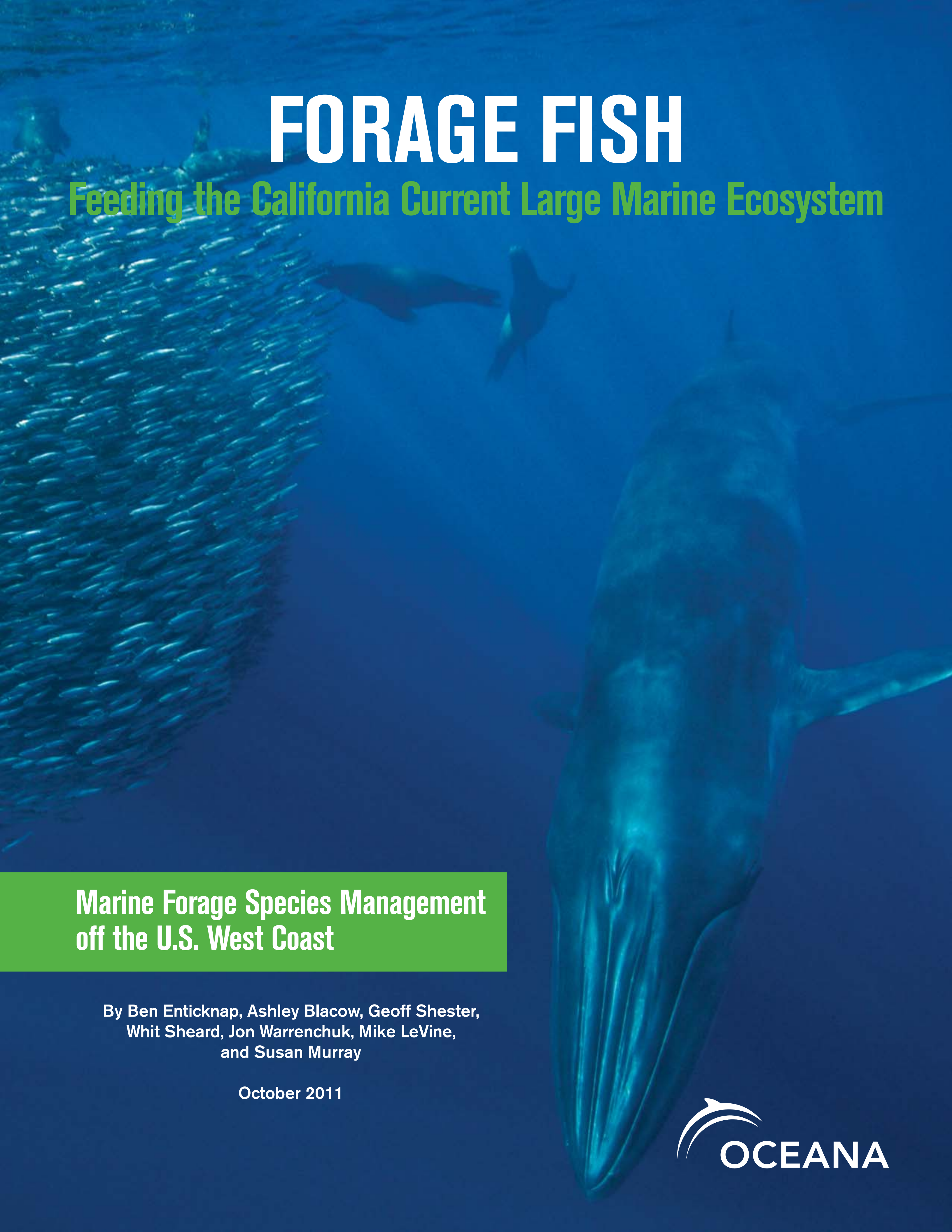

FORAGE FISH

Feeding the California Current Large Marine Ecosystem

Marine Forage Species Management off the U.S. West Coast

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Cover Photo – Brandon Cole – A 40 foot long Bryde's whale and California sea lions feed on a school of Pacific mackerel

Inset Photo – Brandon Cole – School of Pacific mackerel

Back Cover Photo – Brandon Cole – School of Pacific sardines

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Table of Contents

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Executive Summary

In this report we examine the role of forage species in the California Current marine ecosystem, the threats to forage species populations, and the management structures currently in place. At the multiple levels of state, federal, and international management, we identify major gaps in the conservation of the overall forage base that provides the food supply in this ecosystem. We document numerous cases of mismanagement and ample reason for concern, including overly aggressive harvest rates, forage species declines, and a failure by fishery managers to account for existing information on the prey consumption needs of larger animals when making management decisions.

In any ecosystem – on land or sea – food availability is a critical factor directly affecting the health and biodiversity of the system. This is especially true for the California Current Large Marine Ecosystem, spanning from British Columbia to Baja California. This wild ocean ecosystem supports a phenomenal diversity of life. It also contributes to the regulation of our climate and supports a major part of the U.S. and world economy. Unfortunately, individual and cumulative threats to the health of this ocean ecosystem continue to grow, making the path towards sustainable living an ever pressing issue.

The term "forage species" means any fish or invertebrate species that contributes significantly to the diets of other fish, birds, mammals, or sea turtles, or otherwise contributes disproportionately to ecosystem function and resilience due to its role as prey.

One pillar to the long-term sustainability of this ocean ecosystem is healthy populations of forage species that provide the food supply for larger animals. Forage species, such as Pacific herring, Pacific sardine, Northern anchovy, smelts, squid, and krill, are the critical prey for whales, dolphins, sea lions, many types of fish, and millions of seabirds. The abundance and availability of these small schooling fish and invertebrates are key to a vibrant food web and a healthy ecosystem.

Given the increasing global demand for seafood, and in particular wild-caught fish used as feed for the growing aquaculture industry, it is imperative to take action today to avert a crisis tomorrow. The first step is to manage forage species differently than other commercial fish species. There has been some progress. West Coast states, regional fishery managers, and the federal government have already prevented directed fisheries for krill off the U.S. West Coast, citing the importance of these species as a keystone prey in the California Current marine ecosystem food web. Many other important forage species, however, are unmanaged and fisheries could develop at any time and with little warning.

Bryde's whale inhales a mouthful of Pacific sardine

As fisheries for larger species have declined off the U.S. West Coast (e.g., tunas, salmon, and rockfish), the relative contribution of the smaller forage species to commercial landings and value has increased. Yet the value of some forage species to recreational and commercial fisheries, tourism, wildlife viewing, and healthy ecosystems will be much greater if we choose to leave more in the ocean. Tourism, recreation, and fishing reliant on healthy forage species brought in over $23 billion in Gross Domestic Product to California, Oregon, and Washington combined in 2004 alone.[1]

As a society we face a difficult choice about the future of our oceans. Forage species have value if they are caught, but they are also valuable if we leave them in the ocean, as they increase the value of other commercial and recreational fisheries, provide more abundant wildlife and associated tourism, and lead to a more healthy, resilient marine ecosystem. By way of laws and regulations, we directly determine which species should be fully protected and which species can be harvested in a way that sustains the most value to the ecosystem and humans. Those decisions are becoming more complicated as we now must determine if we leave more fish in the oceans where they can contribute to healthy food webs, or whether we remove them for use as industrial feeds for farmed fish and open ocean fish pens. Properly conserving and managing forage species, however, will not only benefit the health of the ecosystem; but will also enhance the cultural, environmental and economic benefits of ocean resources, for both present and future generations.

Role of Forage Species in the California Current Large Marine Ecosystem

One of ten major Large Marine Ecosystems in the United States, the California Current Large Marine Ecosystem is considered globally important for its high productivity and the large number of species it supports.[2] According to the Census of Marine Life, the California Current ecosystem has among the highest number of species of fish, seabirds and marine mammals of all 11 large marine ecosystems in the North Pacific Ocean. The California Current extends 1,900 miles from the northern end of Vancouver Island to Baja California Sur, and includes the Pacific Ocean waters off Washington, Oregon, and California from shore to the 200-mile Exclusive Economic Zone.

California Current Large Marine Ecosystem

The California Current ecosystem is influenced by a series of four currents and is one of five[3] large marine ecosystems in the world that is characterized by productive upwelling. When strong winds blow alongshore towards the equator, warm surface waters are carried offshore and are replaced by deep, cold, nutrient-rich waters.[4] This upwelling fuels phytoplankton blooms and in turn, zooplankton like krill (euphausiids) flourish. These tiny plants and animals create a solid foundation for a food web that supports marine mammals including blue and humpback whales, elephant seals and orcas. Additionally, this food web supports millions of seabirds, endangered sea turtles, slow-growing fragile deep sea corals, crabs, and fish such as salmon, halibut, rockfish and tuna that are vitally important for commercial, recreational, and subsistence harvest.

The California Current is integral to the economy, culture, and well-being of the U.S. West Coast. These waters provide recreational activities, commercial fishing, critical commerce supply links, subsistence and personal use, and a variety of economic activities, including tourism opportunities, for millions of Americans. In 2004, industries dependent on the ocean contributed over $57 billion to the combined Gross Domestic Product of California, Oregon, and Washington.[5] The ocean sector includes marine construction, living resources, minerals, ship and boat building, transportation, tourism and recreation.

Importance of Forage Species

Forage species of the California Current ecosystem are of great cultural, economic and ecological importance. Massive schools of eulachon smelt once pushed up into the rivers of the Pacific Northwest to spawn and were integral to Native American subsistence and trade, and local economies. In the 1930s and 1940s Pacific sardine supported the largest fishery in the western hemisphere. The iconic "Cannery Row" in Monterey, California was built around this ballooning fishery. In 1936 the Pacific sardine fishery peaked at 700,000 metric tons, followed by a dramatic fishery collapse just a few years later. Today Pacific sardine are once again an important part of West Coast fisheries, as are market squid, mackerel, anchovy and others.

