S., B. L. Adams, and L. R. McLain. 1972. Steelhead migration: potential temperature effects as indicated by gill adenosine triphosphatease activities. Science 176:415-416.

Sockeye salmon

Oncorhynchus nerka
Adults



Common Name: sockeye salmon
Scientific Name: *Oncorhynchus nerka*
Other Common Names: red salmon, kokanee (landlocked populations), blueback, redfish, Fraser River salmon, nerka, sau-aui salmon, sukkegh salmon, Kennerly's salmon, kootenary salmon, silver trout, little redfish, princess trout (Shiino 1976)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Salmoniformes
Family: Salmonidae

Value

Commercial: The sockeye salmon is a prized commercial fish because of its excellent flesh color and flavor (Scott and Crossman 1973). It is second only to pink salmon (*O. gorbuscha*) in U.S. salmonid landings, but first in value. In 1985, U.S. fishermen received over $239 million for their sockeye salmon catch (National Marine Fisheries Service 1986). In 1978, U.S. fishermen caught over 19 million sockeye salmon, primarily in Alaska (Forrester 1981). The sockeye salmon is caught throughout the North Pacific (Japan to Oregon), with U.S. fisheries catching most (Fredin 1980). U.S. commercial catches of sockeye salmon have fluctuated dramatically in the past, primarily due to fluctuations in the important Bristol Bay fishery in Alaska (Fredin et al. 1977). The sockeye is primarily captured by gill net and purse seine (occasionally by trolling), primarily during June to August (peak in July).

Recreational: The sockeye salmon (anadromous variety) does not take a hook as readily as other salmonids. Hence, it is not considered an important recreational salmonid in the study area (although large catches do occur in Alaska) (Pacific Marine Fisheries Commission 1987). However, the landlocked variety (kokanee) is a very important freshwater sport fish in California, Oregon, Washington, Idaho, and Alaska (Scott and Crossman 1973, Moyle 1976).

Indicator of Environmental Stress: Upstream migrations may be disrupted when waters have hydrocarbon concentrations of 1-10 ppb (or greater) (Martin et al. 1990). See "Factors Influencing Populations".

Ecological: This species is the third most abundant salmonid in the North Pacific [behind pink and chum salmon (*O. keta)*] (Fredin et al. 1977).

Range

Overall: This is a boreal Pacific species. In Asia, it is found from the southern Kurile Islands to the northern sea coast of the U.S.S.R. In North America, important spawning populations occur from the Columbia River in the south to northern Alaska in the north (French et al. 1976). The oceanic distribution ranges from the eastern Bering Sea south to lat. 45°N, and is associated with the California Current as far south as Los Angeles Harbor (French et al. 1976, Eschmeyer et al. 1983).

Within Study Area: The Columbia River is the southern limit of all sizable runs (Table 1) (Foerster 1968). The sockeye salmon is abundant in Puget Sound (Wydoski and Whitney 1979). Two runs also exist on the northern coast of Washington in Lake Quinault and Lake Ozette (Pauley et al. 1989).

Life Mode

This is an anadromous species with a landlocked variety (kokanee). Eggs and larvae (alevins) are

Table 1. Relative abundance of sockeye salmon in 32 U.S. Pacific coast estuaries.

Estuary	A	S	J	L	E
Puget Sound	◉		◉		
Hood Canal					
Skagit Bay	√		√		
Grays Harbor					
Willapa Bay					
Columbia River	○		○		
Nehalem Bay					
Tillamook Bay					
Netarts Bay					
Siletz River					
Yaquina Bay					
Alsea River					
Siuslaw River					
Umpqua River					
Coos Bay					
Rogue River					
Klamath River					
Humboldt Bay					
Eel River					
Tomales Bay					
Cent. San Fran. Bay *					
South San Fran. Bay					
Elkhorn Slough					
Morro Bay					
Santa Monica Bay					
San Pedro Bay					
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Life Stage

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

benthic and infaunal. Young juveniles (fry and parr) are benthopelagic. Parr become pelagic before they transform into smolts (juveniles that migrate to the ocean). Smolts and ocean-dwelling and maturing juveniles (subadults), and adults are pelagic. Subadults and adults in rivers and streams are bottom-oriented.

Habitat

Type: Eggs, alevins and fry are primarily riverine (some lacustrine); if in lacustrine environments they occur where there is freshwater flow through the redd (Wydoski and Whitney 1979). Parr normally rear in lakes for 1-2 years, feeding primarily in the upper 20 m. However, in some populations parr do not rear in lakes, but move downstream after emerging from the gravel (Foerster 1968). Anadromous stocks usually smoltify after 1-2 years, but kokanee remain and complete their life cycle without going to sea (Moyle 1976). Smolts are riverine and estuarine. Ocean-dwelling juveniles stay in neritic and epipelagic areas until fall and early winter, then move to oceanic areas (Hartt and Dell 1986). While in the ocean, they reside in the upper 61 m (French et al. 1976). Adults are primarily estuarine and riverine.

Substrate: Eggs and alevins reside beneath fine gravel/cobble. Fry and adults occur in the water column, but are associated with gravel bottoms. Parr, smolts, and juveniles live in the water column (Foerster 1968, Hart 1973).

Physical/Chemical Characteristics: Eggs, alevins, fry, and parr live in fresh water, while smolts and adults inhabit fresh to euhaline waters. Ocean-dwelling juveniles do not appear to be affected by salinity changes, but are sensitive to temperature variations (French et al. 1976). Normal spawning temperatures range from 3-7°C (Ricker 1966, Foerster 1968). Adult sockeye salmon migrate in river temperatures of 7.2-15.6°C (Reiser and Bjornn 1979). Recommended incubation guidelines are: dissolved oxygen at or near saturation (lower level of 5.0 mg/l); water temperatures of 4-14°C; apparent velocity (within the redd) more than 20 cm/hr; and spawning sediment composed of less than 25% (by volume) fines (≤6.4 mm) (Reiser and Bjornn 1979). The upper lethal water temperature is 24.4°C (Brett 1952), but growth ceases at temperatures above 20.3°C (Bell 1984). Ocean-dwelling juveniles reside in temperatures of 1.0-13.0°C (French et al. 1976). Low pH can affect the viability of embryos and alevins (Rombough 1983), and nitrogen supersaturation can adversely affect outmigrating smolts (Ebel et al. 1971).

Migrations and Movements: Kokanee do not migrate to sea, but anadromous stocks migrate extensively. Sockeye salmon generally spend 1-2 years rearing in freshwater lakes and 2-3 years in the ocean. However, depending on geographic area, they may spend 0-4 years in fresh water before migrating, and up to 4 years in the ocean (Foerster 1968, Fredin et al. 1977). After emerging from the redd (January-June), fry typically move upstream or downstream into a nursery lake, although some may move directly to estuaries (Foerster 1968). Once in lakes, young sockeye salmon live for approximately 1 month in the littoral zone before moving out into open lake waters, where they reside until they migrate to sea (McCart 1966, Foerster 1968). While residing in lakes, juveniles undertake vertical migrations, probably related to food availability and predation risks (Clark and Levy 1988). Smolts begin to migrate out of lakes when temperatures rise to 4-7°C (usually March-July) and normally at night (Hart 1973). One exception is in Lake Washington, Washington, where smolts migrate both day and night (Simenstad et al. 1982). Sockeye salmon smolts in the Pacific Northwest outmigrate primarily between April and early June (Anas and Gauley 1956, Simenstad et al. 1982). Smolts are 40-130 mm in length when they enter estuaries and are guided to ocean waters by salinity gradients (Healey 1980, Straty and Jaenicke 1980). Residence time in estuaries is shorter than other salmonid species (Healey 1982, Simenstad et al. 1982). Upon entering the ocean, juvenile sockeye salmon (not including Bristol Bay stocks) move north, staying within the coastal belt of the Gulf of Alaska until late-fall or early-winter when they disperse offshore, moving west and south (French et al. 1976, Hartt and Dell 1986). In spring and summer, they move north, but turn south and west again in winter (French et al. 1976). Migrants initially travel 3.9-30.2 km/day (Hartt and Dell 1986) and older fish normally travel 13-33 km/day. Maturing fish may travel 46-56 km/day (French et al. 1976). Sockeye salmon show some diel migrations, moving to the surface at night and deeper during the day (French et al. 1976). North American sockeye salmon populations have a single spawning run, occurring from May to December (depending on geographic location). Pacific Northwest adult sockeye salmon migrate into fresh water during June to August (peaking in early July) (Simenstad et al. 1982, Bohn and McIsaac 1986). Oceanic migration is thought to be guided by a map-compass-calendar system (Quinn 1982), but the natal stream is located by olfaction (Brannon 1982).

Reproduction

Mode: The sockeye salmon is gonochoristic, oviparous, and semelparous (all adults die soon after spawning). Eggs are fertilized externally.

Mating/Spawning: Pacific Northwest stocks spawn from August to December, with an October peak (Wydoski and Whitney 1979, Bell 1984). Except for a few instances, the sockeye salmon spawns in rivers and streams that connect to lakes. Spawning occurs mostly in riffle areas in streams, but also in some lakes down to 30 m (Ricker 1966); spawning usually at depths <8 m (Moyle 1976). Like other salmonids, the female builds the redd by facing upstream and thrashing her caudal fin against the substrate. Males may also make digging movements (McCart 1969). Males and females are territorial, defending the nest site against members of the same sex. During spawning, the male and female place themselves in the redd with vents close together and extrude eggs and sperm with their mouths agape and bodies quivering (Foerster 1968). Females will repeat the digging slightly upstream, burying the previous eggs in the process and creating a new "pocket". A redd typically has 3-10 pockets (usually 5) (Hart 1973) and averages in size at about 1.8 m^2 (Fredin et al. 1977). Males and females may spawn with several different fish. Females defend the nest site after spawning until they tire and die. During their spawning migration, sockeye salmon undergo sexually dimorphic changes; both sexes developing bright red bodies and green heads, while males develop a humped back, hooked snout, and large teeth (Foerster 1968).

Fecundity: Fecundity depends on the size of the female and the stock (Rounsefell 1957, Manzer and Miki 1986). The anadromous sockeye salmon has from 2,200-4,300 eggs per female with 3,500-3,600 eggs per female being average (Hart 1973, Fredin et al. 1977, Bell 1984).

Growth and Development

Egg Size and Embryonic Development: Scott and Crossman (1973) and McPhail and Lindsey (1970) reported sockeye salmon egg diameters of 4.5-5.0 mm, whereas Bell (1984) reported eggs 5.5-6.0 mm in diameter. Embryonic development is indirect and external. Hatching can take slightly less than 50 days or more than 5 months, depending on temperature (Hart 1973, Scott and Crossman 1973).

Age and Size of Larvae: Size at hatching is not reported but probably 20-25 mm total length (TL). After hatching, alevins stay in the gravel for 2-3 weeks (or up to 4 months, depending on temperature) and emerge from March to June (Hanamura 1966, Ricker 1966, Hart 1973, Scott and Crossman 1973, Wydoski and Whitney 1979). At approximately 30 mm TL, alevins become fry (Hanamura 1966, Alaska Department Fish and Game 1985).

Juvenile Size Range: Juveniles range in size from 3 cm to at least 46 cm TL.

Age and Size of Adults: Adults average 63.5 cm TL (50.0-84.0 cm), weighing an average of 3.0-4.0 kg (Fredin et al. 1977, Bell 1984, Kessler 1985) and 3-8 years old (average of 4 years) at spawning (Foerster 1968).

Food and Feeding

Trophic Mode: Larvae feed on their yolk. Juveniles and adults are carnivorous (primarily planktivorous).

Food Items: Spawning adults typically do not feed, however, some will feed when held in net pens. All free-swimming life stages are principally plankton feeders. Planktonic Crustacea, cladocerans (*Daphnia* spp., *Bosmina* spp., etc.), and copepods (*Epischura* spp., *Cyclops* spp., etc.) are eaten, along with a variety of terrestrial and aquatic insects (Ricker 1966, Foerster 1968, Hart 1973, Scott and Crossman 1973, Doble and

Eggers 1978). During their downstream migration, smolts may feed heavily on gammarid amphipods (Muir and Emmett 1988). In estuaries, euphausiids, fish larvae, juvenile shrimp, insects, amphipods, and mysids are eaten (Levy and Yesaki 1982, Simenstad et al. 1982). In the ocean, juvenile sockeye salmon feed on euphausiids, hyperiid amphipods, copepods, decapod larvae, pteropods, juvenile and larval fish, squid, and other invertebrates. The primary prey consumed depends on the location, time of day, and fish's age (Andrievskaya 1957, Allen and Aron 1958, Ito 1964, LeBrasseur 1966, Foerster 1968, Pearcy et al. 1984). In lakes and in the ocean, juvenile sockeye salmon appear to feed primarily at dusk or at night (Doble and Eggers 1978, Pearcy et al. 1984). Parr may not feed during the winter in lakes (Doble and Eggers 1978). Juveniles (ocean- and lake-dwelling) feed near the surface, except in lakes when surface temperatures are high (Foerster 1968).

Biological Interactions

Predation: Primary fish predators of fry and parr in fresh water are coho salmon (*O. kisutch*), cutthroat trout (*O. clarki*), char (*Salvelinus* spp.), rainbow trout (*O. mykiss*), Dolly Varden (*Salvelinus malma*), lake trout (*Salvelinus namaycush*), lake whitefish (*Coregonus clupeaformis*), mountain whitefish (*Prosopium williamsoni*), northern squawfish (*Ptychocheilus oregonensis*), burbot (*Lota lota*), and sculpins (Foerster 1968, Fresh 1984). Gulls, common loon (*Gavia immer*), red-necked grebe (*Podiceps grisegena*), common merganser (*Mergus merganser*), belted kingfisher (*Megaceryle alcyon*), terns, and large predatory birds [osprey (*Pandion haliaetus*) and bald eagle (*Haliaeetus leucocephalus*)] are important avian predators (Fresh 1984). Marine predators include lamprey (*Lampetra* spp.), spiny dogfish (*Squalus acanthias*), salmon shark (*Lamna ditropis*), other salmonids, harbor seal (*Phoca vitulina*), beluga whale (*Delphinapterus leucas*), killer whale (*Orcus orcinus*), and Dall's porpoise (*Phocoenoides dalli*) (Simenstad et al. 1979, Fiscus 1980). Bears and other mammals prey on adults during the spawning migration (Foerster 1968).

Factors Influencing Populations: Primary factors influencing populations appear to be (1) overfishing, (2) reduced production in freshwater environments, and (3) reduced production in marine environments (Foerster 1968, Peterman 1980). Overfishing reduces freshwater escapement and thus limits egg production (Foerster 1968). Mortality in fresh water during early life stages is usually high. Foerster (1968) reported that egg to smolt survival ranged from 0.40-8.52%. This mortality is a result of poor water quality (high and low temperatures, turbidity, sedimentation, velocities, pollutants, etc.) which can be a result of poor forest practices, industrial waste, mining and refining effluents, agriculture practices, and urban development. Physical disturbance of the redd (by erosion, subsequent spawners, ice scour) and predation can also diminish freshwater production (Foerster 1968, Hart 1973). River obstructions such as dams (manmade and natural, such as Hell's Gate and the Fraser River rock slide of 1913) can affect upstream and downstream migrations (Foerster 1968). Columbia River sockeye salmon runs have diminished primarily as a result of dams and irrigation diversions of spawning rivers (Mullan 1986). The abundance of food relative to parr numbers in reservoirs and lakes also affects production; when sockeye parr densities are high, food may limit their growth which in turn can reduce smolt size and marine survival (Foerster 1954, 1968, Kyle et al. 1988). Nutrient fertilization of lakes has been attempted to increase lake primary production and zooplankton standing crop and thus juvenile sockeye salmon growth and survival (LeBrasseur et al. 1978, Hyatt and Stockner 1985). Predators and competition can reduce populations in reservoirs (Foerster 1968). Ocean conditions may also reduce production as a result of density-dependent mortality (Peterman 1980). The Japanese high seas fishery (located west of long. 174°W) intercepts many North American sockeye salmon (Fredin et al. 1977). This fishery took over 46 million North American sockeye over a 20 year period. This catch, together with the accidental mortalities and lost additional weight gain before North American harvest, represents a substantial loss to U.S. fishermen (Ricker 1976, Fredin et al. 1977). Hatchery releases of sockeye salmon are used to maintain this species' abundance in some areas (Wahle and Smith 1979).

References

Alaska Department of Fish and Game. 1985. Alaska habitat management guide, southcentral region, Vol. 1: Life histories and habitat requirements of fish and wildlife. Alaska Dept. Fish Game, Juneau, AK, 429 p.

Allen, G. H., and W. Aron. 1958. Food of salmonid fishes of the western North Pacific Ocean. U.S. Fish. Wildl., Spec. Sci. Rep. Fish. No. 237, 11 p.

Anas, R. E., and J. R. Gauley. 1956. Blueback salmon, *Oncorhynchus nerka*, age and length at seaward migration past Bonneville Dam. U.S. Fish Wildl. Serv., Spec. Sci. Rep. Fish. No. 185, 46 p.

Andrievskaya, L. D. 1957. Pitanie tikhookeanskikh lososei v severo-zapadnoi chasti tikhovo okeana (The food of Pacific salmon in the northwestern Pacific Ocean). [In Russ.] From: Materialy po biologii morskovo perioda zhizni dalnevostochnykh lososei, p. 64-75. Publ. by: Vses Nauchno-Issled. Inst. Morsk. Rybn. Khoz. Okeanogr. (VNIRO), Moscow. (Fish. Res. Board Can., Trans. Ser. No. 821).

Bell, M. C. 1984. Fisheries handbook of engineering requirements and biological criteria. Fish Passage Development and Evaluation Program, U.S. Army Corps Eng., North Pac. Div., Portland, OR, 290 p. (Contract No. DACW57-79-M-1594 and DACW57-80-M-0567).

Bohn, B., and D. McIsaac. 1986. Status report, Columbia River fish runs and fisheries, 1960-85. Oreg. Dept. Fish. Wildl. and Wash. Dept. Fish., Clackamas, OR, 77 p.

Brannon, E. L. 1982. Orientation mechanisms of homing salmonids. *In* E. L. Brannon and E. L. Salo (editors), Proceedings of the salmon and trout migratory behavior symposium, p. 219-227. School Fish., Univ. Wash., Seattle, WA.

Brett, J. R. 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus.* J. Fish. Res. Board Can. 9:265-323.

Clark, C. W., and D. A. Levy. 1988. Diel vertical migrations by juvenile sockeye salmon and the antipredation window. Am. Nat. 131(2):271-290.

Doble, B. D., and D. M. Eggers. 1978. Diel feeding chronology, rate of gastric evacuation, daily ration, and prey selectivity in Lake Washington juvenile sockeye salmon (*Oncorhynchus nerka*). Trans. Am. Fish. Soc. 107(1):36-45.

Ebel, W. J., E. M. Dawley, and B. H. Monk. 1971. Thermal tolerance of juvenile Pacific salmon and steelhead trout in relation to supersaturation of nitrogen gas. Fish. Bull., U.S. 69(4):833-843.

Eschmeyer, W. N., W. S. Herald, and H. Hammann. 1983. A field guide to Pacific coast fishes of North America. Houghton Mifflin Co., Boston, MA, 336 p.

Fiscus, C. H. 1980. Marine mammal - salmonid interactions: a review. *In* W. J. McNeil and D. C. Himsworth (editors), Salmonid ecosystems of the North Pacific, p. 121-132. Oregon State Univ. Press, Corvallis, OR.

Foerster, R. E. 1954. On the relation of adult sockeye salmon (*Oncorhynchus nerka*) returns to known smolt seaward migrations. J. Fish. Res. Board Can. 11(4):339-350.

Foerster, R. E. 1968. The sockeye salmon, *Oncorhynchus nerka.* Fish. Res. Board Can., Bull No. 162, 422 p.

Forrester, C. R. 1981. Statistical yearbook 1978. Internat. North Pac. Fish. Comm., Vancouver, Canada, 123 p.

Fredin, R. A. 1980. Trends in North Pacific salmon fisheries. *In* W. J. McNeil and D. C. Himsworth (editors), Salmonid ecosystems of the North Pacific, p. 59-119. Oregon State Univ. Press, Corvallis, OR.

Fredin, R. A., R. L. Major, R. G. Bakkala, and G. K. Tanonaka. 1977. Pacific salmon and the high seas salmon fisheries of Japan. NWAFC Proc. Rep., Northwest and Alaska Fish. Cent., Nat. Mar. Fish. Serv., NOAA, Seattle, WA, 324 p.

French, R., H. Bilton, M. Osakao, and A. Hartt. 1976. Distribution and origin of sockeye salmon (*Oncorhynchus nerka*) in offshore waters of the North Pacific Ocean. Internat. North Pac. Fish. Comm., Bull. No. 34, 113 p.

Fresh, K. L. 1984. Evaluation of potential species interaction effects in the planning and selection of salmonid enhancement projects. Report prepared by the species interaction work group of the enhancement planning team). NOAA, Nat. Mar. Fish. Serv., Seattle, WA, 80 p.

Hanamura, N. 1966. Sockeye salmon in the far east. Internat. North Pac. Fish. Comm., Bull. No. 18: 1-27.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. No. 180, 740 p.

Hartt, A. C., and M. B. Dell. 1986. Early oceanic migrations and growth of juvenile Pacific salmon and steelhead trout. Internat. North Pac. Fish. Comm., Bull. No. 46:1-105.

Healey, M. C. 1980. The ecology of juvenile salmon in Georgia Strait, British Columbia. *In* W. J. McNeil and D. C. Himsworth (editors), Salmonid ecosystems of the North Pacific, p. 203-229. Oregon State Univ. Press, Corvallis, OR.

Healey, M. C. 1982. Juvenile Pacific salmon in estuaries: the life support system. *In* V. S. Kennedy (editor), Estuarine comparisons, p. 315-341. Academic Press, New York, NY.

Hyatt, K. D., and J. G. Stockner. 1985. Responses of sockeye salmon (*Oncorhynchus nerka*) to fertilization of British Columbia coastal lakes. Can. J. Fish. Aquat. Sci. 42(2):320-331.

Ito, J. 1964. Food and feeding habits of Pacific salmon (genus *Oncorhynchus*) in their oceanic life. Bull. Hokkaido Reg. Fish. Res. Lab. 29:85-97. (Fish. Res. Board Can., Transl. Ser. No. 1309.).

Kessler, D. W. 1985. Alaska's saltwater fishes and other sea life. Alaska Northw. Publ. Co., Anchorage, AK, 358 p.

Kyle, G. G., J. P. Koenings, and B. M. Barrett. 1988. Density-dependent, trophic level responses to an introduced run of sockeye salmon (*Oncorhynchus nerka*) at Frazer Lake, Kodiak Island, Alaska. Can. J. Fish. Aquat. Sci. 45(5):856-867.

LeBrasseur, R. J. 1966. Stomach contents of salmon and steelhead trout in the northeastern Pacific Ocean. J. Fish. Res. Board Can. 23(1):85-100.

LeBrasseur, R. J., C. D. McAllister, W. E. Barraclough, O. D. Kennedy, J. Manzer, D. Robinson, and K. Stephens. 1978. Enhancement of sockeye salmon (*Oncorhynchus nerka*) by lake fertilization in Great Central Lake: summary report. J. Fish. Res. Board Can. 35(12):1580-1596.

Levy, D. A., and I. Yesaki. 1982. Graphical methods for fish stomach analysis. *In*, G. M. Cailliet and C. A. Simenstad (editors), Gutshop 81, fish food habits studies. Proceedings of the third Pacific workshop, p. 16-23. Wash. Sea Grant, Univ. Wash., Seattle, WA.

Manzer, J. I., and I. Miki. 1986. Fecundity and egg retention of some sockeye salmon (*Oncorhynchus nerka*) stocks in British Columbia. Can. J. Fish. Aquat. Sci. 43(8):1643-1655.

Martin, D. J., C. J. Whitmus, L. A. Brocklehurst, A. E. Nevissi, J. M Cox, and K. Kurrus. 1990. Effects of petroleum contaminated waterways on migratory behavior of adult pink salmon. Outer Contin. Shelf Envir. Asses. Prog., Final Rep. Principal Invest. 66:281-529

McCart, P. 1966. Behavior and ecology of sockeye salmon in the Babine River. J. Fish. Res. Board Can. 24(2):375-428.

McCart, P. 1969. Digging behavior of *Oncorhynchus nerka* spawning in streams at Babine Lake, British Columbia. *In* T. G. Northcote (editor), Symposium on salmon and trout in streams. H. R. MacMillan lectures in fisheries, p. 39-51. Inst. Fish., Univ. British Columbia, Vancouver, Canada.

McPhail, J. D., and C. C. Lindsey. 1970. Freshwater fishes of northwestern Canada and Alaska. Fish. Res. Board Can., Bull. No. 173, 381 p.

Moyle, P. B. 1976. Inland fishes of California. Univ. Calif. Press, Berkeley, CA, 405 p.

Muir, W. D., and R. L. Emmett. 1988. The food habits of migrating salmonid smolts passing Bonneville Dam in the Columbia River, 1984. Reg. Riv. Res. Man. 2:1-10.

Mullan, J. W. 1986. Determinants of sockeye salmon abundance in the Columbia River, 1880's-1982: a review and synthesis. U.S. Fish Wildl. Serv. Biol. Rep. 86(12):1-136 p.

National Marine Fisheries Service. 1986. Fisheries of the United States, 1985. Current Fishery Statistics No. 8368. U.S. Dept. Comm., NOAA, Nat. Mar. Fish Serv., Nat. Fish. Stat. Prog., Washington, D.C., 122 p.

Pacific Marine Fisheries Commission. 1987. 40th annual report of the Pacific Marine Fisheries Commission for the year 1986. Pac. Mar. Fish. Comm., Portland, OR, 29 p.

Pauley, G. B, R. Risher, and G. L. Thomas. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest)—sockeye salmon. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.116), U.S. Army Corps Eng. TR EL-82-4, 22 p.

Pearcy, W., T. Nishiyama, T. Fujii, and K. Masuda. 1984. Diel variations in the feeding habits of Pacific salmon caught in gill nets during a 24-hour period in the Gulf of Alaska. Fish. Bull., U.S. 82(2):391-399.

Peterman, R. M. 1980. Testing for density-dependent marine survival in Pacific salmonids. *In* W. J. McNeil and D. C. Himsworth (editors), Salmonid ecosystems of the North Pacific, p. 1-24. Oregon State Univ. Press, Corvallis, OR.

Quinn, T. P. 1982. A model for salmon navigation on the high seas. *In* E. L. Brannon and E. O. Salo (editors), Proceedings of the salmon and trout migratory behavior symposium, p. 229-237. School Fish., Univ. Wash., Seattle, WA.

Reiser, D. W., and T. C. Bjornn. 1979. Habitat requirements of anadromous salmonids. *In* W. R. Meehan (editor), Influence of forest and rangeland management on anadromous fish habitat in the western United States and Canada, p. 1-54. U.S. Forest Serv., Gen. Tech. Rep. PNW-96, Pac. Northw. Forest Range Exp. Sta., Portland, OR.

Ricker, W. E. 1966. Sockeye salmon in British Columbia. Internat. North Pac. Fish. Comm., Bull. No. 18:59-70.

Ricker, W. E. 1976. Review of the rate of growth and mortality of Pacific salmon in salt water, and noncatch mortality caused by fishing. J. Fish. Res. Board Can. 33:1483-1524.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc., Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Rombough, P. J. 1983. Effects of low pH on eyed embryos and alevins of Pacific salmon. Can. J. Fish. Aquat. Sci. 40:1575-1582.

Rounsefell, G. A., 1957. Fecundity of North American Salmonidae. Fish. Bull., U.S. 122(57):451-468.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can., Bull. No. 184, 966 p.

Shiino, S. 1976. List of common names of fishes of the world, those prevailing among English-speaking nations. Science Rep. Shima Marineland No. 4, Kashikojima, Shima, Mie, Japan, 262 p.

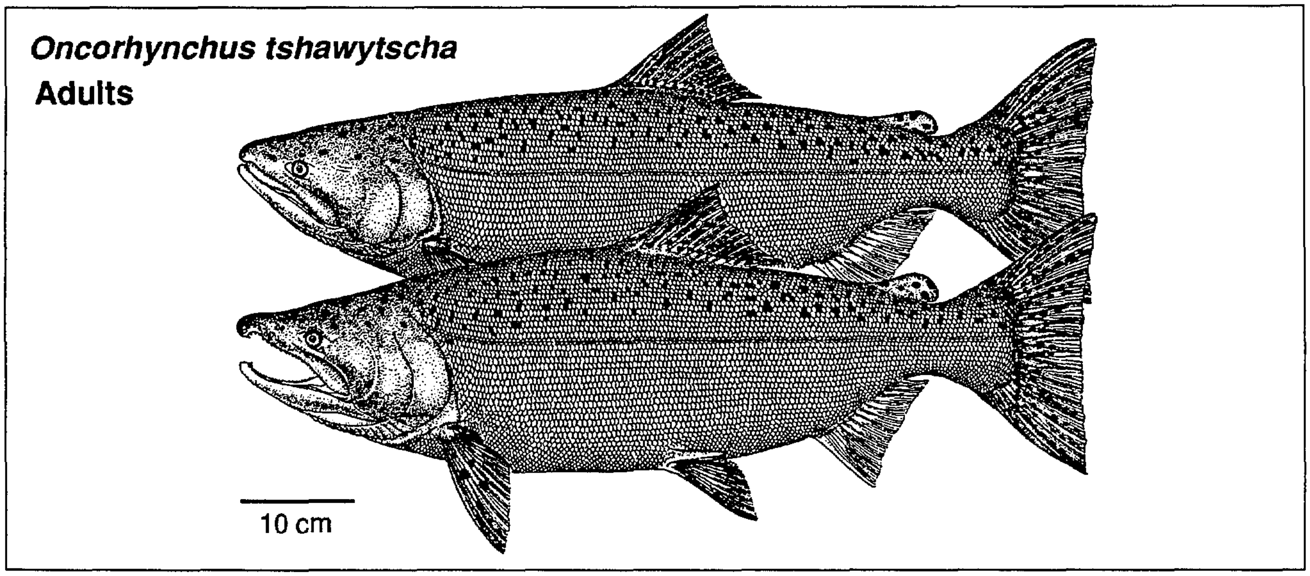
Simenstad, C. A., K. L. Fresh, and E. O. Salo. 1982. The role of Puget Sound and Washington coastal estuaries in the life history of Pacific salmon: an unappreciated function. *In* V. S. Kennedy (editor), Estuarine comparisons, p. 343-364. Academic Press, New York, NY.

Simenstad, C. A., B. S. Miller, C. F. Nyblade, K. Thornburgh, and L. J. Bledsoe. 1979. Food web relationships of northern Puget Sound and the Strait of Juan de Fuca. U.S. Interagency (NOAA, EPA) Energy/ Environ. Res. Dev. Prog. Rep., EPA-600/7-79-259, Washington, D.C., 335 p.

Straty, R. R., and H. W. Jaenicke. 1980. Estuarine influence of salinity, temperature, and food on the behavior, growth, and dynamics of Bristol Bay sockeye salmon. *In* W. J. McNeil and D. C. Himsworth (editors), Salmonid ecosystems of the North Pacific, p. 247-265. Oregon State Univ. Press, Corvallis, OR.

Wahle, R. J., and R. Z. Smith. 1979. A historical and descriptive account of Pacific coast anadromous salmonid rearing facilities and a summary of their releases by region, 1960-1976. NOAA Tech. Rep. NMFS SSRF-736, 35 p.

Chinook salmon



Common Name: chinook salmon
Scientific Name: *Oncorhynchus tshawytscha*
Other Common Names: Columbia River salmon, king salmon, black salmon, blackmouth salmon, chub salmon, hookbill, quinnat salmon, Sacramento River salmon, saw-keivey, spring salmon, tchaviche, tule or tyee salmon, winter salmon (Allen et al. in press)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Salmoniformes
Family: Salmonidae

Value

Commercial: The chinook salmon is the least-abundant Pacific salmon, but it grows the largest and commands the highest price. In 1985, over 12,200 t worth $43 million were landed on the Pacific coast (National Marine Fisheries Service 1986). From 1875 to the 1920s, the Columbia River had the largest chinook salmon run in the world, with annual landings averaging 9,100-18,100 t (Van Hyning 1973). In North America, the chinook salmon is commercially fished from Kotzebue Sound, Alaska, to Santa Barbara, California. It is also commercialy fished along the Kamchatka Peninsula, U.S.S.R., to northern Japan. In California, only ocean trolling is allowed (Frey 1971). In Oregon and Washington, it is captured by gill net, ocean trolling, purse seine, and reef net. It is the most abundant salmon in California (McGinnis 1984). Chinook are often captured far from their place of origin, with large numbers of chinook salmon originating from the Columbia River caught off British Columbia, Canada, and Alaska (Wright 1968). In Puget Sound, Washington, half of the chinook salmon are harvested by Native Americans (Clark 1985). The United States/Canada Pacific Salmon Interception Treaty of 1985 reduced the ocean take of chinook salmon off British Columbia and Alaska by 25% of 1984 catch levels (Phinney 1986).

Recreational: This species is a prized sport fish because of its size, fighting ability, availability, and excellent taste. Along with coho salmon (*O. kisutch*), the chinook salmon supports a sport and charter boat fishery from San Francisco, California, to Alaska. It is sport-caught primarily in marine and estuarine waters, but many are also caught in fresh water. Over 438,000 chinook salmon were sport caught in the United States in 1984 (not including California, Washington, and Oregon freshwater catch) (Pacific Marine Fisheries Commission 1986). The value of the recreational fishery is undetermined, but the value per kg is much higher than for commercial fish (Beauchamp et al. 1983). This species is fished almost year-round in Puget Sound, but primarily fished from summer to fall in other areas.

Indicator of Environmental Stress: Copper adversely affects proper smoltification (Beckman and Zaugg 1988), and smolts in sea water are more sensitive to oil than when in fresh water. Reduced river flows, increased water temperatures, and many other man-induced alterations to the environment can affect this species (see "Factors Affecting Populations").

Ecological: Juveniles are important due to their abundance in many Pacific coast rivers and streams and are one of the most abundant neritic fish in Puget Sound (Simenstad et al. 1979). Adults and juveniles are common in neritic waters off Oregon and Washington (Fisher et al. 1983, Fisher and Pearcy 1985).

Table 1. Relative abundance of five races of chinook salmon in 32 U.S. Pacific coast estuaries.

	Winter *Life Stage*					**Spring** *Life Stage*					**Summer** *Life Stage*					**Fall** *Life Stage*					**Late-fall** *Life Stage*				
Estuary	A	S	J	L	E	A	S	J	L	E	A	S	J	L	E	A	S	J	L	E	A	S	J	L	E
Puget Sound						◉		◉								◉		◉							
Hood Canal						○		◉								◉		◉							
Skagit Bay						◉		◉								◉		◉							
Grays Harbor						◉		●								◉		●							
Willapa Bay																◉		◉							
Columbia River						◉		●			○		●			◉		●							
Nehalem Bay																◉		◉							
Tillamook Bay						○		●								◉		●							
Netarts Bay																√		√							
Siletz River						○		◉								◉		◉							
Yaquina Bay						○		●								◉		●							
Alsea River						○		◉								◉		◉							
Siuslaw River																◉		◉							
Umpqua River						◉		●								◉		●							
Coos Bay						○		●								◉		●							
Rogue River						◉		●								◉		●							
Klamath River						◉		●								●		●							
Humboldt Bay																○		○							
Eel River																◉		●							
Tomales Bay																									
Cent. San Fran. Bay *	○		●			○		●								◉		●			○		●		
South San Fran. Bay			◉			√		◉								√		◉			√		◉		
Elkhorn Slough																									
Morro Bay																									
Santa Monica Bay																√									
San Pedro Bay																									
Alamitos Bay																									
Anaheim Bay																									
Newport Bay																									
Mission Bay																									
San Diego Bay																									
Tijuana Estuary																									
	A	S	J	L	E	A	S	J	L	E	A	S	J	L	E	A	S	J	L	E	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

Range

Overall: This species is recorded as far north as the Coppermine River in Arctic Canada, and south to northeastern Hokkaido, Japan, and southern California (Ventura River) (Hart 1973, Scott and Crossman 1973). It is rarely found in fresh water south of the Sacramento-San Joaquin river system of California (Eschmeyer et al. 1983). This species has been successfully introduced to New Zealand and the Great Lakes (Scott and Crossman 1973).

Within Study Area: The chinook salmon is found in all estuaries north of San Francisco Bay, except Tomales Bay, California (Table 1) (Monaco et al. 1990).

Life Mode

Eggs and alevins (yolk-sac larvae) are benthic and infaunal. Young juveniles (fry and parr) are benthopelagic. Parr become pelagic and acquire a silver color when they transform into smolts (juveniles that migrate to the ocean). Smolts and ocean-dwelling and maturing juveniles (subadults), and adults are pelagic (Alaska Department of Fish and Game 1985). Subadults and adults in rivers and streams are bottom-oriented.

Habitat

Type: The chinook salmon is an anadromous species. Eggs, alevins, fry, and parr occur in riverine areas from just above the intertidal zone to altitudes of 2,268 m above sea level (Allen et al. in press). Smolts are riverine and estuarine. Ocean-dwelling juveniles are neritic and epipelagic, and found within 128 m of the surface (Fredin et al. 1977). Adults may be neritic and estuarine, but are primarily riverine and may travel upstream over 4,700 km from the ocean.

Substrate: Eggs and alevins occur in spawning gravel or cobble that is 1.3-10.2 cm in diameter (Reiser and Bjornn 1979). Juveniles in fresh water are found over various substrates, ranging from silt bottoms to large boulders (Chapman and Bjornn 1968). Juveniles in estuaries occur over mud, sand, gravel, and eelgrass (*Zostera* spp.) (Healey 1980a). Adults in marine waters show no sediment preference, but may be associated with gravel-cobble bottoms in rivers and streams (Alaska Department of Fish and Game 1985).

Physical/Chemical Characteristics: Eggs only develop in fresh water, but larvae can tolerate 15‰ at hatching (Wagner et al. 1969). Three months after hatching they can tolerate full seawater, with faster growing individuals better able to handle salinity changes (Wagner et al. 1969). Juveniles and adults occur in fresh water to euhaline waters. Subadults (i.e., those that have migrated to the marine environment), are found in polyhaline to euhaline waters. Successful egg incubation occurs from just above freezing to 20.0°C (Olsen and Foster 1955), however, best incubation temperatures are 5.0-14.4°C (Bell 1984). The upper lethal temperature for the chinook salmon is 25.1°C (Brett 1952), but may be lower depending on other water quality factors (Ebel et al. 1971). Eggs and alevins are found in areas with flows of 20-150 cm/sec and juveniles where flows are 0.5-60.0 cm/sec (at pool edges). Adults can migrate upstream in flows up to 2.44 m/sec (Thompson 1972). Successful egg development requires redds to have adequate dissolved oxygen (≥5.0 mg/l), water temperatures (4-14°C), substrate permeability, sediment composition (<25% fines, ≤6.4 mm in diameter), surface flows and velocities, and low biochemical oxygen demand (Reiser and Bjornn 1979). Freshwater juveniles avoid waters with ≤4.5 mg/l dissolved oxygen at 20°C (Whitmore et al. 1960). Migrating adults will pass through water with dissolved oxygen levels as low as 3.5-4.0 mg/l (Fujioka 1970, Alabaster 1988, 1989). Excessive silt loads (>4,000 mg/l) may halt chinook salmon movements or migrations (Reiser and Bjornn 1979). Silt can also hinder fry emergence, and limit benthic invertebrate (food) production (Reiser and Bjornn 1979). Low pH decreases egg and alevin survival (Rombough 1983).

Migrations and Movements: Races of chinook salmon have been defined by when the adults migrate from the ocean to fresh water (Mason 1965). In the Columbia River, spring chinook salmon enter from January through May, summer chinook salmon from June through mid-August, and fall chinook salmon during August to November (Galbreath 1966, Netboy 1980, Phinney 1986). Within these races are different "stocks" which separate as they reach their natal streams (Phinney 1986). In California, spring, fall, and winter (December to February) runs exist, while the summer run is now extinct (Frey 1971, Moyle 1976). Fry and smolts stay in fresh water from 1 to 18 months (Beauchamp et al. 1983). Three types of juvenile migrants have been defined according to their use of rivers and estuaries. The first type, "subyearling estuarine smolts", moves into estuaries early after hatching and rears there until late-spring or summer when it moves to the ocean (Healey 1980a, 1982, Levy and Northcote 1982, Levy 1984). The second type, "subyearling riverine smolts", rears for less than one year in the river before smolting and migrating to the estuary and spends only a little time in the estuary (Reimers 1973, Healey 1982). The third type, "yearling riverine smolts", rears for a year in the river and smolts and migrates the spring after hatching (Healey 1982). Reimers (1973) also found two other life history types: emergent fry that move directly downstream and into the ocean, and juveniles that stay in streams or rivers until fall, when they migrate directly to the ocean. Juvenile migration into estuaries has been reported to occur at night (Seiler et al. 1981) and during daylight (Dawley et al. 1986). Juvenile chinook salmon may move quickly through estuaries (Dawley et al. 1986) or reside there for up to 189 days (Simenstad et al. 1982). Peak estuarine outmigration usually occurs in spring and summer, depending on life history (Healey 1982, Kjelson et al. 1982, Simenstad et al. 1982, Myers and Horton 1982, Dawley et al. 1986, McCabe et al. 1986). Chinook salmon spend from 1-8 years (usually 3-4) in the ocean before they return to their natal stream (Wydoski and Whitney 1979). Some may stay in Puget Sound until maturity (Simenstad et al. 1982). Upon entering the ocean, most stocks appear to migrate north (Wright 1968) and many move into the Gulf of Alaska (Hartt and Dell 1986). Chinook salmon produced in streams from the Rogue River (Oregon) and south appear to rear in the ocean off northern California-southern Oregon, while chinook salmon produced in streams from the Elk River (Oregon) and north rear primarily off British Columbia and Alaska (Cramer 1987). During its migrations, the chinook salmon appears to use electromagnetic, olfactory, and visual cues for guidance (Hasler and Scholz 1983, Quinn 1984). Straying to spawning streams other than its natal stream is very limited (Quinn and Fresh 1984).

Reproduction

Mode: This species is gonochoristic, oviparous, and semelparous. All adults die after spawning except some "jacks" (i.e., precocious males that mature early in fresh water) (Miller and Brannon 1982). Eggs are fertilized externally.

Mating/Spawning: The spawning period is specific for each run and/or stock, but can occur from April to February. For example, the Columbia River spring run spawns from July to late September, the summer run from August to mid-November, and the fall run from September to January (Fulton 1968, Netboy 1980, Bell 1984). In the Sacramento River, the winter run spawns during April to July and other runs from July to December (Moyle 1976). Chinook salmon normally spawn in larger rivers and tributaries and in deeper water (10 m) and larger gravel than other Pacific salmon (Scott and Crossman 1973). Females make the redd by lying sideways to the bottom and thrashing their tails. The redd can be 1.2-10.7 m in diameter (Chapman 1943). During spawning, a female will be attended by one dominant male and occasionally other subdominant males. Eggs and sperm are extruded simultaneously, after which the female will bury the eggs and move upstream and repeat the process until spent.

Fecundity: From 2,000-14,000 eggs are laid per female, with 5,000 eggs per female being average (Rounsefell 1957, Moyle 1976, Bell 1984). Fecundity depends on female size, stream latitude, and subpopulation (Alaska Department of Fish and Game 1985).

Growth and Development

Egg Size and Embryonic Development: Chinook salmon eggs are spherical, nonadhesive, and the largest of all the salmonids (6.0-8.5 mm in diameter) (Rounsefell 1957, Scott and Crossman 1973, Wang 1986). Embryonic development is indirect and external. The duration of incubation ranges from 33 to 178 days, depending on levels of dissolved oxygen, water temperature, biochemical oxygen demand, substrate, channel gradient and configuration, water depth, water velocity and discharge (Reiser and Bjornn 1979, Alaska Department of Fish and Game 1985). Time of hatching is dependent on the spawning period, with fall-spawned eggs usually hatching in March and April (Columbia River) and eggs from winter-run fish hatching from May to August (Sacramento River) (Moyle 1976).

Age and Size of Larvae: Larval sizes range from 20-35 mm total length (Wang 1986). Alevins remain in the gravel until the yolk sac is absorbed (usually 2-3 weeks) (Scott and Crossman 1973, Wydoski and Whitney 1979).

Juvenile Size Range: Juveniles are 2-152 cm (usually less than 91 cm) in length, and from a few grams to 61.4 kg (usually less than 11.3 kg) (Wydoski and Whitney 1979, Allen et al. in press).

Age and Size of Adults: Maturity is reached between 1 and 9 years, with most maturing in 3-6 years (Moyle 1976, Eschmeyer et al. 1983). Northern populations mature later, and spend more time in fresh water and at sea (Scott and Crossman 1973). The largest chinook salmon recorded was 147 cm in length and weighed 57 kg (Scott and Crossman 1973), but most are under 22.7 kg (Squire and Smith 1977).

Food and Feeding

Trophic Mode: Larvae feed on their yolk. Juveniles, and adults are carnivorous, "opportunistic" feeders.

Food Items: Juveniles in fresh water eat primarily terrestrial and aquatic insects, Cladocera, amphipods and other crustacea, and sometimes fish (Becker 1973, Higley and Bond 1973, Scott and Crossman 1973, Craddock et al. 1976, Muir and Emmett 1988, Sagar and Glova 1988). In estuaries, juveniles consume gammarid amphipods, insects, harpacticoid copepods, mysids, decapod larvae and fish (Levy and Levings 1978, Levy et al. 1979, Healey 1980a, 1982, Kjelson et al. 1982, Simenstad et al. 1982, Simenstad 1983, McCabe et al. 1986). In the neritic zone, small chinook salmon (those having recently migrated) feed on small (larval and juvenile) fishes, decapod larvae, amphipods, euphausiids, terrestrial insects, and other invertebrates (Healey 1980b, Peterson et al. 1983, Emmett et al. 1986). Larger chinook salmon (captured by sport and commercial fishing) feed primarily on fishes [e.g., northern anchovy (*Engraulis mordax*), scorpaenids, Pacific herring (*Clupea pallasi*), and Pacific sand lance (*Ammodytes hexapterus*)], euphausiids, decapod larvae, squid, and other invertebrates (Silliman 1941, Merkel 1957, Prakash 1962, Ito 1964, Hart 1973, Fresh et al. 1981). Adults do not actively feed in fresh water.

Biological Interactions

Predation: In fresh water, juveniles are eaten by many fishes [e.g., northern squawfish (*Ptychocheilus oregonensis*), channel catfish (*Ictalurus punctatus*), coho salmon, Dolly Varden (*Salvelinus malma*), rainbow trout (*O. mykiss*), cutthroat trout (*O. clarki*), smallmouth bass (*Micropterus dolomieui*), walleye (*Stizostedian vitreum*), and sculpins] and birds [e.g., mergansers, terns, osprey (*Pandion haliaetus*), and belted kingfisher (*Megaceryle alcyon*)] (Buchanan et al. 1981, Gray et al. 1982, Beauchamp et al. 1983, Maule and Horton 1984). In the ocean and estuaries, chinook salmon are prey for pelagic fishes, Pacific lamprey (*Lampetra tridentata*), birds [e.g., common murre (*Uria aalge*), and shearwaters (*Puffinus* spp.)], and marine mammals [e.g., harbor seal (*Phoca vitulina*), sea lions, killer whale (*Orcinus orca*)] (Simenstad et al. 1979, Fiscus 1980, Beach et al. 1981, Alaska Department of Fish and Game 1985). Adults in fresh water are eaten by bald eagle (*Haliaeetus leucocephalus*), bears, and other mammals (Scott and Crossman 1973).

Factors Influencing Populations: High mortality occurs during the early freshwater life stages (eggs, fry, parr). This mortality is caused by redd destruction, siltation and destruction of spawning grounds, extremely high or low water temperatures, low dissolved oxygen, loss of cover, disease, and predation (Reiser and Bjornn 1979). Besides the above factors, man-made changes such as river flow reductions, the creation of dams and reservoirs, pollution, and logging practices, have affected population abundances (Raymond 1979, Netboy 1980, Stevens and Miller 1983). Estuaries appear to play a vital role in chinook salmon life history (MacDonald et al. 1988). In the ocean, this species is affected by disease, predation, food availability, and oceanographic conditions. Overfishing has not allowed optimal spawning escapement and has reduced the age and size structure of some populations (Fraidenburg and Lincoln 1985). Also, the high-seas gill net fishery for squid is taking an unknown number of chinook salmon. The release of millions of juvenile chinook salmon by public and private hatcheries has helped maintain some runs (Phinney 1986), and the United States-Canada Salmon Interception Treaty should allow more escapement in the future. The survival of hatchery smolts to maturity is influenced by time of release, size of release, health of fish, degree of smoltification at release, release location, and ocean conditions (Vreeland 1988). In rivers and streams, juveniles are not as aggressive as coho salmon and steelhead juveniles (Wydoski and Whitney 1979). However, adults typically spawn in deeper water and use larger gravel than other salmonids (Scott and Crossman 1973). The chinook salmon may compete with other salmonid species in the marine environment (Ames 1983) and it is known to feed on the same food as coho salmon (Emmett et al. 1986). In estuaries, juveniles are associated with many other fish species that often feed on similar prey items (McCabe et al. 1983).

References

Alabaster, J. S. 1988. The dissolved oxygen requirements of upstream migrant chinook salmon, *Oncorhynchus tshawytscha*, in the lower Willamette River, Oregon. J. Fish Biol. 32:635-636.

Alabaster, J. S. 1989. The dissolved oxygen and temperature requirements of king salmon, *Oncorhynchus tshawytscha*, in the San Joaquin Delta, California. J. Fish Biol. 34:331-332.

Alaska Department of Fish and Game. 1985. Alaska habitat management guide, southcentral region, Vol. I: Life histories and habitat requirements of fish and wildlife. Alaska Dept. Fish Game, Juneau, AK, 429 p.

Allen, M. J., R. J. Wolotira, Jr., T. M. Sample, S. F. Noel, and C. R. Iten. (in press). Salmonids: life history descriptions and brief harvest summaries for salmonid species of the northeast Pacific Ocean and eastern Bering Sea. Tech. Memo., NOAA, NMFS, Northwest Alaska Fish. Cent., Seattle, WA.

Ames, J. 1983. Salmon stock interactions in Puget Sound: a preliminary look. *In* M. A. Miller (editor), Southeast Alaska coho salmon research and management review and planning workshop, May 18-19, 1982, p. 84-95. Alaska Dept. Fish Game, Juneau, AK, 109 p.

Beach, R. J., A. C. Geiger, S. J. Jeffries, and S. D. Tracy. 1981. Marine mammal - fishery interactions on the Columbia River and adjacent waters, 1981. Second Annual Rep. to NOAA, NMFS, Northwest and Alaska Fish. Cent., Seattle, WA. Wash. Dept. Game, Olympia, WA, 186 p.

Beauchamp, D. A., M. F. Shepard, and G. B. Pauley. 1983. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest) — chinook salmon. U.S. Fish Wildl. Serv., Div. Biol. Serv., FWS/0BS-82/11.6. U.S. Army Corps Eng., TR EL-82-4, 15 p.

Becker, C. D. 1973. Food and growth parameters of juvenile chinook salmon, *Oncorhynchus tshawytscha*, in central Columbia River. Fish. Bull., U.S. 71:387-400.

Beckman, B. J., and W. S. Zaugg. 1988. Copper intoxication in chinook salmon (*Oncorhynchus tshawytscha*) induced by natural spring water: effects of gill Na^+-K^+ ATPase, hematocrit, and plasma glucose. Can. J. Fish. Aquat. Sci. 45:1430-1435.

Bell, M. C. 1984. Fisheries handbook of engineering requirements and biological criteria. Fish Passage Development and Evaluation Program, U.S. Army Corps Eng., North Pac. Div., Portland, OR, 290 p. (Contract No. DACW57-79-M-1594 and DACW57-80-M-0567).

Brett. J. R. 1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus*. J. Fish. Res. Board Can. 9(6):265-323.

Buchanan, D. V., R. M. Hooton, and J. R. Moring. 1981. Northern squawfish (*Ptychocheilus oregonensis*) predation on juvenile salmonids in sections of the Willamette River Basin, Oregon. Can. J. Fish. Aquat. Sci., 38:360-364.

Chapman, W. M. 1943. The spawning of chinook salmon in the main Columbia River. Copeia 1943:168-170.

Chapman, D. W., and T. C. Bjornn. 1968. Distribution of salmonids in streams with special reference to food and feeding. *In* T. G. Northcote (editor), Salmon and trout in streams, p. 153-176. H. R. MacMillan Lectures in Fisheries, Univ. British Columbia, Vancouver, B.C.

Clark, W. G. 1985. Fishing in a sea of court order: Puget Sound salmon management 10 years after the Boldt decision. N. Am. J. Fish. Manag. 5(3b):417-434.

Craddock, D. R., T. H. Blahm, and W. D. Parente. 1976. Occurrence and utilization of zooplankton by juvenile chinook salmon in the lower Columbia River. Trans. Am. Fish. Soc. 105:72-76.

Cramer, S. P. 1987 Oregon studies to increase regional salmon production. Ann. Prog. Rep., Mar. Res. Region, Oregon Dept. Fish Wildl., Portland, OR, 15 p.

Dawley, E. M., R. D. Ledgerwood, T. H. Blahm, C. W. Sims, J. T. Durkin, R. A. Kirn, A. E. Rankis, G. E. Monan, and F. J. Ossiander. 1986. Migrational characteristics, biological observations, and relative survival of juvenile salmonids entering the Columbia River estuary, 1966-1983. Final Rep. to Bonneville Power Adm., Contract DE-A179-84BP39652, 256 p. Available Northwest and Alaska Fish. Cent., 2725 Montlake Blvd. E., Seattle, WA , 98112.

Ebel, W. J., E. M. Dawley, B. H. Monk. 1971. Thermal tolerance of juvenile Pacific salmon and steelhead trout in relation to supersaturation of nitrogen gas. Fish. Bull., U.S. 69(4):833-843.

Emmett, R. L., D. R. Miller, T. H. Blahm. 1986. Food of juvenile chinook, *Oncorhynchus tshawytscha*, and coho, *O. kisutch*, salmon off the northern Oregon and southern Washington coasts, May-September 1980. Calif. Fish Game 72(1):38-46.

Eschmeyer, W. N., W. S. Herald, and H. Hammann. 1983. A field guide to Pacific coast fishes of North America. Houghton Mifflin Co., Boston, MA, 336 p.

Fiscus. C. H. 1980. Marine mammal-salmonid interactions: a review. *In* W. J. McNeil and D. C. Himsworth (editors), Salmonid ecosystems of the North Pacific, p. 121-132. Oregon State Univ. Press, Corvallis, OR.

Fisher, J. P., and W. G. Pearcy. 1985. Studies of juvenile salmonids off the Oregon and Washington coast, 1985. Cruise Rep., Ref. 85-14, Oregon State Univ., Sea Grant College Prog., ORESU-T-85-004, 31 p.

Fisher, J. P., W. G. Pearcy, and A. W. Chung. 1983. Studies of juvenile salmonids off the Oregon and Washington coast, 1982. Cruise Rep., Ref. 83-2, Oregon State Univ., Sea Grant College Prog., ORESU-T-83-003, 41 p.

Fraidenburg, M. E., and R. H. Lincoln. 1985. Wild chinook salmon management: an international conservation challenge. N. Am. J. Fish. Manag. 5(3A):311-329.

Fredin, R. A., R. L. Major, R. G. Bakkala, and G. K. Tanonaka. 1977. Pacific salmon and the high seas salmon fisheries of Japan. Proc. Rep., Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, Seattle, WA, 324 p.

Fresh, K. L., R. D. Cardwell, R. R. Koons. 1981. Food habits of Pacific salmon, baitfish, and their potential competitors and predators in the marine waters of Washington, August 1978 to September 1979. Prog. Rep. No. 145, Wash. Dept. Fish., Olympia, WA, 58 p.

Frey, H. W. 1971. California's living marine resources and their utilization. Calif. Dept. Fish Game, Sacramento, CA, 148 p.

Fujioka, J. F. 1970. Possible effects of low dissolved oxygen content in the Duwamish River estuary on migrating adult chinook salmon. M.S. Thesis. Univ. Wash., Seattle, WA, 77 p.

Fulton, L. A. 1968. Spawning areas and abundance of chinook salmon (*Oncorhynchus tshawytscha*) in the Columbia River basin - past and present. U.S. Fish and Wildl. Serv., SSRF 571, 26 p.

Galbreath, J. L. 1966. Timing of tributary races of chinook salmon through the lower Columbia River based on analysis of tag recoveries. Fish. Comm. Oregon, Res. Briefs 12(1):58-80.

Gray, G. A., G. M. Sonnevil, H. C. Hansel, C. W. Huntington, and D. E. Palmer. 1982. Feeding activity, rate of consumption, daily ration, and prey selection of major predators in the John Day pool. Annual Rep. to Bonneville Power Adm., Portland, OR, 81 p. Available U.S. Fish and Wildl. Serv., Cook, WA.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. No. 180, 740 p.

Hartt, A. C., and M. B. Dell. 1986. Early oceanic migrations and growth of juvenile Pacific salmon and steelhead trout. Internat. North Pac. Fish. Comm., Bull. No. 46:1-105.

Hasler, A. D., and A. T. Scholz. 1983. Olfactory imprinting and homing in salmon. Springer-Verlag, Berlin, 134 p.

Healey, M. C. 1980a. Utilization of the Nanaimo River estuary by juvenile chinook salmon, *Oncorhynchus tshawytscha*. Fish. Bull., U.S. 77(3):653-668.

Healey, M. C. 1980b. The ecology of juvenile salmon in Georgia Strait, British Columbia. *In* W. J. McNeil and D. C. Himsworth (editors), Salmonid ecosystems of the North Pacific, p. 203-229. Oregon State Univ. Press, Corvallis, OR.

Healey, M. C. 1982. Juvenile Pacific salmon in estuaries: the life support system. *In* V. S. Kennedy (editor), Estuarine comparisons, p. 315-342. Academic Press, New York, NY.

Higley, D. L., and C. E. Bond. 1973. Ecology and production of juvenile spring chinook salmon, *Oncorhynchus tshawytscha*, in a eutrophic reservoir. Fish. Bull., U.S. 71(3):877-891.

Ito, J. 1964. Food and feeding habits of Pacific salmon (genus *Oncorhynchus*) in their ocean life. Bull Hokkaido Reg. Fish. Res. Lab. 29:85-97. (Fish. Res. Board Can. Transl. Ser. 1309).

Kjelson, M. A., P. F. Raquel, F. W. Fisher. 1982. Life history of fall-run chinook salmon, *Oncorhynchus tshawytscha* in the Sacramento-San Joaquin estuary, California. *In* V. S. Kennedy (editor), Estuarine comparisons, p. 393-411. Academic Press, New York, NY.

Levy, D. A. 1984. Commentary: variations in estuary utilization among juvenile chinook salmon populations. *In* W. G. Pearcy (editor), The influence of ocean conditions on the production of salmonids in the North Pacific, p. 297-302. Sea Grant Publ., ORESU-W-83-001, Oregon State Univ., Corvallis, OR.

Levy, D. A., and C. D. Levings. 1978. A description of the fish Community of the Squamish River estuary, British Columbia: relative abundance, seasonal changes, and feeding habits of salmonids. Fish. Env. Canada, Fish. Mar. Serv. Manuscr. Rep. No. 1475, 63 p.

Levy, D. A., and T. G. Northcote. 1982. Juvenile salmon residency in a marsh area of the Fraser River estuary. Can. J. Fish. Aquat. Sci. 39:270-276.

Levy, D. A., T. G. Northcote, and G. J. Birch. 1979. Juvenile salmon utilization of tidal channels in the Fraser River estuary, British Columbia. Westwater Res. Cent. Tech. Rep. 23, Univ. British Columbia, Vancouver, B.C., 70 p.

Macdonald, J. S., C. D. Levings, C. D. McAllister, U. H. M. Fagerlund, and J. R. McBride. 1988. A field experiment to test the importance of estuaries for chinook salmon (*Oncorhynchus tshawytscha*) survival: short-term results. Can. J. Fish. Aquat. Sci. 45(8):1366-1377.

Mason, J. E. 1965. Salmon of the north Pacific Ocean - Part IX. Coho, chinook and masu salmon in offshore waters. Internat. North Pac. Fish. Comm., Bull. No. 6, 135.

Maule, A. G., and H. F. Horton. 1984. Feeding ecology of walleye, *Stizostedion vitreum vitreum*, in the mid-Columbia River, with emphasis on the interactions between walleye and juvenile anadromous fishes. Fish. Bull., U.S. 82(2):41-48.

McCabe, G. T., Jr., R. L. Emmett, W. D. Muir, and T. H. Blahm. 1986. Utilization of the Columbia River estuary by subyearling chinook salmon. Northw. Sci. 60(2):113-124.

McCabe, G. T., Jr., W. D. Muir, R. L. Emmett, and J. T. Durkin. 1983. Interrelationships between juvenile salmonids and nonsalmonid fish in the Columbia River estuary. Fish. Bull., U.S. 81(4):815-826.

McGinnis, S. M. 1984. Freshwater fishes of California. Univ. Calif. Press, Berkeley, CA, 316 p.

Merkel, T. J. 1957. Food habits of king salmon, *Oncorhynchus tshawytscha* (Walbaum), in the vicinity of San Francisco, California. Calif. Fish. Game 43(4):249-270.

Miller, R. J., and E. L. Brannon. 1982. The origin and development of life history patterns in Pacific salmonids. *In* E. L. Brannon and E. O. Salo (editors). Salmon and trout migratory behavior symposium, p. 296-309. School Fish., Univ. Wash., Seattle, WA.

Monaco, M. E., R. L. Emmett, S. A. Hinton, and D. M. Nelson. 1990. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume I:

data summaries. ELMR Rep. No. 4. Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 240 p.

Moyle, P. B. 1976. Inland fishes of California. Univ. Calif. Press, Berkeley, CA, 405 p.

Muir, W. D., and R. L. Emmett. 1988. Food habits of migrating salmonid smolts passing Bonneville Dam in the Columbia River, 1984. Reg. Riv. Res. Manag. 2:1-10.

Myers, K. W., and H. F. Horton. 1982. Temporal use of an Oregon estuary by hatchery and wild juvenile salmon. *In* V. S. Kennedy (editor), Estuarine comparisons, p. 377-392. Academic Press, New York, NY.

National Marine Fisheries Service. 1986. Fisheries of the United States, 1985. Current Fishery Statistics No. 8368. U.S. Dept. Comm., NOAA, Nat. Mar. Fish Serv., Nat. Fish. Stat. Prog., Washington, D.C., 122 p.

Netboy, A. 1980. The Columbia River salmon and steelhead trout, their fight for survival. Univ. Wash. Press, Seattle, WA, 180 p.

Olsen, P. A., and R. F. Foster. 1955. Temperature tolerance of eggs and young of Columbia River chinook salmon. Trans. Am. Fish. Soc. 85:203-207.

Pacific Marine Fisheries Commission. 1986. 38th annual report of the Pacific Marine Fisheries Commission for the year 1985. Pac. Mar. Fish. Comm., Portland, OR, 35 p.

Peterson, W. T., R. D. Brodeur, and W. A. Pearcy. 1983. Feeding habits of juvenile salmonids in the Oregon coastal zone in June 1979. Fish. Bull., U.S. 80(4):841-851.

Phinney, L. A. 1986. Chinook salmon of the Columbia River Basin. *In* A. S. Eno, R. L. DiSilvestro, and W. J. Chandler (editors), Audubon wildlife report 1986, p. 715-741. The National Audubon Society, New York, NY.

Prakash, A. 1962. Seasonal changes in feeding of coho and chinook (spring) salmon in southern British Columbia waters. J. Fish Res. Board Can. 19(5):851-866.

Quinn, T. P. 1984. Homing and straying in Pacific salmon. *In* J. D. McCleave, G. P. Arnold, J. J. Dodson, and W. H. Neill (editors), Mechanisms of migration in fishes, p. 357-362. Plenum Press, New York, NY.

Quinn, T. P., and K. Fresh. 1984. Homing and straying in chinook salmon (*Oncorhynchus tshawytscha*) from Cowlitz River hatchery, Washington. Can. J. Fish. Aquat. Sci. 41:1078-1082.

Raymond, H. L. 1979. Effects of dams and impoundments on migrations of juvenile chinook salmon and steelhead from the Snake River, 1966-1975. Trans. Am. Fish. Soc. 108(6):505-529.

Reimers, P. E. 1973. The length of residence of juvenile fall chinook salmon in Sixes River, Oregon. Oregon Fish. Comm. Res. Rep. 4(2):3-42.

Reiser, D. W., and T. J. Bjornn. 1979. Habitat requirements of anadromous salmonids. *In* W. R. Meehan (editor), Influence of forest and rangeland management on anadromous fish habitat in the Western United States and Canada, p. 1-54. U.S. Forest Serv. Gen. Tech. Rep. PNW-96, Northw. Forest Range Exp. Sta., Portland, OR.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc., Spec. Publ. No.12, Am. Fish. Soc., Bethesda, MD, 174 p.

Rombough, P. J. 1983. Effects of low pH on eyed embryos and alevins of Pacific salmon. Can. J. Fish. Aquat. Sci. 40(10):1575-1582.

Rounsefell, G. A. 1957. Fecundity of North American Salmonidae. Fish. Bull., U.S. 122:451-468.

Sagar, P. M., and G. J. Glova. 1988. Diel feeding periodicity, daily ration and prey selection of a riverine population of juvenile chinook salmon, *Oncorhynchus tshawytscha* (Walbaum). J. Fish Biol. 33:643-653.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can., Bull. No.184, 966 p.

Seiler, D., S. Neuhauser, and M. Ackley. 1981. Upstream/downstream salmonid trapping project, 1977-1980. Prog. Rep. No. 144, Wash. Dept. Fish., Olympia, WA, 197 p.

Silliman, R. P. 1941. Fluctuations in the diet of chinook and silver salmon (*Oncorhynchus tshawytscha* and *O. kisutch*) of Washington as related to the troll catch of salmon. Copeia, 2:80-97.

Simenstad, C. A. 1983. The ecology of estuarine channels of the Pacific Northwest coast: a community profile. U.S. Fish. Wildl. Serv., FWS/OBS-83/05, 181 p.

Simenstad, C. A., K. L. Fresh, and E. O. Salo. 1982. The role of Puget Sound and Washington coastal estuaries in the life history of Pacific salmon: an unappreciated function. *In* V. S. Kennedy (editor), Estuarine comparisons, p. 343-364. Academic Press, New York, NY.

Simenstad, C. A., B. S. Miller, C. F. Nyblade, K. Thornburgh, and L. J. Bledsoe. 1979. Food web relationships of northern Puget Sound and the Strait of Juan de Fuca. U.S. Interagency (NOAA, EPA) Energy/ Environ. Res. Dev. Prog. Rep., EPA-600/7-79-259, Washington D.C., 335 p.

Squire, J. L., Jr., and S. E. Smith. 1977. Anglers' guide to the United States Pacific coast. Natl. Mar. Fish. Serv., NOAA, Seattle, WA, 139 p.

Stevens, D. E., and L. W. Miller. 1983. Effects of river flow on abundance of young chinook salmon, American shad, longfin smelt, and delta smelt in the Sacramento-San Joaquin River system. N. Am. J. Fish. Manag. 3:425-437.

Thompson, K. 1972. Determining stream flows for fish life. In Proceedings, Instream flow requirements workshop, p. 31-50. Pac. Northw. River Basin Comm., Vancouver, WA.

Van Hyning, J. M. 1973. Factors affecting the abundance of fall chinook salmon in the Columbia River. Oregon Fish Comm. Res. Rep. 4(1):1-87.

Vreeland, R. R. 1988. Evaluation of the contribution of chinook salmon reared at Columbia River hatcheries to the Pacific salmon fisheries. Ann. Rep. FY 1987, Nat. Mar Fish. Serv., Env. Tech. Serv. Div., Portland, OR, 113 p.

Wagner, H. H., F. P. Conte, and J. L. Fessler. 1969. Development of osmotic and ionic regulation in two races of chinook salmon (*Oncorhynchus tshawytscha*). Comp. Biochem. Physiol. 29:325-341.

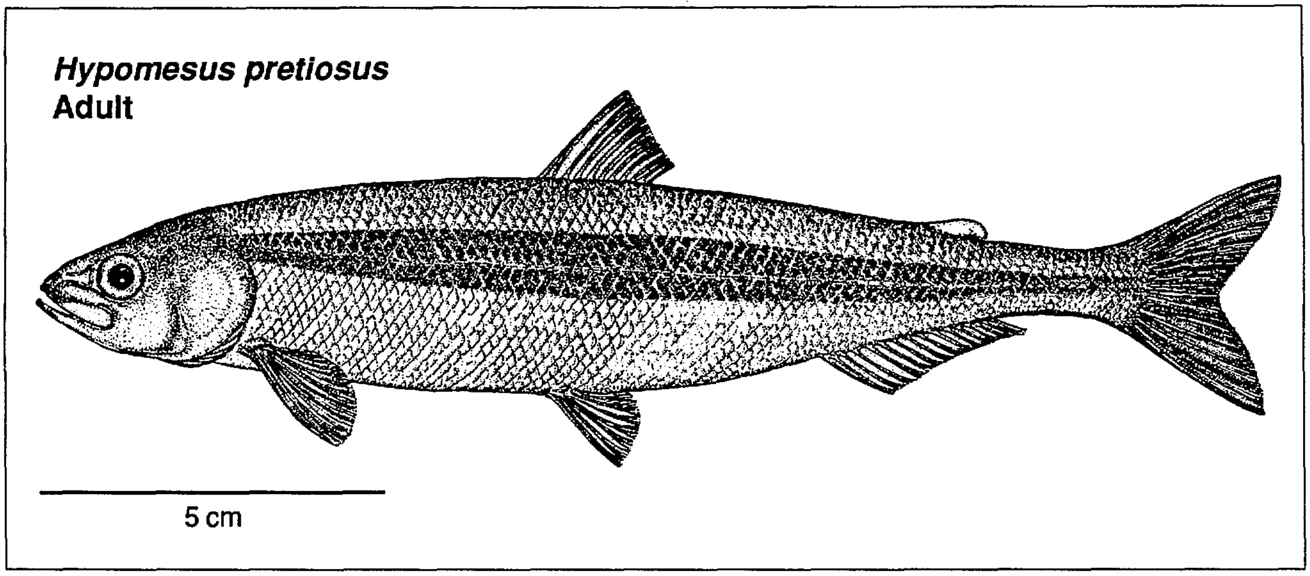
Wang, J. C. S. 1986. Fishes of the Sacramento-San Joaquin estuary and adjacent waters, California: A guide to the early life histories. Tech. Rep. No. 9. Interagency ecological study program for the Sacramento-San Joaquin estuary. Calif. Dept. Water Res., Calif. Dept. Fish Game, U.S. Bureau Reclam., and U.S. Fish Wildl. Serv., various pagination.

Whitmore, C. M., C. E. Warren, and P. Doudoroff. 1960. Avoidance reactions of salmonid and centrarchid fishes to low oxygen concentrations. Trans. Am. Fish. Soc. 89(1):17-26.

Wright, S. G. 1968. The origin and migration of Washington's chinook and coho salmon. Info. Booklet No. 1, Wash. Dept. Fish., Olympia, WA, 25 p.

Wydoski, R. S., and R. R. Whitney. 1979. Inland fishes of Washington. Univ. Wash. Press, Seattle, WA, 220 p.

Surf smelt



Common Name: surf smelt
Scientific Name: *Hypomesus pretiosus*
Other Common Names: Pacific surf smelt, silver smelt
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Salmoniformes
Family: Osmeridae

Value

Commercial: The surf smelt is commercially fished in California and Washington. More than 4 million were taken in California in 1958 (Frey 1971). An average of 51 t are taken annually in Washington, most of which are caught in Puget Sound (Trumble 1983).

Recreational: This species is considered an excellent food fish and is captured by recreational fishermen in Washington, Oregon, and California. It is taken by jump net (in California), jig, and dip net. The numbers taken by recreational anglers are unknown, but thought to be substantial.

Indicator of Environmental Stress: The surf smelt spawns at specific beach sites where appropriate physical conditions for spawning exist. Hence, loss or alteration of these spawning sites can be very detrimental to populations of this species.

Ecological: This species is important prey for many fishes, birds, and mammals. Puget Sound stocks are genetically different from coastal stocks (Kilambi 1965, Kilambi et al. 1965).

Range

Overall: The surf smelt's overall range is from Long Beach, California, to southeast Alaska (Frey 1971).

Within Study Area: This species is occasionally found in California estuaries (Moyle 1976), but is seasonally common to abundant in Oregon and Washington estuaries (Table 1) (Monaco et al. 1990).

Life Mode:

Eggs are benthic. Larvae, juveniles, and adults are pelagic but remain principally inshore. Except in Puget Sound and adjacent areas, this is a nearshore coastal species which does not typically spawn in estuaries but utilizes them for feeding and rearing. It does not appear to form large pelagic schools like the northern anchovy (*Engraulis mordax*). However, schools of surf smelt are often common in Northwest estuaries.

Habitat

Type: Eggs are laid intertidally on beaches. Larvae, juveniles, and adults live in neritic waters.

Substrate: Spawning adults select substrates of coarse sand with fine gravel (Trumble 1983). Larvae, juveniles, and adults can be found over a variety of substrates.

Physical/Chemical Characteristics: All life stages are found in estuarine and marine waters. Beaches used for spawning typically have some freshwater seepage and are usually shaded by trees or bluffs (Schaefer 1936). Water temperature and salinity of the spawning areas do not appear to affect spawning activity, but tide stage and time of day do. Survival of embryos does not appear to be significantly different at salinities of 20, 25, or 30‰ (Middaugh et al. 1987).

