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Information in Support of a Five-Year Status Review of Eulachon (*Thaleichthys pacificus*) Listed under the Endangered Species Act:

Southern Distinct Population Segment

October 2022

U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration
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Cover image: Bucketful of freshly caught adult eulachon (*Thaleichthys pacificus*) captured during the 14 February 2020 Cowlitz River recreational dip-net fishery. Photograph by R. Gustafson, NMFS/NWFSC.

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Southern Distinct Population Segment

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[1] https://repository.library.noaa.gov/

Abbreviations

ADFG	Alaska Department of Fish and Game
AFSC	Alaska Fisheries Science Center
A-SHOP	At-Sea Hake Observer Program
BEUTI	Biologically Effective Upwelling Transport Index
BRDs	biological reduction devices
BRT	Biological Review Team
CCIEA	California Current Integrated Ecosystem Assessment
CDFW	California Department of Fish and Wildlife
CI	confidence interval
COSEWIC	Committee on the Status of Endangered Wildlife in Canada
CP	catcher–processor
CPUE	catch per unit effort
CTD	conductivity, temperature, and depth
CUTI	Coastal Upwelling Transport Index
DBEM	Dynamic Bioclimate Envelope Model
DFO	Fisheries and Oceans Canada
DO	dissolved oxygen
DOC	U.S. Department of Commerce
DPS	distinct population segment
DU	designatable unit
EAL	Eulachon Action Level
EAS	Eulachon Assessment Survey
EBUS	Eastern Boundary Upwelling Systems
EM	electronic monitoring
ENSO	El Niño–Southern Oscillation
ESA	Endangered Species Act
ESM	Earth System Model
FLD	footrope lighting device
FMP	fishery management plan
FO	frequency of occurrence
FRAM	Fishery Resource Analysis and Monitoring (NWFSC)
FSC	food, social, and ceremonial
GIS	Geographic Information System
GOA	Gulf of Alaska
GSI	genetic stock identification *or* gonadosomatic index
HAB	harmful algal bloom
IBD	isolation by distance
IFMP	integrated fishery management plan
IFQ	individiual fishing quota
IPCC	Intergovernmental Panel on Climate Change
IUCN	International Union for the Conservation of Nature
LE	limited entry
LFFA	Lower Fraser Fisheries Alliance
MHW	marine heatwave

MSA	mixed stock analysis
MSCV	mothership catcher vessel
NCA	northern copepod anomaly
NCSFNSS	North Coast Skeena First Nations Stewardship Society
NEP19–22A	northeastern Pacific Ocean MHWs, by year (2019–2022)
NMFS	National Marine Fisheries Service (NOAA)
NOAA	National Oceanic and Atmospheric Administration (DOC)
NPGO	North Pacific Gyre Oscillation
NWFSC	Northwest Fisheries Science Center (NMFS)
OA	ocean acidification
ODFW	Oregon Department of Fish and Wildlife
OMZ	oxygen minimum zone
ONI	Oceanic Niño Index
PCA	principle components analysis
PDO	Pacific Decadal Oscillation
PSU	practical salinity units
RCP	representative concentration pathways
RFLP	restriction fragment length polymorphism
RPA	recovery potential assessment
SARA	Species at Risk Act (Canada)
SD	standard deviation
SE	standard error
SMAs	shrimp management areas
SNPs	single nucleotide polymorphisms
SOG	Strait of Georgia
SROCC	Special Report on Ocean and Cryosphere in a Changing Climate
SSB	spawning stock biomass
SST	sea surface temperature
SSTa	sea surface temperature anomaly
UPI	ocean upwelling indices
USGS	U.S. Geological Survey
Vc	climate change vulnerability
WCBTS	West Coast Bottom Trawl Survey
WCGOP	West Coast Groundfish Observer Program
WCR	West Coast Region (NMFS)
WCVI	west coast Vancouver Island
WDFW	Washington Department of Fish and Wildlife

Plain Language Summary

Background

Eulachon are a species of small silver fish in the smelt family. They are native to the Pacific Northwest, thriving in coastal waters from southwestern Alaska to Northern California. Like Pacific salmon, eulachon spawn in rivers before migrating to the ocean, where they reside near the bottom at up to 650 ft deep. The Southern distinct population segment (DPS) of eulachon was listed as threatened under the Endangered Species Act (ESA) in 2010.

The Northwest Fisheries Science Center, together with NOAA Fisheries' West Coast Region, monitors and reviews the status of eulachon every five years to determine whether they can be removed from the list or have their status changed. Two previous status reviews have been published, one in 2010 and another in 2016.

In this report, we provide an updated review of information we have gathered since 2016, comparing it to the previous two reports and to the 2017 Recovery Plan.

Key Takeaways

- Scientists count egg and larval production of eulachon to estimate the biomass of spawning fish upstream of the collection site.
- The eggs and larvae of eulachon and longfin smelt (a related species) are difficult to distinguish without genetic analysis, which is not typically done, potentially affecting the accuracy of estimates.
- Our surveys in U.S. West Coast groundfish fisheries indicate that there is little interaction with eulachon in these fisheries—or that most eulachon escape or avoid trawl gear.
- The eulachon bycatch we do observe in these sectors may be only a small fraction of all eulachon encounters with fishing gear.
- Studies show that eulachon bycatch in ocean shrimp trawl fisheries can be reduced by installing LEDs on the footrope of shrimp trawl nets.
- Adult eulachon appear to be returning earlier in the season to several rivers within the Southern DPS. This may affect their ability to reproduce successfully, as their migration must be timed to coincide with coastal upwelling and prey abundance. All of these processes may be affected by climate change.
- Many studies indicate that ocean conditions are the primary driver of eulachon abundance. Recent improvements in ocean conditions in the Northern California Current Ecosystem suggest that eulachon abundance should remain moderately high in the near future.

Links used in this section:

- Eulachon: https://www.fisheries.noaa.gov/species/eulachon#conservation-management
- Distinct population segment: https://en.wikipedia.org/wiki/Distinct_population_segment
- Listed as threatened: https://www.federalregister.gov/documents/2010/03/18/2010-5996/endangered-and-threatened-wildlife-and-plants-threatened-status-for-southern-distinct-population
- West Coast Region: https://www.fisheries.noaa.gov/about/west-coast-region
- 2010: https://repository.library.noaa.gov/view/noaa/3734
- 2016: https://repository.library.noaa.gov/view/noaa/17807
- Recovery Plan: https://www.fisheries.noaa.gov/resource/document/recovery-plan-southern-distinct-population-segment-eulachon-thaleichthys
- Longfin smelt: https://www.dfg.ca.gov/delta/data/longfinsmelt/documents/LongfinsmeltFactSheet_July09.pdf
- Bycatch: https://www.fisheries.noaa.gov/topic/bycatch
- Coastal upwelling: https://www.fisheries.noaa.gov/feature-story/new-research-reveals-clearer-picture-upwelling-feeds-west-coast-marine-ecosystem
- California Current Ecosystem: https://www.fisheries.noaa.gov/west-coast/ecosystems/california-current-regional-ecosystem

Executive Summary

On 18 March 2010, the National Marine Fisheries Service (NMFS) published a final rule in the Federal Register to list the Southern Distinct Population Segment (Southern DPS) of eulachon (*Thaleichthys pacificus*, Osmeridae) as threatened under the Endangered Species Act (ESA; USOFR 2010). This listing encompassed all spawning aggregations of eulachon within the states of Washington, Oregon, and California, and extended south from the Skeena River in British Columbia to the Mad River in Northern California. In the 2010 status review (Gustafson et al. 2010), the Biological Review Team's (BRT) determination of overall risk to the species used three biological risk categories: 1) at high risk of extinction, 2) at moderate risk of extinction, or 3) not at risk of extinction. See Gustafson et al. (2010, pp. 171–176, their Table 19) for a description of these qualitative reference levels of extinction risk and a narrative summary of the Southern DPS's viable population elements: abundance, productivity, spatial structure, and diversity. The 2010 BRT determined that the Southern DPS of eulachon was at moderate risk of extinction throughout all of its range (Gustafson et al. 2010).

The ESA requires that NMFS review the status of listed species under its authority at least every five years and determine whether any species should be removed from the list or have their listing status changed. The NMFS West Coast Region (WCR) is responsible for the five-year review process and decision-making regarding proposed changes in listing status. The original status review of the Southern DPS of eulachon occurred in 2010 (Gustafson et al. 2010), and a five-year review of the Southern DPS's status was released in 2016 (Gustafson et al. 2016). After the 2016 five-year status review (Gustafson et al. 2016), NMFS developed and published a recovery plan for the Southern DPS of eulachon. The number-one action item in the recovery plan, formation of a Eulachon Technical Recovery and Implementation Team (ETRIT) with representation from federal, state, local, and tribal/First Nations entities, as well as Canada, was accomplished in 2019. This team now meets quarterly to share new information and coordinate recovery actions.

This current report provides an updated synthesis of information that has become available since the 2016 review, focusing on: 1) new information relevant to the Southern DPS's boundaries; 2) trends and status in abundance, productivity, spatial structure, and diversity; and 3) newly available information on selected threats to the Southern DPS. The information in this report will be incorporated into WCR's review, and WCR will make final determinations about any proposed changes in listing status, taking into account not only biological information but also ongoing or planned protective efforts. Newly available data pertinent to the Southern DPS's spatial delineation are: 1) studies by Benson et al. (2019) that attempted to distinguish between eulachon populations based on differences in otolith microchemistry, 2) studies by Spangler (2020) that showed that some eulachon may be spawning in estuarine habitats and at higher salinities than previously believed, and 3) the genetic population structure studies of Sutherland et al. (2021).

Benson et al. (2019) attempted to detect population differences in eulachon using otolith ratios of various elements—strontium to calcium, barium to calcium, zinc to calcium, and magnesium to calcium. Eulachon otoliths from Oregon, Southeast Alaska, and the Bering Sea were correctly classified to region with an overall accuracy of about 79%. Previously, Hay and

McCarter (2000) reported on attempts to use differences in the elemental makeup of eulachon otoliths to detect stock structure among various rivers on the coast of British Columbia. The results, similar to those of Benson et al. (2019), indicated that there were differences in the elemental composition of eulachon otoliths over a broad geographic range, but that otolith microchemistry was not useful in distinguishing between closely adjacent river populations.

Spangler (2020) demonstrated that some portion of the eulachon population in the Twentymile and Antler Rivers in Alaska spawns in estuarine portions of these rivers, and that eulachon are capable of producing viable larvae in salinities as high as 12 PSU (Practical Salinity Units), but not above about 18 PSU. Spangler (2020) argued that these findings indicate that the ESA designation of critical spawning habitat for the Southern DPS of eulachon should be modified to include estuarine habitat. However, we are unaware of similar observations of estuarine spawning of eulachon in other eulachon-bearing rivers.

Sutherland et al. (2021) developed an improved genetic baseline for 14 eulachon populations ranging from south-central Alaska to the Klamath River in Northern California, based on 521 SNP (single nucleotide polymorphism) loci. Sutherland et al. (2021) expanded the baseline with additional sample populations (Klamath, Sandy, Wannock, Kitimat, and Unuk Rivers) and more temporal sampling (Fraser, Kingcome, Bella Coola, Skeena, and Nass Rivers). Three main groupings were evident: southern rivers (Klamath, Columbia, Cowlitz, Sandy, and Fraser), northern rivers (Kingcome, Klinaklini, Wannock, Bella Coola, Kemano, Skeena, Nass, and Unuk), and the Gulf of Alaska (Twentymile River). These results were similar to those of previous studies using microsatellite DNA loci (Beacham et al. 2005) and SNP loci (Candy et al. 2015); the most obvious genetic break in the Southern DPS of eulachon appears to occur in southern British Columbia north of the Fraser River (Sutherland et al. 2021). The 2010 BRT did not believe that the pattern and level of genetic differentiation in Beacham et al. (2005) provided evidence that eulachon in the Fraser and Columbia Rivers were “markedly separated” from other populations, as required by the joint U.S. Fish and Wildlife Service and National Marine Fisheries Service DPS policy (USOFR 1996). The genetic analyses of Candy et al. (2015) and Sutherland et al. (2021), with essentially the same population structure results as those of Beacham et al. (2005), would not be expected to change the consensus opinion of the BRT as to the northern boundary of the Southern DPS of eulachon.

Yurok Tribe biologists sampled adult eulachon in the Klamath River in northern California using seines and dip nets in spring of 2011–14 (Gustafson et al. 2016). Although the Yurok Tribal Fisheries Program has not conducted any official eulachon surveys since 2014, eulachon have been observed in small numbers (no more than two per night) at the mouth of the Klamath River every year since then.