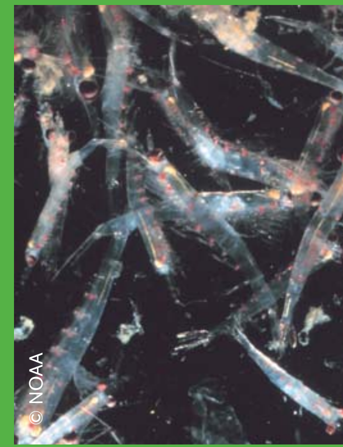
Healthy, abundant and diverse forage populations are also critical to the sustainability of invertebrates, fish, marine mammals, and seabirds. The Pacific Fishery Management Council lists 19 species of marine mammals, 33 species of marine birds, and over 40 species of marine fish that rely on forage species.[6] Among these predators are endangered salmon stocks, endangered birds, depleted rockfish populations, and eight species of whales. An insufficient ocean food supply has been linked to the loss of Sacramento River fall Chinook salmon[7], substantial declines of Coho salmon off Oregon[8], major bird reproductive failures and population declines[9], and marine mammal mortality events[10] in California waters over the last decade. In addition, there has been a 75% drop in top predatory fish populations in the California Current since 2003.[11]

Abundant forage species populations are vital to the sustainability and recovery of economically important commercial and recreational fisheries like Chinook salmon, albacore tuna, yelloweye rockfish, white seabass, barred sand bass, kelp bass, and California halibut.[12,13,14] Forage species are also critical to supporting marine wildlife including humpback whales, sea lions, dolphins, porpoises, seabirds and associated tourism.[15,16,17]

In recent years U.S. West Coast states have seen major seabird die-offs and poor salmon returns to many river systems. Considerable overlap exists in the diet of salmon and seabirds, and they may be responding similarly to fluctuations in a common prey base. Seabird populations tend to parallel the populations of forage prey[19], largely because newborn survival is highly dependent on the parents being able to catch enough high-energy food.[20] For example, the breeding success of the brown pelican has been linked with the abundance and availability of northern anchovy.[21] Therefore, it is important to recognize that top predators require prey abundances that are many times that of their consumption levels alone, since the density of schools and availability of forage species can be a limiting factor to foraging success.[22]

"Forage species such as krill are vital links in the food chain and play an essential role in maintaining ecosystem health. Precautionary measures should be taken to ensure their protection."

- West Coast Governors' Agreement On Ocean Health, 2008



Krill are consumed by both rockfish and humpback whales

Humpback whale

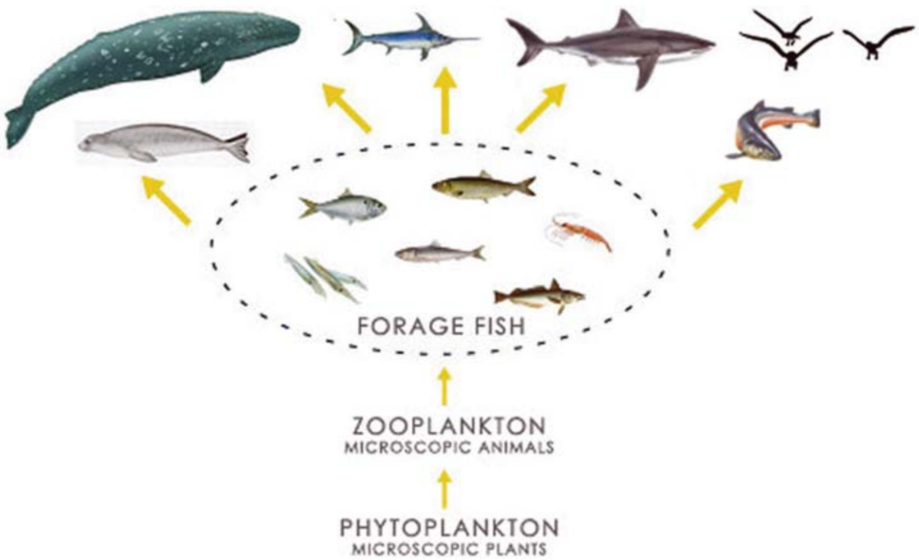
Canary rockfish

When preferred forage species are absent or depleted, marine predators are forced to switch to less nutritionally desirable prey. Preying on species with lower energy content (fat content) may directly adversely affect the health of the predators' populations. The elegant tern is a seabird whose limited geographic range and specialized diet make its population particularly vulnerable to changes in prey abundance. Northern anchovy and Pacific sardine are the bird's preferred prey, but changes in the abundance or distribution of these species in California led to terns relying on lower-energy forage species (such as topsmelt).[23] Over the long term, such dietary changes may decrease survival and reproductive success of this seabird.[24] When alternate prey species are not available due to depletion or seasonal unavailability, reproductive failure and or death may ensue. As another example, when alternate prey species are available, juvenile salmon are more likely to survive since predators have alternate prey upon which to feed.[25]

Elegant tern

> **"Decreased prey resources have caused murrelets to fish further down on the food web, appear partly responsible for poor murrelet reproduction, and may have contributed to its listing under the U.S. Endangered Species Act."**
>
> **– Becker and Beissinger 2006[109]**

Forage Fish: The Vital Link of the Ocean Food Web



Courtesy MFCN

Forage species play an integral role in marine food webs by transferring energy and nutrients from zooplankton to larger animals at the top of the food web like whales, sharks and seabirds

Threats to Forage Species

Forage species face a multitude of threats and stressors, including climate change, ocean acidification, habitat loss, fishing pressure, pollution, and increased demand for forage fish-based feed for aquaculture and agriculture. It is often the synergy of multiple and simultaneous stressors that can lead to the collapse of forage fish populations.[26] A prime example of this is the collapse of the Pacific sardine population in the 1940s due to both extensive fishing pressure and changing oceanographic conditions, which had ramifications throughout the food web[27] and fishing communities like Monterey, California's Cannery Row.

Climate Change

Climate change impacts the survival, growth, reproduction, and distribution of forage fish through gradual warming, changes in oceanographic conditions, and the frequency, intensity, and location of extreme events. Due to their known sensitivity to temperature and oceanographic conditions, forage species are particularly vulnerable to climate change. The impacts of climate change on forage species depend on changes to primary productivity (phytoplankton blooms), transfer of nutrients through the food chain, and the effects on oceanographic conditions that determine reproductive potential and survival. Some studies have predicted significant changes in fishery production based on the effects of climate change on species distribution.[28] Fishing makes fish populations more sensitive to the stresses of climate change.[29] Fishing reduces the age, size and geographic distributions of fish populations, and the biodiversity of marine ecosystems, and these effects are magnified by climate change impacts to species and ecosystems.[30] To increase the resilience of ocean ecosystems to the effects of climate change, the Food and Agriculture Organization of the United Nations recommends taking an ecosystem-based approach to fisheries.[31] In this context, that means considering the impacts of climate change when managing fisheries and incorporating buffers for climate-driven losses in prey populations.

Ocean Acidification

The emerging literature on ocean acidification has highlighted human-caused carbon dioxide emissions as a threat to forage species. In particular, the shells of microscopic organisms like pteropods (a planktonic snail-like animal), which are consumed by krill, herring, and other species, are at risk of dissolving. As ocean pH drops, pteropods may be unable to form calcium carbonate shells, thus threatening their ability to survive.[32] Without pteropods, krill, herring, and other species lose an important food source. Ocean acidification may also have unexpected impacts on forage species physiology. For example, increased ocean acidity is likely to inhibit a squid's ability to transport large amounts of oxygen, thus inhibiting important activities like hunting and avoiding predators, and ultimately imperil their populations.[33] Increased carbon dioxide levels have been shown to have direct lethal effects on krill embryos.[34]

Pteropod shells dissolve as ocean acidification increases

Habitat Loss

Many important forage species depend on suitable spawning habitat along coastal beaches, rivers, estuaries and bays. Loss of spawning habitat due to coastal development, shoreline armoring, aquaculture, dredging, dams and other hydroelectric projects, threaten forage fish populations through the degradation or complete loss of their essential reproductive habitat.

Fishing Pressure

Because of their relative short lifespan and reproductive strategies, many forage species populations fluctuate more widely due to changing environmental conditions than populations of other fish species.[35] This relationship to environmental change has led to a flawed perception that fishing has a small effect on forage species populations or the availability of forage. In fact, scientists have recently concluded that forage species are just as likely, if not more likely, to experience fishery collapses than larger fish.[36] Throughout the world, fishing on small pelagic fish and invertebrates has been linked to declines in their predators.[37,38,39]

On the U.S. West Coast, simulations of Pacific sardine populations show that slight changes in fishing pressure result in drastic changes in the number of years of low fish abundance, as well as changes to the average sardine biomass.[40] In particular, the effects of fishing forage species are more severe in times of low natural productivity. For example, some forage species are less productive during El Niño conditions when ocean water is warmer than usual.[41] Furthermore, the schooling behavior of forage species often means that exploitation rates do not decrease directly as populations decline. Schooling forage fish are easier to catch, even at low population levels. While forage species are affected by many stresses beyond our immediate control, fishing is the greatest factor that we can control.
In the end, it is the compounding effect of low natural productivity and fishing pressure that determines the rate of collapse and the speed of recovery of forage species populations.[42] Fishing can lower forage biomass to a point where the effects of unfavorable ocean conditions are strongly magnified throughout the ecosystem, including other fisheries. Therefore managing forage fisheries relative to natural forage species population fluctuations is critical to maintaining the resilience of ocean food webs in the face of the many pressures on forage species.