Table 1. Relative abundance of surf smelt in 32 U.S. Pacific coast estuaries.

Estuary	A	S	J	L	E
Puget Sound	◉	●	◉	◉	●
Hood Canal	◉	●	◉	●	●
Skagit Bay	◉	●	◉	●	●
Grays Harbor	○		○	○	
Willapa Bay	○		○	○	
Columbia River	○		◉	○	
Nehalem Bay	●		●	○	
Tillamook Bay	●		●	○	
Netarts Bay	√		●	○	
Siletz River	◉		◉	○	
Yaquina Bay	○		●	○	
Alsea River	○		●	○	
Siuslaw River	●		●	○	
Umpqua River	●		●	○	
Coos Bay	◉		●	○	
Rogue River	√		◉	○	
Klamath River	√		○		
Humboldt Bay	○		◉	○	
Eel River	○		●	○	
Tomales Bay	○		○	○	
Cent. San Fran. Bay *	√		√		
South San Fran. Bay	√		√		
Elkhorn Slough			√		
Morro Bay					
Santa Monica Bay					
San Pedro Bay					
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Life Stage

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

Migrations and Movements: Migrations and movements have not been studied. Although specific spawning sites are used, there is no information regarding whether fish return to their natal spawning sites. The seasonal utilization of estuaries by juveniles and adults probably relates to food abundance and refuge from predators. At the beginning of a spawning run, schools are usually composed of individuals of the same sex; female schools usually arrive before male schools (Loosanoff 1937). Later, as more schools arrive, the unisexual character of the schools is lost.

Reproduction

Mode: The surf smelt is gonochoristic, oviparous, and iteroparous. It has external egg fertilization and probably spawns annually after reaching maturity.

Mating/Spawning: Spawning populations can be found nearly year-round along the Pacific coast. However, they spawn at specific beaches at specific times of the year (Penttila 1978). Spawning occurs primarily at high tide and early ebb, from late afternoon to evening (Schaefer 1936, Thompson et al. 1936, Yap-Chiongco 1941). Before a spawning "run", schools appear in the water 0.9-1.2 m from the edge of the beach. During spawning, a female (usually accompanied by 2 to 5 males) moves to the highest point reached by a wave. As they reach the shore, the fishes release their gametes. This process occurs in 2.5-5.0 cm of water and takes about 5 to 10 seconds (Loosanoff 1937). Eggs are usually concentrated at the 2.1-3.4 m tidal levels (upper intertidal zone) (Penttila 1978, Middaugh et al. 1987). Eggs are adhesive and stick to sand grains and wave action covers them with a thin layer of sand. Adults usually eat very little during spawning, but do not die after spawning (Loosanoff 1937).

Fecundity: Females release eggs in batches and spawning can last for several days. Females usually produce 15,000-20,000 eggs, but can produce from 1,300-37,000 eggs (depending on body size) (Leong 1967).

Growth and Development

Egg Size and Embryonic Development: Fertilized eggs are spherical and about 1.0-1.2 mm in diameter (Schaefer 1936). Eggs adhere to gravel substrates by the adhesive zona radiata membrane which ruptures and turns inside out at the time the eggs are fertilized. Embryonic development is indirect and external (Garrison and Miller 1982). After several days embryos detach from the spawning substrates and are washed seaward and down into the gravel substrate in the intertidal zone (Middaugh et al. 1987). Hatching occurs from 8.5 to 30 days after incubation (depending on temperature) and may be initiated by mechanical or chemical stimuli. Eggs are stimulated to hatch by immersion in water (high tide) (Loosanoff 1937). At extremely low temperatures (e.g., during winter) the incubation period may be 90 days or more (Middaugh et al. 1987).

Age and Size of Larvae: Larvae are 5.0-6.5 mm long at hatching. Postlarvae are 17-35 mm in total length (TL) (Yap-chiongco 1941).

Juvenile Size Range: Juveniles range from 35 mm to at least 85 mm TL. Scales first appear when fish are 55-68 mm TL.

Age and Size of Adults: Adults range from 81-178 mm TL. Most mature in their second year but some are gravid in their first. Individuals older than three years are rare, but they may reach 5 years old. Females are typically larger than similarly-aged males (Yapchiongco 1949). Both sexes have asymmetrical gonads, with the left gonad being much more developed (Yap-chiongco 1941). Males have pearl organs (small protuberances on their snouts) during the breeding season while females do not (Yapchiongco 1949). Males are dull olive green on their back while females are bright metallic green (Yap-chiongco 1941).

Food and Feeding

Trophic Mode: Larvae, juveniles, and adults are planktivorous carnivores (typically zooplanktivorous).

Food Items: The surf smelt feeds primarily on planktonic crustacea, including amphipods, euphausiids, copepods, cladocerans, crustacean larvae, and some larval fish (Hart 1973).

Biological Interactions

Predation: This species is eaten by many fishes, including Pacific salmon (*Oncorhynchus* spp.), lingcod (*Ophiodon elongatus*), and striped bass (*Morone saxatilis*) (Frey 1971). It is also commonly eaten by birds and marine mammals.

Factors Influencing Populations: Egg and larval mortality can result from thermal stress, and desiccation. Predation can be high (Penttila 1978, Garrison and Miller 1982) and probably plays a large role in determining population size. The specific beaches used for spawning can be ruined by pollution, bulkheading, and other habitat alterations.

References

Frey, H. W. 1971. California's living marine resources and their utilization. Calif. Dept. Fish Game, Sacramento, CA, 148 p.

Garrison, K. J., and B. S. Miller. 1982. Review of the early life history of Puget Sound fishes. Fish. Res. Inst., School Fish., Univ. Wash., Seattle, WA, 729 p, (FRI-UW-8216).

Hart, J. L. 1973. Pacific Fishes of Canada. Fish. Res. Board Can., Bull. No. 180, 740 p.

Kilambi, R. V. 1965. Heterogeneity among three spawning populations of the surf smelt, *Hypomesus pretiosus* (Girard) in the state of Washington. Ph.D. Thesis, Univ. Wash., Seattle, WA, 154 p.

Kilambi, R. V., F. M. Utter, and A. C. DeLacy. 1965. Differentiation of spawning populations of the surf smelt, *Hypomesus pretiosus* (Girard) by serological methods. J. Mar. Biol. Assoc. India 7(2):364-368.

Leong, Choon-Chiang. 1967. Fecundity of surf smelt, *Hypomesus pretiosus* (Girard) in the state of Washington. M.S. Thesis, Univ. Wash., Seattle, WA, 99 p.

Loosanoff, V. L. 1937. The spawning run of the Pacific surf smelt, *Hypomesus pretiosus* (Girard). Internat. Rev. Hydrobiol. Hydrogr. 36(1-2):170-183.

Middaugh, D. P., M. J. Hemmer, and D. E. Penttila. 1987. Embryo ecology of the Pacific surf smelt, *Hypomesus pretiosus* (Pisces: Osmeridae). Pac. Sci. 41(1-4):44-53.

Monaco, M. E., R. L. Emmett, S. A. Hinton, and D. M. Nelson. 1990. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume I: data summaries. ELMR Rep. No. 4. Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 240 p.

Moyle, P. B. 1976. Inland fishes of California. Univ. Calif. Press, Berkeley, CA, 405 p.

Penttila, D. 1978. Studies of surf smelt (*Hypomesus pretiosus*) in Puget Sound. Tech. Rep. 42, Wash. Dept. Fish., Olympia, WA, 47 p.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Schaefer, M. B. 1936. Contribution to the life history of the surf smelt *Hypomesus pretiosus* in Puget Sound. Wash. Dept. Fish., Biol. Rep. 35B:1-45.

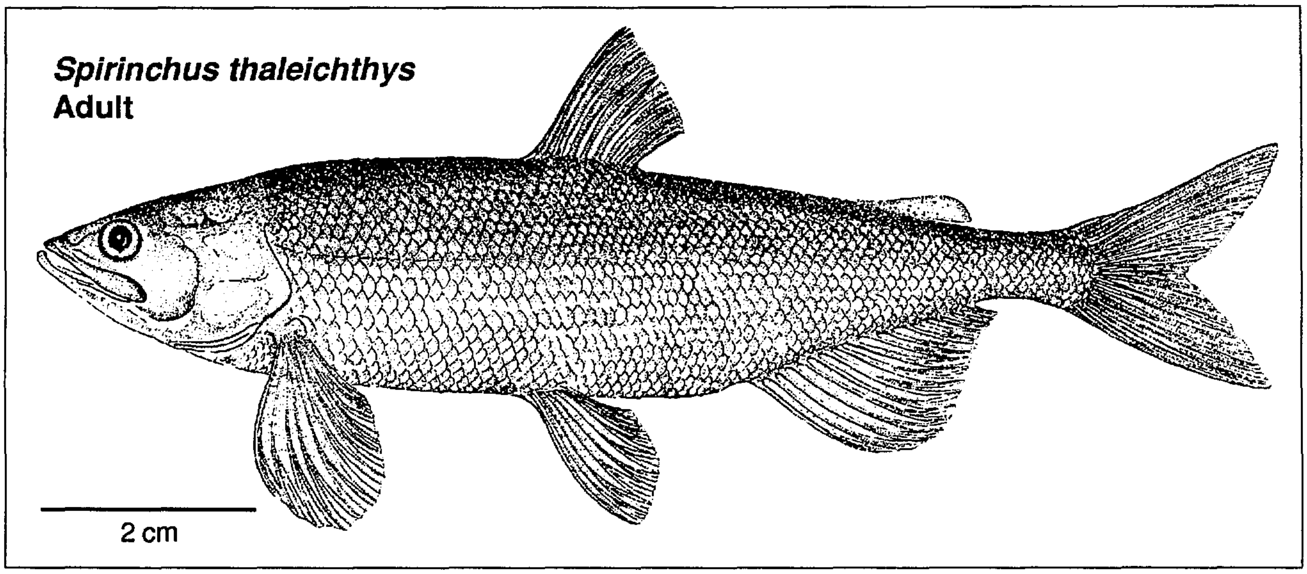
Thompson, W. F., F. H. Bell, L. P. Schultz, H. A. Dunlop, and R. Van Cleve. 1936. The spawning of the silver smelt, *Hypomesus pretiosus*. Ecology 17:148-168.

Trumble, R. J. 1983. Management plan for baitfish species in Washington State. Prog. Rep. 195, Wash. Dept. Fish., Olympia, WA, 106 p.

Yap-Chiongco, J. V. 1941. *Hypomesus pretiosus*: Its development and early life history. Ph.D. Thesis, Univ. Wash., Seattle, WA, 123 p.

Yap-Chiongco, J. V. 1949. *Hypomesus pretiosus*: Its development and early life history. Nat. Appl. Sci. Bull. 9(1):3-108..

Longfin smelt



Common Name: longfin smelt
Scientific Name: *Spirinchus thaleichthys*
Other Common Names: Pacific smelt, long-finned smelt, Sacramento smelt
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Salmoniformes
Family: Osmeridae

Value

Commercial: The longfin smelt is occasionally captured incidentally with other smelt species, and marketed with these species as "smelt" (Skinner 1962). The longfin smelt is seasonally sold at markets in California's San Francisco Bay area (Wang 1986).

Recreational: Presently, only a very limited recreational fishery exists.

Indicator of Environmental Stress: Information regarding population sizes and fluctuations are limited. However, since all life stages use estuaries, any estuarine alterations potentially affect this species. Freshwater flow into estuaries is important for this species (Stevens and Miller 1983, California Department of Fish and Game 1987).

Ecological: The longfin smelt is abundant in many Pacific coast estuaries and is consumed by numerous marine and estuarine vertebrates.

Range

Overall: This species' overall range is from Monterey Bay, California, to Prince William Sound, Alaska (Eschmeyer et al. 1983).

Within Study Area: It is found in most Pacific coast estuaries from San Francisco Bay (Moyle 1976) north to Puget Sound, Washington (Garrison and Miller 1980) (Table 1).

Life Mode

Eggs are benthic and adhesive. Larvae and juveniles are primarily pelagic, while adults are both pelagic and demersal.

Habitat

Type: Eggs are benthic and riverine or upper estuarine. Larvae are pelagic and occur in riverine-marine waters, but are most often found in estuarine environments. Juveniles are primarily pelagic and estuarine. Adults are pelagic but are often found near the bottom in estuarine and marine waters.

Substrate: Type of spawning substrate has not been positively identified, but is thought to be sandy-gravel areas with sand or aquatic plants (Wang 1986). Nektonic life stages occur over a variety of substrates.

Physical/Chemical Characteristics: The longfin smelt is an anadromous, euryhaline species. However, the existence of landlocked freshwater populations indicates that this species does not need marine/estuarine waters to complete its life cycle. Most early life history information pertains to landlocked populations, thus very little data is available for estuarine/marine populations (Garrison and Miller 1980).

Migrations and Movements: Juveniles and adults appear to move to lower estuarine/marine areas in spring and summer, and to upper estuarine areas in fall. In winter, adults move to freshwater spawning

Table 1. Relative abundance of longfin smelt in 32 U.S. Pacific coast estuaries.

	Life Stage				
Estuary	A	S	J	L	E
Puget Sound	○		○	○	
Hood Canal					
Skagit Bay	○		○	○	
Grays Harbor	○	◉	◉	●	○
Willapa Bay	○	◉	◉	●	◉
Columbia River	◉	◉	●	●	◉
Nehalem Bay					
Tillamook Bay	√				
Netarts Bay					
Siletz River					
Yaquina Bay	○	○	○	○	○
Alsea River	√		√		
Siuslaw River	√		√		
Umpqua River	√		√		
Coos Bay	○	○	○	○	○
Rogue River					
Klamath River	○		○		
Humboldt Bay	○	○	○	○	○
Eel River	○	○	○	○	○
Tomales Bay					
Cent. San Fran. Bay *	◉	◉	●	●	◉
South San Fran. Bay	○		○	○	
Elkhorn Slough					
Morro Bay					
Santa Monica Bay					
San Pedro Bay					
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

areas (Ganssle 1966). Adults show diel vertical movements, being found deep during the day and in the upper water column at night (Wydoski and Whitney 1979).

Reproduction

Mode: The longfin smelt is gonochoristic, oviparous, and iteroparous. It has external egg fertilization and spawns in batches.

Mating/Spawning: Spawning occurs in freshwater areas at night during winter (October-March), when river temperatures are 4.4-7.2°C (Wydoski and Whitney 1979), 5.6-6.7°C (Moulton 1974), and 7.0-14.5°C (Wang 1986). During spawning, eggs and sperm are released near the substrate. Once fertilized, the eggs become adhesive. Almost all adults die after spawning.

Fecundity: A female can produce an average of 18,000-24,000 eggs (Hart 1973 Moyle 1976), although fish from landlocked populations may produce much fewer (Wydoski and Whitney 1979).

Growth and Development

Egg Size and Embryonic Development: Fertilized eggs are spherical, 1.2 mm in diameter, and adhesive (Dryfoos 1965). Eggs incubated at 7°C hatch in 40 days (Dryfoos 1965). Embryonic development is indirect and external.

Age and Size of Larvae: At hatching, larvae are reported to be 5.3-9.8 mm long (Dryfoos 1965, Moulton 1970, Wang 1986). Metamorphosis to juvenile probably begins in 30-60 days, depending on temperature.

Juvenile Size Range: Juveniles range from 22 mm to approximately 88 mm long (Moulton 1970, 1974).

Age and Size of Adults: Spawning occurs at age 2, with adults being 8.8-15.2 cm in total length, but averaging 10.0 cm. (Moulton 1974). Size, age, and possibly water temperature influence age at maturation (Moulton 1974).

Food and Feeding

Trophic Mode: Larvae, juveniles, and adults are carnivorous planktivores.

Food Items: Larvae probably consume zooplankton and some phytoplankton. Juveniles and adults eat calanoid copepods, cladocerans, amphipods, and other small crustaceans (Moyle 1976). Adults also prey heavily on the mysid *Neomysis mercedis*.

Biological Interactions

Predation: Larvae, juveniles, and adults are eaten by predatory fishes, birds, and marine mammals. The longfin smelt is an important year-round prey for harbor seals (*Phoca vitulina*) in the Columbia River estuary (Jeffries 1984). It is probably an important prey for piscivorous birds such as gulls and terns.

Factors Influencing Populations: Larval and juvenile survival appears to be the major determinant of adult population size. In San Francisco Bay, juvenile survival appears to correlate directly with freshwater inflow (California Department of Fish and Game 1987). Pulses of freshwater inflow can alter the estuarine distribution and abundance of this species. In San Francisco Bay, there is a positive association between spring river flow and longfin smelt abundance (Stevens and Miller 1983, Armor and Herrgesell 1985, California Department of Fish and Game 1987).

References

Armor, C., and P. L. Herrgesell. 1985. Distribution and abundance of fishes in the San Francisco Bay estuary between 1980 and 1982. Hydrobiol. 129:211-227.

California Department of Fish and Game. 1987. Delta outflow effects on the abundance and distribution of San Francisco Bay fish in invertebrates, 1980-1985. Exhibit 60, entered by the Calif. Dept. Fish Game for the State Water Resources Control Board 1987 Water Quality/Water Rights Proceeding on the San Francisco Bay/Sacramento-San Joaquin Delta. Calif. Dept. Fish Game, Stockton, CA, 345 p.

Dryfoos, R. L. 1965. The life history and ecology of the longfin smelt in Lake Washington. Ph.D. Thesis, Univ. Wash., Seattle, WA, 159 p.

Eschmeyer, W. N., W. S. Herald, and H. Hammann. 1983. A field guide to Pacific coast fishes of North America. Houghton Mifflin Co., Boston, MA, 336 p.

Ganssle, D. 1966. Fishes and decapods of the San Pablo and Suisun Bays. *In* D. W. Kelley (compiler), Ecological studies of the Sacramento-San Joaquin estuary. Calif. Fish Game, Fish Bull. 133:64-94.

Garrison, K. J., and B. S. Miller. 1980. Review of the early life history of Puget Sound fishes. Fish. Res. Inst., Univ. Wash., Seattle, WA., 729 p. (FRI-UW-8216).

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. No.180, 740 p.

Jeffries, S. 1984. Marine mammals of the Columbia River estuary. Col. Riv. Est. Data Dev. Prog., CREST, Astoria, OR, 62 p. plus appendices.

Moulton, L. L. 1970. The 1970 longfin smelt spawning run in Lake Washington with notes on egg development and changes in the population since 1964. M.S. Thesis, Univ. Wash., Seattle, WA, 84 p.

Moulton, L. L. 1974. Abundance, growth, and spawning of the longfin smelt in Lake Washington. Trans. Am. Fish. Soc. 103(1):46-52.

Moyle, P. B. 1976. Inland fishes of California. Univ. Calif. Press, Berkeley, CA, 405 p.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

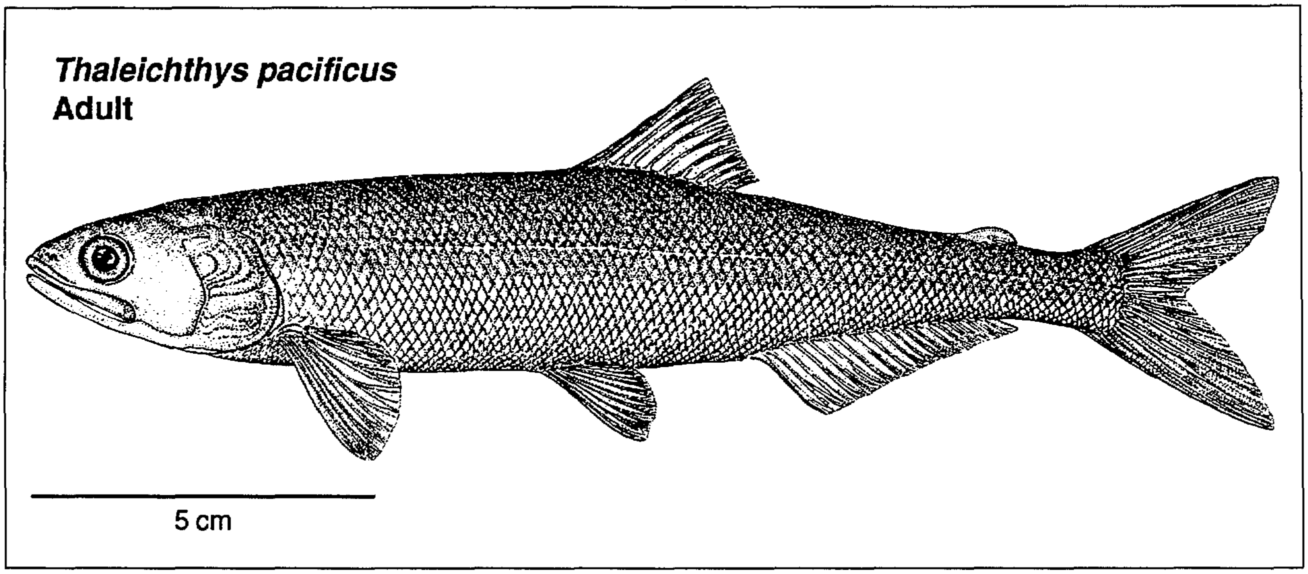
Skinner, J. E. 1962. An historical review of the fish and wildlife resources of the San Francisco Bay area. Water Proj. Bureau Rep. 1, Calif. Dept. Fish Game, Sacramento, CA, 255 p.

Stevens, D. E., and L. W. Miller. 1983. Effects of flow on abundance of young chinook salmon, American shad, longfin smelt, and delta smelt in the Sacramento-San Joaquin River system. N. Am. J. Fish. Manag. 3:425-437.

Wang, J. C. S. 1986. Fishes of the Sacramento-San Joaquin estuary and adjacent waters, California: A guide to the early life histories. Tech. Rep. No. 9. Interagency ecological study program for the Sacramento-San Joaquin estuary. Calif. Dept. Water Res., Calif. Dept. Fish Game, U.S. Bureau Reclam., and U.S. Fish Wildl. Serv. various pagination.

Wydoski, R. S., and R. R. Whitney. 1979. Inland fishes of Washington. Univ. Wash. Press, Seattle, WA, 220 p.

Eulachon



Common Name: eulachon
Scientific Name: *Thaleichthys pacificus*
Other Common Names: candlefish, oilfish, small fish, salvation fish, fathom fish (Scott and Crossman 1973)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Salmoniformes
Family: Osmeridae

Value

Commercial: Major commercial runs occur in the Columbia River and its tributaries, and the Klamath River, California (Moyle 1976). This species is captured by gill net, trawl, and dip net. The 1968-69 lower Columbia River fishery (454 t) was estimated to be worth more than $280,000 (Snyder 1969). In 1985, over 907 t were landed in the Columbia River (Bohn and McIsaac 1986). Almost 862 t were landed in the lower Columbia River in 1987 (McIsaac and Bohn 1988).

Recreational: The eulachon's annual spawning run supports a popular recreational dipnet fishery. Twenty years ago, the sport fishery of the Columbia River and its tributaries had an estimated economic value of $570,000 (Snyder 1969). In many years the number of smelt harvested by the recreational fishery on the Columbia River and its tributaries equals the number harvested commercially.

Indicator of Environmental Stress: All life stages are very sensitive to changes in temperature (Blahm and McConnell 1971). However, information regarding tolerances to chemical pollution is limited.

Ecological: The eulachon is the largest smelt along the Pacific coast of North America and a prey species for many marine vertebrates.

Range

Overall: This species is found from the Klamath River, California, along the Pacific coast to the eastern Bering Sea in Bristol Bay, Alaska, and the Pribilof Islands (Scott and Crossman 1973). A few have been found down to Bodega Head, California (Odemar 1964).

Within Study Area: Major runs occur in the Columbia and Klamath Rivers (Table 1), while many other coastal rivers support small runs (Monaco et al. 1990).

Life Mode

The eulachon is an anadromous species. Eggs are demersal and attach to substrate. Larvae, juveniles, and adults are pelagic.

Habitat

Type: Eggs occur in fresh water. Larvae are found in rivers, estuaries, and the marine neritic zone. Juveniles and adults are found in the marine neritic zone at various depths (Barraclough 1964). During their spawning migration, adults are found near the bottom of estuarine and riverine channels.

Substrate: Eggs are deposited in areas of pea-sized gravel and/or semi-sandy areas with sticks and debris (Smith and Saalfeld 1955).

Physical/Chemical Characteristics: Spawning occurs in riverine areas with moderate water velocities and at temperatures from 4-10°C. Water temperatures colder than 4°C appear to slow or stop adult migrations.

Table 1. Relative abundance of eulachon in 32 U.S. Pacific coast estuaries.

	Life Stage				
Estuary	A	S	J	L	E
Puget Sound	√				
Hood Canal					
Skagit Bay	√				
Grays Harbor	○			○	
Willapa Bay	○			○	
Columbia River	◉	◉		◉	◉
Nehalem Bay					
Tillamook Bay					
Netarts Bay					
Siletz River					
Yaquina Bay					
Alsea River					
Siuslaw River	√				
Umpqua River	○			○	
Coos Bay	√				
Rogue River	√				
Klamath River	◉			○	○
Humboldt Bay	√				
Eel River					
Tomales Bay					
Cent. San Fran. Bay *					
South San Fran. Bay					
Elkhorn Slough					
Morro Bay					
Santa Monica Bay					
San Pedro Bay					
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

Migrations and Movements: Larvae are apparently swept quickly out to sea, spending little time in rivers or estuaries. Adults migrate to spawning grounds from December to April, but usually peak in February and March. Spawning grounds range from just above estuaries to many miles above, but no extensive migrations exist. Ocean movements are unknown, but they are found in the echo scattering layers (Barraclough 1964).

Reproduction

Mode: The eulachon is gonochoristic and iteroparous, however, most die after spawning. It is oviparous; eggs are fertilized externally.

Mating/Spawning: Spawning usually occurs in the lower reaches of rivers or tributaries. Eulachon mass spawn at night and do not build nests (Parente and Snyder 1970, Garrison and Miller 1980).

Fecundity: Approximately 7,000-31,000 eggs are laid, depending on female size (Parente and Snyder 1970).

Growth and Development

Egg Size and Embryonic Development: Eggs are spherical and approximately 1 mm in diameter (Parente and Snyder 1970). Mature eggs have double membranes. After fertilization, the outer membrane ruptures and turns inside out with the outer membrane remaining attached to the inner membrane at a small spot. The adhesive edges of the outer membrane stick to sand or other particles, hence the egg is supported on a peduncle (Hart and McHugh 1944). Embryonic development is indirect and external. Eggs hatch in 19 days at water temperatures of 8.5-11.5°C, and 30-40 days at temperatures of 4.4-7.2°C (Garrison and Miller 1980).

Age and Size of Larvae: Larvae are 4-7 mm at hatching. Postlarvae length is unknown, but probably about 35 mm (Barraclough 1964). Transformation to juvenile stage probably occurs at 30-35 mm in length (Barraclough 1964).

Juvenile Size Range: Juveniles range from 30-140 mm in length.

Age and Size of Adults: Spawning usually occurs at 3 years of age. Spawning adult lengths range from 14.0-20.0 cm, averaging 17.0 cm (Smith and Saalfeld 1955). The eulachon can live to 5 years.

Food and Feeding

Trophic Mode: Larvae, juveniles, and adults are planktivorous.

Food Items: Larvae and postlarvae eat phytoplankton, copepod eggs, copepods, mysids, ostracods, barnacle larvae, cladocerans, worm larvae, and larvae of their own species (Hart 1973). Juveniles and adults consume primarily euphausiids, copepods, and other planktonic crustacea. Adults do not usually feed during their spawning migration.

Biological Interactions

Predation: Many predatory species follow and feed on eulachon during its spawning migration. The spiny dogfish shark (*Squalus acanthias*), sturgeon (*Acipenser* spp.), Pacific halibut (*Hippoglossus stenolepis*), gadids, porpoise, finback whale (*Balaenoptera physalus*), killer whale (*Orcinus orca*), sea lions, seals, and gulls follow eulachon runs (Hart 1973). Harbor seals (*Phoca vitulina*) feed intensively on eulachon in the Columbia

River (Jeffries 1984), and salmon (*Oncorhynchus* spp.) and other fishes eat them at sea (Hart 1973).

Factors Influencing Populations: Temperature changes (Blahm and McConnell 1971) and industrial pollution (Smith and Saalfeld 1955) can have lethal and sublethal effects. Complete failure (i.e., disappearance) of the Cowlitz River run (a Columbia River tributary) from 1949-1952 may have been due to industrial pollution. River flows can also alter migration patterns. The drought year of 1977 caused eulachon to bypass the Cowlitz River and spawn in other rivers (J. Galbreath, Oregon Department of Fish and Wildlife, Clackamas, OR, pers. comm.).

References

Barraclough, W. E. 1964. Contribution to the marine life history of the eulachon, *Thaleichthys pacificus*. J. Fish. Res. Board Can. 21(5):1333-1337.

Blahm, T. H., and R. J. McConnell. 1971. Mortality of adult eulachon (*Thaleichthys pacificus*) subjected to sudden increases in water temperature. Northw. Sci. 45(3):178-182.

Bohn, B. R., and D. McIsaac. 1986. Columbia River fish runs and fisheries 1960-1985. Oreg. Dept. Fish Wildl. and Wash. Dept. Fish., Clackamas, OR, 77 p.

Garrison, K. J., and B. S. Miller. 1980. Review of the early life history of Puget Sound fishes. Fish. Res. Inst., Univ. Wash., Seattle, WA, 729 p. (FRI-UW-8216).

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. No. 180, 740 p.

Hart, J. L., and J. L. McHugh. 1944. The smelts (Osmeridae) of British Columbia. Fish. Res. Board Can., Bull. No. 64, 27 p.

Jeffries, S. 1984. Marine mammals of the Columbia River estuary. Col. Riv. Est. Data Dev. Prog., CREST, Astoria, OR, 62 p. plus appendices.

McIsaac, D., and B. Bohn. 1988. Columbia River fish runs and Fisheries, 1960-1987. Wash. Dept. Fish., and Oreg. Dept. Fish Wildl., Olympia, WA, 83 p.

Monaco, M. E., R. L. Emmett, S. A. Hinton, and D. M. Nelson. 1990. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume I: data summaries. ELMR Rep. No. 4. Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 240 p.

Moyle, P. B. 1976. Inland fishes of California. Univ. Calif. Press, Berkeley, CA, 405 p.

Odemar, M. W. 1964. Southern range extension of the eulachon, *Thaleichthys pacificus*. Calif. Fish. Game, 50(4):305-307.

Parente, W. D., and G. R. Snyder. 1970. A pictorial record of the hatching and early development of the eulachon (*Thaleichthys pacificus*). Northw. Sci. 44(1):50-57.

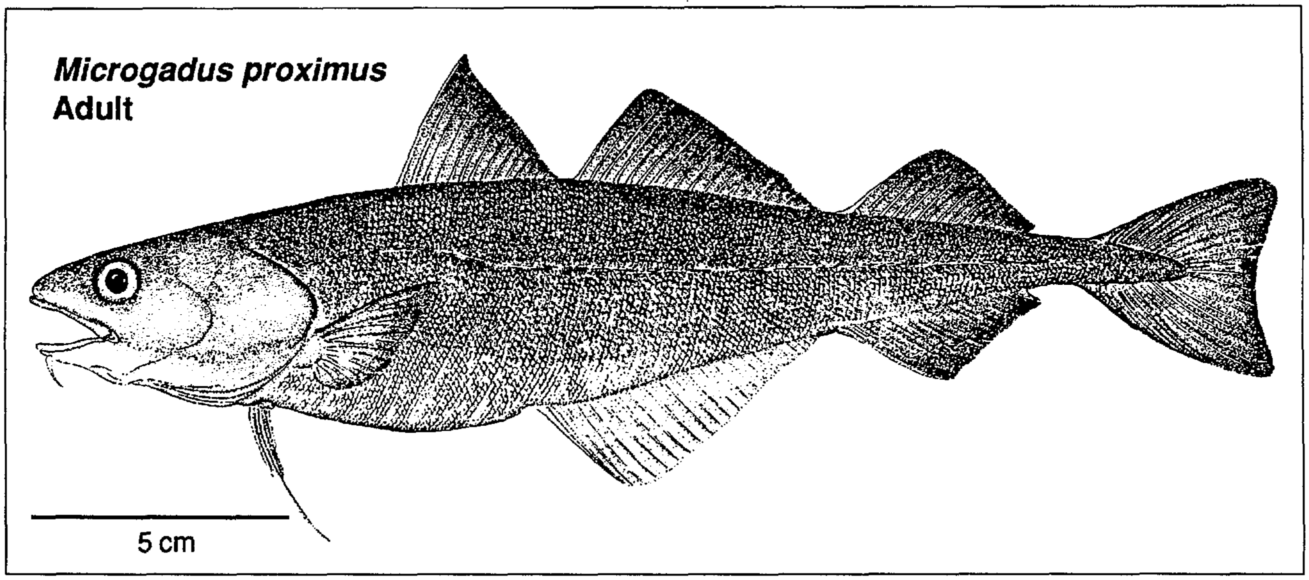
Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Scott, W. B. and E. J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can., Bull. No. 184, 966 p.

Smith, W. E. and R. W. Saalfeld. 1955. Studies on Columbia River smelt, *Thaleichthys pacificus* (Richardson). Wash. Dept. Fish., Fish. Res. Pap. 1(3):3-26.

Snyder, G. R. 1969. Thermal pollution of Columbia River might threaten smelt. Comm. Fish. Rev. 899:58-64.

Pacific tomcod



Common Name: Pacific tomcod
Scientific Name: *Microgadus proximus*
Other Common Names: California tomcod, tomcod, piciata (Gates and Frey 1974)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Gadiformes
Family: Gadidae

Value

Commercial: The Pacific tomcod is not a targeted commercial fish, although some fishermen catch them for personal use (Hart 1973).

Recreational: Although not often targeted, this species is esteemed as a food fish by some anglers and should receive more fishing pressure (Roedel 1953, Beardsley and Bond 1970).

Indicator of Environmental Stress: This is a useful indicator species because it is a demersal fish often found in estuarine and marine areas containing contaminants. Lesions appear more frequently in populations near pollution sources (Malins et al. 1980).

Ecological: The Pacific tomcod is an important prey for harbor seals (*Phoca vitulina*) (Beach et al. 1981) and probably other marine mammals (Simenstad et al. 1979). It is an important predator of shrimp (*Crangon* spp.) (Armstrong et al. 1981, Bottom et al. 1984).

Range

Overall: The Pacific tomcod's overall range is from central California (Isaacson 1965) north to the Gulf of Alaska, Unalaska Island, and Bering Sea (Hart 1973). However, it has not been collected in the Bering Sea recently (Matarese et al. 1981).

Within Study Area: The Pacific tomcod occurs in all estuaries from Elkhorn Slough, California, north through Puget Sound (Table 1) (Ganssle 1966, Aplin 1967, Beardsley and Bond 1970, Bane and Bane 1971, Miller and Borton 1980, Wang 1986).

Life Mode

Eggs have not been found, but are probably demersal and adhesive (Walters 1984, Dunn and Matarese 1987). Larvae and small juveniles (<50 mm) are pelagic, while juveniles and adults are demersal (Richardson and Pearcy 1977, Matarese et al. 1981, Walters 1984).

Habitat

Type: Eggs apparently are released in marine (euhaline) water. Larvae and small juveniles are found in nearshore marine waters (Matarese et al. 1981) and estuaries (Blackburn 1973, Misitano 1977). Adults and juveniles are common in polyhaline to euhaline waters (National Marine Fisheries Service 1981, Bottom et al. 1984, Emmett et al. 1987) and occur primarily in depths <92 m (Hart 1973).

Substrate: Juveniles and adults are found primarily over soft bottoms of mud, silt, and fine sand (Washington 1977, Emmett et al. 1987).

Physical/Chemical Characteristics: The Pacific tomcod is primarily a marine species that utilizes estuaries. Specific salinity and temperature tolerances for each life stage are not available.

Table 1. Relative abundance of Pacific tomcod in 32 U.S. Pacific coast estuaries.

	Life Stage				
Estuary	A	S	J	L	E
Puget Sound	◉	○	◉	○	○
Hood Canal	○	○	○	○	○
Skagit Bay	◉	○	●	○	○
Grays Harbor	○		●	○	
Willapa Bay	○		●	○	
Columbia River	○		●	○	
Nehalem Bay	○		◉	○	
Tillamook Bay	○		◉	○	
Netarts Bay			○	○	
Siletz River	○		○		
Yaquina Bay	○		○	√	
Alsea River	○		○	√	
Siuslaw River	○		○	√	
Umpqua River	○		○	√	
Coos Bay	◉		◉		
Rogue River	○		○		
Klamath River			√		
Humboldt Bay	○		○		
Eel River			√		
Tomales Bay	○		○		
Cent. San Fran. Bay *	√		√		
South San Fran. Bay	√		√		
Elkhorn Slough			√		
Morro Bay					
Santa Monica Bay					
San Pedro Bay					
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Relative abundance

●	Highly abundan
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

Migrations and Movements: This species' movements are not well-studied. Large, older fish move out of estuaries in the early winter and return in the early spring (National Marine Fisheries Service 1981, Walters 1984). This is probably not an active migration, but movement related to prey availability, spawning behavior, and temperature preferences. Larvae can be abundant in some bays (Walters 1984), but most appear in nearshore waters along the open coast (Matarese et al. 1981). Juveniles appear to move to shallow nearshore waters and estuarine areas after their pelagic phase.

Reproduction

Mode: The Pacific tomcod is gonochoristic, oviparous, and iteroparous; eggs are fertilized externally.

Mating/Spawning: The Pacific tomcod apparently has an extended spawning period (Dunn and Matarese 1987). Spawning occurs in marine (euhaline) coastal waters (Waldron 1972, Pearcy and Myers 1974, Misitano 1977) from January to June off San Francisco Bay, California (Wang 1986), winter to spring off Oregon (Richardson and Pearcy 1977, Matarese et al. 1981), and February to May in Port Townsend Bay, Washington (Walters 1984).

Fecundity: Fecundity is estimated to be 1,200 eggs per female (Bane and Bane 1971).

Growth and Development

Egg Size and Embryonic Development: Mature, non-fertilized eggs are spherical and 0.96 mm in diameter (Walters 1984). Embryonic development is indirect and external (Matarese et al. 1981, Walters 1984). No information exists for length of embryogenesis.

Age and Size of Larvae: Larvae range from 2.7-26.3 mm in length. The yolk-sac is absorbed by 3.0 mm (Matarese et al. 1981).

Juvenile Size Range: Juveniles are 26.3 mm to probably 200.0 mm in total length (TL) (Matarese et al. 1981, National Marine Fisheries Service 1981).

Age and Size of Adults: Size and age of adults have not been studied, but maturity is probably reached in 2 years and >200 mm TL (National Marine Fisheries Service 1981). Adults can reach lengths of 310 mm TL (Bane and Bane 1971).

Food and Feeding

Trophic Mode: Larvae are planktonic carnivores. Juveniles and adults are epibenthic, planktonic, and benthic carnivores (depending on fish size and food availability).

Food Items: Larvae eat calanoid and harpacticoid copepods, mysids, and juvenile crangonid shrimp (Walters 1984). Juveniles consume crangonid shrimp, crab megalops, fish larvae, polychaetes, isopods, gammarid amphipods, and calanoid copepods. Adults eat fish [e.g., northern anchovy (*Engraulis mordax*)], gammarid amphipods, crangonid shrimp, crab megalops, polychaetes, mysids, and other invertebrates (Bane and Bane 1971, Armstrong et al. 1981, Bottom et al. 1984).

Biological Interactions

Predation: Larvae are probably consumed by many fishes. Juveniles and adults are eaten by white sturgeon (*Acipenser transmontanus*) (Robert Emmett, pers.

observation) and other large fishes and marine mammals (Simenstad et al. 1979).

Factors Influencing Populations: Successful recruitment of larvae and early juvenile stages is probably related to predation and adequate prey availability. The Pacific tomcod appears to be a fast-growing, early-maturing fish that has a high natural mortality rate (Walters 1984).

References

Aplin, J. A. 1967. Biological survey of San Francisco Bay, 1963-1966. Calif. Dept. Fish Game, Mar. Res. Oper., MRO Ref. 67-4, 131 p.

Armstrong, D. A., B. G. Stevens, and J. C. Hoeman. 1981. Distribution and abundance of Dungeness crab and *Crangon* shrimp and dredging-related mortality of invertebrates and fish in Grays Harbor, Washington. Final Rep. to U.S. Army Corps Eng., Seattle, WA, Contract No. DACW67-80-C-0086, School Fish., Univ. Wash., Seattle, WA, 349 p.

Bane, G. W., and A. W. Bane. 1971. Bay fishes of northern California. Mariscos Publ., Hampton Bays, NY, 143 p.

Beach, R. J., A. C. Geiger, S. J. Jeffries, and S. D. Treacy. 1981. Marine mammal-fishery interactions on the Columbia River and adjacent waters, 1981. NWAFC Proc. Rep. 82-04, Northwest Alaska Fish. Cent., Nat. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E. Seattle, WA, 186 p.

Beardsley, A. J., and C. E. Bond. 1970. Field guide to common marine and bay fishes of Oregon. Agr. Exp. Sta. Bull No. 607, Oregon State Univ., Corvallis, OR, 27 p.

Blackburn, J. E. 1973. Pelagic eggs and larval fish of Skagit Bay. *In* Q. J. Stober and E. O. Salo (editors), Ecological studies of the proposed Kiket Island nuclear power site, p. 71-118, Fish. Res. Inst. Coll. Fish., Univ. Wash., Seattle, WA (FRI-UN-7304).

Bottom, D. L., K. K. Jones, and M. J. Herring. 1984. Fishes of the Columbia River estuary. Col. Riv. Est. Data Dev. Prog., CREST, Astoria, OR, 113 p. plus appendices.

Dunn, J. R., and A. C. Matarese. 1987. A review of the early life history of northeast Pacific gadoid fishes. Fish. Res. 5:163-184.

Emmett, R. L., T. C. Coley, G. T. McCabe, Jr., and R. J. McConnell. 1987. Demersal fishes and benthic invertebrates at four interim dredge disposal sites off the Oregon coast. Proc. Rep., Northwest Alaska Fish. Cent., Nat. Mar. Fish. Serv., Coastal Zone Est. Stud. Div., NOAA, 2725 Montlake Blvd. E., Seattle, WA, 69 p. plus appendices.

Ganssle, D. 1966. Fishes and decapods of San Pablo and Suisun Bays. *In* D. W. Kelley (compiler), Ecological studies of the Sacramento-San Joaquin estuary. Calif. Fish Game., Fish Bull. 133:64-94.

Gates, D. E., and H. W. Frey. 1974. Designated common names of certain marine organisms of California. Calif. Fish Game, Fish. Bull. 161:55-90.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. No. 180, 740 p.

Isaacson, P. A. 1965. Southern range extension of the tomcod, *Microgadus proximus*. Calif. Fish. Game 51:58.

Malins, D. C., B. B. McCain, D. W. Brown, A. K. Sparks, and H. O. Hodgins. 1980. Chemical contaminants and biological abnormalities in central and southern Puget Sound. Tech. Memo. OMPA-2, Northwest Alaska Fish. Cent., Nat. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E. Seattle, WA, 295 p.

Matarese, A. C., S. L. Richardson, and J. R. Dunn. 1981. Larval development of Pacific tomcod, *Microgadus proximus*, in the northeast Pacific Ocean with comparative notes on larvae of walleye pollack, *Theragra chalcogramma*, and Pacific cod, *Gadus macrocephalus* (Gadidae). Fish. Bull., U.S. 78(4):923-940.

Miller, B. S., and S. F. Borton. 1980. Geographical distribution of Puget Sound fishes: maps and data source sheets. 3 vol. Fish. Res. Inst., Coll. Fish., Univ. Wash., Seattle, WA, various pagination.

Misitano, D. A. 1977. Species composition and relative abundance of larval and post-larval fishes in the Columbia River estuary. Fish. Bull., U.S. 75:218-222.

National Marine Fisheries Service. 1981. Columbia River estuary data development program report: salmonid and non-salmonid fish 1981. Unpubl. Rep., Pt. Adams Biol. Field Sta., Northwest and Alaska Fish Cent., P.O Box 155, Hammond, OR, various pagination.

Pearcy, W. G., and S. S. Myers. 1974. Larval fish of Yaquina Bay, Oregon: A nursery ground for marine fishes? Fish. Bull., U.S. 72:201-213.

Richardson, S. L., and W. G. Pearcy. 1977. Coastal and oceanic fish larvae in an area of upwelling off Yaquina Bay, Oregon. Fish. Bull., U.S. 75(1):125-146.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Roedel, P. M. 1953. Common ocean fishes of the California coast. Calif. Fish Game, Fish Bull. 91:1-184.

Simenstad, C. A., B. S. Miller, C. F. Nyblade, D. Thornburgh, and L. J. Bledsoe. 1979. Food web relationships of northern Puget Sound and the Strait of Juan de Fuca: a synthesis of the available knowledge. U.S. Interagency (NOAA/EPA) Energy/Environ. Res. Dev. Prog. Rep., EPS-600/7-79-259, Washington, D.C., 335 p.

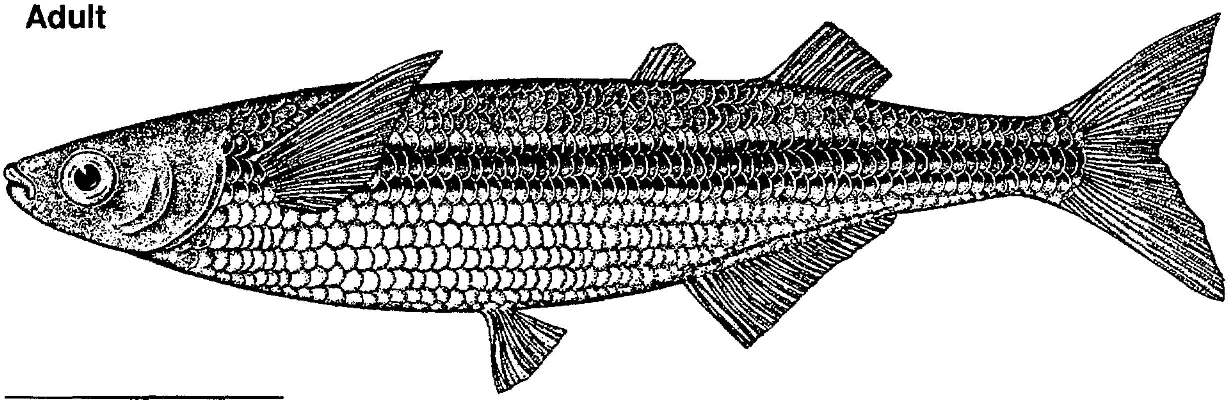
Waldron, K. D. 1972. Fish larvae collected from the northeastern Pacific Ocean and Puget Sound during April and May 1967. Tech. Rep. NMFS SSR F-663, 16 p. Northwest Alaska Fish. Cent., Nat. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA , 16p.

Walters, G. E. 1984. Ecological aspects of larval and juvenile Pacific cod (*Gadus macrocephalus*), walleye pollock (*Theragra chalcogramma*), and Pacific tomcod (*Microgadus proximus*) in Port Townsend, Washington. M.S. Thesis, Univ. Wash., Seattle, WA, 129 p.

Wang, J. C. S. 1986. Fishes of the Sacramento-San Joaquin estuary and adjacent waters, California: a guide to the early life histories. Tech. Rep. No. 9. Interagency ecological study program for the Sacramento-San Joaquin estuary. Calif. Dept. Water Res., Calif. Dept. Fish Game, U.S. Bureau Reclam., and U. S. Fish Wildl. Serv., various pagination.

Washington, P. M. 1977. Recreationally important marine fishes of Puget Sound, Washington. Proc. Rep., Northwest Alaska Fish. Cent., Nat. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E. Seattle, WA, 122 p.

Atherinops affinis
Adult



Common Name: topsmelt
Scientific Name: *Atherinops affinis*
Other Common Names: bay smelt, rainbow smelt, panzarotto, little smelt, least smelt, silverside, capron, jack pescadillo (Walford 1931, Gates and Frey 1974)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Atheriniformes
Family: Atherinidae

Value

Commercial: Although the topsmelt is an excellent food fish (Bane and Bane 1971), there is a very limited commercial catch. The topsmelt represents only about 15-25% of the California "smelt" catch (Bane and Bane 1971). It is usually taken in association with jacksmelt (*Atherinopsis californiensis*) (Frey 1971).

Recreational: It is taken by recreational anglers year round and is one of the most commonly caught fishes from piers in California. Since this species is abundant and can be easily captured by light tackle, it is an important recreational fish for children (Frey 1971).

Indicator of Environmental Stress: The topsmelt can withstand extreme salinities (80‰) (Carpelan 1955), and is an excellent bioassay organism (Reish and Lemay 1988).

Ecological: This species is one of the most abundant pelagic fishes in many Pacific coast estuaries (Allen and Horn 1975, Horn 1980, Allen 1982, Horn and Allen 1985). Five subspecies are presently recognized: 1) *A. affinis oregonia* is a northern variety found from Oregon to Humboldt Bay, California, 2) *A. affinis affinis* occurs from San Francisco Bay (and surrounding areas) to Monterey, California, 3) *A. affinis littoralis* ranges from Monterey down to San Diego Bay, California, 4) *A. affinis cedroscensis* is called the kelp topsmelt, and 5) *A. affinis insularium* is the "island topsmelt", being found around the Santa Barbara Islands, California, (Schultz 1933, Feder et al. 1974). When not in estuaries, it appears to stay in shallow water along the shore line (Hubbs 1918).

Range

Overall: The topsmelt is found from the Gulf of California to Vancouver Island, British Columbia, Canada (one record) (Miller and Lea 1972, Hart 1973, Eschmeyer et al. 1983). However, it is not usually found north of Tillamook Bay, Oregon.

Within Study Area: This species is found in most estuaries of the study area south of Tillamook Bay, Oregon (Table 1) (Schultz 1933, Myers 1980).

Life Mode

Eggs are benthic, larvae are planktonic, and juveniles and adults are schooling pelagic fish. However, juvenile and adults will apparently move into shallow waters and feed on the bottom.

Habitat

Type: Eggs are benthic and found in estuaries, bays, and lagoons. Larvae are also found in embayments. Larvae are planktonic but school near the surface in shallow and open water (Wang 1986). Juveniles and adults are pelagic but are found over a wide range of habitats depending on time of year (Feder et al. 1974). The topsmelt is primarily a marine fish that prefers estuaries, bays, sloughs, and lagoons (Moyle 1976).

Table 1. Relative abundance of topsmelt in 32 U.S. Pacific coast estuaries.

	Life Stage				
Estuary	A	S	J	L	E
Puget Sound					
Hood Canal					
Skagit Bay					
Grays Harbor	√		√		
Willapa Bay	√		√		
Columbia River	√		√		
Nehalem Bay	√		√		
Tillamook Bay	○		○		
Netarts Bay	◉	◉	◉	○	◉
Siletz River					
Yaquina Bay	◉	◉	●	○	◉
Alsea River	○	○	○	○	○
Siuslaw River	◉	◉	◉	○	◉
Umpqua River	○		○		
Coos Bay	●	●	●	○	●
Rogue River					
Klamath River					
Humboldt Bay	○	○	○	○	○
Eel River	○	○	○	○	○
Tomales Bay	◉	◉	●	◉	◉
Cent. San Fran. Bay *	○		○	○	
South San Fran. Bay	◉	●	●	◉	●
Elkhorn Slough	●	●	●	◉	●
Morro Bay	●	●	●	◉	●
Santa Monica Bay	◉	○	◉	○	○
San Pedro Bay	◉	○	◉	○	○
Alamitos Bay	◉	◉	●	◉	◉
Anaheim Bay	◉	◉	●	◉	◉
Newport Bay	◉	◉	●	○	◉
Mission Bay	◉	◉	●	○	◉
San Diego Bay	◉	◉	●	○	◉
Tijuana Estuary	●	●	●	●	●
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

Substrate: Eggs are laid primarily on eelgrass (*Zostera* spp.) and adhere to macroalgae on tidal flats (Schultz 1933). Larvae are often found over soft, unconsolidated sediments and other substrates (Wang 1986). Juveniles and adults occur along sandy beaches, in kelp beds, over rocky reefs, and around piers (Feder et al. 1974).

Physical/Chemical Characteristics: The topsmelt is a euryhaline species (Fronk 1969). Eggs develop successfully in salinities up to 72‰ (Carpelan 1955). Smaller fish may tolerate high salinities better than larger fish (Carpelan 1955). Young-of-the-year are common in mesohaline and oligohaline areas of southern San Francisco Bay (Wang 1986). While juveniles can tolerate salinities ranging from 2-80‰, growth is reduced at higher salinities (Middaugh and Shenker 1988). Optimum survival and growth occurs at salinities of 30‰ (Middaugh and Shenker 1988). The topsmelt is often found in waters of high turbidity. Maximum temperature for proper egg development is between 27.0-28.5°C, and the minimum temperature for egg development appears to be near 12.8°C (Hubbs 1965). Juvenile and adult topsmelt appear to be eurythermal (Carpelan 1955), but temperatures of 26-27°C appear to cause stress (Ehrlich et al. 1979). The upper and lower lethal temperatures for juvenile fish were found to be 31.7°C and 10.4°C, respectively (Doudoroff 1945).

Migrations and Movements: Larvae appear to stay near the surface in slow-moving waters. Although some adults and juveniles will stay in the open waters of some estuaries and bays year-round, most move to neritic areas and coastal kelp beds during fall and winter (Wang 1986). During spring, they are often found near the entrance of bays (Schultz 1933). Adults move into shallow water sloughs and mud flats in late spring and summer to spawn, and follow the salt wedge to upper estuarine areas during summer and fall (Wang 1986).

Reproduction

Mode: The topsmelt is gonochoristic, iteroparous, and oviparous; eggs are fertilized externally.

Mating/Spawning: Spawning occurs in Newport Bay, California, as early as February but most occurs during May and June (Fronk 1969). Spawning occurs from April to October in San Francisco Bay, with peaks in May and June (Wang 1986). Spawning takes place at temperatures of 10-25°C and in shallow water habitats that have appropriate submerged aquatic vegetation (Schultz 1933). Most spawning may occur at night (Fronk 1969). The topsmelt appears to spawn in batches, laying eggs more than once during a spawning season (Fronk 1969, Wang 1986).

Fecundity: Fecundities range from 200 eggs per female (of length 110-120 mm) to about 1,000 eggs per female (of length 160 mm and over) (Fronk 1969).

Growth and Development

Egg Size and Embryonic Development: Eggs are spherical and 1.5-1.7 mm in diameter (Wang 1986). Eggs have a thick chorion bearing 2-8 filaments attached in a random pattern. These filaments cause the eggs to become entangled with eelgrass and other vegetation (Wang 1986). Embryonic development is indirect and external. Hatching time varies from 35 days at 13°C to <9 days at 27°C (Hubbs 1965).

Age and Size of Larvae: Larvae are 4.3-4.9 mm long (total length) at hatching and about 0.0011 g (wet weight). They are also reported to be 5.1-5.4 mm long (standard length) at hatching (Middaugh et al. 1990). They are 9.5-10.0 mm long when the yolk-sac is absorbed. Juvenile characteristics are formed at approximately 18.5 mm (Wang 1986).

Juvenile Size Range: Juveniles are approximately 18.5-120.0 mm long (Schultz 1933, Fronk 1969).

Age and Size of Adults: Northern varieties grow larger than southern subspecies (Schultz 1933). Maturity is reached in two years at about 120 mm in length by *A. affinis littoralis* (Schultz 1933, Fronk 1969). In Oregon, only 5% mature in their second year; most mature in their third year when >200 mm long (Schultz 1933). This species can live up to 8 years and reach lengths up to 37 cm (Schultz 1933, Eschmeyer et al. 1983).

Food and Feeding

Trophic Mode: The topsmelt is omnivorous (Quast 1968, Horn and Allen 1985). Juveniles and adults often feed near the water surface, but feed on the bottom when in shallow water (about 2 m or less). They feed primarily during the day (Hobson et al. 1981).

Food Items: Estuary and bay inhabitants feed primarily on plant material, including *Melosira moniliformis*, *Entermorpha* spp., and other algae and diatoms (Fronk 1969, Moyle 1976, Ruagh 1976). They also consume small crustacea (amphipods, copepods, insects, and cumaceans) and some benthic invertebrates (polychaetes and gastropods) (Horn and Allen 1985). Oceanic inhabitants are primarily planktonic crustacean carnivores. Primary prey include gammarid and caprellid amphipods, mysids, ostracods, copepods, and crustacean larvae (Quast 1968, Fronk 1969).

Biological Interactions

Predation: The topsmelt is an important prey for many piscivorous birds and fishes, including yellowtail (*Seriola lalandei*) and other large fishes (Feder et al. 1974).

Factors Influencing Populations: Population abundance was significantly correlated to temperature and salinity in Newport Bay, California (Allen 1982). No relation was found between abundance indices and river flow in San Francisco Bay (California Department of Fish and Game 1987). This species is commonly impinged on power plant intake screens, but this may not be a significant cause of mortality for the bay population (San Diego Gas and Electric 1980). Since this species uses shallow-water eelgrass areas for spawning, the removal or destruction of this habitat adversely affects topsmelt abundance.

References

Allen, L. G. 1982. Seasonal abundance, composition, and productivity of the littoral fish assemblage in upper Newport Bay, California. Fish. Bull., U.S. 80(4):769-790.

Allen, L. G., and M. H. Horn. 1975. Abundance, diversity and seasonality of fishes in Colorado Lagoon, Alamitos Bay, California. Est. Coast. Mar. Sci. 3:371-380.

Bane, G. W., and A. W. Bane. 1971. Bay fishes of northern California with emphasis on the Bodega Tomales Bay area. Mariscos Publ., Hampton Bays, NY, 143 p.

California Department of Fish and Game. 1987. Delta outflow effects on the abundance and distribution of San Francisco Bay fish and invertebrates, 1980-1985. Exhibit 60, entered by the Calif. Dept. Fish Game for the State Water Resources Control Board 1987 Water Quality/Water Rights Proceeding on the San Francisco Bay/Sacramento-San Joaquin Delta. Calif. Dept. Fish Game, Stockton, CA, 345 p.

Carpelan, L. H. 1955. Tolerance of the San Francisco topsmelt, *Atherinops affinis affinis,* to conditions in salt-producing ponds bordering San Francisco Bay. Calif. Fish Game 41(4):279-284.

Doudoroff, P. 1945. The resistance and acclimatization of marine fishes to temperature changes. II. Experiments with *Fundulus* and *Atherinops*. Biol. Bull. 88(2):197-206.

Ehrlich, K. F., J. M. Hood, G. Muszynski, and G. E. McGowen. 1979. Thermal behavioral responses of selected California littoral fishes. Fish. Bull., U.S. 76(4):837-849.

Eschmeyer, W. N., W. S. Herald, and H. Hammann. 1983. A field guide to Pacific coast fishes of North America. Houghton Mifflin Co., Boston, MA, 336 p.

Feder, H. M., C. H. Turner, and C. Limbaugh. 1974. Observations of the fishes associated with kelp beds in southern California. Calif. Fish Game, Fish Bull. 160, 138 p.

Frey, H. W. 1971. California's living marine resources and their utilization. Calif. Dept. Fish Game, Sacramento, CA, 148 p.

Fronk, R. H. 1969. Biology of *Atherinops affinis littoralis* Hubbs in Newport Bay. M.S. Thesis, Univ. Calif., Irvine, CA, 106 p.

Gates, D. E., and H. W. Frey. 1974. Designated common names of certain marine organisms of California. Calif. Fish Game, Fish Bull. 161:55-90.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. No. 180, 740 p.

Hobson, E. W. N. McFarland, and J. R. Chess. 1981. Crepuscular and nocturnal activities of Californian nearshore fishes, with consideration of their scotopic visual pigments and the photic environment. Fish. Bull., U.S. 79(1):1-30.

Horn, M. H. 1980. Diel and seasonal variation in abundance and diversity of shallow-water fish populations in Morro Bay, California. Fish. Bull., U.S. 78(3):759-770.

Horn, M. H., and L. G. Allen. 1985. Fish community ecology in southern California bays and estuaries. Chapter 8. *In* A. Yanez-Arancibia (editor), Fish community ecology in estuaries and coastal lagoons: towards an ecosystem integration, p. 169-190 DR (R) UN AM Press, Mexico.

Hubbs, C. 1918. The fishes of the genus *Atherinops*, their variation, distribution, relationships, and history. Bull. Amer. Mus. Nat. Hist. 38(13):409-440.

Hubbs, C. 1965. Developmental temperature tolerance and rates of four southern California fishes, *Fundulus parvipinnis*, *Atherinops affinis*, *Leuresthes tenuis*, and *Hypsoblennius* sp. Calif. Fish Game 51(2):113-122.

Middaugh, D. P., M. J. Hemmer, J. M. Shenker, and T. Takita. 1990. Laboratory culture of jacksmelt, *Atherinopsis californiensis*, and topsmelt, *Atherinops affinis* (Pisces:Atherinidae), with a description of larvae. Calif. Fish Game 76(1):4-43.

Middaugh, D. P., and J. M. Shenker. 1988. Salinity tolerance of young topsmelt, *Atherinops affinis*, cultured in the laboratory. Calif. Fish Game 74(4):232-235.

Miller, D. J., and R. N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Fish Game, Fish Bull. 157, 235 p.

Moyle, P. B. 1976. Inland fishes of California. Univ. Calif. Press, Berkeley, CA, 405 p.

Myers, K. W. W. 1980. An investigation of the utilization of four study areas in Yaquina Bay, Oregon, by hatchery and wild juvenile salmonids. M.S. Thesis, Oregon State Univ., Corvallis, OR, 234 p.

Quast, J. C. 1968. Observations on the food of the kelp-bed fishes. Calif. Fish Game, Fish Bull. 139:109-142.

Reish, D. J., and J. A. Lemay. 1988. Bioassay manual for dredged sediments. Research Rep., various pages. Available, U.S. Army Corps Eng., Los Angeles District, Los Angeles, CA, (Contract Number DACW-09-83R-005).

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Ruagh, A. A. 1976. Feeding habits of silversides (Family Atherinidae) in Elkhorn Slough, Monterey Bay, California. M.S. Thesis, Calif. State Univ., Fresno, CA, 60 p.

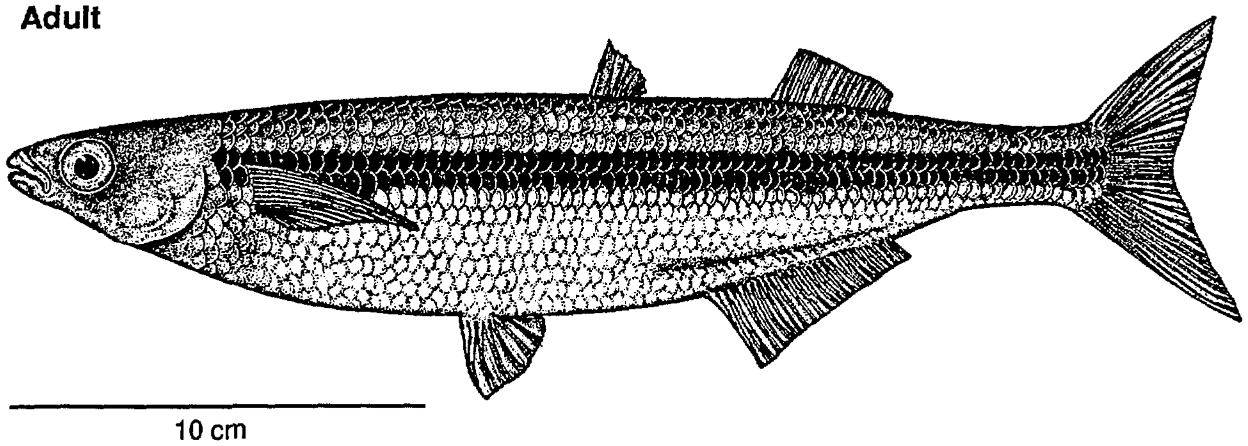
San Diego Gas and Electric. 1980. Silvergate power plant cooling water intake system demonstration (in accordance with section 316(b) Federal Water Pollution Control Act Amendment of 1972). San Diego Gas and Electric, San Diego, CA, various pagination.

Schultz, L. P. 1933. The age and growth of *Atherinops affinis oregonia* Jordan and Snyder and other subspecies of baysmelt along the Pacific coast of the United States. Wash. State Univ. Publ. Biol. 2(3):45-102.

Walford, L. A. 1931. Handbook of common commercial and game fishes of California. Calif. Fish Game, Fish Bull. 28, 181 p.

Wang, J. C. S. 1986. Fishes of the Sacramento-San Joaquin estuary and adjacent waters, California: A guide to the early life histories. Tech. Rep. No. 9. Interagency ecological study program for the Sacramento-San Joaquin estuary. Calif. Dept. Water Res., Calif. Dept. Fish Game, U.S. Bureau Reclam., U.S. Fish Wildl. Serv., various pagination.

Atherinopsis californiensis
Adult



Common Name: jacksmelt
Scientific Name: *Atherinopsis californiensis*
Other Common Names: California smelt, silverside, horse smelt, blue smelt, pescado del rey, peixe rey, pesce rey, jack smelt (Gates and Frey 1974)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Atheriniformes
Family: Atherinidae

Value

Commercial: In 1945, over 907 kg of jacksmelt were landed, primarily from Newport, Monterey, San Francisco, Tomales and Humboldt Bays, California (Frey 1971). Presently, it forms the largest portion of the "smelt" captures in California, but is not considered an important commercial fish. It is primarily caught incidentally during other fisheries.

Recreational: The jacksmelt is commonly captured from California piers (Frey 1971) and is easily caught using light hook and line fishing gear (Frey 1971). In California, there are no recreational catch limits (California Department of Fish and Game 1987a).

Indicator of Environmental Stress: No information is presently available. However, because the jacksmelt uses estuaries for spawning and rearing, degradation of estuarine habitats can affect this species' population.

Ecological: The jacksmelt is an important member of the California nearshore coastal, bay, and estuary fauna (Clark 1929, Allen and DeMartini 1983, California Department of Fish and Game 1987b). It is often found schooling with topsmelt (*Atherinops affinis*) and usually caught within 5 km of shore (Ruagh 1976).

Range

Overall: Overall range is from Santa Maria Bay, Baja California, to Yaquina Bay, Oregon (Miller and Lea 1972, Eschmeyer et al. 1983).

Within Study Area: The jacksmelt is commonly found in most bays and estuaries that have appropriate habitat south of Coos Bay, Oregon (Table 1).

Life Mode

Eggs are demersal and adhesive (Clark 1929). Larvae school and are pelagic (Wang 1986). Juveniles and adults are surface-oriented pelagic schooling fishes (Allen and DeMartini 1983).

Habitat

Type: Eggs are usually found on vegetation in shallow-water nearshore marine habitats as well as estuaries and bays (Wang 1986). Larvae are also found in estuarine, bay, and kelp bed habitats and actively school near the surface. Juveniles and adults are found in neritic, estuarine, and bay environments. Juveniles and adults are most often found in murky water from the surface down to 29 m, but tend to concentrate between 1.5 and 15 m (Feder et al. 1974).

Substrate: Eggs are laid on substrates/vegetation that allow them to become entangled (*Zostera* spp., *Gracillaria* spp., and hydroids, etc.) (Frey 1971, Wang 1986). Larvae are found over a variety of substrates, but mostly sandy and muddy bottoms and in the kelp canopy (Frey 1971). Juveniles and adults prefer sandy bottoms (Feder et al. 1974).

Table 1. Relative abundance of jacksmelt in 32 U.S. Pacific coast estuaries.

Estuary	A	S	J	L	E
Puget Sound					
Hood Canal					
Skagit Bay					
Grays Harbor					
Willapa Bay					
Columbia River					
Nehalem Bay					
Tillamook Bay					
Netarts Bay					
Siletz River					
Yaquina Bay	√		√		
Alsea River					
Siuslaw River					
Umpqua River					
Coos Bay	○		○		
Rogue River					
Klamath River					
Humboldt Bay	○	○	○	○	○
Eel River					
Tomales Bay	●	●	●	●	●
Cent. San Fran. Bay *	●	●	●	●	●
South San Fran. Bay	●	●	●	●	●
Elkhorn Slough	◉	◉	○	◉	◉
Morro Bay	◉	◉	○	○	◉
Santa Monica Bay	◉	◉	◉	○	◉
San Pedro Bay	◉	◉	◉	○	◉
Alamitos Bay					
Anaheim Bay					
Newport Bay	√		√		
Mission Bay	◉	◉	◉	◉	◉
San Diego Bay	○	○	○	○	○
Tijuana Estuary					
	A	S	J	L	E

Life Stage

Relative abundance:
● Highly abundant
◉ Abundant
○ Common
√ Rare
Blank Not present

Life stage:
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

Physical/Chemical Characteristics: Temperature and salinity tolerances of this species are not known. However, the distribution of juvenile and adult jacksmelt in San Francisco Bay shows they occur primarily in polyhaline and euhaline waters (California Department of Fish and Game 1987b). Eggs may hatch in salinities as low as 5‰ (Wang 1986). Optimum larval and juvenile survival and growth appears to be within salinities of 10 to 20‰, indicating larvae may prefer mesohaline salinities (Middaugh and Shenker 1988, Middaugh et al. 1990). The jacksmelt appears to prefer turbid waters (Feder et al. 1974).

Migrations and Movements: This species is seldom found far from shore (Baxter 1960). Jacksmelt move inshore and into bays and estuaries to spawn during late winter and early spring (Clark 1929, Wang 1986).

During summer, large schools of juveniles and some adults reside in bays and estuaries, moving out to coastal waters in the fall.

Reproduction

Mode: The jacksmelt is gonochoristic, iteroparous, and oviparous. It is a batch spawner and eggs are fertilized externally (Clark 1929).

Mating/Spawning: Spawning may occur from October to March with a peak during November-March (Clark 1929), and reportedly year-round in southern California (Feder et al. 1974) In San Francisco Bay, spawning occurs from October to early August (Wang 1986). Spawning in San Pablo Bay is reported to occur from September to April (Ganssle 1966). In Tomales Bay, spawning occurs from January to March (Banerjee 1966). Spawning occurs over marine vegetation in shallow coastal waters and in bays and estuaries where appropriate substrate is available.

Fecundity: Fecundity is not documented, but probably over 2,000 eggs per female.

Growth and Development

Egg Size and Embryonic Development: Unfertilized eggs are spherical and 0.9-2.2 mm in diameter (Clark 1929); fertilized eggs are 1.9-2.5 mm in diameter (Wang 1986). Eggs have a thick, hard chorion that has 15 or 16, 1-2 mm-long filaments attached. These filaments entangle eggs on substrates to form large egg masses (Wang 1986). Embryonic development is indirect and external. The yellowish-orange eggs hatch within seven days at 10-12°C (Wang 1986).

Age and Size of Larvae: After hatching, larvae remain on the bottom for a moment and then actively swim near the surface (Wang 1986). Larvae live on their yolk-sac until it is absorbed (about 48 hours after hatching) (Middaugh et al. 1990). The larval size range is 7.5-8.6 mm long at hatching to about 25 mm long at transformation to juvenile (Clark 1929, Wang 1986). At 8 days, they are 10.5-11.7 mm long; at 24 days they are 17.6-20.3 mm long (Middaugh et al. 1990).

Juvenile Size Range: Juvenile jacksmelt average 110 mm long at the end of their first year, and 180-190 mm at the end of two years (Clark 1929).

Age and Size of Adults: Individuals that grow quickly (>200 mm long) will mature in their second year. However, all individuals mature by their third year (Clark 1929). The largest jacksmelt reported was 78 cm long, but the largest actually measured was 62 cm (Miller and Lea 1972). Maximum age may be 11 years (Frey 1971).

Food and Feeding

Trophic Mode: The jacksmelt is omnivorous (Bane and Bane 1971, Ruagh 1976).

Food Items: Primary prey for this species include algae (*Ulothrix* spp., *Melosira moniliformis*, *Enteromorpha* spp., and other filamentous algae, and benthic diatoms), crustaceans (mysids, copepods, decapod larvae), and detritus (Bane and Bane 1971, Ruagh 1976).

Biological Interactions

Predation: The jacksmelt is eaten by yellowtail (*Seriola lalandei*), kelp bass (*Paralabrax clathratus*), sharks, and other piscivorous fishes (Baxter 1960, Feder et al. 1974). It is probably also eaten by piscivorous birds [e.g., brown pelican (*Pelecanus occidentalis*) and gulls] and marine mammals.

Factors Influencing Populations: Because this species utilizes embayments and estuaries for spawning, it is highly susceptible to adverse effects from pollution and habitat modification. Interestingly, jacksmelt are not commonly found in Anaheim Bay, Alamitos Bay, or Newport Bay, California (Klingbeil et al. 1974, Allen and Horn 1975, Allen 1982), whereas topsmelt are abundant in these bays. Apparently jacksmelt are much more sensitive to salinity and temperature fluctuations than topsmelt. A parasitic nematode often infests the flesh of jacksmelt, thus reducing its commercial and recreational value (Frey 1971). The final host for this parasite is perhaps sharks or pelicans (Frey 1971). Freshwater inflow affects jacksmelt distributions in San Francisco Bay; during years of low freshwater inflow, jacksmelt use San Pablo Bay and Carquinez strait, but in high-flow years they are more abundant in South and Central San Francisco Bay (California Department of Fish and Game 1987b).

References

Allen, L. G. 1982. Seasonal abundance, composition, and productivity of the littoral fish assemblage in upper Newport Bay, California. Fish. Bull., U.S. 80(4):769-790.

Allen, L. G., and E. E. DeMartini. 1983. Temporal and spatial patterns of nearshore distribution and abundance of the pelagic fishes off San Onofre-Oceanside, California. Fish. Bull., U.S. 81(3):569-586.

Allen, L. G., and M. H. Horn. 1975. Abundance, diversity and seasonality of fishes in Colorado Lagoon, Alamitos Bay, California. Est. Coast. Mar. Sci. 3:371-380.