Since the 2016 five-year status review (Gustafson et al. 2016), annual monitoring of eulachon spawning stock biomass (SSB) has continued in the Fraser (1995–2021) and Columbia (2011–21) Rivers, and has expanded to the Grays (2011–13, 2015–16), Cowlitz (2015–18), Naselle (2015–17), and Chehalis (2015–18) Rivers. However, lack of funding has precluded more recent monitoring of eulachon SSB in the Grays, Naselle, and Chehalis Rivers. Mean eulachon SSB in the Columbia River over the previous three five-year periods—2006–10, 2011–15, and 2016–20—was 145 mt, 3,921 mt, and 1,350 mt, respectively. In contrast, mean SSB in the Fraser

River over the same three five-year periods was 20 mt, 127 mt, and 244 mt, respectively. Prior to 2018, the highest ratio of Fraser River to Columbia River SSB had been 0.59 in 2000. In 2018, eulachon were 2.4 times more abundant in the Fraser River than in the Columbia River. Although the cause of the decline in Columbia River SSB in 2017–18 is unknown, it is possibly related to the 2013–16 marine heat wave, known as "the Blob," that reduced productivity of northern copepods and euphausiids, critical prey for eulachon in the California Current.

The 2015 Columbia River eulachon SSB was estimated at 5,021 mt. Subsequently, Columbia River SSB declined each year from 2015 through 2018, to a low of 168 mt in 2018. SSB in 2016 was 2,217 mt, less than half the 2015 estimate. SSB continued to decline in 2017 to 744 mt, the lowest estimated SSB since 2010, followed by the even lower year of 2018 at 168 mt.

Following 2018, Columbia River SSB increased by an order of magnitude to 1,897 mt in 2019. Complete SSB estimates for Columbia River eulachon in 2020 are not available due to COVID-19 pandemic restrictions on field sampling, although SSB after 10 weeks of truncated sampling was about 862 mt and actual SSB was likely at least 1,724 mt. Columbia River SSB rebounded in 2021 to 4,010 mt, the highest SSB since 2015. When total harvest from all fisheries is taken into account, run size of eulachon in 2021 was estimated at 4,082 mt.

On the Olympic Peninsula of Washington, the Lower Elwha Klallam Tribe continued to monitor for eulachon and was able to sample adults and/or larvae in the Elwha, Dungeness, and Lyre Rivers. The Fraser River had an estimated eulachon SSB of 317 mt in 2015, its highest SSB in the previous 12 years. However, Fraser River SSB declined in 2016 and 2017 by an order of magnitude to 44 and 35 mt, respectively. SSB increased again in 2018 to 408 mt, declined to 108 mt in 2019, but increased in 2020 to 624 mt, its highest level since 1996. In 2021, Fraser River SSB declined to 141 mt during the standard seven-week sampling period.

On the mainland coast of British Columbia, north of the Fraser River, no new information on the status of Klinaklini River eulachon has been located since the 2016 status review; however, there were anecdotal reports that large numbers of eulachon were observed in Kingcome River during 2015–17. Wuikinuxv Nation conducts an annual eulachon monitoring survey on the Wannock, Kilbella, and Chuckwalla Rivers in Rivers Inlet; however, results have not been released. Anecdotal information indicates that eulachon began to return to the Bella Coola River in 2012 and the run has been slowly building in numbers, such that multiple schools of eulachon were observed in 2018; however, the run was not large enough to support a food fishery.

The Haisla Fisheries Commission has estimated abundance of adult eulachon in the Kemano River from 2008–21. Abundance has ranged from 27 to 172 mt since 2016. Apparently, there was no eulachon run on the Kemano River in 2020. Most recently, an estimated 36 mt of eulachon returned to the Kemano River in 2021. The Haisla Fisheries Commission eulachon monitoring program detected eulachon in the Kitimat and Kildala Rivers in 2018. Haisla Fisheries Commission surveyed for eulachon eDNA in 12 rivers in Haisla territory (Kitimat, Anderson, Wahtl, Moore, Kildala, Dala, Gilloteyse, Foch, Kemano, Wahoo, Kitlope, and Kawasas) in 2020 and 2021. Nine of these systems were positive for eulachon presence in 2020, and results for the 2021 run year will be available in 2022.

The North Coast Skeena First Nations Stewardship Society coordinates a Skeena River eulachon catch monitoring survey of the eulachon food fishery. An estimated 856,000 eulachon (about 31 mt) and 373,000 eulachon (13.5 mt) were harvested from the Skeena River in 2019 and 2020, respectively.

From late 2013 to mid-2017, the California Current Ecosystem (CCE) experienced both a severe marine heat wave (MHW) in the form of the Blob (2013–16) and a strong El Niño event (2015–16). The impact of the Blob on eulachon abundance is likely reflected in the 2018 Columbia River SSB estimate of slightly more than four million fish, the lowest since 2010. Eulachon returning to the Columbia River in 2018 were mostly from the broodyears 2015 or 2016, which would have entered the CCE in spring to summer of those years, when both the Blob and the strong El Niño of 2015–16 were active. In 2015 and 2016, the biological spring transition never occurred, as northern copepods were absent from surveys along the Newport Hydrographic Line during both years. Euphausiids, the primary prey of juvenile/adult eulachon, experienced very low densities during 2015–16, which likely had negative impacts on eulachon growth and survival. Additional MHWs developed in May 2019, and again in 2020 and 2021, although the latter two MHWs mostly stayed offshore and had low impact on the CCE.

La Niña conditions prevailed from August 2020–May 2021, redeveloped in October 2021, and are predicted to strengthen and last through spring of 2022. Both La Niña conditions and a negative Pacific Decadal Oscillation (which has prevailed since mid-2020) are associated with high productivity in the CCE, which should provide eulachon with positive growth conditions. Other indications of the presence of good ocean conditions for eulachon are the northern copepod biomass anomalies, which were mostly positive in 2020. Early and strong upwelling in 2020 and 2021 fueled very productive conditions in the CCE. However, this high level of primary production has likely led to widespread near-bottom hypoxia on the continental shelf off Washington and Oregon in 2021. How eulachon respond to these hypoxic water events is unknown.

The near-term outlook for eulachon productivity in the CCE is positive, based on the presence of good ocean conditions. The current abundance of northern copepods and depressed numbers of southern copepods in the CCE would be expected to result in increased eulachon survival. The return of good ocean conditions and the likelihood that these conditions will persist into the near future suggests that population stabilization or increases may be widespread in the upcoming return years. The productivity potential—as indicated by life-history characteristics such as low age-at-maturity, small body size, planktonic larvae, and perhaps their high fecundity—confers eulachon with some resilience to environmental perturbations, since they retain the ability to quickly respond to favorable ocean conditions.

Total fleetwide bycatch in U.S. West Coast groundfish fisheries increased from an estimated 56 total eulachon in 2016 and 68 total eulachon in 2017, to an estimated 782 total eulachon in 2018 and 3,121 total eulachon in 2019. Assuming codend mesh sizes have remained relatively unchanged since restrictions on mesh sizes were removed, it is likely that most eulachon would continue to readily pass through the mesh openings of groundfish trawl nets. It is difficult to envision how eulachon are retained in groundfish trawl nets unless the codend becomes plugged. Thus, the observed eulachon bycatch in the groundfish fishery sectors reported in this document may represent a small fraction of all eulachon encounters with bottom and midwater trawl fishing gear in the groundfish fishery. However, we currently have no direct data to estimate escape or avoidance mortality of eulachon in any sector of the groundfish fishery, and we are unaware of any studies that have directly investigated the fate of osmerid smelt species passing through groundfish trawl nets.

Coastwide eulachon bycatch in the combined Washington, Oregon, and California ocean shrimp trawl fisheries declined from 60 million in 2015 to about 4.4 million fish in 2016, and then 649,600 fish in 2017. Coastwide eulachon bycatch was 3.2 million fish in 2018 and 19.8 million fish in 2019. These increases in coastwide bycatch were mostly due to increased bycatch in both Washington and Oregon. Eulachon bycatch and bycatch ratios declined from 2015–17. However, declines in bycatch and bycatch ratios were most dramatic in Oregon and California over this time period. In 2017, comparative bycatch ratios (as number of eulachon per metric ton of shrimp) were 145.4 for Washington, 19.9 for Oregon, and nearly zero for California. The bycatch ratio remained at a very low level during 2018 and 2019 in California; however, the ratio increased in Washington from 367 eulachon/mt of shrimp in 2018 to 1,570 eulachon/mt of shrimp in 2019. In Oregon, the ratio increased from 111 eulachon/mt of shrimp in 2018 to 1,088 eulachon/mt of shrimp in 2019. Sorting-grid bycatch reduction devices (BRDs) are mandated in ocean shrimp trawl fisheries. Washington and Oregon also mandated the use of LED lights on the footrope of each trawl net in 2018, and similar regulations took effect in British Columbia for the 2021–22 season. Although speculative, it may be that BRDs (both deflecting grids and LED lighted footropes) in the ocean shrimp trawl fisheries operate at greatly reduced efficiency when eulachon reach high densities, as they did in 2019.

Acknowledgments

This status review update relied on comments and informational reports submitted by the public and by state, tribal, and federal agencies. The authors acknowledge the efforts of all who contributed to this record, especially the Washington Department of Fish and Wildlife (WDFW), Oregon Department of Fish and Wildlife (ODFW), Fisheries and Oceans Canada (DFO), Yurok Tribal Fisheries Program, Lower Elwha Klallam Tribe, and NMFS's West Coast Region (WCR).

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The bycatch portion of this document was a joint effort of the Eulachon Bycatch Reporting Team, which included, at various times and in various roles, Vanessa Tuttle (At-Sea Hake Observer Program [A-SHOP], NWFSC), Marlene Bellman, Kayleigh Somers, Yong-Woo Lee, Jason Jannot, Kate Richerson (West Coast Groundfish Observer Program [WCGOP], NWFSC), Rick Gustafson, Eric Ward (Conservation Biology Division, NWFSC), Robert Anderson, and Mitch Dennis (WCR). We also gratefully acknowledge the hard work and dedication of observers from A-SHOP and WCGOP, as well as contributions from observer program staff. Thanks are also due to Jeff Hard, Robert Anderson, Jen Zamon, and Shallin Busch for their insightful comments on previous versions of this manuscript.

Introduction

Eulachon (*Thaleichthys pacificus*, Osmeridae) is an anadromous smelt that ranges from Northern California to the southeastern Bering Sea coast of Alaska (Willson et al. 2006, Moody and Pitcher 2010). The declining abundance of eulachon in the southern portion of its range led the Cowlitz Indian Tribe to petition (Cowlitz Indian Tribe 2007) the National Marine Fisheries Service (NMFS) to list eulachon in Washington, Oregon, and California as a threatened or endangered species under the U.S. Endangered Species Act (ESA). A eulachon Biological Review Team (BRT)—consisting of scientists from the Northwest Fisheries Science Center, Alaska Fisheries Science Center, Southwest Fisheries Science Center, U.S. Fish and Wildlife Service, and U.S. Forest Service—was formed by NMFS. The BRT reviewed and evaluated scientific information submitted from state agencies and other interested parties, and compiled by NMFS staff from both published and unpublished literature. The 2010 BRT identified a Southern Distinct Population Segment (Southern DPS) of eulachon that occurs in the California Current and is composed of numerous aggregations that spawn in rivers from Northern California to northern British Columbia. The 2010 BRT concluded that the major threats to the Southern DPS of eulachon include climate change impacts on ocean and freshwater habitat, bycatch in offshore shrimp trawl fisheries, changes in downstream flow timing and intensity due to dams and water diversions, and predation. These threats, together with large declines in abundance, indicated to the 2010 BRT that the Southern DPS of eulachon was at moderate risk of extinction throughout all of its range (Gustafson et al. 2010, 2012).

On 18 March 2010, NMFS published a final rule in the Federal Register to list the Southern DPS of eulachon as threatened under the ESA (USOFR 2010). This listing encompassed all spawning aggregations of eulachon within the states of Washington, Oregon, and California, and extended south from the Skeena River (British Columbia) to the Mad River (Northern California; Figure 1).

The ESA requires that the listing classification of threatened and endangered species be reviewed at least once every five years. The results of this review are used to determine if any listed species should: 1) be removed from the list, 2) have its status changed from threatened to endangered, or 3) have its status changed from endangered to threatened. The original status review of the Southern DPS of eulachon occurred in 2010 (Gustafson et al. 2010), and a five-year review of the Southern DPS's status was released in 2016 (Gustafson et al. 2016). NMFS's West Coast Region (WCR) is responsible for the five-year review process and decision-making regarding proposed changes in listing status. The results of the 2016 five-year status review update, together with other technical reports, the listing record (including designation of critical habitat), and the recovery outline for eulachon were used to inform the 2016 five-year review document (NMFS WCR 2016). Based on the information identified above, NMFS WCR (2016) recommended that the Southern DPS of eulachon remain classified as a threatened species. This decision was formalized in a subsequent Federal Register notice (USOFR 2016).