Purse seiners off the coast of Monterey, CA

Pollution

Pollution, such as oil spills, can have catastrophic effects on forage species through direct developmental effects and acute toxicity.[43] The *Exxon Valdez* oil spill caused the collapse of the Prince William Sound Pacific herring population, which has still not recovered over twenty years later. The loss of Pacific herring has likely affected the recovery of seabirds and marine mammals in this area.[44,45] On November 7, 2007, the container ship, *Cosco Busan* ran into a tower supporting the San Francisco Bay Bridge, spilling 54,000 gallons of bunker fuel oil into the bay. This heavy bunker oil contaminated the shoreline in areas important to herring spawning in months following the spill. Following the spill and subsequent herring spawning, researchers documented reduced herring survival, reduced hatching success and high rates of herring birth defects at the oiled sites.[46]

Images from a study performed by government scientists contrast normal herring embryos raised in clean water (left) with fatally deformed embryos exposed to the type of oil used by the Cosco Busan

Aquaculture

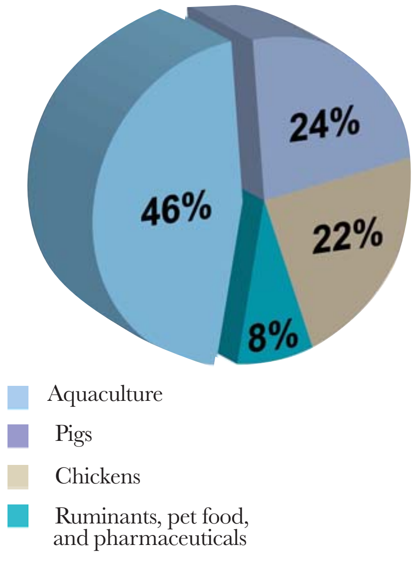
Despite marked increases in feed efficiency, aquaculture's share of global fishmeal and fish oil consumption has more than doubled over the past decade to 68% and 88%, respectively.[48] Total production of farmed fish and shellfish increased threefold from 1995 to 2007. Furthermore, a greater percentage of fish farms now use compound feeds that are derived from wild fish. While feed conversion ratios (amount of fish feed required per quantity of farmed fished produced) are improving, growth in the industry has resulted in an overall increase in the quantity of fish feed used. This growth in the aquaculture sector will likely drive prices of forage fish higher, creating incentives for higher catch rates in existing fisheries and making once uneconomical fisheries feasible.[49]

For several decades, 20 million to 30 million metric tons of fish (1/4 to 1/3 of the global fish catch) have been removed from the marine food web each year to produce fishmeal and fish oil for animal feeds and other industrial purposes.[50] Since the 1960's humans have consumed 10-20% of the total forage fish catch per year.[51] Another 5-9 million metric tons of "low value/trash fish" and other forage fish are used for non-pelleted (farm-made) Aquafeeds.

In 2002, 46% of fishmeal and fish oil produced globally was used for aquaculture, followed by 24% for pigs, and 22% for poultry.[53] Despite improvements in feed efficiency, overall demand, particularly for fish oil, is increasing due to the expansion of aquaculture production. In 2008, 27.2 million tons of the 89.7 million tons of fish caught in the world's oceans went to non-food uses. Of this, 20.8 million tons went to fishmeal and fish oil. The remainder went as a combination of bait, pharmaceuticals, and direct feeding in the aquaculture and the livestock industries.

Pacific sardines being fed to penned bluefin tuna

Fishmeal Uses



Data from Campbell and Alder, 2008

The Economic Value of Forage Species

Like many other forage fish fisheries around the world, forage fish caught off the U.S. West Coast are sold as relatively high volume/low value products. Pacific mackerel is canned for pet food, Pacific sardine is frozen and shipped to Australia to feed penned tuna, and northern anchovy is reduced to meal and oil. Larger Pacific sardine taken off Oregon and Washington are typically sold as bait for Asian longline tuna fisheries. Other vessels target northern anchovy and other forage fish for local live and dead bait markets. A relatively small amount of Pacific mackerel, sardine and anchovy is sold for human consumption.[57]

The same species of wild fish that are used as feed for fish farming or animal farming are also a source of food for marine fish that are captured and used for human consumption, and are food for animals that are in demand for non-consumptive reasons (marine mammals or sea birds). Therefore, it is highly likely that the capture of feed fish is at the expense of other wild fish or animals that mankind values and utilizes, directly or indirectly.

> **" ...the opportunity cost of sardines as prey for other fish and animals has not been explicitly considered in setting catch quotas for sardines."**
>
> **– Hannesson and Herrick. 2010.[58]**

The economic value of forage species cannot be measured by simply summing the landings values of commercial fisheries targeting forage fish. It is highly likely that the capture of forage fish to feed farmed fish will be at the expense of other wildlife like salmon, tuna, whales, and seabirds. Forage species left in the ocean are valuable for two reasons. First, they contribute directly to the size of the forage population in future years. Second, forage fish contribute to the overall abundance of their predators. More forage means more predators. It is those very predators such as salmon and whales that also drive other important sectors of coastal cultures and economies.

Economists would refer to the tradeoff between harvest and the ecosystem as the "opportunity cost" of removing forage fish from the sea. Depending on the value of sardine predators, for example, and the transfer efficiency of sardine biomass into predator biomass, sardines may be more valuable to the coastal economy if left in the water unfished. The trade-offs between healthy ecosystems, tourism, other fisheries, and industrial feeds need to be examined. Specifically, when calculating optimum harvest levels, including the overall benefit to society, managers must consider the other ecological services forage species provide, including their benefit as prey for other commercially important species.

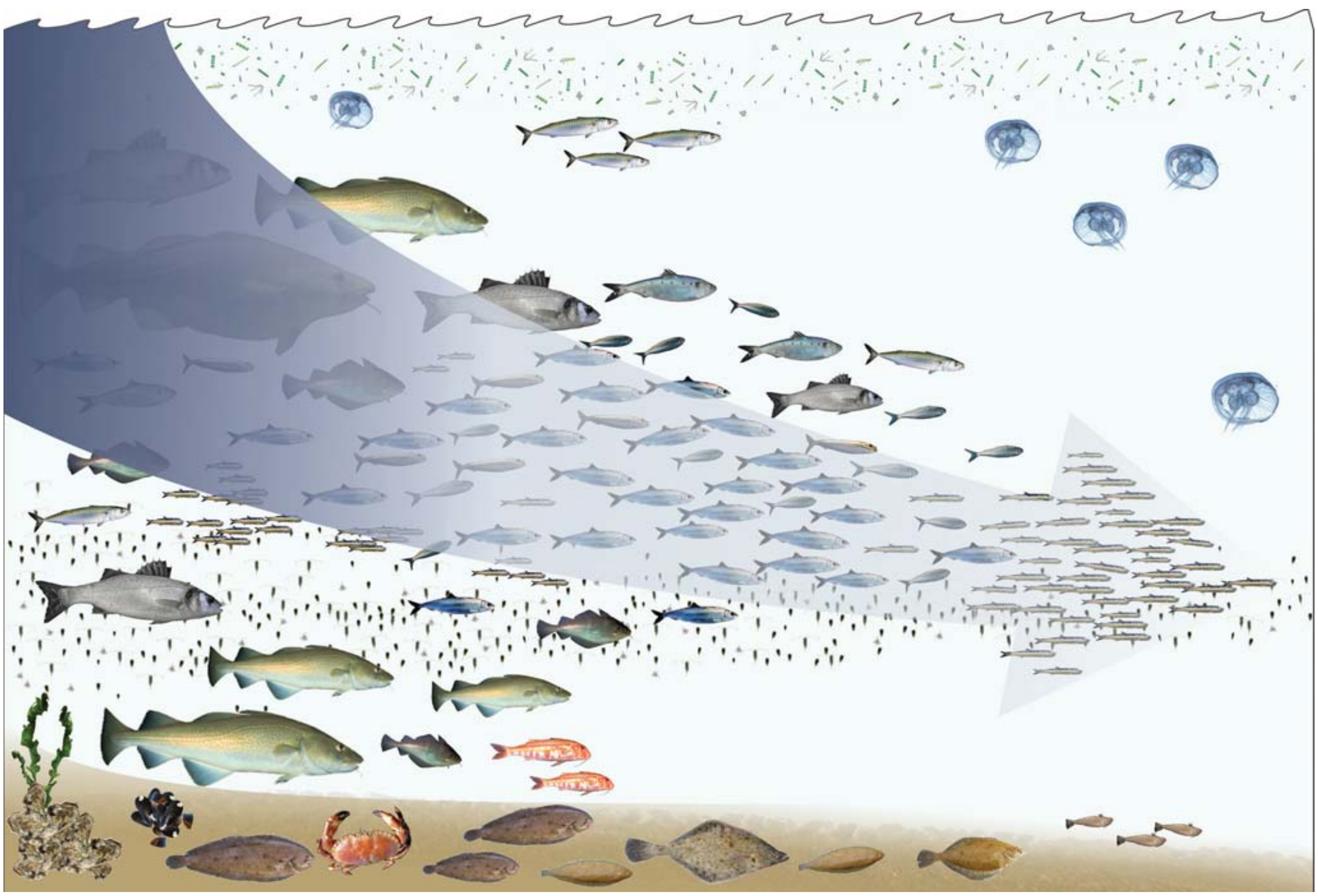
Whale watching provides major revenue on the west coast

Shifting the Management Paradigm

Fishery managers typically do not consider how much prey needs to be left in the ocean to support valuable fisheries and wildlife. Instead, managers use the traditional single-species approach to managing forage species, evaluating each fish species in isolation and determining what catch levels most likely would allow humans to continue to catch that same amount of fish or more in future years. Every major report on ocean management in recent years came to the same conclusion: we need to move away from this single-species "money fish" model to an ecosystem approach that accounts for the needs of other components of the ecosystem, like predators, when setting catch levels.

Although there has been some progress at the state and federal levels of fishery management, there is currently an inadequate accounting for the needs of top predators. To address this gap, an explicit recognition of the dual value forage species play both as prey and as fishery landings is needed, and this must be accounted for in the management process. Similarly, from a scientific perspective, the focus of data collection needs to expand beyond assessing the populations of forage species themselves and include their interactions with oceanographic conditions and predators.

The traditional single-species management approach emphasizes maximizing the catch of individual fish stocks, as opposed to maintaining a healthy ocean ecosystem. Whether managed by individual states, federal entities or international agreement, the underlying principle for determining how much fish can be taken from the ocean is embedded in the philosophy of Maximum Sustainable Yield (MSY). MSY is considered to be the largest long-term average catch or yield that can be taken from a stock, year after year, under prevailing conditions.[59]



Ecosystem-based management is needed to prevent fishing down the food web, which is when fisheries target lower and lower trophic level fish stocks as species in higher trophic levels are sequentially overfished

Based on the concept of MSY, fishery managers seek to maintain high fishery catches by regulating the number or weight of fish caught, the size of the fish caught, and/or the time and space where fishing is allowed to take place.[60]

The single-species MSY approach, however, threatens the sustainability of forage species, and hence the overall ecosystem. This focus on maximizing yield, or fish catch, based on a single-species model that assumes constant relationships between population density and productivity can lead to overfishing in years of unfavorable environmental conditions, poor recruitment, and low productivity.[61] Hypothetically there may be a maximum sustainable yield, but in reality management is dealing with fisheries targeting real fish populations in a dynamic ocean ecosystem with much uncertainty. In practice, the MSY approach is unsuccessful, as evidenced by the global trend of fishing down marine food webs.[62]

Fishing down the food web (see page 13) occurs as fisheries target lower and lower trophic level fish stocks as species in higher trophic levels are sequentially overfished. Despite scientific studies depicting strong forage species-predator relationships, and fisheries policies calling for ecosystem-based management, current management of forage species does not adequately consider their importance in maintaining a healthy ocean. These factors, combined with a fragmented management system, a lack of fundamental biological information, information on stock status, and historic catch records, can have devastating consequences for forage species and their predators.