Bane, G. W., and A. W. Bane. 1971. Bay fishes of northern California with emphasis on the Bodega Tomales Bay area. Mariscos Publ., Hampton Bays, NY, 143 p.

Banerjee, T. 1966. Survey of the fishes of Tomales Bay with notes on the life history of the white seaperch, *Phanerodon furcatus* Girard. M.S. Thesis, Univ. Pacific, Stockton, CA, 81 p.

Baxter, J. L. 1960. Inshore fishes of California. Calif. Dept. Fish Game, Sacramento, CA, 80 p.

California Department of Fish and Game. 1987a. 1987 California sport fishing regulations. Calif. Dept. Fish Game, Sacramento, CA, 12 p.

California Department of Fish and Game. 1987b. Delta outflow effects on the abundance and distribution of San Francisco Bay fish and invertebrates, 1980-1985. Exhibit 60, entered by the California Department of Fish and Game for the State Water Resources Control Board 1987 Water Quality/Water Rights Proceeding on the San Francisco Bay/Sacramento-San Joaquin Delta. Calif. Dept. Fish Game, Stockton, CA, 345 p.

Clark, F. N. 1929. The life history of the California jack smelt, *Atherinopsis californiensis*. Calif. Fish Game, Fish Bull. 16, 22 p.

Eschmeyer, W. N., W. S. Herald, and H. Hammann. 1983. A field guide to Pacific coast fishes of North America. Houghton Mifflin Co., Boston, MA, 336 p.

Feder, H. M., C. H. Turner, and C. Limbaugh. 1974. Observations on fishes associated with kelp beds in southern California. Calif. Fish Game, Fish Bull. 160, 144 p.

Frey, H. W. 1971. California's living marine resources and their utilization. Calif. Dept. Fish Game, Sacramento, CA, 148 p.

Ganssle, D. 1966. Fishes and decapods of San Pablo and Suisun Bays. *In* D. W. Kelley (compiler), Ecological studies of the Sacramento-San Joaquin estuary. Calif. Fish Game, Fish Bull. 133:64-94.

Gates, D. E., and H. W. Frey. 1974. Designated common names of certain marine organisms of California. Calif. Fish Game, Fish Bull. 161:55-90.

Klingbeil, R. A., R. D. Sandell, and A. W. Wells. 1974. An annotated checklist of the elasmobranchs and teleosts of Anaheim Bay. *In* E. D. Lane and C. W. Hill (editors), The marine resources of Anaheim Bay. Calif. Fish Game, Fish Bull. 165:79-90.

Middaugh, D. P., M. J. Hemmer, J. M. Shenker, and T. Takita. 1990. Laboratory culture of jacksmelt, *Atherinopsis californiensis*, and topsmelt, *Atherinops affinis* (Pisces:Atherinidae), with a description of larvae. Calif. Fish Game 76(1):4-43.

Middaugh, D. P., and J. M. Shenker. 1988. Salinity tolerance of young topsmelt, *Atherinops affinis*, cultured in the laboratory. Calif. Fish Game 74(4):232-235.

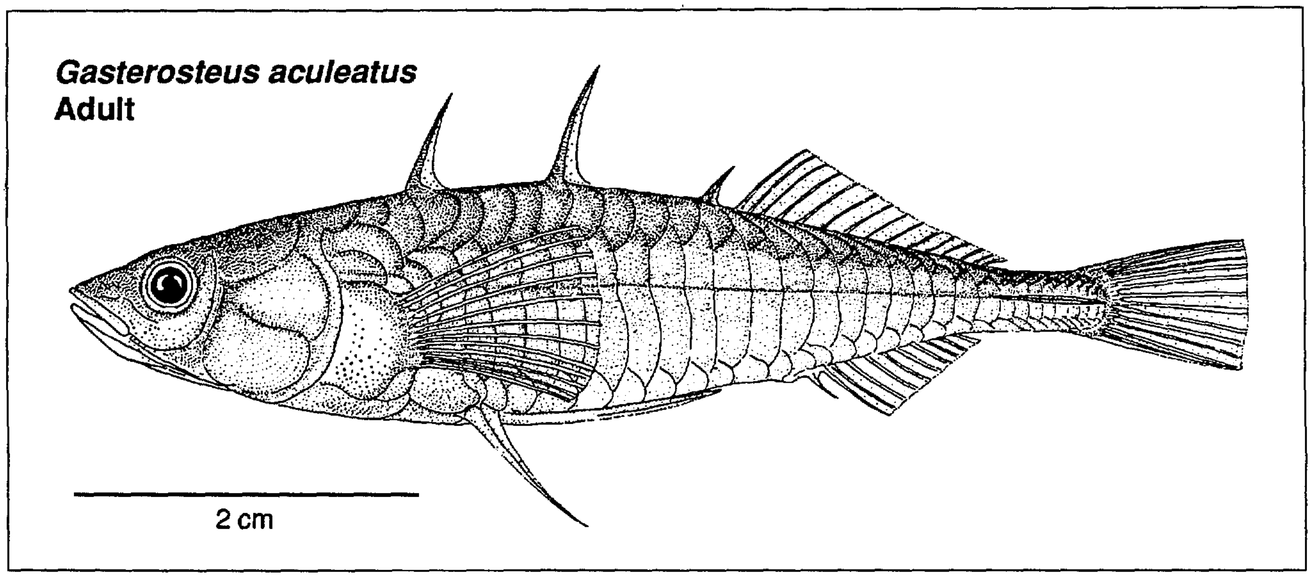
Miller, D. J., and R. N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Fish Game, Fish Bull. 157, 235 p.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Ruagh, A. A. 1976. Feeding habits of silversides (Family Atherinidae) in Elkhorn Slough, Monterey Bay, California. M.S. Thesis, Calif. State Univ. Fresno, CA, 60 p.

Wang, J. C. S. 1986. Fishes of the Sacramento-San Joaquin estuary and adjacent waters, California: A guide to the early life histories. Tech. Rep. No. 9. Interagency ecological study program for the Sacramento-San Joaquin estuary. Calif. Dept. Water Res., Calif. Dept. Fish Game, U.S. Bureau Reclam., U.S. Fish Wildl. Serv., various pagination.

Threespine stickleback



Gasterosteus aculeatus
Adult

Common Name: threespine stickleback
Scientific Name: *Gasterosteus aculeatus*
Other Common Names: common stickleback, two-spined stickleback, stickleback, thornfish, thornback, needle stickleback (Bigelow and Schroeder 1953, Okada 1955, Gates and Frey 1974)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Gasterosteiformes
Family: Gasterosteidae

Value

Commercial: This species is not commercially harvested.

Recreational: The threespine stickleback is a good aquarium fish and commonly used for studying fish behavior and physiology (Carlander 1969, Wootton 1976).

Indicator of Environmental Stress: Because the threespine stickleback is easy to collect and hold in laboratory conditions, it has often been used as an experimental animal for testing water pollution (Wootton 1976). For example, heavy metals have been found to be highly toxic to this species (Wootton 1976).

Ecological: The threespine stickleback is prey for many species of fishes and birds, and is an important resident of shallow-water estuarine habitats and lakes. It also colonizes irrigation canals and reservoirs (Moyle 1976, Simenstad 1983). Different morphological forms exist (each having distinct habitats with little hybridization) leading scientists to describe many subspecies (see "Life Mode") (Hagen 1967, Miller and Hubbs 1969, Wootton 1976). Trophic phenotypes have also been identified (Lavin and McPhail 1986).

Range

Overall: Overall distribution is amphiboreal (interrupted northern circumpolar range), found between lat. 35°N and 70°N in Europe (Wootton 1976). In eastern North America it is found from Chesapeake Bay north to Baffin Island, while in western North America it occurs from Baja California, Mexico, to St. Lawrence Island, Alaska (McPhail and Lindsey 1970, Scott and Crossman 1973, Wootton 1976, Wydoski and Whitney 1979). In the western North Pacific, it is found from the Bering Sea south to northern Japan (Andriyashev 1954, Okada 1955).

Within Study Area: The anadromous plated form (trachurus) is found in all Pacific coast estuaries from the San Lorenzo River in north Monterey Bay, California, through Washington (Table 1) (Miller and Hubbs 1969, Wootton 1976). The southern distribution of the anadromous form appears to be limited by high temperatures (Bell 1976). The non-anadromous form has a wider distribution (Wooton 1976).

Life Mode

Eggs are demersal and are laid by the female in a nest built by a male. Larvae are free-swimming, but stay with the nest, which is guarded by the male. Juveniles and adults are pelagic, but typically do not travel far from shore. However, some have been captured far out at sea (Clemens and Wilby 1961, Wootton 1976). Within the study area, at least two morphological varieties occur. The trachurus form is anadromous, migrating from marine waters to brackish and fresh waters to breed. It possesses a complete set of lateral

Table 1. Relative abundance of threespine stickleback in 32 U.S. Pacific coast estuaries.

	Life Stage				
Estuary	A	S	J	L	E
Puget Sound	○	○	◉	○	○
Hood Canal	○	○	◉	○	○
Skagit Bay	●	●	●	○	○
Grays Harbor	◉	◉	●	○	○
Willapa Bay	◉	◉	●	○	○
Columbia River	◉	◉	●	○	○
Nehalem Bay	○	○	◉	○	○
Tillamook Bay	○	○	○	○	○
Netarts Bay	◉	◉	●	◉	◉
Siletz River	○	○	○	○	○
Yaquina Bay	○	○	◉	○	○
Alsea River	○	○	◉	○	○
Siuslaw River	●	○	◉	○	○
Umpqua River	◉	◉	●	○	◉
Coos Bay	○	○	◉	○	○
Rogue River	○	○	○	○	○
Klamath River	◉	◉	◉	◉	◉
Humboldt Bay	●	●	●	○	○
Eel River	◉	○	◉	○	○
Tomales Bay	○	○	○	○	○
Cent. San Fran. Bay *	●	◉	●	◉	◉
South San Fran. Bay	◉	○	◉	○	○
Elkhorn Slough	○		○		
Morro Bay	○		○		
Santa Monica Bay					
San Pedro Bay					
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

bony plates, and is silver in color. The leiurus form spends its entire life in fresh water, has few lateral bony plates, and is olive-brown in color (Scott and Crossman 1973, Moyle 1976, Garrison and Miller 1980).

Habitat

Type: All life stages are typically found associated with vegetation in shallow water bays, lakes, and slow-moving rivers. This species occurs primarily in low-lying coastal streams and lakes (Moyle 1976). However, threespine sticklebacks have been found up to 500 miles out to sea (McPhail and Lindsey 1970). Breeding and nest building occurs on the bottom in shallow water areas in both freshwater and marine habitats, but the success of reproduction in marine environments is uncertain (Vrat 1949, Hart 1973).

Substrate: Although adults and juveniles are found over a variety of substrates, breeding male sticklebacks normally attempt to build their nests over soft mud or sand bottoms that have vegetation nearby (Scott and Crossman 1973, Wootton 1976, Wydoski and Whitney 1979)

Physical/Chemical Characteristics: The threespine stickleback can tolerate minimum dissolved oxygen concentrations as low as 0.25-0.50 mg/l (Wootton 1976). Maximum temperature before mortality is 26°C (Blahm and Snyder 1975). This species can withstand a wide range of salinities, but this depends on water temperature, degree of sexual maturity, and morphological form (leiurus or trachurus) (Wootton 1976). The migratory trachurus form loses its ability to tolerate fresh water during fall (Wootton 1976). Spawning occurs at temperatures of 15.8-18.5°C (Vrat 1949) in very shallow fresh to polyhaline waters (Morrow 1980, Wang 1986).

Migrations and Movements: The freshwater form winters in deep water and moves to shallow water in spring (Morrow 1980). The anadromous form migrates into shallow fresh and brackish waters of coastal estuaries in the spring to spawn (Wydoski and Whitney 1979, Whoriskey and FitzGerald 1989). Surviving spawners (massive post-spawning mortality can occur) and juveniles move back to sea in the fall (Wang 1986). Anadromous juveniles may start moving to sea at about 5 weeks of age (Bakker and Feuth-De Bruijn 1988). Sticklebacks have been found far out to sea, but these individuals may be lost from the population (Quinn and Light 1989); most sticklebacks stay close to shore (Bigelow and Schroeder 1953, McPhail and Lindsey 1970). Juveniles and non-breeding adults form loose schools, probably to aid in finding food and protection from predators. During the breeding season in estuaries (spring and early summer), adults breed in shallow water. After the breeding season, adults and juveniles move into deeper open waters.

Reproduction

Mode: The threespine stickleback is gonochoristic, polygamous, oviparous, and iteroparous; eggs are fertilized externally (Vrat 1949).

Mating/Spawning: Spawning occurs from early spring (March) to fall (October), depending on location. However, the anadromous form spawns primarily in June and July in the U.S. (Vrat 1949, Moyle 1976, Wootton 1976, Wydoski and Whitney 1979, Wang 1986). In the Mediterranean, sticklebacks begin breeding in March, when water temperatures are 10°C and the spawning season lasts about 50 days (Crivelli and Britton 1987). During the breeding season the male becomes territorial (McPhail and Lindsey 1970, Wootton 1976), its body develops green and orange-red spawning colors, and the eyes become blue. The male builds a nest out of available material (sand, algae, etc.). The nest can be an irregular cocoon with two openings or a hollow sandy pit below a pad of material (Wang 1986). The male performs a zig-zag dance to entice the female to his nest to deposit her eggs. After she has deposited her eggs and left, the male fertilizes them. Males may spawn with many different females, and females with different males. After rearing one clutch, the male may rebuild his nest and starts again (Moyle 1976, Wootton 1976, Morrow 1980). Depending on food supply, a female may spawn up to 20 times during a spawning season (Wootton 1976). Highly aggressive males appear to have lower breeding success than less aggressive males (Ward and FitzGerald 1987).

Fecundity: Females lay about 20-300 eggs per spawning (depending on female size) (Wootton 1976); average fecundity is probably near 200 (Bolduc and FitzGerald 1989). Overall seasonal fecundity appears to be related to the amount of time spent on the breeding grounds (Bolduc and FitzGerald 1989). Trachurus forms are more fecund than leiurus forms (Wootton 1976, Mori 1990).

Growth and Development

Egg Size and Embryonic Development: Eggs are spherical and 1.1-1.9 mm in diameter (Vrat 1949, Wootton 1976, Wang 1986). Embryonic development is indirect and external. Eggs take 7 or 8 days to hatch at 18-19°C (Wootton 1976, Wang 1986). However, time to hatching can range from 6-40 days depending on temperature (Wootton 1976).

Age and Size of Larvae: Larvae are 3.0-5.5 mm at hatching, depending on location. Metamorphosis to juvenile begins in about 30 days at approximately 10 mm total length (TL) (Vrat 1949, Bigelow and Schroeder 1953, Wootton 1976, Wang 1986).

Juvenile Size Range: Juveniles are probably 11-30 mm TL, depending on location and availability of food (Wootton 1976).

Age and Size of Adults: Most populations of sticklebacks mature within one year and at approximately 30 mm TL (Jones and Hynes 1950, Wootton 1976). They can live to 4 years and 76-85 mm long (Wootton 1976, Wydoski and Whitney 1979). Some are reported to have grown larger than 102 mm (Scott and Crossman 1973). In California, the maximum age is probably 2 or 3 years (Moyle 1976, Wang 1986).

Food and Feeding

Trophic Mode: Larvae are planktonic carnivores. Juveniles and adults are opportunistic carnivores that will feed on benthic and planktonic organisms depending on prey availability (Hart 1973, Scott and Crossman 1973, Wydoski and Whitney 1979). Sticklebacks prefer planktonic prey, but will switch to benthic prey as zooplankton densities are reduced (Ibrahim and Huntingford 1989). Sticklebacks may not feed on the most abundant zooplankton if it is too large to be ingested (Williams and Delbeek 1988), and may be slow in exploiting new food resources (Moyle 1976). In areas where sympatric stickleback species occur, competition for food is not thought to occur because of abundance of prey and morphological constraints on feeding behavior (Delbeek and Williams 1988).

Food Items: While in freshwater and estuarine habitats, the threespine stickleback consumes calanoid copepods, cyclopoid copepods, cladocerans (e.g., *Daphnia* spp.), ostracods, aquatic insect larvae, snails, terrestrial insects, annelids, spiders, larval fish, and amphipods (e.g., *Corophium* spp.) (Manzer 1976). In marine environments, calanoid copepods (*Centropages typicus*, *Eurytemora* spp., and others), copepod nauplii, euphausiid larvae, decapod larvae, and clam larvae are eaten (Maitland 1965, Hart 1973, Moyle 1976, Wydoski and Whitney 1979, Worgan and FitzGerald 1981, Bottom et al. 1984, Snyder 1984). Female sticklebacks will cannibalize eggs if a nest is left unguarded by a male (Smith and Whoriskey 1988).

Biological Interactions

Predation: The threespine stickleback is an important prey for many fishes [e.g., cutthroat trout (*Oncorhynchus clarki*), rainbow trout (*O. mykiss*), lake trout (*Salvelinus namaycush*), Dolly Varden (*Salvelinus malma*), northern pike (*Esox lucius*), northern squawfish (*Ptychocheilus oregonensis*), yellow perch (*Perca flavescens*)], birds (e.g., herons, gulls, terns, diving ducks, and mergansers), and some mammals (Hart 1973, Wootton 1976, Morrow 1980). Adult sticklebacks also eat stickleback eggs and larvae.

Factors Influencing Populations: In lakes, the threespine stickleback may compete with sockeye salmon (*O. nerka*) for food (Foerster 1968). However, sticklebacks usually do not inhabit the limnetic zone (where sockeye typically reside), so food competition is probably minimal (Manzer 1976). A variety of parasites are believed to affect the stickleback's feeding behavior and susceptibility to predation (Wootton 1976, Milinski 1986). Temperature, food availability, predation, competition, and parasitism play a role in determining population size, but which factor has the greatest influence is unknown (Wootton 1976). The number of lateral plates appears to be directly related to predation pressure (Morrow 1980). Population abundances are also influenced by harsh environmental conditions during breeding and overwintering (Whoriskey et al. 1986). Spawners using brackish-water pools appear to suffer greater egg cannibalism and bird predation than freshwater spawners (Kedney et al. 1987).

References

Andriyashev, A. P. 1954. Fishes of the northern seas of the U.S.S.R. Acad. Sci. Union Soviet Soc. Rep. No. 53 (In Russian). Transl. by Israel Prog. Sci. Transl. Ltd., 1964, 617 p.

Bakker, T. C. M., and E. Feuth-De Bruijn. 1988. Juvenile territoriality in stickleback *Gasterosteus aculeatus* L., Anim. Behav. 36(5):1556-1559.

Bell, M. A. 1976. Evolution of phenotypic diversity in *Gasterosteus aculeatus* superspecies on the Pacific coast of North America. Sys. Zool. 25(3):211-227.

Bigelow, H. B., and W. C. Schroeder. 1953. Fishes of the Gulf of Maine. Fish. Bull., U. S. 74(53):1-577.

Blahm, T. H., and G. R. Snyder. 1975. Effect of increased water temperature on survival of adult threespine stickleback and juvenile yellow perch in the Columbia River. Northw. Sci. 49(4):267-270.

Bolduc, F., and G. J. FitzGerald. 1989. The role of selected environmental factors and sex ratio upon egg production in threespine sticklebacks, *Gasterosteus aculeatus*. Can. J. Zool. 67:2013-2020.

Bottom, D. L., K. K. Jones, and M. J. Herring. 1984. Fishes of the Columbia River estuary. Col. Riv. Data Dev. Prog., CREST, Astoria, OR, 113 p. plus appendices.

Carlander, K. D. 1969. Handbook of freshwater fishery biology. Iowa State Univ. Press, Ames, IA, 752 p.

Clemens, W. A., and G. V. Wilby. 1961. Fishes of the Pacific coast of Canada. Fish. Res. Board Can., Bull. No. 68, 443 p.

Crivelli, A. J., and R. H. Britton. 1987. Life history adaptations of *Gasterosteus aculeatus* in a Mediterranean wetland. Envir. Biol. Fish. 18(2):109-125.

Delbeek, J. C., and D. D. Williams. 1988. Feeding selectivity of four species of sympatric stickleback in brackish-water habitats in eastern Canada. J. Fish Biol. 32:41-62.

Foerster, R. E. 1968. The sockeye salmon. Fish. Res. Board Can., Bull. No. 162, 422 p.

Garrison, K. J., and B. S. Miller. 1980. Review of the early life history of Puget Sound fishes. Fish. Res. Inst., Univ. Wash., Seattle, WA, 729 p. (FRI-UW-8216).

Gates, D. E., and H. W. Frey. 1974. Designated common names of certain marine organisms of California. Calif. Fish Game, Fish Bull. 161:55-90.

Hagen, D. W. 1967. Isolating mechanisms in threespine sticklebacks. J. Fish. Res. Board Can., 24(8):1637-1691.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. No.180, 740 p.

Ibrahim, A. A., and F. A. Huntingford. 1989. Laboratory and field studies on diet choice in three-spined sticklebacks, *Gasterosteus aculeatus* L., in relation to profitability and visual features of prey. J. Fish Biol. 34:245-257.

Jones, J. W., and H. B. N. Hynes. 1950. The age and growth of *Gasterosteus aculeatus, Pygosteus pungitius* and *Spinachia vulgaris*, as shown by their otoliths. J. Anim. Ecol. 19:59-73.

Kedney, G. I., V. Boule, and G. J. FitzGerald. 1987. The reproductive ecology of threespine sticklebacks breeding in fresh and brackish water. Am. Fish. Soc. Symp. 1:151-161.

Lavin, P. A., and J. D. McPhail. 1986. Adaptive divergence of trophic phenotype among freshwater populations of the threespine stickleback (*Gasterosteus aculeatus*). Can. J. Fish. Aquat. Sci. 43(12):2455-2463.

Maitland, P. S. 1965. The feeding relationships of salmon, trout, minnows, stone loach and three-spined sticklebacks in the River Endrick, Scotland. J. Anim. Ecol. 34(1):109-133.

Manzer, J. I. 1976. Distribution, food, and feeding of the threespine stickleback, *Gasterosteus aculeatus*, in Great Central Lake, Vancouver Island, with comments on competition for food with juvenile sockeye salmon, *Oncorhynchus nerka*. Fish. Bull., U.S. 74(3):647-668.

McPhail, J. D., and C. C. Lindsey. 1970. Freshwater fishes of northwestern Canada and Alaska. Fish. Res. Board Can., Bull. No. 173, 381 p.

Milinski, M. 1986. A review of competitive resource sharing under constraints in sticklebacks. J. Fish Biol. 29(suppl. A):1-14.

Miller, R. R., and C. L. Hubbs. 1969. Systematics of *Gasterosteus aculeatus* with particular reference to intergradation and introgression along the Pacific coast of North America: a commentary on a recent contribution. Copeia 1969(1):52-69.

Mori, S. 1990. Two morphological types in the reproductive stock of three-spined stickleback, *Gasterosteus aculeatus*, in Lake Harutori, Hokkaido Island. Env. Biol. Fish. 27:21-31.

Morrow, J. E. 1980. The freshwater fishes of Alaska. Alaska Northw. Publ. Co., Anchorage, AK, 248 p.

Moyle, P. B. 1976. Inland fishes of California. Univ. Calif. Press, Berkeley, CA, 405 p.

Okada, Y. 1955. Fishes of Japan. Maruzen Co., Ltd., Tokyo, Japan, 434 p.

Quinn, T. P., and J. T. Light. 1989. Occurrence of threespine sticklebacks (*Gasterosteus aculeatus*) in the open North Pacific Ocean: migration or drift? Can. J. Zool. 67:2850-2852.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can., Bull. No. 184, 966 p.

Simenstad, C. A. 1983. The ecology of estuarine channels of the Pacific Northwest coast: a community profile. U.S. Fish Wildl. Serv., FWS/OBS-83/05, 181 p.

Smith, R. S., and F. G. Whoriskey, Jr. 1988. Multiple clutches: female threespine sticklebacks lose the ability to recognize their own eggs. Anim. Behav. 36(6):1838-1839.

Snyder, R. J. 1984. Seasonal variation in the diet of the threespine stickleback, *Gasterosteus aculeatus*, in Contra Costa County, California. Calif. Fish Game 70(3):167-172.

Vrat, V. 1949. Reproductive behavior and development of eggs of the three-spined stickleback (*Gasterosteus aculeatus*) of California. Copeia 4:252-260.

Wang, J. C. S. 1986. Fishes of the Sacramento-San Joaquin estuary and adjacent waters, California: A guide to the early life histories. Tech. Rep. No. 9. Interagency ecological study program for the Sacramento-San Joaquin estuary. Calif. Dept. Water Res., Calif. Dept. Fish Game, U.S. Bureau Recl., and U.S. Fish Wildl. Serv., various pagination.

Ward, G., and G. J. FitzGerald. 1987. Male aggression and female mate choice in the threespine stickleback, *Gasterosteus aculeatus* L. J. Fish. Biol. 30:679-690.

Whoriskey, F. G., and G. J. FitzGerald. 1989. Breeding-season habitat use by sticklebacks (Pisces: Gasterosteidae) at Isle Verte, Quebec. Can. J. Zool. 67:2126-2130.

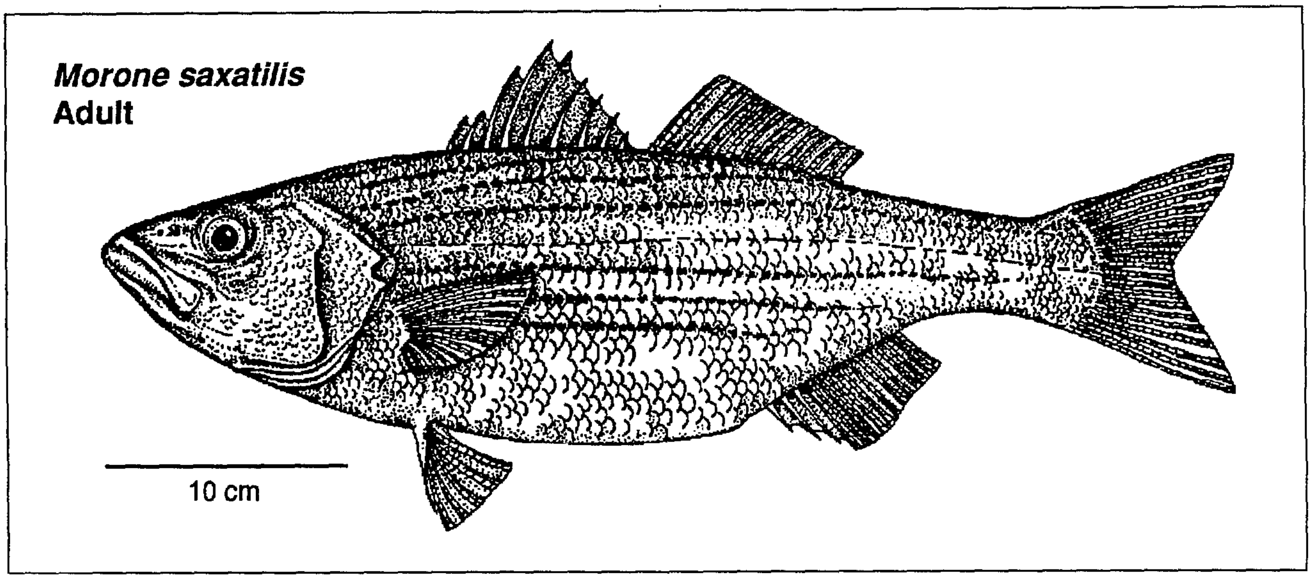
Whoriskey, F. G., G. J. FitzGerald, and S. G. Reebs. 1986. The breeding-season population structure of three sympatric territorial sticklebacks (Pisces: Gasterosteidae). J. Fish. Biol. 29:635-648.

Williams, D. D., and J. C. Delbeek. 1988. Biology of the threespine stickleback, *Gasterosteus aculeatus*, and the blackspotted stickleback, *G. wheatlandi*, during their marine pelagic phase in the Bay of Fundy, Canada. Env. Biol. Fish. 24(1):33-41.

Wootton, R. J. 1976. The biology of the sticklebacks. Academic Press, New York, NY, 387 p.

Worgan, J. P., and G. J. FitzGerald. 1981. Diel activity and diet of three sympatric sticklebacks in tidal salt marsh pools. Can. J. Zool. 59:2375-2379.

Striped bass



Common Name: striped bass
Scientific Name: *Morone saxatilis*
Other Common Names: striper, streaked bass, squidhound, rock, rock bass, rock fish, greenhead, linesider, roller (Gates and Frey 1974, Fay et al. 1983)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Perciformes
Family: Percichthyidae

Value

Commercial: Small numbers (135 yearlings) of striped bass were introduced to California's San Francisco Bay in 1879, and 300 were released in 1882. In 1899, 560 t were landed in San Francisco Bay (Hassler 1988). Historically, this species was commercially caught on the Pacific coast in San Francisco Bay and Coos Bay, Oregon. Until 1915, the annual San Francisco Bay catch usually exceeded 454 t; thereafter only twice did harvest exceed this value (Smith and Kato 1979). In 1935, commercial fishing for striped bass in the San Francisco Bay system was prohibited because of demands by sport anglers (Smith and Kato 1979, Stevens et al. 1987). Oregon has prohibited commercial fishing for this species since1976 (Parks 1978).

Recreational: The striped bass is an important sport fish from north/central California to southern Oregon. It is highly sought because of its fighting ability, large size, easy accessibility, and excellent taste. Most are taken by hook and line using artificial or natural baits. In the San Francisco Bay system, most sport fishing took place in San Pablo Bay and the Delta, but now occurs in San Francisco Bay proper (Stevens 1977). The San Francisco Bay striped bass fishery was one of the most important recreational fisheries on the Pacific coast, with annual landings ranging from 107,000 to 403,000 fish in 1978 and 1975, respectively (White 1986). The value of this fishery was estimated to be over $45 million (Meyer Resources 1985, cited by Stevens et al. 1987). However, stock size has dropped dramatically; only slightly more than 72,000 were caught along the Pacific Coast in 1985 (National Marine Fisheries Service 1986).

Indicator of Environmental Stress: It appears that certain petrochemicals interact with other pollutants (polychlorinated biphenyls and heavy metals) to adversely affect striped bass populations in San Francisco Bay (Whipple 1984). High concentrations of organochlorines, metals, and petrochemicals have been found in striped bass tissues (Whipple et al. 1983). Correlations exist between pollutants and parasite burdens, body condition, liver condition, and egg and gonad conditions. Fish exposed to a chronic pollutant stress have significant reductions in reproductive capacity, fecundity, and gametic viability (Whipple 1984).

Ecological: In the estuaries where it occurs, *M. saxatilis* is one of the most important predators of estuarine fishes and invertebrates.

Range

Overall: On the Pacific coast, the striped bass is found from about 40 km south of California-Mexico border to Barkley Sound, British Columbia (Miller and Lea 1972), but is not common south of Monterey, California, or north of the Siuslaw River, Oregon (Parks 1978). On the Atlantic coast, it occurs from the St. Lawrence River

Table 1. Relative abundance of striped bass in 32 U.S. Pacific coast estuaries.

	Life Stage				
Estuary	A	S	J	L	E
Puget Sound	√				
Hood Canal					
Skagit Bay	√				
Grays Harbor					
Willapa Bay					
Columbia River					
Nehalem Bay					
Tillamook Bay					
Netarts Bay					
Siletz River	√				
Yaquina Bay	√				
Alsea River					
Siuslaw River	○	○	○	○	○
Umpqua River	○	○	○	○	○
Coos Bay	○	○	○	○	○
Rogue River					
Klamath River	√				
Humboldt Bay					
Eel River					
Tomales Bay	○				
Cent. San Fran. Bay *	◉	○	◉	◉	○
South San Fran. Bay	◉		○		
Elkhorn Slough					
Morro Bay					
Santa Monica Bay	√				
San Pedro Bay					
Alamitos Bay					
Anaheim Bay					
Newport Bay	√				
Mission Bay	√				
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Relative abundance:

● Highly abundant

◉ Abundant

○ Common

√ Rare

Blank Not present

Life stage:

A - Adults

S - Spawning adults

J - Juveniles

L - Larvae

E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

down to the St. Johns River, Florida, and into streams that flow into the Gulf of Mexico from Florida to Louisiana (Moyle 1976). Stocking into reservoirs has established some self-sustaining freshwater populations (Moyle 1976).

Within Study Area: *M. saxatilis* was introduced to the Sacramento-San Joaquin River system during the 1870s. It is found mainly in estuaries from San Francisco Bay north to the Siuslaw River (Table 1) (Monaco et al. 1990). It has been stocked in some southern California bays, but these populations are not self-sustaining (Horn et al. 1984).

Life Mode

Eggs are non-adhesive, slightly heavier than fresh water, and are swept along with currents (Albrecht 1964, Scott and Crossman 1973, Wang 1986). Larvae are initially feeble swimmers- if they encounter still water they settle to the bottom and die (Skinner 1962). Postlarval stages ("fry") inhabit lower river channels and upper estuarine shallow-water bays and sloughs (Skinner 1962, Sasaki 1966a, Wang 1986). Juveniles, subadults, and adults are pelagic but are somewhat bottom-oriented (Skinner 1962, Sasaki 1966b), as are the eggs and early larvae (Turner 1976). Juveniles and adults are anadromous and form small separate (by size or age) schools or feeding groups (Raney 1952).

Habitat

Type: Eggs and larvae are found in lower riverine (freshwater) areas and upper estuarine (oligohaline) areas. Young-of-the-year also occur in these areas, with many moving to more saline environments (mesohaline and polyhaline) in the fall (Calhoun 1953, Sasaki 1966a). Juveniles may also move into rivers upstream of estuaries (Turner 1972). Older juveniles may be found in all estuarine areas, but appear to prefer certain areas (Skinner 1962), perhaps because of food availability and temperature. Young striped bass can be highly abundant in mixing areas of estuaries where fresh water and salt water mix (Turner 1972). This area is often referred to as the "null zone" or "critical zone". Adults are found in the lower estuary (polyhaline and euhaline waters) from late spring to early fall, in the upper (mesohaline and oligohaline) areas in late fall and winter, and in freshwater and oligohaline areas during spawning. Temperature appears to be an important determinant of the estuarine distributions of juveniles and adults (Coutant 1986, 1987).

Substrate: Eggs and larvae are swept over various sediments. Juveniles appear to prefer clean sandy bottoms, but have been found over gravel beaches, rock, mud, and mixed sand and silt bottoms (Setzler et al. 1980). Adults and subadults are also found over various substrates, such as sandy beaches, rocky shores, and mussel beds (Setzler et al. 1980).

Physical/Chemical Characteristics: Striped bass eggs are found in fresh water to 11‰ salinity (Rulifson et al. 1982). Optimum salinities for egg survival are 1.5-3.0‰ (Mansueti 1958, cited by Fay et al. 1983). Eggs can withstand temperatures of 12-24°C (Fay et al. 1983), with the optimum being 18°C (Morgan et al. 1981). Larvae tolerate temperatures of 10-25°C, but optimal temperatures for survival are 15-22°C (Fay et al. 1983). Preferred temperatures change as the fish grow older (Coutant 1986). Adults can withstand temperatures as high as 35°C, but become stressed at temperatures above 25°C (Moyle 1976). They tolerate temperatures of 0-32°C, but prefer 20-24°C (Fay et al.

1983, Coutant 1986). Adults can also withstand low dissolved oxygen (4.0 ppm) and high turbidity, but this will inhibit reproduction (Moyle 1976). Optimum spawning temperatures are 15.6-20.0°C, with spawning ceasing at 21.1°C (Moyle 1976). Dissolved oxygen levels below 4.0 ppm with temperatures of 22.2°C reduced egg survival by more than 50% (Turner and Farley 1971). Low oxygen levels (2.0-3.5 ppm) may have eliminated some spawning areas in the Delaware River, New Jersey (Setzler et al. 1980).

Migrations and Movements: Atlantic population prespawners may travel long distances upriver in fresh water (Scott and Crossman 1973), however Pacific populations do not. Unlike some east coast populations that make extensive coastal migrations, Sacramento-San Joaquin River populations and other Pacific coast populations appear to spend most of their lives in bays and estuaries. This may be related to the cool oceanic temperatures found off the Pacific coast (Radovich 1963). San Francisco Bay adults move into bays (some into the Delta) in the fall, overwinter in the Bay and Delta, and then after spawning in spring, move back to salt water (Calhoun 1952, Moyle 1976). Eggs and larvae are transported downstream by river flow into lower river and estuarine areas or may stay in the general spawning area if this is an area where outflow is balanced by tidal currents (Moyle 1976). Larvae school within 4 or 5 days of hatching and are found primarily in shallow water shore zones of fresh and brackish waters (Rulifson et al. 1982). Although there is some straying, each Pacific coast river system appears to have a distinct stock (McGie and Mullen 1979).

Reproduction

Mode: The striped bass is gonochoristic (occasionally hermaphroditic), polygamous, and oviparous; eggs are fertilized externally. It is iteroparous, but mature females may not spawn every year (Raney 1952, Scott and Crossman 1973).

Mating/Spawning: Spawning occurs in riverine (freshwater) or slightly brackish waters in the upper portions of estuaries (Hart 1973). In California, spawning begins in April, and peaks in May and early June, depending on temperature, river flow, and salinity (Turner 1972, 1976). Striped bass are mass spawners. During spawning runs they will gather close to shore with groups (5-30 fish) breaking off to spawn in the main river channel. Actual spawning occurs near the surface, with individuals frequently turning on their sides and splashing at the surface (Woodhull 1947, Moyle 1976). Spawning activity usually peaks during late afternoon or early evening (Moyle 1976). Fertilization is external, and must occur within one hour after eggs are extruded from the female. High concentrations of total dissolved solids (>180 ppm) may block spawning migrations (Farley 1966, Radtke 1966). Cooler water temperatures in spring allow striped bass to move further upriver to spawn (Farley 1966). Successful spawning requires the following: 1) a large river, 2) water velocities sufficient to keep eggs and larvae suspended off the bottom but not so fast that it washes them to calm waters before the larvae can swim, and 3) an estuary where young can feed and grow (Moyle 1976). Striped bass have a tendency to return to the same spawning area each year (Chadwick 1967).

Fecundity: Fecundity depends on the age and size of the female. In San Francisco Bay, mean fecundity ranges from 243,000 (for 4 year-olds) to 1,427,000 for 8 year-olds and older (Stevens et al. 1985). Up to 5,300,000 eggs may be produced by very large females (Skinner 1962, Wang 1986).

Growth and Development

Egg Size and Embryonic Development: Eggs are 3.3-4.2 mm in diameter, averaging 3.3 mm in California populations (Woodhull 1947, Doroshev 1970). Eggs are spherical, nonadhesive, slightly heavier than fresh water, and nearly transparent when developing (Wang 1986). Embryonic development is indirect and external. Eggs hatch in about 1.5-3.5 days (temperature dependent), 2 days at optimum temperatures (16-19°C) (Doroshev 1970). Hatching times range from 48 hours (at 17.8-19.4°C) to 70-74 hours (at 14.4-15.6°C) (Scott and Crossman 1973).

Age and Size of Larvae: Larvae are 2.0-3.7 mm total length (TL) at hatching, averaging 2.9-5.0 mm TL on the Pacific coast (Wang 1986). Absorption of the yolk sac is highly variable and dependent on temperature; from 3 days at 24°C to 9 days at 12°C (Setzler et al. 1980). Development from the finfold stage (metamorphose) to juvenile varies with temperature, reportedly taking 23 days at 24°C to 68 days at 15°C (Rogers et al. 1977, cited by Hassler 1988). Final length of larvae before the development of the second dorsal fin ranges from 25.0 to 36.0 mm (Hardy 1978).

Juvenile Size Range: Juveniles are typically 2-3 cm fork length (FL) in their first year, 23-35 cm FL in their second, 38-39 cm FL in their third, and 48-50 cm FL in their fourth year. Thereafter, growth is only 1-3 cm/year (Moyle 1976). Striped bass in Oregon tend to grow larger than California stocks (McGie and Mullen 1979).

Age and Size of Adults: Some males may mature at the end of their first year, but most mature during their second and third year; all are mature by the fifth year (Moyle 1976). Most females mature during their fourth or fifth year (87%) and all are mature by their seventh (Hart 1973; Moyle 1976). At first spawning, males average 25 cm FL, while females average 45 cm FL. The maximum size is 122 cm long and 41 kg, but fish in Pacific populations are usually less than 4.5 kg (Eschmeyer et al. 1983). The maximum age of the striped bass is >30 yr, and these are usually females (Moyle 1976).

Food and Feeding

Trophic Mode: Striped bass larvae are pelagic carnivores. Juveniles and adults are opportunistic, top-level epibenthic and pelagic carnivores that feed on invertebrates and fish (depending on the striped bass' size and food availability) (Moyle 1976). They are reported to not feed continuously, but gorge themselves and then wait until digestion is complete (Scott and Crossman 1973). They feed most intensively from after spawning through October.

Food Items: On the Pacific coast, the food habits of striped bass in the Sacramento-San Joaquin Delta have been well-studied. Large juveniles and adults feed on fishes and large invertebrates such as *Crangon* spp., while smaller juveniles are primarily invertebrate feeders; *Neomysis mercedis*, *Corophium* spp., *Crangon* spp., and copepods and cladocera, are primary prey (Ganssle 1966, Turner 1972). Important fish prey for larger juveniles and adults include threadfin shad (*Dorosoma petenense*), threespine stickleback (*Gasterosteus aculeatus*), American shad (*Alosa sapidissima*), pond smelt (*Hypomesus olidus*), juvenile chinook salmon (*Oncorhynchus tshawytscha*), northern anchovy (*Engraulis mordax*), Pacific staghorn sculpin (*Leptocottus armatus*), various smelt species, and young-of-the-year striped bass (Johnson and Calhoun 1952, Stevens 1966).

Biological Interactions

Predation: Man and large marine mammals [e.g., harbor seals (*Phoca vitulina*) and sea lions] are probably the only predators of adult striped bass. Juveniles are prey for large striped bass and other piscivorous fishes.

Factors Influencing Populations: Survival of larvae appears to strongly determine recruitment to the adult life stage. Factors which affect larval survival are temperature, salinity, predation, food availability (Eldridge et al. 1981), and pollution. One of the major determinants is the amount of freshwater discharge during summer. Normally, the higher the summer flows, the higher the larval survival rate (Sommani 1972, Turner 1972, Turner and Chadwick 1972). However, recent research in the San Francisco Bay system indicates that production of young bass has been exceptionally low since 1977 (even considering river flows). Reasons for this decline include increased adult mortality, inadequate egg production, reduced plankton food for young striped bass as a result of water diversions, large numbers of eggs and young bass being entrained by freshwater diversions, and high levels of contaminants (Stevens et al. 1985, California Department of Fish and Game 1987). Adult mortality may also be increasing because changes in water flow have "squeezed" (i.e., limited its preferred habitat) this species between its thermal and dissolved oxygen preferences or requirements (Coutant 1985, 1986, 1987). An overall decrease in the San Francisco Bay population appears to be due to the interactive effects of reduced freshwater flows, increased freshwater diversions, decreased bay flushing, and increased body burdens of pollutants which have reduced egg production and egg and larval survival (Setzler-Hamilton et al. 1988). High rates of infestation by ectoparasites (e.g., *Nerocila californiensis*) in some bays may be detrimental (Horn et al. 1984). Successful reproduction in Oregon appears to depend on optimal conditions of temperature and river flow, often resulting in the striped bass population being dominated by one year-class (McGie and Mullen 1979).

References

Albrecht, A. B. 1964. Some observations on factors associated with survival of striped bass eggs and larvae. Calif. Fish Game 50(2):100-113.

Calhoun, A. J. 1952. Annual migrations of California striped bass. Calif. Fish Game 38(3):391-403.

Calhoun, A. J. 1953. Distribution of striped bass fry in relation to major water diversions. Calif. Fish Game 39(3):279-299.

California Department of Fish and Game. 1987. Factors affecting striped bass abundance in the Sacramento-San Joaquin River system. Exhibit 25, entered by the California Department of Fish and Game for the State Water Resources Control Board 1987 Water Quality/ Water Rights Proceeding on the San Francisco Bay/ Sacramento-San Joaquin Delta. Calif. Dept. Fish Game, Stockton, CA, 149 p. plus appendices.

Chadwick, H. K. 1967. Recent migrations of the Sacramento-San Joaquin River striped bass population. Trans. Am. Fish. Soc. 96(3):327-342.

Coutant, C. C. 1985. Striped bass, temperature, and dissolved oxygen: a speculative hypothesis for environmental risk. Trans. Am. Fish. Soc. 114:31-61.

Coutant, C. C. 1986. Thermal niches of striped bass. Sci. Am. 255(2):98-104.

Coutant, C. C. 1987. Thermal preference: when does an asset become a liability? Envir. Biol. Fish. 18(3):161-172.

Doroshev, S. I. 1970. Biological features of the eggs, larvae and young of the striped bass [*Roccus saxatilis* (Walbaum)] in connection with the problem of its acclimatization in the USSR. J. Ichthyol. 10:235-248.

Eldridge, M. B., J. A. Whipple, D. Eng, M. J. Bowers, and B. M. Jarvis. 1981. Effects of food and feeding factors on laboratory-reared striped bass larvae. Trans. Am. Fish. Soc. 110:111-120.

Eschmeyer, W. N., W. S. Herald, and H. Hammann. 1983. A field guide to Pacific coast fishes of North America. Houghton Mifflin Co., Boston, MA, 336 p.

Farley, T. C. 1966. Striped bass, *Roccus saxatilis*, spawning in the Sacramento-San Joaquin River systems during 1963 and 1964. *In* J. L. Turner and D. W. Kelley (compilers), Ecological studies of the Sacramento-San Joaquin Delta. Calif. Fish Game, Fish Bull. 136:28-43.

Fay, C. W., R. J. Neves, and G. B. Pardue. 1983. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Mid-Atlantic) — striped bass. U.S. Fish Wildl., Div. Biol. Serv., FWS/OBS-82/11.8. U.S. Army Corps Eng., TR EL-82-4, 36 p.

Ganssle, D. 1966. Fishes and decapods of the San Pablo and Suisun Bays. *In* D. W. Kelley (compiler), Ecological studies of the Sacramento-San Joaquin estuary. Calif. Fish Game, Fish Bull. 133:64-94.

Gates, D. E., and H. W. Frey. 1974. Designated common names of certain marine organisms of California. Calif. Fish Game, Fish Bull. 161:55-90.

Hardy, J. P., Jr. 1978. Development of fishes of the mid-Atlantic Bight. Vol. III. Aphredoderidae through Rachycentridae. U.S. Dept Int., U.S. Fish Wildl. Serv., FWS/OBS-78/12.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. No. 180, 740 p.

Hassler, T. J. 1988. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest) — striped bass. U.S. Fish. Wildl. Serv. Biol. Rep. 82(11.82). U.S. Army Corps. Eng., TR EL-82-4, 29 p.

Horn, M. H., L. G. Allen, and F. D. Hagner. 1984. Ecological status of striped bass, *Morone saxatilis*, in upper Newport Bay, California. Calif. Fish Game 70(3):180-182.

Johnson, W. C., and A. J. Calhoun. 1952. Food habits of California striped bass. Calif. Fish Game 38(4):531-534.

Mansueti, R. J. 1958. Eggs, larvae, and young of the striped bass. Chesapeake Lab. Biol. Contr. No. 112, 35 p.

McGie, A. M., and R. E. Mullen. 1979. Age, growth, and population trends of striped bass, *Morone saxatilis*, in Oregon. Info. Rep. Ser., Fish. No. 79-8. Oregon Dept. Fish Wildl., Corvallis, OR, 57 p.

Meyer Resources. 1985. The economic value of striped bass, *Morone saxatilis*, chinook salmon, *Oncorhynchus tshawytscha*, and steelhead trout, *Salmo gairdneri*, of the Sacramento and San Joaquin river systems. Admin. Rep. 85-3, Anad. Fish. Branch, Calif. Dept. Fish Game, Sacramento, CA.

Miller, D. J., and R. N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Fish Game, Fish Bull. 157, 235 p.

Monaco, M. E., R. L. Emmett, S. A. Hinton, and D. M. Nelson. 1990. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume I: data summaries. ELMR Rep. No. 4. Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 240 p.

Morgan, R. P., II, V. J. Rasin, Jr., and R. L. Copp. 1981. Temperature and salinity effects on development of striped bass eggs and larvae. Trans. Am. Fish. Soc. 110:95-99.

Moyle, P. B. 1976. Inland fishes of California. Univ. Calif. Press, Berkeley, CA, 405 p.

National Marine Fisheries Service. 1986. Marine recreational fishery statistics survey, Pacific coast, 1985. Current Fishery Statistics, No. 8328. Nat. Mar. Fish. Serv., NOAA, Washington, D.C., 109 p.

Parks, N. B. 1978. The Pacific Northwest commercial fishery for striped bass, 1922-1974. Mar. Fish. Rev. 40(1):18-20.

Radovich, J. 1963. Effect of ocean temperature on the seaward movements of striped bass, *Roccus saxatilis*, on the Pacific coast. Calif. Fish Game 49(3):191-206.

Radtke, L. D. 1966. Distribution of adult and subadult striped bass, *Roccus saxatilis*, in the Sacramento-San Joaquin Delta. *In* J. L. Turner and D. W. Kelley (compilers), Ecological studies of the Sacramento-San Joaquin Delta. Calif. Fish Game, Fish Bull. 136:15-27.

Raney, E. C. 1952. The life history of the striped bass, *Roccus saxatilis* (Walbaum). Bull. Bingham Oceanogr. Coll. 4(1):1-95.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Rogers, B. A., D. T. Westin, and S. B. Saila. 1977. Life stage duration in Hudson River striped bass. Mar. Tech. Rep. No. 3, Univ. Rhode Island, Kingston, RI, 111 p.

Rulifson, R. A., M. T. Huish, and R. W. Thoesen. 1982. Status of anadromous fishes in southeastern U.S. estuaries. *In* V. S. Kennedy (editor), Estuarine comparisons, p. 413-425, Academic Press, New York, NY.

Sasaki, S. 1966a. Distribution of young striped bass, *Roccus saxatilis*, in the Sacramento-San Joaquin Delta. *In* J. L. Turner and D. W. Kelley (compilers), Ecological studies of the Sacramento-San Joaquin Delta. Calif. Fish Game, Fish Bull. 136:44-58.

Sasaki, S. 1966b. Distribution of juvenile striped bass, *Roccus saxatilis*, in the Sacramento-San Joaquin Delta. *In* J. L. Turner and D. W. Kelley (compilers), Ecological studies of the Sacramento-San Joaquin Delta. Calif. Fish Game, Fish Bull. 136:59-67.

Scott, W. B., and E. J. Crossman. 1973. Freshwater fishes of Canada. Fish. Res. Board Can., Bull. No. 184, 966 p.

Setzler, E. M., W. R. Boynton, K. V. Wood., H. H. Zion, L. Lubbers, N. K. Mountford, P. Frere, L. Tucker, and J. A. Mihursky. 1980. Synopsis of biological data on striped bass, *Morone saxatilis* (Walbaum). FAO Synopsis No. 121, 69 p.

Setzler-Hamilton, E. M., J. A. Whipple, and R. B. MacFarlane. 1988. Striped bass populations in Chesapeake and San Francisco Bays: Two environmentally impacted estuaries. Mar. Poll. Bull. 19(9):466-477.

Skinner, J. E. 1962. An historical review of the fish and wildlife resources of the San Francisco Bay Area. Water Proj. Br. Rep. No. 1, Calif. Dept. Fish Game, Sacramento, CA, 226 p.

Smith, S. E., and S. Kato. 1979. The fisheries of San Francisco Bay: past, present and future. *In* T.J. Conomos (editor), San Francisco Bay: the urbanized estuary, p. 445-468. Am. Assoc. Adv. Sci, and Calif. Acad. Sci., San Francisco, CA.

Sommani, P. 1972. A study on the population dynamics of striped bass (*Morone saxatilis* Walbaum) in the San Francisco Bay estuary. Ph.D. Thesis., Univ. Wash., Seattle, WA, 114 p.

Stevens, D. E. 1966. Food habits of striped bass, *Roccus saxatilis*, in the Sacramento-San Joaquin Delta. *In* J. L. Turner and D. W. Kelley (compilers), Ecological studies of the Sacramento-San Joaquin Delta. Calif. Fish Game, Fish Bull. 136:68-96.

Stevens, D. E. 1977. Striped bass (*Morone saxatilis*) year class strength in relation to river flow in the Sacramento-San Joaquin estuary, California. Trans. Am. Fish. Soc. 106(1):34-42.

Stevens, D. E., D. K. Kohlhorst, L. W. Miller, and D. W. Kelley. 1985. The decline of striped bass in the Sacramento-San Joaquin estuary, California. Trans. Am. Fish. Soc. 114:12-30.

Stevens, D. E., H. K. Chadwick, and R. E. Painter. 1987. American shad and striped bass in California's Sacramento-San Joaquin river system. Am. Fish. Soc. Symp. 1:66-78.

Turner, J. L. 1972. Striped bass. In J. E. Skinner (editor), Ecological studies of the Sacramento-San Joaquin estuary. Delta Fish Wildl. Protection Study Rep. No. 8, p. 36-43. Calif. Dept. Fish Game, Sacramento, CA.

Turner, J. L. 1976. Striped bass spawning in the Sacramento and San Joaquin rivers in central California from 1963 to 1972. Calif. Fish Game 62(2):106-118.

Turner, J. L., and H. K. Chadwick. 1972. Distribution and abundance of young-of-the-year striped bass, *Morone saxatilis*, in relation to river flow in the Sacramento-San Joaquin estuary. Trans. Am. Fish. Soc. 101(3):442-452.

Turner, J. L. and T. C. Farley. 1971. Effects of temperature, salinity, and dissolved oxygen on survival of striped bass eggs and larvae. Calif. Fish Game 57:268-273.

Wang, J. C. S. 1986. Fishes of the Sacramento-San Joaquin estuary and adjacent waters, California: A guide to the early life histories. Tech. Rep. No. 9. Interagency ecological study program for the Sacramento-San Joaquin estuary. Calif. Dept. Water Res., Calif. Dept. Fish Game, U.S. Bureau Reclam., and U.S. Fish Wildl. Serv., various pagination.

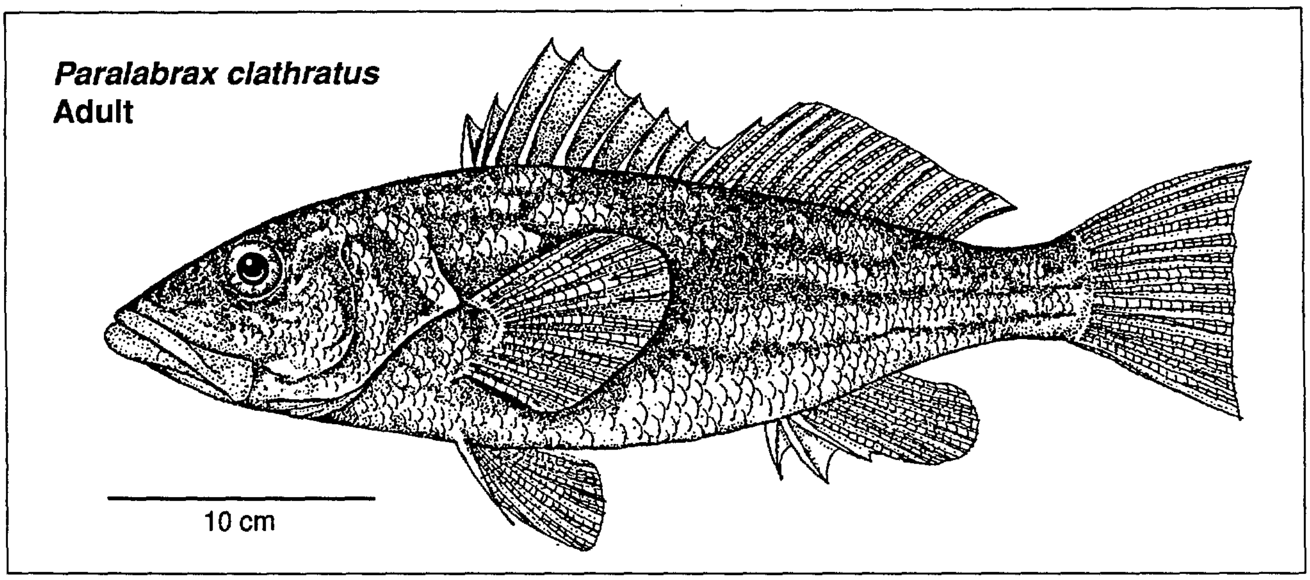
Whipple, J. A. 1984. The impact of estuarine degradation and chronic pollution on populations of anadromous striped bass (*Morone saxatilis*) in the San Francisco Bay-Delta, California. A summary for managers and regulators. SWAFC Adm. Rep. T-84-01, 47 p. Southw. Fish. Center, Tiburon Fish. Lab., Nat. Mar. Fish. Serv., NOAA, 3150 Paradise Drive, Tiburon, CA 94920.

Whipple, J. A., D. G. Crosby, and M. Jung. 1983. Third progress report, Cooperative striped bass study. California State Water Resources Control Board, Toxic Substances Control Program, Spec. Proj. Rep. No. 83-3sp, 208 p.

White, J. R. 1986. The striped bass sport fishery in the Sacramento-San Joaquin estuary, 1969-1979. Calif. Fish Game 72(1):17-37.

Woodhull, C. 1947. Spawning habits of the striped bass (*Roccus saxatilis*). Calif. Fish Game 33(2):97-102.

Kelp bass



Common Name: kelp bass
Scientific Name: *Paralabrax clathratus*
Other Common Names: California kelp bass, rock bass, sand bass, cabrilla, calico bass, bull bass, kelp salmon, lockee cod (Gates and Frey 1974)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Perciformes
Family: Serranidae

Value

Commercial: Since 1953, it has been illegal to sell kelp bass harvested in California waters. A limited commercial catch may occur in Mexican waters (Frey 1971).

Recreational: The kelp bass is an important sport fish in southern California, prized for its excellent taste, good fighting ability, year-round availability, and relatively high abundance. It is caught from about Tomales Bay, California, to central Baja California, but most effort occurs from Point Conception south to San Diego, California. Over 2.5 million were captured in 1985, the second highest catch of recreational fish in southern California (U.S. Department of Commerce 1986). It is usually caught by party and private boats fishing over kelp beds and trolling with bait. Some are also caught by spearfishing and shore and pier fishermen using hook and line (Young 1963, Quast 1968a, Frey 1971).

Indicator of Environmental Stress: This species is dependent on healthy kelp beds. Temperatures above 24°C (e.g., waste discharges from metropolitan centers) appear to be detrimental to kelp beds (Quast 1968b). Industrial and domestic wastes are released in large quantities near some kelp bass habitat, but the effects of these pollutants on kelp bass survival is unclear.

Ecological: It is an abundant top-level predator in kelp beds off southern California, with juveniles and small adults often abundant in the surf zone (but not intertidally) (Quast 1968a).

Range

Overall: The kelp bass' overall range is from Magdalena Bay, Baja California (including Guadalupe Island, Mexico) to the Columbia River (Miller and Lea 1972).

Within Study Area: This species is commonly found south of Point Conception, but is rare in shallow water bays and lagoons such as Newport Bay (Bane 1968), Anaheim Bay, Alamitos Bay, and San Diego Bay (Table 1). Juveniles can be common at times in Mission Bay, California (Noah 1985). It is abundant in Santa Monica and San Pedro Bays, California (Quast 1968a, Carlisle 1969, Fay et al. 1978), and may be found in developed areas (e.g., marinas and harbors) (Horn and Allen 1981, Stephens and Zerba 1981, Allen et al. 1983).

Life Mode

Eggs and larvae are pelagic, while juveniles and adults are benthopelagic (Young 1963, Quast 1968a, Feder et al. 1974).

Habitat

Type: Eggs and larvae are neritic-epipelagic and occur near the surface. Juveniles are distributed from the surf zone out to depths of 30 m, but occur primarily inshore at depths of 8-20 m (Quast 1968a, Feder et al.

Table 1. Relative abundance of kelp bass in 32 U.S. Pacific coast estuaries.

Estuary	A	S	J	L	E
Puget Sound					
Hood Canal					
Skagit Bay					
Grays Harbor					
Willapa Bay					
Columbia River					
Nehalem Bay					
Tillamook Bay					
Netarts Bay					
Siletz River					
Yaquina Bay					
Alsea River					
Siuslaw River					
Umpqua River					
Coos Bay					
Rogue River					
Klamath River					
Humboldt Bay					
Eel River					
Tomales Bay					
Cent. San Fran. Bay *					
South San Fran. Bay					
Elkhorn Slough					
Morro Bay					
Santa Monica Bay	◉	○	◉	○	○
San Pedro Bay	◉	○	◉	○	○
Alamitos Bay	√		√		
Anaheim Bay	√		√		
Newport Bay	√		√		
Mission Bay	○		○	○	
San Diego Bay	√		√	√	
Tijuana Estuary	√		√		
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

1974) Adults are found from the surf zone out to depths of 183 m, but are most common between 2 and 21 m (Quast 1968a, Feder et al. 1974). Juveniles and adults can be found throughout the water column depending on habitat complexity (Quast 1968a). This species is considered a kelp bed "cosmopolite", occurring throughout the water column (Larson and DeMartini 1984).

Substrate: Eggs and larvae are not substrate dependent. Juveniles are found among inshore seaweeds such as eelgrass (*Zostera* spp.), as well as in clumps of feather boa kelp, in the kelp canopy, algae holdfast regions, and in rocky areas below kelp beds (Feder et al. 1974). Adults also prefer areas containing habitat relief. This relief can be kelp beds or rocky bottoms, including submarine canyons and cliffs (Quast 1968a). Larger adults often live in deep rocky areas containing little or no algae (Feder et al. 1974).

Physical/Chemical Characteristics: A euhaline species, it is primarily found in waters of 33.5-34.5‰ and temperatures of 13-28°C (Quast 1968c, MBC Applied Environmental Sciences 1987). This species will avoid areas with high turbidity (Quast 1968a).

Migrations and Movements: No migrations are known to occur. Adult home ranges appear to be up to 40 ha, depending on habitat structure (Quast 1968a). Very few kelp bass will move more than 16 km (Young 1963). As adult kelp bass are harvested from areas with good habitat, bass from adjacent areas will move in to replace them (Quast 1968a).

Reproduction

Mode: The kelp bass is gonochoristic, oviparous, and iteroparous. It is a broadcast spawner; eggs are fertilized externally (Quast 1968a, Feder et al. 1974).

Mating/Spawning: Spawning takes place in relatively deep water (to 46 m) over rough bottom in or near kelp. Spawning occurs from April to November, probably peaking during June and July (Quast 1968a, Frey 1971, Feder et al. 1974). Successful spawning probably only occurs from Point Conception to Magdalena Bay, Baja California (Quast 1968a). Larger individuals mature earlier and remain reproductively active longer. Hundreds of kelp bass may aggregate in a small area during spawning (Feder et al. 1974). Males often develop a yellow color on their snout during the breeding season (Quast 1968a).

Fecundity: Unknown.

Growth and Development

Egg Size and Embryonic Development: Eggs are spherical and range from 0.94-0.97 mm in diameter (Butler et al. 1982). Embryonic development is indirect and external. At 19°C, eggs hatch in 36.0-40.5 hours.

Age and Size of Larvae: Larval lengths range from 2.2-16.5 mm (Butler et al. 1982). Yolk-sac absorption takes about 5 days at 19°C. At 21°C, larvae transform to juveniles 28 days after hatching (Butler et al. 1982). Yolk-sac larvae of three *Paralabrax* species are indistinguishable (Butler et al. 1982).

Juvenile Size Range: Juveniles range in size from 1.6-35.0 cm (Quast 1968a, Butler et al. 1982), and are about 10 cm after 1 year.

Age and Size of Adults: Some may mature in 2 or 3 years at 18 cm, with most males maturing at 25 cm, and females at 35 cm in length (Quast 1968a, Frey 1971, Feder et al. 1974). The kelp bass is a relatively slow-growing fish; a 31 cm long fish may be 4-6 years old. Maximum age may be 31 years, and maximum size is reportedly 72 cm and 6.6 kg (Young 1963, Eschmeyer et al. 1983).

Food and Feeding

Trophic Mode: Larvae, juveniles, and adults are opportunistic, generalized carnivores.

Food Items: Once their yolk sac is used, larvae probably feed on small pelagic crustacea and other plankton. Juveniles consume primarily invertebrates such as crabs (*Pleuronocodes planipes* and others), isopods, gammarid and caprellid amphipods, pistol shrimp (*Alphaeus* spp.), caridean shrimps, euphausiids, mysids, polychaetes, coelenterates, but also small fish and algae (Quast 1968a, Diaz and Hammann 1987). Adults feed on similar organisms as juveniles, but shift to eating primarily larger taxa such as pipefish (*Syngnathus* spp.), giant kelp fish (*Heterostichus rostratus*), topsmelt (*Atherinops affinis*), pleuronectids, engraulids, embiotocids, cottids, serranids, gobiids, and cephalopods. Fish and cephalopods (primarily *Octopus* spp.) are the dominant prey of large adult kelp bass (Young 1963, Quast 1968a, 1968d, Feder et al. 1974). The kelp bass appears to have two general feeding peaks during the year, one in the spring and one in the fall (Quast 1968a). While normally a solitary feeder, it may assemble to feed on schooling bait fish, and even leap from the water if actively pursuing prey (Feder et al. 1974). The kelp bass typically feeds by searching substrates and kelp stipes, and foraging into crevices. It appears to prefer prey from the water column (Diaz and Hammann 1987) and only rarely forages near the surface (Quast 1968a). It feeds primarily during the day and retreats into cover at night (Hobson et al. 1981, Hobson and Chess 1986)

Biological Interactions

Predation: The kelp bass is a cannibalistic species (Quast 1968a) that avoids predation by hiding at night (Ebling and Bray 1976). Other predators of small kelp bass may include giant sea bass (*Stereolepis gigas*) and broomtail grouper (*Mycteroperca xenarcha*) (MBC Applied Environmental Sciences 1987). Large kelp bass probably have few predators other than man.

Factors Influencing Populations: This species may compete with the barred sand bass (*P. nebulifer*) where they co-occur, however barred sand bass prefer slightly different habitat (Turner et al. 1969). Because of the kelp bass' slow growth and nonmigratory behavior, intense sport fishing may have a detrimental effect on populations. Recreational landings decreased from 1981 to 1984, but whether this was a result of reduced population sizes, reduced fishing effort, or related to El Niño is unclear (MBC Applied Environmental Sciences 1987). Isolated populations do not appear to be genetically different (Beckwitt 1983).

References

Allen, L. G., M. H. Horn, F. A. Edmands II, and C. A. Usui. 1983. Structure and seasonal dynamics of the fish assemblage in the Cabrillo Beach area of Los Angeles Harbor, California. Bull. S. Calif. Acad. Sci. 82(2):47-70.

Bane, G. W. 1968. Fishes of the upper Newport Bay. Univ. Calif. Irvine Res. Ser. 3:1-114.

Beckwitt, R. 1983. Genetic structure of Genyonemus lineatus, *Seriphus politus* (Sciaenidae) and *Paralabrax clathratus* (Serranidae) in southern California. Copeia 1983(3):691-696.

Butler, J. L., H. G. Moser, G. S. Hageman, and L. E. Nordgren. 1982. Developmental stages of three California sea bass (*Paralabrax*, Pisces, Serranidae). Calif. Coop. Ocean. Fish. Invest. Rep. 23:252-268.

Carlisle, J. G., Jr. 1969. Results of a six-year trawl study in an area of heavy waste discharge: Santa Monica Bay, California. Calif. Fish Game 55(1):26-46.

Diaz, M. E. D, and M. G. Hammann. 1987. Trophic relations among fishes associated to a kelp forest, *Macrocystis pyrifera*, in Baha de Todos Santos, Baja California, Mexico. Ciencias Mar. 13(4):81-96.

Ebling, A. W., and R. N. Bray. 1976. Day versus night activity of reef fishes in a kelp forest off Santa Barbara, California. Fish. Bull., U.S. 74(4):703-717.

Eschmeyer, W. N., W. S. Herald, and H. Hammann. 1983. A field guide to Pacific coast fishes of North America. Houghton Mifflin Co., Boston, MA, 336 p.

Fay, R. C., J. A. Vallee, and P. Brophy. 1978. An analysis of fish catches obtained with an otter trawl in Santa Monica Bay, 1969-73. Calif. Fish Game 64(2):104-116.

Feder, H. M., C. H. Turner, and C. Limbaugh. 1974. Observations on fishes associated with kelp beds in southern California. Calif. Fish Game, Fish Bull. 160:1-144.

Frey, H. W. 1971. California's living marine resources and their utilization. Calif. Dept. Fish Game, Sacramento, CA, 148 p.

Gates, D. E., and H. W. Frey. 1974. Designated common names of certain marine organisms of California. Calif. Fish Game, Fish Bull. 161:55-90.

Hobson, E. S., and J. R. Chess. 1981. Relationships among fishes and their prey in a nearshore sand community off southern California. Env. Biol. Fish 17(3):201-226.

Hobson, E. S., W. N. McFarland, and J. R. Chess. 1981. Crepuscular and nocturnal activities of Californian nearshore fishes, with consideration of their scotopic visual pigments and the photic environment. Fish. Bull., U.S. 79(1):1-30.

Horn, M. H., and L. G. Allen. 1981. A review and synthesis of ichthyofaunal studies in the vicinity of Los Angeles and Long Beach Harbors, Los Angeles County, California. Final Rep. to U.S. Fish Wildl. Serv., Dept. Biol. Sci., Calif. State Univ., Fullerton, CA, 96 p.

Larson, R. J., and E. E. DeMartini. 1984. Abundance and vertical distribution of fishes in a cobble-bottom kelp forest off San Onofre, California. Fish. Bull., U.S. 82(1):37-53.

MBC Applied Environmental Sciences. 1987. Ecology of important fisheries species offshore California. Min. Man. Serv., U.S. Dept. Int., Washington, D.C., 251 p.

Miller, D. J., and R. N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Fish Game, Fish Bull. 157, 235 p.

Noah, M. D. 1985. Appendix A. Structure, abundance and distribution of the fish and macroinvertebrate communities inhabiting Mission Bay, California between November 1979 and February 1981. *In* E. A. Weirich, M. D. Noah, and S. J. Schwarz (preparers), San Diego River and Mission Bay improvements, Draft suppl. environ. assess., 37 p. plus appendices. U.S. Army Corps Eng., Los Angeles, CA.

Quast, J. C. 1968a. Observations on the food and biology of the kelp bass, *Paralabrax clathratus* with notes on its sportfishery at San Diego, California. *In* W. J. North, and C. L. Hubbs (editors), Utilization of kelp-bed resources in southern California. Calif. Fish Game, Fish Bull. 139:81-108.

Quast, J. C. 1968b. Effects of kelp harvesting on the fishes of the kelp beds. *In* W. J. North, and C. L. Hubbs (editors), Utilization of kelp-bed resources in southern California. Calif. Fish Game, Fish Bull. 139:143-212.

Quast, J. C. 1968c. Some physical aspects of the inshore environment, particularly as it affects kelp-bed fishes. *In* W. J. North, and C. L. Hubbs (editors), Utilization of kelp-bed resources in southern California. Calif. Fish Game, Fish Bull. 139:25-34.

Quast, J. C. 1968d. Observations on the food of the kelp-bed fishes. *In* W. J. North, and C. L. Hubbs (editors), Utilization of kelp-bed resources in southern California. Calif. Fish Game, Fish Bull. 139:109-142.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

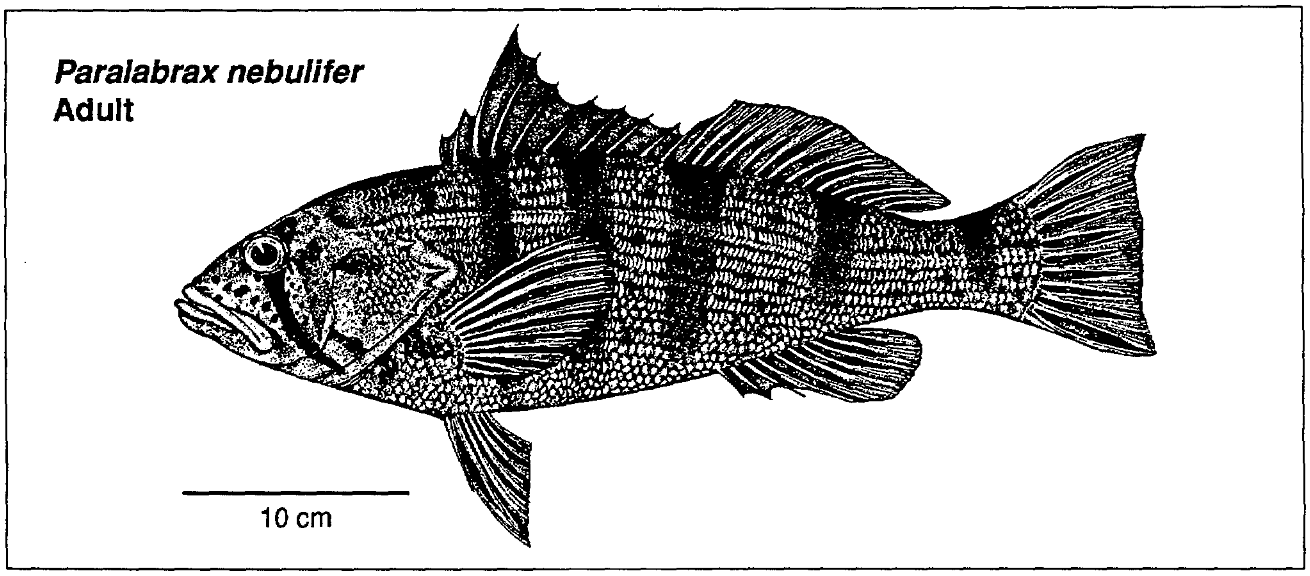
Stephens, J. S., Jr., and K. E. Zerba. 1981. Factors affecting fish diversity on a temperate reef. Env. Biol. Fish. 6(1):111-121.