The present report summarizes new and additional information that has become available since the previous five-year review (Gustafson et al. 2016), related to: 1) delineation of the geographical boundaries of the Southern DPS; 2) the Southern DPS's viable population elements of abundance, productivity, spatial structure, and diversity; and 3) major threats

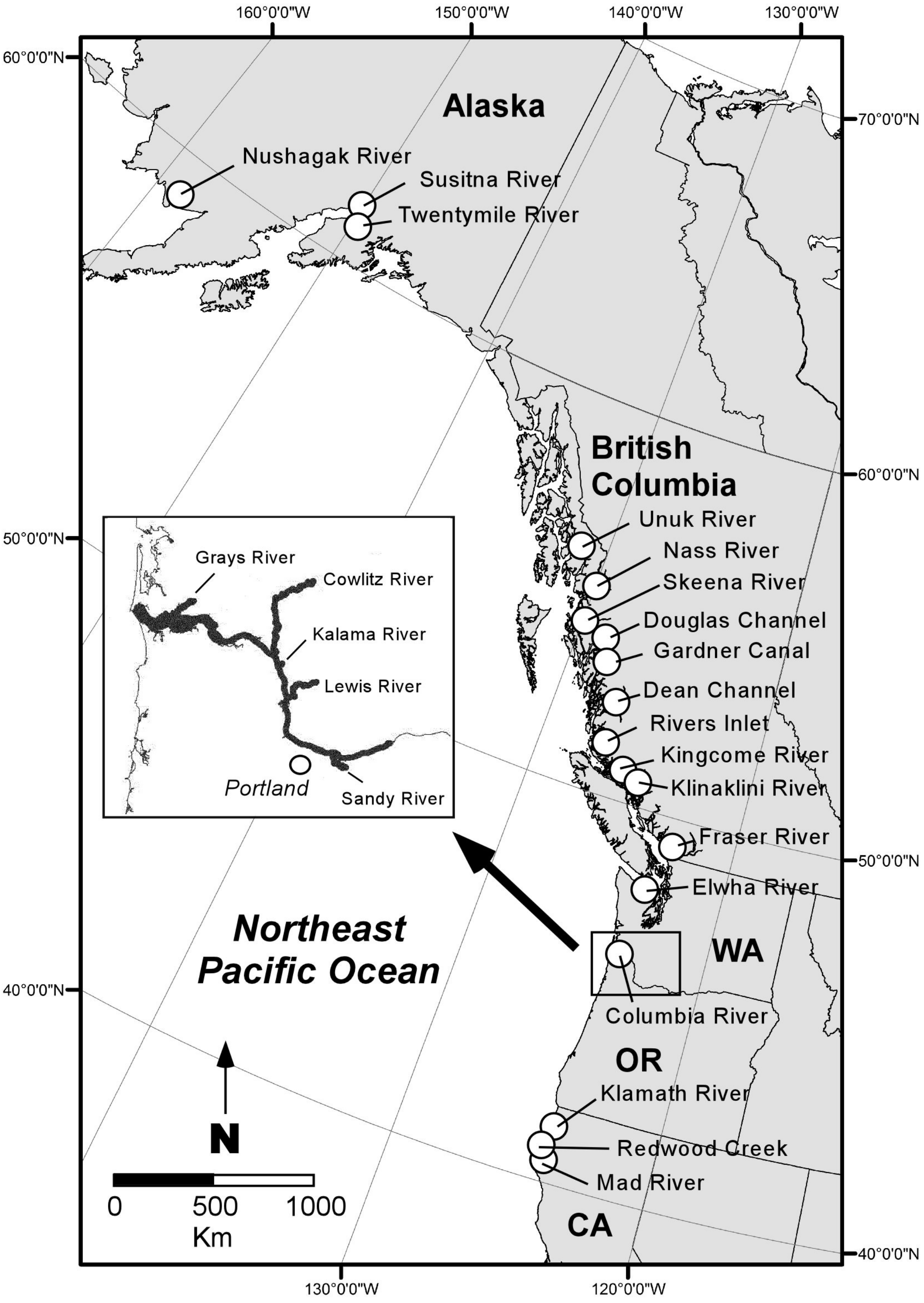

Figure 1. Schematic presentation showing the location of select eulachon spawning rivers and other locations mentioned in the text.

to the Southern DPS. This information will inform the decision as to whether the Southern DPS is likely to have moved from “moderate risk of extinction” to either of the other two categories, “high risk of extinction” or “low risk of extinction.” The information in this report will be incorporated into the WCR review, and WCR will make a final determination about any proposed changes in listing status, taking into account not only biological information but also ongoing or planned protective efforts.

The 2010 status review of eulachon in Washington, Oregon, and California (Gustafson et al. 2010) presented an extensive review of eulachon life history and ecology, as well as extensive information bearing on evaluation of extinction risk and the original delineation of the boundaries of the Southern DPS. Emphasis in the present document is on new and additional information that was not available at the time of the status review (Gustafson et al. 2010) or the first five-year review (Gustafson et al. 2016).

Eulachon Life History

Adult eulachon typically spawn at age-2–5, when they are 160–250 mm in length (fork length), in the lower portions of rivers that have prominent spring, peak-flow events or freshets (Hay and McCarter 2000, Willson et al. 2006). Many rivers within the range of eulachon have consistent yearly spawning runs; however, eulachon may appear in other rivers only on an irregular or occasional basis (Hay and McCarter 2000, Willson et al. 2006). The spawning migration typically begins when river temperatures are from 0–10°C, which usually occurs between December and June. Run timing and duration may vary interannually, and multiple runs occur in some rivers (Willson et al. 2006). Eulachon in the Southern DPS are semelparous, although some individuals in Alaska may spawn more than once (Willson et al. 2006). Fecundity reportedly ranges from 7,000–60,000 eggs, which are approximately 1 mm in diameter (Smith and Saalfeld 1955, Parente and Snyder 1970). Milt and eggs are released over sand or coarse gravel. Eggs become adhesive after fertilization and hatch in 3 to 8 weeks, depending on temperature. Newly hatched larvae are transparent, slender, and about 4–8 mm in length (total length). Larvae are transported rapidly by spring freshets to estuaries (Hay and McCarter 2000, Willson et al. 2006). Juveniles disperse onto the continental shelf within the first year of life (Hay and McCarter 2000, Gustafson et al. 2010) and are taken in research trawl surveys beginning at age-1+ over the continental shelf off the U.S. West Coast, most often at depths from 50–200 m.

Summary of 2010 Status Review Conclusions

Delineation of the Southern DPS of eulachon

An “ESA species” may consist of a taxonomically named species or subspecies or, in the case of vertebrate organisms, a distinct population segment. A DPS must be “discrete” from the remainder of the species to which it belongs and “significant” to the species as a whole (USOFR 1996); however, if multiple DPSes cannot be identified, then the “ESA species” is the taxonomic species or subspecies. A population may be considered discrete if it is markedly separated from other populations of the same taxon because of physical, physiological, ecological, or behavioral factors (genetic or morphological differences may provide evidence of this separation). If a population segment is considered discrete, its biological and ecological significance is then evaluated on the basis of whether: 1) it occurs in an ecological setting unusual or unique for the species, 2) its loss would result in a significant gap in the species' range, 3) it represents the only surviving indigenous occurrence of the species, or 4) it differs markedly from other populations of the species in its genetic characteristics (USOFR 1996).

In considering the discreteness criterion (USOFR 1996), the 2010 BRT concluded that the weight of the available evidence indicated that there are multiple discrete populations of eulachon. In addition to the genetic data, the 2010 BRT considered the strong ecological and environmental break that occurs between the California Current and Alaska Current oceanic domains as contributing evidence for discreteness. The 2010 BRT also considered, but did not weigh heavily, the latitudinal differences in spawn timing, body size, and vertebral counts among samples from different rivers. Overall, the 2010 BRT believed that genetic and ecological data provided strong evidence that eulachon south of the Nass River were discrete from those in the Nass River and northward, but that there was also evidence (from the genetic data) suggesting that Fraser and Columbia River groups may be discrete from more northern groups.

In evaluating the significance criteria (USOFR 1996), the 2010 BRT focused primarily on criteria 1 (ecological setting), 2 (evidence that loss would result in a significant gap in the range of the species), and 4 (markedly differs in genetic characteristics). The 2010 BRT concluded that there was evidence supporting the significance criteria under the scenario of there being one DPS south of the Nass River/Dixon Entrance, or under an alternate scenario of there being one DPS inclusive of eulachon in the Fraser River to California. In particular, there is evidence under either scenario for a significant break in ecological setting, and loss of a putative DPS defined by either boundary would without question result in a significant gap (or reduction) in the range of the overall species. The 2010 BRT also considered whether the available genetic data provided any evidence for "markedly different" populations, but concluded that although the genetic data provide evidence for discreteness (lack of gene flow), there was little evidence to support the existence of deep intraspecific phylogenetic breaks that the 2010 BRT believed were necessary to be considered "marked." Support for a discrete and significant eulachon population south of the Nass River/Dixon Entrance was provided by evidence that eulachon in this southern area are "markedly separated on the basis of ecological and physiological features" from eulachon to the north. In summary, the 2010 BRT believed the evidence most strongly supported one DPS south of the Nass River/Dixon Entrance (Gustafson et al. 2010).

After consideration of the all available scientific data, the 2010 BRT determined that the petitioned unit of eulachon that spawn in rivers in Washington, Oregon, and California is not a species under the ESA, as it does not meet all the biological criteria to be considered a DPS as defined by the joint U.S. Fish and Wildlife Service and National Marine Fisheries Service policy on vertebrate populations (USOFR 1996). However, the 2010 BRT did determine that eulachon spawning in Washington, Oregon, and California are part of a DPS that extends beyond the conterminous United States and that the northern boundary of the DPS occurs in northern British Columbia south of the Nass River (most likely)—or in southern British Columbia north of the Fraser River (less likely). The 2010 BRT proposed that this DPS be termed the Southern DPS of eulachon. The 2010 BRT found it difficult to identify a clear northern terrestrial or river boundary for this Southern DPS as the majority of the 2010 BRT believed this boundary is largely associated with oceanographic, not terrestrial, processes and is largely defined by the extent of the northern California Current (Gustafson et al. 2010). However, it was the majority opinion of the 2010 BRT that the northern boundary of the Southern DPS is south of the Nass River on the north coast of British Columbia. The 2010 BRT also concluded that eulachon spawning in the Nass River and further north consist of at least one additional (northern) DPS (Gustafson et al. 2010, 2012).

Status of the Southern DPS of eulachon

The 2010 BRT qualitatively ranked threats to the Southern DPS of eulachon in four subareas: the Klamath River, the Columbia River, the Fraser River, and British Columbia coastal rivers south of the Nass River. In each case, the 2010 BRT ranked climate change impacts on ocean conditions as the most serious threat to persistence of eulachon. Climate change impacts on freshwater habitat and eulachon bycatch were scored as moderate- to high-risk in all subareas of the Southern DPS, and dams and water diversions in the Klamath and Columbia Rivers and predation in the Fraser River and British Columbia coastal rivers were ranked within the top four threats in their respective regions (Gustafson et al. 2010).

The 2010 BRT was concerned that although eulachon are a relatively poorly monitored species, the weight of the available information indicated that the Southern DPS of eulachon had experienced an abrupt decline in abundance throughout its range in the early to mid-1990s. Considering this large decline, in addition to other risk factors, the 2010 BRT determined that the Southern DPS of eulachon was at moderate risk of extinction throughout all of its range (Gustafson et al. 2010, 2012).

Summary of 2016 Five-Year Status Review Update

Review of 2016 DPS conclusions

Information from published and unpublished sources was reviewed for the 2016 status review update (Gustafson et al. 2016) in order to assess whether sufficient data existed to justify a reconsideration of the boundary of the Southern DPS of eulachon. The only newly available data pertinent to the Southern DPS delineation question were population genetic studies of Flannery et al. (2009, 2013) and Candy et al. (2015).

Genetic evidence summarized in 2010 and 2016 status reviews

The 2010 status review (Gustafson et al. 2010) reviewed four published genetic studies of genetic population structure in eulachon. One of these studies (McLean et al. 1999) used restriction fragment length polymorphism (RFLP) analysis to examine variation in mitochondrial DNA. The other studies (McLean and Taylor 2001, Kaukinen et al. 2004, Beacham et al. 2005) analyzed microsatellite DNA loci. The most extensive study of eulachon, in terms of sample size and number of loci examined, was that of Beacham et al. (2005). Beacham et al. (2005) examined microsatellite DNA variation in eulachon collected at nine sites ranging from the Columbia River to Cook Inlet, Alaska, using the 14 loci developed by Kaukinen et al. (2004). A cluster analysis of genetic distances showed genetic affinities among the populations in the Fraser, Columbia, and Cowlitz Rivers, and also among the Kemano, Klinaklini, and Bella Coola Rivers along the central British Columbia coast. In particular, there was evidence of a genetic discontinuity north of the Fraser River, with Fraser and Columbia/Cowlitz samples being approximately 3–6 times more divergent from samples farther to the north than they were from each other (Beacham et al. 2005). However, the 2010 BRT noted that there was some uncertainty about the genetic population structure due to the small number of temporally replicated samples in all of the above studies. Beacham et al. (2005) found genetic differences among sampling years within three separate populations (Nass, Kemano, and Bella Coola Rivers) in British Columbia that were similar to levels of genetic differentiation among these three geographically separated populations, indicating a lack of temporal stability in the pattern of population structure.