In order to protect the food web of the California Current Large Marine Ecosystem, fishery management must shift the paradigm to manage for ecologically sustainable populations of forage species. This means moving away from traditional single-species management to Ecosystem-Based Management (EBM) by explicitly considering scientific uncertainty in stock assessments, predator-prey relationships, and bycatch (taking of untargeted species) when determining catch levels. Fishery managers need to shift the focus from the MSY to Ecologically Sustainable Yield (ESY) where the full impacts of fishing on the ecosystem are evaluated and considered.[63] ESY is an estimate of the amount, rate, distribution and time period of fishing that can occur without diminishing the ecological role of fish and invertebrate species. Fishery scientists and ecologists agree that a wide range of exploitation rates can result in catch levels nearly as high as maximum levels. Yet setting exploitation at the lower end of this range reduces ecosystem impacts, rebuilds total biomass, prevents species collapse, reduces the costs of fishing, and increases profit margins over the long term.[64,65] Specific to forage species, a recent study found widespread impacts of harvesting forage species across five different ecosystems, including the California Current. The study's authors recommended maintaining forage biomass levels much greater than MSY biomass levels (over 75% of their unfished levels) and fishing rates less than half of MSY rates.[66]

Sockeye salmon

Management Overview

FEDERAL GOVERNMENT

The National Marine Fisheries Service (NMFS) is the lead federal agency responsible for the stewardship of the nation's offshore living marine resources and their habitat. NMFS works closely with the Pacific Fishery Management Council (PFMC), which advises the agency on all federal fisheries management occurring off the U.S. West Coast. In addition to federal managers, the PFMC includes representatives from the States of Washington, Oregon, California, Idaho; Native American Tribes; and appointed members of the public who generally represent various commercial and recreational fishing interests. NMFS and the PFMC manage fisheries that directly target key forage species like Pacific sardine, Pacific mackerel, and market squid. Additionally they manage some important forage species that have no directed fishery, like shortbelly rockfish and krill. A directed fishery is one that targets a specific species of fish. Fisheries for forage species are generally managed by NMFS in one of two federal plans: the Coastal Pelagic Species Fishery Management Plan (FMP) and the Groundfish FMP.

What's working

The PFMC and NMFS have taken some precautionary actions to protect forage species and their role in the marine ecosystem. In 2006, recognizing the importance of krill as a key prey for blue whales, salmon, seabirds and many other species, the PFMC unanimously voted to recommend that NMFS prohibit krill harvest off the U.S. West Coast. After much delay, in July 2009, NOAA officially adopted the ban on krill harvest throughout the U.S. West Coast Exclusive Economic Zone (EEZ).

In 2010, the PFMC, recognizing the value of shortbelly rockfish as forage, voted to set the 2011-2012 catch levels for this species at less than 1% of the allowable biological catch. This is another example where fishery managers have recognized the role of an important forage species as prey in the ecosystem and taken action to protect that ecological role.

© NOAA

NOAA vessels like the Pisces offer fisheries scientists the ability to collect valuable data to monitor and manage fish populations

What's not working

Lack of Management

There are many important forage species like whitebait smelt, Pacific sandlance, and lanternfishes (myctophids) that receive no management by NMFS and the PFMC. There are presently no plans in place that recognize the important role these species play in the California Current ecosystem, or to protect them from any potential or future fishing effects. The PFMC and NMFS have the authority to take proactive measures, like they did with krill, to prevent the development of new fisheries for these and other key forage species.

Overfishing

Federal law requires that fishery managers prevent overfishing and inlcude in fishery management plans objective and measurable criteria for determining when a fish stock is overfished.[68] Having these management thresholds in place is critical for triggering plans to rebuild depleted populations to healthy levels and to prevent further declines. To date, the PFMC and NMFS have failed to identify overfished thresholds for market squid, northern anchovy and jack mackerel. This failure to designate legally required thresholds risks jeopardizing these populations and the marine life that depends on them.

Pacific jack mackerel

The overfished thresholds identified for other targeted forage species, like Pacific sardine and Pacific mackerel, are too low, making the chances of overfishing more likely. Furthermore, the overfished level for Pacific sardine is currently set at 50,000 metric tons, less than 4% of their biomass at maximum sustainable yield (Bmsy). NMFS guidelines on preventing overfishing state that the overfished threshold should be 50% of the biomass that produces MSY, or a reasonable proxy, but certainly not as low as 4%. These thresholds clearly do not account for ecosystem needs and are far too low to protect Pacific sardine populations. Furthermore, the 2010 Pacific sardine assessment found that the 2010 sardine biomass is at the lowest level in the past 23 years and that the combined fishing pressure from the U.S., Mexico, and Canada exceeded the total overfishing limit in 2009, the most recent year for which coast-wide fishing levels are available.[69]

Failing to account for ecosystem needs

The Magnuson-Stevens Fishery Conservation and Management Act mandates that fish catch levels be set in a manner that protects marine ecosystems. Fisheries are to be managed at “Optimum Yield”, defined as the amount of fish which “will provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunities, and taking into account the protection of marine ecosystems.”[70] Optimum Yield is described as Maximum Sustainable Yield “as reduced by any relevant economic, social, or ecological factor.”[71] While the federal law requires Optimum Yield and NMFS has agreed that ecological conditions and ecosystem factors should be taken into account, they have failed to do so in any of the Pacific fishery management plans.

Rosy rockfish

Currently a wealth of existing data and analytical methods are available to address ecological factors relevant to the harvest strategy of forage species. Diet information, which indicates the existence and strength of predator-prey relationships, has been published by NOAA for U.S. West Coast species.[72] In addition, food web models of the California Current have been published.[73,74] These models provide the ability to qualitatively and quantitatively describe the impacts of removing forage species on other marine species, and to evaluate food web resilience and biodiversity. This existing ecological data must be incorporated into the setting of Optimum Yield.

Failure to adequately address uncertainty

Fishery scientists use a complex set of tools and methods for estimating the abundance of fish populations in the ocean. Unfortunately, these estimates come with a great deal of uncertainty. Managers must set buffers to account for scientific and management uncertainty; not doing so puts the fish population at risk. The current fishery management process fails to address or even acknowledge many major uncertainties in overfishing limits and allowable catch levels, including uncertainty in the optimal harvest rate, the effects of climate change, and ecosystem interactions.

Unfortunately, the results of operating large scale commercial fisheries based on uncertain stock assessments and aggressive management decisions has proven to be overfishing, with likely ecosystem-wide impacts. In January 2000, following intensive fishing pressure, a risky fishery management strategy and highly uncertain scientific advice, the West Coast groundfish fishery was declared a commercial fishery disaster, as seven species of groundfish were overfished. As of June 30, 2011 seven stocks of West Coast fish species, including rockfish, flatfish, and salmon, are considered to be overfished.

STATE GOVERNMENT

Washington

The Washington Department of Fish and Wildlife (WDFW) is responsible for state-managed fisheries off Washington. Among West Coast states, Washington became a leader in forage fish management in 1998 when it adopted a Forage Fish Management Plan.[79] The Forage Fish Management Plan provides a strong conservation framework that emphasizes maintaining the role of forage species in the ecosystem over commercial and recreational harvest. The Forage Fish Management Plan includes important policy statements such as "maintain[ing] healthy populations of forage fish species and individual stocks of forage fish while assuring the integrity of the ecosystem and habitat upon which marine resources depend" and "consider[ing] the role of forage fish in the marine ecosystem and the need to supply sufficient quantities of forage fish for ecosystem needs."

Beginning in the early 1970s, the State of Washington started to address forage fish issues in the Puget Sound Basin as the state began work to identify critical spawning habitats. The State of Washington has since adopted a "no net loss" approach to documented herring, surf smelt, and Pacific sand lance spawning habitats and has listed these habitats as "marine habitats of special concern."[80] State laws now control the timing and extent of development on and near these spawning grounds. Efforts are ongoing to document currently unknown holding and spawning areas. A lack of sufficient biological data, including documentation of distribution and abundance, for other forage fish species (e.g., whitebait smelt, night smelt, longfin smelt) has led to a lack of protection for the spawning and holding areas of these species.

While the State of Washington has acted as a leader with regard to forage fish conservation and management, more work is needed to identify forage fish spawning habitats on Washington's outer coast and to eliminate activities that are destructive to forage fish spawning areas in Puget Sound. With continued human population growth in the Puget Sound Basin, there will likely be increasing pressures for development in the marine nearshore zone with impacts to both known and undocumented spawning sites. Washington can continue to improve its forage fish management by committing to population surveys, continuing to identify spawning habitats both in Puget Sound and along the outer Washington coast, dedicating effort to assessment of the lesser known forage species of the state, and working with the public to increase awareness about forage fish and their critical habitats. The State of Washington also plays a key role on the Pacific Fishery Management Council where they can help advance an ecosystem-based approach to fisheries management, including ecologically sustainable catch levels, along with other West Coast states and the federal government.

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Threatened Forage Species:

Eulachon

In March 2010, the National Marine Fisheries Service (NMFS) listed the southern distinct population of Pacific eulachon (a.k.a. hooligan or Columbia River smelt) as threatened under the Endangered Species Act. NMFS identified climate change, habitat loss and bycatch in commercial fisheries as some of the greatest threats to the recovery of this ecologically and culturally important fish species.[86] In January 2011, NMFS issued a proposal to designate critical habitat for eulachon in some Pacific Northwest rivers, creeks and estuaries where eulachon spawn, but failed to propose designation of any marine waters, where eulachon spend 95-98% of their life.[87]

NMFS also failed to adequately address the issue of the bycatch of eulachon in other fisheries. In 2007 the state managed California, Oregon and Washington pink shrimp fishery caught approximately 10,360 pounds of eulachon as bycatch.[88] The fishery took over 26,600 pounds in 2008 and over 23,800 pounds in 2009.[89, 90] The 2009 bycatch of eulachon represents over 800,000 individual fish. State managers are exploring gear modifications to try to limit the amount of eulachon bycatch in the shrimp fishery, but other mechanisms must be considered as well, such as time and area closures and an overall hard cap on the amount of eulachon bycatch that can be taken. The Canadian pink shrimp fishery off British Columbia also takes this population of threatened eulachon as bycatch.