Turner, C. H., E. E. Ebert, and R. R. Given. 1969. Man-made reef ecology. Calif. Fish Game, Fish Bull. 146, 221 p.

U.S. Department of Commerce. 1986. Marine recreational fishery statistics survey, Pacific coast. U.S. Dept. Comm., NOAA, Current Fish. Stat. No. 8328, 109 p.

Young, P. H. 1963. The kelp bass (*Paralabrax clathratus*) and its fishery, 1947-1958. Calif. Fish Game, Fish Bull. 122:1-67.

Barred sand bass



Common Name: barred sand bass
Scientific Name: *Paralabrax nebulifer*
Other Common Names: California rock bass, rock bass, Johnny verde, kelp bass, sand bass, ground bass, sugar bass, cabrilla, California sand bass (Gates and Frey 1974)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Perciformes
Family: Serranidae

Value

Commercial: No commercial fishery exists in the United States for the barred sand bass, but this species is harvested in Mexico (Frey 1971).

Recreational: The barred sand bass is an important sport fish in southern California. It is highly sought after because of its good taste, fighting ability, availability, and relatively high abundance. It is often captured with the kelp bass (*Paralabrax clathratus*) and regularly seen by skin divers, snorkelers, and glass-bottom-boat sightseers (Frey 1971). It is usually caught by spearfishing and shore and pier fisherman using hook and line. Over 1.7 million barred sand bass were captured in 1985 (U.S. Department of Commerce 1986).

Indicator of Environmental Stress: Industrial and domestic wastes may be affecting barred sand bass habitat, but adverse effects have not been documented. However, a morphological anomaly (bilateral asymmetry) has become more prevalent in fish from southern California populations. This condition may be a result of sublethal pollution effects related to increasing human populations (Valentine et al. 1973).

Ecological: This is an important fish in California reef communities. The greatest abundance of adults appears to be near "edge" habitats where rocky and sandy areas meet (Quast 1968).

Range

Overall: The barred sand bass' overall range is from Magdelana Bay, Baja California, to Santa Cruz, California (including Guadalupe Island) (Miller and Lea 1972). It is not common north of Pt. Conception, California, but is occasionally taken in Monterey Bay, California (Roedel 1953).

Within Study Area: This species is found in all bays and estuaries from the Tijuana Estuary to Santa Monica Bay, California (Table 1) (Monaco et al. 1990).

Life Mode

Eggs and larvae are pelagic, while juveniles and adults are benthopelagic. Adults usually remain within a few meters over the substrate. (Feder et al. 1974). This species is more bottom-oriented than kelp bass.

Habitat

Type: The barred sand bass inhabits shallow neritic environments down to depths of 183 m (Miller and Lea 1972). Adults and subadults are most numerous between depths of 5.2 and 26 m (Feder et al. 1974). It is common over nearshore sandy flats, near kelp beds, rocky areas, and bays (Squire and Smith 1977), and can be the dominant fish on rocky reefs (Turner et al. 1969). Small, immature sand bass prefer sheltered bays or harbors, especially around breakwaters. Juveniles are often found in mouths of bays in eelgrass

Table 1. Relative abundance of barred sand bass in 32 U.S. Pacific coast estuaries.

Estuary	A	S	J	L	E
Puget Sound					
Hood Canal					
Skagit Bay					
Grays Harbor					
Willapa Bay					
Columbia River					
Nehalem Bay					
Tillamook Bay					
Netarts Bay					
Siletz River					
Yaquina Bay					
Alsea River					
Siuslaw River					
Umpqua River					
Coos Bay					
Rogue River					
Klamath River					
Humboldt Bay					
Eel River					
Tomales Bay					
Cent. San Fran. Bay *					
South San Fran. Bay					
Elkhorn Slough					
Morro Bay					
Santa Monica Bay	◉	○	◉	○	○
San Pedro Bay	◉	○	◉	○	○
Alamitos Bay	○		○		
Anaheim Bay	○		○		
Newport Bay	○		○		
Mission Bay	◉		◉	○	
San Diego Bay	○		◉	○	
Tijuana Estuary	√		√		
	A	S	J	L	E

Life Stage

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

(*Zostera* spp.) beds during fall and winter (Feder et al. 1974). It is the most common trawl-caught fish in Mission Bay (Noah 1985), and is also common in San Diego Bay (Lockheed Ocean Science Laboratories 1983), and lower Newport Bay, California (Allen 1976). Bays and estuaries appear to play an important role in this species early life history (Kramer and Hunter 1987).

Substrate: Preferred substrates range from sandy-bottom flats to rocky areas and kelp beds. Spawning occurs over flat sandy bottoms (Turner et al. 1969). Young juveniles are often found in and near eelgrass beds (Feder et al. 1974).

Physical/Chemical Characteristics: No information is available, but the barred sand bass is probably a euhaline species. It may be more sensitive to cool water temperatures than the kelp bass (Frey 1971).

Migrations and Movements: The barred sand bass moves to sandy flat bottoms to spawn, and then back to rocky reefs (Turner et al. 1969). Like the kelp bass, it appears to be nonmigratory (Turner et al. 1969). The barred sand bass seeks cover in caves and holes if frightened (Feder et al. 1974) and may feed actively at night.

Reproduction

Mode: This species is gonochoristic, oviparous, and iteroparous. It is a broadcast spawner; eggs are fertilized externally (Feder et al. 1974).

Mating/Spawning: Spawning occurs from April to fall. This species forms spawning "schools" over sandy flat bottoms (Frey 1971). The age, size, and frequency of adult spawning is not documented.

Fecundity: Unknown

Growth and Development

Egg Size and Embryonic Development: Eggs are 0.94-0.97 mm in diameter and indistinguishable from kelp bass eggs (Butler et al. 1982). Embryonic development is indirect and external. Eggs hatch in 36.0-40.5 h at 19°C.

Age and Size of Larvae: Yolk-sac larvae are not distinguishable from *P. clathratus* or *P. maculotofasciatus* (Butler et al. 1982). Larvae range in length from 2.2-11.0 mm (Butler et al. 1982). Larval development is probably the same as *P. clathratus*-larval yolk-sac is absorbed in 5 days (at 19°C), and larval transformation occurs when they are 11 mm long (Butler et al. 1982).

Juvenile Size Range: Minimum juvenile size is 12 mm.

Age and Size of Adults: Age and size when mature is not known. This species reaches a maximum length of 65 cm (Miller and Lea 1972) and probably lives as long as the kelp bass (31 years). A 20 year-old fish was 63 cm (Turner et al. 1969).

Food and Feeding

Trophic Mode: Larvae, juveniles, and adults are carnivorous.

Food Items: Larvae probably feed on small pelagic crustaceans and other plankton once their yolk sac is depleted. Small sand bass prefer a variety of crustaceans (shrimp, amphipods, crabs), molluscs (octopus, squid), polychaetes, ophiuroids, and fish (engraulids and embiotocids) (Feder et al. 1974). Crabs eaten are primarily spider and cancroid types (Quast 1968). Large bass prefer fish such as northern anchovy (*Engraulis mordax*) (Frey 1971) and other perciform fishes (*Artedius* spp., and *Runula* spp.) (Quast 1968).

Biological Interactions

Predation: The barred sand bass is probably cannibalistic and may have similar predators as kelp bass [e.g., giant sea bass (*Stereolepis gigas*) and broomtail grouper (*Mycteroperca xenarcha*)]. Large barred sand bass probably have few predators except man.

Factors Influencing Populations: Barred sand bass and kelp bass are often found in the same habitat, but barred sand bass prefer sandy-rocky areas more than the kelp beds that the kelp bass prefers. As such, the barred sand bass is more abundant on manmade reefs (Turner et al. 1969). Large numbers of barred sand bass have only been in southern California waters since 1957. Before this period, sand bass were insignificant in the sport catch. Its higher abundance now may relate to increased coastal water temperatures (Frey 1971). Because of its slow growth and nonmigratory behavior, intense sport fishing may have a detrimental effect on the abundance of this species.

References

Allen, L. G. 1976. Abundance, diversity, seasonality and community structure of the fish populations of Newport Bay, California. M.A. Thesis, Calif. State Univ., Fullerton, CA, 107 p.

Butler, J. L., H. G. Moser, G. S. Hageman, and L. E. Nordgren. 1982. Developmental stages of three California sea bass (*Paralabrax*, Pisces, Serranidae). Calif. Coop. Ocean. Fish. Invest. Rep. 23:252-268.

Feder, H. M., C. H. Turner, and C. Limbaugh. 1974. Observations on fishes associated with kelp beds in southern California. Calif. Fish Game, Fish Bull. 160:1-144.

Frey, H. W. 1971. California's living marine resources and their utilization. Calif. Dept. Fish Game, Sacramento, CA, 148 p.

Gates, D. E., and H. W. Frey. 1974. Designated common names of certain marine organisms of California. Calif. Fish Game, Fish Bull. 161:55-90.

Kramer, S. H., and J. R. Hunter. 1987. Southern California wetland/shallow water habitat investigation. Ann. Rep., Nat. Mar. Fish. Serv., La Jolla, CA, 12 p.

Lockheed Ocean Science Laboratories. 1983. Distribution and abundance of fishes in central San Diego Bay, California: a study of fish habitat utilization. Rep. to Dept. of Navy, Contract No. N62474-82-C-1068, San Diego, CA, 38 p. plus appendices.

Miller, D. J., and R. N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Fish Game, Fish Bull. 157, 235 p.

Monaco, M. E., R. L. Emmett, S. A. Hinton, and D. M. Nelson. 1990. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume I: data summaries. ELMR Rep. No. 4. Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 240 p.

Noah, M. D. 1985. Appendix A. Structure, abundance and distribution of the fish and macroinvertebrate communities inhabiting Mission Bay, California between November 1979 and February 1981. *In* E. A. Weirich, M. D. Noah, and S. J. Schwarz (preparers), San Diego River and Mission Bay improvements, Draft suppl. environ. assess., 37 p. plus appendices, U.S. Army Corps Eng., Los Angeles, CA.

Quast, J. C. 1968. Observations on the food of the kelp-bed fishes. *In* W. J. North, and C. L. Hubbs (editors), Utilization of kelp-bed resources in southern California. Calif. Fish Game, Fish Bull. 139:109-142.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Roedel, P. M. 1953. Common ocean fishes of the California Coast. Calif. Fish Game, Fish Bull. 91, 184 p.

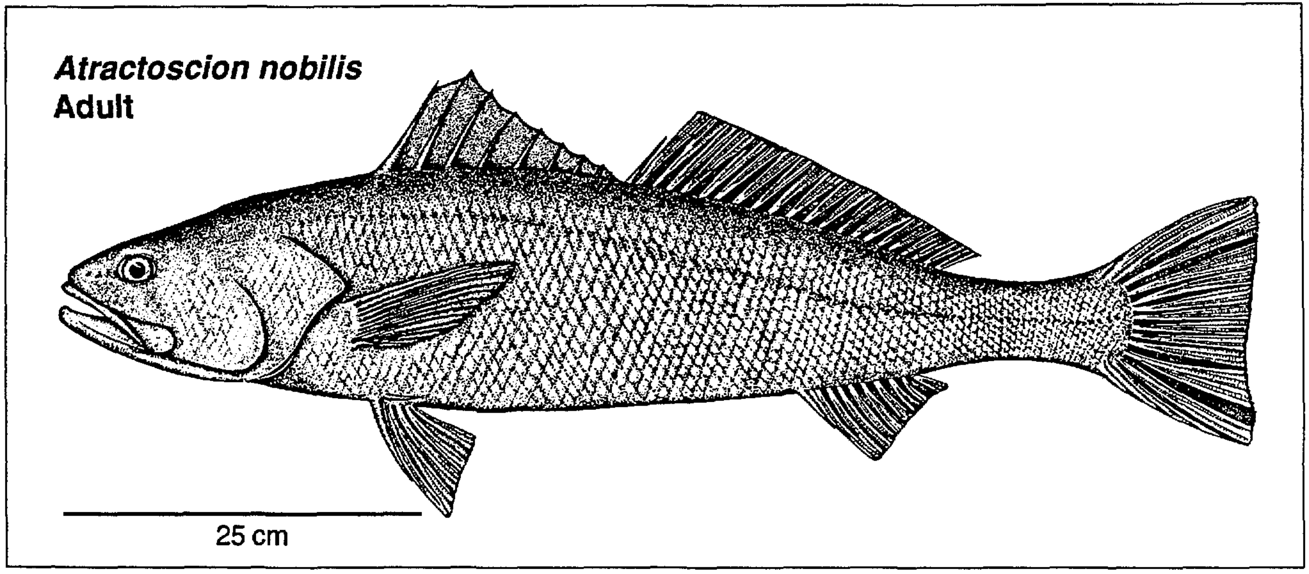
Squire, J. L. Jr., and S. E. Smith. 1977. Anglers' guide to the United States Pacific coast. Marine fish, fishing grounds and facilities. NOAA, U.S. Dept. Comm., Seattle, WA, 139 p.

Turner, C. H., E. E. Ebert, and R. R. Given. 1969. Man-made reef ecology. Calif. Fish Game, Fish Bull. 146, 221 p.

U.S. Department of Commerce. 1986. Marine recreational fishery statistics survey, Pacific coast. U.S. Dept. Comm., NOAA, Current Fish. Stat. No. 8328, 109 p.

Valentine, D. W., M. E. Soule, and P. Samollow. 1973. Asymmetry analysis in fishes: a possible statistical indicator of environmental stress. Fish. Bull., U.S. (2):357-370.

White seabass



Common Name: white seabass
Scientific Name: *Atractoscion nobilis*
Other Common Names: California white fish, sea trout, weakfish, king croaker, white croaker (Gates and Frey 1974)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Perciformes
Family: Sciaenidae

Value

Commercial: The white seabass is commercially fished in California and Mexico (Frey 1971). The commercial season in California is closed from March 14- May 16 (during part of the spawning period). Legally, fish must be at least 71 cm in length (Schultze 1986). This species was historically caught by lampera, purse seine, hook and line, and drift and set gill nets (Frey 1971). Now it is almost exclusively captured by set gill nets. Gill net mesh sizes must be 8.9 cm or larger (Schultze 1986). Set nets are typically set near rocky headlands. From 1957 to 1961, much of the California catch occurred north of Point Conception, apparently reflecting a period of warmer ocean temperatures. After ocean temperatures returned to normal, catch levels dropped in this region, and have remained low (<1% of U.S. catch) (Vojkovich and Reed 1983). Although landings have fluctuated widely, they have dropped markedly since 1971 (Vojkovich and Reed 1983). The five-year average from 1980 to 1984 was 159 t landed. However, in 1985, only 56 t of white seabass were landed, but it was worth $241,000 (National Marine Fisheries Service 1986). Prior to 1982, most of the U.S. catch (80%) was taken in Mexican waters, but fishing has not been allowed in these waters since then (Vojkovich and Reed 1983).

Recreational: In California, there is a limit of 3 fish per day per person and fish must be >71 cm in length (Vojkovich and Reed 1983). The white seabass has been caught by hook and line (using live bait or lures) from piers, jetties, and private and party boats for the past 100 years (Frey 1971, Vojkovich and Reed 1983). Some are also taken by skindivers. This is a prized sport fish because it is excellent eating, difficult to capture, and may reach trophy size (Frey 1971). The sport catch peaked in 1949 (64,000 fish) and has declined since (Vojkovich and Reed 1983). Many of the white seabass hooked by sportsmen are below legal size, but kept because fisherman cannot separate them from other croakers (or they are ignorant of the regulations) (Vojkovich and Reed 1983). Historically, coastal Native Americans used white seabass otoliths as jewelry (Fitch and Lavenberg 1971).

Indicator of Environmental Stress: Larvae and small juveniles appear to heavily utilize nearshore areas. Therefore, human-caused environmental degradation may be affecting recruitment (Vojkovich and Reed 1983). Juveniles may be easily affected by industrial and domestic pollution (Fitch and Lavenberg 1971). This pollution can cause hemorrhages of the eyes, blindness, and perhaps stimulate increased rates of parasitism by external parasites (Fitch 1958).

Ecological: The white seabass is a major predator in southern California nearshore waters. Fossil otoliths have been found in California marine Pleistocene deposits that are 10-12 million years old (Fitch and Lavenberg 1971).

Table 1. Relative abundance of white seabass in 32 U.S. Pacific coast estuaries.

	Life Stage				
Estuary	A	S	J	L	E
Puget Sound					
Hood Canal					
Skagit Bay	√				
Grays Harbor					
Willapa Bay					
Columbia River					
Nehalem Bay					
Tillamook Bay					
Netarts Bay					
Siletz River					
Yaquina Bay	√				
Alsea River					
Siuslaw River					
Umpqua River					
Coos Bay	√				
Rogue River					
Klamath River					
Humboldt Bay	√		√		
Eel River					
Tomales Bay	√		√		
Cent. San Fran. Bay *	√		√		
South San Fran. Bay	√		√		
Elkhorn Slough					
Morro Bay					
Santa Monica Bay	O	O	O	√	O
San Pedro Bay	O	O	O	√	O
Alamitos Bay					
Anaheim Bay			√		
Newport Bay			√		
Mission Bay			√		
San Diego Bay	√		√		
Tijuana Estuary			√		
	A	S	J	L	E

Relative abundance:
● Highly abundant
◉ Abundant
O Common
√ Rare
Blank Not present

Life stage:
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

Range

Overall: This species has been recorded in coastal waters from Magdalena Bay, Baja California to Juneau, Alaska. There is also an isolated population occurring in the northern section of the Gulf of California (Frey 1971, Miller and Lea 1972). It is most abundant between Point Conception and Ballenas Bay, Baja California (Frey 1971), but this range shifts with water temperature fluctuations (Skogsberg 1939, Thomas 1968, Frey 1971).

Within Study Area: Although it is possible to find white seabass throughout the study area, it is very rare north of Point Conception. This species is common in San Pedro and Santa Monica Bays, but rare in other southern California bays and estuaries (Table 1) (Horn 1974, Horn and Allen 1981, Allen et al. 1983). However, it appears to have been once common in Newport Bay, California (Skogsberg 1939).

Life Mode

Eggs, larvae, juveniles and adults are all pelagic. Juveniles may utilize the kelp canopy for cover (Feder et al. 1974). Adults may form loose schools (Fitch 1958, Feder et al. 1974).

Habitat

Type: Newly-metamorphosed white seabass occur in open coastal waters just outside the breaker line (Kramer and Hunter 1988). This habitat is often less than 8 m deep. Juveniles and adults occur from the surface to depths of 122 m, with adults primarily found from 3-46 m (Fitch and Lavenberg 1971). Very small fish are found in bays and shallow nearshore waters near the surf zone, mid-sized fish are found in the mainland kelp beds close to shore, and larger fish are often caught near rocky headlands and offshore islands (Frey 1971).

Substrate: It is most often found over sandy bottoms or along the edges of kelp beds (Squire and Smith 1977). Schools can be found over rocky bottoms and among giant kelp just below the canopy (Feder et al. 1974).

Physical/Chemical Characteristics: White seabass occur in waters with salinities of 32-34‰ and temperatures of 13-30°C (Vojkovich and Reed 1983). Larvae have been successfully reared at temperatures of 18.7-21.7°C (Moser et al. 1983).

Migrations and Movements: Some data indicate that they migrate north in the spring and southward in the fall, wintering off Baja California. This migration appears to correlate with spawning (Frey 1971). This species may feed more actively at night than day (Skogsberg 1939, Fitch and Lavenberg 1971)

Reproduction

Mode: The white seabass is gonochoristic, oviparous, and iteroparous; eggs are fertilized externally.

Mating/Spawning: Spawning occurs from March to August, peaking from April to June (Thomas 1968, Frey 1971, Vojkovich and Reed 1983). During the spawning period, spawners appear to congregate nearshore in certain areas (e.g., Long Point and Palos Verdes Peninsula, California), but specific spawning sites have not been identified (Thomas 1968, Frey 1971). Successful spawning probably occurs from Santa Rosa Island, California to Santa Maria Bay, Baja California (based on larval distributions) (Moser et al. 1983).

Fecundity: Unknown.

Growth and Development

Egg Size and Embryonic Development: Eggs are spherical and 1.24-1.32 mm in diameter (Moser et al. 1983). Embryonic development is indirect and external. Eggs hatch in about 3 days at temperatures of 16.5-20.0°C (Moser et al. 1983).

Age and Size of Larvae: Larvae are 2.8-15.5 mm in length (Moser et al. 1983). Metamorphosis to juvenile begins at about 33.0 mm standard length (SL), and 72 days after hatching (Moser et al. 1983).

Juvenile Size Range: Juveniles range in length from 33.0 mm SL to probably 50 cm SL for males and 60 cm SL for females (Frey 1971, Moser et al. 1983).

Age and Size of Adults: Some males mature at about 51 cm total length, and some females at 61 cm long (one year later) (Frey 1971). However, all white seabass are mature at 80 cm (Vojkovich and Reed 1983). Many females mature at age three, and most all are mature by age four (Fitch and Lavenberg 1971). This is the largest member of the Sciaenidae family in California and may reach sizes over 1.2 m and 36 kg (individuals weighing over 27 kg are rare). The largest white seabass reported was 1.7 m and weighed 38 kg (Squire and Smith 1977). Most commercially-caught fish are 9-18 kg (Frey 1971). Scale analyses indicate that these are 3-20 year-old fish, but many may actually be older (Frey 1971). The 18 kg fish are often 20 years old or older (Fitch and Lavenberg 1971).

Food and Feeding

Trophic Mode: Larvae, juveniles, and adults are carnivorous.

Food Items: Larvae feed on planktonic crustaceans and other plankton (Moser et al. 1983). Juveniles eat fish, such as northern anchovy (*Engraulis mordax*), Pacific sardine (*Sardinops sagax*), chub mackerel (*Scomber japonicus*), and squid (*Loligo opalescens*), and pelagic red crabs (*Pleuroncodes planipes*) when available (Thomas 1968, Fitch 1958).

Biological Interactions

Predation: Eggs, larvae, and juveniles are probably eaten by many predators. Adults probably have few predators except man, but marine mammals and sharks will feed on gill-netted fish (Fitch and Lavenberg 1971).

Factors Influencing Populations: Historically, this species' population size has fluctuated widely. Oceanographic conditions and changes in forage species may affect its distribution (Skogsberg 1939, Vojkovich and Reed 1983). In southern California, attempts are being made to enhance the white seabass fishery by rearing juveniles in hatcheries and then releasing them into the ocean (Crooke and Taucher 1988).

References

Allen, L. G., M. H. Horn, F. A. Edmands II, and C. A. Usui. 1983. Structure and seasonal dynamics of the fish assemblage in the Cabrillo Beach area of Los Angeles Harbor, California. Bull. S. Calif. Acad. Sci. 82(2):47-70.

Crooke, S., and C. Taucher. 1988. Ocean hatcheries - wave of the future? Outdoor Calif. 49(3):10-13.

Feder, H. M., C. H. Turner, and C. Limbaugh. 1974. Observations on fishes associated with kelp beds in southern California. Calif. Fish Game, Fish Bull. 160:1-144.

Fitch, J. E. 1958. Offshore fishes of California. Calif. Fish Game, Sacramento, CA, 80 p.

Fitch, J. E., and R. J. Lavenberg. 1971. Marine food and game fishes of California. Calif. Nat. History Guides 28, Univ. Calif. Press, Berkeley, CA, 179 p.

Frey, H. W. 1971. California's living marine resources and their utilization. Calif. Dept. Fish Game, Sacramento, CA, 148 p.

Gates, D. E., and H. W. Frey. 1974. Designated common names of certain marine organisms of California. Calif. Fish Game, Fish Bull. 161:55-90.

Horn, M.H. 1974. Fishes. *In* A summary of knowledge of the southern California coastal zone and offshore areas, Chapter 11. S. Calif. Ocean Stud. Consort., Fullerton, CA, 124 p.

Horn, M. H., and L. G. Allen. 1981. A review and synthesis of ichthyofaunal studies in the vicinity of Los Angeles and Long Beach Harbors, Los Angeles County, California. Final Rep. to U.S. Fish Wildl. Serv., Dept. Biol. Sci., Calif. State Univ., Fullerton, CA, 96 p.

Kramer, S. H., and J. R. Hunter. 1988. Southern California wetland/shallow water habitat investigation. Ann. Rep., Nat. Mar. Fish. Serv., La Jolla, CA, 15 p.

Miller, D. J., and R. N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Fish Game, Fish Bull. 157, 235 p.

Moser, H. G., D. A. Ambrose, M. S. Busby, J. L. Butler, E. M. Sandknop, B. Y. Sumida, and E. G. Stevens.

1983. Description of early stages of white seabass, *Atractoscion nobilis*, with notes on distribution. Calif. Coop. Ocean. Fish. Invest. Rep. 24:182-193.

National Marine Fisheries Service. 1986. Fisheries of the United States, 1985. Current Fishery Statistics No. 8368. U.S. Dept. Comm., Nat. Ocean. Atm. Adm., Nat. Mar. Fish Serv., Nat. Fish. Stat. Prog., Washington, D.C., 122 p.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Schultze, D. L. 1986. Digest of California commercial fish laws, January 1, 1986. Calif. Dept. Fish Game, Sacramento, CA, 40 p.

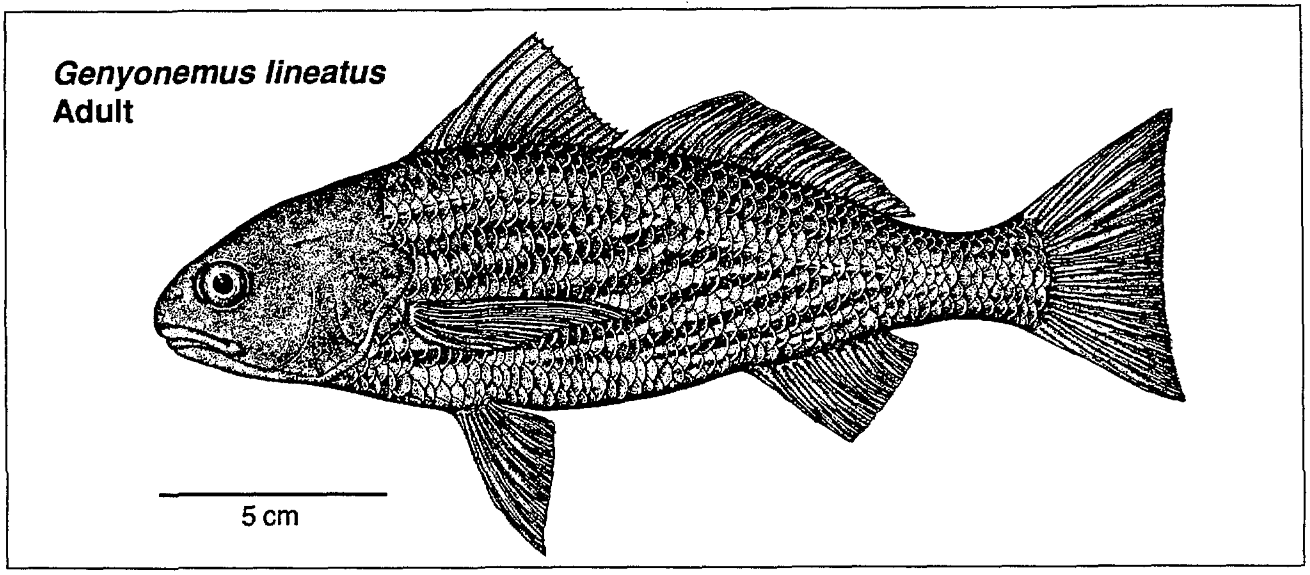
Skogsberg, T. 1939. The fishes of the family Sciaenidae (croakers) of California. Calif. Fish Game, Fish Bull. 54:1-62.

Squire, J. L., Jr., and S. E. Smith. 1977. Anglers' guide to the United States Pacific coast. NOAA, Seattle, WA, 139 p.

Thomas, J. C. 1968. Management of the white seabass (*Cynoscion nobilis*) in California waters. Calif. Fish Game, Fish. Bull. 142:1-34.

Vojkovich, M.,and R. J. Reed. 1983. White seabass, *Atractoscion nobilis*, in California-Mexican waters: status of the fishery. Calif. Coop. Ocean. Fish. Invest. Rep. 24:79-83.

White croaker



Common Name: white croaker
Scientific Name: *Genyonemus lineatus*
Other Common Names: California white seabass, sea trout, weakfish, king croaker, white croaker, kingfish, tomcod, tommy, roncky (Roedel 1953, Frey 1971, Gates and Frey 1974, Squire and Smith 1977)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Perciformes
Family: Sciaenidae

Value

Commercial: The white croaker is sold in fresh-fish markets, however, it is not a prime market fish because of its soft flesh (Bane and Bane 1971, Eschmeyer et al. 1983). It is also caught and sold for bait (Hart 1973). In the southern California Bight, it is now primarily caught by bottom set gill nets (7.0 cm stretch), but was once caught by otter trawl, round haul net, and hook and line (Love et al. 1984). Over 453 t were landed in 1952, 1953, 1960, and 1965 (Baxter 1960, Frey 1971). About 200 t/year are now landed, with the largest catches occurring in January and February (spawning season) (Love et al. 1984). In 1982, fishermen received 13-18¢/kg for their catch. Vietnamese fishermen have recently started fishing for this species in Monterey Bay, California, receiving 33-110¢/kg for their catch (Love et al. 1984).

Recreational: The white croaker is an important sport fish in California. Although small (and wrongly thought of as wormy), it is a good food fish (Skogsberg 1939, Squire and Smith 1977, Love et al. 1984). It is commonly caught from piers and boats with hook and line using various baits and lures (Eschmeyer et al. 1983). It is so easily caught in some localities that it is consider a nuisance (Baxter 1960). This species can be caught year-round and is especially popular with some ethnic groups. Over 249,000 white croakers were caught by anglers in 1985 (U.S. Department of Commerce 1986). Most white croaker kept by anglers are 21-25 cm total length (TL) and 5-7 years old (Love et al. 1984).

Indicator of Environmental Stress: High concentrations of polychlorinated biphenyls (PCBs) and other contaminants in the tissues of white croaker pose a potential health threat to humans, resulting in the closure of some fishing areas (Puffer et al. 1982). White croakers found near southern California sewer outfalls are often malformed and diseased. Diseases include cancerous growths on lips (neoplasia), bulging and missing eyes, warped bodies, and high parasitism rates. These conditions are probably a result of toxic effluents (Baxter 1960, Frey 1971, Phillips et al. 1972). Since the white croaker accumulates contaminants (Castle and Woods 1972) it is a good indicator species for pollution and is a target species of the National Status and Trends Program (Ocean Assessments Division 1984).

Ecological: This is an abundant (often dominant) species in nearshore shallow waters with sandy substratum in southern California, both within bays and estuaries, and just outside the surf zone (Roedel 1953, Squire and Smith 1977, Love et al. 1984). White croaker larvae are often second in abundance only to northern anchovy (*Engraulis mordax*) in the southern California ichthyoplankton (Love et al. 1984), and this species often occurs with queenfish (*Seriphus politus*) (Roedel 1953). Fossil otoliths have been found in Pliocene deposits 12 to 20 million years old (Baxter 1960).

Table 1. Relative abundance of white croaker in 32 U.S. Pacific coast estuaries.

Estuary	A	S	J	L	E
Puget Sound					
Hood Canal					
Skagit Bay					
Grays Harbor					
Willapa Bay					
Columbia River					
Nehalem Bay					
Tillamook Bay					
Netarts Bay					
Siletz River					
Yaquina Bay					
Alsea River					
Siuslaw River					
Umpqua River					
Coos Bay					
Rogue River					
Klamath River					
Humboldt Bay	○		○		
Eel River					
Tomales Bay	○	○	○	○	○
Cent. San Fran. Bay *	○	○	○	○	○
South San Fran. Bay	○	○	○	○	○
Elkhorn Slough				◉	
Morro Bay					
Santa Monica Bay	●	●	●	●	●
San Pedro Bay	●	●	●	●	●
Alamitos Bay	○		◉	○	
Anaheim Bay	○		○	○	
Newport Bay	√		○	○	
Mission Bay	√		√	○	
San Diego Bay	○		○	√	
Tijuana Estuary	√		√	○	
	A	S	J	L	E

Life Stage

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

Range

Overall: The white croaker's overall range is from Magdalena Bay, Baja California, to Vancouver Island, British Columbia (Miller and Lea 1972, Hart 1973, Eschmeyer et al. 1983). It is generally not abundant north of San Francisco Bay, and is rare north of California (Frey 1971).

Within Study Area: This species is found in almost all bays and estuaries south of Humboldt Bay, California, but is extremely rare north of Humboldt Bay (Table 1) (Reish 1968, Bane and Bane 1971, Allen 1976, Horn and Allen 1981, Allen et al. 1983).

Life Mode

Eggs are pelagic, and larvae are benthopelagic to epibenthic (Schlotterbeck and Connally 1982, Love et al. 1984). Juveniles and adults are primarily epibenthic schooling fishes (Eschmeyer et al. 1983, Wang 1986), but they may occur in midwater or at times near the surface (Skogsberg 1939, Love et al. 1984).

Habitat

Type: The white croaker is neritic and normally found inshore in waters less than 30 m deep, but it occurs to depths of 183 m (Eschmeyer et al. 1983, Love et al. 1984). It is common in bays and estuaries (Wang 1986). Juveniles occur in waters <27 m deep; large croakers inhabit greater depths (Love et al. 1984). The highest larval densities in southern California are found in a narrow band along the coast at depths between 15 and 22 m (Watson 1982, Love et al. 1984) and within 5 km of shore (Barnett et al. 1984). Juveniles occur primarily in a narrow coastal band between the 18 and 27 m isobaths (Love et al. 1984).

Substrate: Eggs and larvae are found over sand and gravel bottoms (Wang 1986). Adults and juveniles are found mostly over sandy bottoms, but may occasionally be found in kelp beds (Roedel 1953, Love et al. 1984).

Physical/Chemical Characteristics: The white croaker is found in euhaline to mesohaline waters (Wang 1986). The optimal temperature range for metabolism is broad (11-17°C), and may account for this species' wide depth and latitudinal distributions (Love et al. 1984).

Migrations and Movements: Adults appear to move shoreward to spawn in shallow waters. Eggs and early larvae apparently remain within this shallow "band". Larvae appear to drift into bays and estuaries on incoming tides (Wang 1986) and migrate to the bottom after hatching (Schlotterbeck and Connally 1982, Jahn et al. 1988). Early juveniles initially reside in waters 3-6 m deep, but move to deeper waters as they grow (Love et al. 1984).

Reproduction

Mode: The white croaker is gonochoristic, oviparous, and iteroparous. It is a broadcast spawner; eggs are fertilized externally.

Mating/Spawning: Spawning occurs in shallow nearshore waters essentially year-round in California, with specific spawning times dependent on location (Skogsberg 1939, Bane and Bane 1971, Hart 1973, Goldberg 1976, Eldridge 1977, Love et al. 1984). It spawns primarily from November to April in southern California, often peaking during February and March (Goldberg 1976, Schlotterbeck and Connally 1982, Love et al. 1984). It is also known to spawn in San Francisco Bay, Tomales Bay, and Elkhorn Slough, California, and coastal waters of northern Mexico (Love et al. 1984, Wang 1986). The white croaker may have a protracted spawning season off Monterey, California, because of cooler water temperatures there (Love et al. 1984). During spawning, water temperatures range from 8.0-19.0°C, with surface waters of 13-14°C at peak spawning (Love et al. 1984, Wang 1986). A batch spawner, the white croaker spawns 18-24 times per season, with large females spawning earlier and longer than small individuals (Love et al. 1984). This species appears to utilize two spawning centers from south of Point Conception to the Mexican border: one center north and south of the Palos Verdes Peninsula (from Redondo Beach to Laguna Beach), and a smaller center around Ventura (Love et al. 1984).

Fecundity: Batch fecundity is estimated to be 800 to 37,200 eggs per female (Love et al. 1984).

Growth and Development

Egg Size and Embryonic Development: Eggs are 0.5-0.9 mm in diameter, averaging 0.85 mm (Watson 1982). Embryonic development is indirect and external. In one study, all eggs hatched in 52 hr at 20°C (Watson 1982).

Age and Size of Larvae: Larvae range from 1.8-2.8 mm standard length at hatching (Watson 1982, Wang 1986).

Juvenile Size Range: Juveniles are 1.3 to about 13 cm total length (TL) (Love et al. 1984).

Age and Size of Adults: Maturity is reached in 1 to 4 years, with about 50% maturing in 1 year; all are mature at 19 cm TL (Love et al. 1984). Males appear to mature at about 12 cm and females at 13 cm TL (Love et al. 1984). Females grow faster than males, and both grow at fairly constant rates throughout their lives (Love et al. 1984). The largest specimen recorded was 39 cm and 0.7 kg (Squire and Smith 1977). White croaker may live for 12 to 15 years (Love et al. 1984).

Food and Feeding

Trophic Mode: Larvae, juveniles, and adults are omnivorous bottom feeders, feeding primarily at night. However, juveniles may feed in midwater during the day (Allen 1982).

Food Items: Larvae eat rotifers, tintinnids, dinoflagellates, polychaete larvae, lamellibranch larvae, copepods, amphipods, and invertebrate eggs. Very small larvae eat primarily rotifers, while larger larvae prey on copepods (Jahn et al. 1988). Small juveniles (<87 mm TL) eat mainly zooplankton, including cladocerans, amphipods, ostracods, mysids, euphausiids, crab zoea and megalopae, larval polychaetes, cumaceans, chaetognaths, cyprids, copepods, and fish larvae (Phillips et al. 1972). Larger juveniles and adults switch from zooplankton to benthic and epibenthic organisms, consuming a wide variety of fish [northern anchovy (*Engraulis mordax*) and others], squid, shrimp, octopus, polychaetes, crabs, clams, and other living and dead organisms (Skogsberg 1939, Baxter 1960, Allen 1982).

Biological Interactions

Predation: The white croaker is eaten by sea lions, Pacific bottlenose dolphin (*Tursiops truncatus*), California halibut (*Paralichthys californicus*), black sea bass (*Stereolepis gigas*), bluefin tuna (*Thunnus thynnus*), and probably other piscivorous animals (Fitch 1958, Baxter 1960)

Factors Influencing Populations: High levels of contaminants apparently can impair reproduction (Cross and Hose 1988). Concentrations of PCBs and DDT in this species are directly related to its reproductive state (Cross 1986). Pollutants may cause tail rot and liver damage (Phillips et al. 1972). Because the white croaker utilizes nearshore coastal habitats for spawning and rearing, it is directly affected by man's activities in these areas.

References

Allen, L. G. 1976. Abundance, diversity, seasonality and community structure of the fish populations of Newport Bay, California. M.A. Thesis, Calif. State Univ., Fullerton, CA, 107 p.

Allen, M. J. 1982. Functional structure of soft-bottom fish communities of the southern California shelf. Ph.D. Diss., Univ. Calif., San Diego, CA, 577 p.

Allen, L. G., M. H. Horn, F. A. Edmands II, and C. A. Usui. 1983. Structure and seasonal dynamics of the fish assemblage in the Cabrillo Beach area of Los Angeles Harbor, California. Bull. S. Calif. Acad. Sci. 82(2):47-70.

Bane, G. W., and A. W. Bane. 1971. Bay fishes of northern California with emphasis on the Bodega Tomales Bay area. Mariscos Publ., Hampton Bays, NY, 143 p.

Barnett, A. M., A. E. Jahn, P. D. Sertic, and W. Watson. 1984. Distribution of ichthyoplankton off San Onofre, California, and methods for sampling very shallow coastal waters. Fish. Bull., U.S. 82(1):97-111.

Baxter, J. L. 1960. Inshore fishes of California. Calif. Dept. Fish Game, Sacramento, CA, 80 p.

Castle, W. T., and L. A. Woods, Jr. 1972. DDT residues in white croakers. Calif. Fish Game 58:(3):198-203.

Cross, J. N. 1986. Seasonal changes in DDT and PCB concentrations in white croaker are related to the reproductive cycle. Coastal Water Res. News 1(2):2.

Cross, J. N., and J. E. Hose. 1988. Evidence for impaired reproduction in white croaker (*Genyonemus lineatus*) from contaminated areas of southern California. Mar. Env. Res. 24(1-4):185-188.

Eldridge, M. B. 1977. Factors influencing distribution of fish eggs and larvae over eight 24-hr samplings in Richardson Bay, California. Calif. Fish Game 63(2):101-116.

Eschmeyer, W. N., E. S. Herald, and H. Hammann. 1983. A field guide to Pacific coast fishes of North America. Houghton Mifflin Company, Boston, MA, 336 p.

Fitch, J. E. 1958. Offshore fishes of California. Calif. Dept. Fish Game, Sacramento, CA, 80 p.

Frey, H. W. 1971. California's living marine resources and their utilization. Calif. Dept. Fish Game, Sacramento, CA, 148 p.

Gates, D. E., and H. W. Frey. 1974. Designated common names of certain marine organisms of California. Calif. Fish Game, Fish Bull. 161:55-90.

Goldberg, S. R. 1976. Seasonal spawning cycles of the Sciaenid fishes *Genyonemus lineatus* and *Seriphus politus*. Fish. Bull., U.S. 74(4):983-984.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. No. 180, 740 p.

Horn, M. H., and L. G. Allen. 1981. A review and synthesis of ichthyofaunal studies in the vicinity of Los Angeles and Long Beach Harbors, Los Angeles County, California. Final Rep. to U.S. Fish Wildl. Serv., Dept. Biol. Sci., Calif. State Univ., Fullerton, CA, 96 p.

Jahn, A. E., D. M. Gadomski, and M. L. Sowby. 1988. On the role of food-seeking in the suprabenthic habit of larval white croaker, *Genyonemus lineatus* (Pisces: Sciaenidae). Fish. Bull., U.S. 86(2):251-262.

Love, M. S., G. E. McGowen, W. Westphal, R. J. Lavenberg, and L. Martin. 1984. Aspects of the life history and fishery of the white croaker, *Genyonemus lineatus* (Sciaenidae), off California. Fish. Bull., U.S. 82(1):179-198.

Miller, D. J., and R. N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Fish Game, Fish Bull. 157, 235 p.

Ocean Assessments Division. 1984. The national status and trends program for marine environmental quality: program description (mimeo). Ocean Assess. Div., Nat. Ocean Serv., Nat. Ocean. Atm. Adm., Rockville, MD, 28 p.

Phillips, L., C. Terry, and J. Stephens. 1972. Status of the white croaker (*Genyonemus lineatus*) in the San Pedro Region. Rep. to Southern Calif. Coast. Water Res. Proj., Longbeach, CA, 47 p.

Puffer, H. W., M. J. Duda, and S. P. Azen. 1982. Potential health hazards from consumption of fish caught in polluted coastal waters of Los Angeles County. N. Am. J. Fish. Man. 2:74-79.

Reish, D. J. 1968. Marine life of Alamitos Bay. Forty-Niner Shops, Inc., Long Beach, CA, 92 p.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Roedel, P. M. 1953. Common ocean fishes of the California coast. Calif. Fish Game, Fish Bull. 91, 184 p.

Schlotterbeck, R. E., and D. W. Connally. 1982. Vertical stratification of three nearshore southern California larval fishes (*Engraulis mordax, Genyonemus lineatus*, and *Seriphus politus*). Fish. Bull., U.S. 80(4):895-902.

Skogsberg, T. 1939. The fishes of the family Sciaenidae (croakers) of California. Calif. Fish Game, Fish Bull. 54, 62 p.

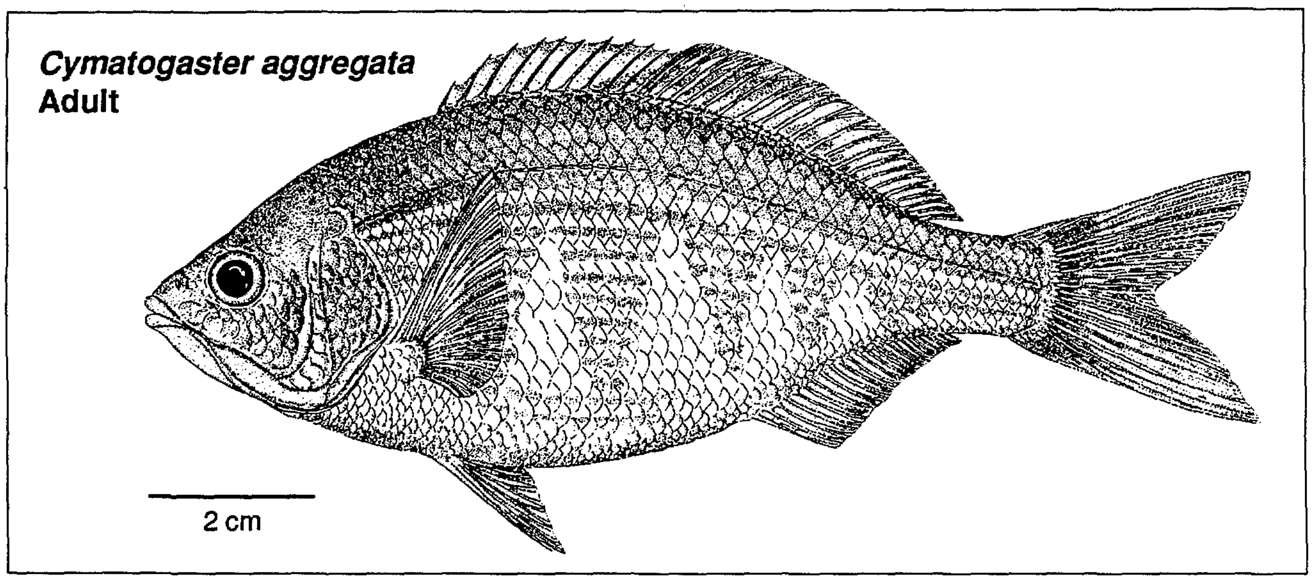
Squire, J. L., Jr., and S. E. Smith. 1977. Anglers' guide to the United States Pacific Coast. NOAA, Seattle, WA, 139 p.

U.S. Department of Commerce. 1986. Marine recreational fishery statistics survey, Pacific coast. U.S. Dept. Comm., Nat. Ocean. Atm. Adm., Current Fish. Stat. No. 8328, 109 p.

Wang, J. C. S. 1986. Fishes of the Sacramento-San Joaquin estuary and adjacent waters, California: a guide to the early life histories. Tech. Rep. No. 9. Interagency Ecological Study Program for the Sacramento-San Joaquin estuary. Calif. Dept. Water Res, Calif. Dept. Fish Game, U.S. Bureau Reclam., and U.S. Fish Wildl. Serv., various pagination.

Watson, W. 1982. Development of eggs and larvae of the white croaker, *Genyonemus lineatus* Ayres (Pisces: Sciaenidae), off the southern California coast. Fish. Bull., U.S. 80(3):403-416.

Shiner perch



Common Name: shiner perch
Scientific Name: *Cymatogaster aggregata*
Other Common Names: shiner seaperch, shiner surfperch, yellow shiner, shiner, bayperch, poggie, sparada, minny, bay perch, seven-eleven perch (Roedel 1953, Gates and Frey 1974, Washington 1977, Eschmeyer et al. 1983)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Perciformes
Family: Embiotocidae

Value

Commercial: The shiner perch is not commercially important, although some are landed for use as bait (Frey 1971) and human consumption (Roedel 1953). This species is considered to be a delicacy by some (Washington 1977, Wydoski and Whitney 1979).

Recreational: The shiner perch is commonly caught by children fishing with small hooks in estuaries and bays (Baxter 1960, Eschmeyer et al. 1983). It is occasionally used for bait in California's San Francisco Bay striped bass fishery (Smith and Kato 1979).

Indicator of Environmental Stress: The shiner perch has been used to assess the toxicity of some common organochlorine insecticides (Earnest and Benville 1972). Because this species utilizes nearshore polluted environments, it may have body burden pesticide levels higher than other fishes (Earnest and Benville 1971).

Ecological: The shiner perch is a small yet abundant species in many estuaries and bays. It is preyed upon by numerous birds, mammals, and fishes (Simenstad et al. 1979, Wydoski and Whitney 1979).

Range

Overall: Overall range is from Todos Santos Bay, Baja California, to Port Wrangell, Alaska (Roedel 1953, Bane and Bane 1971). The shiner perch is scarce at the northern and southern ends of its range, but abundant from San Diego, California, to Ketchikan, Alaska (Morrow 1980).

Within Study Area: This species is common to abundant in all Pacific coast estuaries and bays from San Diego Bay, California, through Puget Sound, Washington (Table 1) (Horn 1974, Morrow 1980, Proctor et al. 1980).

Life Mode

The shiner perch is a live-bearer; eggs are retained within the female and juveniles are born fully developed. Juveniles and adults are primarily neritic and pelagic (Garrison and Miller 1982).

Habitat

Type: This species occurs primarily in nearshore shallow-water marine, bay, and estuarine habitats, both intertidally and subtidally. It is commonly associated with aquatic vegetation (eelgrass, *Zostera* spp.) and docks and pilings (Bane 1968). During spring and summer, juveniles prefer intertidal and shallow-water subtidal habitats in bays and estuaries (Shaw et al. 1974, Moyle 1976). In winter, they occur primarily in neritic marine habitats, occasionally as deep as 70 m (Hart 1973, Wydoski and Whitney 1979).

Substrate: The shiner perch prefers sandy and muddy bottoms (Bane and Bane 1971), but may be found over

Table 1. Relative abundance of shiner perch in 32 U.S. Pacific coast estuaries.

	Life Stage		
Estuary	A	P	J
Puget Sound	●	◉	●
Hood Canal	●	◉	●
Skagit Bay	●	◉	●
Grays Harbor	◉	◉	●
Willapa Bay	◉	◉	●
Columbia River	◉	◉	●
Nehalem Bay	◉	◉	●
Tillamook Bay	◉	◉	●
Netarts Bay	●	●	●
Siletz River	●	●	●
Yaquina Bay	●	●	●
Alsea River	●	●	●
Siuslaw River	●	●	●
Umpqua River	●	●	●
Coos Bay	●	●	●
Rogue River	●	●	●
Klamath River	◉	◉	◉
Humboldt Bay	●	●	●
Eel River	●	●	●
Tomales Bay	◉	◉	●
Cent. San Fran. Bay *	◉	◉	●
South San Fran. Bay	●	◉	●
Elkhorn Slough	●	◉	●
Morro Bay	●	◉	●
Santa Monica Bay	○	○	○
San Pedro Bay	○	○	○
Alamitos Bay	○	○	◉
Anaheim Bay	○	○	◉
Newport Bay	○	○	◉
Mission Bay	◉	◉	●
San Diego Bay	◉	◉	●
Tijuana Estuary	√		√
	A	P	J

Relative abundance:
● Highly abundant
◉ Abundant
○ Common
√ Rare
Blank Not present

Life stage:
A - Adults
P- Parturition
J - Juveniles

* Includes Central San Francisco, Suisun, and San Pablo bays.

substrates ranging from silt-clay to boulders (Simenstad 1983). In Yaquina Bay, Oregon, 95% were collected on eelgrass beds (Bayer 1979, 1981).

Physical/Chemical Characteristics: Juveniles and adults occur in oligohaline to euhaline waters (Moyle 1976, Simenstad 1983) and occasionally in fresh water (Beardsley and Bond 1970, Moyle 1976). While in estuaries they are normally found in salinities >8-10‰ (Moyle 1976). During the spring and summer when adults are giving birth, large schools are found in mesohaline and polyhaline waters (Ganssle 1966, Moyle 1976). The upper lethal temperature is 26.5-30.0°C (Stober 1973). The shiner perch is reported to occur in temperatures ranging from 4 to 21°C (Tarp 1952), but shiner perch left Anaheim Bay, California, when temperatures exceeded 18.5°C (Odenweller 1975). It is not normally found at depths >30 m in California (Bane 1968), but is commonly captured at depths between 18 and 73 m in Puget Sound in winter (Wydoski and Whitney 1979). This species has been taken as deep as 128 m (Clemens and Wilby 1961).

Migrations and Movements: The shiner perch forms loose schools that move seasonally- onshore and into shallow water marine areas, estuaries, and bays in the spring, and offshore into deeper marine waters in the fall and winter (Bane and Robinson 1970, Stober et al. 1973, Wydoski and Whitney 1979). No coastal (north-south) migrations are known to occur. During the prespawning period, adults stay in shallow waters during daylight and move to deeper waters at night. After this period, most adults reverse this movement by schooling in deeper water during the day and moving to shallow water at night (Gordon 1965 as cited by Wiebe 1968). Adults and juveniles appear to school in separate areas (Shaw et al. 1974). The shiner perch may use intertidal eelgrass beds significantly more at night than day (Bayer 1981).

Reproduction

Mode: This species is gonochoristic and iteroparous. It is ovoviviparous; eggs are fertilized internally (Wiebe 1968, Garrison and Miller 1982).

Mating/Spawning: The shiner perch performs elaborate courtship and mating behavior. This behavior has been broken down into six phases: (1) male(s) will chase females, (2) one male will isolate one female from other females, (3) the male will aggressively protect his female from other male shiner perch, (4) with his dorsal fin raised, the male will swim in a figure-eight interspersed with wide circular sweeps in front of and around the female; this may continue for many minutes and be interrupted periodically by aggressive attacks against other males, (5) the male becomes limp and quivers near the female, this is associated with rapid jaw and dorsal fin movement, (6) the male turns on its side and applies his anal fin appendages to the urogenital region to copulate with the female (Wiebe 1968). The courtship behavior can be lengthy, but copulation may last only a fraction of a second (Wiebe 1968). Mating occurs primarily in the spring-summer in California (Bane and Robinson 1970, Shaw 1971), April-July in British Columbia (Hart 1973), and probably summer in Oregon and Washington. Sperm is apparently stored in the female for several months before fertilization occurs in the winter (Eigenmann 1892, Wiebe 1968). Females give birth during April and May in California (Odenweller 1975), June and July in British Columbia (Wiebe 1968), July and August in Puget Sound (Wydoski and Whitney 1979) and spring in Oregon (Beardsley and Bond 1970).

Fecundity: The reproductive capacity of this species is directly related to female size; small young females produce as few as five young, while larger older females can produce over 20 (Wilson and Millemann 1969). A female may produce up to 36 young (Clemens and Wilby 1961).

Growth and Development

Egg Size and Embryonic Development: Embryonic development is direct and internal. Eggs are 0.3 mm in diameter (Eigenmann 1892). Embryos are initially 0.45 mm in sagittal section (Wang 1986). Embryos develop spatulate vascular expansions of tissue at the margins of the dorsal and anal fins to aid in oxygen and carbon dioxide exchange (Turner 1952). During later stages of development, a fold of ovarian tissue may invade the opercular opening of some embryos (Turner 1952).

Age and Size of Larvae: There is no larval stage; embryonic development is direct and internal.

Juvenile Size Range: At birth, the fully-developed shiner perch averages 34.0-43.7 mm long (Wilson and Millemann 1969, Wang 1986). Juveniles are less than 5.0 cm long (Shaw 1971).

Age and Size of Adults: The shiner perch can live for 8 years and grow to 20 cm in length (Beardsley and Bond 1970, Wydoski and Whitney 1979). However, fish over 6 years old are rare and most are under 16.5 cm in length (Anderson and Bryan 1970). Males are smaller than females and are rarely longer than 13.0 cm (Anderson and Bryan 1970). Growth is very rapid the first year and then slows considerably (Anderson and Bryan 1970, Bane and Robinson 1970, Odenweller 1975). Males mature soon after birth, but are not mature at birth as earlier thought (Shaw 1971, Garrison and Miller 1982). Most females mature their first year (Wilson and Millemann 1969, Shaw 1971, Shaw et al. 1974), except in British Columbia (Gordon 1965 as cited in Garrison and Miller 1982).

Food and Feeding

Trophic Mode: Embryos receive oxygen and nutrition from highly-developed ovarian cavity tissues and fluids (Wiebe 1968). Juveniles and adults are omnivorous (Bane and Bane 1971). Food eaten depends on sex, age, and season (Hart 1973). Juveniles and adults will feed on benthos or plankton, depending on prey availability (Odenweller 1975). Juveniles and adults can be nocturnal or day feeders (Hobson et al. 1981, Hobson and Chess 1986).

Food Items: Juveniles and small adults eat primarily copepods (Hart 1973). Other prey include gammarid amphipods, algae, mussels, barnacle appendages, polychaetes, bivalves, crab larvae, cladocera, isopods, and mysids (Bane and Robinson 1970, Bane and Bane 1971, Hart 1973, Odenweller 1975, Bottom et al. 1984).

Biological Interactions

Predation: The shiner perch is eaten by many species of large marine fishes [e.g., sturgeon (*Acipenser spp.*), salmon (*Oncorhynchus* spp.), and barred sand bass (*Paralabrax nebulifer*)] (Wydoski and Whitney 1979). It is a seasonally important prey for harbor seal (*Phoca vitulina*) (Simenstad et al. 1979, Jeffries et al. 1984) and piscivorous birds such as cormorant (*Phalacrocorax* spp.), great blue heron (*Ardia herodias*), and bald eagles (*Haliaeetus leucocephalus*) (Bayer 1979, M. G. Garrett 1985, Pacific Power and Light, Portland, OR, pers. comm.).

Factors Influencing Populations: There is little information available regarding the factors influencing shiner perch populations. High water temperatures may reduce the length of estuarine residence (Odenweller 1975). The availability and quality of estuarine areas for giving birth and rearing may also limit shiner perch abundance. The shiner perch populations in San Pedro Bay and adjacent areas have been declining since 1974, but it is not known why (Stephens et al. 1983).

References

Anderson, R. D., and C. F. Bryan. 1970. Age and growth of three surfperches (Embiotocidae) from Humboldt Bay California. Trans. Am. Fish. Soc. 3:475-482.

Bane, G. W. 1968. Fishes of the upper Newport Bay. Univ. Calif. Irvine Res. Ser. 3:1-114.

Bane, G. W., and A. W. Bane. 1971. Bay fishes of northern California with emphasis on the Bodega Tomales Bay area. Mariscos Publ., Hampton Bays, New York, NY, 143 p.

Bane, G. W., and M. Robinson. 1970. Studies on the shiner perch, *Cymatogaster aggregata* Gibbons, in upper Newport Bay, California. Wasmann J. Biol. 28(2):259-268.

Baxter, J. L. 1960. Inshore fishes of California. Calif. Dept. Fish Game, Sacramento, CA, 80 p.

Bayer, R. D. 1979. Intertidal shallow-water fishes and selected macroinvertebrates in the Yaquina estuary, Oregon. Unpubl. Rep., 134 p. Oregon State Univ. Marine Sci. Cent. Library, Newport, OR.

Bayer, R. D. 1981. Shallow-water intertidal ichthyofauna of the Yaquina estuary, Oregon. Northw. Sci. 55(3):182-193.

Beardsley, A. J., and C. E. Bond. 1970. Field guide to common marine and bay fishes of Oregon. Agr. Exp. Sta. Bull. No. 607, Oregon State Univ., Corvallis, OR, 27 p.

Bottom, D. L., K. K. Jones, and M. J. Herring. 1984. Fishes of the Columbia River estuary. Columbia River Data Dev. Prog., CREST, Astoria, OR, 113 p. plus appendices.

Clemens, W. A., and G. V. Wilby. 1961. Fishes of the Pacific coast of Canada. Fish. Res. Board Can., Bull. No. 68, 443 p.

Earnest, R. D., and P. E. Benville, Jr. 1971. Correlation of DDT and lipid levels for certain San Francisco Bay fish. Pest. Monitor. J. 5(3):235-241.

Earnest, R. D., and P. E. Benville, Jr. 1972. Acute toxicity of four organochlorine insecticides to two species of surf perch. Calif. Fish Game 58(2):127-132.

Eigenmann, C. L. 1892. *Cymatogaster aggregata* Gibbons; a contribution to the ontogeny of viviparous fishes. Bull. U.S. Fish Comm. Vol. XII:401-478.

Eschmeyer, W. N., W. S. Herald, and H. Hammann. 1983. A field guide to Pacific coast fishes of North America. Houghton Mifflin Co., Boston, MA, 336 p.

Frey, H. W. 1971. California's living marine resources and their utilization. Calif. Dept. Fish Game, Sacramento, CA, 148 p.

Ganssle, D. 1966. Fishes and decapods of San Pablo and Suisun Bays. *In* D. W. Kelley (compiler), Ecological studies of the Sacramento-San Joaquin estuary. Calif. Fish Game, Fish Bull. 133:64-94,

Garrison, K. J., and B. S. Miller. 1982. Review of the early life history of Puget Sound fishes. Fish. Res. Inst., Univ. Wash., Seattle, WA, 729 p. (FRI-UW-8216).

Gates, D. E., and H. W. Frey. 1974. Designated common names of certain marine organisms of California. Calif. Fish Game, Fish Bull. 161:55-90.

Gordon, C. D. 1965. Aspects of the age and growth of *Cymatogaster aggregata* Gibbons. M.S. Thesis, Univ. British Columbia, Vancouver, B.C., 90 p.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. No. 180, 740 p.

Hobson, E. S., and J. R. Chess. 1986. Relationships among fishes and their prey in a nearshore sand community off southern California. Env. Biol. Fish. 17(3):201-226.

Hobson, E. S., W. N. McFarland, and J. R. Chess. 1981. Crepuscular and nocturnal activities of California nearshore fishes, with consideration of their scotopic visual pigments and the photic environment. Fish. Bull., U.S. 79(1):1-30.

Horn, M. H. 1974. Fishes. *In* A summary of knowledge of the southern California coastal zone and offshore areas, Chapter 11. South. Calif. Ocean Stud. Consort., Fullerton, CA, 124 p.

Jeffries, S. J., S. D. Treacy, and A. C. Geiger. 1984. Marine mammals of the Columbia River estuary. Columbia River Estuary Data Dev. Prog., CREST, Astoria, OR, 62 p. plus appendices.

Morrow, J. E. 1980. The freshwater fishes of Alaska. Alaska Northw. Publ. Co., Anchorage, AK, 248 p.

Moyle, P. B. 1976. Inland fishes of California. Univ. Calif. Press, Berkeley, CA, 405 p.

Odenweller, D. B. 1975. The life history of the shiner surfperch, *Cymatogaster aggregata* Gibbons, in Anaheim Bay, California. *In* E. D. Lane and C. W. Hill (editors), The marine resources of Anaheim Bay. Calif. Fish Game, Fish Bull. 165:107-115.

Proctor, C. M., J. C. Garcia, D. V. Galvin, G. B. Lewis, and L. C. Loehr. 1980. An ecological characterization of the Pacific Northwest coastal region. 5 vol. U.S. Fish Wildl. Serv., Biol. Serv. Prog. (FWS/OBS-79/11 through 79/15), various pagination.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Roedel, P. M. 1953. Common ocean fishes of the California coast. Calif. Fish Game, Fish Bull. 91, 184 p.

Shaw, E. 1971. Evidence of sexual maturation in young adult shiner perch, *Cymatogaster aggregata* Gibbons (Perciformes, Embiotocidae). Am. Mus. Nov. 2479:1-10.

Shaw, E., J. Allen, and R. Stone. 1974. Notes on collection of shiner perch, *Cymatogaster aggregata* in Bodega Harbor, California. Calif. Fish Game 60(1):15-22.

Simenstad, C. A. 1983. The ecology of estuarine channels of the Pacific Northwest coast: a community profile. U.S. Fish Wildl. Serv., FWS/OBS-83/05, 181 p.

Simenstad, C. A., B. S. Miller, C. F. Nyblade, D. Thornburgh, and L. J. Bledsoe. 1979. Food web relationships of northern Puget Sound and the Strait of Juan de Fuca: a synthesis of the available knowledge. U.S. Interagency (NOAA, EPA) Enery/Environ. Res. Dev. Prog. Rep. EPA-60017-79-259, Washington, D.C., 335 p.

Smith, S. E., and S. Kato. 1979. The fisheries of San Francisco Bay: past, present and future. *In* T.J. Conomos (editor), San Francisco Bay: the urbanized estuary, p. 445-468. Am. Assoc. Adv. Sci, and Calif. Acad. Sci., San Francisco, CA.

Stephens, J. S., Jr., P. A. Morris, and W. Westphal. 1983. Assessing the effects of a coastal steam electric generating station on fishes occupying its receiving waters. *In* D. F. Soule and D. Walsh (editors), Waste disposal in the oceans; minimizing impact, maximizing benefits, p. 194-208. Westview Press, Boulder, CO.

Stober, Q. J. 1973. Summary and overview of experimental thermal effects studies. *In* Q. J. Stober and E. O. Salo (editors), Ecological studies of the proposed Kiket Island nuclear power site, p. 441-448. Fish. Res. Inst., Coll. Fish., Univ. Wash., Seattle, WA (FRI-UW-7304).

Stober, Q. J., D. T. Griggs, and D. L. Mayer. 1973. Species diversity of the marine fish community in north Skagit Bay. *In* Q., J. Stober and E. O. Salo (editors), Ecological studies of the proposed Kiket Island nuclear power site, p. 373-400. Fish. Res. Inst., Coll. Fish., Univ. Wash., Seattle, WA (FRI-UW-7304).

Tarp, F. H. 1952. A revision of the family Embiotocidae (the surfperches). Calif. Fish Game, Fish Bull. 88, 99 p.

Turner, C. L. 1952. An accessory respiratory device in embryos of the embiotocid fish, *Cymatogaster aggregata*, during gestation. Copeia 1952(3):146-147.

Wang, J. C. S. 1986. Fishes of the Sacramento-San Joaquin estuary and adjacent waters, California: A guide to the early life histories. Tech. Rep. 9. Interagency ecological study program for the Sacramento-San Joaquin estuary. Calif. Dept. Water Res., Calif. Dept. Fish Game, U.S. Bureau Reclam., and U.S. Fish Wildl. Serv., various pagination.

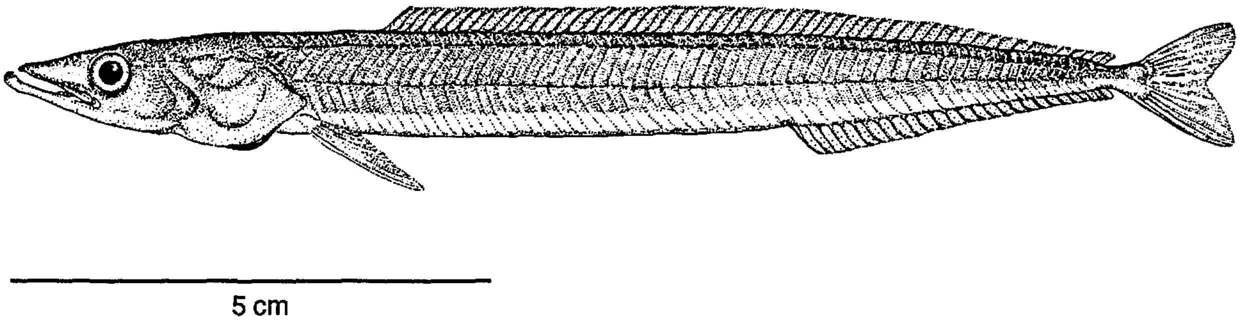
Washington, P. M. 1977. Recreationally important marine fishes of Puget Sound, Washington. Proc. Rep., Northwest Alaska Fish. Cent., Nat. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA, 122 p.

Wiebe, J. P. 1968. The reproductive cycle of the viviparous seaperch, *Cymatogaster aggregata* Gibbons. Can. J. Zool. 46:1221-1234.

Wilson, D. C., and R. E. Millemann. 1969. Relationships of female age and size to embryo number and size in the shiner perch, *Cymatogaster aggregata*. J. Fish. Res. Board Can. 267:2339-2344.

Wydoski, R. S., and R. R. Whitney. 1979. Inland fishes of Washington, Univ. Wash. Press, Seattle, WA, 220 p.

Ammodytes hexapterus
Adult



Common Name: Pacific sand lance
Scientific Name: *Ammodytes hexapterus*
Other Common Names: sandlance, sand launce, sand eel
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Perciformes
Family: Ammodytidae

Value

Commercial: The Pacific sand lance is not commercially fished in the U.S. and Canada except for a limited amount for use as bait. Commercial fisheries exist in Japan and Europe; the Japanese Pacific sand lance fishery takes about 100,000 t/year (Field 1987).

Recreational: This species is not generally used for human consumption, but is reported to be delicious (Clemens and Wilby 1961). It is mostly used as bait for larger fishes.

Ecological: The Pacific sand lance is an important prey for many different species of marine vertebrates (Hart 1973) and some invertebrates. It is the main prey for many seabirds in the northern Gulf of Alaska (Sanger 1987) and was the dominant fish captured in a nearshore habitat (<30 m deep) in Alaska (Houghton 1987). Because of its life history characteristics, it is not often sampled by normal trawl gear. Two *Ammodytes* species occur off Japan that are morphologically very similar but probably distinct species: *A. hexapterus* and *A. personatus* (Okamoto 1989).

Indicator of Environmental Stress: Oil-contaminated sediment reduces the amount of time that this species will stay burrowed (Pearson et al. 1984). Contaminated sediments (300 ppm and 3,000 ppm oil) may also cause hemorrhaging in the head and gill regions of Pacific sand lance (Pearson et al. 1984).

Range

Overall: Overall range is from southern California to Alaska and the Bering Sea, from Arctic Alaska to the Sea of Japan (Eschmeyer et al. 1983). The center of abundance appears to be in the Gulf of Alaska (Trumble 1973). It is also found in Arctic waters, Hudson Bay, the northwest Atlantic Ocean, and Europe (Leim and Scott 1966).

Within Study Area: The Pacific sand lance is common to highly abundant in Puget Sound, but has highly patchy distributions in marine areas of many other Pacific coast estuaries (Table 1) (Monaco et al. 1990).

Life Mode

Eggs are demersal and adhesive. Larvae, juveniles, and adults are pelagic and schooling, but juveniles and adults are occasionally demersal (Garrison and Miller 1982).

Habitat

Type: Adults and juveniles rest and escape from predators by burrowing into clean, unconsolidated substrates. A neritic species, it is usually associated with clean sand bottoms in areas <100 m deep (Trumble 1973). However, it may be found to depths of 275 m (Allen and Smith 1988). Since it needs clean, unconsolidated sand to burrow into and still have sufficient oxygen, these burrow areas typically have high bottom current velocities. Hence, areas with suitable current velocities and substrate types are

Table 1. Relative abundance of Pacific sand lance in 32 U.S. Pacific coast estuaries.

	Life Stage				
Estuary	A	S	J	L	E
Puget Sound	○	●	●	●	●
Hood Canal	○	●	●	●	●
Skagit Bay	○	●	●	●	●
Grays Harbor	○		◉	○	
Willapa Bay	○		◉	○	
Columbia River	○		○	○	
Nehalem Bay	◉		◉	○	
Tillamook Bay	◉		◉	○	
Netarts Bay	◉		◉	○	
Siletz River	○		○	○	
Yaquina Bay	○		○	○	
Alsea River	○		○	○	
Siuslaw River	○		○	○	
Umpqua River	◉		◉	○	
Coos Bay	○		○	○	
Rogue River					
Klamath River					
Humboldt Bay	○		○	○	
Eel River	√		√		
Tomales Bay	○	○	○	○	○
Cent. San Fran. Bay *	√		√		
South San Fran. Bay	√		√		
Elkhorn Slough	√		√		
Morro Bay					
Santa Monica Bay					
San Pedro Bay					
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

critical for defining proper habitat (Auster and Stewart 1986). This type of habitat is often found at the mouths of estuaries and may be the reason these fish are often found there.

Substrate: Larvae are found over a variety of substrates. When pelagic, juveniles and adults are found over various substrates. When they burrow, they choose clean, unconsolidated sand (perhaps with some small gravel). Eggs are also found in these substrates.

Physical/Chemical Characteristics: The Pacific sand lance is primarily a marine species; larvae are found in full seawater to mesohaline waters (Wang 1986). However, it is often found in sandy areas near freshwater seeps.

Migrations and Movements: No migration has been documented, but juveniles and adults probably move into coastal and estuarine waters during spring and summer to feed and escape from predators. In summer, they are most abundant in nearshore habitats (Craig 1987). In Alaska, 1- and 2-year-old sand lance appear to move inshore in early summer and then offshore beginning in late August (Houghton 1987). On the Atlantic coast, newly-hatched *Ammodytes* spp. larvae are found throughout the water column in well-mixed shelf waters, with most larvae found in waters less than 10-20 m deep. Larger larvae appear to spend the day near the bottom and move up into the water column at night. By April and May, most pre-metamorphosis juveniles were captured at night, indicating they were near the bottom or burrowed in the substrate during the day (Potter and Lough 1987). At night, *A. hexapterus* juveniles and adults appear to burrow into the bottom (Girsa and Danilov 1976, Hobson 1986). During winter, adults are relatively inactive and remain buried in clean sand except when spawning (Pinto 1984). Juveniles and adults often form mixed feeding schools with Pacific herring (*Clupea pallasi*), but they may also form dense "balls" or tight monospecific schools during the day.

Reproduction

Mode: The Pacific sand lance is gonochoristic, oviparous, and iteroparous; eggs are fertilized externally.

Mating/Spawning: The spawning biology of this species is not well-studied, but is assumed to be similar to that of the Atlantic sand lance (*A. americanus*). The Pacific sand lance spawns in marine waters during the winter (November-March) (Andriyashev 1954, Fitch and Lavenberg 1975, Wang 1986) in varying depths of water, and probably in strong currents (Andriyashev 1954). Along Kodiak Island, Alaska, spawning occurs intertidally at high tide in October (Dick and Warner 1982).

Fecundity: This species' fecundity is unknown, but other *Ammodytes* species have been found to have 3,300-22,100 eggs per female, averaging 6,800 per female (Andriyashev 1954).