The 2016 five-year status review update (Gustafson et al. 2016) examined two genetic studies of population structure among samples of eulachon: one utilizing microsatellite-DNA differentiation (Flannery et al. 2009, 2013) and another utilizing newly developed single nucleotide polymorphisms (SNPs; Candy et al. 2015). Flannery et al. (2009, 2013) examined eulachon population structure among 26 rivers in Alaska by analyzing variation at the same 14 microsatellite DNA loci used by Beacham et al. (2005) to analyze population structure in British Columbia and the Columbia River. All collections occurred in either 2003 or 2004, and there was no temporal sampling at any of the 26 locations (Flannery et al. 2013). Eulachon in Alaska exhibited a low degree of genetic divergence, with a broad-scale regional level of population structure. Samples from the northern region (Yakutat Forelands, Cook Inlet, and Prince William Sound) were significantly different from samples obtained from the southern region (Behm and Lynn Canals, Stikine Strait, and Berners Bay; Flannery et al. 2013); however, there was little inter-regional differentiation. According to Flannery et al. (2013): "The level of genetic divergence between regions was four times as great as that within regions" (p. 1040). The fine-scale genetic population structure that Beacham et al. (2005) described, based on samples of eulachon from British Columbia and the Columbia River, was absent in Alaskan eulachon (Flannery et al. 2013). Candy et al. (2015) examined eulachon population structure among 12 sampling locations ranging from Washington (Columbia and Cowlitz Rivers) to south-central Alaska (Twentymile and Kenai Rivers in Cook Inlet) by analyzing genetic variation among a panel of 3,911 putatively neutral SNPs and a panel of 193 putatively adaptive SNPs. There was no temporal sampling at any of the 12 locations included in the Candy et al. (2015) study.

According to Candy et al. (2015), the neutral and adaptive eulachon SNP panels showed a regional population structure that was similar to that observed by Beacham et al. (2005) using microsatellite DNA markers. Candy et al. (2015) interpreted their results as indicating that "…there is a three-population southern Columbia–Fraser group (Cowlitz, Columbia, and Fraser Rivers), a seven-population British Columbia (BC)–SE Alaska group (Stikine, Nass, Skeena, Klinaklini, Kingcome, Kemano and Bella Coola Rivers) and a two-population northern Gulf of Alaska (GOA) group (Twentymile and Kenai Rivers)" (p. 8).

Surprisingly, pairwise F_{ST} comparisons for the neutral SNPs showed that Columbia River eulachon were not significantly differentiated from any other population: all pairwise $F_{ST} \leq 0.0000$ (Candy et al. 2015, their Table 2). However, the adaptive SNPs displayed statistically significant pairwise F_{ST} values for the Columbia River sample compared to all other rivers except the Cowlitz River. The Columbia River sample consisted of larval eulachon collected downstream of the Cowlitz River (Candy et al. 2015), so these larvae may have originated from mainstem spawning in the Columbia River or from some other tributary source (e.g., Cowlitz, Kalama, Lewis, or Sandy Rivers) upstream of the sampling location.

NMFS WCR (2016) determined "that no new information… has become available since the previous status review that would justify a change in boundaries for the Southern DPS of eulachon" (p. 11).

Conclusions of the 2016 status review of the Southern DPS

The 2016 status review (Gustafson et al. 2016) noted that adult spawning abundance of the Southern DPS of eulachon had clearly increased since the original ESA listing occurred in 2010. A number of data sources indicated that adult eulachon abundance in some rivers within the Southern DPS were substantially higher from 2011–15, compared to indications of very low abundance from 2005–10. The improvement in estimated abundance in the Columbia River at the time of the 2016 status review, relative to the time of listing, was likely due to both changes in biological status and improved monitoring. The documentation of eulachon returning to the Naselle, Chehalis, Elwha, and Klamath Rivers from 2011–15 was attributed to both changes in biological status and improved monitoring.

The 2016 status review (Gustafson et al. 2016), noted that annual monitoring of spawning stock biomass (SSB) had continued in the Fraser River (1995–2015) and expanded to the Columbia (2011–15), Grays (2011–13, 2015), Cowlitz (2015), Naselle (2015), and Chehalis (2015) Rivers, since the time of listing in 2010. It was also noted that the Washington Department of Fish and Wildlife (WDFW) had developed retrospective estimates of historical SSB in the Columbia River for 2000–10 using pre-2011 expansions of eulachon larval densities. These retrospective estimates indicated that total eulachon run biomass in the Columbia River might have been as high as 3,150 mt in 2001 and as low as 35 mt in 2005. Mean SSB over the five-year period (2006–10) immediately prior to the 2010 BRT's analysis was estimated at 20 mt in the Fraser River and 153 mt in the Columbia River. In contrast, mean SSB in the previous five years (2011–15) was estimated at 127 mt in the Fraser River and 4,007 mt in the Columbia River.

The 2016 status review noted that the situation in the Klamath River was also more positive than it was at the time of the 2010 status review, with small numbers of adult eulachon (7, 40, 112, and about 1,000) being documented in the Klamath River in the spawning seasons of 2011–14. However, it had not been possible to calculate estimates of SSB in the Klamath River. Since Moody's (2008) compilation of information on eulachon abundance, very little additional data on the status of eulachon in coastal rivers north of the Fraser River had become available. Anecdotal observations noted in the 2016 status review indicated that the Skeena (2010–15), Kemano (2015), and Kingcome (2012) Rivers had supported substantial runs of spawning eulachon in recent years; however, eulachon in the Kitimat River (2012, 2014) had reportedly remained at low levels.

The 2016 status review concluded that although eulachon abundance in monitored populations had generally improved, especially in the 2013–15 return years, recent poor ocean conditions and the likelihood that these conditions would persist into the near future suggested that population declines may be widespread in the upcoming return years. Therefore, the 2016 status review suggested that it was too early to tell whether increases in abundance and apparent spatial distribution in the Southern DPS of eulachon would persist or whether a return to the severely depressed abundance years of the mid-to-late 1990s and late 2000s would reoccur. The conclusions of the 2016 status review update for the Southern DPS of eulachon (Gustafson et al. 2016) resulted in a recommendation (NMFS WCR 2016) and decision (USOFR 2016) that the Southern DPS remain classified as a threatened species.

Eulachon Recovery Plan

NMFS developed and published a recovery plan for the Southern DPS of eulachon (NMFS 2017). The plan was authored by Robert Anderson (Eulachon Recovery Coordinator, NMFS West Coast Regional Office), with contributions from the Eulachon Recovery Team and the Eulachon Stakeholder Group (members are listed in the plan document; NMFS 2017). The recovery plan (NMFS 2017) stated: "The purpose of this Recovery Plan is to identify a strategy for rebuilding and assuring the long-term viability of eulachon in the wild, allowing ultimately for the species' removal from the Federal list of endangered and threatened species" (p. 107). The recovery goals, objectives, and delisting criteria, as articulated in the eulachon recovery plan (NMFS 2017, pp. 102–106), are as follows:

> A. Recovery goal
>
> The goal of this Recovery Plan is to:
>
> 1. Increase the abundance and productivity of eulachon.
> 2. Protect and enhance the genetic, life history, and spatial diversity of eulachon throughout its geographical range.
> 3. Reduce existing threats to warrant delisting of the species.
>
> B. Recovery objectives and delisting criteria
>
> Eulachon will no longer be in danger of extinction or likely to become endangered in the foreseeable future when all four subpopulations[1] exhibit a combination of abundance and productivity sufficient to maintain genetic, life history, and spatial diversity across a range of conditions allowing for adaptation to changing environmental conditions; and threats have been addressed to an extent sufficient to maintain those biological characteristics throughout the foreseeable future.

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[1] The BRT used the "subpopulation" concept as a way to geographically subdivide the Southern DPS and evaluate the threat scores, since threats had different levels of severity in different parts of the Southern DPS. Therefore, the "subpopulation" concept used by the BRT is a geographical construct and is not synonymous with the population biology concept of demographically independent populations.

The recovery goal can be subdivided into discrete component objectives that, collectively, describe the conditions necessary for achieving the recovery goal. The Eulachon Recovery Team identified four recovery objectives:

1. Ensure subpopulation viability.
2. Conserve spatial structure and temporal distribution patterns.
3. Conserve existing genetic and life history diversity and provide opportunities for interchange of genetic material between and within subpopulations.
4. Eliminate or sufficiently reduce the severity of threats.

In order to determine when recovery objectives have been met, we [WCR] must provide objective, measurable criteria that can be applied to a determination that eulachon be removed from the Endangered Species List. Recovery criteria need to be established for each recovery objective and require evidence that the species' status has improved to a point where it is viable.

The delisting criteria are based on the best available scientific information and incorporate the most current understanding of the DPS and the threats it faces. As this recovery plan is implemented, additional information will become available that can increase certainty about whether the threats have been abated, whether improvements in subpopulation and DPS status have occurred, and whether linkages between threats and changes in eulachon status are understood. These delisting criteria will be assessed through an adaptive management program and NMFS may review whether the criteria may warrant revision during its five-year reviews of the [DPS]. As the biological status of eulachon improves over time, the ESA five-year status review process can be used to articulate the changes in viability parameters and ESA listing factors that might warrant a review of whether the [DPS] should be delisted. The five-year status review process will be used to evaluate this DPS's progress toward recovery and determine if any future change in ESA listing status is warranted.

There is much uncertainty in our knowledge regarding many of the anthropogenic and natural factors that could be limiting eulachon abundance and productivity. If we [WCR] address the highest ranked threats and do not observe a positive response in the species' demographics, then we [WCR] may need to develop additional threat-based objectives and criteria. The proposed recovery approach serves to address the most pressing gaps in knowledge, addresses critical demographic factors required for recovery, and targets the reduction or elimination of threats so that the recovery objectives outlined in this plan have the greatest likelihood of being achieved. Because many of the threats to the recovery of eulachon are not directly manageable, the recovery strategy pursues simultaneous actions to address critical demographic factors, the range of threats, and knowledge gaps. Climate impacts on ocean conditions, i.e., as measured by large-scale spatial and temporal shifts in oceanic–atmospheric patterns in the northeast Pacific

Ocean associated with both natural climate variability and anthropogenic-forced climate change, is likely the principal threat to eulachon, as it is the one phenomenon that correlates with the recent species-wide declines in abundance. Therefore, actions must be taken to understand the mechanisms by which these large-scale spatial and temporal shifts in oceanic–atmospheric patterns in the northeast Pacific Ocean affect eulachon productivity, recruitment, and persistence.

The criteria are organized below according to (1) biological recovery criteria which address abundance, productivity, spatial structure, and genetic and life history diversity; and (2) qualitative/quantitative threat-based recovery criteria which address the threats impeding recovery....

The ESA requires that recovery plans for listed species contain "measurable and objective criteria" that when met would result in the removal of the species from the endangered species list. To be removed from the list, a species needs to be no longer in danger of or threatened with extinction. Court rulings and NMFS policy indicate that delisting criteria must include both biological criteria and listing factor criteria that address the threats to a species (i.e., the five factors in ESA section 4[a][1][b]). The viability criteria relate most directly to the biological delisting criteria; however, they are not synonymous. NMFS establishes delisting criteria based on both science and policy considerations. For instance, science can identify the best metrics for assessing extinction risk and thresholds of those metrics associated with a given level of risk, but setting the acceptable level of risk for purposes of the ESA is a policy decision.

1. **Abundance:** Each subpopulation is self-sustaining, i.e., each subpopulation has a less than 5% probability of extinction in 100 years.
2. **Productivity:** Each subpopulation has a stable or increasing growth rate greater than 1 across multiple generations.
3. **Spatial Structure and Temporal Distribution:** Eulachon subpopulations are distributed in a manner that insulates against loss from local catastrophic events and provides for re-colonization of a subpopulation that is affected by such an event.
4. **Genetic and Life History Diversity:** Eulachon subpopulations exhibit high certainty that genetic and life history diversity is sufficient to sustain natural production across a range of conditions, and eulachon subpopulations exhibit high certainty that changes in phenotypical traits represent positive natural adaptations to prevailing environmental conditions.
5. **Threats:** For each subpopulation, the threats listed in [our] Table 2.2 have been diminished such that they do not limit attainment of the desired biological status of the DPS, and all the factors in section 4(a)(l) of the ESA have been addressed.