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In 1956 Kelso, Washington was dubbed the "Smelt Capital of the World"

Northern anchovy

Oregon

Severe declines of eulachon, now listed as threatened under the Endangered Species Act (ESA), have prompted recent action by Oregon to close all recreational smelt fishing in estuaries, bays and rivers. In 2010, all commercial fisheries for smelt (family Osmeridae) were closed by the State of Oregon, including ocean fisheries and the Columbia River smelt fishery.[82] State rules allow for the bycatch of smelt in commercial fisheries, like the Oregon pink shrimp fishery that takes thousands of endangered eulachon each year (see eulachon text box on page 17).

Unlike Washington, the State of Oregon does not have a comprehensive forage fish plan. Oregon-based fisheries for forage species, like Pacific sardine and northern anchovy, are managed primarily by the National Marine Fisheries Service. Fisheries for Columbia River eulachon are managed jointly with the State of Washington.

Surf smelt were also once abundant off the Oregon coast. In fact, the coastal town of Yachats, Oregon has long held an annual smelt festival. The local surf smelt population began to decline in the early 1980s and smelt ceased to return to the area almost entirely by 2000.[83] Despite the declining numbers of surf smelt, they are not listed as threatened or endangered. In fact, state management allows all recreational anglers to take 25 pounds a day in marine waters.

The State of Oregon manages fisheries for other important forage fish – Pacific saury, Pacific herring, California market squid, jack mackerel, Pacific mackerel, shortbelly rockfish and northern anchovy – as open access fisheries. As a result, there is no incentive for individuals to conserve fish stocks.[84] Globally, open access fisheries have been demonstrated to be a poor way to conserve fish stocks or ecosystem health because there is no way to exclude newcomers from the fishery and limited ability to control the exploitation level. Oregon's open access management regime allows any person or company with an Oregon commercial fishing permit to target these species. Some of these species have limited controls at the federal level, in the Coastal Pelagic Species FMP, but little is done at the state level to manage these species other than to monitor landings.

Oregon has taken proactive measures to prohibit the comercial harvest of smelts and krill. In 2003 Oregon passed a law banning the commercial harvest of all species of krill.[85] This state action helped convince the federal government to take parallel action to prohibit the harvest of krill in federally managed waters. The recent prohibition on the commercial harvest of all smelt species was driven largely in response to the listing of eulachon as threatened under the federal Endangered Species Act and by a lack of funding for Oregon's "developmental fisheries program" where smelt species were formerly managed.

The State of Oregon needs to fully develop forage species conservation and management by moving toward an ecosystem-based approach. This plan must include actions to identify and protect forage fish spawning habitats and account for ecosystem needs when setting catch levels.

What is more, the State of Oregon must implement an ecologically significant network of marine protected areas and reserves throughout the state's ocean waters. In November 2010 three coastal Oregon community teams recommended marine reserves and protected areas for the northern Oregon coast. These community recommendations include specific provisions to protect forage species, including one marine protected area off Heceta Head which would specifically prohibit fishing for forage species for the protection of seabirds feeding in the area.

A comprehensive forage fish plan for Oregon is needed to help focus on long-term conservation of all important forage species.

Pacific bluefin tuna

California

The California Department of Fish and Game (CDFG) is responsible for state-managed fisheries off California with the California Fish and Game Commission (CFGC) as the decision-making body. Fisheries are managed under the state's Marine Life Management Act (MLMA). The State of California does not have a comprehensive forage fish management plan, nor does it have any formal recognition of forage species in the MLMA or in state policy.

Under the MLMA, Fishery Management Plans (FMPs) were envisioned to be the primary tool for fishery management. Due to chronic underfunding and the comprehensive requirements of FMPs, however, only three FMPs have been completed in the last decade. While the three FMPs stated an intention to move toward "ecosystem-based management", neither the MLMA nor the FMPs define what "ecosystem-based management" means in the context of the managed species or provide a framework for evaluating whether management is ecosystem-based.[92] While FMPs are required to summarize existing information on the ecological role of target species, the effect of the fishery on their ecological role, and the influence of oceanographic conditions on the target species, the CFGC is not required in any way to account for these factors in management decisions.

The State of California does not have a comprehensive forage fish management plan, nor does it have any formal recognition of forage species in the MLMA or in state policy.

Blue whale

Market squid

Some California-based fisheries for forage species, such as Pacific sardine and northern anchovy, are managed primarily by the National Marine Fisheries Service. The State of California enforces those management decisions for the component of the fishery that occurs in state waters and monitors landings. Market squid and Pacific herring are the two main forage species currently managed by the CDFG. Market squid is managed through the Market Squid Fishery Management Plan, while Pacific herring is managed through an annual Supplemental Environmental Document by CDFG and the CFGC. In addition, some regulations exist on fishing gear and monitoring of landings for smelts and silversides.

The MLMA contains provisions for the development of new fisheries that do not currently exist, termed "Emerging Fisheries." The state's current policy is to promote the development of such fisheries and not to regulate them until they have emerged (e.g., landings and participation have increased).[93] However, until a new fishery has been officially declared an "Emerging Fishery" by CDFG, the state does not have authority to regulate it. Therefore, it is unclear whether California can prevent new fisheries from developing on forage species under current law.

California is now completing its implementation of the Marine Life Protection Act by creating a new, improved network of marine protected areas (including several no-take marine reserves) in state waters. Unfortunately, protecting forage species and key foraging areas were not specific objectives of the scientific guidelines used in developing the network. The marine protected areas, however, do a little of both by protecting some key nearshore spawning areas for market squid and other forage species, and protecting several areas in the vicinities of seabird colonies and marine mammal haul-outs.

Reliance of key predators on forage species

CHINOOK SALMON

(Oncorhynchus tshawytscha)

The Chinook salmon is the largest of the Pacific Ocean salmon species and has great cultural, economic and ecological value. These fish are renowned for their great migrations from the streams where they are hatched, across vast stretches of the Pacific Ocean, and back as adults to spawn in their streams of origin. In the California Current ecosystem, juvenile and adult Chinook salmon prey heavily on Pacific sardine, herring, northern anchovy, krill and juvenile rockfish. Pacific herring, Pacific sardine and northern anchovy make up 48% of the diet of Chinook salmon by weight.[94] Nine evolutionary significant units of Chinook salmon in Washington, Oregon and California, comprising dozens of independent stocks, are listed as threatened or endangered under the U.S. Endangered Species Act.[95]

CALIFORNIA SEA LIONS

(Pelecanus occidentalis californicus)

California sea lions have increased in number since the end of directed hunting in the 1940s.[103] In the United States, the major breeding areas are located in the Channel Islands off Southern California. However, in 2010, as a result of shifts in their prey, a record number of yearling sea lions were stranded on California beaches, while adults from Southern California migrated north to Monterey and Oregon in search of food. The top five prey items for California sea lions are northern anchovy, market squid, Pacific hake, jack mackerel, and shortbelly rockfish.[104]

YELLOWEYE ROCKFISH

(Sebastes ruberrimus)

Yelloweye rockfish are an exceptionally long-lived and slow growing rockfish species that has been overfished. Living up to 118 years old, this is one of the longest lived rockfishes.[96] The current low population size is a result of overfishing and the species is now managed by NMFS under a rebuilding plan. The primary food source of yelloweye rockfish are small planktivores (fish that eat plankton) like northern anchovy and Pacific sardine, which make up 32% of their diet.[97] Other rockfish like black rockfish and blue rockfish also prey heavily on these forage species.[98] The population of yelloweye rockfish is not estimated to recover until the year 2074.

ALBACORE TUNA

(Thunnus alalunga)

Albacore tuna is one of the most prized and lucrative fish on the U.S. West Coast, both commercially and recreationally. In 2009, the commercial fishery for albacore tuna was worth over $27 million, about 90% of the total value of highly migratory species (e.g., tunas, swordfish, sharks).[99] Over 80% of albacore tuna diet is composed of small planktivores, primarily northern anchovy and Pacific sardines[100], making it among the species most dependent on these forage fish.

CALIFORNIA BROWN PELICANS

(Pelecanus occidentalis californicus)

Forage fish availability is likely the most important factor influencing brown pelican breeding success.[105] Brown pelican productivity is associated with the abundance and availability of northern anchovy, which in some years makes up over 92% of their diet.[106]

MARBLED MURRELET

(Brachyramphus marmoratus)

Listed as threatened under the Endangered Species Act, the marbled murrelet is a small seabird that nests in coastal old growth forests from central California to Alaska and feeds on forage fish in coastal nearshore waters. In California's Monterey Bay ecosystem, marbled murrelets historically fed on sardine.[107] The collapse of the California sardine fishery in the late 1940s reduced the availability of sardine for the marbled murrelet. Over time, these birds made a fundamental prey switch, from sardine to smaller forage species like krill. This prey switch requires spending more time and energy foraging since it takes 80 krill to match the energy found in a single Pacific sardine.

COMMON MURRE

(Uria aalge)

The common murre is one of the most abundant seabird species in the California Current. During the breeding season, juvenile Pacific hake and northern anchovy constitute the majority of adult murre diets, yet market squid dominate their diet in the wintering season. However, chicks consume primarily (>80%) northern anchovy, Pacific sardine, and juvenile rockfish. In 2004, adult common murres from Cape Blanco, Oregon to Point Conception, California were estimated to consume 225,000 metric tons of prey, rivaling the largest commercial fisheries off the West Coast.

BLUE WHALE

(Brachyramphus marmoratus)

Endangered blue whales are the largest animals to have ever lived on earth. They feed exclusively on tiny krill at rates of up to two metric tons per day.[101] With their great size (up to 33 meters and 172 metric tons), blue whales have the highest average daily energy requirements of any species.[102] Therefore blue whales feed only in exceptionally productive areas like the northern Channel Islands, Monterey Bay Canyon, and Gulf of the Farallones, around the Farallon Islands off San Francisco.