Growth and Development:

Egg Size and Embryonic Development: Fertilized eggs are spherical and 0.88-1.20 mm in diameter (Pinto 1984). They also have an oil globule and adhere to sand grains (Williams et al. 1964). Embryonic development is indirect and external. Near Japan, eggs hatch in 33 days at 6.2°C, with optimal temperature being 8.2°C (Inoue et al. 1967). At 9°C, eggs hatch in 24 days (Pinto 1984).

Age and Size of Larvae: Larvae apparently stay in sand until they are 4-5 mm standard length (SL) (Reay 1970). At hatching, they are 4.9-5.7 mm SL (noue et al. 1967, Pinto 1984) and grow to 30-40 mm long before metamorphosis.

Juvenile Size Range: The juvenile size range is unknown, but probably from 0.4 cm up to 10.0 cm total length.

Age and Size of Adults: This species may become sexually mature after 1 to 3 years (approximately 10 cm long). In Alaska, juveniles appear to mature at 2 or 3 years (Dick and Warner 1982). Few along the California coast reach 20 cm long, but this species can grow to 28 cm in length (Hart 1973). The Pacific sand lance may live to be 8 years old (Fitch and Lavenberg 1975).

Food and Feeding

Trophic Mode: Larvae, juveniles, and adults are planktivorous carnivores.

Food Items: Small larvae eat diatoms and dinoflagellates, while larger larvae consume copepods and copepod nauplii (Garrison and Miller 1982). Juveniles and adults feed primarily on copepods (Simenstad et al. 1979), with other plankton being supplementary (Hart 1973). In Alaska, juveniles and adults feed on zooplankton (primarily euphausiids in winter and copepods in summer), but their diet varies greatly between years (Craig 1987).

Biological Interactions

Predation: The Pacific sand lance is eaten by crabs, seals, whales, and many species of fish, including Pacific cod (*Gadus macrocephalus*), Pacific halibut (*Hippoglossus stenolepis*), Pacific hake (*Merluccius productus*), sole, lingcod (*Ophiodon elongatus*), scorpaenids, salmonids, and sculpins. Many birds also prey on the sand lance, including kittiwake (*Rissa* spp.), common murres (*Uria aalge*), puffins, rhinoceros auklet (*Cerorhinca monocerata*), ancient murrelet (*Synthliboramphus antiquum*), sooty shearwater (*Puffinus griseus*), cormorants (*Phalacrocorax* spp.), red-throated loon (*Gavia stellata*), and gulls (Field 1987). It is an important prey for juvenile salmonids off Oregon and Washington (Peterson et al. 1983, Emmett et al. 1986), and the primary fish prey for salmonids in the Strait of Juan de Fuca (Beacham 1986). This species is also a primary forage fish along the northern shore of the Alaska Peninsula (Craig 1987). Intense predation often occurs when the Pacific sand lance undertakes the transition from sediment burrows to life in the water column (Hobson 1986).

Factors Influencing Populations: Little is known concerning factors that influence populations, but larval survival and predation on all life stages are believed to be most important. Major spawning areas have not been positively identified, but the areas where prolarvae have been found indicate spawning occurs in and at the mouths of bays and estuaries (Wang 1986). Larval fish surveys in the northwestern Atlantic showed a 20-fold increase in abundance of *Ammodytes* species from 1974 to 1979, reflecting a 50-fold change in adult spawning biomass (Field 1987). Studies of other *Ammodytes* species indicate water temperature during spawning season may affect recruitment, and some density-dependent effects of recruitment and growth have been noted. Increases in populations of the Newfoundland and North Seas may be related to decreases in predator populations (cod and mackerel) (Field 1987). In the lower Columbia River estuary, the Pacific sand lance is the dominant fish captured during annual hopper dredging operations (K. Larson, U.S. Corps of Engineers, Portland District, Portland, OR, pers. comm.).

References

Allen, M. J., and G. B. Smith. 1988. Atlas of zoogeography of common fishes in the Bering Sea and northeastern Pacific. NOAA Tech. Rep. NMFS 66, 151 p.

Andriyashev, A. P. 1954. Fishes of the northern seas of the USSR. Akad. Nauk SSR, Opred. po. Faune SSR 53, 556 p. (1964 transl. available, Nat. Tech. Int. Serv., Springfield, VA).

Auster, P. J., and L. L. Stewart. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (North Atlantic)—sand lance. US. Fish Wildl. Serv. Biol. Rep. 82(11.66), U.S. Army Corps Eng., TR EL-82-4, 11 p.

Beacham, T. D. 1986. Type, quantity, and size of food of Pacific salmon (*Oncorhynchus*) in the Strait of Juan de Fuca, in British Columbia. Fish. Bull., U.S. 84(1):77-89.

Clemens, W. A., and G. V. Wilby. 1961. Fishes of the Pacific coast of Canada. Fish. Res. Board Can., Bull. No. 68, 443 p.

Craig, P. 1987. Forage fishes in the shallow waters of the north Aleutian Shelf. *In* M. J. Allen and R. R. Ware (editors), Forage fishes of the southeastern Bering Sea, Conference proceedings, p. 49-54. U.S. Dept. Int., Min. Manag. Serv., Anchorage, AK.

Dick, M. H., and I. M. Warner. 1982. Pacific sand lance, *Ammodytes hexapterus* Pallas, in the Kodiak Island group. Syesis 15:43-50.

Emmett, R. L., D. R. Miller, and T. H. Blahm. 1986. Food of juvenile chinook, *Oncorhynchus tshawytscha*, and coho, *O. kisutch*, salmon off the northern Oregon and southern Washington coasts, May-September 1980. Calif. Fish Game 72(1): 38-46.

Eschmeyer, W. N., W. S. Herald, and H. Hammann. 1983. A field guide to Pacific coast fishes of North America. Houghton Mifflin Co., Boston, MA, 336 p.

Field, L. J. 1987. Pacific sand lance, *Ammodytes hexapterus*, with notes on related *Ammodytes* species. *In* N. J. Wilimovsky, L. S. Incze, and S. J. Westrheim (editors), Species synopses, life histories of selected fish and shellfish of the northeast Pacific and Bering Sea, p. 15-33. Wash. Sea Grant Prog., and Fish. Res. Inst., Univ. Wash, Seattle, WA.

Fitch, J. E., and R. J. Lavenberg. 1975. Tidepool and nearshore fishes of California. Calif. Nat. Hist. Guides: 38, Univ. Calif. Press, Berkeley, CA, 156 p.

Garrison, K. J., and B. S. Miller. 1982. Review of the early life history of Puget Sound fishes. Fish. Res. Inst., Univ. Wash., Seattle, WA, 729 p. (FRI-UW-8216).

Girsa, I. I., and A. N. Danilov. 1976. The defensive behavior of the white sea sand lance *Ammodytes hexapterus*. J. Ichthyol. 16:862-865.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. No. 180, 740 p.

Hobson, E. S. 1986. Predation on the Pacific sand lance, *Ammodytes hexapterus* (Pisces: Ammodytidae), during the transition between day and night in southeastern Alaska. Copeia 1986:223-226.

Houghton, J. P. 1987. Forage fish use of inshore habitats north of the Alaska peninsula. *In* M. J. Allen, and R. R. Ware (editors), Forage fishes of the southeastern Bering Sea, Conference proceedings, p. 39-47. U.S. Dept. Int., Min. Manag. Serv., Anchorage, AK.

Inoue, A., S. Takamori, K. Kuniyaki, S. Kobayashi, and S. Nishina. 1967. Studies on fishery biology of the sand-lance, *Ammodytes personatus* (Girard). Bull. Naikai Reg. Fish. Res. Lab. 25(121):1-335 (In Japanese, English summary).

Leim, A. H., and W. B. Scott. 1966. Fishes of the Atlantic coast of Canada. Fish. Res. Board Can. Bull. No. 155, 485 p.

Monaco, M. E., R. L. Emmett, S. A. Hinton, and D. M. Nelson. 1990. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume I: data summaries. ELMR Rep. No. 4. Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 240 p.

Okamoto, H. 1989. A genetic comparison of sympatric populations of sand lance (Genus *Ammodytes*) from the region east of Cape Soya, Japan. Can. J. Fish. Aquat. Sci. 46:1945-1951.

Pearson, W. H., D. L. Doodruff, P. C. Sugarman, and B. L. Olla. 1984. The burrowing behavior of sand lance, *Ammodytes hexapterus*: effects of oil-contaminated sediment. Mar. Environ. Res. 11:17-32.

Peterson, W. T., R. D. Brodeur, and W. A. Pearcy. 1983. Feeding habits of juvenile salmonids in the Oregon coastal zone in June 1979. Fish Bull., U.S. 80(4):841-851.

Pinto, J. 1984. Laboratory spawning of *Ammodytes hexapterus* from the Pacific coast of North America with a description of its eggs and early larvae. Copeia 1984:242-244.

Potter, D. C., and R. G. Lough. 1987. Vertical distribution and sampling variability of larval and juvenile sand lance (*Ammodytes* sp.) on Nantucket Shoals and Georges Bank. J. Northw. Atl. Fish. Sci. 7:107-116.

Reay, P. J. 1970. Synopsis of biological data on North Atlantic sand-eels of the genus *Ammodytes* (*A. tobianus*, *A. dubius*, *A. americanus*, and *A. marinus*). FAO Fish. Synop. 82, various pagination.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Sanger, G. A. 1987. Trophic interactions between forage fish and seabirds in the southeastern Bering Sea. *In* M. J. Allen and R. R. Ware (editors), Forage fishes of the southeastern Bering Sea, Conference proceedings, p. 19-28. U.S. Dept. Int., Min. Manag. Serv., Anchorage, AK.

Simenstad, C. A., B. S. Miller, C. F. Nyblade, D. Thornburgh, and L. J. Bledsoe. 1979. Food web relationships of northern Puget Sound and the Strait of Juan de Fuca: a synthesis of the available knowledge. U.S. Interagency (NOAA, EPA) Energy/Environ. Res. Dev. Prog. Rep., EPA-600/7-79-259, Washington, D.C., 335 p.

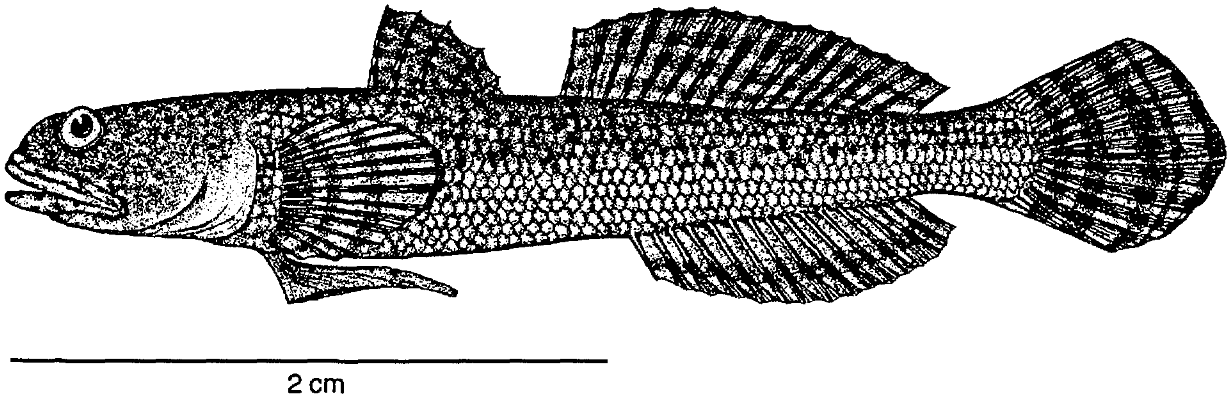
Trumble, R. J. 1973. Distribution, relative abundance, and general biology of selected underutilized fishery resources of the eastern north Pacific Ocean. M.S. Thesis, Univ. Wash., Seattle, WA, 178 p.

Wang, J. C. S. 1986. Fishes of the Sacramento-San Joaquin estuary and adjacent waters, California: A guide to the early life histories. Tech. Rep. No. 9. Interagency ecological study program for the Sacramento-San Joaquin estuary. Calif. Dept. Water Res., Calif. Dept. Fish Game, U.S. Bureau Reclam., and U.S. Fish Wildl. Serv., various pagination.

Williams, G. C., S. W. Richards, and E. G. Farnworth. 1964. Eggs of *Ammodytes hexapterus* from Long Island, New York. Copeia 1964:242-243.

Arrow goby

Clevelandia ios
Adult



Common Name: arrow goby
Scientific Name: *Clevelandia ios*
Other Common Names: mud goby (Gates and Frey 1974)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Perciformes
Family: Gobiidae

Value

Commercial: This species has no commercial value.

Recreational: This species has no recreational value.

Indicator of Environmental Stress: The arrow goby is easy to keep in aquaria and is an excellent bioassay organism (Reish and Lemay 1988). However, very little is known about this species' pollution tolerances.

Ecological: The arrow goby is an important component of the ichthyofauna in many California estuaries, where it plays a critical role in the food webs. It is the most abundant goby in Elkhorn Slough (Cailliet et al. 1977), Anaheim Bay (Macdonald 1975), and Newport Bay, California (Allen 1982). The arrow goby is commonly associated with the ghost shrimp (*Callianassa* spp.), but the shrimp probably derives no direct benefits from the use of its burrows by arrow gobies (Hoffman 1981). However, the arrow goby benefits from this association by having a refuge from predation and a residence during low tide. The arrow goby also uses the burrows of the innkeeper worm (*Urechis* spp.) and mud shrimp (*Upogebia* spp.). However, goby abundance may not correlate with the density of any of these species' burrows (Macdonald 1975).

Range

Overall: The arrow goby is found from the Gulf of California, Baja California, to Vancouver Island, British Columbia (Miller and Lea 1972).

Within Study Area: This species is found in most Pacific coast estuaries, but is most abundant in southern California bays, estuaries, and lagoons (Table 1) (Monaco et al. 1990).

Life Mode

Eggs are semi-adhesive and demersal. Larvae are pelagic, while juveniles and adults are demersal and live freely or commensally in the burrows of the innkeeper worm (Ricketts et al. 1985), and mud and ghost shrimps (Prasad 1948).

Habitat

Type: All life stages are found in intertidal and subtidal areas of bays, estuaries, and lagoons (Prasad 1948, Carter 1965, Brothers 1975, Wang 1986). Larvae are most abundant in areas of high salinity in San Francisco Bay, California (Wang 1986, California Department of Fish and Game 1987). Juveniles and adults are found in oligohaline to euhaline waters (California Department of Fish and Game 1987).

Substrate: Eggs are laid on mud, sand, and sometimes gravel (Wang 1986). Larvae can be found over a wide range of substrates. Juveniles and adults prefer bottoms of mixed sand and mud, but they can also be found on clay/sand (Prasad 1948) and other substrates.

Physical/Chemical Characteristics: Eggs are found at temperatures >10°C (Wang 1986). Juveniles and adults are eurythermal, withstanding temperatures from

Table 1. Relative abundance of arrow goby in 32 U.S. Pacific coast estuaries.

Estuary	A	S	J	L	E
Puget Sound	O	O	O	O	O
Hood Canal	O	O	O	O	O
Skagit Bay	O	O	O	O	O
Grays Harbor	O	O	O	O	O
Willapa Bay	O	O	O	O	O
Columbia River					
Nehalem Bay					
Tillamook Bay	√		√		
Netarts Bay	√		√		
Siletz River					
Yaquina Bay	O	O	O	O	O
Alsea River					
Siuslaw River	√		√		
Umpqua River	√		√		
Coos Bay	O	O	O	O	O
Rogue River					
Klamath River					
Humboldt Bay	O	O	O	O	O
Eel River					
Tomales Bay	O	◉	◉	◉	◉
Cent. San Fran. Bay *	O	◉	◉	◉	◉
South San Fran. Bay	O	◉	◉	◉	◉
Elkhorn Slough	◉	◉	◉	◉	◉
Morro Bay	◉	◉	◉	◉	◉
Santa Monica Bay	√		√		
San Pedro Bay	O	O	O	O	O
Alamitos Bay	◉	◉	◉	◉	◉
Anaheim Bay	◉	◉	◉	◉	◉
Newport Bay	◉	◉	●	◉	◉
Mission Bay	●	◉	●	◉	◉
San Diego Bay	◉	◉	◉	◉	◉
Tijuana Estuary	◉	◉	◉	◉	◉
	A	S	J	L	E

Life Stage

Relative abundance:

●	Highly abundant
◉	Abundant
O	Common
√	Rare
Blank	Not present

Life stage:
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

4-26°C (Prasad 1948). Arrow gobies may inhabit the cooler waters in invertebrate burrows when intertidal bay waters reach high temperatures (Macdonald 1972). The arrow goby spawns in polyhaline to euhaline waters (Wang 1986). Juvenile and adults are euryhaline, tolerating fresh water and salinities greater than seawater (Carter 1965). However, prolonged exposure to fresh water or low salinities can result in death (L. G. Allen, Calif. State Univ., Northridge, CA, pers. comm.). This species is also tolerant of low oxygen concentrations (Carter 1965).

Migrations and Movements: Pelagic larvae are widely transported within bays and lagoons and probably to offshore waters (Nordby 1982, Wang 1986). Intertidal-dwelling juveniles and adults do not appear to migrate down to subtidal habitats during low tide, but take refuge within invertebrate burrows and intertidal pools (MacGinitie 1935, Prasad 1948, Macdonald 1975). Arrow gobies are most active at low light levels (Macdonald 1975). Light reflected from the silver belly of a threatened goby can stimulate other gobies to search for cover, thus causing gobies in an entire area to retreat into burrows (Macdonald 1975). In some northern estuaries they may only use *Callianassa* spp. burrows during spring and summer (Hoffman 1981).

Reproduction

Mode: The arrow goby is gonochoristic, oviparous, and possibly iteroparous; eggs are fertilized externally.

Mating/Spawning: Spawning occurs on intertidal mud or sand flats of estuaries, bays, or lagoons (Wang 1986). It may spawn year-round, depending on estuary (Brothers 1975). The principal spawning period is from December to September. Peak spawning activity in many southern California estuaries is from February to June (Prasad 1948, Macdonald 1975), and from November to April in Mission Bay, California (Brothers 1975). The female's abdomen becomes swollen near spawning time and the yellow color of the eggs shows through the abdominal wall. Females may also develop a streak of black pigment on the anal fin. Males show a considerable increase in pigmentation during the spawning season; dorsal fins and the upper half of the pectoral fins become darker and a black streak is found on the anal fin (Prasad 1948). Females become lethargic near spawning time, while males are very active. Male breeding behavior includes fighting, chasing, nipping, and belly-flashing (Macdonald 1975). No nest is built, eggs are deposited singly or in small groups (Prasad 1948), with 15-25 eggs laid at a time (MacGinitie 1935). Eggs are laid on walls of a burrow which is about 10 cm deep (Wang 1986).

Fecundity: Fecundity ranges from 300-1,200 eggs per female, depending on body size (Brothers 1975).

Growth and Development

Egg Size and Embryonic Development: Eggs are elliptical, club-shaped (Prasad 1948, Brothers 1975, Wang 1986), and 0.735 mm long and 0.645 mm wide (MacGinitie 1935, Brothers 1975). They are adhesive only at the anchoring point (Prasad 1948). Embryonic development is indirect and external. At 15-15.5°C, hatching takes 10-12 days. No parental care is provided (Macdonald 1975).

Age and Size of Larvae: Larval lengths range from 2.75-3.20 mm at hatching (Prasad 1948, Brothers 1975). Transformation to juvenile occurs at about 14.0 mm after the larvae develop the external characteristics of adults (Prasad 1948).

Juvenile Size Range: Juveniles are from 14.0 mm to at least 29.0 mm long (Prasad 1948). Juveniles are less than one year old (Prasad 1948, Brothers 1975).

Age and Size of Adults: The arrow goby matures in at least one year, when it is longer than 29 mm. All females are mature by a length of 34 mm (Prasad 1948, Brothers 1975). Some gobies may mature after one summer if they settled in spring (Brothers 1975). The maximum size reported is 52 mm (Carter 1965). Most live for only 1 year, but a few will live 2-3 years (Prasad 1948, Brothers 1975). The sex of individuals >19 mm long can be distinguished by the shape of their anal papillae (Prasad 1948).

Food and Feeding

Trophic Mode: This species is primarily carnivorous (Macdonald 1975). Larvae are planktonic feeders, while juveniles and adults are epibenthic/benthic feeders (Prasad 1948, Brothers 1975, Macdonald 1975).

Food Items: Larvae feed primarily on the copepod *Acartia tonsa* and probably other zooplankton. Juveniles and adults consume harpacticoid and cyclopoid copepods, ostracods, nematodes, and oligochaetes. Gammarid and caprellid amphipods, and large oligochaetes are important prey for larger gobies (Prasad 1948, Macdonald 1975). Other food may include isopods, filamentous algae, crustacean nauplii and zoeae, diatoms, and tintinnids (Prasad 1948). However, these items may only be eaten incidentally with other prey (Macdonald 1975). Besides the above prey, pieces of food released by a ghost shrimp (while it tears its food) may be snatched and eaten (MacGinitie 1934, cited by Carter 1965).

Biological Interactions

Predation: This species is consumed by many predators, including: California halibut (*Paralichthys californicus*) (Haaker 1975), walleye surfperch (*Hyperprosopon argenteum*), California corbina (*Menticirrhus undulatus*), white croaker (*Genyonemus lineatus*), Pacific staghorn sculpin (*Leptocottus armatus*), diamond turbot (*Hypsopsetta guttulata*), queenfish (*Seriphus politus*), specklefin midshipman (*Porichthys myriaster*), round stingray (*Urolophis halleri*), shovelnose guitarfish (*Rhinobatos productus*), California killifish (*Fundulus parvipinnis*), and probably many species of piscivorous birds [gulls, greater yellowleg (*Totanus melanoleucos*), and short-billed dowitcher (*Limnodromus griseus*)] (Prasad 1948, Brothers 1975, Macdonald 1975).

Factors Influencing Populations: Predation probably plays a major role in determining population size (Macdonald 1975). Other important factors include parasites, competition with other fishes, and stress from spawning (Brothers 1975). The arrow goby is an estuary-dependent species, hence, any factor which impacts tidal flats and invertebrate burrows probably directly affects arrow goby abundance. However, annual freshwater inflow was not found to influence arrow goby populations in San Francisco Bay (California Department of Fish and Game 1987).

References

Allen, L. G. 1982. Seasonal abundance, composition, and productivity of the littoral fish assemblage in upper Newport Bay, California. Fish Bull., U.S. 80(4):769-790.

Brothers, E. B. 1975. The comparative ecology and behavior of three sympatric California gobies. Ph. D. Thesis, Univ. Calif., San Diego, CA, 365 p.

Cailliet, G. M., B. Antrim, D. Ambrose, S. Pace, and M. Stevenson. 1977. Species composition, abundance and ecological studies of fishes, larval fishes, and zooplankton in Elkhorn slough. *In* J. Nybakken, G. Cailliet, and W. Broenkow (editors). Ecological and hydrographic studies of Elkhorn Slough Moss Landing Harbor and nearshore coastal waters July 1974 to June 1976, p. 216-386, Moss Landing Marine Lab., Moss Landing, CA.

California Department of Fish and Game. 1987. Delta outflow effects on the abundance and distribution of San Francisco Bay fish and invertebrates, 1980-1985. Exhibit 60, entered by the California Department of Fish and Game for the State Water Resources Control Board 1987 Water Quality/Water Rights Proceeding on the San Francisco Bay/Sacramento-San Joaquin Delta. Calif. Dept. Fish Game, Stockton, CA, 345 p.

Carter, W. R., III. 1965. Racial variations of the arrow goby, *Clevelandia ios* (Jordan and Gilbert) 1882 in Puget Sound and on the coast of Washington State. M.S. Thesis, Univ. Wash., Seattle, WA, 88 p.

Gates, D. E., and H. W. Frey. 1974. Designated common names of certain marine organisms of California. Calif. Fish Game, Fish Bull. 161:55-90.

Haaker, P. L. 1975. The biology of the California halibut, *Paralichthys californicus* (Ayres). *In* E. D. Lane and C. W. Hill (editors), The marine resources of Anaheim Bay. Calif. Fish Game, Fish Bull. 165:137-151.

Hoffman, C. J. 1981. Associations between the arrow goby *Clevelandia ios* (Jordan and Gilbert) and the ghost shrimp *Callianassa californiensis* Dana in natural and artificial burrows. Pac. Sci. 35(3):211-216.

Horn, M. H., and L. G. Allen. 1985. Fish community ecology in southern California bays and estuaries. Chapter 8. *In* A. Yanez-Arancibia (editor), Fish community ecology in estuaries and coastal lagoons: towards an ecosystem integration, p. 169-190. DR (R) UNAM Press, Mexico.

Macdonald, C. K. 1972. Aspects of the life history of the arrow goby, *Clevelandia ios* (Jordan and Gilbert), in Anaheim Bay, California, with comments on the cephalic-lateralis system in the fish family Gobiidae. M.S. Thesis, Calif. State Univ. Long Beach, CA, 157 p.

Macdonald, C. K. 1975. Notes on the family Gobiidae from Anaheim Bay. *In* E. D. Lane and C. W. Hill (editors), The marine resources on Anaheim Bay. Calif. Fish Game, Fish Bull. 165:117-121.

MacGinitie, G. E. 1934. The natural history of *Callianassa californiensis* Dana. Am. Midl. Nat. 15:166-177.

MacGinitie, G. E. 1935. Ecological aspects of a California marine estuary. Am. Midl. Nat. 16(5):629-765.

Miller, D. J., and R. N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Fish Game, Fish Bull. 157, 235 p.

Monaco, M. E., R. L. Emmett, S. A. Hinton, and D. M. Nelson. 1990. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume I: data summaries. ELMR Rep. No. 4. Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 240 p.

Nordby, C. S. 1982. The comparative ecology of ichthyoplankton within Tijuana estuary and in adjacent nearshore waters. M.S. Thesis, San Diego State Univ., San Diego, CA, 101 p.

Prasad, R. R. 1948. Life history of *Clevelandia ios* (Jordan and Gilbert). Ph.D. Thesis, Stanford Univ., Stanford, CA, 141 p.

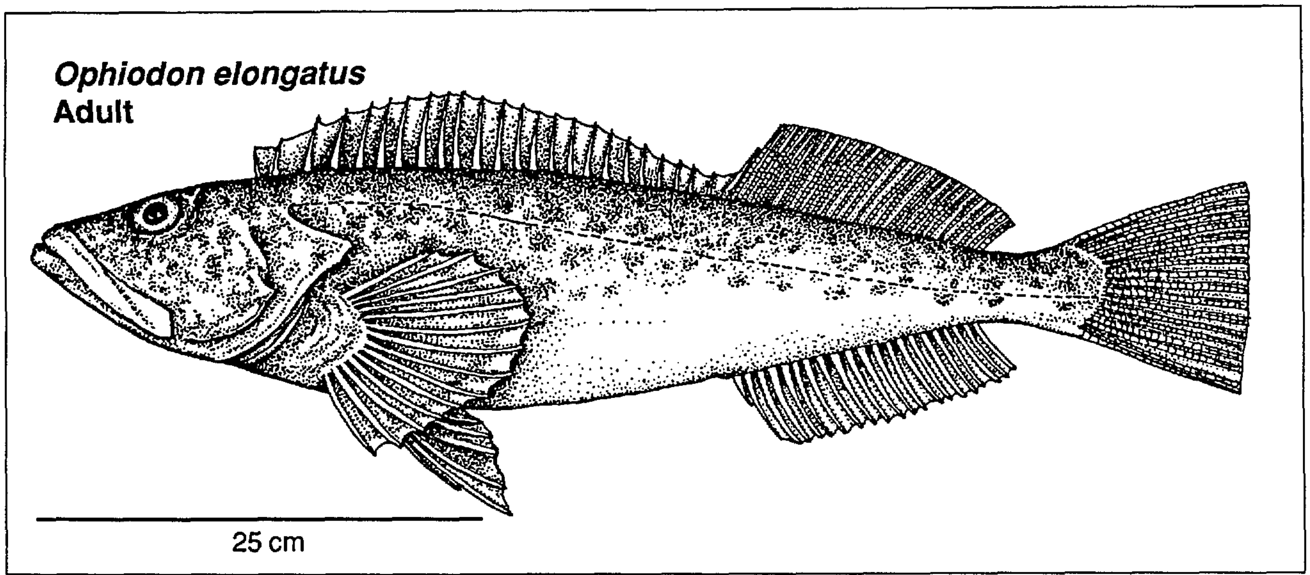
Reish, D. J., and J. A. Lemay. 1988. Bioassay manual for dredged sediments. Res. Rep. to U.S. Army Corps Eng., Los Angeles District, Los Angeles, CA, 36 p. plus appendices.

Ricketts, E. F., J. Calvin, J. W. Hedgpeth, and D. W. Phillips. 1985. Between Pacific tides. Stanford Univ. Press, Stanford, CA, 652 p.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Amer. Fish. Soc. Spec. Publ., No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Wang, J. C. S. 1986. Fishes of the Sacramento-San Joaquin estuary and adjacent waters, California: A guide to the early life histories. Tech. Rep. No. 9. Interagency ecological study program for the Sacramento-San Joaquin estuary. Calif. Dept. Water Res., Calif. Dept. Fish Game, U.S. Bureau of Reclam., and U.S. Fish Wildl. Serv. various pagination.

Lingcod



Common Name: lingcod
Scientific Name: *Ophiodon elongatus*
Other Common Names: cultus cod (McClane 1978)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Perciformes
Family: Hexagrammidae

Value

Commercial: The lingcod is an important commercial species, with over 4,000 t landed in 1985, worth $2.9 million (National Marine Fisheries Service 1986). It is harvested from California to Alaska using trawls, long lines, and gill nets. Since the 1960s, there has been a general reduction of commercial catches in both Canadian and American waters (Cass 1981, Bargmann 1981). It is the eighth most important commercial species in Puget Sound, Washington (by dollar value) (Bargmann 1981). In Washington coastal waters, most commercial catches occur between 40 and 100 fathoms (80-200 m) (Jagielo 1988).

Recreational: This is a prized sport fish because of its size and excellent taste (Eschmeyer et al. 1983). It is the top California sport fish (by poundage) between Pt. Arguello and the Oregon border (Frey 1971), and the seventh most important sport fish in Puget Sound (by number) (Bargmann 1981). This species is taken by anglers using hook and line from boats, piers, and shore, and also by spearfishing divers.

Indicator of Environmental Stress: Eggs require well-oxygenated water (Giorgi and Congleton 1984). Oil and other petrochemical spills may reduce populations (Shaw and Hassler 1989). The lingcod may also concentrate heavy metals (Shaw and Hassler 1989).

Ecological: This species is a major predator of smaller fishes and crustaceans in rocky reef habitats and kelp beds.

Range

Overall: The lingcod is found along coastal areas from Baja California to Kodiak and Shumigan Islands in the Gulf of Alaska (Hart 1973). It is most abundant from Point Conception, California, to Cape Spencer, Alaska (MBC Applied Environmental Sciences 1987).

Within Study Area: The lingcod is common in Puget Sound and present in many other estuaries of the study area (Table 1) (Monaco et al. 1990). Small coastal estuaries are used primarily by juveniles.

Life Mode

Eggs are demersal and adhesive. Larvae and small juveniles (≤70 mm long) are epipelagic, while larger juveniles and adults are demersal (Miller and Geibel 1973). Adults are found in marine waters, intertidally and deeper (down to approximately 475 m), but are most abundant at depths between 100-150 m (Allen and Smith 1988) Juveniles settle out of the plankton into nearshore shallow-water areas (<20 m deep), often where there is some freshwater runoff and lower salinities (Day et al. 1986).

Habitat

Type: Eggs are laid in marine, rocky subtidal areas (to at least 19 m below low tide) where adults reside. The pelagic larvae occur in the near-surface waters in marine and estuarine areas (Hart 1973). Juveniles are found in intertidal areas of shallow estuarine bays and

Table 1. Relative abundance of lingcod in 32 U.S. Pacific coast estuaries.

	Life Stage				
Estuary	A	S	J	L	E
Puget Sound	○	○	○	○	○
Hood Canal	○	○	○	○	○
Skagit Bay	○	○	○	○	○
Grays Harbor			○	○	
Willapa Bay			○	○	
Columbia River			√		
Nehalem Bay			○		
Tillamook Bay			○		
Netarts Bay			○		
Siletz River					
Yaquina Bay	○		○		
Alsea River			√		
Siuslaw River			√		
Umpqua River			○		
Coos Bay	√		○	○	
Rogue River					
Klamath River					
Humboldt Bay	○	○	○	○	○
Eel River					
Tomales Bay			○	○	
Cent. San Fran. Bay *			○	○	
South San Fran. Bay			√		
Elkhorn Slough			√		
Morro Bay			√		
Santa Monica Bay	√		√		
San Pedro Bay	√		√		
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

to at least 61 m depth in the ocean (Miller and Geibel 1973). This species is commonly found on steep rocky reefs, near algae and seagrass beds, and in areas with strong tidal currents. Males are usually found in waters <185 m deep.

Substrate: Eggs are laid in rocky crevices and overhangs. Juveniles are found on sandy bottoms, while adults prefer rocky reefs or kelp beds.

Physical/Chemical Characteristics: Currents may influence spawning site selection and eggs are usually laid in euhaline areas having swift currents (Giorgi 1981, Giorgi and Congleton 1984). Juveniles are found in marine and mixing zones of estuaries, but their salinity tolerances are unknown. Adults are typically found in marine waters at temperatures of 5-15°C (MBC Applied Environmental Sciences 1987).

Migrations and Movements: Adults apparently move into shallow-water habitats during the spawning season (winter) (Miller and Geibel 1973), but in general, adults are relatively sedentary. In spring, pelagic larvae (approximately 20 mm in length) are transported inshore. In late spring, (May and June) juveniles settle out or move into shallow-water coastal areas and estuaries (Phillips and Barraclough 1977). Juveniles appear to move away from shallow-water sandy habitats in the fall and early winter, but like adults, do not appear to show extensive migrations.

Reproduction

Mode: The lingcod is gonochoristic, oviparous, and iteroparous; eggs are fertilized externally.

Mating/Spawning: Spawning occurs from November to March off California, and December to March/April in Puget Sound (LaRiviere et al. 1981). Peak spawning takes place in December and January in California (Miller and Geibel 1973), and February and March in Washington (LaRiviere et al. 1981). Females extrude eggs, along with a yellow secretion, directly onto the spawning site. The eggs adhere to the rocks and each other. The male then swims over the egg mass and fertilizes them with his milt. The egg laying and fertilization continues until the female leaves the nest site (Wilby 1937). The male stays and guards the eggs and may fan the eggs with his pectoral fins (Garrison and Miller 1982). Males may be monogamous or polygamous and are commonly found guarding more than one egg mass (Garrison and Miller 1982). Larger fish often spawn earlier than smaller fish.

Fecundity: From 6,000-500,000 eggs can be laid, depending on the size of the female (Phillips 1959).

Growth and Development

Egg Size and Embryonic Development: Eggs are spherical and 2.8 mm in diameter when laid, and 3.5 mm in diameter after fertilized and water hardened (Wilby 1937). The egg mass can be large, up to 33 kg (Forrester 1969). Embryonic development is indirect and external. Eggs hatch in about 6 weeks, with eggs on the outside of the mass hatch first (Jewell 1968).

Age and Size of Larvae: Larvae are approximately 7 mm long at hatching and grow to 55 mm in length before metamorphosis (MBC Applied Environmental Sciences 1987).

Juvenile Size Range: Juveniles grow from 5.5 to 60.0 cm long (female) or 50.0 cm long (male) in California before reaching maturity (Miller and Geibel 1973). Fish in more northerly populations tend to grow larger before reaching maturity.

Age and Size of Adults: In California, most females mature at 60.0 cm total length (TL) (3 years), and most males at 50.0 cm TL (some 2 years) (Miller and Geibel 1973). The lingcod matures at slightly larger sizes north of California (Hart 1973), but grows faster in the southern part of their range, where both males and females average 50.0 cm after 3 years. Female lingcod can grow to more than 152 cm long (Eschmeyer et al. 1983), 32 kg, and 20 years old (Miller and Geibel 1973). However, males usually never grow longer than 90 cm (MBC Applied Environmental Sciences 1987).

Food and Feeding

Trophic Mode: Larvae are carnivorous zooplanktivores. Juveniles and adults are carnivorous.

Food Items: Larvae eat copepods, copepod nauplii and eggs, and other crustaceans. Small juveniles feed on crustaceans, but as they grow they concentrate their feeding on small fishes. Adults are top-level carnivores and feed on Pacific herring (*Clupea harengus*), sand lance (*Ammodytes hexapterus*), flounders, Pacific hake (*Merluccius productus*), rockfishes (*Sebastes* spp.), and large crustaceans. They are also cannibalistic (Hart 1973). However, females do not eat during spawning (MBC Applied Environmental Sciences 1987).

Biological Interactions

Predation: Invertebrates (gastropods, crabs, starfishes, sea urchins) and vertebrates [spiny dogfish (*Squalus acanthias*) and Pacific staghorn sculpin (*Leptocottus armatus*)] prey on eggs (LaRiviere et al. 1981, MBC Applied Environmental Sciences 1987). Larvae and juveniles are eaten by other fishes, including adult lingcod. Besides humans, probably only marine mammals and large sharks are predators on adults.

Factors Influencing Populations: Overfishing can be a problem because of this species' slow growth and limited mobility (Bargmann 1982). Poor water circulation reduces embryo survival (Giorgi and Congleton 1984). Estuarine dredging may alter natural open-sand rearing areas (Buckley et al. 1984). Predation, cannibalism, disease, and poor larval survival may limit recruitment. Year-class strength apparently varies widely due to many factors (Cass 1981, Day et al. 1986).

References

Allen, M. J., and G. G. Smith. 1988. Atlas and zoogeography of common fishes in the Bering Sea and northeastern Pacific. NOAA Tech. Rep. NMFS 66, 151 p.

Bargmann, G. 1981. Management of lingcod in Puget Sound. *In* A. Cass (chairman), Proceedings of the February 25-26, 1981 international lingcod workshop, p. 103-115. Unpubl. Rep., Pacific Biol. Sta., Nanaimo, B.C., Canada.

Bargmann, G. G. 1982. The biology and fisheries for lingcod (*Ophiodon elongatus*) in Puget Sound. Tech. Rep. 66, Wash. Dept. Fish., Olympia, WA, 69 p.

Buckley, R., G. Hueckel, B. Benson, S. Quinnell, and M. Canfield. 1984. Enhancement research on lingcod (*Ophiodon elongatus*) in Puget Sound. Prog. Rep. 216, Wash. Dept. Fish., Olympia, WA, 93 p.

Cass, A. 1981. Juvenile lingcod purse seine survey and its application to estimate densities during pelagic development. *In* A. Cass (chairman), Proceedings of the February 25-26, 1981 international lingcod workshop, p. 73-102. Unpubl. Rep., Pacific Biol. Sta., Nanaimo, B.C. Canada.

Day, M. E., C. A. Coomes, P. L. Striplin, and D. Grosse. 1986. Review and annotated bibliography of juvenile lingcod and flatfish populations inhabiting Grays Harbor with reference to potential adverse impacts caused by dredging. Final Rep. to U.S. Corps of Eng., Seattle District, Seattle, WA, 140 p.

Eschmeyer, W. N., W. S. Herald, and H. Hammann. 1983. A field guide to Pacific coast fishes of North America. Houghton Mifflin Co., Boston, MA, 336 p.

Forrester, C. R. 1969. Life history information on some groundfish species. Fish. Res. Board Can. Tech. Rep. No. 105, 17 p.

Frey, H. W. 1971. California's living marine resources and their utilization. Calif. Dept. Fish Game, Sacramento, CA, 148 p.

Garrison, K. J., and B. S. Miller. 1982. Review of the early life history of Puget Sound fishes. Fish. Res. Inst., Univ. Wash., Seattle, WA, 729 p (FRI-UW-8216).

Giorgi, A. E. 1981. The environmental biology of the embryos, egg masses and nesting sites of the lingcod, *Ophiodon elongatus*. NWAFC Proc. Rep. 81-06, 107

p. Northwest Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Blvd. E., Seattle, WA, 98112.

Giorgi, A. E., and J. L. Congleton. 1984. Effects of current velocity on development and survival of lingcod, *Ophiodon elongatus,* embryos. Env. Biol. Fish. 10(1/2):15-27.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. No. 180. 740 p.

Jagielo, T. 1988. The spatial, temporal, and bathymetric distribution of coastal lingcod trawl landings and effort in 1986. Prog. Rep. No. 268, Wash. Dept. Fish, Olympia, WA, 46 p.

Jewell, E. D. 1968. SCUBA diving observations on lingcod spawning at a Seattle breakwater. Wash. Dept. Fish., Fish Res. Pap. 3:27-34.

LaRiviere, M. G., D. D. Jessup, and S. B. Mathews. 1981. Lingcod, *Ophiodon elongatus,* spawning and nesting in San Juan Channel, Washington. Calif. Fish Game 67(4):231-239.

MBC Applied Environmental Sciences. 1987. Ecology of important fisheries species offshore California. Min. Man. Serv., U.S. Dept. Int., Wash., D.C., 251 p.

McLane, A. J. 1978. McClanes field guide to saltwater fishes of North America. Holt, Rinehart, and Winston, Inc., New York, NY, 283 p.

Miller, D. J., and J. J. Geibel. 1973. Summary of blue rockfish and lingcod life histories; a reef ecology study; and giant kelp, *Macrocystis pyrifera,* experiments in Monterey Bay, California. Calif. Fish Game, Fish Bull. 158, 137 p.

Monaco, M. E., R. L. Emmett, S. A. Hinton, and D. M. Nelson. 1990. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume I: data summaries. ELMR Rep. No. 4. Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 240 p.

National Marine Fisheries Service. 1986. Fisheries of the United States, 1985. Current Fishery Statistics No. 8368. U.S. Dept. Comm., NOAA, Nat. Mar. Fish. Serv., Nat. Fish. Stat. Prog., Washington, D.C., 122 p.

Phillips, J. B. 1959. A review of the lingcod, *Ophiodon elongatus.* Calif. Fish Game 45(1):19-27.

Phillips, A. C., and W. W. Barraclough. 1977. On the early life history of the lingcod (*Ophiodon elongatus*). Can. Fish. Mar. Serv. Tech. Rep. No. 756, 35 p.

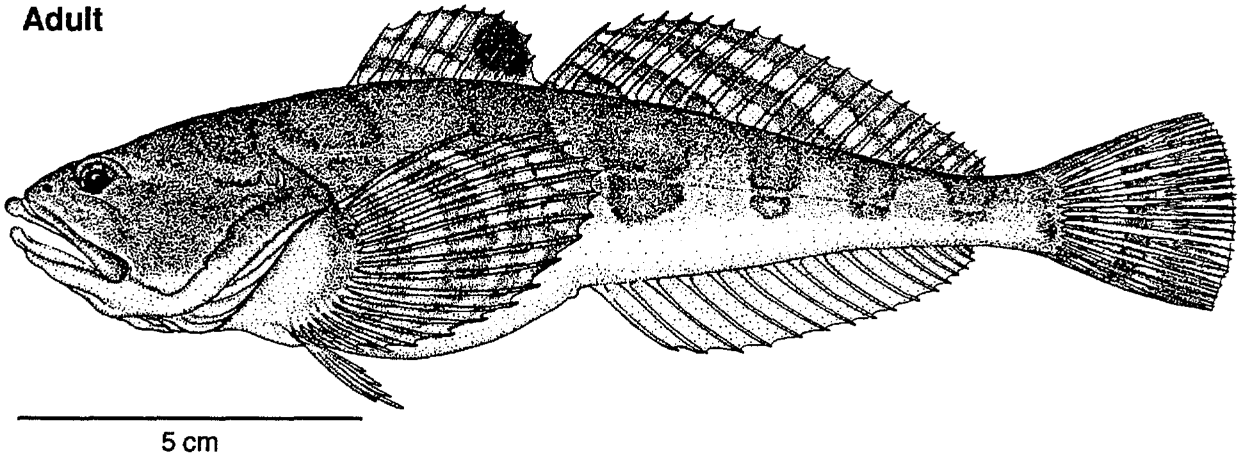
Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Shaw, W. N., and T. J. Hassler. 1989. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Northwest)—lingcod. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.119), U.S. Army Corps Eng., TR EL-82-4, 10 p.

Wilby, G. V. 1937. The lingcod, *Ophiodon elongatus,* Girard. Bull. Biol. Board Can. 54:1-24.

Pacific staghorn sculpin

Leptocottus armatus
Adult



Common Name: Pacific staghorn sculpin
Scientific Name: *Leptocottus armatus*
Other Common Names: staghorn sculpin, bullhead, cabezon, buffalo sculpin, smooth cabezon (Gates and Frey 1974)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Perciformes
Family: Cottidae

Value

Commercial: This species has no commercial value.

Recreational: The Pacific staghorn sculpin is usually captured incidentally with other fisheries, such as those for sturgeon (*Acipenser* spp.) and salmon (*Oncorhynchus* spp.), and is thus considered a nuisance by some. It is not usually consumed by anglers, but is easily captured in shallow waters and sometimes used as bait (Reish 1968).

Indicator of Environmental Stress: Since this species is distributed throughout most Pacific coast estuaries and may spend its entire life within estuaries, it is a target species of the National Status and Trends Program (Ocean Assessments Division 1984).

Ecological: The Pacific staghorn sculpin is an important predator of ghost shrimp, *Callianassa californiensis* (Posey 1986). It is a common estuarine fish that is eaten by various fishes, birds, and mammals.

Range

Overall: This species is found from southern California to the Gulf of Alaska (Wydoski and Whitney 1979).

Within Study Area: It occurs in all estuaries within the study area (Table 1) (Monaco et al. 1990).

Life Mode

Eggs are demersal, adhesive, and are probably laid in marine waters. Larvae are planktonic (marine and estuarine), and juveniles and adults are demersal.

Habitat

Type: This is a euryhaline species. Juveniles are found in shallow water, riverine, estuarine, and marine habitats. Older and larger Pacific staghorn sculpins reside in marine and highly saline estuarine areas (Wydoski and Whitney 1979).

Substrate: Newly-settled juveniles prefer clean sand (Marliave 1975, cited by Garrison and Miller 1980). Older juveniles and adults are also found primarily in sandy habitats. Planktonic larvae and benthic living juveniles and adults can be found over substrates ranging from soft mud to rock (Wang 1986).

Physical/Chemical Characteristics: The location of egg masses has not been discovered (Garrison and Miller 1980). However, optimum egg survival and development in the laboratory occurs in salinities of 26‰, while best larval survival occurs in salinities of 10.2-17.6‰ (Jones 1962). Juveniles withstand larger fluctuations in salinity and are more tolerant of low salinity than eggs, larvae, or adults (Jones 1962). Small juveniles are found intertidally, while larger juveniles and adults are found subtidally. This species is not normally found below 50 m depth. Juveniles have wide salinity and temperature tolerances, withstanding salinities near 67.5‰ at 25°C, 37.5‰ at 29°C, and 0.0‰ at 10°C (Morris 1960).

Table 1. Relative abundance of Pacific staghorn sculpin in 32 U.S. Pacific coast estuaries.

Estuary	A	S	J	L	E
Puget Sound	◉	○	◉	○	○
Hood Canal	◉	○	◉	○	○
Skagit Bay	◉	○	◉	○	○
Grays Harbor	◉	○	◉	○	○
Willapa Bay	◉	○	◉	○	○
Columbia River	◉	○	◉	○	○
Nehalem Bay	◉		◉	○	
Tillamook Bay	◉	○	◉	○	○
Netarts Bay	◉	○	●	○	○
Siletz River	◉	○	◉	○	○
Yaquina Bay	●	○	●	○	○
Alsea River	●	○	●	○	○
Siuslaw River	●	○	●	○	○
Umpqua River	●	○	●	○	○
Coos Bay	●	○	●	○	○
Rogue River	◉	○	◉	○	○
Klamath River	◉	○	◉	○	○
Humboldt Bay	◉	○	◉	○	○
Eel River	○	○	◉	○	○
Tomales Bay	◉	○	●	◉	○
Cent. San Fran. Bay *	◉	○	●	◉	○
South San Fran. Bay	◉	◉	●	◉	◉
Elkhorn Slough	○		●	●	
Morro Bay	○		●	◉	
Santa Monica Bay	√	√	√	√	√
San Pedro Bay	√		√		
Alamitos Bay	○	○	◉	○	○
Anaheim Bay	○	○	◉	○	○
Newport Bay			√		
Mission Bay	√		◉	○	
San Diego Bay	○		◉	○	
Tijuana Estuary	○		○	○	
	A	S	J	L	E

Life Stage

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

Migrations and Movements: Although no true "migration" exists, the Pacific staghorn sculpin shows seasonal movements within estuaries. Small juveniles settle-out in the lower marine areas of estuaries in winter and then move up into freshwater areas in spring and early summer (Conley 1977). There is a tendency to move down into estuarine and then marine waters as they grow (Jones 1962). After spawning, adults may leave shallow spawning grounds and move to deeper offshore waters (Tasto 1975). However, many appear to spend their entire life in estuaries.

Reproduction

Mode: The Pacific staghorn sculpin is gonochoristic, oviparous, and iteroparous; eggs are fertilized externally.

Mating/Spawning: Spawning occurs from October to March or April, peaking in January and February (Jones 1962, Wang 1986).

Fecundity: Fecundity averages 5,000 eggs per female (Jones 1962) and ranges from 2,000-11,000 eggs per female (Moyle 1976).

Growth and Development

Egg Size and Embryonic Development: Eggs are 1.36-1.50 mm in diameter (average 1.43 mm). Embryonic development is indirect and external. Eggs hatch in 9-14 days after fertilization at 15±5°C.

Age and Size of Larvae: At hatching, larvae range from 3.9-4.8 mm total length (TL) (Jones 1962). Metamorphosis to juvenile begins after about 2 months, when larvae are 15-20 mm standard length (Matarese et al. 1989).

Juvenile Size Range: The juvenile size range is from about 20 mm to approximately 120 mm TL (Jones 1962).

Age and Size of Adults: The Pacific staghorn sculpin matures in 1 year and usually >12.0 cm TL. This species can live as long as 3 years and grow to 20.3 cm in length in California (Jones 1962), and up to 10 years and 22.9 cm in length in Washington (Wydoski and Whitney 1979).

Food and Feeding

Trophic Mode: Larvae are planktivorous, while juveniles and adults are carnivorous.

Food Items: Juveniles feed primarily on benthic and epibenthic organisms, including the amphipod *Corophium* spp., other gammarids, decapod crustaceans, and the polychaete *Neanthes* spp. Large juveniles and adults consume fish and large crustaceans (*Crangon* spp.) (Jones 1962, Tasto 1975, Conley 1977, Smith 1980, Posey 1986).

Biological Interactions

Predation: This species is eaten by large fishes, ducks, loons (*Gavia* spp.), cormorants (*Phalacrocorax* spp.), gulls, and marine mammals (Tasto 1975, Treacy 1984). To reduce predation, the Pacific staghorn sculpin will try to partially bury itself in the sediment. It will also erect its opercular spines laterally with the sharp recurved hooks facing upward to deter predators (Tasto 1975).

Factors Influencing Populations: Larval success probably determines overall recruitment. Newly-settling juveniles use shallow tidal flats and pools, hence destruction of this habitat will affect this life stage. The Pacific staghorn sculpin may compete with the introduced yellowfin goby (*Acanthogobius flavimanus*) in estuaries where both species exist (Usui 1981).

References

Conley, R. L. 1977. Distribution, relative abundance, and feeding habits of marine and juvenile anadromous fishes of Everett Bay, Washington. M.S. Thesis, Univ. Wash., Seattle, WA, 57 p.

Garrison, K. J., and B. S. Miller. 1980. Review of the early life history of Puget Sound fishes. Fish. Res. Inst., Univ. Wash., Seattle, WA, 729 p. (FRI-UW-8216).

Gates, D. E., and H. W. Frey. 1974. Designated common names of certain marine organisms of California. Cal. Fish Game, Fish Bull. 161:55-90.

Jones, A. C. 1962. The biology of the euryhaline fish *Leptocottus armatus armatus* Girard (Cottidae). Univ. Calif. Publ. Zool. 67(4):321-368.

Marliave, J. B. 1975. The behavioral transformation from the planktonic larval stage of some marine fishes reared in the laboratory. Ph. D. Thesis, Univ. British Columbia, Vancouver, B.C., Canada, 231 p.

Matarese, A. C., A. W. Kendall, Jr., D. M. Blood, and B. M. Vinter. 1989. Laboratory guide to early life history stages of Northeast Pacific fishes. NOAA Tech. Rep., NMFS 80, 652 p.

Monaco, M. E., R. L. Emmett, S. A. Hinton, and D. M. Nelson. 1990. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume I: data summaries. ELMR Rep. No. 4. Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 240 p.

Morris, R. W. 1960. Temperature, salinity, and southern limits of three species of Pacific cottid fishes. Limnol. Oceanogr. 5(2):175-179

Moyle, P. B. 1976. Inland fishes of California. Univ. Calif. Press, Berkeley, CA, 405 p.

Ocean Assessments Division 1984. The national status and trends program for marine environmental quality: program description (mimeo). Ocean Assess. Div., Nat. Ocean Surv., Nat. Ocean. Atm. Adm., Rockville, MD, 28 p.

Posey, M. H. 1986. Predation on a burrowing shrimp: distribution and community consequences. J. Exp. Mar. Biol. Ecol. 103:143-161.

Reish, D. J. 1968. Marine life of Alamitos Bay. Forty-Niner Shops, Inc., Long Beach, CA, 92 p.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Smith, J. E. 1980. Seasonality, spatial dispersion patterns and migration of benthic invertebrates in an intertidal marsh-sandflat system of Puget Sound, Washington, and their relation to waterfowl foraging and the feeding ecology of staghorn sculpin, *Leptocottus armatus*. Ph.D. Thesis, Univ. Wash., Seattle, WA, 176 p.

Tasto, R. N. 1975. Aspects of the biology of Pacific staghorn sculpin, *Leptocottus armatus* (Girard), in Anaheim Bay. *In* E. E. Lane and C. W. Hill (editors), The marine resources of Anaheim Bay. Calif. Fish. Game, Fish Bull. 165:123-135.

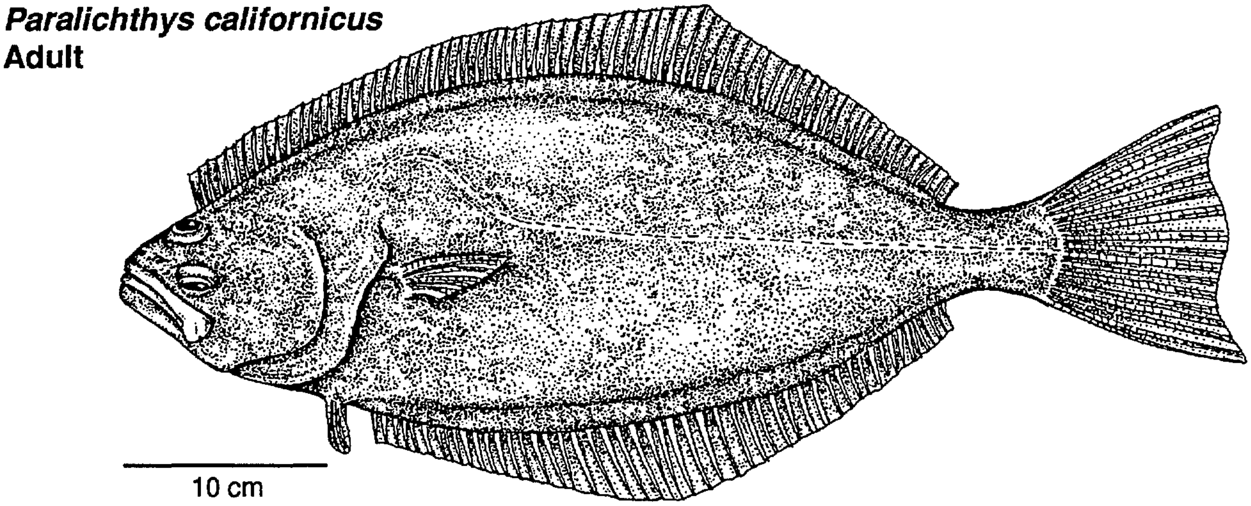
Treacy, S. 1984. Marine mammals of the Columbia River estuary. Columbia River Estuary Data Development Program, CREST, Astoria, OR, 62 p. plus appendices.

Usui, C. A. 1981. Behavioral, metabolic, and seasonal size comparisons of an introduced gobiid fish, *Acanthogobius flavimanus* and a native cottid, *Leptocottus armatus,* from upper Newport Bay, California. M.S. Thesis, Cal. State Univ, Fullerton, CA, 52 p.

Wang, J. C. S. 1986. Fishes of the Sacramento-San Joaquin estuary and adjacent waters, California: A guide to the early life histories. Tech. Rep. No. 9. Interagency ecological study program for the Sacramento-San Joaquin estuary. Calif. Dept. Water Res., Calif. Dept. Fish Game, U.S. Bureau Reclam., and U.S. Fish Wildl. Serv., various pagination.

Wydoski, R. S., and R. R. Whitney. 1979. Inland fishes of Washington. Univ. Wash. Press, Seattle, WA, 220 p.

Paralichthys californicus
Adult



Common Name: California halibut
Scientific Name: *Paralichthys californicus*
Other Common Names: Monterey halibut, bastard halibut, chicken halibut, southern halibut, alabato (Ginsburg 1952, Roedel 1953)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Pleuronectiformes
Family: Bothidae

Value

Commercial: The California halibut is commercially fished from Eureka to San Diego, California, with most caught between San Francisco and San Diego (MBC Applied Environmental Sciences 1987). The center of the fishery was originally southern California to Baja California, but it has shifted northward (Frey 1971). This species is harvested by set gill net, trammel net, and trawl nets (Schultze 1986). Fish must be >56 cm or at least 1.8 kg (in round) or 1.6 kg dressed weight. Moreover, no more than 4 less than 56 cm in length can be kept for noncommercial uses when caught incidentally in trawls. Open season for California halibut trawling grounds (Point Arguello to Point Magu) is June 16 through March 14 (Schultze 1986). California fisherman landed an average of 534 t per year from 1983 to 1987, receiving $0.64-1.59/kg in 1987 (California Department of Fish and Game 1988). Since 1973, catches have steadily increased (California Department of Fish and Game 1988). In 1987, most were caught in March and the fewest in September (California Department of Fish and Game 1988). Mexican catches are highest during summer and fall (Roedel 1953). The commercial fishery is biased toward females because they grow faster than males (Reed and MacCall 1988). Incidental catches of seabirds in gill nets set for California halibut and white croaker (*Genyonemus lineatus*) are a problem.

Recreational: The California halibut is a highly desirable species because of its excellent taste and large size (Frey 1971). Over 916,000 were caught by anglers in 1985 (U.S. Department of Commerce 1986). Average size caught is 2.7-3.2 kg, but pier-caught fish are usually much smaller (Squire and Smith 1977). This species is rarely caught in waters >18.3-27.4 m deep (Squire and Smith 1977). From Morro Bay to Tomales Bay, California, fishing is best from summer to early fall (Squire and Smith 1977). This species is caught primarily from piers and boats using hook and line and live bait (Roedel 1953). In California, only fish >56 cm long are legal to keep (Reed and MacCall 1988); anglers are allowed to take 5/day except in the Bodega and Tomales Bay areas (California Department of Fish and Game 1987)

Indicator of Environmental Stress: The size and health of California halibut populations probably reflects the health of southern California shallow waters because this species depends on these areas for its early life stages (see "Factors Influencing Populations").

Ecological: This is the largest *Paralichthys* species in U.S. waters (Ginsburg 1952). It is common along sandy nearshore areas and a top predator in nearshore sandy bottom environments in southern California.

Range

Overall: The California halibut's overall range is from Magdalena Bay, Baja California, to the Quillayute River, Washington; an isolated population exists in the

Table 1. Relative abundance of California halibut in 32 U.S. Pacific coast estuaries.

Estuary	*Life Stage* A	S	J	L	E
Puget Sound					
Hood Canal					
Skagit Bay					
Grays Harbor					
Willapa Bay					
Columbia River					
Nehalem Bay					
Tillamook Bay					
Netarts Bay					
Siletz River					
Yaquina Bay					
Alsea River					
Siuslaw River					
Umpqua River					
Coos Bay					
Rogue River					
Klamath River					
Humboldt Bay			√		
Eel River					
Tomales Bay			○	○	
Cent. San Fran. Bay *	√		○	○	
South San Fran. Bay	√		○	○	
Elkhorn Slough	√		○	√	
Morro Bay	√		○	√	
Santa Monica Bay	◉	○	◉	◉	○
San Pedro Bay	○	○	◉	◉	○
Alamitos Bay			◉		
Anaheim Bay	○		◉		
Newport Bay	√		○	√	√
Mission Bay	○		◉		
San Diego Bay	○		◉		
Tijuana Estuary	○		◉		
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

Gulf of California (Ginsburg 1952, Miller and Lea 1972, Eschmeyer et al. 1983, Allen et al. in prep.).

Within Study Area: This species is common in all bays and estuaries south of Tomales Bay, California, and abundant in most estuaries south of Point Conception. It is rare or absent in estuaries north of Tomales Bay (Table 1) (Chapman 1963, Bane 1968, Bane and Bane 1971, Miller and Lea 1972, Fierstine et al. 1973, Haaker 1975, Cailliet et al. 1977, Horn and Allen 1981, Lockheed Ocean Science Laboratories 1983, Wang 1986).

Life Mode

Eggs and larvae are pelagic (Ahlstrom and Moser 1975, Ahlstrom et al. 1984). Larvae are most abundant in coastal waters during March through September (Ahlstrom and Moser 1975, Walker et al. 1987). Juveniles and adults are benthic or demersal, however they often will pursue food well off the bottom (Frey 1971). Eggs occur primarily between the 6 and 20 m isobaths; larvae between 12 and 45 m isobaths (Haaker 1975, Plummer et al. 1983). Small juveniles are found primarily in coastal embayments and estuaries, but they also occur in very shallow open coastal waters (Clark 1930, Fierstine et al. 1973, Haaker 1975, Barry and Cailliet 1981, Horn and Allen 1981, Plummer et al. 1983, Noah 1985, Kramer and Hunter 1987, 1988).

Habitat

Type: Eggs and larvae are found primarily along a shallow water "band" in nearshore open coastal waters (Ahlstrom and Moser 1975). Larvae ≤10 mm long are found throughout the water column, primarily between the 12 and 45 m isobaths and within 2-5 km of shore (Barnett et al. 1984). Larvae are found in bays and estuaries, but are not abundant there (Leithiser 1977, McGowen 1977, Nordby 1982, Wang 1986). Small juveniles are found just outside the surf zone and in estuaries and bays (Haaker 1975, Plummer et al. 1983, Kramer and Hunter 1987, 1988). Adults and older juveniles occur nearshore, with larger and older individuals occurring deeper (to about 60 m depth) (Haaker 1975, Plummer et al. 1983). Adults are normally found at 6-40 m depths (Ginsburg 1952), but can be found to 183 m (Eschmeyer et al. 1983). Adults may be abundant in the surf zone during the spring as they prey on spawning California grunion (*Leuresthes tenuis*) (Fitch 1958).

Substrate: Juveniles and adults prefer sandy bottoms (Eschmeyer et al. 1983), but are also common near rocks, sand dollar beds, and in channels entering coastal embayments (Fitch and Lavenberg 1971).

Physical/Chemical Characteristics: The California halibut is found in water temperatures of 10-25°C, with a preference for 20.8°C (Ehrlich et al. 1979). Young halibut (subyearlings and yearlings) are eurythermal, but older halibut appear to be stenothermal (Kucas and Hassler 1986). Eggs, larvae, and adults are found in euhaline waters, but juveniles often occur in oligohaline to euhaline conditions (Haaker 1975, Allen et al. in prep.). Juveniles are relatively tolerant of reduced dissolved oxygen and increased water temperatures (Waggoner and Feldmeth 1971).

Migrations and Movements: Larvae occur in a coastal band from San Francisco to southern Baja California (Ahlstrom and Moser 1975). They apparently settle out in shallow water areas on the open coast and also in bays and estuaries, placing the newly-settled juveniles in or near their rearing habitat (Frey 1971, Haaker 1975, Plummer et al. 1983, Kramer and Hunter 1988).

Primary settlement times are from February to August (Kramer and Hunter 1988). Juveniles reside in bays and estuaries for about 2-3 years and then emigrate out to shallow open coastal waters. Males are about 20 cm and females 25 cm in length when they migrate (Haaker 1975). Subadults and adults generally show very limited along-shore movements (Ginsburg 1952, Haaker 1975); only a few individuals have shown large migrations (Fitch and Lavenberg 1971). Adults move into shallow coastal waters (4-6 m deep) in early spring to spawn (Ginsburg 1952, Haaker 1975). Juveniles and adults lie partially buried in the sediments when inactive (Allen 1982).

Reproduction

Mode: The California halibut is gonochoristic, oviparous, and iteroparous. It is a broadcast spawner and eggs are fertilized externally.

Mating/Spawning: From larval abundance information it appears that some spawning may occur year-round, with most spawning from January to August (Ahlstrom and Moser 1975, Wang 1986). In southern California, spawning occurs from February to July, peaking in May. The actual depth of spawning is uncertain (Allen 1988), but is known to occur over sandy substrates (Ginsburg 1952, Frey 1971, Feder et al. 1974, Haaker 1975). Successful spawning likely occurs along the coastal zone from San Francisco Bay to Magdalena Bay, California, and probably in the Gulf of California (Ahlstrom and Moser 1975, MBC Applied Environmental Sciences 1987).

Fecundity: Unknown.

Growth and Development

Egg Size and Embryonic Development: California halibut eggs are 0.74-0.84 mm in diameter (Ahlstrom et al. 1984). Embryonic development is indirect and external; eggs hatch approximately 2 days after fertilization at 16°C.

Age and Size of Larvae: Larvae are 2.0 mm long at hatching (Ahlstrom and Moser 1975, Ahlstrom et al. 1984). The yolk-sac is depleted about 6 days after hatching (Gadomski and Petersen 1988). Time to settlement is 5-6 weeks at 16°C (Gadomski and Petersen 1988), or 20-29 days at 18.3-21.9°C (Allen 1982). Metamorphosis occurs at a length of 7.5-9.4 mm.

Juvenile Size Range: Juveniles range in length from 0.8-43.0 cm.

Age and Size of Adults: Some males mature as small as 20 cm in length (2-3 years), while females begin maturing at 37.5 cm (4-6 years) (Roedel 1953, Fitch and Lavenberg 1971, Frey 1971, Haaker 1975). This species is estimated to grow 3.8-8.8 cm/year and live to 30 years, with females growing faster and larger than males (Frey 1971, Haaker 1975, MBC Applied Environmental Sciences 1987, Reed and MacCall 1988). The largest California halibut reported was 1.5 m total length (TL) and 33.6 kg (Miller and Lea 1972, Squire and Smith 1977, MBC Applied Environmental Sciences 1987).

Food and Feeding

Trophic Mode: Larvae, juveniles, and adults are carnivorous, probably feeding primarily during the daytime. Initially, the California halibut feeds on small invertebrates, then switches to feed almost exclusively on fish as it grows (Haaker 1975). This species is an ambush feeder that locates prey by sight and possibly via the lateral line (Haaker 1975, Allen 1982, Hobson and Chess 1987).

Food Items: Larvae most likely feed on plankton. Small juveniles feed on crustaceans (mysids, shrimp, gammarid amphipods, harpacticoid copepods), squids, octopus, and fish (gobies, killifish, and others). Large juveniles and adults consume primarily fish (Haaker 1975, Allen 1982, Roberts et al. 1982, Plummer et al. 1983, Allen 1988) and the northern anchovy (*Engraulis mordax*) is the most common fish eaten. Other fishes eaten by the California halibut include sardines, atherinids, sciaenids, gobies, embiotocids, and other flatfishes (Quast 1968, Allen 1982). Arrow gobies (*Clevelandia ios*) are particularly important prey for juvenile halibut rearing in estuaries and bays (Haaker 1975).

Biological Interactions

Predation: Sea lions eat California halibut caught in trammel nets (Fitch and Lavenberg 1971). Other predators include Pacific angel shark (*Squatina californica*), Pacific electric ray (*Torpedo californica*), large California halibut, and bottlenose dolphin (*Tursiops truncatus*) (Fitch and Lavenberg 1971, Frey 1971, Feder et al. 1974). Parasites (both external and internal) commonly attack this species; infestation rates increase with age and size of fish (Haaker 1975). Parasites include isopods, copepods, nematodes, trematodes, and cestodes (Haaker 1975).

Factors Influencing Populations: Although landings have increased since 1972, historical records indicate an overall decline in the population of California halibut (Plummer et al. 1983). Landings have fluctuated widely, but are presently about 25% of those of 1920 (Frey 1971, MBC Applied Environmental Sciences 1987). The population decline may be a result of large-scale changes in the marine environment, overfishing, alterations and destruction of estuarine habitat, or a shift in population centers (Plummer et al. 1983). Pollution, (e.g., water soluble fractions of crude oil) can reduce hatching success, reduce size of larvae at hatching, produce morphological and anatomical abnormalities, and reduce feeding and growth rates (MBC Applied Environmental Sciences 1987). Initiation of feeding by larvae appears critical for larval survival (Gadomski and Petersen 1988). Natural production has recently been augmented by hatchery production (Crooke and Taucher 1988). Substantial genetic variation between two populations of California halibut in the southern California Bight, suggests that the natural population is subdivided (Hedgecock and Bartley 1988). Wide fluctuations in young-of-the-year recruitment exist, but no exact cause has been identified (Allen 1988). Southern California estuaries and protected shallow water habitats play a critical role in the life history of this species.

References

Ahlstrom, E. H., and H. G. Moser. 1975. Distributional atlas of fish larvae in the California current region: flatfishes, 1955 through 1960. Calif. Coop. Ocean. Fish. Invest., Atlas No. 23., 207 p.

Ahlstrom, E. H., K. Amaoka, D. A. Hensley, H. G. Moser, and B. Y. Sumida. 1984. Pleuronectiformes; development. *In* H. G. Moser (chief editor), Ontogeny and systematics of fishes, p. 640-670. Allen Press, Inc., Lawrence, KS.

Allen, L. G. 1988. Recruitment, distribution, and feeding habits of young-of-the-year California halibut (*Paralichthys californicus*) in the vicinity of Alamitos Bay-Long Beach Harbor, California, 1983-1985. Bull. So. Calif. Acad. Sci. 87(1):19-30.

Allen, M. J. 1982. Functional structure of soft-bottom fish communities of the southern California shelf. Ph.D. Diss., Univ. Calif., San Diego, CA, 577 p.

Allen, M. J., R. J. Wolotira, Jr., T. M. Sample, S. F. Noel, and C. R. Iten. In prep. Living resources of the northeastern Pacific. Unpubl. mansc., Alaska Fish. Cent., Nat. Mar. Fish. Serv., NOAA, Seattle, WA.

Bane, G. W. 1968. Fishes of the upper Newport Bay. Univ. Calif. Irvine Res. Ser. 3:1-114.

Bane, G. W., and A. W. Bane. 1971. Bay fishes of northern California with emphasis on the Bodega Tomales Bay area. Mariscos Publ., Hampton Bays, NY, 143 p.

Barnett, A.M., A. E. Hahn, P. D. Sertic, and W. Watson. 1984. Distribution of ichthyoplankton off San Onofre, California, and methods for sampling shallow coastal waters. Fish. Bull., U.S. 82(1):97-111.

Barry, J. P., and G. M. Cailliet. 1981. The utilization of shallow marsh habitats by commercially important fishes in Elkhorn Slough, California. Cal.-Nev. Wildl. Trans. 1981:38-47.

Cailliet, G. M., B. Antrim, D. Ambrose, S. Pace, and M. Stevenson. 1977. Species composition, abundance and ecological studies of fishes, larval fishes, and zooplankton in Elkhorn Slough. *In* Ecologic and hydrographic studies of Elkhorn Slough, Moss Landing Harbor and nearshore coastal waters, p. 216-386. Moss Landing Marine Lab., Moss Landing, CA.

California Department of Fish and Game. 1987. 1987 California sport fishing regulations. Calif. Dept. Fish Game, Sacramento, CA, 12 p.

California Department of Fish and Game. 1988. Review of some California fisheries for 1987. Calif. Coop. Ocean. Fish. Invest. Rep. 29:11-20.

Chapman, G. A. 1963. Mission Bay, a review of previous studies and the status of the sport fishery. Calif. Fish Game 49(1):30-43.

Clark, G. H. 1930. California halibut. Calif. Fish Game 16(4):315-317.

Crooke, S., and C. Taucher. 1988. Ocean hatcheries - wave of the future? Outdoor Calif. 49(3):10-13.

Ehrlich, K. F., J. H. Hood, S. Muszynski, and G. E. McGowen. 1979. Thermal behavior responses of selected California littoral fishes. Fish. Bull., U.S. 76(4):837-849.

Eschmeyer, W. N., E. S. Herald, and H. Hammann. 1983. A field guide to Pacific coast fishes of North America. Houghton Mifflin Co., Boston, MA, 336 p.

Feder, H. M., C. H. Turner, and C. Limbaugh. 1974. Observations on fishes associated with kelp beds in southern California. Calif. Fish Game, Fish Bull. 160:1-144.

Fierstine, H. L., K. F. Kline, and G. R. Garman. 1973. Fishes collected in Morro Bay, California between January, 1968 and December, 1970. Calif. Fish Game 59(1):73-88.

Fitch, J. E. 1958. Offshore fishes of California. Calif. Dept. Fish Game, Sacramento, CA, 80 p.

Fitch, J. E., and R. J. Lavenberg. 1971. Marine food and game fishes of California. Calif. Nat. Hist. Guide 28, Univ. Calif. Press, Berkeley, CA, 179 p.