The eulachon recovery program (NMFS 2017, p. 108) presents numerous specific descriptions of actions organized under seven priority recovery actions:

1. Establish a eulachon technical recovery and implementation team.
2. Implement outreach and education strategies.
3. Near-term research priorities.
4. Conserve spatial structure and temporal distribution.
5. Eliminate or sufficiently reduce the severity of threats.
6. Assess regulatory measures, including the inadequacy of existing regulatory mechanisms.
7. Develop a research, monitoring, evaluation, and adaptive management plan.

The eulachon recovery plan provides full descriptions of the specific recovery actions (NMFS 2017, pp. 108–116).

Eulachon Technical Recovery and Implementation Team

The number one priority action of the ESA Recovery Plan for the Southern DPS of eulachon called for establishment of "a eulachon technical recovery and implementation team to develop an overall framework for funding, prioritization, implementation, and reporting of recovery actions" (NMFS 2017, p. 108). NMFS has formed a team of interested stakeholders, the Eulachon Technical Recovery and Implementation Team (ETRIT). To date, the ETRIT is composed of the following members:

- Cowlitz Indian Tribe
- Lower Elwha Klallam Tribe
- Jamestown S'Klallam Tribe
- Quileute Nation
- Yakama Nation
- Confederated Tribes of Warm Springs
- Yurok Tribe
- Haisla Fisheries Commission
- Clallam County Marine Resources Committee
- Washington Department of Fish and Wildlife
- Oregon Department of Fish and Wildlife
- California Department of Fish and Wildlife
- National Marine Fisheries Service
- Fisheries and Oceans Canada (DFO)

Other interested tribes, states, agencies, and organizations may be added over time.

ETRIT's vision is: "To conserve and protect eulachon and its habitat so that its long-term survival is secured and it can be considered for removal from the list of threatened and endangered species." In addition, participants on ETRIT have identified the following as vital to recovery of the Southern DPS of eulachon: 1) escapement to sustain all subpopulations across multiple generations, 2) abundance to support sustained ecosystem function, and 3) opportunity for harvest in line with historical uses (including opportunities for harvest in line with traditional tribal food, ceremonial, and oil-rendering purposes; non-tribal recreational take; and historical commercial landings). The following strategic goals have also been articulated by ETRIT:

1. Healthy, self-sustained, biologically viable populations of eulachon throughout the historic range, including spawning within each of the four subpopulations listed in the recovery plan, with the Southern DPS represented by multiple and abundant year-classes in marine and freshwater environments.
2. Eulachon populations sufficiently abundant and productive enough to provide historical ecological benefits as a forage fish species.
3. Eulachon populations sufficiently abundant and productive to provide cultural and other benefits, including harvest in line with historical uses.
4. Sufficient, informed, appropriate, and broad public and private support, including financial and nonfinancial, to recover eulachon populations in the Southern DPS.

To date, ETRIT has held two annual two-day workshops (Ridgefield, Washington, on 27–28 September 2018 and Arcata, California, on 24–25 September 2019). Further workshops have been delayed due to the COVID-19 pandemic. ETRIT has met regularly via quarterly phone or virtual online teleconferences throughout 2019–21.

New and Additional Information

New Life-History Research Results

General life history

Dealy and Hodes (2019) examined marine migration patterns, catch trends, body size, sex ratio, maturity, stomach contents, and presence/absence of teeth in eulachon sampled in monthly bottom trawls in the Strait of Juan de Fuca, Haro Strait, and the Strait of Georgia (SOG) in British Columbia from October 2017 to June 2018. These data indicated that "Juan de Fuca Strait likely provides an important year-round marine habitat for eulachon feeding and growth as well as being a migration corridor to and from [the Fraser River and] the west coast of Vancouver Island" (Dealy and Hodes 2019, p. 23). Furthermore, Dealy and Hodes (2019) stated:

> Seasonal variation in catches in the Strait of Georgia [and Haro Strait]… are consistent with a pre-spawning migration pattern of Fraser River-bound eulachon moving from Juan de Fuca during winter to mid-spring months. …Given when peak CPUE levels were observed in the [Strait of Georgia and Haro Strait] and the relatively uniform distribution of fish lengths greater than 150 mm observed… compared to the Juan de Fuca samples, these findings could be interpreted to suggest that most of the fish sampled were likely Fraser River-bound eulachon moving inward from Juan de Fuca Strait. (p. 23)

Euphausiids (krill) were the most common prey item in eulachon stomachs, although 68%, 88%, and 99% of eulachon stomachs were empty in samples from the Strait of Juan de Fuca, Haro Strait, and the SOG near the Fraser River, respectively (Dealy and Hodes 2019). Mean and minimum body length measurements increased and the frequency of eulachon with teeth decreased in sampled eulachon from the Strait of Juan de Fuca toward the Fraser River. Eulachon samples from the Strait of Juan de Fuca had a multimodal length distribution in each month of the survey, although a multimodal length distribution was less evident in Haro Strait and in the SOG near the Fraser River. Although length distributions appeared bimodal in some cases, there may have been more than two overlapping size and age distributions that were difficult to distinguish (Dealy and Hodes 2019). Dealy and Hodes (2019) stated:

> …wide ranges in variability between fish lengths and maturity stages demonstrate that maturing and spawning eulachon may be comprised of different ages…. Fish length distributions for maturity stages 3 to 5 had such overlap that differences are not clearly detectable, thus limiting the use of length data as a proxy for sexual maturity and age. (p. 24)

Dealy and Hodes (2019) also noted that, just as there is a high degree of uncertainty in assigning age based on eulachon otolith "growth patterns," there is also uncertainty associated with assigning fish of a certain length to a particular age, and that no validated ageing method is universally accepted for age determination of eulachon.

Dealy and Hodes (2021) expanded their examination of eulachon distribution, life history, and migration patterns to Chatham Sound, British Columbia, which MacConnachie et al. (2016a) suggested was an important rearing area for juvenile eulachon and a staging area for eulachon destined to spawn in the Nass or Skeena Rivers. Dealy and Hodes (2021) conducted monthly bottom trawl surveys from July 2018 to March 2019 and collected data on eulachon catch per unit effort (CPUE, in kg/hr), length, weight, sex, stomach contents, maturity, presence of teeth, and presence of parasites, and sampled tissue for future genetic analysis. Eulachon were caught in 90% of sets (*n* = 162) and comprised 6% of the total catch weight. Highest eulachon catches (>100 kg/hr) occurred over bottom depths from 87–186 m. Average CPUE was lowest in February (20 kg/hr) and March (22 kg/hr), when adult eulachon were spawning, and highest in July (81 kg/hr) and November (146 kg/hr; Dealy and Hodes 2021).

Standard length of eulachon ranged from 44–208 mm (*n* = 6,863), and weights ranged from 1–86 g (*n* = 5,475). Mean length increased from July to November, and "those caught in February and March were smaller on average," most likely due to larger fish being away on the spawning grounds (Dealy and Hodes 2021, pp. 8–9). Correspondingly:

> The presence of eulachon with developing gonads in Chatham Sound increased in frequency from July to November. In February and March, eulachon had relatively smaller bodies with less-developed gonads, likely also corresponding to the spawning period and migration of mature individuals towards estuaries and rivers. (p. viii)

Sex ratios (male:female) were approximately 1:1 from July to November, but approximated 1:2 in February and March when about 25% of specimens were of undetermined sex. About 54% of eulachon stomachs were empty, and euphausiids were found "occurring in about half (42–65%) of stomachs sampled (*n* = 1,421) in all months except November (22%) and February (14%)" (Dealy and Hodes 2021, pp. 8–9). About 3% of stomachs contained unidentified remains, unidentified fishes, and shrimp. A single partially digested juvenile eulachon "was found in the stomach of a 165 mm long female eulachon specimen sampled in November" (Dealy and Hodes 2021, p. 16).

One line of evidence that eulachon are semelparous is that, similar to other anadromous species, they resorb their teeth prior to spawning to aid in gonadogenesis, and very few spawning eulachon retain their teeth (Hay 2002, Hay et al. 2002, 2003). It has also been stated: "we observe only eulachon with well-developed teeth in the sea" (Hay et al. 2002, p. 4). Dealy and Hodes (2021) examined 3,560 eulachon for presence of teeth and found:

> …relatively few fish had reduced or no teeth (<3% of specimens) and these occurred most frequently in February and March. Eulachon with no teeth were [primarily male] and only caught in February (*n* = 10). (p. 17)

However, retention of teeth in significant numbers of spawning eulachon in the Twentymile River, Alaska (84% and 97% for females, and 3% and 32% for males in 2000 and 2001, respectively), indicates that some of these fish may survive spawning, return to the sea, and begin feeding again (Spangler 2002, Spangler et al. 2003).

Dealy and Hodes (2021) stated:

> Females that appeared to have spawned and returned to the marine environment were collected frequently in July and September, possibly providing some evidence of iteroparity, which has not been previously described for Eulachon. However, further histological analysis is required to confirm this finding, as resolving the potential for repeat spawning would provide useful information for future stock assessments and is a key knowledge gap for the species. (p. viii)

Dealy and Hodes (2021) found:

> Stage 6 "spent" females… in low proportions (2–4%) on surveys in February, March, July, and September. Proportions of stage 7 "recovering" females were highest in July (13%) and September (30%). No male eulachon specimens showed indications of having previously spawned. (p. 21)

King et al. (2019) and Boldt et al. (2020a) reported on results of Fisheries and Oceans Canada (DFO) integrated pelagic ecosystem surveys on the Vancouver Island continental shelf in the summers of 2017 and 2018, and in summer of 2019, respectively. Data collected included eulachon standard lengths and weight, a caudal fin clip for genetic stock identification, and stomach content analysis (King et al. 2019, Boldt et al. 2020a). Stomach analyses consisted of 10, 95, and 106 eulachon stomachs in 2017, 2018, and 2019, respectively. The only identifiable remains in eulachon stomachs were euphausiids, which were found in 90%, 62%, and 41% of stomachs examined across these three years. Other stomachs were mostly empty, although a few contained unidentifiable remains. Eulachon in 2018 were dominated by specimens <150 mm in length (King et al. 2019). In 2019, eulachon ranged in length from 85–188 mm, with the majority being from 150–175 mm (Boldt et al. 2020a). Plots of eulachon length frequency and double log-transformed length–weight regressions were provided for eulachon sampled in 2018 (King et al. 2019) and 2019 (Boldt et al. 2020a).

Lloyd and Langness (2018) reported on fecundity, egg diameter, sex ratio, age structure, changes in tooth absorption, and adult length and weight of Columbia River eulachon collected during the 2013 and 2015–18 spawning runs. Mean fecundity and egg size estimates were obtained in 2013 (fecundity = 31,583; diameter = 1.03 mm; $n = 31$), 2015 (fecundity = 29,931; diameter = 0.89 mm; $n = 27$), 2016 (fecundity = 34,082; diameter = 0.90 mm; $n = 50$), 2017 (fecundity = 39,761; diameter = 1.01 mm; $n = 22$), and 2018 (fecundity = 31,829; diameter = 1.02 mm; $n = 7$). Using a mix of samples from 2013 ($n = 30$), 2015 ($n = 26$), and 2016 ($n = 46$), Lloyd and Langness (2018) calculated that 801 eggs are produced per gram of female body weight. Fecundity was correlated with both fork length ($r^2 = 0.488$) and body weight ($r^2 = 0.657$).

Sex ratios (male:female) were mostly obtained from commercial fishery sampling, except for 2013, when research sampling provided estimates from the estuary (1.07:1; $n = 715$) and freshwater (1.96:1; $n = 130$) regions of the lower Columbia River (Lloyd and Langness 2018). Sex ratios and average number of fish per pound were 1.3:1 ($n = 914$) and 11.6 ($n = 1{,}055$) in 2015. In 2016, sex ratios were 1.69:1 ($n = 706$) from freshwater sampling, and one estuary sample provided a sex ratio of 0.88:1 (*n* = 105). Average fish per pound estimates were 11.5 for males and 10.2 for females in 2016 (*n* = 559). In 2017, sex ratios were 1.61:1 (*n* = 1,153) and average fish per pound were 9.6 for males and 10.1 for females (*n* = 1,153). In 2018, only 118 fish were sampled due to low eulachon abundance; sex ratio was 1.31:1 and number of fish per pound was estimated at 9.2 for males and 10.4 for females (Lloyd and Langness 2018). Eulachon caught in the Columbia River estuary are at or near a sex ratio of 1:1.

Langness et al. (2020b) reported on gonadosomatic index (GSI), sex ratio, age structure, changes in tooth absorption, and adult length and weight of Columbia River eulachon collected during the 2019 spawning run. Eulachon specimens were sampled from salmonid test fisheries (*n* = 14 males), screw traps in the Grays River (*n* = 99; 97 males, 2 females), and dip netting in the Cowlitz River (*n* = 627; 345 males, 282 females). GSI averaged 27.9% (*n* = 66, range 22.8–34.9%) in 2019. Average GSI from 2012–18 ranged from 19.4–25.9%. Thus, "the 2019 range and average GSI values are higher than those observed during the previous seven years" (Langness et al. 2020b, p. 48). Sex ratios (male:female) obtained from dip-netted eulachon in the Cowlitz River were 1.22:1 (*n* = 627). In 2019, Langness et al. (2020b) examined 152 (91 males, 61 females) eulachon for tooth resorption; 11.5% of females and 58.6% of males lacked all teeth, while 1.6% of females and 5.5% of males "had at least one tooth intact" (p. 43). Lack of teeth was most notable in eulachon returning to the Columbia River in 2013, 2018, and 2019 (Langness et al. 2020b).