Pacific sardine

Forage Species Profiles

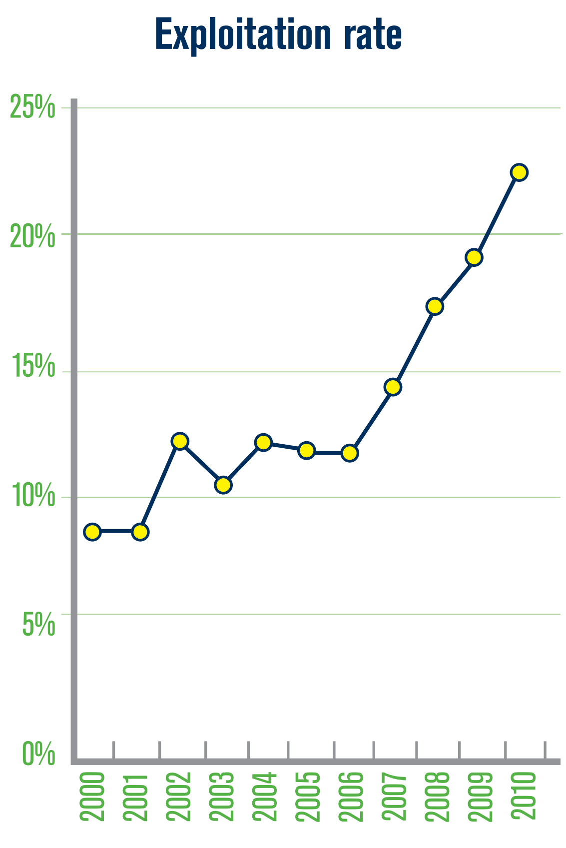
PACIFIC SARDINE
(Sardinops sagax)

Pacific sardine are a major forage species in the California Current. Feeding primarily on plankton, they play a critical role in transferring energy from low to higher trophic levels. Sardine populations are highly variable, as their recruitment depends largely on oceanographic conditions. On the U.S. West Coast, Pacific sardine and northern anchovy populations appear to have an inverse relationship, where periods of low sardine abundance are marked by dramatic increases in anchovy populations and vice versa.[123] These fluctuations are thought to be related to large scale changes in ocean temperature where warmer than average temperatures are more favorable for sardine and cooler than average temperatures are more favorable for anchovy populations.

Pacific sardines are managed by the Pacific Fishery Management Council within the Coastal Pelagic Species (CPS) FMP. Sardine management takes place through an innovative framework that has the potential to serve as a model for ecosystem-based forage species management. In this framework, a minimum cutoff biomass is "set-aside" such that fishing quotas are set on a percentage of the biomass above the cutoff and the fishery is closed if the total population drops below the cutoff. The current cutoff for Pacific sardine is 150,000 metric tons, however, this level was set without considering what is required to provide adequate forage. The percentage of the remaining biomass that can be fished increases (to15%) in warmer ocean conditions when the population is thought to be more productive and decreases (to 5%) in cooler, less favorable conditions. Finally, there is a maximum catch value that cannot be exceeded regardless of how large the population becomes. This prevents overcapitalization and provides a level of precaution when stock assessments are uncertain. The Pacific sardine control rule currently employs a maximum catch threshold of 200,000 metric tons. Other targeted forage species do not have this important control in place.

While these fishery management concepts are steps in the right direction, the implementation has failed to maintain the sardine stock at or above maximum sustainable yield (MSY) levels due to flawed assumptions and the failure of managers to respond to new information. Since implementation of the harvest policy in 2000, coast-wide exploitation rates have increased, the biomass has been maintained below the single-species MSY level (1,408,000 metric tons (Bmsy)), the increasing catch from Canada and Mexico has not been addressed, and the temperature-recruitment relationship used to justify the fraction parameter (allowing higher exploitation under favorable environmental conditions) has been shown to be invalid.[124,125] In 2010, NMFS ignored evidence from its own stock assessment that coast-wide overfishing was occurring (i.e., total catch exceeding overfishing levels). Meanwhile, catch levels continue to be set according to the existing harvest control rule despite clear scientific evidence that its underlying parameters are flawed.

Pacific sardine near kelp forest



Coastwide exploitation rates on Pacific sardine since 2000. Data from Hill, K.T., Lo, N.C.H., Macewicz, B.J., Crone, P.R., and Felix-Uraga, R. Assessment of the Pacific Sardine Resource in 2010 for U.S. Management in 2011. NOAA Technical Memorandum NMFS-SWFSC-469. December 2010.

Pacific hake

PACIFIC HAKE
(*Merluccius productus*)

The fishery for Pacific hake, also known as Pacific whiting, is among the top three fisheries by volume on the U.S. West Coast (along with market squid and sardine).[126] Pacific hake play an important role in shaping the California Current ecosystem, as they are both a major provider and consumer of forage. Because almost 80% of their diet is zooplankton, they transfer significant energy up the food web. However, as they grow larger, they consume other forage species. Making up the other 20% of their diet are other planktivores like sardines and anchovies.[127] Juvenile Pacific hake provide prey for migrating and surface seabirds, demersal sharks (those that live near the seafloor) and rockfish. Pacific hake are major prey for large flatfish (37%), pinnipeds (fin-footed marine mammals) (20%), pelagic sharks (those that live in the upper part of the ocean) and sablefish (black cod). Despite sharing many characteristics to other species managed under the Coastal Pelagic Species FMP (e.g., importance as forage, highly variable recruitment based on oceanographic conditions), they are managed in the Groundfish FMP by the Pacific Fishery Management Council. Regardless of which plan they are in, managers must begin to account for their ecological role in the ecosystem when setting catch levels.

JUVENILE ROCKFISH
(*Sebastes spp.*)

Most people do not consider rockfish to be in the same category of important forage species as other species like squid, sardines, or anchovy. However, the juveniles of some rockfish can be extremely abundant and in fact are a primary food source in the California Current. In particular, shortbelly rockfish are the most abundant juvenile rockfish in the California Current and have been recognized for decades as a primary prey item for marine mammals, seabirds, Chinook salmon, and other commercially important fishes.[134, 135, 136, 137, 138, 139,140] For many breeding California seabirds, as much as 90% of their diet is composed of pelagic stages of juvenile rockfish during the late spring and early summer breeding seasons, and unexploited species (such as shortbelly) generally account for more than two thirds of the juvenile rockfish identified.[141,142] Shortbelly rockfish are described as important prey for thresher sharks, longnose skate, and jumbo squid. They are also eaten by other rockfish species, including bocaccio and chilipeppers.[143] Furthermore, there is a significant relationship between juvenile rockfish abundance (particularly shortbelly rockfish) and seabird breeding productivity.[144]

Juvenile rockfish and krill

PACIFIC HERRING
(*Clupea pallasii*)

Pacific herring are a critically important forage species off California, Oregon and Washington. Herring are utilized as forage at each stage of their life history from egg to adult, serving as prey for marine mammals and seabirds as well as commercial and recreational fish species. Pacific herring spawning sparks short-term, frenzied feeding at multiple levels of the marine food web. Animals that prey on herring eggs include ctenophores (gelatinous invertebrates), chaetognaths (worms), jellyfish, juvenile salmonids, sturgeon, smelt, surfperches, crabs and at least 20 species of birds.[128] Adult herring are also prey for many seabirds, salmon, seals, California sea lions, porpoises, northern fur seals, killer whales, dogfish, steelhead trout, Pacific cod, sablefish, hake, lingcod, several species of rockfish (black, yelloweye, quillback and tiger rockfish), striped bass, cutthroat trout, sculpin, and sand sole.[129]

Pacific herring are commercially harvested for roe (fish egg) products, bait, pet food, and fresh fish; additionally herring eggs are harvested after herring spawn on kelp. Pacific herring are currently managed by individual states. However this species may soon be added as an Ecosystem Component Species to the federal CPS FMP, primarily to monitor their populations, to recognize the importance of this species as forage, and to monitor herring bycatch in other federally managed fisheries. NMFS established the Ecosystem Component Species management category as a new way for fishery managers to recognize and protect species that are important in the ecosystem yet which are not the focus of major federal commercial fisheries.

While California state managers have aimed to harvest between 0-15% of the spawning biomass, the actual exploitation rate was above 20% in the 1990s.[130] The main herring stock in California, the San Francisco Bay population, recently crashed in 2007. As a result, managers decreased the harvest rate and subsequently closed the fishery in 2009 as the biomass fell to a new historic low. The population has responded to these management decisions and is showing signs of recovery; however, the age structure of the population is still highly skewed, with few older herring that were previously the backbone of the fishery.

Although California fishery managers have recognized the importance of herring as forage and have taken measures to help the stock recover, there is still no explicit accounting for the needs of predators in herring management. A fishery management plan is in its early stages of development, though progress has been stalled by lack of funds. In 2010, CDFG reopened the fishery at a 5% harvest rate, but the long-term management goals and the ability to provide adequate forage for predators remain unclear.

The State of Oregon allows an open access fishery for herring in ocean waters. In 2008, a record 55.8 metric tons of herring were landed as part of the Oregon sardine fishery. The only commercial roe-herring fishery, however, takes place in Yaquina Bay, Oregon. Yet the Yaquina Bay fishery has only opened twice since 1999 due to low herring returns.[131] There are relatively small fisheries in the Umpqua estuary and Columbia River estuary that target herring for bait (~4 metric tons per year), plus recreational fisheries in Oregon's bays and estuaries.