Frey, H. W. 1971. California's living marine resources and their utilization. Calif. Dept. Fish Game, Sacramento, CA, 148 p.

Gadomski, D. M., and J. H. Petersen. 1988. Effects of food deprivation on the larvae of two flatfishes. Mar. Ecol. Prog. Ser. 44:103-111.

Ginsburg, I. 1952. Flounders of the genus *Paralichthys* and related genera in American waters. Fish. Bull., U.S. 71:1-351.

Haaker, P. L. 1975. The biology of the California halibut, *Paralichthys californicus* (Ayres), in Anaheim Bay, California. *In* E. D. Lane and C. W. Hill (editors), The marine resources of Anaheim Bay. Calif. Fish Game, Fish Bull. 165:137-151.

Hedgecock, D., and D. M. Bartley. 1988. Allozyme variation in the California halibut, *Paralichthys californicus*. Calif. Fish Game 74(2):119-127.

Hobson, E. S., and J. R. Chess. 1987. Relationships among fishes and their prey in a nearshore sand community off southern California. Env. Biol. Fish. 17(3):201-226.

Horn, M. H., and L. G. Allen. 1981. Ecology of fishes in upper Newport Bay, California: seasonal dynamics and community structure. Mar. Res. Tech. Rep. No. 45, Calif. Fish Game, Long Beach, CA, 102 p.

Kramer, S. H., and J. R. Hunter. 1987. Southern California wetland/shallow water habitat investigation. Ann. Rep., Nat. Mar. Fish. Serv., Southw. Fish. Cent., La Jolla, CA, 12 p.

Kramer, S. H., and J. R. Hunter. 1988. Southern California wetland/shallow water habitat investigation. Ann. Rep., Nat. Mar. Fish. Serv., Southw. Fish. Cent., La Jolla, CA, 15 p.

Kucas, S. T., and T. J. Hassler. 1986. Species profiles: life histories and environmental requirements of coastal fishes and invertebrates (Pacific Southwest)—California halibut. U.S. Fish Wildl. Serv. Biol. Rep. 82(11.44). U.S. Army Corps Eng., TR EL-82-4, 8 p.

Leithiser, R. M. 1977. The seasonal abundance and distribution of larval fishes in Anaheim Bay, California. M.S. Thesis, Calif. State Univ., Long Beach, CA, 132 p.

Lockheed Ocean Science Laboratories. 1983. Distribution and abundance of fishes in central San Diego Bay, California: a study of fish habitat utilization. Rep. to Dept. of Navy, San Diego, CA. 38 p. plus appendices (Contract No. N62474-82-C-1068).

MBC Applied Environmental Sciences. 1987. Ecology of important fisheries species offshore California. Rep. to Min. Manag. Serv., U.S. Dept. Int., Washington, D.C., 251 p. (Contract No. MMS 14-12-0001-30294).

McGowen, G. E. 1977. Ichthyoplankton populations in south San Diego Bay and related effects of an electricity generating station. M.S. Thesis, San Diego State Univ., San Diego, CA, 88 p.

Miller, D. J., and R. N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Fish Game, Fish Bull. 157, 235 p.

Noah, M. D. 1985. Structure, abundance and distribution of the fish and macroinvertebrate communities inhabiting Mission Bay, California between November 1979 and February 1981. Appendix A. *In* San Diego River and Mission Bay improvements, Draft suppl. environ. assess., U.S. Army Corps Eng., Los Angeles, CA. 37 p.

Nordby, C. S. 1982. A comparative ecology of ichthyoplankton within Tijuana estuary and in adjacent nearshore waters. M.S. Thesis, San Diego State Univ., San Diego, CA, 101 p.

Plummer, K. M., E. E. DeMartini, and D. A. Roberts. 1983. The feeding habits and distribution of juvenile-small adult California halibut (*Paralichthys californicus*) in coastal waters off northern San Diego county. Calif. Coop. Ocean. Fish. Invest. Rep. 24:194-201.

Quast, J. C. 1968. Observations on the food of the kelp-bed fishes. *In* W. J. North and C. L. Hubbs (editors), Utilization of kelp-bed resources in southern California. Calif. Fish Game, Fish. Bull. 139:109-142.

Reed, R. J., and A. D. MacCall. 1988. Changing the size limit: how it could affect California halibut fisheries. Calif. Coop. Ocean. Fish. Invest. Rep. 29:158-166.

Roberts, D., E. DeMartini, C. Engel, and K. Plummer. 1982. A preliminary evaluation of prey selection by juvenile-small adult California halibut (*Paralichthys* *californicus*) in nearshore coastal waters off southern California. *In* G. M. Cailliet and C. A. Simenstad (editors), Gutshop 81, fish food habits studies, Proceedings of the third Pacific workshop, p. 214-223. Wash. Sea Grant Publ., Seattle, WA.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Roedel, P. M. 1953. Common ocean fishes of the California coast. Calif. Fish Game, Fish Bull. 91, 184 p.

Schultze, D. L. 1986. Digest of California commercial fish laws, January 1, 1986. Calif. Dept. Fish Game, Sacramento, CA, 40 p.

Squire, J. L., Jr., and S. E. Smith. 1977. Anglers' guide to the United States Pacific coast. NOAA, Seattle, WA, 139 p.

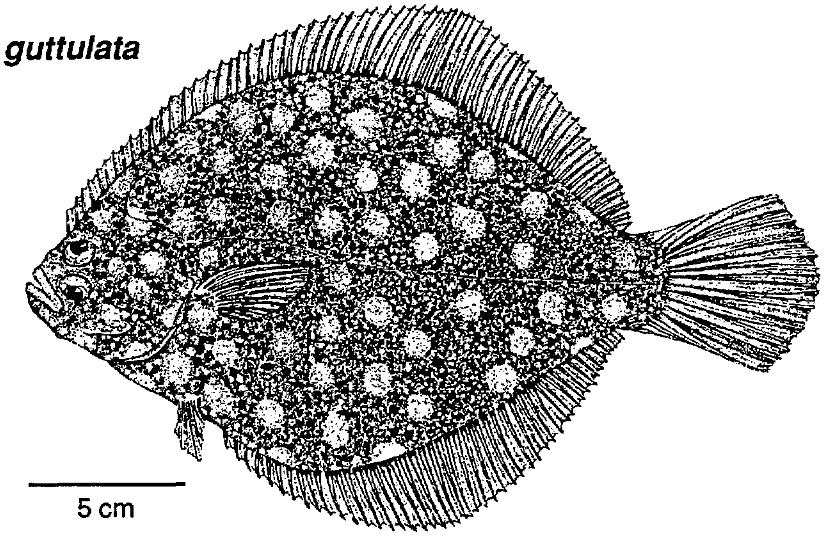
U.S. Department of Commerce. 1986. Marine recreational fishery statistics survey, Pacific coast. U.S. Dept. Comm., Nat. Ocean. Atm. Adm., Current Fish. Stat. No. 8328, 109 p.

Waggoner, J. P., III, and C. R. Feldmeth. 1971. Sequential mortality of the fish fauna impounded in construction of a marina at Dana Point, CA. Calif. Fish Game 57(3):167-176.

Walker, H. J., Jr., W. Watson, and A. Barnett. 1987. Seasonal occurrence of larval fishes in the nearshore southern California Bight off San Onofre, California. Est. Coast. Shelf Sci. 25:91-109.

Wang, J. C. S. 1986. Fishes of the Sacramento-San Joaquin estuary and adjacent waters, California: a guide to the early life histories. Tech. Rep. No. 9, prepared for the interagency ecological study program for the Sacramento-San Joaquin estuary. Calif. Dept. Water Res, Calif. Dept. Fish Game, U.S. Bureau Reclam., and U.S. Fish Wildl. Serv., various pagination.

Diamond turbot



Common Name: diamond turbot
Scientific Name: *Hypsopsetta guttulata*
Other Common Names: diamond flounder, turbot, halibut, sole (Gates and Frey 1974)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Pleuronectiformes
Family: Pleuronectidae

Value

Commercial: The diamond turbot is of little commercial value because of its small size. It is usually included with other turbots when reporting catch (Baxter 1960, Bane and Bane 1971). It has a slight iodine flavor, but is excellent eating (Baxter 1960, Feder et al. 1974).

Recreational: The average weight of a sport-caught fish is 0.6 kg. It is caught year-round, with bays and estuaries (e.g., Newport and Mission Bays in California) providing the best fishing (Squire and Smith 1977).

Indicator of Environmental Stress: This species appears to be dependent on bays and estuaries, thus population sizes and fish health may reflect the condition of these systems. It is a target species of the National Status and Trends Program (Ocean Assessments Division 1984).

Ecological: The diamond turbot is often the dominant flatfish in southern California bays and estuaries (Lane 1975).

Range

Overall: The diamond turbot is found from Magdalena Bay, Baja California to Cape Mendocino, California. There is also an isolated population in the Gulf of California (Miller and Lea 1972).

Within Study Area: This species is common to abundant in nearshore coastal bays and estuaries from the Tijuana estuary to Tomales Bay, California (Table 1) (Chapman 1963, Aplin 1967, Bane and Bane 1971, Fierstine et al. 1973, Lane 1975, Allen 1976, Cailliet et al. 1977, Horn and Allen 1981, Noah 1985, Zedler and Nordby 1986). It is also found adjacent to kelp beds (usually buried in sand or near solid objects) between the 1.2-18.2 m isobaths (Feder et al. 1974).

Life Mode

Eggs and larvae are pelagic (McGowen 1977, Wang 1986). Juveniles and adults are benthic or demersal (Lane 1975).

Habitat

Type: Eggs and larvae occur in estuaries (Eldridge 1977, McGowen 1977, Wang 1986) and shallow coastal waters, usually within 2 km of shore (Barnett et al. 1984). Juveniles and adults are found in bays, estuaries and sloughs, and nearshore coastal waters down to 152.4 m, but prefer depths <4.6 m (Roedel, 1953, Miller and Lea 1972, Fitch and Lavenberg 1975, Squire and Smith 1977, Eschmeyer et al. 1983).

Substrate: Eggs and larvae are found over various substrates, and juveniles and adults are found on sand and mud bottoms (Feder et al. 1974, Lane 1975, Squire and Smith 1977).

Physical/Chemical Characteristics: Eggs and larvae are found in euhaline-polyhaline waters, while juveniles and adult occur in euhaline-mesohaline conditions.

Table 1. Relative abundance of diamond turbot in 32 U.S. Pacific coast estuaries.

	Life Stage				
Estuary	A	S	J	L	E
Puget Sound					
Hood Canal					
Skagit Bay					
Grays Harbor					
Willapa Bay					
Columbia River					
Nehalem Bay					
Tillamook Bay					
Netarts Bay					
Siletz River					
Yaquina Bay					
Alsea River					
Siuslaw River					
Umpqua River					
Coos Bay					
Rogue River					
Klamath River					
Humboldt Bay					
Eel River					
Tomales Bay	√		√	○	√
Cent. San Fran. Bay *	√		√		
South San Fran. Bay	√		○	○	○
Elkhorn Slough	√		○		
Morro Bay	√		○		
Santa Monica Bay	○	○	√	○	○
San Pedro Bay	○	○	○	○	○
Alamitos Bay	◉		◉	○	
Anaheim Bay	◉		◉	○	
Newport Bay	◉	√	◉		
Mission Bay	○		◉	○	○
San Diego Bay	○		◉	◉	◉
Tijuana Estuary	√		○	√	
	A	S	J	L	E

Relative abundance:	
●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

The maximum salinity tolerated by juveniles and adults is 60‰ (Carpelan 1961). Juveniles and adults are probably eurythermal; upper temperature limits are unknown. Densities of eggs and larvae were positively correlated with distance from thermal plant discharge and dissolved oxygen, and were negatively correlated with temperature and light extinction coefficients (McGowen 1977).

Migrations and Movements: Larvae appear to settle on sandy sediments in the shallow waters in or near bays and estuaries (Lane 1975). Once individuals are in a bay, they do not appear to move widely. However, a general movement of larger fish to lower portions of bays and estuaries is indicated and adults appear to move out of bays and estuaries to spawn (Lane 1975).

Reproduction

Mode: The diamond turbot is gonochoristic, oviparous, and iteroparous; eggs are fertilized externally. It is probably a broadcast spawner.

Mating/Spawning: Larval distributions and abundances indicate that spawning occurs all year with a winter peak (depending on area) (Fitch and Lavenberg 1975, McGowen 1977, Wang 1986). Spawning has been recorded during September-February in Anaheim Bay (Lane 1975, Gadomski and Petersen 1988), and June-October in Richardson Bay (Eldridge 1975, Eldridge 1977). The diamond turbot may have a specific temperature preference for spawning. This temperature probably occurs in winter in southern California (14-16°C) (McGowen 1977, Walker et al. 1987), and spring and summer near San Francisco Bay.

Fecundity: Unknown.

Growth and Development

Egg Size and Embryonic Development: Eggs are spherical, ranging in diameter from 0.78-0.90 mm, averaging 0.84 mm (Eldridge 1975, Sumida et al. 1979, Wang 1986). Embryonic development is indirect and external.

Larval Size Range: The yolk-sac is depleted in 5 days at 17°C (Gadomski and Petersen 1988). The larval life stage lasts at least 5-6 weeks at 16°C (Gadomski and Petersen 1988). Larvae average 1.6 mm standard length (SL) at hatching, and grow 7-8 mm before metamorphosis (about 11.0 mm long) (Eldridge 1975, Sumida et al. 1979, Gadomski and Petersen 1988).

Juvenile Size Range: Juveniles settle out of the water column at metamorphosis (about 11.0 mm SL) (Eldridge 1975, Sumida et al. 1979, Gadomski and Petersen 1988).

Age and Size of Adults: Females mature in 2-3 years (about 180 mm TL). The largest diamond turbot reported was 46 cm TL and the heaviest was a approximately 0.9 kg (Baxter 1960, Miller and Lea 1972, Fitch and Lavenberg 1975). Individuals 30.5-38.1 cm long are probably 8-9 years old (Fitch and Lavenberg 1975).

Food and Feeding

Trophic Mode: Larvae are planktivorous and juveniles and adults are carnivorous. Juveniles and adults appear to feed diurnally, foraging on or in the substrate (Lane 1975). Adult and juvenile diamond turbot in Anaheim Bay, California, consumed 3.76% of their body weight each day (Lane et al. 1979).

Food Items: Larvae probably eat zooplankton and phytoplankton. Juveniles and adults consume polychaetes, clams and clam siphons, gastropods, ghost shrimp (*Callianassa* spp.), amphipods, cumaceans, various crustaceans, and small fish (Fitch and Lavenberg 1975, Lane 1975). Large diamond turbot (≥25 g) eat more molluscs, fish, and large crustaceans than smaller turbot (Lane 1975).

Biological Interactions

Predation: Predators probably include the Pacific electric ray (*Torpedo californica*), Pacific angel shark (*Squatina californica*), and other large piscivorous fishes (Fitch and Lavenberg 1975). Birds (such as herons) and cormorants (*Phalocrocorax* spp.) are also predators.

Factors Influencing Populations: The diamond turbot population in San Francisco Bay increases in abundance during wet years (Armor and Herrgesell 1985, California Department of Fish and Game 1987). Mortality rates for 1- and 2-year-old fish are very high (Lane 1975), and many adults apparently die after spawning (Lane 1975). Few adults live beyond 2 years in Anaheim Bay (Lane 1975). For larvae, the onset of initial feeding is important for their survival (Gadomski and Petersen 1988). The diamond turbot is dependent on bays and estuaries, hence the health of these habitats is critical to this species' survival.

References

Allen, L. G. 1976. Abundance, diversity, seasonality and community structure of the fish populations of Newport Bay, California. M.A. Thesis, Calif. State Univ., Fullerton, CA, 107 p.

Aplin, J. A. 1967. Biological survey of San Francisco Bay. 1963-1966. MRO Ref. No. 67-4. Calif. Dept. Fish Game, Menlo Park, CA, 131 p.

Armor, C., and P. L. Herrgesell. 1985. Distribution and abundance of fishes in the San Francisco Bay estuary between 1980 and 1982. Hydrobiol. 129:211-227.

Bane, G. W., and A. W. Bane. 1971. Bay fishes of northern California with emphasis on the Bodega Tomales Bay area. Mariscos Publ., Hampton Bays, NY, 143 p.

Barnett, A. M., A. E. Jahn, P. D. Sertic, and W. Watson. 1984. Distribution of ichthyoplankton off San Onofre, California, and methods for sampling very shallow coastal waters. Fish. Bull., U.S. 82(1):97-111.

Baxter, J. L. 1960. Inshore fishes of California. Calif. Dept. Fish Game, Sacramento, CA, 80 p.

Cailliet, G. M., B. Antrim, D. Ambrose, S. Pace, and M. Stevenson. 1977. Species composition, abundance and ecological studies of fishes, larval fishes, and zooplankton in Elkhorn Slough. *In* Ecologic and hydrographic studies of Elkhorn Slough, Moss Landing Harbor and nearshore coastal waters, p. 216-386. Moss Landing Marine Lab., Moss Landing, CA.

California Department of Fish and Game. 1987. Delta outflow effects on the abundance and distribution of San Francisco Bay fish and invertebrates, 1980-1985. Exhibit 60, entered by the Calif. Dept. Fish Game for the State Water Resources Control Board 1987 Water Quality/Water Rights Proceeding on the San Francisco Bay/Sacramento-San Joaquin Delta. Calif. Dept. Fish Game, Stockton, CA, 345 p.

Carpelan, L. H. 1961. Salinity tolerances of some fishes of a southern California coastal lagoon. Copeia 1961(1):32-39.

Chapman, G. A. 1963. Mission Bay, a review of previous studies and the status of the sportfishery. Calif. Fish Game 49(1):30-43.

Eldridge, M. B. 1975. Early larvae of the diamond turbot, *Hypsopsetta guttulata*. Calif. Fish Game 61(1):26-34.

Eldridge, M. B. 1977. Factors influencing distribution of fish eggs and larvae over eight 24-hr samplings in Richardson Bay, California. Calif. Fish Game 63(2):101-116.

Eschmeyer, W. N., E. S. Herald, and H. Hammann. 1983. A field guide to Pacific coast fishes of North America. Houghton Mifflin Co., Boston, MA, 336 p.

Feder, H. M., C. H. Turner, and C. Limbaugh. 1974. Observations on fishes associated with kelp beds in southern California. Calif. Fish Game, Fish Bull. 160:1-144.

Fierstine, H. L., K. F. Kline, and G., R. Garman. 1973. Fishes collected in Morro Bay, California between January 1968 and December 1970. Calif. Fish Game 59(1):73-88.

Fitch, J. E., and R. J. Lavenberg. 1975. Tidepool and nearshore fishes of California. Calif. Nat. Hist. Guides 38, Univ. Calif. Press, Berkeley, CA, 156 p.

Gadomski, D. M., and J. H. Petersen. 1988. Effects of food deprivation on the larvae of two flatfishes. Mar. Ecol. Prog. Ser. 44:103-111.

Gates, D. E., and H. W. Frey. 1974. Designated common names of certain marine organisms of California. Calif. Fish Game, Fish Bull. 161:55-88.

Horn, M. H., and L. G. Allen. 1981. Ecology of fishes in upper Newport Bay, California: seasonal dynamics and community structure. Mar. Res. Tech. Rep. No. 45, Calif. Dept. Fish Game, Long Beach, CA, 102 p.

Lane, E. D. 1975. Quantitative aspects of the life history of the diamond turbot, *Hypsopsetta guttulata* (Girard), in Anaheim Bay. *In* E. D. Lane and C. W. Hill (editors), The marine resources of Anaheim Bay. Calif. Fish Game, Fish Bull. 165:153-173.

Lane, E. D., M. C. S. Kingsley, and D. E. Thorton. 1979. Daily feeding and food conversion efficiency of the diamond turbot: an analysis based on field data. Trans. Am. Fish. Soc. 108:530-535.

McGowen, G. E. 1977. Ichthyoplankton populations in south San Diego Bay and related effects of an electricity generating station. M.S. Thesis, San Diego State Univ, San Diego, CA, 88 p.

Miller, D. J., and R. N. Lea. 1972. Guide to the coastal marine fishes of California. Calif. Fish Game, Fish Bull. 157, 235 p.

Noah, M. D. 1985. Structure, abundance and distribution of the fish and macroinvertebrate communities inhabiting Mission Bay, California between November 1979 and February 1981. Appendix A. San Diego River and Mission Bay improvements, Draft suppl. environ. assess. U.S. Army Corps Eng., Los Angeles, CA, 37 p. plus appendices.

Ocean Assessments Division. 1984. The national status and trends program for marine environmental quality: program description (mimeo). Ocean Assessments Division, NOS/NOAA, Rockville, MD, 28 p.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Roedel, P. M. 1953. Common ocean fishes of the California coast. Calif. Fish Game, Fish Bull. 91, 184 p.

Squire, J. L., Jr., and S. E. Smith. 1977. Anglers' guide to the United States Pacific Coast. U.S. Dept. Comm., NOAA, Seattle, WA, 139 p.

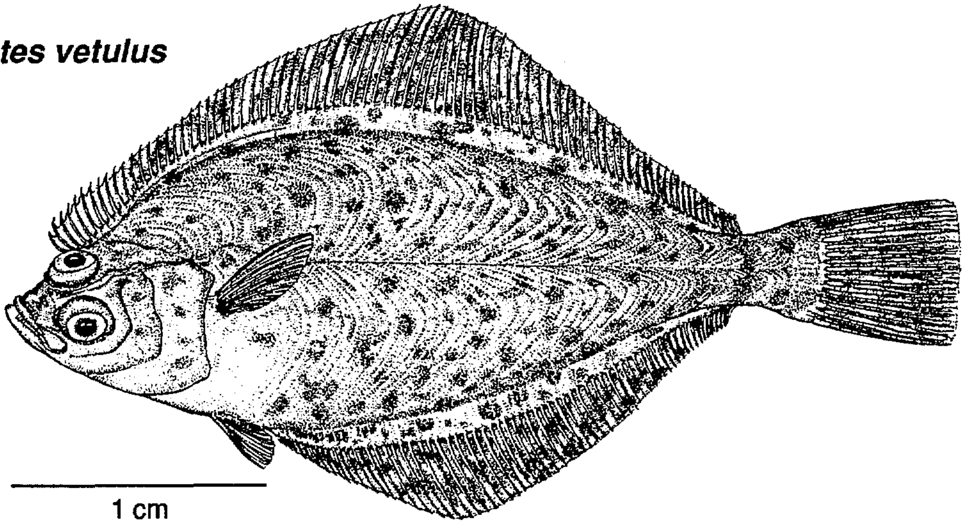
Sumida, B. Y., E. H. Ahlstrom, and H. G. Moser. 1979. Early development of seven flatfishes of the eastern North Pacific with heavily pigmented larvae (Pisces, Pleuronectiformes). Fish. Bull., U.S. 77(1):105-145.

Walker, H. J., Jr., W. Watson, and A. Barnett. 1987. Seasonal occurrence of larval fishes in the nearshore southern California Bight off San Onofre, California. Est. Coast. Shelf Sci. 25:91-109.

Wang, J. C. S. 1986. Fishes of the Sacramento-San Joaquin estuary and adjacent waters, California: a guide to the early life histories. Tech. Rep. No. 9, prepared for the interagency ecological study program for the Sacramento-San Joaquin estuary. Calif. Dept. Water Res, Calif. Dept. Fish Game, U.S. Bureau Reclam., and U.S. Fish Wildl. Serv., various pagination.

Zedler, J. B., and C. S. Nordby. 1986. The ecology of Tijuana estuary, California: an estuarine profile. U.S. Fish Wildl. Serv. Biol. Rep 85(7.5), 104 p.

English sole



Common Name: English sole
Scientific Name: *Pleuronectes* (or *Parophrys*) *vetulus*
A recent review of the family Pleuronectidae indicates that this species may belong to the genus *Pleuronectes* (Sakamoto 1984)
Other Common Names: California sole, lemon sole, common sole, pointed nose sole, sharp nose sole (Washington 1977)
Classification (Sakamoto 1984)
Phylum: Chordata
Class: Osteichthyes
Order: Pleuronectiformes
Family: Pleuronectidae

Value

Commercial: The English sole is a moderately important commercial fish, captured primarily by trawls. Over 2,500 t were landed in the U.S. in 1986, primarily in Washington and California (Pacific Marine Fisheries Commission 1987). It is the most abundant flatfish species in Puget Sound, Washington (Pedersen and DiDonato 1982). Females dominate the commercial catch because males rarely grow to marketable size (Pedersen and DiDonato 1982). The English sole has an "iodine" taste which some people prefer and is marketed as fillets of sole (Clemens and Wilby 1961, Hart 1973). It is second only to Dover sole (*Microstomus pacificus*) in flatfish pounds landed on the Pacific coast (Pacific Marine Fisheries Commission 1987).

Recreational: This is not an important recreational fish, although it is caught using hook and line by boat, shore, and pier anglers. Boat anglers caught over 1,400 in Washington waters in 1984 (Hoines et al. 1984).

Indicator of Environmental Stress: This species often accumulates contaminants and is a target species for the National Status and Trends Program (Ocean Assessments Division 1984). The English sole apparently develops cancerous tumors as a result of exposure to contaminants (Malins et al. 1983). Three types of superficial papillomas have been identified from subyearling English sole; all three appear to cause substantial mortality. Tumors and liver lesions may be caused by exposure to contaminants such as aromatic hydrocarbons (Krahn et al. 1986, 1987).

Ecological: The English sole is a very important flatfish in shallow-water, soft-bottom marine and estuarine environments along the Pacific Coast (Westrheim 1955, Washington 1977, Hogue and Carey 1982, Krygier and Pearcy 1986).

Range

Overall: This species' overall range is from central Baja California, Mexico to Unimak Island, Alaska (Hart 1973). It is most abundant north from Pt. Conception, California.

Within Study Area: Juveniles are found in nearly all Pacific coast estuaries from San Pedro Bay, California, to Puget Sound (Table 1). However, Elkhorn Slough, California appears to be the most southern estuary where they are abundant.

Life Mode

Eggs and larvae are pelagic, while juveniles and adults are demersal (Budd 1940, Forrester 1969, Hart 1973).

Habitat

Type: Eggs are neritic and pelagic, but sink just before hatching (Hart 1973). Larvae are also pelagic and are found primarily in waters <200 m deep (Laroche and

Table 1. Relative abundance of English sole in 32 U.S. Pacific coast estuaries.

Estuary	*Life Stage* A	S	J	L	E
Puget Sound	◉	◉	●	●	●
Hood Canal	◉	◉	●	●	●
Skagit Bay	◉	◉	◉	◉	●
Grays Harbor			◉	○	
Willapa Bay			◉	○	
Columbia River			◉	○	
Nehalem Bay			◉	○	
Tillamook Bay			●	○	
Netarts Bay			◉	○	
Siletz River			◉	○	
Yaquina Bay			●	○	
Alsea River			●		
Siuslaw River			◉	○	
Umpqua River			◉	○	
Coos Bay			◉	○	
Rogue River			√		
Klamath River			√		
Humboldt Bay			●	○	
Eel River			○	○	
Tomales Bay			◉	○	
Cent. San Fran. Bay *			◉	○	
South San Fran. Bay			◉	√	
Elkhorn Slough			◉	√	
Morro Bay			○	√	
Santa Monica Bay	○	○	○	○	○
San Pedro Bay	○		√	√	
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

Richardson 1979). Adults are found in nearshore coastal waters down to 550 m depth, but primarily in depths <250 m (Allen and Smith 1988). In Canadian waters, this species is commercially abundant between 36 and 128 m depths (Forrester 1969). Juveniles reside primarily in shallow-water coastal, bay, and estuarine areas (Westrheim 1955, Ketchen 1956, Van Cleve and El-Sayed 1969, Olson and Pratt 1973, Pearcy and Myers 1974, Laroche and Holton 1979, Toole 1980, National Marine Fisheries Service 1981, Krygier and Pearcy 1986, Rogers et al. 1988).

Substrate: Eggs are buoyant and larvae are pelagic. Adults and juveniles prefer soft bottoms composed of fine sands and mud (Ketchen 1956). In Puget Sound, juveniles and adults prefer shallow (<12 m deep) muddy substrates (Becker 1984). Males show a preference for fine sediments (Becker 1988).

Physical/Chemical Characteristics: Adults are found primarily in marine (euhaline) waters. Juveniles and larvae occur in polyhaline and euhaline waters. Optimum conditions for larval survival were found to be salinities of 25-28‰ and temperatures of 8-9°C (Alderdice and Forrester 1968). No spawning occurs at temperatures below approximately 7.8°C (Jackson 1981). Temperatures >18°C appear to be the upper thermal tolerance (reduced daily ration and growth) for juvenile English sole (Yoklavich 1982). The upper lethal limit for this species is 26.1°C (Ames et al. 1978).

Migrations and Movements: Adults make limited migrations/movements. Those off Washington and British Columbia show a northward post-spawning migration in the spring on their way to summer feeding grounds, and a southerly movement in the fall (Garrison and Miller 1982). Tagging studies have identified separate stocks based on this species' limited movements and meristic characteristics (Jow 1969). Tidal currents appear to be the mechanism by which English sole move into estuaries (Boehlert and Mundy 1987); larvae are transported to nearshore nursery areas (i.e., shallow coastal waters and estuaries) by currents. Larvae metamorphose into juveniles in spring and early summer and rear until fall/winter at which time most emigrate to deeper waters (Olson and Pratt 1973). Although many postlarvae may settle outside of estuaries, apparently most will enter estuaries during some part of their first year of life (Gunderson et al. 1990). Early- and late-stage larvae undergo diel vertical migrations (Misitano 1970, 1976). There is a general movement to deeper waters as fish grow (Ketchen 1956). Smaller fish tend to be restricted to shallow waters, with larger fish more abundant in deeper water (English 1967, Misitano 1970, Sopher 1974).

Reproduction

Mode: The English sole is gonochoristic, oviparous, and iteroparous; eggs are fertilized externally (Garrison and Miller 1982).

Mating/Spawning: Spawning occurs over soft-bottom mud substrates at depths of 50-70 m (Ketchen 1956). Spawning occurs from winter to early spring depending on the stock: from January to May in Monterey Bay stocks, peaking in March or April (Budd 1940); in Bodega Bay-Point Monterey stocks, from December to April, peaking January or February (Villadolid 1927, cited in Garrison and Miller 1982); Santa Monica Bay-Santa Barbara Channel stocks from December to April; in Eureka-Oregon border stocks during October to May (Jow 1969); in Oregon stocks from January to April, peaking in February or March (Harry 1959); in

Puget Sound stocks, from January to April, peaking in February or March (Smith 1936); in Hecata Strait, British Columbia stocks, from late December to early April, peaking in February (Ketchen 1956).

Fecundity: Five- to six-year-old females (36-38 cm in length) can produce about 1 million eggs, while large fish (43 cm) may produce nearly 2 million eggs (Ketchen 1947, Harry 1959, Forrester 1969).

Growth and Development

Egg Size and Embryonic Development: Fertilized eggs are spherical and average 0.98 mm in diameter (Orsi 1968). Embryonic development is indirect and external. The planktonic eggs hatch in 3.5 days at 12°C, or 11.8 days at 4°C (Alderdice and Forrester 1968).

Age and Size of Larvae: After hatching, larvae float with their yolk sac up. The yolk sac is absorbed in 9-10 days (Orsi 1968), with the planktonic larvae taking from 8-10 weeks to metamorphose to benthic living juveniles (Laroche et al. 1982). Larvae are 2.0-2.8 mm total length (TL) at hatching (Orsi 1968) and grow to 18-26 mm before becoming juveniles (Misitano 1976, Garrison and Miller 1982).

Juvenile Size Range: Juveniles range in size from 18 mm to about 26 cm long (depending on sex) (Harry 1959).

Age and Size of Adults: Some females mature as 3-year-olds and 26 cm long, but all females over 35 cm long are mature. Males mature earlier, beginning at 2 years and 21 cm in length. All males are mature at lengths >29 cm (Harry 1959). In Puget Sound, all 2-year-old males are mature, but most females do not mature until they are 4 years old (Smith 1936).

Food and Feeding

Trophic Mode: Larvae are planktivorous. Juveniles, and adults are carnivorous, apparently feeding primarily during daylight hours (Becker 1984).

Food Items: Larvae probably eat different life stages of copepods and other small planktonic organisms. Larvae appear to have a strong preference for appendicularians (Botsford et al. 1989). Juveniles feed on harpacticoid copepods, gammarid amphipods, cumaceans, mysids, polychaetes, small bivalves, clam siphons, and other benthic invertebrates (Simenstad et al. 1979, Allen 1982, Hogue and Carey 1982, Becker 1984, Bottom et al. 1984). Small juvenile English sole concentrate their feeding on harpacticoid copepods and other epibenthic crustaceans until they reach approximately 50-65 mm in length, then they switch to feeding primarily on polychaetes (Toole 1980). Off Oregon, adult English sole feed on a variety of benthic organisms, but primarily polychaetes, amphipods, molluscs, ophiouroids, and crustaceans (Kravitz et al. 1976). English sole feed primarily by day, using sight and smell, and sometimes dig for prey (Allen 1982, Hulberg and Oliver 1979).

Biological Interactions

Predation: Larvae are probably eaten by larger fishes. A juvenile English sole's main predators are probably piscivorous birds such as great blue heron (*Ardia herodias*), larger fishes, and marine mammals. Adults may be eaten by marine mammals, sharks, and other large fishes. The English sole's sharp anterior anal spine may provide a defense against predators (Allen 1982).

Factors Influencing Populations: Upwelling (and thus water temperatures) during the larval and spawning period affects eventual recruitment (Ketchen 1956, Kruse and Tyler 1983). Growth appears to be affected by upwelling (Kreuz et al. 1982) and cohort abundance of age-1 fish (Peterman and Bradford 1987). Models have been developed to identify oceanographic conditions that influence English sole recruitment (Kruse and Tyler 1983), but it appears that numerous physical and biological parameters combine to control year-class strength (Botsford et al. 1989). Important recruitment processes include the timing of spawning, surface temperatures during larval development, onshore transport of larvae, and age- and density-dependent growth and mortality of juveniles and young adults (Botsford et al. 1989). At high population densities, a myxosporidian disease can infect this species and make its flesh "milky" (Hart 1973). Because the English sole uses nearshore coastal and estuarine waters as nursery areas (Krygier and Pearcy 1986, Rogers et al. 1988), it is exposed to numerous toxic materials which can result in a high incidence of diseased fish in some estuaries. Since this species relies heavily on estuaries for rearing, the alteration and pollution of estuarine habitats adversely affects this species (Gunderson et al. 1990).

References

Alderdice, D. F., and C. R. Forrester. 1968. Some effects of salinity and temperature on early development and survival of the English sole (*Parophrys vetulus*). J. Fish. Res. Board Can. 25(3):495-521.

Allen, M. J. 1982. Functional structure of soft-bottom fish communities of the southern California shelf. Ph.D. Diss. Univ. Calif., San Diego, CA, 577 p.

Allen, M. J., and G. B. Smith. 1988. Atlas and zoogeography of common and marine fishes in the northeast Pacific Ocean and Bering Sea. NOAA Tech. Rep. NMFS 66,151 p.

Ames, W. E., J. R. Hughes, and G. F. Slusser. 1978. Upper lethal water temperature levels for English sole (*Parophrys vetulus*) and rock sole (*Lepidopsetta bilineata*) subjected to gradual thermal increases. Northw. Sci. 52(3):285-291.

Becker, D. S. 1984. Resource partitioning by small-mouthed pleuronectids in Puget Sound, Washington. Ph.D. Diss. Univ. Wash., Seattle, WA, 138 p.

Becker, D. S. 1988. Relationships between sediment character and sex segregation in English sole, *Parophrys vetulus*. Fish. Bull., U.S. 86(3):517-524.

Boehlert, G. W., and B. C. Mundy. 1987. Recruitment dynamics of metamorphosing English sole, *Parophrys vetulus*, to Yaquina Bay, Oregon. Estuar. Coastal Shelf Sci. 25:261-281.

Botsford, L. W., D. A. Armstrong, and J. M. Shenker. 1989. Oceanographic influences on the dynamics of commercially fished populations. *In* M. R. Landry and B. M. Hickey (editors), Coastal oceanography of Washington and Oregon, p. 511-565. Elsevier Sci. Publ., B.V., Amsterdam.

Bottom, D. L., K. K. Jones, and M. J. Herring. 1984. Fishes of the Columbia River estuary. Col. Riv. Estuary Data Devel. Prog., CREST, Astoria, OR, 113 p. plus appendices.

Budd, P. L. 1940. Development of the eggs and early larvae of six California fishes. Calif. Fish Game, Fish Bull. 56:1-50.

Clemens, W. A., and G. V. Wilby. 1961. Fishes of the Pacific coast of Canada. Fish. Res. Board Can., Bull. No. 68, 443 p.

English, T. S. 1967. Preliminary assessment of the English sole in Port Gardner, Washington. J. Water Pollution Control Fed. 39(3):1337-1350.

Forrester, C. R. 1969. Life history information on some groundfish species. Fish. Res. Board Can., Tech. Rep. No. 105, 17 p.

Garrison, K. J., and B. S. Miller. 1982. Review of the early life history of Puget Sound fishes. Fish. Res. Inst., Univ. Wash., Seattle, WA, 729 p. (FRI-UW-8216).

Gunderson, D. R., D. A. Armstrong, Y. B. Shi, and R. A. McConnaughey. 1990. Patterns of estuarine use by juvenile English sole (*Parophrys vetulus*) and Dungeness crab (*Cancer magister*). Estuaries 13(1):59-71.

Harry, G. Y. 1959. Time of spawning, length of maturity, and fecundity of the English, petrale, and Dover soles (*Parophrys vetulus, Eopsetta jordani*, and *Microstomus pacificus*, respectively). Fish. Comm. Oreg. Res. Briefs 7(1):5-13.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. No. 180, 740 p.

Hogue, E. W., and A. G. Carey, Jr. 1982. Feeding ecology of 0-age flatfishes at a nursery ground on the Oregon coast. Fish. Bull., U.S. 80(3): 555-565.

Hoines, L. J., W. D. Ward., and C. Smitch. 1984. Washington State sport catch report 1984. Wash. Dept. Fish., Olympia, WA, 58 p.

Hulberg, L. W., and J. S. Oliver. 1979. Prey availability and the diets of two co-occurring flatfish. *In* S. J. Lipovsky and C. A. Simenstad (editors), Fish food habits studies, proceedings of the second Pacific Northwest technical workshop, p. 29-36. Wash. Sea Grant, Univ. Wash, Seattle, WA, (WSG-WO-79-1).

Jackson, C. 1981. Flatfishes: A systematic study of the Oregon pleuronectid production system and its fishery. Sea Grant College Prog., Oregon State Univ., Corvallis, OR, 40 p. (ORESU-T-81-001).

Jow, T. 1969. Results of English sole tagging off California. Pac. Mar. Fish. Comm., Bull. 7:16-33.

Ketchen, K. S. 1947. Studies on lemon sole development and egg production. Fish. Res. Board Can., Prog. Rep. Pac. Coast Sta. 73:68-70.

Ketchen, K. S. 1956. Factors influencing the survival of the lemon sole (*Parophrys vetulus*) in Hecata Strait, British Columbia. J. Fish Res. Board Can. 13:647-694.

Krahn, M. M., L. D. Rhodes, M. S. Myers, L. K. Moore, W. D. MacLeod, Jr., and D. C. Malins. 1986. Associations between metabolites of aromatic compounds in bile and the occurrence of hepatic lesions in English sole (*Parophrys vetulus*) from Puget Sound, Washington. Arch. Environ. Contam. Toxicol. 15:61-67.

Krahn, M. M, D. G. Burrows, W. D. MacLeod, Jr., and D. C. Malins. 1987. Determination of individual metabolites of aromatic compounds in hydrolyzed bile of English sole (*Parophrys vetulus*) from polluted sites in Puget Sound, Washington. Arch. Environ. Contam. Toxicol. 16:511-522.

Kravitz, M. J., W. G. Pearcy, and M. P. Guin. 1976. Food of five species of cooccurring flatfishes on Oregon's continental shelf. Fish. Bull., U.S. 74:984-990.

Kreuz, K. F, A. V. Tyler, G. H. Kruse, and R. L. Demory. 1982. Variation in growth of Dover soles and English soles as related to upwelling. Trans. Am. Fish. Soc. 111(2):180-192.

Kruse, G. H., and A. V. Tyler. 1983. Simulation of temperature and upwelling effects on the English sole (*Parophrys vetulus*) spawning season. Can. J. Fish. Aquat. Sci. 40:230-237.

Krygier, E. E., and W. G. Pearcy. 1986. The role of estuarine and offshore nursery areas for young English sole, *Parophrys vetulus* Girard, of Oregon. Fish. Bull., U.S. 84(1):119-132.

Laroche, W. A., and R. L. Holton. 1979. Occurrence of 0-age English sole, *Parophrys vetulus*, along the Oregon coast: an open coast nursery area? Northw. Sci. 53:94-96.

Laroche, J. L., and S. L. Richardson. 1979. Winter-spring abundance of larval English sole, *Parophrys vetulus*, between the Columbia River and Cape Blanco, Oregon during 1972-1975 with notes on occurrences of three other pleuronectids. Estuar. Coastal Mar. Sci. 8:455-476.

Laroche, J. L, S. L. Richardson, and A. Rosenberg. 1982. Age and growth of a pleuronectid, *Parophrys vetulus*, during the pelagic larval period in Oregon coastal waters. Fish. Bull. U.S. 80(1):93-104.

Malins, D. C., M. S. Myers, and W. T. Roubal. 1983. Organic free radicals associated with idiopathic liver lesions of English sole (*Parophrys vetulus*) from polluted marine environments. Envir. Sci. Tech. 17(11):679-685.

Misitano, D. A. 1970. Aspects of the early life history of English sole (*Parophrys vetulus*) in Humboldt Bay, California. M.S. Thesis, Humboldt State College, Eureka, CA, 54 p.

Misitano, D. A. 1976. Size and stage of development of larval English sole, *Parophrys vetulus*, at time of entry into Humboldt Bay. Calif. Fish Game 62(1):93-98.

National Marine Fisheries Service. 1981. Columbia River estuary data development program report, salmonid and non-salmonid fish. Unpubl. manuscr., various pagination, Northwest Alaska Fish. Cent., Nat. Mar. Fish. Serv., P.O. Box 155, Hammond, OR, 97121.

Ocean Assessments Division. 1984. The national status and trends program for marine environmental quality: Program description (mimeo). Ocean Assessments Division, NOS/NOAA, Rockville, MD, 28 p.

Olson, R. E., and I. Pratt. 1973. Parasites as indicators of English sole (*Parophrys vetulus*) nursery grounds. Trans. Am. Fish. Soc. 102: 405-411.

Orsi, J. J. 1968. The embryology of the English sole, *Parophrys vetulus*. Calif. Fish Game 54(3):133-155.

Pacific Marine Fisheries Commission. 1987. 39th annual report of the Pacific Marine Fisheries Commission for the year 1986. Pac. Fish. Man. Comm., Portland, OR, 29 p.

Pearcy, W. G., and S. S. Myers. 1974. Larval fishes of Yaquina Bay, Oregon: A nursery ground for marine fishes? Fish. Bull., U.S. 72:201-213.

Pedersen, M., and G. DiDonato. 1982. Groundfish management plan for Washington's inside waters. Prog. Rep. No. 170, Wash. Dept. Fish., Olympia, WA, 123 p.

Peterman, R. M. and M. J. Bradford. 1987. Density-dependent growth of age 1 English sole (*Parophrys vetulus*) in Oregon and Washington coastal waters. Can. J. Fish. Aquat. Sci. 44:48-53.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Rogers, C. W., D. R. Gunderson, and D. A. Armstrong. 1988. Utilization of a Washington estuary by juvenile English sole, *Parophrys vetulus*. Fish. Bull., U. S. 86(4):823-831.

Sakamoto, K. 1984. Interrelationships of the family Pleuronectidae (Pisces: Pleuronectiformes). Mem. Fac. Fish. Hokkaido Univ. 31(1/2):85-215.

Simenstad, C. A., B. S. Miller, C. F. Nyblade, K. Thornburgh, and L. J. Bledsoe. 1979. Food web relationships of northern Puget Sound and the Strait of

Juan de Fuca. U.S. Interagency (NOAA, EPA) Energy/ Environ. Res. Dev. Prog. Rep., EPA-600/7-79-259. Washington, D.C., 335 p.

Smith, R. T. 1936. Report on the Puget Sound otter trawl investigations. Wash. Dept. Fish. Biol. Rep. 36B:1-61.

Sopher, T. R. 1974. A trawl survey of the fishes of Arcata Bay, California. M.S. thesis, Humboldt State Univ., Arcata, CA, 103 p.

Toole, C. L. 1980. Intertidal recruitment and feeding in relation to optimal utilization of nursery areas by juvenile English sole (*Parophrys vetulus*: Pleuronectidae). Environ. Biol. Fish. 5:383-390.

Van Cleve, R., and S. Z. El-Sayed. 1969. Age, growth, and productivity of an English sole (*Parophrys vetulus*) population in Puget Sound, Washington. Pac. Mar. Fish. Comm. Bull. 7:51-71.

Villadolid, D. V. 1927. The flatfish (Heterosomata) of the Pacific coast of the United States. Ph.D. Thesis, Stanford Univ., Palo Alto, CA, 332 p.

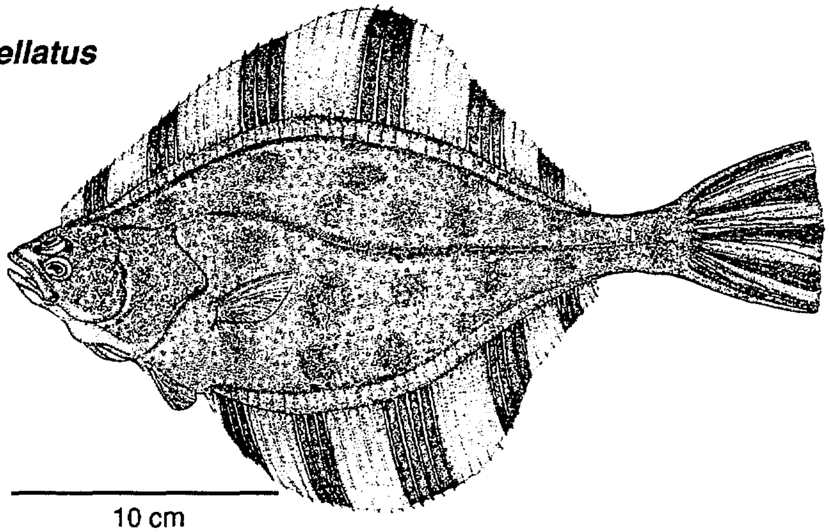
Washington, P. M. 1977. Recreationally important marine fishes of Puget Sound, Washington. Proc. Rep., Northwest Alaska Fish. Cent., NOAA, Nat. Mar. Fish. Serv., Seattle, WA, 122 p.

Westrheim, S. J. 1955. Size composition, growth, and seasonal abundance of juvenile English sole (*Parophrys vetulus*) in Yaquina Bay. Fish Comm. Oregon, Res. Briefs 6(2):4-9.

Yoklavich, M. 1982. Growth, food consumption, and conversion efficiency of juvenile English sole (*Parophrys vetulus*). *In* G. M. Cailliet and C. M. Simenstad (editors), Gutshop 81, Fish food habits studies, Proceedings of the third Pacific workshop, p. 97-105. Wash. Sea Grant, Univ. Wash., Seattle, WA.

Starry flounder

Platichthys stellatus
Adult



Common Name: starry flounder
Scientific Name: *Platichthys stellatus*
Other Common Names: California flounder, grindstone flounder, great flounder, roughjacket, diamond flounder, sole, flounder, emery flounder (Gates and Frey 1974, Washington 1977)
Classification (Robins et al. 1980)
Phylum: Chordata
Class: Osteichthyes
Order: Pleuronectiformes
Family: Pleuronectidae

Value

Commercial: The starry flounder is a moderately important flatfish species landed by the Pacific coast trawl fishery from the Bering Sea to Southern California. From 1981 to 1983, an average of over 1,300 t were landed, of which 90% were taken by U.S. fishermen. Most of the catch comes from Puget Sound, Washington (Pedersen and DiDonato 1982), and coastal areas of Oregon and Washington (Washington Department of Fisheries 1985, Lukas and Carter 1987).

Recreational: This species is a fairly important sport fish for anglers from central California to Alaska. It is fished year-round from boats, piers, and shore (Frey 1971) and is captured primarily in estuaries and adjacent near-shore shallow waters (Beardsley and Bond 1970, Squire and Smith 1977, Wydoski and Whitney 1979). Sport fishermen caught approximately 43,000 starry flounders in 1985 (National Marine Fisheries Service 1986).

Indicator of Environmental Stress: This is a target species for the National Status and Trends Program because it is common in estuaries and often accumulates contaminants (Ocean Assessments Division 1984).

Ecological: The starry flounder is the most abundant flatfish in many Pacific coast estuaries north of San Francisco Bay, California (National Marine Fisheries Service 1981, Bottom et al. 1984, Pedersen and DiDonato 1982). It is prey for marine mammals (Jeffries et al. 1984) and piscivorous birds.

Range

Overall: The starry flounder is distributed Arctic-circumboreal and found in the eastern Pacific Ocean from Santa Ynez River, California, north through the Bering and Chukchi Seas to Bathurst Inlet in Arctic Canada. In the western Pacific, it is found along the Kamchatka Peninsula south to Tokyo Bay, Japan (Orcutt 1950, Okada 1955, Wilimovsky 1964, Allen and Smith 1988).

Within Study Area: This species is found in all study area estuaries from Morro Bay, California (Orcutt 1950), north through Washington (Table 1) (Monaco et al. 1990).

Life Mode

Eggs and larvae are pelagic, while juveniles and adults are demersal (Orcutt 1950, Garrison and Miller 1982, Wang 1986). The starry flounder is unusual in that along the coasts of California, Oregon, and Washington, 50% are right-eyed and 50% are left-eyed; in Alaska 70% are left-eyed, and in Japan nearly 100% are left-eyed (Orcutt 1950, Miller 1965, Policansky 1982a).

Habitat

Type: Eggs are buoyant and found at the surface in

Table 1. Relative abundance of starry flounder in 32 U.S. Pacific coast estuaries.

Estuary	A	S	J	L	E
Puget Sound	◉	◉	◉	○	○
Hood Canal	◉	◉	◉	○	○
Skagit Bay	◉	◉	◉	◉	○
Grays Harbor	○		◉	○	
Willapa Bay	○		◉	○	
Columbia River	○		◉	○	
Nehalem Bay	○		◉	○	
Tillamook Bay	○		◉	○	
Netarts Bay			○	○	
Siletz River	○		◉	○	
Yaquina Bay	○		◉	○	
Alsea River	○		◉	○	
Siuslaw River	○		○	○	
Umpqua River	○		◉	○	
Coos Bay	○		◉	○	
Rogue River			◉	○	
Klamath River			◉	○	
Humboldt Bay	○		○	○	
Eel River	○		◉	○	
Tomales Bay	○		◉	○	
Cent. San Fran. Bay *	◉		●	○	√
South San Fran. Bay	○		○	○	
Elkhorn Slough	○		◉		
Morro Bay			○		
Santa Monica Bay					
San Pedro Bay					
Alamitos Bay					
Anaheim Bay					
Newport Bay					
Mission Bay					
San Diego Bay					
Tijuana Estuary					
	A	S	J	L	E

Life Stage

Relative abundance:

●	Highly abundant
◉	Abundant
○	Common
√	Rare
Blank	Not present

Life stage:

A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

* Includes Central San Francisco, Suisun, and San Pablo bays.

nearshore marine waters (Orcutt 1950, Yusa 1957). Larvae are planktonic and found primarily nearshore (within 37 km) and in estuaries (Eldridge and Bryan 1972, Waldron 1972, Misitano 1977, Richardson and Pearcy 1977). Juveniles commonly invade far up rivers (Moyle 1976), but appear to be estuarine-dependent. Adults have been found in marine waters to 375 m depth, but most are captured at depths <150 m (Frey 1971, Allen and Smith 1988).

Substrate: Eggs and larvae have no substrate preference. Juveniles and adults prefer soft bottom types (mud, sand, gravel) but not rock (Orcutt 1950, Pedersen and DiDonato 1982).

Physical/Chemical Characteristics: Eggs are found in euhaline to polyhaline waters. Larvae are primarily euhaline, but may be found in polyhaline waters. Juveniles prefer brackish bays (mesohaline) (Pedersen and DiDonato 1982, Simenstad 1983), but also occur in fresh water. Adults occur primarily in euhaline and mesohaline waters, but are sometimes found in fresh water (Hart 1973, Garrison and Miller 1982). This species is found at water temperatures from 0.0 to 21.5°C. Temperatures ≥28.0°C are lethal (Stober 1973).

Migrations and Movements: The starry flounder does not migrate extensively (Pedersen and DiDonato 1982). However, tagging studies have shown that there is some movement along the coast (Westrheim 1955). It also has seasonal bathymetric migrations probably related to spawning. Adults move inshore during winter and early spring and offshore during summer and fall. Juveniles move far up into rivers, but as they mature they tend to reside in estuaries (Morrow 1980).

Reproduction

Mode: The starry flounder is gonochoristic, oviparous, and iteroparous; eggs are fertilized externally (Orcutt 1950).

Mating/Spawning: Spawning occurs near river mouths and sloughs in shallow water (<45 m deep) (Orcutt 1950, Garrison and Miller 1982), apparently at water temperatures of 11°C (Alaska Department of Fish and Game 1986). Spawning may occur in and outside of San Francisco Bay (Eldridge 1977, Wang 1986). Spawning takes place primarily from winter to early spring, depending on area: November to January near Elkhorn Slough (Orcutt 1950), and February to April in Puget Sound and British Columbia (Smith 1936, Hart 1973).

Fecundity: Fecundities range from 900,000 to over 11 million eggs per female, depending on female size (Orcutt 1950, Garrison and Miller 1982).

Growth and Development

Egg Size and Embryonic Development: Eggs are spherical and 0.89-1.28 mm in diameter (Orcutt 1950, Yusa 1957, Garrison and Miller 1982). Embryonic development is indirect and external. Eggs hatch in 2.8-14.7 days, depending on temperature (Orcutt 1950, Yusa 1957).

Age and Size of Larvae: Newly hatched larvae are 1.93-2.08 mm long (Orcutt 1950) or 2.58-3.36 mm long (Yusa 1957). Larvae take 39-75 days to metamorphose to bottom-dwelling postlarvae (Policansky 1982b). Metamorphosis occurs when larvae are 6.6-7.7 mm long (Policansky 1982b).

Juvenile Size Range: Juveniles range in size from approximately 7 mm (Policansky 1982b) to 17-30 cm long, depending on sex and location (Orcutt 1950, Campana 1984).

Age and Size of Adults: Males mature in 2 or 3 years at 17-30 cm in length, while some females mature in 3 or 4 years at 23-35 cm; all females are mature after 4 years (Orcutt 1950, Campana 1984). The maximum ages reported for males and females are 24 and 17 years, respectively (Campana 1984), and the maximum size is 91 cm (17 kg) (Orcutt 1950, Hart 1973).

Food and Feeding

Trophic Mode: Larvae are planktivores. Juveniles and adults are benthically-oriented carnivores (Orcutt 1950). Adults do not feed during the spawning period and juveniles and adults apparently cease feeding in cold temperatures (probably <5°C) (Orcutt 1950, Miller 1965).

Food Items: Larvae eat phytoplankton and zooplankton. Small juveniles (<100 mm long) eat copepods and other small crustaceans. Larger juveniles and adults eat amphipods (*Corophium* spp. and *Eogammarus* spp.), isopods, decapods (*Crangon* spp. and *Cancer* spp.), polychaetes, bivalves (*Siliqua* spp., *Mya arenaria*, *Macoma* spp., and *Yoldia* spp.), echinoderms (*Ophiura* spp. and *Diamphiodia craterodmeta*) and occasionally fish, e.g., northern anchovy (*Engraulis mordax*) (Orcutt 1950, Miller 1965, Bane and Bane 1971, Jewett and Feder 1980, McCabe et al. 1983).

Biological Interactions

Predation: The starry flounder is eaten by birds [great blue heron (*Ardea herodias*) and cormorants (*Phalacrocorax* spp.)] and marine mammals [harbor seal (*Phoca vitulina*) and sea lions] (Simenstad et al. 1979, Jeffries et al. 1984). To reduce predation, juveniles and adults will cover themselves with sand or mud and change their color to match the bottom (Orcutt 1950).

Factors Influencing Populations: Contaminants can impair reproductive success (Whipple et al 1978, Spies et al. 1985) and may cause fin erosion disease and lethal skin tumors (Wellings et al. 1976, Campana 1983). Endoparasitic flukes and monogenetic trematodes have been found on the gills (Bane and Bane 1971). Population sizes are probably greatly influenced by egg and larvae survival (Norcross and Shaw 1984). Harvesting by commercial and recreational fishermen may affect population sizes. Since juveniles are found almost exclusively in estuaries, alteration and destruction of estuarine habitat undoubtedly affects this species population.

References

Alaska Department of Fish and Game. 1985. Alaska habitat management guide. Southcentral Region, Vol. I: Life histories and habitat requirements of fish and wildlife. Alaska Dept. Fish Game, Juneau, AK, 429 p.

Allen, M. J., and G. B. Smith. 1988. Atlas and zoogeography of common marine fishes in the northeast Pacific Ocean and Bering Sea. NOAA Tech. Rep. NMFS 66, 151 p.

Bane, G. W., and A. W. Bane. 1971. Bay fishes of northern California. Mariscos Publ., Hampton Bays, NY, 143 p.

Beardsley, A. J., and C. E. Bond. 1970. Field guide to common marine and bay fishes of Oregon. Agr. Exp. Sta., Sta. Bull. 607, Oregon State Univ., Corvallis, OR, 27 p.

Bottom, D. L., K. K. Jones, and M. J. Herring. 1984. Fishes of the Columbia River estuary. Col. Riv. Est. Data Dev. Prog., CREST, Astoria, OR, 113 p. plus appendices.

Campana, S. E. 1983. Mortality of starry flounders (*Platichthys stellatus*) with skin tumors. Can. J. Fish. Aquat. Sci. 40(2):200-207.

Campana, S. E. 1984. Comparison of age determination methods for the starry flounder. Trans. Am. Fish. Soc. 113:365-369.

Eldridge, M. B. 1977. Factors influencing distribution of fish eggs and larvae over eight 24-hour samplings in Richardson Bay, California. Calif. Fish Game 63(2):101-116.

Eldridge, M. B., and C. F. Bryan. 1972. Larval fish survey of Humboldt Bay, California. NOAA Tech. Rep. NMFS SSRF-665, 8 p.

Frey, H. W. 1971. California's living marine resources and their utilization. Calif. Dept. Fish Game, Sacramento, CA, 148 p.

Garrison, K. J., and B. S. Miller. 1982. Review of the early life history of Puget Sound fishes. Fish. Res. Inst., Univ. Wash., Seattle, WA, 729 p. (FRI-UW-8216).

Gates, D. E., and H. W. Frey. 1974. Designated common names of certain marine organisms of California. Calif. Fish Game, Fish Bull. 61:55-90.

Hart, J. L. 1973. Pacific fishes of Canada. Fish. Res. Board Can., Bull. No. 180, 740 p.

Jeffries, S. J., S. D. Treacy, and A. C. Geiger. 1984. Marine mammals of the Columbia River estuary. Col. Riv. Estuary Data Dev. Prog., CREST, Astoria, OR, 62 p. plus appendices.

Jewett, S. C., and H. M. Feder. 1980. Autumn food of adult starry flounders, *Platichthys stellatus*, from the northeastern Bering Sea and the southeastern Chukchi Sea. J. Cons. Int. Explor. Mer. 39(1):7-14.

Lukas, J., and C. Carter. 1987. 1985 pounds and value of commercially caught fish and shellfish landed in Oregon. Oregon Dept. Fish Wildl., Portland, OR, 79 p.

McCabe, G. T., Jr., W. D. Muir, R. L. Emmett, and J. T. Durkin. 1983. Interrelationships between juvenile salmonids and nonsalmonid fish in the Columbia River estuary. Fish. Bull., U. S. 81(4):815-826.

Miller, B. S. 1965. Food and feeding studies on adults of two species of pleuronectids (*Platichthys stellatus* and *Psettichthys melanostictus*) in East Sound, Orcas Island (Washington). M.S. thesis, Univ. Wash., Seattle, WA, 131 p.

Misitano, D. A. 1977. Species composition and relative abundance of larval and post-larval fishes in the Columbia River estuary, 1973. Fish. Bull., U.S. 75:218-222.

Monaco, M. E., R. L. Emmett, S. A. Hinton, and D. M. Nelson. 1990. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume I: data summaries. ELMR Rep. No. 4. Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 240 p.

Morrow, J. E. 1980. The freshwater fishes of Alaska. Alaska Northw. Publ. Co., Anchorage, AK, 248 p.

Moyle, P. B. 1976. Inland fishes of California. Univ. Calif. Press, Berkeley, CA, 405 p.

National Marine Fisheries Service. 1981. Columbia River estuary data development program report, salmonid and non-salmonid fish. Unpubl. manuscr., various pagination, Northw. Alaska Fish. Cent., P.O. Box 155, Hammond, OR, 97121.

National Marine Fisheries Service. 1986. Marine recreational fishery statistics survey, Pacific coast, 1985. U.S. Dept. Comm., NOAA, Nat. Mar. Fish. Serv., Washington, D.C., 109 p.

Norcross, B. L., and R. F. Shaw. 1984. Oceanic and estuarine transport of fish eggs and larvae: a review. Trans. Am. Fish. Soc. 113:153-165.

Ocean Assessments Division. 1984. The national status and trends program for marine environmental quality: Program description (mimeo). NOAA, NOS, Ocean Assessments Division, Rockville, MD, 28 p.

Okada, Y. 1955. Fishes of Japan. Maruzen Co., Ltd., Tokyo, Japan, 434 p.

Orcutt, H. G. 1950. The life history of the starry flounder *Platichthys stellatus* (Pallas). Calif. Fish Game, Fish. Bull. 78:1-64.

Pedersen, M., and G. DiDonato. 1982. Groundfish management plan for Washington's inside waters. Prog. Rep. No. 170, Wash. Dept. Fish., Olympia, WA, 123 p.

Policansky, D. 1982a. The asymmetry of flounders. Sci. Am. 246(5):116-122.

Policansky, D. 1982b. Influence of age, size, and temperature on metamorphosis in the starry flounder, *Platichthys stellatus*. Can. J. Fish. Aquat. Sci. 39(3):514-517.

Richardson, S. L., and W. G. Pearcy. 1977. Coastal and oceanic fish larvae in an area of upwelling off Yaquina Bay, Oregon. Fish. Bull., U.S. 75:125-146.

Robins, C. R., R. M. Bailey, C. E. Bond, J. R. Brooker, E. A. Lachner, R. N. Lea, and W. B. Scott. 1980. A list of common and scientific names of fishes from the United States and Canada. Am. Fish. Soc. Spec. Publ. No. 12, Am. Fish. Soc., Bethesda, MD, 174 p.

Simenstad, C. A. 1983. The ecology of estuarine channels of the Pacific Northwest coast: a community profile. U.S. Fish Wildl. Serv. FWS/OBS-83/05. 181 p.

Simenstad, C. A., B. S. Miller, C. F. Nyblade, D. Thornburgh, and L. J. Bledsoe. 1979. Food web relationships of northern Puget Sound and the Strait of Juan de Fuca: a synthesis of the available knowledge. U. S. Interagency (NOAA, EPA) Energy/Environ. Res. Dev. Prog. Rep. EPA-600/7-79-259, Washington, D.C., 335 p.

Smith, R. T. 1936. Report on the Puget Sound otter trawl investigations. Wash. Dept. Fish. Biol. Rep. 36B:1-61.

Spies, R. B., D. W. Rice, Jr., P. A. Montagna, R. R. Ireland, J. S. Felton, S. K. Healy, and P. R. Lewis. 1985. Pollutant body burdens and reproduction in *Platichthys stellatus* from San Francisco Bay. Lawrence Livermore Nat. Lab., Livermore, CA, 95 p.

Squire, J. L., and S. E. Smith. 1977. Anglers' guide to the United States Pacific coast: Marine fish, fishing grounds, and facilities. NOAA, Seattle, WA, 139 p.

Stober, Q. J. 1973. Summary and overview of experimental thermal effects studies. *In* Q. J. Stober and E. O. Salo (editors), Ecological studies of the proposed Kiket Island nuclear power site, p. 441-448. Final Rep. to Snohomish County P.U.D. and Seattle City Light. Coll. Fish., Fish. Res. Inst., Univ. Wash., Seattle, WA (FRI-UW-7304).

Waldron, K. D. 1972. Fish larvae collected from the northeastern Pacific Ocean and Puget Sound during April and May 1967. NOAA Tech. Rep. NMFS SSRF-663, 16 p.

Wang, J. C. S. 1986. Fishes of the Sacramento-San Joaquin estuary and adjacent waters, California: A guide to the early life histories. Tech. Rep. No. 9. Interagency ecological study program for the Sacramento-San Joaquin estuary. Calif. Dept. Water Res., Calif. Dept. Fish Game, U.S. Bureau Reclam., and U.S. Fish Wildl. Serv., various pagination.

Washington Department of Fisheries. 1985. 1985 Fisheries Statistical Report. Wash. Dept. Fish., Olympia, WA, 101 p.

Washington, P. M. 1977. Recreationally important marine fishes of Puget Sound, Washington. Proc. Rep., Northwest Alaska Fish. Cent., Nat. Mar. Fish. Serv., NOAA, Seattle, WA, 122 p.

Wellings, S. R., C. E. Alpers, B. B. McCain, and B. S. Miller. 1976. Fin erosion disease of starry flounder (*Platichthys stellatus*) and English sole (*Parophrys vetulus*) in the estuary of the Duwamish River, Seattle, Washington. J. Fish. Res. Board Can. 33:2577-2586.

Westrheim, S. J. 1955. Migrations of starry flounder (*Platichthys stellatus*) tagged in the Columbia River. Oregon Fish. Comm. Res. Briefs 6(1):33-37.

Whipple, J. A., T. G. Yocom, D. R. Smart, and M. H. Cohen. 1978. Effects of chronic concentrations of petroleum hydrocarbons on gonadal maturation in starry flounder (*Platichthys stellatus*) [Pallas]. *In* The proceedings of the conference of assessment of ecological impacts of oil spills, p. 757-806. Amer. Inst. Biol. Sci., Keystone, CO.

Wilimovsky, N. J. 1964. Inshore fish fauna of the Aleutian archipelago. Proc. Alaska Sci. Conf. 14:172-190.

Wydoski, R. S. and R. R. Whitney. 1979. Inland fishes of Washington, Univ. Wash. Press, Seattle, WA, 220 p.

Yusa, T. 1957. Eggs and larvae of flatfishes in the coastal waters of Hokkaido, Embryonic development of the starry flounder *Platichthys stellatus* (Pallas). Bull. Hokkaido Reg. Fish. Res. Lab, 15:1-14.

Glossary

ABYSSAL ZONE—Ocean bottom at depths between 4,000 and 6,000 m.

ABYSSOPELAGIC—Living in the water column at depths between 4,000 and 6,000 m; the abyssopelagic zone.

ADDUCTOR MUSCLE—A muscle that pulls a part of the body toward the median axis of the body. In bivalve molluscs, this muscle is used to close the shell halves and hold them together.

ALEUTIAN PROVINCE—A zoogeographic designation for the area of coastal faunal distributions that, based on minimum temperature requirements, extends from Puget Sound, Washington, to the Bering Strait, Alaska.

ALEVIN—The larval stage of trout and salmon that feeds on its yolk sac and lives under gravel.

ALGAE—A collective, or general name, applied to a number of primarily aquatic, photosynthetic groups (taxa) of plants and plant-like protists. They range in size from single cells to large, multicellular forms like the giant kelps. They are the food base for almost all marine animals. Important taxa are the dinoflagellates (division Pyrrophyta), diatoms (div. Chrysophyta), green algae (div. Chlorophyta), brown algae (div. Phaeophyta), and red algae (div. Rhodophyta). Cyanobacteria are often called blue-green algae, although blue-green bacteria is a preferable term.

AMPHI-NORTH PACIFIC—A population distribution where a species is distributed on the east and west rims of the Pacific Ocean, but not on the northern rim.

AMPHIPODA—An order of laterally compressed crustaceans with thoracic gills, no carapace, and similar body segments. Although most are <1 cm long, they are an important component of zooplankton and benthic invertebrate communities. A few species are parasitic.

ANADROMOUS—Life cycle where an organism spends most of its life in the sea, and migrates to freshwater to spawn.

ANTHROPOGENIC—Refers to the effects of human activities.

ARCTIC REGION—The oceans north of the 0°C winter isotherm. Along the Pacific coast, this corresponds to 60° N in the Bering Sea.

AREAL—Refers to a measure of area.

ASCIDIAN—A tunicate (class Ascidiacea) that has a generalized sac-like, cellulose body and is usually attached to the substratum.

BATHYAL—The zone of ocean bottom at depths of 200 to 4,000 m, primarily on the continental slope and rise.

BATHYMETRIC—A depth measurement. Also refers to a migration from waters of one depth to another.

BATHYPELAGIC—Ocean depths from 1,000 to 4,000 m.

BENTHIC—Pertaining to the bottom of an ocean, lake, or river. Also refers to sessile and crawling animals which reside in or on the bottom.

BIGHT—An inward bend or bow in the coastline.

BIOMASS—The total mass of living tissues (wet or dried) of an organism or collection of organisms of a species or trophic level, from a defined area or volume.

BIVALVIA—Bilaterally symmetrical molluscs (also referred to as Pelecypoda) that have two lateral calcareous shells (valves) connected by a hinge ligament. They are mostly sedentary filter feeders. This class includes clams, oysters, scallops, and mussels.

BOREAL REGION—The oceans of the northern hemisphere between the 0 and13°C winter isotherms. In neritic waters of western North America, it extends from Point Conception, California, to the southern Bering Sea, Alaska.

BRANCHIAL—A structure or location on an organism associated with the gills.

BRYOZOA—Minute, moss-like colonial animals of the phylum Bryozoa.

BYSSAL THREAD—A tuft of filament, chemically similar to silk, that attaches certain molluscs to substrates.

CALCAREOUS—Composed of calcium or calcium carbonate.

CARNIVORE—An animal that feeds on the flesh of other animals. See PARASITISM and PREDATION.

CESTODE—A parasitic, ribbon-like worm having no intestinal canal; class Cestoda (e.g., tapeworms).

CHEMOTAXIS—A response movement by an animal either toward or away from a specific chemical stimulus.

CHORDATA—A phylum of animals which includes the subphyla Vertebrata, Cephalochordata, and Urochordata. At some stage of their life cycles, these organisms have pharyngeal gill slits, a notochord, and a dorsal, hollow nerve cord.

CILIA—Hair-like processes of certain cells, often capable of rhythmic beating that can produce locomotion or facilitate the movement of fluids.

CIRRI—Flexible, thread-like tentacles or appendages of certain organisms.

CLINE—A series of differing physical characteristics within a species or population, reflecting gradients or changes in the environment (e.g., body size or color).

COLONY—A group of organisms living in close proximity. An invertebrate colony is a close association of individuals of a species which are often mutually dependent and in physical contact with each other. A vertebrate colony is usually a group of individuals brought together for breeding and rearing young.

COMMENSALISM—A relationship between two species, where one species benefits without adversely affecting the other.

COMMUNITY—A group of plants and animals living in a specific region under relatively similar conditions. Further restrictions are often used, such as the algal community, the invertebrate community, the benthic gastropod community, etc.

COMPETITION—Two types exist - interspecific and intraspecific. Interspecific competition exists when two or more species use one or more limited resources such as food, attachment sites, protective cover, or dissolved ions. Intraspecific competition exist when individuals of a single species compete for limited resources needed for survival and reproduction. This form of competition includes the same resources involved in interspecific competition as well as mates and territories. It is generally more intense than interspecific competition because resource needs are essentially identical among conspecifics. See NICHE.

CONGENER—Referring to members of the same genus.

CONTINENTAL SHELF—The submerged continental land mass, not usually deeper than 200 m. The shelf may extend from a few miles off the coastline to several hundred miles.

CONTINENTAL SLOPE—The steeply sloping seabed that connects the continental shelf and continental rise.

COPEPODA—A subclass of crustaceans with about 4,500 species, including several specialized parasitic orders. The free-living species are small (one to several mm) and have cylindrical bodies, one median eye, and two long antennae. One order is planktonic (Calanoida), one is benthic (Harpacticoida), and one has both planktonic and benthic species (Cyclopoida). In most species, the head appendages form a complex apparatus used to sweep in and possibly filter prey (especially algae). Thoracic appendages are used for swimming or crawling on the bottom. One of the most abundant group of animals on earth, they are a major link in aquatic food webs.

CREPUSCULAR—Relates to animals whose peak activity is during the twilight hours of dawn and dusk.

CRUSTACEA—A large class of over 26,000 species of mostly aquatic arthropods having five pairs of head appendages, including laterally opposed jaw-like mandibles and two pairs of antennae. Most have well-developed compound eyes and variously modified two-branched body appendages. The body segments are often differentiated into a thorax and an abdomen. Some common members are crabs, shrimp, lobsters, copepods, amphipods, isopods, and barnacles.

CTENIDIA—The comblike respiratory apparatus of molluscs.

CTENOPHORA—A phylum of mostly marine animals that have oval, jellylike bodies bearing eight rows of comb-like plates that aid swimming (e.g., ctenophores and comb jellies).

DECOMPOSERS—Bacteria and fungi that break down dead organisms of all types to simple molecules and ions.

DEMERSAL—Refers to swimming animals that live near the bottom of an ocean, river, or lake. Often refers to eggs that are denser than water and sink to the bottom after being laid.