Recently, Zamon et al. (2021) reported that eulachon sampled in the estuary of the lower Columbia River with trawl nets showed a sex ratio of nearly 1:1. Zamon et al. (2021) also stated:

> Observations suggested that eulachon occurred in low densities and remained dispersed in deeper waters of the estuary for at least 2 mo before upstream migration. The estuary may therefore serve as an important staging area prior to upstream migration and subsequent spawning. (p. 179)

Age structure

Methods of estimating age in eulachon have included counting presumed annular rings on scales and otoliths, and assigning fish of a certain length to a particular age. However, these methods have not been validated for any population of eulachon (Ricker et al. 1954, Hay and McCarter 2000, Clarke et al. 2007, Benson et al. 2019, Dealy and Hodes 2019). Age validation "requires either a mark-recapture study or the identification of known-age fish in the population" (Beamish and McFarlane 1983, p. 741). Using age estimates from counts of scale or otolith circuli, or from analyses of length frequency data, is challenging. Age determination based on counting annuli on scales or sectioned otoliths may be one to three years younger than ages determined from counting annuli on otolith surfaces (Ricker et al. 1954, Hay and McCarter 2000, Clarke et al. 2007, Benson et al. 2019). Clarke et al. (2007, p. 1480) noted that many dark bands or pseudo-annuli are present in whole and polished otoliths "that have been interpreted as winter growth zones in past ageing attempts" and that "sectioned otoliths viewed under transmitted light can reveal fewer zones." Benson et al. (2019) also stated:

> Eulachon otoliths had multiple translucent and opaque bands surrounding the core…. One annual growth zone was defined as a pair of one opaque and one translucent zone…. [T]ranslucent zones are associated with wintertime and counted to determine the age…. The interpretation of eulachon otolith surface patterns was complicated by some otoliths having multiple non-annual translucent zones…. Classification of the otolith first year was also complicated by the intermittent presence of non-annual translucent zones that appear around the core of the otolith. (p. 633)

Lloyd and Langness (2018) determined age structure of their samples from surface reading of whole otoliths and these data, as well as representative lengths and weights of samples from 2013–18, are presented both graphically and in tabular form. Lloyd and Langness (2018) stated:

> Two age readers independently aged samples and the percent agreement between readers was 58% for 2018 commercial samples (62% in 2015, 61% in 2016 & 75% in 2017). Despite the poor agreement, 91% of disagreements were ±1 year resulting in an average percent error index of about 6%, with no bias between readers. The poor agreement between readers highlights the difficulty of ageing eulachon otoliths and the need to develop more specific ageing criteria through validation of annuli formation. (p. 143)

Langness et al. (2020b) determined age structure of their 2019 samples from surface reading of 735 whole otoliths. A subset of these otoliths (*n* = 120) were read by two WDFW age readers, with 73% agreement between the two readers for 2019 samples. Most disagreements involved plus or minus one year between readers. Despite these inconsistencies in precision, and the lack of a validated ageing methodology for eulachon, Langness et al. (2020b) applied their age structure and length-at-age results to stock-recruitment models and the von Bertalanffy growth function for Columbia River eulachon.

Determination of age from eulachon length-frequency data is also problematic (Clarke et al. 2007, Benson et al. 2019, Dealy and Hodes 2019). Length distributions in some studies (Hay and McCarter 2000, Hay et al. 2003) have shown a multimodal pattern indicative of age classes, whereas other studies (Clarke et al. 2007, Dealy and Hodes 2019) have revealed that size distributions and age classes of larger-sized fish may be overlapping, making it very difficult to distinguish age classes based on size.

Clarke et al. (2007) pioneered a method to estimate eulachon age from analysis of seasonal variations in barium (Ba) and calcium (Ca) incorporated into otoliths. They used laser-ablation inductively coupled plasma mass spectrometry to reconstruct the Ba:Ca profile of eulachon otoliths from the core out to the otolith margin. Barium and calcium are incorporated into the aragonitic matrix of fish otoliths in proportion to their concentration in the environment (Bath et al. 2000). Barium concentrations are normally about three times greater in deep-ocean waters than in surface waters; however, for about three months during the summer, wind-driven upwelling of deep barium-rich waters occurs off the U.S. West Coast. This results in eulachon otoliths having low Ba:Ca levels in the outer region of the otolith in February and March and high levels in the summer (Clarke et al. 2007, Benson et al. 2019). Plots of the elemental concentrations of Ba:Ca from the otolith core to the margin reveal peaks and troughs; significant Ba:Ca troughs, representing winter, are counted to derive the specimen's age. The 2010 status review (Gustafson et al. 2010) reviewed the results of the Clarke et al. (2007) study.

Benson et al. (2019) expanded upon the study of Clarke et al. (2007) by examining seasonal otolith microchemistry as an aid to ageing eulachon from offshore collections in Oregon, Southeast Alaska, and in the southeastern Bering Sea. Benson et al. (2019, p. 640) "estimated the maximum age of eulachon to be 5 years and determined that non-annual translucent zones often occurred inside of the actual first year's zone." Variations in elemental signatures of Ba:Ca and Zn:Ca (zinc [Zn] is linked to feeding and growth, which drops in the winter periods) were "useful as annual markers" for both Oregon and Bering Sea samples, and the space between annual growth zones on otoliths decreased with age in both the Oregon and Bering Sea samples.

All otoliths from the Oregon samples (*n* = 31) "displayed at least one prominent non-annual translucent zone inside of the first year" (Benson et al. 2019, p. 634), and additional apparent nonannual translucent zones made it difficult to distinguish annual growth zones. Oregon specimens had well defined peaks and troughs for Ba:Ca, which suggested that 25 of the Oregon eulachon were two years old and four were three years old at capture (Benson et al. 2019). Bering Sea eulachon otolith surfaces "had well-defined annuli and were easier to interpret than Oregon otolith surface patterns" (Benson et al. 2019, p. 634). Ten of the Bering Sea eulachon were two years old, 47 were three years old, and the remaining eight were four years old at capture.

Southeast Alaska specimens displayed Ba:Ca peaks and troughs that were difficult to associate with seasonal cycles. In some cases, the Zn:Ca "concentration decreased gradually over the life of the fish and it was difficult to determine any significant drops in the elemental signature" (Benson et al. 2019, p. 634). Benson et al. (2019, pp. 640–641) stated: "Before such an approach for age determination can be applied to eulachon in Southeast Alaska, further work is needed to establish the seasonality in their otoliths' elemental signatures and to understand the link between otolith microchemistry, fish physiology, and regional environmental factors."

According to Benson et al. (2019):

> Overall, the ages determined from otolith translucent zone counts were similar to the ages derived from the Ba:Ca signatures for the Oregon and Bering Sea specimens…. Two Bering Sea specimens had only two troughs in the Ba:Ca signature while otolith growth zone counts suggested an age estimate of 3 years…. For Southeast Alaska, matched results of both elemental signature counts and otolith growth zone counts were available from 64 specimens with the majority of fish aged 2 and 3 years (*n* = 57) and the rest aged 4 and 5 years (*n* = 7). Twenty-five specimens [from Southeast Alaska] had discrepancies between elemental signature counts and otolith growth zone counts, but there was no evidence of bias, with 12 specimens having higher elemental signature ages and 13 having higher otolith ages…. (p. 636)

Clarke et al. (2007) and Benson et al. (2019) studies on eulachon age structure in eulachon sampled from the California Current Ecosystem suggest that a nonannual translucent zone often occurs inside of the actual first year's growth zone on the otolith's surface, and that additional nonannual translucent zones made it difficult to distinguish annual growth zones. These nonannual translucent zones may be misinterpreted as annual age lines when surface-reading otolith age.

Trophic interactions

Osgood et al. (2016) examined archived stomach content records from 1966–68 to determine historical diets of eulachon, Pacific herring, and five species of juvenile salmon in the SOG during the spring and early summer months. These historical data indicated that calanoid copepods and cladocerans accounted for 73% and 13%, respectively, of individual larval and juvenile eulachon stomach contents (*n* = 109; Osgood et al. 2016). Osgood et al. (2016, p. 590) speculated that the relatively high diet specialization of eulachon, in concert with "recent declines in copepod abundance within the Strait of Georgia (Mackas et al. 2013), may have contributed to eulachon population declines and the poor recovery of this species" in the Fraser River.

Although currently Pacific herring (*Clupea pallasii*) are the most important forage fish as prey for Pacific salmon in the SOG, eulachon were historically the most consumed prey species, "occurring in 28% of all piscivorous fish stomachs" in 1966–68 (Osgood et al. 2016, p. 580). Eulachon were the most abundant species in these records, and were found in the stomachs of 37% of sockeye salmon (*Oncorhynchus nerka*; *n* = 72), 14% of chum salmon (*O. keta*; *n* = 73), 29% of pink salmon (*O. gorbuscha*; *n* = 35), 3% of coho salmon (*O. kisutch*; *n* = 35), 19% of Chinook salmon (*O. tshawytscha*; *n* = 41), and 47% of Pacific herring (*n* = 74). Eulachon were also the most frequently found fish prey in both sockeye salmon and Pacific herring stomachs, and constituted the largest proportion of fish consumed in the stomachs of Pacific herring (70%), Chinook salmon (55%), pink salmon (47%), and chum salmon (54%). Osgood et al. (2016, p. 591) proposed that this historically high consumption of eulachon by Pacific salmon, compared to eulachon's low importance in contemporary Pacific salmon diets, "suggests that the loss of this energy-rich food has caused shifts in the feeding ecology of Pacific salmon that may have implications for their growth and survival rates." Osgood et al. (2016) further postulated that the large contemporary importance of Pacific herring in the diets of Pacific salmon in the SOG is likely a response to declines in the availability of eulachon, particularly the Fraser River population.

Size frequency in offshore eulachon sampling

Body length (fork length, nearest cm) of a select number of juvenile eulachon were measured from a subset of the observed bycatch of eulachon in state-operated U.S. West Coast ocean shrimp trawl fisheries during the month of May for the years 2011–20 (Figure 2). Similarly, body length (standard length, nearest mm) of a select number of juvenile eulachon were also measured during DFO shrimp and multispecies small mesh trawl surveys conducted in May 2011–18 and 2020 offshore of the west coast of Vancouver Island (WCVI; Flostrand 2019, p. 77, their Figure 18-3). Standard length is length from the tip