The State of Washington reports that less than half of the Washington herring stocks are healthy, or even 'moderately healthy.'[132] The genetically distinct Cherry Point herring stock used to be Washington's largest herring population from the 1970s to mid-1990s, but it is now considered to be in critical condition after its abundance dropped dramatically. The Northwest San Juan Island herring population is considered to have disappeared, and the Strait of Juan de Fuca herring population is in critical condition. The only current commercial fishery is in Puget Sound and uses lampara seines to target herring, which are sold as bait for recreational salmon and groundfish fisheries. The Puget Sound herring fishery lands, on average, 387 tons of herring per year.[133]

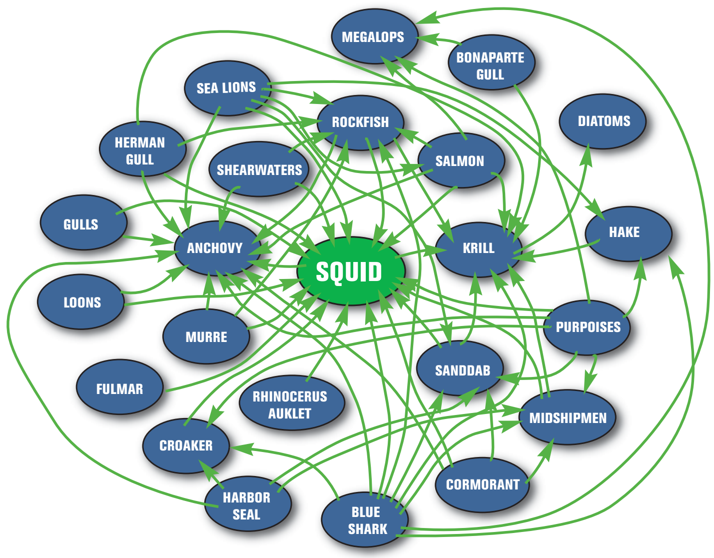
Workers sort Pacific herring

MARKET SQUID

(Doryteuthis opalescens)

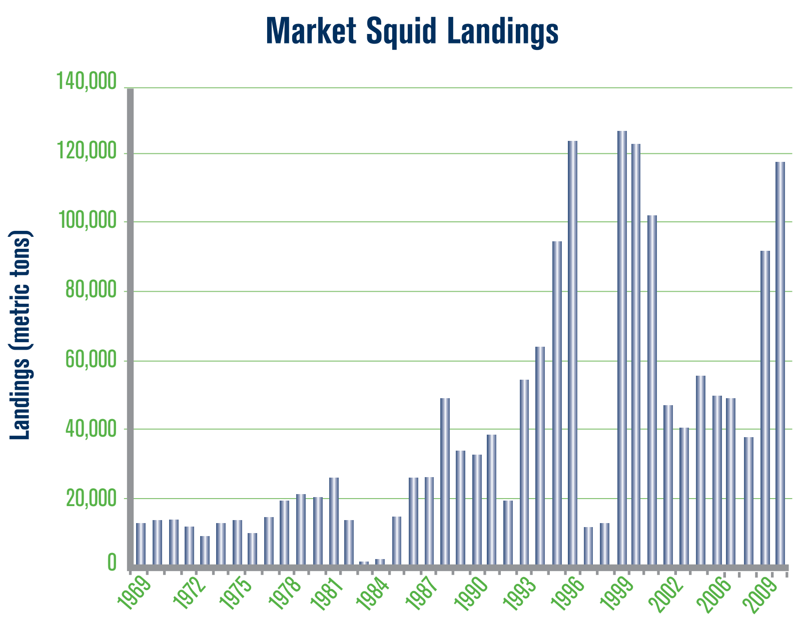
Market squid are an important forage species in the California Current for a long list of predators including pinnipeds (such as sea lions and seals), whales, dolphins, seabirds, and marine fish, over 15 of which are endangered species.[146] Market squid have short life spans (they have been aged to 10 months), and the current population fluctuates massively. In recent years, this fishery has been the largest and most valuable commercial fishery in California.

Some precautionary regulations have been implemented to protect the stock such as weekend fishery closures and marine protected areas that will protect significant spawning grounds. The Market Squid Fishery Management Plan (MSFMP) repeatedly recognizes the importance of squid as forage, but the actual catch levels do not adequately reflect their importance.

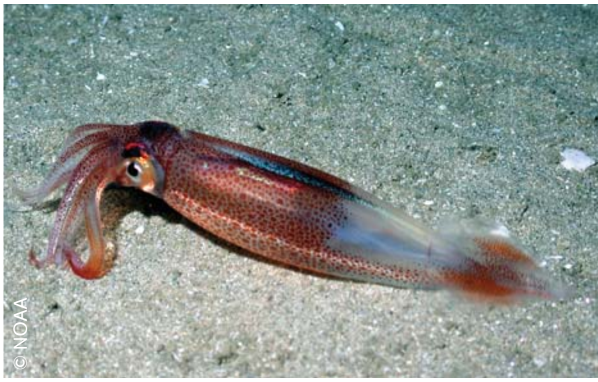


Food web for market squid, Doryteuthus opalescens, involving commercially important fish and key birds and marine mammals (adapted from Morejohn et. al. 1978).

Serious concerns remain about the total catch limits established in the MSFMP. Since little data was available on squid biomass to estimate Maximum Sustainable Yield, the MSFMP referred to NMFS' guidance suggesting it is reasonable to use recent average catch from a period when there is no qualitative or quantitative evidence of declining abundance. Catch levels in the late 1990s were by far the highest in history and catch limits were set based on the average of the three highest consecutive catch years on record, despite the fact that it preceded a major decline in abundance. Without any biomass estimates, this catch limit is extremely risky even from a single-species perspective and completely disregards the strong evidence for the important role of squid as forage. Essentially, squid are being removed at historically high levels without knowing the current population size.



Market Squid Landings from MSFMP and the Pacific Fisheries Information Network (PacFIN).



Market squid

Northern anchovy

NORTHERN ANCHOVY

(Engraulis mordax)

Northern anchovy are small, schooling, pelagic forage fish found along the Pacific coast from Baja California to British Columbia. An extensive list of marine fish, birds and mammals in the California Current region depend on anchovy as prey, including tunas, salmon, sharks, seals, whales and dolphins.[147] Northern anchovy make up over 92% of the diet of nesting brown pelicans off southern California.[148] There are three sub-populations divided into the northern, central, and southern sections of their range. The central subpopulation previously supported relatively large commercial fisheries in the U.S. and Mexico. Anchovies move offshore in winter and are abundant nearshore, in bays, and estuaries in the spring, summer and fall. Currently no published estimates of the northern anchovy populations exist. In fact, no stock estimates have been conducted since the mid-1990s, despite the high importance of anchovy to predators (from seabirds to salmon), on-going directed commercial fisheries, bait and recreational fisheries, and bycatch. Commercial fisheries for northern anchovy are managed by NMFS under the CPS FMP in cooperation with individual states. On average, between 2000 and 2009, over 9,600 metric tons of anchovy were landed each year on the West Coast.[149]

Delta smelt

SMELT

(Osmeridae)

Smelt is a general term used to describe a group of small marine, estuarine and anadromous forage fish, in the family Osmeridae.[150] In the California Current, there are two anadromous smelt, eulachon *(Thaleichthys pacificus)* and longfin smelt *(Spirinchus thaleichthys)*, that spend most of their lives in marine waters, but spawn in coastal rivers and streams. In 1956 Kelso, Washington was dubbed the "Smelt Capital of the World" for the large runs of eulachon that once traveled up the Columbia River to spawn.[151] Eulachon populations have since crashed off the U.S. West Coast and are now listed as threatened. Whitebait smelt *(Allosmerus elongates)* and night smelt *(Spirinchus starksi)* are strictly marine smelt species, and surf smelt *(Hypomesus pretiosus)* is a marine/estuarine species. The delta smelt *(Hypomesus transpacificus)* is endemic to the Sacramento-San Joaquin estuary of California and is listed as an endangered species. Capelin *(Mallotus villosus)* mostly live at higher latitudes, but the southern range of this marine smelt extends into the northern California Current system to approximately the Strait of Juan de Fuca, Washington. Arctic rainbow smelt *(Osmerus mordax dentex)* extend as far south as Vancouver Island, British Columbia. All of these smelt species are important prey for many other fish, birds and mammals in the California Current ecosystem, including recreationally and commercially important species like salmon and halibut.

Topsmelt *(Atherinops affinis)* and jacksmelt *(Atherinopsis californiensis)* are also important marine forage fish of the California Current, yet are not true smelt. These fish belong to the family Atherinidae *(silversides)*, which includes California grunion *(Leuresthes tenuis)*.

KRILL

(Euphausiidae)

Eighty-five species of krill have been identified throughout the world's oceans, eight of which dominate the krill community in the California Current ecosystem. Many of the fish species that depend on krill directly or indirectly, including salmon, rockfish, hake and flatfish, support important recreational and commercial marine fisheries. The planet's largest animal, the blue whale, feeds almost exclusively on krill. During the peak summer feeding season off California, blue whales concentrate on large krill schools, with individual whales consuming roughly two tons of krill per day.[152] Two West Coast krill species, *Euphausia pacifica* and *Thysanoessa spinifera*, form large, dense aggregations near the surface. The sub-tropical *Nyctiphanes simplex* is abundant in U.S. West Coast waters during strong El Niño years, and also forms large surface swarms. *Nematocelis difficilis* is very abundant in the California Current, but it does not migrate to the surface, preferring deeper habitats. The other known krill species in the California Current are T*. gregaria, E. recurva, E. gibboides*, and *E. eximia.*[153]

Recognizing the importance of krill in the marine ecosystem, NMFS officially adopted a ban on krill harvest throughout the West Coast Exclusive Economic Zone (three to 200 nautical miles offshore) in July 2009. This decision adds upon krill protections already in place in Alaska's state and federal waters, as well as the prohibition on directed harvest of krill in California, Oregon, and Washington state waters (zero to three nautical miles offshore).

Pacific mackerel

PACIFIC AND JACK MACKEREL

(Scomber japonicus and Trachurus symmetricus)

Pacific mackerel and jack mackerel are coastal pelagic fish species that play an important ecological role in the California Current for top predators like bluefin tuna, pelagic sharks, swordfish, marlin, seals and toothed whales. [154,155] Pacific and jack mackerel form large surface schools that are the target of these apex predators, but are also targeted by another top predator - humans. Pacific and jack mackerel fisheries are managed by the National Marine Fisheries Service and Pacific Fishery Management Council as part of the Coastal Pelagic Species Fishery Management Plan. The status of the jack mackerel population off the U.S. West Coast is unknown, and the Pacific mackerel population is at relatively low levels, complicated by uncertainties in estimating the population size. Despite this uncertainty, federal managers allow commercial and recreational fisheries, mostly off central and southern California, to take up to 31,000 metric tons of jack mackerel per year and over 40,000 metric tons of Pacific mackerel.[156]

PACIFIC SAND LANCE

(Ammodytes hexapterus)

The Pacific sand lance range extends across the Pacific Rim from southern California, north to the Aleutian Islands, and west to Japan. They inhabit relatively shallow depths in bays, estuaries and the open ocean from the intertidal zone to approximately 47 meters. At every stage in its life cycle, sand lance are valuable prey for salmon, seabirds, seals, minke whales and other fish and marine mammals. 35% of juvenile salmon diets are composed of sand lance, while juvenile Chinook salmon depend on sand lance for up to 60% of their diet.[157] Pacific sand lance have a highly unusual behavior of burrowing into the seafloor sediment at night for protection from predators. During the day sand lance travel in large schools, feeding on plankton. These large schools are pushed up from below into tight defensive balls by salmon, dog sharks and sea lions. From above, flocks of gulls, cormorants, murres and auklets dive on the balls of sand lance as they approach the surface. Adult sand lance spawn in the upper intertidal zone of sandy-gravel beaches. Some sand lance are taken for recreational purpose and bait off the U.S. West Coast, but presently no commercial fishery exists. In Japan, however, roughly 10,000 tons of sand lance are taken each year by commercial fisheries using trawls and seines.[158,159]

Important Forage Species of the California Current

The list of included species is adapted from the Pacific Fishery Management Council[160] and several studies of predator diets. The composition of the list is ongoing and may be modified as additional analysis and information come forward.