DEPOSIT FEEDER—An animal that ingest small organisms, organic particles, and detritus from soft sediments, or filters organisms and detritus from such substrates.

DESICCATE—To dry completely.

DETRITIVORE—An organism that eats small fragments of partially decomposed organic material (detritus) and its associated microflora. See DECOMPOSER.

DIATOMS—Single-celled protistan algae of the class Bacillariophyceae that have intricate siliceous shells composed of two halves. They range in size from about 10 to 200 microns. Diatoms sometimes remain attached after cellular divisions, forming chains or colonies. These are the most numerous and important group of phytoplankters in the oceans, and form the primary food base for marine ecosystems.

DIEL—Refers to a 24-hour activity cycle based on daily periods of light and dark.

DIMORPHISM—A condition where a population has two distinct physical forms (morphs). In sexual dimorphism, secondary sexual characteristics are markedly different (e.g., size, color, and behavior).

DINOFLAGELLATE—A planktonic, photosynthetic, unicellular algae that typically has two flagella, one being in a groove around the cell and the other extending from the center of the cell.

DIRECT DEVELOPMENT—See EMBRYONIC DEVELOPMENT.

DISPERSAL—The spreading of individuals throughout suitable habitat within or outside the population range. In a more restricted sense, the movement of young animals away from their point of origin to locations where they will live at maturity.

DISSOCHONCH—The adult shell secreted by newly-settled clam larvae or plantigrades.

DISTRIBUTION—(1) A species distribution is the spatial pattern of its population or populations over its geographic range. See RANGE. (2) A population depth distribution is the proportion or number of all individuals, or those of various sizes or ages, at different depth strata. (3) A population age distribution is the proportions of individuals in various age classes. (4) Within a population, individuals may be distributed evenly, randomly, or in groups throughout suitable habitat.

DIURNAL—Refers to daylight activities, or organisms most active during daylight. See DIEL.

ECHINODERMATA—A phylum of radially-symmetrical marine animals, possessing a water vascular system, and a hard, spiny skeleton (e.g., sea stars, sea urchins, and sand dollars).

ECTOPARASITE—A parasite that attacks (and usually attaches to) a host animal or plant on the outside. Feeding periods and/or attachment time may be brief compared to internal (endo-) parasites.

EELGRASS—Vascular flowering plants of the genus *Zostera* that are adapted to living under water while rooted in shallow sediments of bays and estuaries.

EL NIÑO CURRENT—An intermittent warm water current from the tropics that overrides the opposing cold current along the Pacific coasts of North and South America (see GYRE). This raises near-surface temperatures, depresses the thermocline, and often suppresses upwelling, resulting in drastic drops in primary productivity and reduced recruitment of marine animals. This is most pronounced on the coast of Peru. Effects are not as severe in North America, but northward shifts in distributions of "southern" species are common in El Niño years.

EMBRYONIC DEVELOPMENT—The increase in cell number, body size, and complexity of organ systems as an individual develops from a fertilized egg until hatching or birth. In direct development, individuals at birth or hatching are essentially miniatures of the adults. In indirect development, newly hatched individuals differ greatly from the adult, and go through periodic, major morphological changes (larval stages and metamorphosis) before becoming a juvenile.

EMIGRATION—A movement out of an area by members of a population. See IMMIGRATION.

ENDEMIC—Refers to a species or taxonomic group that is native to a particular geographical region.

EPIBENTHIC—Located on the bottom, as opposed to in the bottom.

EPIDERMAL—Refers to an animal's surface or outer layer of skin.

EPIFAUNA—Animals living on the surface of the bottom.

EPIPELAGIC—The upper sunlit zone of oceanic water where phytoplankton live and organic production takes place (approximately the top 200 m). See EUPHOTIC.

EPIPHYTIC—Refers to organisms which live on the surface of a plant (e.g., mosses growing on trees).

EPIPODAL—A structure or location associated with the leg or foot; typically refers to arthropod anatomy.

ESCARPMENT—A steep slope in topography, as in a cliff or along the continental slope.

ESTUARY—A semi-enclosed body of water with an open connection to the sea. Typically there is a mixing of sea and fresh water, and the influx of nutrients from both sources results in high productivity.

EUHALINE—Water with salt concentrations of 30-40‰.

EUPHOTIC—Refers to the upper surface zone of a water body where light penetrates and phytoplankton (algae) carry out photosynthesis. See EPIPELAGIC.

EURYHALINE—Refers to an organism that is tolerant of a wide range of salinities.

EURYTHERMAL—Refers to an organism that is tolerant of a wide range of temperatures.

EXTANT—Existing or living at the present time; not extinct.

FAUNA—All of the animal species in a specified region.

FECUNDITY—The potential of an organism to produce offspring (measured as the number of gametes). See REPRODUCTIVE POTENTIAL.

FILTER FEEDER—Any organism that filters small animals, plants, and detritus from water or fine sediments for food. Organs used for filtering include gills in clams and oysters, baleen in whales, and specialized appendages in crustaceans and marine worms.

FINGERLING—Refers to a small juvenile fish (often a salmonid) that is about 100 mm long.

FLAGELLATE—Refers to cells that have motility organelles or microorganisms that possess one or more flagellum used for locomotion.

FLORA—All of the plant species in a specified region

FOOD WEB (CHAIN)—The feeding relationships of several to many species within a community in a given area during a particular time period. Two broad types are recognized: 1) grazing webs involving producers (e.g., algae), herbivores (e.g., copepods), and various combinations of carnivores and omnivores, and 2) detritus webs involving scavengers, detritivores, and decomposers that feed on the dead remains or organisms from the grazing webs, as well as on their own dead. A food chain refers to organisms on different trophic levels, while a food web refers to a network of interconnected food chains. See TROPHIC LEVEL.

FOULING—Occurs when large numbers of plants or animals attach and grow on various structures (floats, pipes, and pilings), often interfering with their use. Fouling organisms include barnacles, mussels, bryozoans, and sponges.

FRESH WATER—Water that has a salt concentration of 0.0-0.5‰.

FRY—Very young fish. For trout and salmon, they are young that have just emerged from the gravel and are actively feeding.

GAMETE—A reproductive cell. When two gametes unite they form an embryonic cell (zygote).

GASTROPODA—The largest class of the Phylum Mollusca. This group includes terrestrial snails and slugs as well as aquatic species such as whelks, turbans, limpets, conchs, abalones, and nudibranchs. Most have external shells that are often spiraled (but this has been lost or is reduced in some), and move on a flat, undulating foot. They are mostly herbivorous and scrape food with a radula, an organ analogous to a tongue.

GONOCHORISTIC—Refers to a species that has separate sexes (i.e., male and female individuals).

GROUNDFISH—Fish species that live on or near the bottom, often called bottomfish.

GYRE—An ocean current that follows a circular or spiral path around an ocean basin, clockwise in the northern hemisphere and counterclockwise in the southern hemisphere.

HABITAT—The particular type of place where an organism lives within a more extensive area or range. The habitat is characterized by its biological components and/or physical features (e.g., sandy bottom of the littoral zone, or on kelp blades within 10 m of the water surface).

HAPLOSPORIDIAN—A unicellular protozoan occurring in vertebrate and invertebrate hosts, often causing disease.

HERBIVORE—An animal that feeds on plants (phytoplankton, large algae, or higher plants).

HERMAPHRODITIC—Refers to an organism having both male and female sex organs on the same individual.

HOLARCTIC—The entire Arctic, including the Paleoarctic (Europe and Asia) and the Nearctic (North America). Also, the entire arctic region in oceanography.

HYDROZOA—A class of the phylum Cnidaria. The primary life stage is nonmotile and has a sac-like body composed of two layers of cells and a mouth that opens directly into the body cavity. A second life stage, the free-living medusa, often resembles the common jellyfish.

HYPERSALINE—Water with a salt concentration over 40‰.

HYPOLIMNION—The cold bottom water zone of a lake below the thermocline.

IMMIGRATION—A movement of individuals into a new population or region. See EMIGRATION, MIGRATION, and RECRUITMENT.

INCIDENTAL CATCH—Catch of a species that was not the focus of a fishery, but taken along with the species being sought.

INDIRECT DEVELOPMENT—See EMBRYONIC DEVELOPMENT.

INFAUNA—Animals living in bottom substrates.

INNER SHELF—The continental shelf extending from the mean low tide line to a depth of 20 m.

INSTAR— The intermolt stage of a young arthropod.

INSULAR—Of or pertaining to an island or its characteristics (i.e., isolated).

INTERTIDAL—The ocean or estuarine shore zone exposed between high and low tides.

ISOBATH—A contour mapping line that indicates a specified constant depth.

ISOPODA—An order of about 4,000 species of dorsoventrally compressed crustaceans that have abdominal gills and similar abdominal and thoracic segments. Terrestrial pillbugs and thousands of benthic marine species are included. Most species are scavengers and/or omnivores; a few are parasitic.

ISOTHERM—A contour line connecting points of equal mean temperature for a given sampling period.

ITEROPAROUS—Refers to an organism that reproduces several times during its lifespan (i.e., does not die after spawning).

KELT—A spent (i.e., spawned out) trout.

KINESIS—A randomly directed movement by an animal in response to a sensory stimulus such as light, heat, or touch. When the response is directed, it is called a taxis. See CHEMOTAXIS.

LACUSTRINE—Pertaining to, or living in, lakes or ponds.

LAGOON—A shallow pond or channel linked to the ocean, but often separated by a reef or sandbar.

LARVAE—An early developmental stage of an organism that is morphologically different from the juvenile or adult form. See EMBRYONIC DEVELOPMENT.

LATERAL LINE—A pressure sensory system located in a line of pores under the skin on both sides of most fishes. The system is connected indirectly with the inner ear and senses water pressure changes due to water movement (including sound waves).

LITTORAL—The shore area between the mean low and high tide levels. Water zones in this area include the littoral pelagic zone and the littoral benthic zone.

MANTLE—The upper fold of skin in molluscs that encloses the gills and most of the body in a cavity above the muscular foot. In squids and allies, the mantle is below the body and behind the tentacles (derived from the foot) due to the shift in the dorsal-ventral axis. The mantle produces the shell in species having them.

MEAN LOWER LOW WATER (MLLW)—The arithmetic mean of the lower low water heights of a mixed tide over a specific 19-year Metonic cycle (the National Tidal Datum Epoch). Only the lower low water of each tidal day is included in the mean.

MEGALOPAE—The larval stage of a crab characterized by an adult-like abdomen, thoracic appendages, and a developed carapace.

MEIOFAUNA—Very small animals, usually < 0.5 mm in diameter.

MERISTIC—Refers to countable measurements of segments or features such as vertebrae, fin rays, and scale rows. Counts of these are used in population comparisons and classifications.

MESOHALINE—Water with a salt concentration of 5-18‰.

MESOPELAGIC—Ocean zone of intermediate depths from about 200-1,000 m below the surface, where light penetration drops rapidly and ceases.

METAMORPHOSIS—Process of transforming from one body form to another form during development (e.g., tadpole changing to a frog). See EMBRYONIC DEVELOPMENT.

METRIC TON (t)—A unit of mass or weight equal to 2,204.6 lb.

MIGRATION—Movement by a population or subpopulation from one location to another (often periodic or seasonal, and over long distances). Vertical migrations in the water column may be daily or seasonal within the same area. Migrations between deep and shallow areas are usually seasonal and related to breeding. Many marine birds and mammals have seasonal latitudinal migrations associated with breeding. See EMIGRATION, IMMIGRATION, RANGE, and RECRUITMENT.

MILT—The seminal fluid and sperm of male fish.

MOLT—The process of shedding and regrowing an outer skeleton or covering at periodic intervals. Crustaceans and other arthropods molt their exoskeletons, grow rapidly, and produce larger exoskeletons. Most reptiles, birds, and mammals, molt skin, feathers, and fur, respectively.

MORPHOLOGY—The appearance, form, and structure of an organism.

MORPHOMETRICS—The study of comparative morphological measurements.

MORTALITY—Death rate expressed as a proportion of a population or community of organisms. Mortality is caused by a variety of sources, including predation, disease, environmental conditions, etc.

MOTILE—Capable of or exhibiting movement or locomotion.

MUTUALISM—An interaction between two species where both benefit. Some authorities consider true mutualism to be obligatory for both species, while mutually beneficial relationships that are not essential for either species are classified as protocooperative (e.g., the blacksmith cleaning fish eating external parasites from sea basses).

NACREOUS MATERIAL—A calcareous, lustrous secretion in the inner surface of the shell of many molluscs. Foreign particles lodging between the inner shell surface and the mantle are covered by nacre, sometimes forming pearls.

NANOPLANKTON—Microscopic, planktonic organisms smaller than 20 microns in diameter.

NATAL—Pertaining to birth or hatching.

NEKTONIC—Refers to pelagic animals that are strong swimmers, live above the substrate in the water column, and can move independently of currents.

NEMERTEA—A phylum of unsegmented, elongate marine worms having a protrusible proboscis and no body cavity, and live mostly in coastal mud or sand; nemerteans.

NERITIC—An oceanic zone extending from the mean low tide level to the edge of the continental shelf. See INNER SHELF, LITTORAL, and OCEANIC ZONES.

NEUSTON—Organisms that live on or under the water surface, often dependent on surface tension for support.

NICHE—The fundamental niche is the full range of abiotic and biotic factors under which a species can live and reproduce. The realized niche is the set of actual conditions under which a species or a population of a species exists, and is largely determined by interactions with other species.

NOCTURNAL—Refers to night, or animals that are active during night.

OCEANIC—Living in or produced by the ocean.

OCEANIC ZONE—Pelagic waters of the open ocean beyond the continental shelf. See BATHYPELAGIC, EPIPELAGIC, ABYSSOPELAGIC, MESOPELAGIC, and NERITIC.

OLIGOHALINE—Water with a salt concentration of 0.5-5.0‰.

OMNIVORE—An animal that eats both plants and animals.

OOCYTES—The cells in ovaries that will mature into eggs.

OREGON PROVINCE—A zoogeographical designation for faunal distributions that extends from Cape Flattery, Washington, to Point Conception, California.

OTOLITHS—Small calcareous nodules located in the inner ear of fishes used for sound reception and equilibration. They are often used by biologists to assess daily or seasonal growth increments.

OUT-MIGRATION—Movement of animals out of or away from an area (e.g., juvenile salmonids moving from rivers to the ocean).

OVIGEROUS—The condition of being ready to release mature eggs; egg-bearing.

OVIPAROUS—Refers to animals that produce eggs that are laid and hatch externally. See OVOVIVIPAROUS and VIVIPAROUS.

OVIPOSITION—The process of placing eggs on or in specific places, as opposed to randomly dropping or broadcasting them.

OVOVIVIPAROUS—Refers to animals whose eggs are fertilized, developed, and hatched inside the female, but receive no nourishment from her. See OVIPAROUS and VIVIPAROUS.

PALP—An organ attached to the head appendages of various invertebrates; usually associated with feeding functions.

PARASITISM—An obligatory association where one species (parasite) feeds on, or uses the metabolic mechanisms of the second (host). Unlike predators, parasites usually do not kill their hosts, although hosts may later die from secondary causes that are related to a weakened condition produced by the parasite. Parasitism may also be fatal when high parasite densities develop on or in the host.

PARR—The freshwater life stage of juvenile salmon and trout that has a series of dark, vertical bars on its sides (parr marks).

PARTURITION—The act of giving birth. See SPAWN.

PATHOGEN—A microorganism or virus that produces disease and can cause death.

PEDIVELIGER—The larval stage of bivalves during which a functional pedal (footlike) organ develops.

PELAGIC—Pertaining to the water column, or to organisms that live in the water column.

PELAGIVORE—A carnivore that feeds in the water column.

PHYLOGENY—Refers to evolutionary relationships and lines of descent.

PHYTOPLANKTON—Microscopic plants and plant-like protists (algae) of the epipelagic and neritic zones that are the base of offshore food webs. They drift with currents, but usually have some ability to control their level in the water column. See ALGAE and DIATOMS.

PISCIVOROUS—Refers to a carnivorous animal that eats fish.

PLANKTIVOROUS—Refers to an animal that eats phytoplankton and/or zooplankton.

PLANKTON—See PHYTOPLANKTON and ZOOPLANKTON.

PLANTIGRADE—A young, newly settled post-larval clam.

PLEOPODS—Paired swimming appendages on the abdomen of crustaceans.

POLYCHAETA—A class of segmented, mostly marine, annelid worms that bear bristles and fleshy appendages on most segments.

POLYHALINE—Water with a salt concentration between 18 and 30‰.

POPULATION—All individuals of the same species occupying a defined area during a given time. Environmental barriers may divide the population into local breeding units (demes) with restricted immigration and interbreeding between the localized units. See SPECIES, SUBSPECIES, and SUBPOPULATION.

PREDATION—An interspecific interaction where one animal species (predator) feeds on another animal or plant species (prey) while the prey is alive or after killing it. The relationship tends to be positive (increasing) for the predator population and negative (decreasing) for the prey population. See PARASITISM, SYMBIOTIC, CARNIVORE, and TROPHIC LEVEL.

PRODUCTION—Gross primary production is the amount of light energy converted to chemical energy in the form of organic compounds by autotrophs like algae. The amount left after respiration is net primary production and is usually expressed as biomass or calories/unit area/unit time. Net production for herbivores and carnivores is based on the same concept, except that chemical energy from food, not light, is used and partially stored for life processes. Efficiency of energy transfers between trophic levels ranges from 10-65% (depending on the organism and trophic level). Organisms at high trophic levels have only a fraction of the energy available to them that was stored in plant biomass. After respiration loss, net production goes into growth and reproduction, and some is passed to the next trophic level. See FOOD WEB and TROPHIC LEVEL.

PROKARYOTIC—Organisms that have nuclear bodies, but lack chromosomes, nucleoli, and nuclear membranes.

PROTANDRY—A type of hermaphroditism in which an individual initially develops as a male, then reverses to function as a female. Common for some species of shrimp.

PROTISTAN—Pertaining to the eukaryotic unicellular organisms of the kingdom Protista, including such groups as algae, fungi, and protozoans.

PROTOZOA—A varied group of either free-living or parasitic unicellular flagellate and amoeboid organisms.

PYCNOCLINE—A zone of marked water density gradient that is usually associated with depth.

RACE—An intraspecific group or subpopulation characterized by a distinctive combination of physiological, biological, geographical, or ecological traits. In salmonids, a race is determined by when it returns to its natal stream.

RADULA—A toothed belt or tongue in the buccal cavity of most molluscs that is used to scrape food particles from a surface, or modified otherwise to serve a variety of feeding habits.

RANGE—(1) The geographic range is the entire area where a species is known to occur or to have occurred (historical range). The range of a species may be continuous, or it may have unoccupied gaps between populations (discontinuous distribution). (2) Some populations, or the entire species, may have different seasonal ranges. These may be overlapping, or they may be widely separated with intervening areas that are at most briefly occupied during passage on relatively narrow migration routes. (3) Home range refers to the local area that an individual or group uses for a long period or life. See DISTRIBUTION and TERRITORY.

RECRUITMENT—The addition of new members to a population or stock through successful reproduction and immigration.

RED TIDE—A reddish coloration of sea waters caused by a large bloom of red flagellates. The accumulation of metabolic by-products from these organisms is toxic to fish and many other marine species. The accumulation of these metabolites in shellfish makes shellfish toxic to humans.

REDD—A gravel nest dug by spawning female salmon and trout. After eggs are released and fertilized by the male, the female covers them with gravel by sweeping movements of the tail.

REPRODUCTIVE POTENTIAL—The total number of offspring possible for a female of a given species to produce if she lives to the maximum reproductive age. This is found by multiplying the number of possible reproductive periods by the average number of eggs or offspring produced by females of each age class. This potential is seldom realized, but this and the age of first reproduction, or generation time, determine the maximum rate of population increase under ideal conditions.

RESIDUALISM—Occurs when juvenile salmon smolts do not migrate to sea but revert back to parr, usually loosing their ability to osmoregulate in seawater.

RHEOTAXIS—A response movement by an animal toward or away from stimulation by a water current.

RIVERINE—Pertaining to a river or formed by a river or stream.

ROE—The egg-laden ovary of fish, or the egg mass of certain crustaceans.

RUN—A group of migrating fish (e.g., a salmon run).

SALT WEDGE—A wedge-shaped layer of salt water that intrudes upstream beneath a low-density freshwater lens that has "thinned" while flowing seaward.

SAN DIEGO PROVINCE—A zoogeographical designation for faunal distributions that, based on minimum temperature requirements, extends from Point Conception, California, to Magdalena Bay, Baja California Sur.

SCAVENGER—Any animal that feeds on dead animals and remains of animals killed by predators. See DECOMPOSER and DETRITIVORE.

SEAMOUNT—An undersea mountain rising more than 3000 feet (914 m) from the sea floor, but having a summit at least 1000 feet (305 m) below sea level (in contrast to an island).

SEDENTARY—Refers to animals that are attached to a substrate or confined to a very restricted area (or those that do not move or move very little). See SESSILE.

SEMELPAROUS—Animals that have a single reproductive period during their lifespan.

SESSILE—Refers to an organisms that is permanently attached to the substrate. See SEDENTARY.

SETTLEMENT—The act of or state of making a permanent residency. Often refers to the period when fish and invertebrate larvae change from a planktonic to a benthic existence.

SHOAL—(1) A sand bar in a body of water that is exposed at low tide. (2) An area of shallow water. (3) A group of fish (school). (4) As a verb, to collect in a crowd or school.

SIPHONS—The "necks" or tubes of clams and other bivalves that carry water containing food and oxygen into the gills, and then expels water containing waste products (exhalent siphon).

SLOUGH—A shallow inlet or backwater whose bottom may be exposed at low tide. Sloughs often border estuaries and typically have a stream passing through them.

SMOLT—A juvenile salmon or anadromous trout that is in the process of migrating to the ocean and physiologically adapting to seawater. Smolts are usually very silvery and have very faint parr marks. See PARR.

SPAT—Juvenile bivalve molluscs which have settled from the water column to the substrate to begin a benthic existence.

SPAWN—The release of eggs and sperm during mating. Also, the bearing of offspring by species with internal fertilization. See PARTURITION.

SPECIES—(1) A fundamental taxonomic group ranking after a genus. (2) A group of organisms recognized as distinct from other groups, whose members can interbreed and produce fertile offspring. See POPULATION, SUBPOPULATION, and SUBSPECIES.

SPERMATOPHORE—A capsule or gelatinous packet (extruded by a male) containing sperm and used to transfer sperm to females. Spermatophores are produced by certain invertebrates and some primitive vertebrates.

SPIROCHETE—A spiral-shaped, non-flagellated bacterium of the order Spirochaetales. This group can be free-living or parasitic. Some members cause diseases.

SPIT—A long, narrow sand bar or peninsula extending into a body of water which is at least partly connected to the shore. See SHOAL.

SPOROCYST—A simple larval stage of parasitic trematode worms. Contact with the host causes a metamorphosis from an earlier stage to this stage.

STENOHALINE—Pertaining to organisms that are restricted to a narrow range of salinities, in contrast to EURYHALINE.

STIPE—A thickened, stalk-like structure in kelps that bears other structures, such as blades. Also, the basal portion of the thallus or plant body of alga.

STOCK—A related group or subpopulation. See POPULATION and SUBPOPULATION.

SUBADULTS—Maturing individuals that are not yet sexually mature.

SUBLITTORAL—The benthic zone along a coast, or lake that extends from mean low tide to depths of about 200 m.

SUBPOPULATION—A breeding unit (deme) of a larger population. These units may differ little genetically and taxonomically. See SUBSPECIES. Subpopulations may intergrade with some interbreeding, or they may occupy a common seasonal range prior to the mating season. The units may have different reproduction times and be separated spatially or temporally. See RACE, STOCK, and POPULATION.

SUBSPECIES—A taxonomic class assigned to populations and/or subpopulations when interbreeding (gene flow) between populations is limited, and there are significant differences in some combination of characteristics between subspecies (e.g., appearance, anatomy, ecology, physiology, and behavior). While successful interbreeding can occur when the groups are in contact, under natural conditions reproductive isolation is complete and the groups are considered distinct. Classification of such groups is based on the comparative study and judgement of phylogenists. A second epithet for each subspecies is added to the binomial for the species (e.g., *Oncorhynchus clarki clarki*). See SPECIES, POPULATION, and SUBPOPULATION.

SUBTIDAL—See SUBLITTORAL.

SUPRALITTORAL—The splash zone of land (adjacent to the sea) that is above the mean high tide level.

SUSPENSION FEEDER—An animal that feeds directly or by filtration on minute organisms and organic debris that is suspended in the water column.

SYMBIOSIS—The relationship between two interacting organisms that is positive, negative, or neutral in its effects on each species. See COMPETITION, MUTUALISM, PARASITISM, and PREDATION.

TAXONOMY—A system of describing, naming, and classifying animals and plants into related groups based on common features (e.g., structure, embryology, and biochemistry).

TEMPERATE REGION—Oceanic waters between the 13 and 20°C winter isotherms. The temperate region of the neritic zone on the Pacific coast of North America extends from Point Conception, California, to Magdalena Bay, Baja California Sur.

TEMPORAL—Pertaining to time. Used to describe organism activities, developmental stages, and distributions as they relate to daily, seasonal, or geologic time periods.

TERRITORY—An area occupied and used by an individual, pair, or larger social group, and from which other individuals or groups of the species are excluded, often with the aid of auditory, olfactory, and visual signals, threat displays, and outright combat.

TEST—A rigid calcareous exoskeleton produced by some echinoderms in the class Echinoidea (e.g., sea urchins and sand dollars).

THERMOCLINE—A relatively narrow boundary layer of water where temperature decreases rapidly with depth. Little water or solute exchange occurs across the thermocline, which is maintained by solar heating of the upper water layers.

TREMATODA—A class of parasitic flatworms of the phylum Platyhelminthes. Trematodes have one or more muscular, external suckers and are also known as flukes.

TRIPLOIDY—The occurrence of three times the haploid number of chromosomes. When genetically engineered, randomly occurring traits may be selected for commercial applications. For example, the Pacific oyster experiences a degradation in flesh quality associated with spawning. Non-reproducing triploid cultures avoid this seasonal problem.

TROCHOPHORE—A molluscan larval stage (except in Cephalopoda) following gastrulation (embryonic stage characterized by the development of a simple gut). It is commonly ciliated, biconically shaped, and free-swimming; it establishes an evolutionary link between annelids and molluscs, since both groups display a similar life stage.

TROPHIC LEVEL—The feeding level in an ecosystem food chain characterized by organisms that occupy a similar functional position. At the first level are autotrophs or producers (e.g., kelps and diatoms); at the second level are herbivores (e.g., copepods and snails); at the third level and above are carnivores (e.g., salmon and seals). Omnivores feed at the second and third levels. Decomposers and detritivores may feed at all trophic levels. See FOOD WEB and PRODUCTION.

TROPICAL REGION—Oceanic waters between the 20°C winter isotherms in the southern and northern hemispheres. Tropical neritic waters along the west coasts of North and South America extend from the southern tip of Baja California, Mexico, to about lat. 5°S along the coast of Peru.

TURBELLARIA—A class of mostly aquatic, non-parasitic flatworms that are leaf-shaped and covered with cilia.

UPWELLING—The process whereby prevailing seasonal winds create surface currents that allow nutrient rich cold water from the ocean depths to move into the euphotic or epipelagic zone. This process breaks down the thermocline and increases primary productivity, and ultimately fish abundance.

VELICONCHA—A bivalve larval stage. A veliconcha has two larval shells and moves by using its velum.

VELIGER—A ciliated larval stage common in molluscs. This stage forms after the trochophore larva and has some adult features, such as a shell and foot.

VELUM—The ciliated swimming organ of a larval mollusc.

VIVIPAROUS—Refers to animals that produce live offspring; eggs are retained and fertilized in the female (as compared to OVIPAROUS).

WATER COLUMN—The water mass between the surface and the bottom.

YEAR-CLASS—Refers to animals of a species population hatched or born in the same year at about the same time; also known as a cohort. Strong year-classes result when there is high larval and juvenile survival; the reverse is true for weak year-classes. The effects of strong and weak year-classes on population size and structure may persist for years in species with long lives. Variation in year-class strength often affects fisheries. See DISTRIBUTION and STOCK.

ZOEA—An early larval stage of various marine crabs and shrimp; zoea have many appendages and long dorsal and anterior spines.

ZOOPLANKTON—Animal members of the plankton. Most range in size from microscopic to about 2.54 cm in length. They reside primarily in the epipelagic zone and feed on phytoplankton and each other. Although they have only a limited ability to swim against currents, many undertake diel migrations. Taxa include protozoa, jellyfish, comb jellies, arrowworms, lower chordates, copepods, water fleas, krill, and the larvae of many fish and invertebrates that are not planktonic as adults.

Appendices

Appendix 1: Summary table example: Spatial distribution and relative abundance

		West Coast Estuaries																							
		Puget Sound			Hood Canal			Skagit Bay			Grays Harbor			Willapa Bay			Columbia River			Nehalem Bay			Tillamook Bay		
Species/Life Stage		T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S
Blue mussel *Mytilis edulis*	A		●	●		◉	◉		◉	●		○	○		○	○			○			◉			◉
	S		●	●		◉	◉		◉	●		○	○		○	○			○			◉			◉
	J		●	●		◉	◉		◉	●		○	○		○	○			○			◉			◉
	L		●	●		◉	◉		◉	●		○	○		○	○			○			◉			◉
	E		●	●		◉	◉		◉	●		○	○		○	○			○			◉			◉
Pacific oyster *Crassostrea gigas*	A		●	●		●	●			○		●	●		●	●								●	
	S																								
	J		●	●		●	●			○		●	●		●	●								●	
	L																								
	E																								
Horseneck gaper *Tresus capax*	A		○	◉		◉	◉		○	◉			○			○								○	◉
	S			○			◉			○			○			○								○	◉
	J		○	◉		◉	◉		○	◉			○			○								○	◉
	L		○	○		◉	◉		○	○			○			○								○	◉
	E			○			◉			○			○			○								○	◉
Pacific gaper *Tresus nuttallii*	A		◉	◉		◉	◉		○	○															
	S		◉	◉		◉	◉			○															
	J		◉	◉		◉	◉		○	○															
	L		◉	◉		◉	◉		○	○															
	E		◉	◉		◉	◉			○															
California jackknife clam *Tagelus californianus*	A																								
	S																								
	J																								
	L																								
	E																								
Pacific littleneck clam *Protothaca staminea*	A		●	●		●	●		●	●		○	○		○	○						●		○	◉
	S		●	●		●	●		●	●		○	○		○	○						●		○	◉
	J		●	●		●	●		●	●		○	○		○	○						●		○	◉
	L		●	●		●	●		●	●		○	○		○	○						●		○	◉
	E		●	●		●	●		●	●		○	○		○	○						●		○	◉
		T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S
		Puget Sound			Hood Canal			Skagit Bay			Grays Harbor			Willapa Bay			Columbia River			Nehalem Bay			Tillamook Bay		
		West Coast Estuaries																							

Relative Abundance

●	Highly Abundant
◉	Abundant
○	Common
Blank	Not Present, Rare, or No Data Available

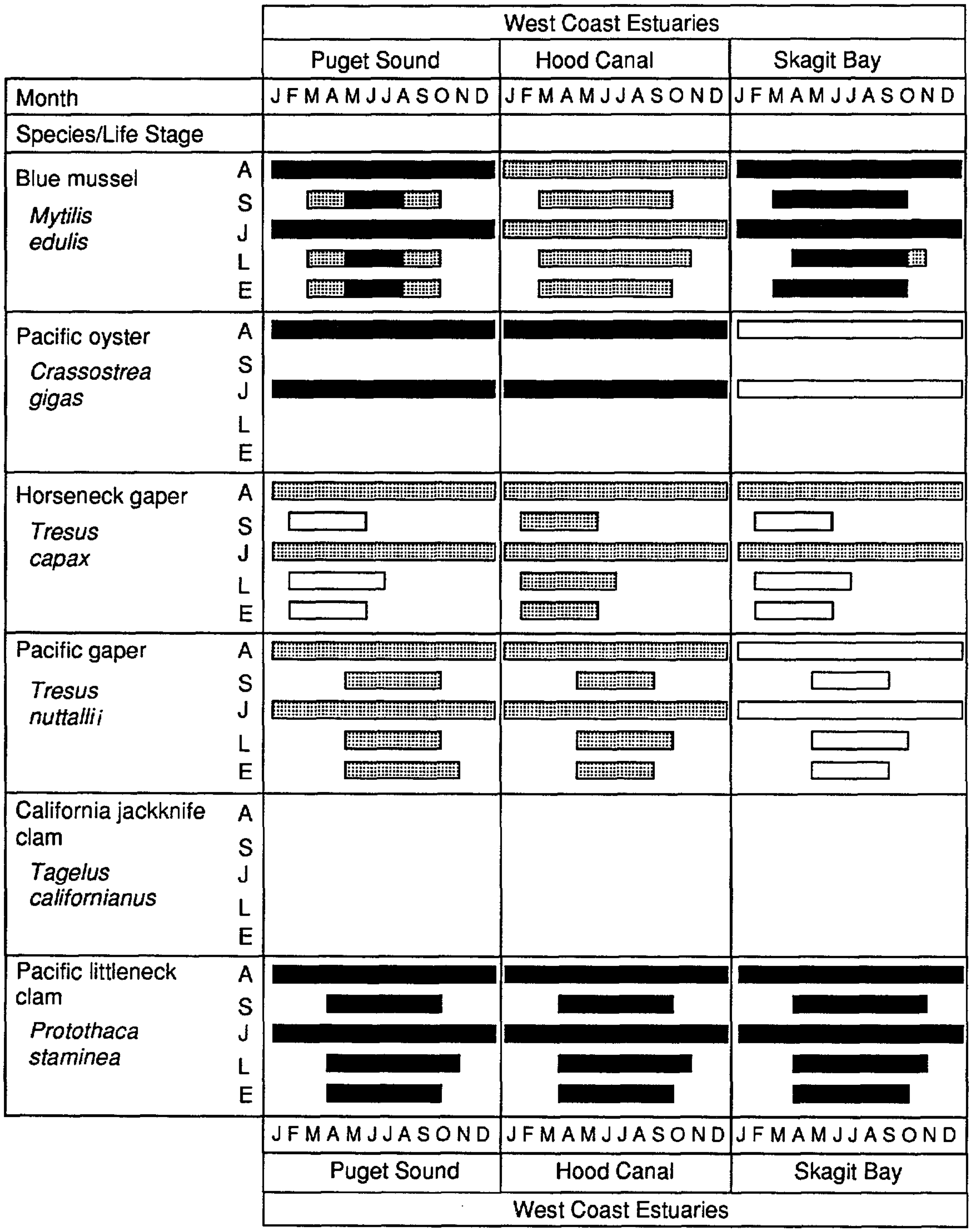
Salinity Zone

T - Tidal Fresh
M - Mixing
S - Seawater

Life Stage/Activity

A - Adults
S - Spawning
J - Juveniles
L - Larvae
E - Eggs

Appendix 2: Summary table example: Temporal distribution



Relative Abundance

■	Highly Abundant
▨	Abundant
☐	Common
Blank	Not present, Rare, or No Data Available

Life Stage/Activity

A - Adults
S - Spawning
J - Juveniles
L - Larvae
E - Eggs

Appendix 3: Summary table example: Data reliability

Species/Life Stage		West Coast Estuaries							
		Puget Sound	Hood Canal	Skagit Bay	Grays Harbor	Willapa Bay	Columbia River	Nehalem Bay	Tillamook Bay
Blue mussel *Mytilis edulis*	A	■	■	■	■	■	■	□	▣
	S	■	▣	▣	▣	■	□	□	□
	J	■	■	■	■	■	■	□	▣
	L	■	▣	▣	▣	■	□	□	□
	E	■	▣	▣	▣	■	□	□	□
Pacific oyster *Crassostrea gigas*	A	■	■	■	■	■	■	■	■
	S	■	■	■	■	■	■	■	■
	J	■	■	■	■	■	■	■	■
	L	■	■	■	■	■	■	■	■
	E	■	■	■	■	■	■	■	■
Horseneck gaper *Tresus capax*	A	■	■	■	■	■	■	■	■
	S	■	■	■	▣	□	■	□	□
	J	■	■	■	■	■	■	■	■
	L	▣	▣	■	□	□	■	□	□
	E	■	■	■	□	□	■	□	□
Pacific gaper *Tresus nuttallii*	A	■	■	■	■	■	■	■	■
	S	□	□	□	■	■	■	■	■
	J	■	■	■	■	■	■	■	■
	L	□	□	□	■	■	■	■	■
	E	□	□	□	■	■	■	■	■
California jackknife clam *Tagelus californianus*	A	■	■	■	■	■	■	■	■
	S	■	■	■	■	■	■	■	■
	J	■	■	■	■	■	■	■	■
	L	■	■	■	■	■	■	■	■
	E	■	■	■	■	■	■	■	■
Pacific littleneck clam *Protothaca staminea*	A	■	■	■	■	□	■	■	■
	S	▣	▣	▣	□	□	■	□	■
	J	■	■	■	■	□	■	■	■
	L	□	□	▣	□	□	■	□	■
	E	□	□	▣	□	□	■	□	■
		Puget Sound	Hood Canal	Skagit Bay	Grays Harbor	Willapa Bay	Columbia River	Nehalem Bay	Tillamook Bay
		West Coast Estuaries							

Reliability

■	Highly Certain
▣	Moderately Certain
□	Reasonable Inference

Life Stage/Activity

A - Adults
S - Spawning
J - Juveniles
L - Larvae
E - Eggs

Appendix 4: Presence/absence of 47 species in west coast estuaries

Note: Due to post-publication revisions of the presence/absence information in *Volume I* (Table 5, pp. 185-197), data in this appendix has been updated and supersedes that presented in *Volume I*.

Index to Appendix 4: Page location of presence/absence table for each species and estuary

	Estuary			
Common and Scientific Name	Puget Sound Hood Canal Skagit Bay Grays Harbor Willapa Bay Columbia River Nehalem Bay Tillamook Bay	Netarts Bay Siletz River Yaquina Bay Alsea River Siuslaw River Umpqua River Coos Bay Rogue River	Klamath River Humboldt Bay Eel River Tomales Bay Cent. S. Fran./Suisun/San Pablo Bays South San Fran. Bay Elkhorn Slough Morro Bay	Santa Monica Bay San Pedro Bay Alamitos Bay Anaheim Bay Newport Bay Mission Bay San Diego Bay Tijuana Estuary
Blue mussel (*Mytilus edulis*) Pacific oyster (*Crassostrea gigas*) Horseneck gaper (*Tresus capax*) Pacific gaper (*Tresus nuttallii*) California jackknife clam (*Tagelus californianus*) Pacific littleneck clam (*Protothaca staminea*) Manila clam (*Venerupis japonica*) Softshell (*Mya arenaria*) Geoduck (*Panopea abrupta*) Bay shrimp (*Crangon franciscorum*) Dungeness crab (*Cancer magister*) Leopard shark (*Triakis semifasciata*) Green sturgeon (*Acipenser medirostris*) White sturgeon (*Acipenser transmontanus*) American shad (*Alosa sapidissima*) Pacific herring (*Clupea pallasi*) Deepbody anchovy (*Anchoa compressa*) Slough anchovy (*Anchoa delicatissima*) Northern anchovy (*Engraulis mordax*)	292	293	294	295
Cutthroat trout (*Oncorhynchus clarki*) Pink salmon (*Oncorhynchus gorbuscha*) Chum salmon (*Oncorhynchus keta*) Coho salmon (*Oncorhynchus kisutch*) Steelhead (*Oncorhynchus mykiss*) Sockeye salmon (*Oncorhynchus nerka*) Chinook salmon (*Oncorhynchus tshawytscha*) Surf smelt (*Hypomesus pretiosus*) Longfin smelt (*Spirinchus thaleichthys*) Eulachon (*Thaleichthys pacificus*) Pacific tomcod (*Microgadus proximus*) Topsmelt (*Atherinops affinis*)	296	297	298	299
Jacksmelt (*Atherinopsis californiensis*) Threespine stickleback (*Gasterosteus aculeatus*) Striped bass (*Morone saxatilis*) Kelp bass (*Paralabrax clathratus*) Barred sand bass (*Paralabrax nebulifer*) White seabass (*Atractoscion nobilis*) White croaker (*Genyonemus lineatus*) Shiner perch (*Cymatogaster aggregata*) Pacific sand lance (*Ammodytes hexapterus*) Arrow goby (*Clevelandia ios*) Lingcod (*Ophiodon elongatus*) Pacific staghorn sculpin (*Leptocottus armatus*) California halibut (*Paralichthys californicus*) Diamond turbot (*Hypsopsetta guttulata*) English sole (*Pleuronectes vetulus*) Starry flounder (*Platichthys stellatus*)	300	301	302	303

		Puget Sound			Hood Canal			Skagit Bay			Grays Harbor			Willapa Bay			Columbia River			Nehalem Bay			Tillamook Bay		
Species		T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S
Blue mussel	A		√	√		√	√		√	√		√	√		√	√			√			√		√	√
Mytilus	J		√	√		√	√		√	√		√	√		√	√			√			√		√	√
edulis	L		√	√		√	√		√	√		√	√		√	√			√			√		√	√
Pacific oyster	A		√	√		√	√			√		√	√		√	√								√	
Crassostrea	J		√	√		√	√			√		√	√		√	√								√	
gigas	L																								
Horseneck gaper	A		√	√		√	√		√	√			√			√						√		√	√
Tresus	J		√	√		√	√		√	√			√			√						√		√	√
capax	L		√	√		√	√		√	√			√			√								√	√
Pacific gaper	A		√	√		√	√		√	√			√			√									
Tresus	J		√	√		√	√		√	√			√			√									
nuttallii	L		√	√		√	√		√	√															
California jackknife clam	A																								
Tagelus	J																								
californianus	L																								
Pacific littleneck clam	A		√	√		√	√		√	√		√	√		√	√						√		√	√
Protothaca	J		√	√		√	√		√	√		√	√		√	√						√		√	√
staminea	L		√	√		√	√		√	√		√	√		√	√						√		√	√
Manila clam	A		√	√		√	√		√	√		√	√		√	√								√	
Venerupis	J		√	√		√	√		√	√		√	√		√	√								√	
japonica	L		√	√		√	√		√	√		√	√		√	√								√	
Softshell	A		√	√		√	√		√	√		√	√		√	√		√			√			√	√
Mya	J		√	√		√	√		√	√		√	√		√	√		√			√			√	√
arenaria	L		√	√		√	√		√	√		√	√		√	√		√			√			√	√
Geoduck	A		√	√		√	√			√															
Panopea	J		√	√		√	√			√															
abrupta	L		√	√		√	√			√															
Bay shrimp	A		√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
Crangon	J		√	√		√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
franciscorum	L		√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
Dungeness crab	A		√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
Cancer	J		√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
magister	L		√	√		√	√		√	√		√	√		√	√		√	√			√			√
Leopard shark	A																								
Triakis	J																								
semifasciata	P																								
Green sturgeon	A			√								√	√		√	√		√	√						
Acipenser	J																							√	√
medirostris	L																								
White sturgeon	A			√			√				√	√	√	√	√	√	√	√	√	√	√	√			√
Acipenser	J										√	√	√	√	√	√	√	√	√	√	√	√			√
transmontanus	L																								
American shad	A			√			√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√			
Alosa	J							√	√	√	√	√	√	√	√	√	√	√	√	√	√	√			√
sapidissima	L																								
Pacific herring	A		√	√		√	√		√	√						√		√	√		√	√		√	√
Clupea	J		√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
pallasi	L		√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
Deepbody anchovy	A																								
Anchoa	J																								
compressa	L																								
Slough anchovy	A																								
Anchoa	J																								
delicatissima	L																								
Northern anchovy	A		√	√			√		√	√		√	√		√	√		√	√		√	√		√	√
Engraulis	J		√	√			√		√	√		√	√		√	√		√	√		√	√		√	√
mordax	L		√	√			√		√	√		√	√		√	√		√	√		√	√		√	√
		T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S
		Puget Sound			Hood Canal			Skagit Bay			Grays Harbor			Willapa Bay			Columbia River			Nehalem Bay			Tillamook Bay		

Legend:

T = Tidal fresh zone
M = Mixing zone
S = Seawater zone

A = Adults
J = Juveniles
L = Larvae
P = Parturition

√ = Species / lifestage is present
Blank = Species / lifestage is not present

		Netarts Bay			Siletz River			Yaquina Bay			Alsea River			Siuslaw River			Umpqua River			Coos Bay			Rogue River		
Species		T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S
Blue mussel	A			√			√			√			√			√			√			√			√
Mytilus	J			√			√			√			√			√			√			√			√
edulis	L			√			√			√			√			√			√			√			
Pacific oyster	A			√					√										√		√	√			
Crassostrea	J			√					√										√		√	√			
gigas	L																								
Horseneck gaper	A			√					√	√			√			√			√		√	√			
Tresus	J			√					√	√			√			√			√		√	√			
capax	L			√					√	√			√			√			√		√	√			
Pacific gaper	A			√						√															
Tresus	J			√						√															
nuttallii	L			√						√															
California jackknife clam	A																								
Tagelus	J																								
californianus	L																								
Pacific littleneck clam	A			√					√	√			√			√					√	√			
Protothaca	J			√					√	√			√			√					√	√			
staminea	L			√					√	√			√			√					√	√			
Manila clam	A			√						√												√			
Venerupis	J			√						√												√			
japonica	L			√																		√			
Softshell	A		√	√		√			√	√		√	√		√			√			√	√			
Mya	J		√	√		√			√	√		√	√		√			√			√	√			
arenaria	L		√	√		√			√	√		√	√		√			√			√	√			
Geoduck	A			√																					
Panopea	J			√																					
abrupta	L			√																					
Bay shrimp	A		√	√		√	√		√	√		√	√		√	√		√	√		√	√			
Crangon	J		√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√			
franciscorum	L		√	√		√	√		√	√		√	√		√	√		√	√		√	√			
Dungeness crab	A		√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
Cancer	J		√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
magister	L			√			√			√			√			√			√		√	√			
Leopard shark	A																					√			
Triakis	J																								
semifasciata	P																								
Green sturgeon	A								√	√			√			√		√	√		√	√	√	√	√
Acipenser	J								√	√			√			√		√	√		√	√	√	√	√
medirostris	L																								
White sturgeon	A							√	√	√			√			√	√	√	√		√	√	√	√	√
Acipenser	J							√	√	√			√			√	√	√	√		√	√	√	√	√
transmontanus	L																								
American shad	A							√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Alosa	J							√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
sapidissima	L																			√					
Pacific herring	A		√	√					√	√		√	√		√	√		√	√		√	√			√
Clupea	J		√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
pallasi	L		√	√					√	√		√	√		√			√	√		√	√			
Deepbody anchovy	A																								
Anchoa	J																								
compressa	L																								
Slough anchovy	A																								
Anchoa	J																								
delicatissima	L																								
Northern anchovy	A			√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
Engraulis	J			√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
mordax	L								√	√			√								√	√		√	√
		T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S
		Netarts Bay			Siletz River			Yaquina Bay			Alsea River			Siuslaw River			Umpqua River			Coos Bay			Rogue River		

Legend:
T = Tidal fresh zone
M = Mixing zone
S = Seawater zone

A = Adults
J = Juveniles
L = Larvae
P = Parturition

√ = Species / lifestage is present
Blank = Species / lifestage is not present

		Klamath River			Humboldt Bay			Eel River			Tomales Bay			Central San Francisco Bay[1]			South San Francisco Bay			Elkhorn Slough			Morro Bay		
Species		T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	*	M	S	*	*	S	*	*	S
Blue mussel	A					√	√			√			√		√	√		√	√			√			√
Mytilus	J					√	√			√			√		√	√		√	√			√			√
edulis	L					√	√			√			√		√	√		√	√			√			√
Pacific oyster	A					√	√						√			√			√			√			√
Crassostrea	J					√	√						√			√			√			√			√
gigas	L																								
Horseneck gaper	A					√	√																		
Tresus	J					√	√																		
capax	L					√	√																		
Pacific gaper	A					√	√						√			√			√			√			√
Tresus	J					√	√						√			√			√			√			√
nuttallii	L					√	√						√			√						√			√
California jackknife clam	A												√			√						√			√
Tagelus	J												√			√						√			√
californianus	L												√			√						√			√
Pacific littleneck clam	A					√	√						√			√			√			√			√
Protothaca	J					√	√						√			√			√			√			√
staminea	L					√	√						√			√			√			√			√
Manila clam	A					√	√						√		√	√		√	√			√			
Venerupis	J					√	√						√		√	√		√	√			√			
japonica	L					√	√						√		√	√		√	√						
Softshell	A					√	√		√				√		√	√		√	√			√			√
Mya	J					√	√		√				√		√	√		√	√			√			√
arenaria	L					√	√		√				√		√	√		√	√			√			√
Geoduck	A						√																		√
Panopea	J						√																		√
abrupta	L						√																		√
Bay shrimp	A						√		√	√			√		√	√		√	√						
Crangon	J					√	√	√	√	√			√	√	√	√		√	√						
franciscorum	L					√	√		√	√			√		√	√		√	√						
Dungeness crab	A		√	√		√	√		√	√			√			√			√			√			√
Cancer	J		√	√		√	√		√	√			√		√	√		√	√			√			√
magister	L						√			√			√		√	√		√	√			√			
Leopard shark	A					√	√						√		√	√		√	√			√			√
Triakis	J					√	√						√		√	√		√	√			√			√
semifasciata	P						√						√			√		√	√			√			√
Green sturgeon	A	√	√	√		√	√	√	√	√				√	√	√		√	√						
Acipenser	J	√	√	√		√	√	√	√	√				√	√	√		√	√						
medirostris	L													√											
White sturgeon	A			√										√	√	√		√	√						
Acipenser	J	√	√	√			√			√				√	√	√		√	√						
transmontanus	L													√											
American shad	A	√	√	√				√	√	√				√	√	√									
Alosa	J	√	√	√			√	√	√	√				√	√	√		√	√						
sapidissima	L																								
Pacific herring	A			√		√	√		√	√			√			√			√			√			√
Clupea	J		√	√		√	√		√	√			√		√	√		√	√			√			√
pallasi	L					√	√		√	√			√		√	√		√	√			√			
Deepbody anchovy	A																								
Anchoa	J																								
compressa	L																								
Slough anchovy	A																								
Anchoa	J																								
delicatissima	L																								
Northern anchovy	A		√	√		√	√		√	√			√		√	√		√	√			√			√
Engraulis	J		√	√		√	√		√	√			√		√	√		√	√			√			√
mordax	L			√									√		√	√		√	√			√			√
		T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	*	M	S	*	*	S	*	*	S
		Klamath River			Humboldt Bay			Eel River			Tomales Bay			Central San Francisco Bay[1]			South San Francisco Bay			Elkhorn Slough			Morro Bay		

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[1] Includes San Pablo and Suisun Bays.

Legend:

T = Tidal fresh zone
M = Mixing zone
S = Seawater zone
* = Salinity zone is not present

A = Adults
J = Juveniles
L = Larvae
P = Parturition

√ = Species / lifestage is present
Blank = Species / lifestage is not present

		Santa Monica Bay			San Pedro Bay			Alamitos Bay			Anaheim Bay			Newport Bay			Mission Bay			San Diego Bay			Tijuana Estuary		
Species		*	*	S	*	*	S	*	*	S	*	*	S	*	*	S	*	*	S	*	*	S	*	*	S
Blue mussel	A			√			√			√			√			√			√			√			√
Mytilus	J			√			√			√			√			√			√			√			√
edulis	L			√			√			√			√			√			√			√			√
Pacific oyster	A																								
Crassostrea	J																								
gigas	L																								
Horseneck gaper	A																								
Tresus	J																								
capax	L																								
Pacific gaper	A			√			√			√			√			√			√			√			√
Tresus	J			√			√			√			√			√			√			√			√
nuttallii	L			√			√			√			√			√			√			√			√
California jackknife clam	A			√			√			√			√			√			√			√			√
Tagelus	J			√			√			√			√			√			√			√			√
californianus	L			√			√			√			√			√			√			√			√
Pacific littleneck clam	A			√			√			√			√			√			√			√			√
Protothaca	J			√			√			√			√			√			√			√			√
staminea	L			√			√			√			√			√			√			√			√
Manila clam	A																								
Venerupis	J																								
japonica	L																								
Softshell	A																								
Mya	J																								
arenaria	L																								
Geoduck	A						√																		
Panopea	J						√																		
abrupta	L						√																		
Bay shrimp	A																								
Crangon	J																								
franciscorum	L																								
Dungeness crab	A																								
Cancer	J																								
magister	L																								
Leopard shark	A			√			√			√			√			√			√			√			
Triakis	J			√			√			√			√			√			√			√			
semifasciata	P			√			√																		
Green sturgeon	A																								
Acipenser	J																								
medirostris	L																								
White sturgeon	A																								
Acipenser	J																								
transmontanus	L																								
American shad	A																								
Alosa	J																								
sapidissima	L																								
Pacific herring	A			√			√																		
Clupea	J			√			√																		
pallasi	L																								
Deepbody anchovy	A			√			√			√			√			√			√			√			
Anchoa	J			√			√			√			√			√			√			√			
compressa	L									√			√			√			√			√			
Slough anchovy	A						√			√			√			√			√			√			√
Anchoa	J						√			√			√			√			√			√			√
delicatissima	L									√						√			√			√			
Northern anchovy	A			√			√			√			√			√						√			
Engraulis	J			√			√			√			√			√						√			
mordax	L			√			√			√			√			√			√			√			√
		*	*	S	*	*	S	*	*	S	*	*	S	*	*	S	*	*	S	*	*	S	*	*	S
		Santa Monica Bay			San Pedro Bay			Alamitos Bay			Anaheim Bay			Newport Bay			Mission Bay			San Diego Bay			Tijuana Estuary		

Legend:
T = Tidal fresh zone
M = Mixing zone
S = Seawater zone
* = Salinity zone is not present

A = Adults
J = Juveniles
L = Larvae
P = Parturition

√ = Species / lifestage is present
Blank = Species / lifestage is not present

		Puget Sound			Hood Canal			Skagit Bay			Grays Harbor			Willapa Bay			Columbia River			Nehalem Bay			Tillamook Bay		
Species		T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S
Cutthroat trout	A	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Oncorhynchus	J	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
clarki	L																								
Pink salmon	A	√	√	√	√	√	√	√	√	√	√	√	√				√	√	√						
Oncorhynchus	J	√	√	√	√	√	√	√	√	√															
gorbuscha	L				√																				
Chum salmon	A	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Oncorhynchus	J	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
keta	L																								
Coho salmon	A	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Oncorhynchus	J	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
kisutch	L																								
Steelhead - fall	A																								
Oncorhynchus	J																								
mykiss (F)	L																								
Steelhead - half pounder	A																								
Oncorhynchus	J																								
mykiss (H)	L																								
Steelhead - summer	A	√	√	√	√	√	√	√	√	√							√	√	√				√	√	√
Oncorhynchus	J	√	√	√	√	√	√	√	√	√							√	√	√				√	√	√
mykiss (S)	L																								
Steelhead - winter	A	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Oncorhynchus	J	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
mykiss (W)	L																								
Sockeye salmon	A	√	√	√				√	√	√							√	√	√						
Oncorhynchus	J	√	√	√				√	√	√							√	√	√						
nerka	L																								
Chinook salmon - fall	A	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Oncorhynchus	J	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
tshawytscha (F)	L																								
Chinook salmon - late fall	A																								
Oncorhynchus	J																								
tshawytscha (LF)	L																								
Chinook salmon - winter	A																								
Oncorhynchus	J																								
tshawytscha (W)	L																								
Chinook salmon - spring	A	√	√	√	√	√	√	√	√	√	√	√	√				√	√	√				√	√	√
Oncorhynchus	J	√	√	√	√	√	√	√	√	√	√	√	√				√	√	√				√	√	√
tshawytscha (Sp)	L																								
Chinook salmon - summer	A																√	√	√						
Oncorhynchus	J																√	√	√						
tshawytscha (Su)	L																								
Surf smelt	A		√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
Hypomesus	J		√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
pretiosus	L		√	√		√			√	√		√	√		√	√		√	√		√	√			√
Longfin smelt	A		√	√					√	√		√	√		√	√		√	√						√
Spirinchus	J		√	√					√	√		√	√		√	√		√	√						
thaleichthys	L		√	√					√	√	√	√	√	√	√	√	√	√	√						
Eulachon	A			√						√	√	√	√	√	√	√	√	√	√						
Thaleichthys	J																								
pacificus	L										√	√	√	√	√	√	√	√	√						
Pacific tomcod	A		√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
Microgadus	J		√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
proximus	L		√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
Topsmelt	A												√			√			√			√		√	√
Atherinops	J												√			√			√			√		√	√
affinis	L																								
		T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S
		Puget Sound			Hood Canal			Skagit Bay			Grays Harbor			Willapa Bay			Columbia River			Nehalem Bay			Tillamook Bay		

Legend:

T = Tidal fresh zone	A = Adults	√ = Species / lifestage is present
M = Mixing zone	J = Juveniles	Blank = Species / lifestage is not present
S = Seawater zone	L = Larvae	

		Netarts Bay			Siletz River			Yaquina Bay			Alsea River			Siuslaw River			Umpqua River			Coos Bay			Rogue River		
Species		T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S
Cutthroat trout	A	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Oncorhynchus	J	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
clarki	L																								
Pink salmon	A							√	√	√	√	√	√										√	√	√
Oncorhynchus	J																								
gorbuscha	L																								
Chum salmon	A	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√			√	√	√	√			√
Oncorhynchus	J	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√				√	√	√			
keta	L																								
Coho salmon	A	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Oncorhynchus	J	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
kisutch	L																								
Steelhead - fall	A																								
Oncorhynchus	J																								
mykiss (F)	L																								
Steelhead - half pounder	A																								
Oncorhynchus	J																						√	√	√
mykiss (H)	L																								
Steelhead - summer	A				√	√	√				√	√	√				√	√	√				√	√	√
Oncorhynchus	J				√	√	√				√	√	√				√	√	√				√	√	√
mykiss (S)	L																								
Steelhead - winter	A	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Oncorhynchus	J	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
mykiss (W)	L																								
Sockeye salmon	A																								
Oncorhynchus	J																								
nerka	L																								
Chinook salmon - fall	A	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Oncorhynchus	J	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
tshawytscha (F)	L																								
Chinook salmon - late fall	A																								
Oncorhynchus	J																								
tshawytscha (LF)	L																								
Chinook salmon - winter	A																								
Oncorhynchus	J																								
tshawytscha (W)	L																								
Chinook salmon - spring	A				√	√	√	√	√	√	√	√	√				√	√	√	√	√	√	√	√	√
Oncorhynchus	J				√	√	√	√	√	√	√	√	√				√	√	√	√	√	√	√	√	√
tshawytscha (Sp)	L																								
Chinook salmon - summer	A																								
Oncorhynchus	J																								
tshawytscha (Su)	L																								
Surf smelt	A		√	√		√	√		√	√		√	√		√	√		√	√		√	√			√
Hypomesus	J		√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
pretiosus	L			√			√			√			√			√			√			√			√
Longfin smelt	A							√	√	√			√			√			√	√	√	√			
Spirinchus	J								√	√			√			√			√		√	√			
thaleichthys	L							√												√	√	√			
Eulachon	A															√	√	√	√			√	√	√	√
Thaleichthys	J																								
pacificus	L																√	√	√						
Pacific tomcod	A					√	√		√	√		√	√		√	√		√	√		√	√		√	√
Microgadus	J		√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
proximus	L			√					√	√		√	√		√	√		√	√						
Topsmelt	A		√	√					√	√		√	√		√	√			√		√	√			
Atherinops	J		√	√					√	√		√	√		√	√			√		√	√			
affinis	L		√	√					√	√		√	√		√	√					√	√			
		T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S
		Netarts Bay			Siletz River			Yaquina Bay			Alsea River			Siuslaw River			Umpqua River			Coos Bay			Rogue River		

Legend:

T = Tidal fresh zone	A = Adults	√ = Species / lifestage is present
M = Mixing zone	J = Juveniles	Blank = Species / lifestage is not present
S = Seawater zone	L = Larvae	

		Klamath River			Humboldt Bay			Eel River			Tomales Bay			Central San Francisco Bay[1]			South San Francisco Bay			Elkhorn Slough			Morro Bay		
Species		T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	*	M	S	*	*	S	*	*	S
Cutthroat trout	A	√	√	√	√	√	√	√	√	√															
Oncorhynchus	J	√	√	√	√	√	√	√	√	√															
clarki	L																								
Pink salmon	A	√	√	√									√												
Oncorhynchus	J																								
gorbuscha	L																								
Chum salmon	A	√	√	√			√	√	√	√															
Oncorhynchus	J	√	√	√																					
keta	L																								
Coho salmon	A	√	√	√	√	√	√	√	√	√	√	√	√												
Oncorhynchus	J	√	√	√	√	√	√	√	√	√	√	√	√												
kisutch	L																								
Steelhead - fall	A	√	√	√																					
Oncorhynchus	J	√	√	√																					
mykiss (F)	L																								
Steelhead - half pounder	A																								
Oncorhynchus	J	√	√	√				√	√	√															
mykiss (H)	L																								
Steelhead - summer	A	√	√	√				√	√	√															
Oncorhynchus	J	√	√	√				√	√	√															
mykiss (S)	L																								
Steelhead - winter	A	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√									√
Oncorhynchus	J	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√									√
mykiss (W)	L																								
Sockeye salmon	A																								
Oncorhynchus	J																								
nerka	L																								
Chinook salmon - fall	A	√	√	√	√	√	√	√	√	√				√	√	√			√						
Oncorhynchus	J	√	√	√	√	√	√	√	√	√				√	√	√			√						
tshawytscha (F)	L																								
Chinook salmon - late fall	A													√	√	√			√						
Oncorhynchus	J													√	√	√			√						
tshawytscha (LF)	L																								
Chinook salmon - winter	A													√	√	√									
Oncorhynchus	J													√	√	√			√						
tshawytscha (W)	L																								
Chinook salmon - spring	A	√	√	√										√	√	√			√						
Oncorhynchus	J	√	√	√										√	√	√			√						
tshawytscha (Sp)	L																								
Chinook salmon - summer	A																								
Oncorhynchus	J																								
tshawytscha (Su)	L																								
Surf smelt	A			√		√	√		√	√			√		√	√			√						
Hypomesus	J		√	√		√	√		√	√			√		√	√			√			√			
pretiosus	L					√	√		√	√			√												
Longfin smelt	A			√	√	√	√	√	√	√				√	√	√		√	√						
Spirinchus	J			√		√	√		√	√				√	√	√		√	√						
thaleichthys	L				√	√	√	√	√	√				√	√	√		√	√						
Eulachon	A	√	√	√			√																		
Thaleichthys	J																								
pacificus	L	√	√	√																					
Pacific tomcod	A					√	√						√		√	√		√	√						
Microgadus	J			√		√	√			√			√		√	√		√	√			√			
proximus	L																								
Topsmelt	A					√	√		√	√			√		√	√		√	√			√			√
Atherinops	J					√	√		√	√			√		√	√		√	√			√			√
affinis	L					√	√		√	√			√			√		√	√			√			√
		T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	*	M	S	*	*	S	*	*	S
		Klamath River			Humboldt Bay			Eel River			Tomales Bay			Central San Francisco Bay[1]			South San Francisco Bay			Elkhorn Slough			Morro Bay		

[1] Includes San Pablo and Suisun Bays.

Legend:

T = Tidal fresh zone	A = Adults	√ = Species / lifestage is present
M = Mixing zone	J = Juveniles	Blank = Species / lifestage is not present
S = Seawater zone	L = Larvae	
* = Salinity zone is not present		

Species		Santa Monica Bay			San Pedro Bay			Alamitos Bay			Anaheim Bay			Newport Bay			Mission Bay			San Diego Bay			Tijuana Estuary		
		*	*	S	*	*	S	*	*	S	*	*	S	*	*	S	*	*	S	*	*	S	*	*	S
Cutthroat trout	A																								
Oncorhynchus	J																								
clarki	L																								
Pink salmon	A																								
Oncorhynchus	J																								
gorbuscha	L																								
Chum salmon	A																								
Oncorhynchus	J																								
keta	L																								
Coho salmon	A																								
Oncorhynchus	J																								
kisutch	L																								
Steelhead - fall	A																								
Oncorhynchus	J																								
mykiss (F)	L																								
Steelhead - half pounder	A																								
Oncorhynchus	J																								
mykiss (H)	L																								
Steelhead - summer	A																								
Oncorhynchus	J																								
mykiss (S)	L																								
Steelhead - winter	A																								
Oncorhynchus	J																								
mykiss (W)	L																								
Sockeye salmon	A																								
Oncorhynchus	J																								
nerka	L																								
Chinook salmon - fall	A			√																					
Oncorhynchus	J																								
tshawytscha (F)	L																								
Chinook salmon - late fall	A																								
Oncorhynchus	J																								
tshawytscha (LF)	L																								
Chinook salmon - winter	A																								
Oncorhynchus	J																								
tshawytscha (W)	L																								
Chinook salmon - spring	A																								
Oncorhynchus	J																								
tshawytscha (Sp)	L																								
Chinook salmon - summer	A																								
Oncorhynchus	J																								
tshawytscha (Su)	L																								
Surf smelt	A																								
Hypomesus	J																								
pretiosus	L																								
Longfin smelt	A																								
Spirinchus	J																								
thaleichthys	L																								
Eulachon	A																								
Thaleichthys	J																								
pacificus	L																								
Pacific tomcod	A																								
Microgadus	J																								
proximus	L																								
Topsmelt	A			√			√			√			√			√			√			√			√
Atherinops	J			√			√			√			√			√			√			√			√
affinis	L			√			√			√			√			√			√			√			√
		*	*	S	*	*	S	*	*	S	*	*	S	*	*	S	*	*	S	*	*	S	*	*	S
		Santa Monica Bay			San Pedro Bay			Alamitos Bay			Anaheim Bay			Newport Bay			Mission Bay			San Diego Bay			Tijuana Estuary		

Legend:

T = Tidal fresh zone	A = Adults	√ = Species / lifestage is present
M = Mixing zone	J = Juveniles	Blank = Species / lifestage is not present
S = Seawater zone	L = Larvae	
* = Salinity zone is not present		

Species		Puget Sound			Hood Canal			Skagit Bay			Grays Harbor			Willapa Bay			Columbia River			Nehalem Bay			Tillamook Bay		
		T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S
Jacksmelt	A																								
Atherinopsis	J																								
californiensis	L																								
Threespine stickleback	A	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√		√	√	√	√	√	√
Gasterosteus	J	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√		√	√	√	√	√	√
aculeatus	L	√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√	
Striped bass	A			√						√															
Morone	J																								
saxatilis	L																								
Kelp bass	A																								
Paralabrax	J																								
clathratus	L																								
Barred sand bass	A																								
Paralabrax	J																								
nebulifer	L																								
White seabass	A									√															
Atractoscion	J																								
nobilis	L																								
White croaker	A																								
Genyonemus	J																								
lineatus	L																								
Shiner perch	A		√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
Cymatogaster	J	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
aggregata	P		√			√			√			√			√			√			√	√		√	√
Pacific sand lance	A		√	√		√	√		√	√			√			√		√	√		√	√		√	√
Ammodytes	J		√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
hexapterus	L		√	√		√	√		√	√		√	√		√	√		√	√			√			√
Arrow goby	A		√	√		√	√		√	√		√	√		√	√									√
Clevelandia	J		√	√		√	√		√	√		√	√		√	√									√
ios	L		√	√		√	√		√	√		√	√		√	√									
Lingcod	A			√			√			√															
Ophiodon	J		√	√		√	√		√	√		√	√		√	√		√	√			√			√
elongatus	L		√	√		√	√		√	√		√	√		√	√									
Pacific staghorn sculpin	A		√	√		√	√		√	√		√	√		√	√	√	√	√		√	√		√	√
Leptocottus	J	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
armatus	L		√	√		√	√		√	√			√			√		√	√			√			√
California halibut	A																								
Paralichthys	J																								
californicus	L																								
Diamond turbot	A																								
Hypsopsetta	J																								
guttulata	L																								
English sole	A			√			√			√															
Pleuronectes	J		√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
vetulus	L		√	√		√	√		√	√		√	√		√	√		√	√			√		√	√
Starry flounder	A		√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
Platichthys	J	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
stellatus	L		√	√		√	√		√	√		√	√		√	√		√			√	√		√	√
		T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S
		Puget Sound			Hood Canal			Skagit Bay			Grays Harbor			Willapa Bay			Columbia River			Nehalem Bay			Tillamook Bay		

Legend:
T = Tidal fresh zone
M = Mixing zone
S = Seawater zone

A = Adults
J = Juveniles
L = Larvae
P = Parturition

√ = Species / lifestage is present
Blank = Species / lifestage is not present

		Netarts Bay			Siletz River			Yaquina Bay			Alsea River			Siuslaw River			Umpqua River			Coos Bay			Rogue River		
Species		T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S
Jacksmelt	A									√											√	√			
Atherinopsis	J									√											√	√			
californiensis	L																								
Threespine stickleback	A		√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
Gasterosteus	J		√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
aculeatus	L		√		√	√		√	√		√	√		√	√		√	√		√	√		√	√	
Striped bass	A						√			√				√			√	√	√	√	√				
Morone	J													√			√	√	√	√	√				
saxatilis	L													√			√			√					
Kelp bass	A																								
Paralabrax	J																								
clathratus	L																								
Barred sand bass	A																								
Paralabrax	J																								
nebulifer	L																								
White seabass	A									√												√			
Atractoscion	J																								
nobilis	L																								
White croaker	A																								
Genyonemus	J																								
lineatus	L																								
Shiner perch	A		√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
Cymatogaster	J		√	√		√	√	√	√	√	√	√	√		√	√		√	√		√	√		√	√
aggregata	P		√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
Pacific sand lance	A			√			√			√			√			√			√			√			
Ammodytes	J			√			√			√			√			√			√			√			
hexapterus	L			√			√			√			√			√			√			√			
Arrow goby	A			√					√	√					√			√	√		√	√			
Clevelandia	J			√					√						√			√	√		√	√			
ios	L								√												√	√			
Lingcod	A									√												√			
Ophiodon	J			√						√			√			√			√		√	√			
elongatus	L																					√			
Pacific staghorn sculpin	A		√	√		√	√		√	√		√	√		√	√		√	√		√	√		√	√
Leptocottus	J	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√		√	√
armatus	L			√			√			√			√			√			√			√			√
California halibut	A																								
Paralichthys	J																								
californicus	L																								
Diamond turbot	A																								
Hypsopsetta	J																								
guttulata	L																								
English sole	A																								
Pleuronectes	J		√	√		√	√		√	√		√	√		√	√		√	√		√	√			√
vetulus	L			√			√			√						√			√			√			
Starry flounder	A					√	√		√	√		√	√		√	√		√	√		√	√			
Platichthys	J		√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√
stellatus	L		√	√		√	√		√	√			√			√			√			√			√
		T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	T	M	S
		Netarts Bay			Siletz River			Yaquina Bay			Alsea River			Siuslaw River			Umpqua River			Coos Bay			Rogue River		

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		Klamath River			Humboldt Bay			Eel River			Tomales Bay			Central San Francisco Bay[1]			South San Francisco Bay			Elkhorn Slough			Morro Bay		
Species		T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	*	M	S	*	*	S	*	*	S
Jacksmelt	A					√	√						√		√	√		√	√			√			√
Atherinopsis	J					√	√						√		√	√		√	√			√			√
californiensis	L					√	√						√		√	√		√	√			√			√
Threespine stickleback	A	√	√	√	√	√	√	√	√	√			√	√	√	√		√	√			√			√
Gasterosteus	J	√	√	√	√	√	√	√	√	√			√	√	√	√		√	√			√			√
aculeatus	L	√	√		√	√		√	√				√	√	√			√							
Striped bass	A			√									√	√	√	√		√	√						
Morone	J													√	√	√		√	√						
saxatilis	L													√	√										
Kelp bass	A																								
Paralabrax	J																								
clathratus	L																								
Barred sand bass	A																								
Paralabrax	J																								
nebulifer	L																								
White seabass	A						√						√			√			√						
Atractoscion	J						√						√		√	√			√						
nobilis	L																								
White croaker	A						√						√			√		√	√						
Genyonemus	J						√						√		√	√		√	√						
lineatus	L												√		√	√		√	√			√			
Shiner perch	A		√	√		√	√		√	√			√		√	√		√	√			√			√
Cymatogaster	J		√	√		√	√		√	√			√		√	√		√	√			√			√
aggregata	P		√	√		√	√		√	√			√		√	√		√	√			√			√
Pacific sand lance	A						√			√			√			√			√			√			
Ammodytes	J						√			√			√			√			√			√			
hexapterus	L						√						√												
Arrow goby	A					√	√						√		√	√		√	√			√			√
Clevelandia	J					√	√						√		√	√		√	√			√			√
ios	L					√	√						√		√	√		√	√			√			√
Lingcod	A						√																		
Ophiodon	J					√	√						√		√	√			√			√			√
elongatus	L						√						√			√									
Pacific staghorn sculpin	A		√	√		√	√		√	√			√		√	√		√	√			√			√
Leptocottus	J		√	√		√	√		√	√			√	√	√	√		√	√			√			√
armatus	L			√			√			√			√		√	√		√	√			√			√
California halibut	A														√	√		√	√			√			√
Paralichthys	J						√						√		√	√		√	√			√			√
californicus	L												√			√			√			√			√
Diamond turbot	A												√			√		√	√			√			√
Hypsopsetta	J												√		√	√		√	√			√			√
guttulata	L												√					√	√						
English sole	A																								
Pleuronectes	J			√		√	√		√	√			√		√	√		√	√			√			√
vetulus	L					√	√			√			√		√	√			√			√			√
Starry flounder	A					√	√			√			√		√	√		√	√			√			
Platichthys	J	√	√	√	√	√	√	√	√	√			√	√	√	√		√	√			√			√
stellatus	L			√		√	√			√			√		√	√		√	√						
		T	M	S	T	M	S	T	M	S	T	M	S	T	M	S	*	M	S	*	*	S	*	*	S
		Klamath River			Humboldt Bay			Eel River			Tomales Bay			Central San Francisco Bay[1]			South San Francisco Bay			Elkhorn Slough			Morro Bay		

[1] Includes San Pablo and Suisun Bays.