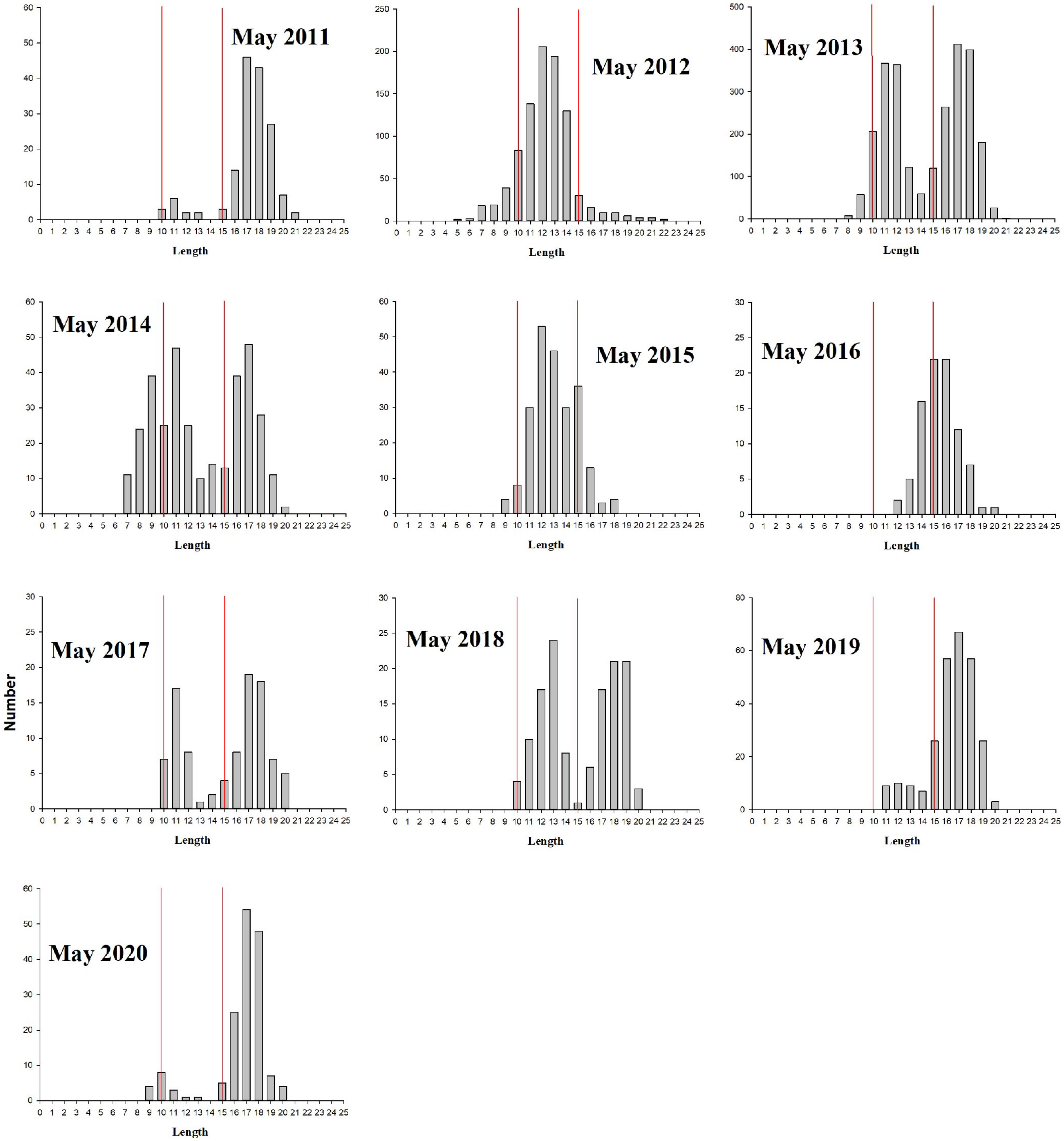

Figure 2. Fork lengths (cm) of juvenile eulachon caught as bycatch in U.S. West Coast ocean shrimp fisheries in May 2011–20. Red vertical lines at 10 and 15 cm assist in comparisons between positions and shapes of annual length distributions.

of the snout to the base of the caudal peduncle, and fork length is length from the tip of the snout to the center of the fork in the tail or caudal fin. Fork length is greater than standard length; 100 and 150 mm standard length equals 109 and 163 mm fork length, respectively (for conversions between the two, see Buchheister and Wilson 2005). Length histograms of eulachon caught at sea typically appear to have either a unimodal or bimodal distribution, representative of different size cohorts. DFO (2021a) stated:

> Length-frequency histograms tend to reveal multi-modal distributions with different age classes distinguished by different length ranges, i.e. generally younger fish are shorter and older fish are longer. Fish that are typically less than 50 mm standard length are generally estimated to be less than one year old and are not well represented in the sample…. Fish that are 50 to 130 mm are generally estimated to be approximately one to two years old. However, there can be considerable overlap in length ranges between ages, especially in fish older than one year old…. Trends in length frequencies can vary considerably between years… which can be a function of changes in age compositions, as well as changes in growth rates between years and between stocks. In general, however, smaller fish are typically younger than larger fish. (p. 25)

Comparison of length histograms from 2011–20 in Figure 2 (this report) and Figure 18.3 in Flostrand (2019) reveals remarkably similar trends in year-to-year growth patterns (either unimodal or bimodal length distributions) of cohorts of juvenile eulachon sampled as bycatch in the state-operated U.S. West Coast ocean shrimp fishery and the WCVI small mesh multispecies survey. The similarity of these eulachon body-length data during the same season of the year suggests that growth patterns of eulachon off the U.S. West Coast and off WCVI are in synchrony. Perhaps these stocks are responding to the same environmental drivers and/or originated from the same parent stock in both locations, and share similar early growth histories.

New Information Related to Delineation of the Southern DPS of Eulachon

Information from published and unpublished reports was reviewed to assess whether sufficient data existed to justify a reconsideration of the boundary of the Southern DPS of eulachon. Newly available data pertinent to the Southern DPS's spatial delineation were: 1) studies by Benson et al. (2019) that attempted to distinguish between eulachon populations based on differences in otolith microchemistry, 2) studies by Spangler (2020) that showed that some eulachon may be spawning in estuarine habitats and at higher salinities than previously believed, and 3) genetic population structure studies of Sutherland et al. (2021).

Otolith microchemistry

Benson et al. (2019) attempted to detect regional group differences in eulachon sampled off Oregon, Southeast Alaska, and in the southeastern Bering Sea using otolith ratios of strontium, barium, zinc, and magnesium to calcium (Sr:Ca, Ba:Ca, Zn:Ca, Mg:Ca). Otoliths from these three regions were correctly classified to region with an overall accuracy of 79.4% using otolith microchemistry. Only 51.6% of specimens from Oregon were correctly classified to their region (*n* = 31; 16 classified to Oregon, 15 to Southeast Alaska). However, 82.5% of specimens from Southeast Alaska (*n* = 97; 80 classified to Southeast Alaska, eight to Oregon, and nine to the Bering Sea) and 87.3% of specimens from the Bering Sea (*n* = 71; 62 classified to Bering Sea, and nine to Southeast Alaska) were correctly classified to their regions of origin (Benson et al. 2019).

Previously, Hay and McCarter (2000) and Hay and Beacham (2005) reported on attempts to use differences in the elemental makeup of eulachon otoliths to detect stock structure among various rivers on the coast of British Columbia. The results indicated that there were differences in the elemental composition of eulachon otoliths over a broad geographic range, but that "elemental analysis was not useful to distinguish between closely adjacent stocks" (Hay and Beacham 2005, p. 10).

Estuary spawning

Spangler (2020) recently completed a study of "how salinity affects fertilization and hatching success of eulachon" (p. 16) in laboratory experiments on eulachon eggs and sperm obtained from ripe pre-spawn adults from the Twentymile River in south-central Alaska. Gametes were obtained from 10 female and 10 male eulachon and placed in glass trays previously filled with seawater diluted to the test static salinities of 0, 6, 12, 18, 25, and 30 Practical Salinity Units (PSU). The experiment was replicated three times at each salinity. Percent fertilization success after 24 hours was recorded and "fertilized eggs were identified by their light gray appearance, whereas unfertilized eggs turned an opaque white color" (Spangler 2020, p. 17). Mean percent fertilization success of the three replicates was 98.6% at 0 and 6 PSU, 98.9% at 12 and 18 PSU, 95.6% at 24 PSU, and 0% at 30 PSU.

Spangler (2020) performed two experiments, replicated three times, to determine percent hatching success of fertilized eulachon eggs in seawater diluted to the static salinities of 0, 6, 12, 18, 25, and 30 PSU. One experiment was conducted in aerated glass trays at 6°C and the second experiment used 6 × 2-cm glass slides with eggs attached, suspended in aerated "1,000-mL beakers filled with the test salinity water," which "were placed in a bath of sea water pumped continuously from the ocean that ranged from 4 to 8°C" (Spangler 2020, p. 17). With the exception of the 30-PSU treatment, eggs in both experiments "were exposed to the same set of experimental salinity levels in which they were fertilized" (Spangler 2020, pp. 17–18). Eggs fertilized at 0 PSU were used in the 30 PSU hatching experiments, since no successful fertilization occurred at 30 PSU. No eggs hatched in either experiment at 18, 24, or 30 PSU. Mean hatching success was 39.6% in glass trays and 24.4% in beakers at 0 PSU; 44.7% in trays and 11.6% in beakers at 6 PSU; and 3.5% in trays and 7.9% in beakers at 12 PSU. These results indicate that eulachon are "capable of producing viable larvae in the brackish water of estuaries" at 12 PSU, but not above about 18 PSU (Spangler 2020).

Similarly, previous studies had found eulachon egg survival was greatly influenced by salinity greater than 16 parts per thousand (ppt; Willson et al. 2006). Lewis et al. (2002, p. 118) cited Farara (1996), who observed that:

> …eulachon eggs began to detach from the substrate [in the Kemano River] at 15 ppt and those that detached subsequently died. Survival to hatch was 21% in a freshwater control, but only 0.05% at a salinity of 16.5 ppt and 0% at a salinity of 22 ppt.

Spangler (2020) also demonstrated that eulachon spawn partially in brackish areas of estuaries in the Twentymile and Antler Rivers in Alaska, by measuring salinities and egg locations, and by tracking radio-tagged eulachon during their spawning migrations. Spangler (2020) argued that these findings indicate that changes should be considered for both the ESA designation of eulachon critical habitat for spawning for the Southern DPS of eulachon, and for locations where outmigrant eggs and larvae are monitored for evaluation of SSB. The original 2010 BRT was aware of similar observations of estuarine spawning in the Twentymile River (Spangler et al. 2003). However, we are unaware of similar observations of estuarine spawning of eulachon in other eulachon-bearing rivers.

New genetic information

Sutherland et al. (2021) developed an improved genetic baseline of 521 variant single nucleotide polymorphism (SNP) loci, genotyped in 1,989 individuals from 14 populations ranging from south-central Alaska (Twentymile River) to Northern California (Klamath River). This amplicon SNP panel uses a subset of the top-discriminating SNP markers from the Candy et al. (2015) study, filtered through alignment with a eulachon reference genome assembly (Sutherland et al. 2021). A number of locations with 35 or fewer individual samples (including the Elwha River, Washington, and Kitimat River, British Columbia) were removed from the baseline, since the low sample sizes resulted in a lack of resolving power as shown by these locations being consistently outside of the main clusters in dendrograms. Three main groupings were evident: southern rivers (Klamath, Columbia, Cowlitz, Sandy, and Fraser), northern rivers (Kingcome, Klinaklini, Wannock, Bella Coola, Kemano, Skeena, Nass, and Unuk), and the Gulf of Alaska (Twentymile River). These results were similar to those of Candy et al. (2015), and: “The general trend of the data was similar between the SNP and microsatellite results, with a large divide between the populations to the south of the Fraser River, inclusive, and the populations to the north of the Fraser River, with Twentymile River as an outgroup” (Sutherland et al. 2021, pp. 84–85). Although there appears to be significant isolation by distance (IBD) across the entire range of locations, as evidenced by a pairwise comparison of physical distance (km) and F_{ST} (a measure of genetic differentiation) between locations ($r^2 = 0.708$), there is no IBD evident within regions. Separation of the southern rivers group from northern rivers “had high bootstrap support (>99.99%)” in dendrograms (Sutherland et al. 2021, p. 82). Moreover:

> Within the southern grouping, there was some clustering of Columbia River populations together, but the Cowlitz River population… grouped into a cluster with Klamath River, and more broadly with the Fraser River… rather than with the other Columbia River populations (Columbia River, Sandy River). Cowlitz River and Klamath River are grouped closely together, and in 87% of trees Cowlitz and Klamath Rivers group together without the Fraser River. In general these populations were very similar (e.g., Fraser River versus Columbia River: $F_{ST} = 0.0079$… Fraser River versus Klamath River: $F_{ST} = 0.0021$… and Klamath River versus Columbia River: $F_{ST} = 0.0091$…. (p. 82)

Within the northern grouping, the Kingcome, Klinaklini, and Bella Coola Rivers “had high genetic similarity with each other (mean $F_{ST} = 0.0021$),” as did the Kemano and Wannock Rivers ($F_{ST} = 0.0043$; Sutherland et al. 2021, p. 82). The Skeena and Nass Rivers “were nearly indistinguishable… $F_{ST} = 0.0009$,” and the “Unuk River clustered outside of the north coast and central coast groupings, but still within the larger northern grouping” (Sutherland et al. 2021, p. 82).

Some rivers (Klamath, Fraser, Kingcome, Bella Coola, and Skeena) were sampled in multiple years above the 35-sample threshold, and for these rivers, “there was often close clustering of the different collection years, but not always” (Sutherland et al. 2021, p. 82). For example, Fraser River 2018 and 2019 clustered closely, but not with Fraser 2014; the largest difference was between collections taken in 2014 and 2018 (pairwise $F_{ST} = 0.0106$). Similarly, there was close clustering between Skeena River 2010 and 2013 (but not 2001) and “Bella Coola River 1998 and 2017 (but not 2013 or 2018)” (Sutherland et al. 2021, p. 82). On the other hand, F_{ST} values for “Bella Coola River 1998 and 2017 collections, Klamath River 2013 and 2014 collections, and Skeena River 2001 versus 2010 and 2013 were not significantly different from zero” (Sutherland et al. 2021, p. 83). Sutherland et al. (2021, p. 87) noted that some of this variance across sampling years in the same river may be influenced by occurrence of multiple runs in some rivers with variable spawning times “if there is only a single sampling event per year.” In the future, this improved genetic baseline will be applied to mixed stock analysis of at-sea sampled eulachon to improve estimates of where eulachon from specific rivers are distributed and which rivers are most impacted from at-sea bycatch risk (Sutherland et al. 2021).