Seabirds plunge feed on forage fish like sardines, anchovies, mackerel, and squid

Common Name	Scientific Name
California market squid	Doryteuthis opalescens
Northern anchovy	Engraulis mordax
Pacific herring	Clupea pallasi
Pacific sardine	Sardinops sagax
Pacific mackerel	Scomber japonicus
Jack mackerel	Trachurus symmetricus
Pacific hake YOY	Merluccius productus
Rockfishes YOY	Sebastes spp.
Krill	Euphausiidae
Neon flying squid	Ommastrephes bartramii
Boreal clubhook squid	Onychoteuthis borealijaponica
American shad	Alosa sapidissima
Surf smelt	Hypomesus pretiosus
Night smelt	Spirinchus starksi
Longfin smelt	Spirinchus thaleichthys
Eulachon	Thaleichthys pacificus
Whitebait smelt	Allosmerus elongatus
Delta smelt	Hypomesus transpacificus
Capelin	Mallotus villosus
Topsmelt	Atherinops affinis
Jacksmelt	Atherinops californiensis
Lantern fish	Myctophidae
Pacific saury	Cololabis saira
Pacific sandlance	Ammodytes hexapterus
Shortbelly rockfish	Sebastes jordani
Californian grunion	Leuresthes tenuis
Codfishes YOY	Gadidae
Pacific tomcod	Microgadus proximus
Greenlings YOY	Hexagrammos spp.
Pacific sanddab	Citharichthys spp.
Surfperches	Embiotocidae
Sculpins	Cottidae
Midshipmen	Porichthys spp.
White croaker	Genyonemus lineatus
Kelpfish	Clinidae
Gunnels	Pholididae
Pricklebacks	Stichaeidae
Deep-sea smelts	Bathylagidae

* major commercial fishery – A “major fishery” is defined as a commercial fishery with greater than 1,000 metric tons annually landed on average from 1996-2010. Pacific Fisheries Information Network (PacFin) Report #307, 1996-2010, Pacific States Marine Fisheries Commission, Portland Oregon

YOY indicates young of the year.

Management	Major Fishery?*	Population Status
California Market Squid FMP and NMFS CPS FMP	yes	unknown
NMFS: CPS FMP/WA Forage FMP	yes	unknown
Various levels of state management (CA, OR, WA) Washington Forage Fish Management Plan	yes	stocks range from moderately healthy to critically low
NMFS: CPS FMP/WA Forage FMP	yes	stock below sustainble biomass levels (Bmsy)
NMFS: CPS FMP	yes	low
NMFS: CPS FMP	yes	unknown
NMFS: Groundfish FMP	yes	considered healthy/large uncertainty
NMFS Groundfish FMP and states (e.g. CA Nearshore FMP)	yes	some rockfishes overfished, some healthy, some unknown
NMFS: CPS FMP, OR/WA/CA fishery prohibitions	no	unknown
No active management	no	unknown
No active management	no	unknown
No active management	no	unknown, assumed healthy
No active management/WA Forage FMP	no	unknown
No active management/WA Forage FMP	no	unknown
No active management/WA Forage FMP	no	active petition to list CA population as threatened species under federal ESA. CA listed as threatened
NMFS: ESA Threatened as of 2010/WA Forage FMP and OR/WA joint Columbia River Eulachon Management Plan	no	threatened
No active management/WA Forage FMP	no	unknown
California endangered species/ U.S. Fish and Wildlife Service threatened species	no	federal ESA threatened/CA endangered
No active management/WA Forage FMP	no	unknown (southern extent of range is WA)
No active management	no	unknown
NMFS: Proposed EC species in CPS FMP	no	unknown
No active management	no	unknown
No active management	no	unknown
No active management/WA Forage FMP	no	unknown
NMFS: Fishery through 2012 in Groundfish FMP	no	depressed
CDFG - recreational fishery only	no	unknown
NMFS: Groundfish FMP	no	unknown
No active management	no	unknown
NMFS: Groundfish FMP	no	unknown
NMFS: Groundfish FMP	no	unknown
No active management	no	unknown
No active management	no	unknown
No active management	no	unknown
No active management	no	unknown
No active management	no	unknown
No active management	no	unknown
No active management	no	unknown
No active management	no	unknown

RECOMMENDATIONS

THE FOLLOWING RECOMMENDATIONS APPLY TO FORAGE SPECIES MANAGEMENT AT THE STATE, FEDERAL AND INTERNATIONAL LEVEL

1) Establish Ecosystem-based Management Policies Recognizing and Protecting the Role of Forage Species in the Ecosystem

A new general policy must be established that recognizes, accounts for, prioritizes, and protects the important role forage species play in the California Current Large Marine Ecosystem with its top priority the long-term health of the ecosystem.

2) "Freeze the Menu" for Forage Species

Prohibit development of new commercial fisheries for forage species. The most conservative approach to protecting forage species is to ban commercial fishing on these species before it begins. The National Marine Fisheries Service and the Pacific Fishery Management Council demonstrated this to be a successful approach to ensuring the long-term health and productivity of the marine ecosystem when protecting krill off the U.S. West Coast. This approach to protect forage species has also been employed by the North Pacific Fishery Management Council in the Gulf of Alaska, Aleutian Islands, Bering Sea and the Arctic.

Krill harvest was prohibited off the U.S. west coast in 2009

3) Move Existing Fisheries to an Ecologically Sustainable Yield Approach

Each forage species targeted by commercial fisheries must be managed using an Ecologically Sustainable Yield approach where the full impacts of fishing on the ecosystem are evaluated and considered. An ESY approach will ensure sufficient abundance of forage species for the ecosystem including fish, invertebrates, sea birds, marine mammals and other marine life when calculating appropriate catch levels. Depending on the specific context of each fishery, this would include various combinations of the following approaches:

- Establish forage reserves (e.g., cutoff value in Pacific sardine management) based on consumption needs of predators, such that they provide sufficient biomass to support healthy populations of those predators.

- Develop an index of the overall health of the forage base and reduce fishing pressure if the index drops below threshold levels.

- Develop oceanographic triggers for changes to harvest rates (e.g., if El Niño conditions are predicted, set a lower fishing mortality rate).

- Account for climate change and ocean acidification impacts. Managers should leave a buffer for climate-driven losses in prey populations.

- Establish ecosystem-based biomass targets and minimum level limits for forage species harvest control rules.

- Keep fishing mortality rates below the maximum fishing mortality that would maintain the species ability to serve as forage.

- Incorporate predator-prey relationships into stock assessments.[161]

- Set maximum catch thresholds for all actively targeted forage species.

4) Identify and Protect Key Forage Species Habitats and Foraging Grounds

Similar to actions taken by Washington State in Puget Sound, West Coast states must identify and protect forage fish spawning habitats from development. The National Marine Fisheries Service must identify and designate critical habitat for the threatened eulachon smelt in all of its key habitats including rivers, bays and ocean waters. Managers should also identify key foraging grounds for predators and enact time/area closures for fishing gears or other activities that impact forage species during the places and times that the areas are known to serve as key foraging areas, to prevent localized forage depletion.

Sardines congregate off the west coast certain times of the year and attract countless numbers of top predators like marlin

Schooling Pacific sardine

5) Promote Higher Value Products

Most forage species are sold as low value products such as aquafeeds and bait. As a result, the fishing industry currently has an incentive to maximize harvest levels in a "low value, high volume" business model. However, if a shift to ecosystem-based management of forage species were accompanied by an increase in value per pound of landings, the industry could maintain its profitability in a "higher value, lower volume" model. Such a shift would compensate and provide incentives for leaving more forage species biomass in the ocean. Rather than removing forage species from the California Current ecosystem and exporting them to low value international markets, we should leave more in the ocean and promote higher value domestic markets such as those for direct human consumption.

6) Conduct Additional Research and Data Collection

Management of forage species, especially harvest rates, should consider multi-decadal oscillations as well as anthropogenic factors such as climate change and impacts of ocean acidification. For example, what are the key environmental indicators that predict the productivity of forage species stocks and how should harvest rates be altered in accordance with ocean temperature regime shifts? While much information is known, more research should be conducted on predator-prey relationships to help managers account for predator needs when setting catch levels. Additionally, improved monitoring of non-target forage species populations is needed and can be accomplished through existing or future surveys and fishery catches.

CONCLUSION

The health and biodiversity of the California Current Large Marine Ecosystem depends on abundant populations of forage species. Forage species literally feed and sustain our oceans; they are the lifeline for the sea. From whales and seabirds to tuna and salmon, forage species feed wildlife populations that we rely on and cherish for cultural, recreational and economic reasons.

In this review of forage species conservation and management off the U.S. West Coast, Oceana has found that regional managers and state lawmakers have made some important decisions to protect forage species such as the state and federal prohibitions on commercial fishing for krill, and the forward thinking Washington State Forage Fish Management Plan. We have also found, however, major gaps in the species that are managed and protected, and severe flaws in the management of fisheries that target forage species. In this report, we documented numerous cases of mismanagement and ample reason for concern, including overly aggressive harvest rates, species declines, and a failure to account for existing information on the prey consumption needs of larger animals that rely on forage species.

In order to protect the food web of the California Current marine ecosystem, significant improvements must be made to maintain an abundant supply of forage species. These improvements do not require shutting down existing fisheries, but they do require new policies and management change. Policy makers and fishery managers must take on the challenge of moving away from managing one species at a time in isolation and shift towards an ecosystem-based management approach that includes a focus on the conservation of forage species. The full California Current forage base must be recognized, accounted for and protected. The full set of recommendations provided in this report offers a practical and tangible path forward toward an ecosystem-based approach that helps to ensure healthy oceans for everyone.

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Blue rockfish schooling in a giant kelp forest located in Point Lobos State Marine Reserve, California


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