Legend:
T = Tidal fresh zone
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S = Seawater zone
* = Salinity zone not present

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√ = Species / lifestage is present
Blank = Species / lifestage is not present

		Santa Monica Bay			San Pedro Bay			Alamitos Bay			Anaheim Bay			Newport Bay			Mission Bay			San Diego Bay			Tijuana Estuary		
Species		*	*	S	*	*	S	*	*	S	*	*	S	*	*	S	*	*	S	*	*	S	*	*	S
Jacksmelt	A			√			√									√			√			√			
Atherinopsis	J			√			√									√			√			√			
californiensis	L			√			√												√			√			
Threespine stickleback	A																								
Gasterosteus	J																								
aculeatus	L																								
Striped bass	A			√												√			√						
Morone	J																								
saxatilis	L																								
Kelp bass	A			√			√			√			√			√			√			√			√
Paralabrax	J			√			√			√			√			√			√			√			√
clathratus	L			√			√												√			√			
Barred sand bass	A			√			√			√			√			√			√			√			√
Paralabrax	J			√			√			√			√			√			√			√			√
nebulifer	L			√			√												√			√			
White seabass	A			√			√															√			
Atractoscion	J			√			√						√			√			√			√			√
nobilis	L			√			√																		
White croaker	A			√			√			√			√			√			√			√			√
Genyonemus	J			√			√			√			√			√			√			√			√
lineatus	L			√			√			√			√			√			√			√			√
Shiner perch	A			√			√			√			√			√			√			√			√
Cymatogaster	J			√			√			√			√			√			√			√			√
aggregata	P			√			√			√			√			√			√			√			
Pacific sand lance	A																								
Ammodytes	J																								
hexapterus	L																								
Arrow goby	A			√			√			√			√			√			√			√			√
Clevelandia	J			√			√			√			√			√			√			√			√
ios	L						√			√			√			√			√			√			√
Lingcod	A			√			√																		
Ophiodon	J			√			√																		
elongatus	L																								
Pacific staghorn sculpin	A			√			√			√			√						√			√			√
Leptocottus	J			√			√			√			√			√			√			√			√
armatus	L			√						√			√						√			√			√
California halibut	A			√			√						√			√			√			√			√
Paralichthys	J			√			√			√			√			√			√			√			√
californicus	L			√			√									√									
Diamond turbot	A			√			√			√			√			√			√			√			√
Hypsopsetta	J			√			√			√			√			√			√			√			√
guttulata	L			√			√			√			√						√			√			√
English sole	A			√			√																		
Pleuronectes	J			√			√																		
vetulus	L			√			√																		
Starry flounder	A																								
Platichthys	J																								
stellatus	L																								
		*	*	S	*	*	S	*	*	S	*	*	S	*	*	S	*	*	S	*	*	S	*	*	S
		Santa Monica Bay			San Pedro Bay			Alamitos Bay			Anaheim Bay			Newport Bay			Mission Bay			San Diego Bay			Tijuana Estuary		

Legend:
T = Tidal fresh zone
M = Mixing zone
S = Seawater zone
* = Salinity zone is not present

A = Adults
J = Juveniles
L = Larvae
P = Parturition

√ = Species / lifestage is present
Blank = Species / lifestage is not present

Appendix 5: Life history tables: Life history characteristics of 47 west coast species

Index to Appendix tables 5A-5D: Page location of Biogeography, Habitat Associations, Biological Attributes and Economic Value, and Reproduction tables for each species.

Appendix Table 5A. Biogeography

Life stage/activity
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

		BIOGEOGRAPHY																						
		Marine				Estuarine																Riverine		
						Salinity Range									Estuary Type				Stratification					
						SAB			Venice System															
	Life stage/activity	Beach	Continental shelf	Continental slope	Oceanic	Tidal Fresh (0-0.5‰)	Mixing (0.5-25.0‰)	Seawater (>25.0‰)	Limnetic (0-0.5‰)	Oligohaline (0.5-5‰)	Mesohaline (5-18‰)	Polyhaline (18-30‰)	Euhaline (>30‰)	Drowned river	Bar-built	Fjord	Tectonic	Highly	Moderately	Homogeneous	Coastal plain	Piedmont	Upland	Life stage/activity
Blue mussel *Mytilus edulis*	A	●	●				●	●			●	●	●	●	●	●	●	●	●	●				A
	S	●	●				●	●			●	●	●	●	●	●	●	●	●	●				S
	J	●	●				●	●			●	●	●	●	●	●	●	●	●	●				J
	L	●	●				●	●			●	●	●	●	●	●	●	●	●	●				L
	E	●	●				●	●			●	●	●	●	●	●	●	●	●	●				E
Pacific oyster *Crassostrea gigas*	A						●	●			●	●	●	●	●	●	●	●	●	●				A
	S						●	●			●	●	●	●	●	●	●	●	●	●				S
	J						●	●			●	●	●	●	●	●	●	●	●	●				J
	L						●	●			●	●	●	●	●	●	●	●	●	●				L
	E						●	●			●	●	●	●	●	●	●	●	●	●				E
Horseneck gaper *Tresus capax*	A	●	●				●	●				●	●	●	●	●	●	●	●	●				A
	S	●	●				●	●				●	●	●	●	●	●	●	●	●				S
	J	●	●				●	●				●	●	●	●	●	●	●	●	●				J
	L	●	●				●	●				●	●	●	●	●	●	●	●	●				L
	E	●	●				●	●				●	●	●	●	●	●	●	●	●				E
Pacific gaper *Tresus nuttallii*	A	●	●				●	●				●	●	●	●	●	●	●	●	●				A
	S	●	●				●	●				●	●	●	●	●	●	●	●	●				S
	J	●	●				●	●				●	●	●	●	●	●	●	●	●				J
	L	●	●				●	●				●	●	●	●	●	●	●	●	●				L
	E	●	●				●	●				●	●	●	●	●	●	●	●	●				E
California jackknife clam *Tagelus californianus*	A						●	●			●	●	●	●	●				●	●				A
	S						●	●			●	●	●	●	●				●	●				S
	J						●	●			●	●	●	●	●				●	●				J
	L						●	●			●	●	●	●	●				●	●				L
	E						●	●			●	●	●	●	●				●	●				E
Pacific littleneck clam *Protothaca staminea*	A	●	●				●	●			●	●	●	●	●	●	●	●	●	●				A
	S	●	●				●	●			●	●	●	●	●	●	●	●	●	●				S
	J	●	●				●	●			●	●	●	●	●	●	●	●	●	●				J
	L	●	●				●	●			●	●	●	●	●	●	●	●	●	●				L
	E	●	●				●	●			●	●	●	●	●	●	●	●	●	●				E
Manila clam *Venerupis japonica*	A						●	●			●	●	●	●	●	●	●	●	●	●				A
	S						●	●			●	●	●	●	●	●	●	●	●	●				S
	J						●	●			●	●	●	●	●	●	●	●	●	●				J
	L						●	●			●	●	●	●	●	●	●	●	●	●				L
	E						●	●			●	●	●	●	●	●	●	●	●	●				E
Softshell *Mya arenaria*	A						●	●			●	●	●	●	●	●	●	●	●	●				A
	S						●	●			●	●	●	●	●	●	●	●	●	●				S
	J						●	●			●	●	●	●	●	●	●	●	●	●				J
	L						●	●			●	●	●	●	●	●	●	●	●	●				L
	E						●	●			●	●	●	●	●	●	●	●	●	●				E

<u>Life stage/activity</u>
A - Adults
S - Spawning adults
M - Mating
J - Juveniles
L - Larvae
E - Eggs
P - Parturition

		BIOGEOGRAPHY																						
		Marine				Estuarine															Riverine			
						Salinity Range								Estuary Type				Stratification						
						SAB			Venice System															
	Life stage/activity	Beach	Continental shelf	Continental slope	Oceanic	Tidal Fresh (0-0.5‰)	Mixing (0.5-25.0‰)	Seawater (>25.0‰)	Limnetic (0-0.5‰)	Oligohaline (0.5-5‰)	Mesohaline (5-18‰)	Polyhaline (18-30‰)	Euhaline (>30‰)	Drowned river	Bar-built	Fjord	Tectonic	Highly	Moderately	Homogeneous	Coastal plain	Piedmont	Upland	Life stage/activity
Geoduck *Panopea abrupta*	A	●	●				●	●				●	●		●	●		●	●	●				A
	S	●	●				●	●				●	●		●	●		●	●	●				S
	J	●	●				●	●				●	●		●	●		●	●	●				J
	L	●	●				●	●				●	●		●	●		●	●	●				L
	E	●	●				●	●				●	●		●	●		●	●	●				E
Bay shrimp *Crangon franciscorum*	A		●				●	●		●	●	●	●	●	●	●	●	●	●	●				A
	S		●				●	●			●	●	●	●	●	●	●	●	●	●				S
	J		●			●	●	●		●	●	●	●	●	●	●	●	●	●	●	●			J
	L		●				●	●			●	●	●	●	●	●	●	●	●	●				L
	E		●				●	●			●	●	●	●	●	●	●	●	●	●				E
Dungeness crab *Cancer magister*	A	●	●				●	●			●	●	●	●	●	●	●	●	●	●				A
	M		●					●					●			●		●						M
	J		●				●	●			●	●	●	●	●	●	●	●	●	●				J
	L		●				●	●				●	●	●	●	●	●	●	●	●				L
	E	●	●					●					●			●		●						E
Leopard shark *Triakis semifasciata*	A	●	●					●				●	●	●	●		●		●	●				A
	M		●					●				●	●	●	●		●		●	●				M
	J	●	●					●				●	●	●	●		●		●	●				J
	P		●					●				●	●	●	●		●		●	●				P
Green sturgeon *Acipenser medirostris*	A	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●		A
	S																					●		S
	J	●	●			●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●		J
	L					●			●					●							●	●		L
	E																					●		E
White sturgeon *Acipenser transmontanus*	A	●	●			●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	A
	S																					●	●	S
	J	●	●			●	●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	J
	L					●			●					●							●	●	●	L
	E																					●	●	E
American shad *Alosa sapidissima*	A		●	●		●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	A
	S					●			●					●							●	●	●	S
	J		●			●	●	●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	J
	L					●			●					●							●	●	●	L
	E					●			●					●							●	●	●	E
Pacific herring *Clupea pallasi*	A	●	●	●			●	●			●	●	●	●	●	●	●	●	●	●				A
	S	●	●				●	●				●	●	●	●	●	●	●	●	●				S
	J	●	●				●	●			●	●	●	●	●	●	●	●	●	●				J
	L	●	●				●	●			●	●	●	●	●	●	●	●	●	●				L
	E	●	●				●	●			●	●	●	●	●	●	●	●	●	●				E

Life stage/activity
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

		BIOGEOGRAPHY																						
		Marine				Estuarine																Riverine			
						Salinity Range								Estuary Type				Stratification						
						SAB			Venice System															
	Life stage/activity	Beach	Continental shelf	Continental slope	Oceanic	Tidal Fresh (0-0.5‰)	Mixing (0.5-25.0‰)	Seawater (>25.0‰)	Limnetic (0-0.5‰)	Oligohaline (0.5-5‰)	Mesohaline (5-18‰)	Polyhaline (18-30‰)	Euhaline (>30‰)	Drowned river	Bar-built	Fjord	Tectonic	Highly	Moderately	Homogeneous	Coastal plain	Piedmont	Upland	Life stage/activity
Deepbody anchovy *Anchoa compressa*	A		●					●					●		●					●				A
	S							●					●		●					●				S
	J		●					●					●		●					●				J
	L							●					●		●					●				L
	E							●					●		●					●				E
Slough anchovy *Anchoa delicatissima*	A		●					●					●		●					●				A
	S							●					●		●					●				S
	J		●					●					●		●					●				J
	L							●					●		●					●				L
	E							●					●		●					●				E
Northern anchovy *Engraulis mordax*	A		●	●			●	●			●	●	●	●	●	●	●	●	●	●				A
	S		●					●					●	●		●	●	●	●					S
	J		●	●			●	●			●	●	●	●	●	●	●	●	●	●				J
	L		●				●	●			●	●	●	●	●	●	●	●	●	●				L
	E		●					●					●	●		●	●	●	●					E
Cutthroat trout *Oncorhynchus clarki*	A		●			●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●		A
	S					●			●												●	●		S
	J		●			●	●	●	●	●	●	●	●	●	●	●		●	●	●	●	●		J
	L					●			●												●	●		L
	E					●			●												●	●		E
Pink salmon *Oncorhynchus gorbuscha*	A		●			●	●	●	●	●	●	●	●	●		●		●	●	●	●	●	●	A
	S					●			●					●		●					●	●	●	S
	J	●	●	●	●	●	●	●	●	●	●	●	●	●		●		●	●	●	●	●	●	J
	L					●			●					●		●					●	●	●	L
	E					●			●					●		●					●	●	●	E
Chum salmon *Oncorhynchus keta*	A		●			●	●	●	●	●	●	●	●	●		●		●	●	●	●	●	●	A
	S					●			●					●		●					●	●	●	S
	J	●	●	●	●	●	●	●	●	●	●	●	●	●		●		●	●	●	●	●	●	J
	L					●			●					●		●					●	●	●	L
	E					●			●					●		●					●	●	●	E
Coho salmon *Oncorhynchus kisutch*	A		●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	A
	S					●			●					●	●	●	●				●	●	●	S
	J	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	J
	L					●			●					●	●	●	●				●	●	●	L
	E					●			●					●	●	●	●				●	●	●	E
Steelhead *Oncorhynchus mykiss*	A		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	A
	S					●			●					●	●	●	●				●	●	●	S
	J		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	J
	L					●			●					●	●	●	●				●	●	●	L
	E					●			●					●	●	●	●				●	●	●	E

Life stage/activity
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

		BIOGEOGRAPHY																						
		Marine				Estuarine															Riverine			
						Salinity Range								Estuary Type				Stratification						
						SAB			Venice System															
	Life stage/activity	Beach	Continental shelf	Continental slope	Oceanic	Tidal Fresh (0-0.5‰)	Mixing (0.5-25.0‰)	Seawater (>25.0‰)	Limnetic (0-0.5‰)	Oligohaline (0.5-5‰)	Mesohaline (5-18‰)	Polyhaline (18-30‰)	Euhaline (>30‰)	Drowned river	Bar-built	Fjord	Tectonic	Highly	Moderately	Homogeneous	Coastal plain	Piedmont	Upland	Life stage/activity
Sockeye salmon *Oncorhynchus nerka*	A		●			●	●	●	●	●	●	●	●	●		●		●	●	●	●	●	●	A
	S								●												●	●	●	S
	J		●	●	●	●	●	●	●	●	●	●	●	●		●		●	●	●	●	●	●	J
	L								●												●	●	●	L
	E								●												●	●	●	E
Chinook salmon *Oncorhynchus tshawytscha*	A		●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	A
	S					●			●					●	●	●	●				●	●	●	S
	J	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	J
	L					●			●					●	●	●	●				●	●	●	L
	E					●			●					●	●	●	●				●	●	●	E
Surf smelt *Hypomesus pretiosus*	A	●	●				●	●			●	●	●	●	●	●		●	●	●				A
	S	●					●	●				●	●			●		●	●	●				S
	J		●				●	●		●	●	●	●	●	●	●		●	●	●				J
	L	●					●	●				●	●			●		●	●	●				L
	E	●					●	●				●	●			●		●	●	●				E
Longfin smelt *Spirinchus thaleichthys*	A		●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			A
	S					●			●					●	●	●		●	●	●	●			S
	J		●				●	●		●	●	●	●	●	●	●	●	●	●	●				J
	L					●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			L
	E					●			●					●	●	●		●	●	●	●			E
Eulachon *Thaleichthys pacificus*	A		●	●		●	●	●	●	●	●	●	●	●		●		●	●	●	●	●		A
	S					●			●					●		●		●	●	●	●	●		S
	J		●	●																				J
	L					●	●	●	●	●	●	●	●	●		●		●	●	●	●	●		L
	E					●			●					●		●		●	●	●	●	●		E
Pacific tomcod *Microgadus proximus*	A		●				●	●				●	●	●	●	●	●	●	●	●				A
	S		●					●					●			●								S
	J		●				●	●			●	●	●	●	●	●	●	●	●	●				J
	L		●					●				●	●	●	●	●	●	●	●	●				L
	E		●					●					●			●								E
Topsmelt *Atherinops affinis*	A	●	●				●	●			●	●	●	●	●		●	●	●	●				A
	S						●	●				●	●	●	●		●	●	●	●				S
	J	●	●				●	●			●	●	●	●	●		●	●	●	●				J
	L						●	●			●	●	●	●	●		●	●	●	●				L
	E						●	●				●	●	●	●		●	●	●	●				E
Jacksmelt *Atherinopsis californiensis*	A		●				●	●			●	●	●	●	●		●	●	●	●				A
	S		●				●	●				●	●	●	●		●	●	●	●				S
	J		●				●	●			●	●	●	●	●		●	●	●	●				J
	L		●				●	●			●	●	●	●	●		●	●	●	●				L
	E		●				●	●				●	●	●	●		●	●	●	●				E

Life stage/activity
A - Adults
S - Spawning adults
M - Mating
J - Juveniles
L - Larvae
E - Eggs
P - Parturition

		BIOGEOGRAPHY																						
		Marine				Estuarine															Riverine			
						Salinity Range								Estuary Type				Stratification						
						SAB			Venice System															
	Life stage/activity	Beach	Continental shelf	Continental slope	Oceanic	Tidal Fresh (0-0.5‰)	Mixing (0.5-25.0‰)	Seawater (>25.0‰)	Limnetic (0-0.5‰)	Oligohaline (0.5-5‰)	Mesohaline (5-18‰)	Polyhaline (18-30‰)	Euhaline (>30‰)	Drowned river	Bar-built	Fjord	Tectonic	Highly	Moderately	Homogeneous	Coastal plain	Piedmont	Upland	Life stage/activity
Threespine stickleback *Gasterosteus aculeatus*	A	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			A
	S					●	●		●	●	●			●	●	●	●	●	●	●	●			S
	J	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			J
	L					●	●		●	●	●			●	●	●	●	●	●	●	●			L
	E					●	●		●	●	●			●	●	●	●	●	●	●	●			E
Striped bass *Morone saxatilis*	A	●	●			●	●	●	●	●	●	●	●	●			●	●	●		●			A
	S					●			●					●			●	●	●		●			S
	J					●	●	●	●	●	●	●	●	●			●	●	●		●			J
	L					●	●	●	●	●	●	●	●	●			●	●	●		●			L
	E					●	●		●	●	●			●			●	●	●		●			E
Kelp bass *Paralabrax clathratus*	A	●	●	●				●					●		●					●				A
	S		●					●					●											S
	J	●	●					●					●		●					●				J
	L		●					●					●		●					●				L
	E		●					●					●											E
Barred sand bass *Paralabrax nebulifer*	A	●	●					●					●		●					●				A
	S		●					●					●											S
	J	●	●					●					●		●					●				J
	L		●					●					●		●					●				L
	E		●					●					●											E
White seabass *Atractoscion nobilis*	A		●					●					●	●	●		●			●				A
	S		●					●					●											S
	J	●	●					●					●	●	●		●			●				J
	L	●	●					●					●		●					●				L
	E		●					●					●											E
White croaker *Genyonemus lineatus*	A	●	●				●	●			●	●	●	●	●		●		●	●				A
	S		●					●					●	●			●							S
	J	●	●				●	●			●	●	●	●	●		●		●	●				J
	L	●	●				●	●			●	●	●	●	●		●		●	●				L
	E		●					●					●	●			●							E
Shiner perch *Cymatogaster aggregata*	A	●	●				●	●			●	●	●	●	●	●	●	●	●	●				A
	M						●	●			●	●	●	●	●	●	●	●	●	●				M
	J	●	●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●				J
	P						●	●			●	●	●	●	●	●	●	●	●	●				P
Pacific sand lance *Ammodytes hexapterus*	A	●	●				●	●			●	●	●	●	●	●	●	●	●	●				A
	S	●	●					●				●	●			●	●	●	●	●				S
	J	●	●				●	●			●	●	●	●	●	●	●	●	●	●				J
	L	●	●					●			●	●	●	●	●	●	●	●	●	●				L
	E	●	●					●				●	●			●	●	●	●	●				E

Life stage/activity
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

	Life stage/activity	BIOGEOGRAPHY																						Life stage/activity
		Marine				Estuarine															Riverine			
						Salinity Range								Estuary Type				Stratification						
						SAB			Venice System															
		Beach	Continental shelf	Continental slope	Oceanic	Tidal Fresh (0-0.5‰)	Mixing (0.5-25.0‰)	Seawater (>25.0‰)	Limnetic (0-0.5‰)	Oligohaline (0.5-5‰)	Mesohaline (5-18‰)	Polyhaline (18-30‰)	Euhaline (>30‰)	Drowned river	Bar-built	Fjord	Tectonic	Highly	Moderately	Homogeneous	Coastal plain	Piedmont	Upland	
Arrow goby *Clevelandia ios*	A		●				●	●		●	●	●	●	●	●	●	●	●	●	●				A
	S						●	●			●	●	●	●	●	●	●	●	●	●				S
	J		●				●	●		●	●	●	●	●	●	●	●	●	●	●				J
	L		●				●	●			●	●	●	●	●	●	●	●	●	●				L
	E						●	●			●	●	●	●	●	●	●	●	●	●				E
Lingcod *Ophiodon elongatus*	A		●				●	●				●	●	●	●	●		●	●	●				A
	S		●					●					●		●	●		●		●				S
	J		●				●	●			●	●	●	●	●	●	●	●	●	●				J
	L		●					●					●	●	●	●	●	●	●	●				L
	E		●					●					●		●	●		●		●				E
Pacific staghorn sculpin *Leptocottus armatus*	A		●				●	●			●	●	●	●	●	●	●	●	●	●				A
	S							●					●	●	●	●	●	●	●	●				S
	J		●			●	●	●		●	●	●	●	●	●	●	●	●	●	●	●			J
	L		●				●	●				●	●	●	●	●	●	●	●	●				L
	E							●					●	●	●	●	●	●	●	●				E
California halibut *Paralichthys californicus*	A		●					●					●	●	●		●		●	●				A
	S		●																					S
	J	●	●				●	●				●	●	●	●		●		●	●				J
	L	●	●				●	●					●	●	●		●		●	●				L
	E		●					●					●											E
Diamond turbot *Hypsopsetta guttulata*	A		●				●	●			●	●	●	●	●		●		●					A
	S		●					●					●							●				S
	J		●				●	●			●	●	●	●	●		●		●					J
	L		●					●					●		●		●		●	●				L
	E		●					●					●		●		●		●	●				E
English sole *Pleuronectes vetulus*	A		●					●					●			●		●						A
	S		●																					S
	J	●	●				●	●			●	●	●	●	●	●	●	●	●	●				J
	L	●	●				●	●				●	●	●	●	●	●	●		●				L
	E		●					●					●			●		●	●	●				E
Starry flounder *Platichthys stellatus*	A		●	●			●	●				●	●	●	●	●	●	●	●					A
	S		●													●		●						S
	J		●			●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●			J
	L		●				●	●			●	●	●	●	●	●	●	●	●	●				L
	E		●					●					●	●		●		●						E

Appendix Table 5B. Habitat Associations

Life stage/activity
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

		HABITAT ASSOCIATIONS																													
		Habitats							Substrate preference									Domain													
																		Benthic							Pelagic		Estuarine				
																		Littoral		Sublittoral			Bathyal								
	Life stage/activity	Lake	River/stream	Estuarine	Bay	Coastal- high energy waves/currents	Coastal- low energy waves/currents	Offshore	Mud/clay/silt	Sand/granule	Pebble	Cobble	Boulder	Rocky outcrop (bedrock)	Estuarine vegetation	Marine vegetation	None	Intertidal (0-3 m)	Subtidal (3-10 m)	Inner shelf (10-50 m)	Middle shelf (50-100 m)	Outer shelf (100-200 m)	Mesobenthal (200-500 m)	Bathyobenthal (>500 m)	Neritic	Oceanic	Mainstem channel	Subsidiary channel	Channel edge	Intertidal flat	Life stage/activity
Blue mussel *Mytilus edulis*	A			●	●	●	●					●	●	●				●	●	●							●	●	●	●	A
	S			●	●	●	●										●	●	●	●							●	●	●	●	S
	J			●	●	●	●					●	●	●				●	●	●							●	●	●	●	J
	L			●	●	●	●										●								●		●	●	●	●	L
	E			●	●	●	●										●								●		●	●	●	●	E
Pacific oyster *Crassostrea gigas*	A			●	●				●	●	●	●	●	●				●	●								●	●	●	●	A
	S			●	●												●	●	●								●	●	●	●	S
	J			●	●				●	●	●	●	●	●				●	●								●	●	●	●	J
	L			●	●												●								●		●	●	●	●	L
	E			●	●												●								●		●	●	●	●	E
Horseneck gaper *Tresus capax*	A			●	●		●		●	●								●	●	●							●	●	●	●	A
	S			●	●		●										●	●	●	●							●	●	●	●	S
	J			●	●		●		●	●								●	●	●							●	●	●	●	J
	L			●	●		●										●								●		●	●	●	●	L
	E			●	●		●										●								●		●	●	●	●	E
Pacific gaper *Tresus nuttallii*	A			●	●		●		●	●								●	●	●							●	●	●	●	A
	S			●	●		●										●	●	●	●							●	●	●	●	S
	J			●	●		●		●	●								●	●	●							●	●	●	●	J
	L			●	●		●										●								●		●	●	●	●	L
	E			●	●		●										●								●		●	●	●	●	E
California jackknife clam *Tagelus californianus*	A			●	●				●	●								●	●								●	●	●	●	A
	S			●	●												●	●	●								●	●	●	●	S
	J			●	●				●	●								●	●								●	●	●	●	J
	L			●	●												●								●		●	●	●	●	L
	E			●	●												●								●		●	●	●	●	E
Pacific littleneck clam *Protothaca staminea*	A			●	●		●		●	●	●	●						●	●	●							●	●	●	●	A
	S			●	●		●										●	●	●	●							●	●	●	●	S
	J			●	●		●		●	●	●	●						●	●	●							●	●	●	●	J
	L			●	●		●										●								●		●	●	●	●	L
	E			●	●		●										●								●		●	●	●	●	E
Manila clam *Venerupis japonica*	A			●	●				●	●	●	●						●	●										●	●	A
	S			●	●												●	●	●										●	●	S
	J			●	●				●	●	●	●						●	●										●	●	J
	L			●	●												●								●		●	●	●	●	L
	E			●	●												●								●		●	●	●	●	E
Softshell *Mya arenaria*	A			●	●				●	●								●	●								●	●	●	●	A
	S			●	●												●	●	●								●	●	●	●	S
	J			●	●				●	●								●	●								●	●	●	●	J
	L			●	●												●								●		●	●	●	●	L
	E			●	●												●								●		●	●	●	●	E

Life stage/activity
A - Adults
S - Spawning adults
M - Mating
J - Juveniles
L - Larvae
E - Eggs
P - Parturition

		HABITAT ASSOCIATIONS																													
		Habitats							Substrate preference									Domain													
																		Benthic							Pelagic		Estuarine				
																		Littoral		Sublittoral			Bathyal								
	Life stage/activity	Lake	River/stream	Estuarine	Bay	Coastal- high energy waves/currents	Coastal- low energy waves/currents	Offshore	Mud/clay/silt	Sand/granule	Pebble	Cobble	Boulder	Rocky outcrop (bedrock)	Estuarine vegetation	Marine vegetation	None	Intertidal (0-3 m)	Subtidal (3-10 m)	Inner shelf (10-50 m)	Middle shelf (50-100 m)	Outer shelf (100-200 m)	Mesobenthal (200-500 m)	Bathyobenthal (>500 m)	Neritic	Oceanic	Mainstem channel	Subsidiary channel	Channel edge	Intertidal flat	Life stage/activity
Geoduck *Panopea abrupta*	A			●	●			●	●	●								●	●	●	●						●	●	●	●	A
	S			●	●			●									●	●	●	●	●						●	●	●	●	S
	J			●	●			●	●	●								●	●	●	●						●	●	●	●	J
	L			●	●			●									●								●		●	●	●	●	L
	E			●	●			●									●								●		●	●	●	●	E
Bay shrimp *Crangon franciscorum*	A			●	●			●	●	●								●	●	●							●	●	●		A
	S			●	●			●	●	●								●	●	●							●	●	●		S
	J			●	●			●	●	●								●	●	●							●	●	●	●	J
	L			●	●			●									●	●	●	●					●		●	●	●	●	L
	E			●	●			●									●	●	●	●							●	●			E
Dungeness crab *Cancer magister*	A			●	●	●		●	●	●	●							●	●	●	●	●					●	●	●		A
	M					●		●										●	●	●	●										M
	J			●	●	●		●	●	●	●				●			●	●	●	●						●	●	●	●	J
	L			●	●	●		●									●								●		●	●			L
	E					●		●																							E
Leopard shark *Triakis semifasciata*	A			●	●		●		●	●	●	●			●	●	●	●	●	●							●	●	●	●	A
	M			●	●		●																								M
	J			●	●		●		●	●	●	●			●	●	●	●	●	●							●	●	●	●	J
	P																														P
Green sturgeon *Acipenser medirostris*	A		●	●	●			●	●	●	●	●	●	●	●		●	●	●	●							●	●	●	●	A
	S		●									●	●	●																	S
	J		●	●	●			●	●	●	●	●	●	●	●		●	●	●	●							●	●	●	●	J
	L		●	●								●	●	●																	L
	E		●									●	●	●																	E
White sturgeon *Acipenser transmontanus*	A			●	●			●	●	●	●	●	●	●	●		●	●	●	●							●	●	●	●	A
	S		●									●	●	●																	S
	J			●	●			●	●	●	●	●	●	●	●		●	●	●	●							●	●	●	●	J
	L		●	●					●	●	●	●	●	●	●		●														L
	E		●									●	●	●																	E
American shad *Alosa sapidissima*	A		●	●				●									●								●	●	●	●	●		A
	S		●	●						●																	●	●			S
	J	●	●	●			●	●									●								●	●	●	●	●	●	J
	L		●	●													●										●	●			L
	E		●	●					●	●																	●	●			E
Pacific herring *Clupea pallasi*	A			●	●			●									●								●	●	●	●	●		A
	S			●	●										●	●		●	●											●	S
	J			●	●			●									●								●	●	●	●	●	●	J
	L			●	●			●									●								●		●	●	●	●	L
	E			●	●										●	●		●	●											●	E

Life stage/activity
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

		HABITAT ASSOCIATIONS																													
		Habitats							Substrate preference									Domain													
																		Benthic							Pelagic		Estuarine				
																		Littoral		Sublittoral			Bathyal								
	Life stage/activity	Lake	River/stream	Estuarine	Bay	Coastal- high energy waves/currents	Coastal- low energy waves/currents	Offshore	Mud/clay/silt	Sand/granule	Pebble	Cobble	Boulder	Rocky outcrop (bedrock)	Estuarine vegetation	Marine vegetation	None	Intertidal (0-3 m)	Subtidal (3-10 m)	Inner shelf (10-50 m)	Middle shelf (50-100 m)	Outer shelf (100-200 m)	Mesobenthal (200-500 m)	Bathyobenthal (>500 m)	Neritic	Oceanic	Mainstem channel	Subsidiary channel	Channel edge	Intertidal flat	Life stage/activity
Deepbody anchovy *Anchoa compressa*	A				●		●										●								●		●	●	●	●	A
	S				●												●										●				S
	J				●		●										●								●		●	●	●	●	J
	L				●												●										●	●	●	●	L
	E				●												●										●	●	●		E
Slough anchovy *Anchoa delicatissima*	A				●		●										●								●		●	●	●		A
	S				●												●										●				S
	J				●		●										●								●		●	●	●		J
	L				●												●										●	●	●		L
	E				●												●										●	●	●		E
Northern anchovy *Engraulis mordax*	A			●	●		●	●									●								●	●	●	●	●		A
	S			●			●	●									●								●	●					S
	J			●	●		●	●									●								●	●	●	●	●		J
	L			●	●		●	●									●								●	●	●	●	●		L
	E			●			●	●									●								●	●					E
Cutthroat trout *Oncorhynchus clarki*	A	●	●	●			●	●		●	●	●													●		●	●	●	●	A
	S		●							●	●																				S
	J	●	●	●			●	●		●	●	●													●		●	●	●	●	J
	L		●							●	●																				L
	E		●							●	●																				E
Pink salmon *Oncorhynchus gorbuscha*	A		●	●			●			●	●														●		●	●	●		A
	S		●	●						●	●																				S
	J		●	●			●	●									●								●	●	●	●	●	●	J
	L		●	●						●	●																				L
	E		●	●						●	●																				E
Chum salmon *Oncorhynchus keta*	A		●	●			●			●	●														●		●	●	●	●	A
	S		●	●						●	●																				S
	J		●	●			●	●									●								●	●	●	●	●	●	J
	L		●	●						●	●																				L
	E		●	●						●	●																				E
Coho salmon *Oncorhynchus kisutch*	A		●	●			●			●	●														●		●	●	●	●	A
	S		●							●	●																				S
	J		●	●			●	●		●	●														●	●	●	●	●	●	J
	L		●							●	●																				L
	E		●							●	●																				E
Steelhead *Oncorhynchus mykiss*	A		●	●			●	●		●	●	●	●												●	●	●	●	●	●	A
	S		●							●	●																				S
	J		●	●			●	●		●	●	●													●	●	●	●	●	●	J
	L		●							●	●																				L
	E		●							●	●																				E

<u>Life stage/activity</u>
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

		HABITAT ASSOCIATIONS																													
		Habitats							Substrate preference									Domain													
																		Benthic							Pelagic		Estuarine				
																		Littoral		Sublittoral			Bathyal								
	Life stage/activity	Lake	River/stream	Estuarine	Bay	Coastal- high energy waves/currents	Coastal- low energy waves/currents	Offshore	Mud/clay/silt	Sand/granule	Pebble	Cobble	Boulder	Rocky outcrop (bedrock)	Estuarine vegetation	Marine vegetation	None	Intertidal (0-3 m)	Subtidal (3-10 m)	Inner shelf (10-50 m)	Middle shelf (50-100 m)	Outer shelf (100-200 m)	Mesobenthal (200-500 m)	Bathyobenthal (>500 m)	Neritic	Oceanic	Mainstem channel	Subsidiary channel	Channel edge	Intertidal flat	Life stage/activity
Sockeye salmon *Oncorhynchus* *nerka*	A	●	●	●			●			●	●														●		●	●	●	●	A
	S	●	●							●	●																				S
	J	●	●	●			●	●									●								●	●	●	●	●	●	J
	L	●	●							●	●																				L
	E	●	●							●	●																				E
Chinook salmon *Oncorhynchus* *tshawytscha*	A	●	●	●		●	●			●	●	●													●		●	●	●	●	A
	S		●							●	●	●																			S
	J	●	●	●		●	●			●	●	●													●	●	●	●	●	●	J
	L		●							●	●	●																			L
	E		●							●	●	●																			E
Surf smelt *Hypomesus* *pretiosus*	A			●	●	●	●	●									●								●	●	●	●	●	●	A
	S			●		●	●			●								●													S
	J			●	●	●	●	●									●								●	●	●	●	●	●	J
	L			●		●	●	●		●								●													L
	E			●		●	●			●								●													E
Longfin smelt *Spirinchus* *thaleichthys*	A		●	●	●		●	●									●								●		●	●	●		A
	S		●	●	●					●																	●				S
	J			●	●		●	●									●								●		●	●	●		J
	L		●	●	●					●															●		●	●	●		L
	E		●	●	●					●																	●				E
Eulachon *Thaleichthys* *pacificus*	A		●	●				●									●								●	●	●	●	●		A
	S		●							●																	●				S
	J							●									●								●	●					J
	L		●	●				●		●															●	●	●	●	●		L
	E		●							●																	●				E
Pacific tomcod *Microgadus* *proximus*	A			●		●	●	●	●										●	●	●						●	●	●		A
	S						●																								S
	J			●		●	●	●	●										●	●	●						●	●	●		J
	L			●			●	●									●										●	●	●		L
	E						●																								E
Topsmelt *Atherinops* *affinis*	A			●	●		●	●									●								●		●	●	●	●	A
	S			●	●		●								●	●		●												●	S
	J			●	●		●	●									●								●		●	●	●	●	J
	L			●	●		●										●										●	●	●	●	L
	E			●	●		●								●	●		●												●	E
Jacksmelt *Atherinopsis* *californiensis*	A			●	●	●	●	●		●															●		●	●	●	●	A
	S			●	●										●	●		●											●	●	S
	J			●	●	●	●	●		●															●		●	●	●	●	J
	L			●	●				●																		●	●	●	●	L
	E			●	●										●	●		●											●	●	E

Life stage/activity
A - Adults
S - Spawning adults
M - Mating
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E - Eggs
P - Parturition

		HABITAT ASSOCIATIONS																													
		Habitats							Substrate preference									Domain													
																		Benthic							Pelagic		Estuarine				
																		Littoral		Sublittoral			Bathyal								
	Life stage/activity	Lake	River/stream	Estuarine	Bay	Coastal- high energy waves/currents	Coastal- low energy waves/currents	Offshore	Mud/clay/silt	Sand/granule	Pebble	Cobble	Boulder	Rocky outcrop (bedrock)	Estuarine vegetation	Marine vegetation	None	Intertidal (0-3 m)	Subtidal (3-10 m)	Inner shelf (10-50 m)	Middle shelf (50-100 m)	Outer shelf (100-200 m)	Mesobenthal (200-500 m)	Bathyobenthal (>500 m)	Neritic	Oceanic	Mainstem channel	Subsidiary channel	Channel edge	Intertidal flat	Life stage/activity
Threespine stickleback *Gasterosteus aculeatus*	A	●	●	●	●												●								●	●	●	●	●	●	A
	S	●	●	●	●				●						●			●	●									●	●		S
	J	●	●	●	●												●								●		●	●	●	●	J
	L	●	●	●	●												●											●	●		L
	E	●	●	●	●				●						●			●	●									●	●		E
Striped bass *Morone saxatilis*	A		●	●		●		●									●	●							●		●	●	●		A
	S		●	●					●	●								●	●								●				S
	J		●	●						●								●	●								●	●	●	●	J
	L		●	●														●	●								●	●	●		L
	E		●	●					●	●								●	●								●				E
Kelp bass *Paralabrax clathratus*	A				●	●	●	●				●	●	●		●		●	●	●					●		●				A
	S						●										●		●	●					●						S
	J				●	●	●	●								●			●	●					●		●	●	●		J
	L				●		●										●		●	●					●						L
	E						●										●		●	●					●						E
Barred sand bass *Paralabrax nebulifer*	A			●	●	●	●	●		●	●			●	●	●		●	●	●					●		●	●	●		A
	S									●															●						S
	J			●	●	●	●	●		●					●	●		●	●	●					●		●	●	●		J
	L			●	●	●											●								●		●	●	●		L
	E			●	●	●											●								●						E
White seabass *Atractoscion nobilis*	A					●		●		●				●		●			●	●					●						A
	S																								●						S
	J			●	●	●			●	●				●	●	●		●	●						●		●	●	●		J
	L			●	●	●		●									●								●		●	●	●		L
	E							●									●								●						E
White croaker *Genyonemus lineatus*	A			●	●		●	●		●						●		●	●	●	●	●			●		●	●	●	●	A
	S									●								●	●						●						S
	J			●	●		●	●		●						●		●	●	●					●		●	●	●	●	J
	L			●	●		●			●								●	●						●		●	●	●		L
	E									●								●	●						●						E
Shiner perch *Cymatogaster aggregata*	A			●	●		●	●	●	●					●										●		●	●	●	●	A
	M			●	●		●		●	●					●												●	●	●	●	M
	J			●	●		●		●	●					●										●		●	●	●	●	J
	P			●	●		●		●	●					●												●	●	●	●	P
Pacific sand lance *Ammodytes hexapterus*	A			●	●	●		●		●								●	●	●	●				●		●				A
	S			●		●				●								●	●	●					●		●				S
	J			●	●	●		●		●								●	●	●	●				●		●				J
	L			●		●		●		●															●		●				L
	E			●		●				●								●	●	●					●		●				E

Life stage/activity
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

		HABITAT ASSOCIATIONS																													
		Habitats							Substrate preference									Domain													
																		Benthic							Pelagic		Estuarine				
																		Littoral		Sublittoral			Bathyal								
	Life stage/activity	Lake	River/stream	Estuarine	Bay	Coastal- high energy waves/currents	Coastal- low energy waves/currents	Offshore	Mud/clay/silt	Sand/granule	Pebble	Cobble	Boulder	Rocky outcrop (bedrock)	Estuarine vegetation	Marine vegetation	None	Intertidal (0-3 m)	Subtidal (3-10 m)	Inner shelf (10-50 m)	Middle shelf (50-100 m)	Outer shelf (100-200 m)	Mesobenthal (200-500 m)	Bathyobenthal (>500 m)	Neritic	Oceanic	Mainstem channel	Subsidiary channel	Channel edge	Intertidal flat	Life stage/activity
Arrow goby *Clevelandia ios*	A			●	●				●	●								●	●								●	●	●	●	A
	S			●	●				●	●								●	●								●	●	●	●	S
	J			●	●				●	●								●	●								●	●	●	●	J
	L			●	●												●								●		●	●	●	●	L
	E			●	●				●	●								●	●								●	●	●	●	E
Lingcod *Ophiodon elongatus*	A					●	●	●					●	●		●		●	●	●	●	●	●								A
	S					●		●					●	●				●	●	●											S
	J			●	●	●	●	●		●			●	●		●		●	●	●							●				J
	L					●		●																	●	●					L
	E					●		●					●	●				●	●	●											E
Pacific staghorn sculpin *Leptocottus armatus*	A			●	●		●	●	●	●	●	●	●	●				●	●	●	●						●	●	●	●	A
	S			●	●		●												●								●				S
	J		●	●	●		●		●	●	●	●	●	●	●			●	●	●							●	●	●	●	J
	L			●	●		●																		●	●	●	●	●		L
	E			●	●		●												●								●				E
California halibut *Paralichthys californicus*	A				●		●	●		●								●	●	●	●	●					●				A
	S						●			●									●												S
	J			●	●		●	●	●	●								●	●	●	●	●					●	●	●	●	J
	L			●	●		●	●									●								●		●				L
	E						●			●															●						E
Diamond turbot *Hypsopsetta guttulata*	A			●	●		●		●	●								●	●	●	●						●	●	●	●	A
	S						●											●	●												S
	J			●	●		●		●	●								●	●	●							●	●	●	●	J
	L			●	●		●										●								●		●				L
	E						●										●								●						E
English sole *Pleuronectes vetulus*	A						●	●	●										●	●	●	●	●				●				A
	S						●		●											●	●										S
	J			●	●	●	●	●	●	●								●	●	●	●						●	●	●	●	J
	L			●	●		●	●									●								●	●	●	●			L
	E						●	●									●								●	●					E
Starry flounder *Platichthys stellatus*	A			●	●		●	●	●	●								●	●	●	●	●					●	●			A
	S						●			●										●											S
	J		●	●	●		●		●	●								●	●	●							●	●	●	●	J
	L			●	●		●										●								●	●	●				L
	E						●										●								●						E

Appendix Table 5C. Biological Attributes and Economic Value

Life stage/activity
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

		BIOLOGICAL ATTRIBUTES																Economic Value		
		Feeding type					Spatial strategy					Longevity								
	Life stage/activity	Carnivore	Herbivore	Omnivore	Planktivore	Detritivore	Coastal migrant	Ocean migrant	Freshwater resident	Estuarine resident	Marine resident	1 day	1-30 days	1-12 months	1-5 years	5-20 years	> 20 years	Recreational	Commercial	Life stage/activity
Blue mussel *Mytilus edulis*	A				●	●				●	●						●	●	●	A
	S									●	●									S
	J				●	●				●	●				●					J
	L				●					●	●			●						L
	E									●	●		●							E
Pacific oyster *Crassostrea gigas*	A				●	●				●							●	●	●	A
	S									●										S
	J				●	●				●					●					J
	L				●					●			●							L
	E									●		●	●							E
Horseneck gaper *Tresus capax*	A				●	●				●						●		●	●	A
	S									●										S
	J				●	●				●					●					J
	L				●					●			●							L
	E									●		●								E
Pacific gaper *Tresus nuttallii*	A				●	●				●						●		●	●	A
	S									●										S
	J				●	●				●					●					J
	L				●					●			●							L
	E									●		●								E
California jackknife clam *Tagelus californianus*	A				●	●				●						●	●	●	●	A
	S									●										S
	J				●	●				●					●					J
	L				●	●				●			●	●						L
	E									●		●								E
Pacific littleneck clam *Protothaca staminea*	A				●	●				●	●					●		●	●	A
	S									●	●									S
	J				●	●				●	●				●	●				J
	L				●					●	●		●							L
	E									●	●	●								E
Manila clam *Venerupis japonica*	A				●	●				●						●		●	●	A
	S									●										S
	J				●	●				●					●					J
	L				●					●			●							L
	E									●		●								E
Softshell *Mya arenaria*	A				●	●				●						●		●	●	A
	S									●										S
	J				●	●				●					●					J
	L				●	●				●				●						L
	E									●		●								E

Life stage/activity
A - Adults
S - Spawning adults
M- Mating
J - Juveniles
L - Larvae
E - Eggs
P- Parturition

		BIOLOGICAL ATTRIBUTES																Economic Value		
		Feeding type					Spatial strategy					Longevity								
	Life stage/activity	Carnivore	Herbivore	Omnivore	Planktivore	Detritivore	Coastal migrant	Ocean migrant	Freshwater resident	Estuarine resident	Marine resident	1 day	1-30 days	1-12 months	1-5 years	5-20 years	> 20 years	Recreational	Commercial	Life stage/activity
Geoduck *Panopea abrupta*	A				●	●				●	●						●	●	●	A
	S									●	●									S
	J				●	●				●	●				●					J
	L				●					●	●		●							L
	E									●	●	●								E
Bay shrimp *Crangon franciscorum*	A	●				●				●	●				●			●	●	A
	S									●	●									S
	J	●				●				●				●						J
	L	●								●				●						L
	E									●	●			●						E
Dungeness crab *Cancer magister*	A	●								●	●					●		●	●	A
	M										●									M
	J	●								●	●				●					J
	L	●			●					●	●			●						L
	E										●			●						E
Leopard shark *Triakis semifasciata*	A	●					●			●	●					●		●	●	A
	M									●	●									M
	J	●					●			●	●									J
	P									●	●									P
Green sturgeon *Acipenser medirostris*	A	●					●		●	●	●						●	●	●	A
	S								●											S
	J	●					●		●	●	●					●		●	●	J
	L								●				●							L
	E								●				●							E
White sturgeon *Acipenser transmontanus*	A	●					●		●	●	●						●	●	●	A
	S								●											S
	J	●					●		●	●	●					●		●	●	J
	L								●				●							L
	E								●				●							E
American shad *Alosa sapidissima*	A				●		●	●	●	●	●				●	●		●	●	A
	S								●											S
	J				●				●	●	●				●					J
	L								●					●						L
	E								●				●							E
Pacific herring *Clupea pallasi*	A				●		●	●		●	●					●		●	●	A
	S									●	●								●	S
	J				●		●	●		●	●				●			●	●	J
	L				●					●	●			●						L
	E									●	●		●						●	E

Life stage/activity
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

		BIOLOGICAL ATTRIBUTES																Economic Value		
		Feeding type					Spatial strategy					Longevity								
	Life stage/activity	Carnivore	Herbivore	Omnivore	Planktivore	Detritivore	Coastal migrant	Ocean migrant	Freshwater resident	Estuarine resident	Marine resident	1 day	1-30 days	1-12 months	1-5 years	5-20 years	> 20 years	Recreational	Commercial	Life stage/activity
Deepbody anchovy *Anchoa compressa*	A				●					●	●				●			●		A
	S									●										S
	J				●					●				●				●		J
	L				●					●			●							L
	E									●			●							E
Slough anchovy *Anchoa delicatissima*	A				●					●					●			●		A
	S									●										S
	J				●					●				●				●		J
	L				●					●				●						L
	E									●			●							E
Northern anchovy *Engraulis mordax*	A				●		●			●	●				●	●		●	●	A
	S									●	●									S
	J				●		●			●	●			●	●			●	●	J
	L				●					●	●			●						L
	E									●	●		●							E
Cutthroat trout *Oncorhynchus clarki*	A	●							●	●	●				●	●		●		A
	S								●											S
	J	●					●		●	●	●				●	●		●		J
	L								●				●							L
	E								●					●						E
Pink salmon *Oncorhynchus gorbuscha*	A	●							●	●	●				●			●	●	A
	S								●											S
	J	●					●	●	●	●	●				●					J
	L								●					●						L
	E								●					●						E
Chum salmon *Oncorhynchus keta*	A	●							●	●	●				●	●		●	●	A
	S								●											S
	J	●					●	●	●	●	●				●	●		●		J
	L								●					●						L
	E								●					●						E
Coho salmon *Oncorhynchus kisutch*	A	●							●	●	●				●	●		●	●	A
	S								●											S
	J	●					●	●	●	●	●				●	●		●	●	J
	L								●					●						L
	E								●					●						E
Steelhead *Oncorhynchus mykiss*	A	●						●	●	●	●					●		●	●	A
	S								●											S
	J	●						●	●	●	●				●					J
	L								●				●							L
	E								●					●						E

Life stage/activity
A - Adults
S - Spawning adults
J - Juveniles
L - Larvae
E - Eggs

		BIOLOGICAL ATTRIBUTES																Economic Value		
		Feeding type					Spatial strategy					Longevity								
	Life stage/activity	Carnivore	Herbivore	Omnivore	Planktivore	Detritivore	Coastal migrant	Ocean migrant	Freshwater resident	Estuarine resident	Marine resident	1 day	1-30 days	1-12 months	1-5 years	5-20 years	> 20 years	Recreational	Commercial	Life stage/activity
Sockeye salmon *Oncorhynchus nerka*	A	●							●	●	●				●	●		●	●	A
	S								●											S
	J	●			●		●	●	●	●	●				●	●				J
	L								●					●						L
	E								●					●						E
Chinook salmon *Oncorhynchus tshawytscha*	A	●							●	●	●				●	●		●	●	A
	S								●											S
	J	●					●	●	●	●	●				●	●		●	●	J
	L								●					●						L
	E								●					●						E
Surf smelt *Hypomesus pretiosus*	A	●			●		●			●	●				●			●	●	A
	S									●	●									S
	J	●			●		●			●	●				●					J
	L	●			●					●	●			●						L
	E									●	●		●							E
Longfin smelt *Spirinchus thaleichthys*	A	●			●		●		●	●	●				●			●		A
	S								●	●										S
	J	●			●		●		●	●	●				●					J
	L	●			●				●	●				●						L
	E								●	●				●						E
Eulachon *Thaleichthys pacificus*	A	●			●		●		●	●	●				●			●	●	A
	S								●											S
	J	●			●		●				●				●					J
	L	●			●				●	●	●			●						L
	E								●				●	●						E
Pacific tomcod *Microgadus proximus*	A	●								●	●				●			●		A
	S										●									S
	J	●								●	●				●					J
	L	●									●									L
	E										●									E
Topsmelt *Atherinops affinis*	A			●			●			●	●				●	●		●	●	A
	S									●	●									S
	J			●	●		●			●	●				●					J
	L			●	●					●	●			●						L
	E									●	●		●	●						E
Jacksmelt *Atherinopsis californiensis*	A			●			●			●	●				●	●		●	●	A
	S									●	●									S
	J			●	●		●			●	●				●					J
	L			●	●					●	●		●	●						L
	E									●	●		●							E

Life stage/activity
A - Adults
S - Spawning adults
M- Mating
J - Juveniles
L - Larvae
E - Eggs
P- Parturition

		BIOLOGICAL ATTRIBUTES															Economic Value		
		Feeding type					Spatial strategy					Longevity							
	Life stage/activity	Carnivore	Herbivore	Omnivore	Planktivore	Detritivore	Coastal migrant	Ocean migrant	Freshwater resident	Estuarine resident	Marine resident	1 day	1-30 days	1-12 months	1-5 years	5-20 years	> 20 years	Recreational	Commercial	Life stage/activity
Threespine stickleback *Gasterosteus aculeatus*	A	●					●		●	●	●				●					A
	S								●	●										S
	J	●			●				●	●	●			●						J
	L	●			●				●	●			●							L
	E								●	●			●	●						E
Striped bass *Morone saxatilis*	A	●					●		●	●	●						●	●		A
	S								●											S
	J	●							●	●					●	●				J
	L	●							●	●			●							L
	E								●	●		●	●							E
Kelp bass *Paralabrax clathratus*	A	●									●						●	●	●	A
	S										●									S
	J	●								●	●				●					J
	L	●			●						●		●							L
	E										●	●	●							E
Barred sand bass *Paralabrax nebulifer*	A	●								●	●						●	●	●	A
	S										●									S
	J	●								●	●									J
	L	●			●					●	●		●							L
	E										●		●							E
White seabass *Atractoscion nobilis*	A	●					●	●			●						●	●	●	A
	S										●									S
	J	●								●	●				●					J
	L	●			●					●	●		●							L
	E										●		●							E
White croaker *Genyonemus lineatus*	A	●					●			●	●					●		●	●	A
	S										●									S
	J	●								●	●				●					J
	L	●			●					●	●		●							L
	E										●		●							E
Shiner perch *Cymatogaster aggregata*	A	●								●	●					●		●		A
	M									●										M
	J	●								●			●	●						J
	P				●					●										P
Pacific sand lance *Ammodytes hexapterus*	A	●			●		●			●	●				●	●		●	●	A
	S									●	●									S
	J	●			●		●			●	●				●					J
	L	●			●					●	●			●						L
	E									●	●		●	●						E

Life stage/activity
A - Adults
S - Spawning adults
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E - Eggs

		BIOLOGICAL ATTRIBUTES																Economic Value		
		Feeding type					Spatial strategy					Longevity								
	Life stage/activity	Carnivore	Herbivore	Omnivore	Planktivore	Detritivore	Coastal migrant	Ocean migrant	Freshwater resident	Estuarine resident	Marine resident	1 day	1-30 days	1-12 months	1-5 years	5-20 years	> 20 years	Recreational	Commercial	Life stage/activity
Arrow goby *Clevelandia ios*	A	●								●					●					A
	S									●										S
	J	●								●				●						J
	L	●			●					●			●							L
	E									●			●							E
Lingcod *Ophiodon elongatus*	A	●									●					●		●	●	A
	S										●									S
	J	●								●	●				●			●		J
	L	●			●						●			●						L
	E										●			●						E
Pacific staghorn sculpin *Leptocottus armatus*	A	●								●	●				●	●		●		A
	S									●	●									S
	J	●								●	●				●			●		J
	L	●			●					●	●			●						L
	E									●	●		●							E
California halibut *Paralichthys californicus*	A	●									●						●	●	●	A
	S										●									S
	J	●								●	●				●					J
	L	●			●						●			●						L
	E										●		●							E
Diamond turbot *Hypsopsetta guttulata*	A	●								●	●					●		●		A
	S										●									S
	J	●								●	●				●					J
	L	●			●						●			●						L
	E										●		●							E
English sole *Pleuronectes vetulus*	A	●									●					●		●	●	A
	S										●									S
	J	●								●	●				●					J
	L	●			●						●			●						L
	E										●		●							E
Starry flounder *Platichthys stellatus*	A	●					●			●	●					●		●	●	A
	S										●									S
	J	●			●				●	●					●					J
	L	●			●					●	●			●						L
	E										●		●							E

Appendix Table 5D. Reproduction

	REPRODUCTION																											
	Fertilization/ Egg Development					Spawning type				Spawning behavior				Temporal Schedule								Periodicity				Domain		
	External	Internal	Oviparous	Ovoviviparous	Viviparous	Anadromous	Iteroparous	Semelparous	Batch spawner	Broadcast spawner	Nest builder	Egg/young guarder	Egg/young bearer	Early spring	Late spring	Early summer	Late summer	Early fall	Late fall	Early winter	Late winter	Annual spawning	2 or more per year	2 or more years	Undescribed	Oceans	Estuaries	Rivers
Blue mussel *Mytilus edulis*	●		●				●			●				●	●	●	●	●	●	●	●	●				●	●	
Pacific oyster *Crassostrea gigas*	●		●				●			●						●	●	●				●					●	
Horseneck gaper *Tresus capax*	●		●				●		●	●				●							●	●				●	●	
Pacific gaper *Tresus nuttallii*	●		●				●		●	●				●	●	●	●	●	●	●	●	●				●	●	
California jackknife clam *Tagelus californianus*	●		●				●		●	●				●	●	●	●	●	●	●	●	●					●	
Pacific littleneck clam *Protothaca staminea*	●		●				●		●	●				●	●	●	●					●				●	●	
Manila clam *Venerupis japonica*	●		●				●		●	●						●	●	●	●			●					●	
Softshell *Mya arenaria*	●		●				●			●					●	●	●	●				●	●				●	
Geoduck *Panopea abrupta*	●		●				●		●	●					●	●	●					●				●	●	
Bay shrimp *Crangon franciscorum*	●		●				●						●	●	●	●	●	●	●	●	●		●			●	●	
Dungeness crab *Cancer magister*		●	●				●						●	●	●	●	●	●				●				●		
Leopard shark *Triakis semifasciata*		●		●			●						●	●								●				●	●	
Green sturgeon *Acipenser medirostris*	●		●			●	●			●				●	●	●									●			●
White sturgeon *Acipenser transmontanus*	●		●			●	●			●				●	●	●						●		●				●
American shad *Alosa sapidissima*	●		●			●	●		●	●				●	●	●						●						●
Pacific herring *Clupea pallasi*	●		●				●		●	●				●	●					●	●	●					●	
Deepbody anchovy *Anchoa compressa*	●		●				●		●	●					●	●	●					●					●	
Slough anchovy *Anchoa delicatissima*	●		●				●		●	●					●	●	●	●				●					●	
Northern anchovy *Engraulis mordax*	●		●				●		●	●				●	●	●	●	●	●	●	●	●				●	●	
Cutthroat trout *Oncorhynchus clarki*	●		●			●	●		●		●							●	●	●	●	●						●
Pink salmon *Oncorhynchus gorbuscha*	●		●			●		●	●		●					●	●	●	●								●	●
Chum salmon *Oncorhynchus keta*	●		●			●		●	●		●					●	●	●	●	●	●							●
Coho salmon *Oncorhynchus kisutch*	●		●			●		●	●		●			●				●	●	●	●							●
Steelhead *Oncorhynchus mykiss*	●		●			●	●		●		●			●	●	●					●	●						●
Sockeye salmon *Oncorhynchus nerka*	●		●			●		●	●		●						●	●	●	●								●
Chinook salmon *Oncorhynchus tshawytscha*	●		●			●		●	●		●				●	●	●	●	●	●	●							●

	REPRODUCTION																											
	Fertilization/ Egg Development					Spawning type				Spawning behavior				Temporal Schedule								Periodicity				Domain		
	External	Internal	Oviparous	Ovoviviparous	Viviparous	Anadromous	Iteroparous	Semelparous	Batch spawner	Broadcast spawner	Nest builder	Egg/young guarder	Egg/young bearer	Early spring	Late spring	Early summer	Late summer	Early fall	Late fall	Early winter	Late winter	Annual spawning	2 or more per year	2 or more years	Undescribed	Oceans	Estuaries	Rivers
Surf smelt *Hypomesus pretiosus*	●		●				●		●	●				●	●	●	●	●	●	●	●	●				●	●	
Longfin smelt *Spirinchus thaleichthys*	●		●			●	●			●				●						●	●	●					●	●
Eulachon *Thaleichthys pacificus*	●		●			●	●			●				●	●						●	●					●	●
Pacific tomcod *Microgadus proximus*	●		●				●			●				●	●	●				●	●	●				●		
Topsmelt *Atherinops affinis*	●		●				●		●	●				●	●	●	●	●				●				●	●	
Jacksmelt *Atherinopsis californiensis*	●		●				●		●	●				●	●	●	●	●	●	●	●	●				●	●	
Threespine stickleback *Gasterosteus aculeatus*	●		●				●				●	●		●	●	●	●	●				●					●	●
Striped bass *Morone saxatilis*	●		●				●			●				●	●	●						●					●	●
Kelp bass *Paralabrax clathratus*	●		●				●			●					●	●	●	●	●			●				●		
Barred sand bass *Paralabrax nebulifer*	●		●				●			●				●	●	●	●	●	●			●				●		
White seabass *Atractoscion nobilis*	●		●				●			●				●	●	●	●					●				●		
White croaker *Genyonemus lineatus*	●		●				●		●	●				●	●	●	●	●	●	●	●	●				●		
Shiner perch *Cymatogaster aggregata*		●			●		●						●	●	●	●	●					●				●	●	
Pacific sand lance *Ammodytes hexapterus*	●		●				●			●										●	●	●				●	●	
Arrow goby *Clevelandia ios*	●		●				●							●	●	●	●	●	●	●	●	●					●	
Lingcod *Ophiodon elongatus*	●		●				●				●	●		●	●					●	●	●				●		
Pacific staghorn sculpin *Leptocottus armatus*	●		●				●			●				●					●	●	●	●				●	●	
California halibut *Paralichthys californicus*	●		●				●			●				●	●	●	●				●	●				●		
Diamond turbot *Hypsopsetta guttulata*	●		●				●			●				●	●	●	●	●	●	●	●	●				●		
English sole *Pleuronectes vetulus*	●		●				●			●				●	●				●	●	●	●				●		
Starry flounder *Platichthys stellatus*	●		●				●			●				●						●	●	●				●	●	

Appendix 6: Terms used in life history tables

BIOGEOGRAPHY

Marine- Distribution of life stages in seawater areas.
- *Beach-* Exposed shore areas receiving ocean waves and wash.
- *Continental shelf-* Waters over the gradually-sloping continental seabed from shore to a depth of about 200 m.
- *Continental slope-* Waters over the steeply-sloping seabed from continental shelf to 1000 m.
- *Oceanic-* The open ocean waters beyond the continental shelf. Defined here as the ocean beyond the continental slope.

Estuarine- Distribution of life stages in estuarine areas.

Salinity Range: SAB (Strategic Assessment Branch classification)
- *Tidal fresh-* Salinities of 0.0-0.5‰.
- *Mixing-* Salinities of 0.5-25.0‰.
- *Seawater-* Salinities >25‰.

Salinity Range: Venice classification
- *Limnetic-* Salinities of 0.0-0.5‰.
- *Oligohaline-*Salinities of 0.5-5.0‰.
- *Mesohaline-* Salinities of 5-18‰.
- *Polyhaline-* Salinities of 18-30‰.
- *Euhaline-* Salinities >30‰.

Estuary type
- *Drowned river-* Estuaries resulting from valleys being inundated by rising sea levels (e.g., Grays Harbor and Columbia River estuary).
- *Bar-built-* Estuaries resulting from the building of barrier islands or spits (e.g., Netarts Bay and Humboldt Bay).
- *Fjord-* Glacier-formed estuaries with deeply-carved, steep-sided channels (e.g., Puget Sound and Hood Canal).
- *Tectonic-* Estuaries formed by faulting or sinking of the earth's crust (e.g., Tomales Bay and South San Francisco Bay).

Stratification
- *Highly-* Very little mixing between surface and bottom layers, resulting in marked differences between surface and bottom salinities.
- *Moderately-* Moderate mixing between surface and bottom layers primarily due to tidal-induced turbulence. Surface salinities are usually lower than bottom salinities.
- *Homogeneous-* High mixing of surface and bottom layers resulting in equivalent salinities.

Riverine- Distribution of life stages in freshwater areas.
- *Coastal plain-* River portions in the relatively flat land along a coast.
- *Piedmont-* River portions at the base of mountains.
- *Upland-* River portions in mountainous areas.

HABITAT ASSOCIATIONS

Habitats- General habitat of life stages.
- *Lake-* Freshwater non-flowing areas with riverine connections to the sea.
- *River/stream-* Areas with flowing fresh water.
- *Estuarine-* Embayment with tidal fresh, mixing, and seawater zones.
- *Bay-* Semi-enclosed water body that has predominantly seawater salinities.
- *Coastal (high energy)-* Nearshore areas subject to significant wave or current action.
- *Coastal (low energy)-* Nearshore areas subject to only minor wave or current action.
- *Offshore-* Offshore areas beyond the coastal high or low energy areas.

Substrate preference- Size of substrate that life stages reside on or in.

- *Mud/clay/silt-* Fine substrates <0.0625 mm in diameter.
- *Sand/granule-* Substrates 0.0625-4.0 mm in diameter.
- *Pebble-* Substrates 4-64 mm in diameter.
- *Cobble-* Substrates 64-256 mm in diameter.
- *Boulder-* Large substrate >256 mm in diameter.
- *Rocky outcrop (bedrock)-* Exposed solid rock.
- *Estuarine vegetation-* Aquatic plants within an estuary.
- *Marine vegetation-* Aquatic plants in marine waters.
- *None-* No reported preference.

Domain- Specific habitat where life stages occur.

Benthic-Littoral

- *Intertidal (0-3 m)-* On the bottom from the high tide mark to depths of 3 m.
- *Subtidal (3-10 m)-* On the bottom at depths of 3-10 m.

Benthic-Sublittoral

- *Inner shelf (10-50 m)-* On the bottom of the continental shelf at depths of 10-50 m.
- *Middle shelf (50-100 m)-* On the bottom of the continental shelf at depths of 50-100 m.
- *Outer shelf (100-200 m)-* On the bottom to the edge of the continental shelf at depths of 100-200 m.

Benthic-Bathyal

- *Mesobenthal (200-500 m)-* On the bottom of the continental slope at depths of 200-500 m.
- *Bathyobenthal (>500 m)-* On the bottom of and beyond the continental slope at depths >500 m.

Pelagic

- *Neritic-* Residing within the water column from the shore to the edge of the continental shelf.
- *Oceanic-* Residing within the water column beyond the edge of the continental shelf.

Estuarine

- *Mainstem channel-* The deep, drowned river channel of an estuary
- *Subsidiary channel-* Small tributary channels emptying into the mainstem channel of an estuary.
- *Channel edge-* Rim of an estuarine channel where the bottom slopes upward and meets shallow flats.
- *Intertidal flat-* Shallow, often almost level estuarine areas alternately covered and left bare by tidal waters.

BIOLOGICAL ATTRIBUTES AND ECONOMIC VALUE

Feeding type- Trophic role of life stages.

- *Carnivore-* A flesh-eating organism.
- *Herbivore-* A plant-eating organism.
- *Omnivore-* An organism that eats both plants and animals.
- *Planktivore-* A plankton-eating organism.
- *Detritivore-* A detritus-eating organism.

Spatial strategy- Use of habitats by life stages.

- *Coastal migrant-* An organism which migrates within nearshore waters of the continental shelf.
- *Ocean migrant-* An organism which migrates in ocean waters beyond the continental shelf.
- *Freshwater resident-* An organism which resides primarily in freshwater habitats.
- *Estuarine resident-* An organism which resides primarily in estuarine habitats (salinities ≥0.5 and ≤25‰).
- *Marine resident-* An organism which resides primarily in seawater habitats (salinities >25‰).

Longevity- Average lifespan of a particular life stage (*1 day to >20 years*).

Economic Value- Monetary worth (direct and indirect) from harvesting a species.

- *Recreational-* Harvested by sport anglers.
- *Commercial-* Harvested by professional fishermen for sale in markets.

REPRODUCTION

Fertilization/Egg Development- Method of egg fertilization and development.

- *External-* Egg fertilization occurs after eggs and sperm are shed into the water.
- *Internal-* Egg fertilization occurs when a male inseminates an egg within a female.
- *Oviparous-* Eggs are laid and fertilized externally.
- *Ovoviviparous-* Eggs are fertilized and incubated internally, and usually released as larvae. Little or no maternal nourishment is provided.
- *Viviparous-* Eggs are fertilized, incubated, and develop internally until birth. Maternal nourishment is provided.

Mating Type- Mate selection strategy.

- *Monogamous-* A single male and a single female pair for a prolonged and exclusive relationship.
- *Polygamous-* A male mates with numerous females or vice-versa.
- *Broadcast spawner-* Numerous males and females release gametes during mass spawning.

Spawning- Spawning mode.

- *Anadromous-* Species spends most of its life at sea but migrates to fresh water to spawn.
- *Iteroparous-* Species reproduces repeatedly during a lifetime.
- *Semelparous-* Species reproduces only once during a lifetime.
- *Batch spawn-* Species spawns (releases gametes) several times during a reproductive period.

Parental Care- Type of egg protection.

- *Protected-* Eggs are protected by parent(s); eggs are buoyant or attached to substrates, but not buried.
- *Nests-* Eggs develop in the shelter of a nest.

Temporal Schedule- Period when spawning typically occurs.

- *Early spring-* From mid-March through April.
- *Late spring-* From May to mid-June.
- *Early summer-* From mid-June through July.
- *Late summer-* From August to mid-September.
- *Early fall-* From mid-September through October.
- *Late fall-* From November to mid-December.
- *Early winter-* From mid-December through January.
- *Late winter-* From February to mid-March.

Periodicity- Frequency of spawning events.

- *Annual spawning-* Spawning once each year, usually during a restricted season.
- *2 or more per year-* Spawning more than once each year (more than one spawning season).
- *2 or more years-* Spawning events separated by at least two years.
- *Undescribed-* Spawning frequency not documented.

Domain- Location of spawning.

- *Oceans-* Spawning occurs primarily in open marine waters.
- *Estuaries-* Spawning occurs primarily in estuarine waters (to head of tide).
- *Rivers-* Spawning occurs primarily in fresh water, above head of tide.

NOAA's Estuarine Living Marine Resources Program

The Strategic Environmental Assessments (SEA) Division of NOAA's Office of Ocean Resources Conservation and Assessment (ORCA) was created in response to the need for comprehensive information on the effects of human activities on the Nation's coastal ocean. The SEA Division performs assessments of the estuarine and coastal environments and of the resources of the U.S. Exclusive Economic Zone (EEZ).

In June 1985, the National Oceanic and Atmospheric Administration (NOAA) began a program to develop a comprehensive information base on the life history, relative abundance and distribution of selected fishes and invertebrates in estuaries throughout the Nation (Monaco 1986). This program, the Estuarine Living Marine Resources (ELMR) program, is conducted jointly by the Strategic Environmental Assessments Division of the Office of Ocean Resources Conservation and Assessment and laboratories of the National Marine Fisheries Service (NMFS). Currently, the Point Adams (Hammond), OR; Galveston, TX; Beaufort, NC; and Oxford, MD laboratories are compiling information for the contiguous West Coast, Gulf of Mexico, Southeast, and Northeast regions. Also, the Virginia Institute of Marine Science is compiling data for the Chesapeake Bay area.

Three salinity zones, as defined in Volume 1 of NOAA's *National Estuarine Inventory Data Atlas* (NOAA 1985), provided the spatial framework for organizing information on species distribution and abundance within each estuary. These salinity zones are tidal fresh (0.0 to 0.5‰), mixing (0.5 to 25.0‰), and seawater (25.0‰ and greater). The primary data developed for each species for each salinity zone include spatial and temporal distributions and relative abundance by life stage (i.e., adult, spawning or mating adults, juvenile, larva, and egg). In addition, a detailed estuarine life history summary is written for each species.

Additional information on this or other programs of NOAA's Strategic Environmental Assessments Division is available from:

Strategic Environmental Assessments Division
Office of Ocean Resources Conservation and Assessment
National Oceanic and Atmospheric Administration
6001 Executive Blvd., Rm. 220
Rockville, Maryland 20852
FTS/Comm. (301) 443-0453/8921

Reports available from NOAA's Estuarine Living Marine Resources program include:

Monaco, M. E., T. E. Czapla, D. M. Nelson, and M. E. Pattilo. 1989. Distribution and abundance of fishes and invertebrates in Texas estuaries. ELMR Rep. No. 3. Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 107 p.

Monaco, M. E., D. M. Nelson, R. L. Emmett, and S. A. Hinton. 1990. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume I: Data summaries. ELMR Rep. No. 4. Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 240 p.

Bulger, A. J., B. P. Hayden, M. E. Monaco, D. M. Nelson, and M. G. McCormick-Ray. 1990. A proposed estuarine classification: analysis of species salinity ranges. ELMR Rep. No. 5. Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 28 p.

Williams, C. W., D. M. Nelson, M. E. Monaco, L. C. Clements, S. L. Stone, L. R. Settle, C. Iancu, and E. A. Irlandi. 1990. Distribution and abundance of fishes and invertebrates in eastern Gulf of Mexico estuaries. ELMR Rep. No. 6. Strategic Assessment Branch, NOS/NOAA, Rockville, MD, 105 p.

Czapla, T. E., M. E. Pattillo, D. M. Nelson, and M. E. Monaco. 1991. Distribution and abundance of fishes and invertebrates in central Gulf of Mexico estuaries. ELMR Rep. No. 7. NOAA/NOS Strategic Environmental Assessments Division, Rockville, MD, 82 p.

Emmett, R. L., S. L. Stone, S. A. Hinton, and M. E. Monaco. 1991. Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume II: Species life history summaries. ELMR Rep. No. 8. NOAA/NOS Strategic Environmental Assessments Division, Rockville, MD, 329 p.

D. M. Nelson, E. A. Irlandi, L. R. Settle, L. C. Coston-Clements, and M. E. Monaco. 1991. Distribution and abundance of fishes and invertebrates in southeast estuaries. ELMR Rep. No. 9. NOAA/NOS Strategic Environmental Assessments Division, Rockville, MD, 167 p.