Impact of genetic population studies on Southern DPS boundary delineation

The 2010 BRT considered whether the available genetic data (McLean et al. 1999, McLean and Taylor 2001, Beacham et al. 2005) provided any evidence for “markedly different” populations, but concluded that, although the genetic data provide evidence for discreteness (lack of gene flow), there was little evidence to support the existence of deep intraspecific phylogenetic breaks that the 2010 BRT believed were necessary to be considered “marked.” However, support for both a discrete and a significant eulachon population south of the Nass River/Dixon Entrance was provided by evidence that eulachon in this southern area are “markedly separated on the basis of ecological and physiological features” from eulachon to the north (Gustafson et al. 2010).

Candy et al. (2015) invoked both meristic (vertebral counts) and genetic (SNP and microsatellite DNA data) information to bring into question the 2010 BRT’s majority opinion that the northern boundary of the Southern DPS of eulachon extends to the Skeena River. Candy et al. (2015, p. 11) stated that “the data suggested that the southern distinct population segment… extends only as far north as the Fraser River, instead of possibly the Nass River as proposed by Gustafson et al. (2012).” Firstly, meristic data in the form of differences in average vertebral counts of eulachon among river systems were considered largely uninformative, for purposes of determining discreteness and significance, by the 2010 BRT. As Levesque and Therriault (2011, p. 5) stated: “…meristic series vary as a function of temperature and that variation in vertebral number can be environmentally induced.” At best, these meristic data indicate that eulachon from southern rivers experienced warmer temperatures during development than eulachon developing in more northern rivers, and that complete mixing of northern and southern groups does not occur, as this would overwhelm the differences in the mean vertebral counts. As most vertebrate poikilotherms exhibit similar latitudinal clines in these meristic characters, their similar occurrence in eulachon offers, at best, weak evidence that eulachon in the southern and northern portion of their range are “markedly separated” from one another. Secondly, the pattern and level of genetic differentiation of eulachon displayed in Candy et al. (2015) and Sutherland et al. (2021) were similar to those reviewed by the 2010 BRT based on the Beacham et al. (2005) study. The 2010 BRT did not believe that the then-available genetic data provided evidence that eulachon in the Fraser and Columbia Rivers were “markedly separated” from other populations, as required by the joint U.S. Fish and Wildlife and National Marine Fisheries Service DPS policy (USOFR 1996). It should be emphasized that the discreteness and significance criteria define a DPS, which is likely to be composed of many stocks, and these criteria incorporate evidence of discreteness and significance for many factors, not just genetic differentiation.

The 2010 BRT was concerned that Beacham et al. (2005) compared microsatellite DNA variation of samples between the Fraser and Columbia Rivers taken in only a single year, and, thus, that the temporal stability of genetic variation observed between these two rivers could not be adequately assessed. Nevertheless, after review of the Beacham et al. (2005) study, the 2010 status review (Gustafson et al. 2010, p. 64) stated that “there appears to be little doubt that there is some genetic structure within eulachon and that the most obvious genetic break appears to occur in southern British Columbia north of the Fraser River.” The studies of Candy et al. (2015) and Sutherland et al. (2021) verify these results with a new class of genetic markers (i.e., SNPs). In the case of Sutherland et al. (2021), additional sample populations (Klamath, Sandy, Wannock, Kitimat, and Unuk Rivers) and more temporal sampling (Fraser, Kingcome, Bella Coola, Skeena, and Nass Rivers) have expanded the baseline. The genetic analyses of Candy et al. (2015) and Sutherland et al. (2021), with essentially parallel eulachon population structure results to those of Beacham et al. (2005), would not be expected to change the consensus opinion of the BRT as to the northern boundary of the Southern DPS of eulachon.

Recent Information on Status of Eulachon North of the Southern DPS

IUCN species-wide assessment of eulachon

The International Union for Conservation of Nature (IUCN) published a range-wide (from Monterey Bay, California, to Nushagak River and Pribilof Islands, Bering Sea, Alaska) assessment of eulachon[2] for potential inclusion on its Red List of threatened species in March 2013. IUCN concluded that, based on the IUCN criteria, eulachon would qualify to be:

> Listed as Least Concern in view of the large extent of occurrence, large number of subpopulations, and large population size. Trend over the past 10 years or three generations is uncertain; species may be declining but probably not fast enough to qualify for any of the threatened categories under Criterion A (reduction in population size).

Nass and Skeena Rivers, British Columbia

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) designated the northern British Columbia Nass/Skeena Rivers eulachon population as Threatened in May 2011 (COSEWIC 2011). The status of this population was re-examined in 2013 and the designation was changed to Special Concern (COSEWIC 2013). According to COSEWIC (2013):

> Recent information from this area indicates the population appears stable and threats in the freshwater environment are considered to be small. However, the abundance of the species in adjacent areas has declined substantially in the recent past. The causes of these declines are poorly understood and are likely to be due to threats in both the spawning habitat and the marine environment. Threats in the marine environment would also affect the Nass and Skeena rivers population. This population could become Threatened in a relatively short period of time if marine survival deteriorates or threats in the spawning area increase. (p. viii)

Alaska

Gulf of Alaska

NMFS's Alaska Fisheries Science Center (AFSC) prepares a biennial report on the status of forage species in odd years in the Gulf of Alaska (GOA). This "report relies mainly on data from the odd-year bottom trawl surveys in the GOA as well as acoustic-survey results" (Ormseth 2020, p. 1); however, "because they lack swim bladders, eulachon are not detected

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[2] https://www.iucnredlist.org/species/202415/18236183

in acoustic surveys" (Ormseth 2020, p. 7). The bottom trawl surveys do not sample the water column where many forage fish are present; however, eulachon occur closer to the seafloor than other forage fish, "so the bottom trawl surveys are a more reliable sampler of this species" (Ormseth 2020, p. 6). Estimates of eulachon biomass in the GOA have ranged from a low in 1983 of about 7,100 mt to a high of 113,480 mt in 2013, and were most recently estimated at 34,500 mt in 2019 (Figure 3; Ormseth 2020). According to Ormseth (2020):

> …the bottom trawl biomass estimate for eulachon fluctuates, with particular years producing especially high estimates… The FO [frequency of occurrence in hauls] of eulachon is more consistent, ranging from 19% to 40%.[3] As the FO data suggest, eulachon are found throughout the GOA survey area, but the highest CPUEs are observed in the central GOA, particularly in the vicinity of Shelikof Strait [between Kodiak Island and the mainland of the Alaska Peninsula]. (p. 7)

Significant levels of eulachon bycatch have occurred in the central GOA, mostly in trawl fisheries targeting walleye pollock (*Theragra chalcogramma*; Ormseth 2020). Estimated bycatch of combined eulachon and "other osmerids," which are likely made up mostly of

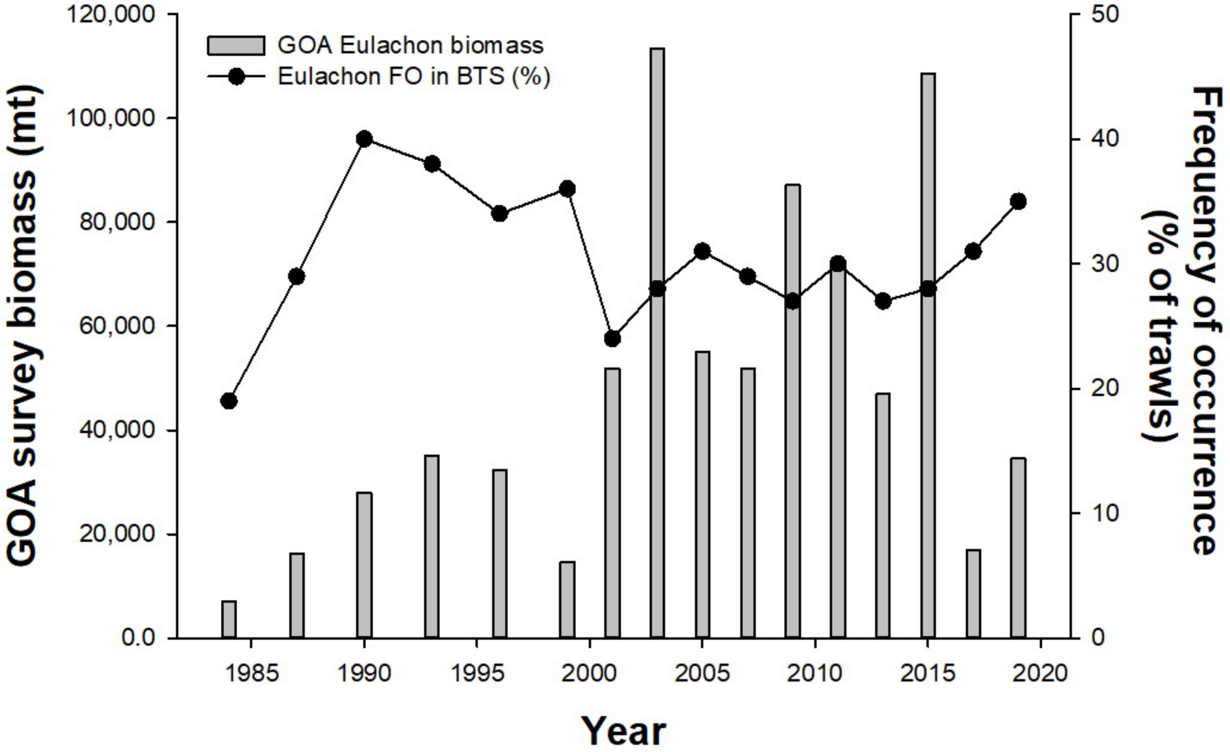

Figure 3. Gulf of Alaska (GOA) eulachon biomass and frequency of occurrence (FO) in tows in the AFSC Bottom Trawl Survey (BTS), 1985–2019. Eulachon in the GOA are not part of the Southern DPS of eulachon.

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[3] See Figure 3.

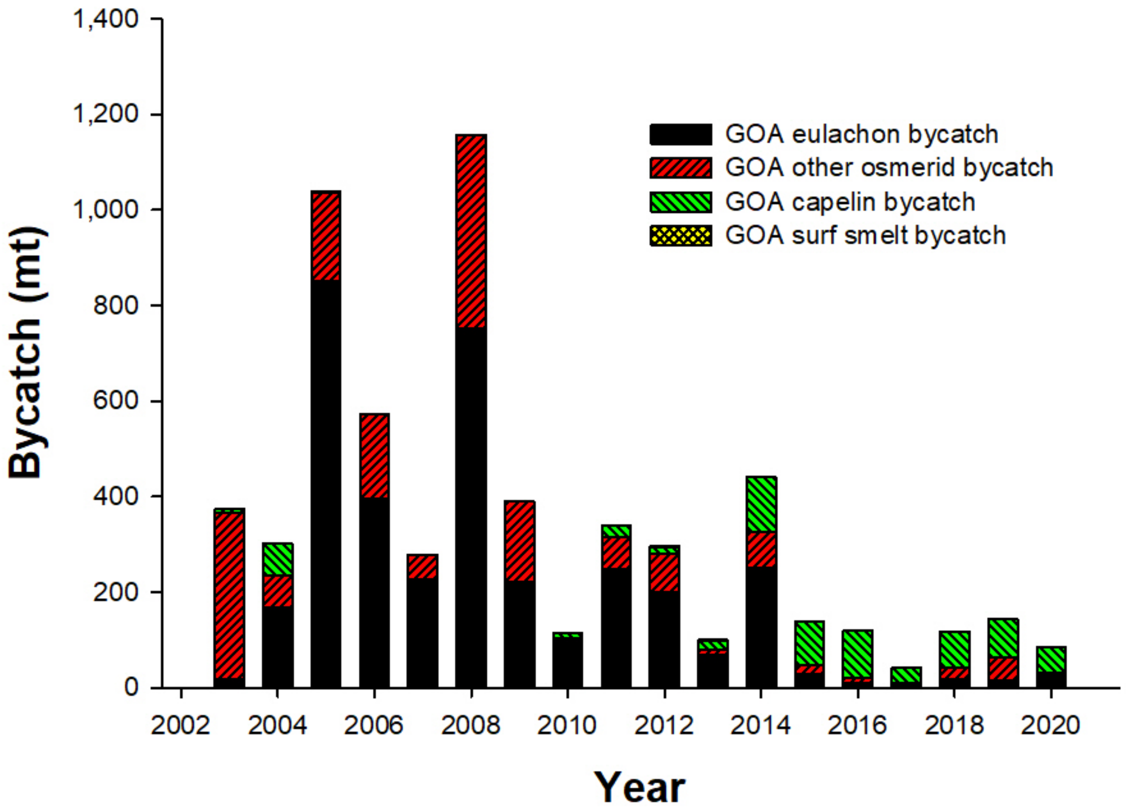

Figure 4. Eulachon and osmerid bycatch in Gulf of Alaska (GOA) walleye pollock fishery, 2003–20. Surf smelt bycatch occurs in most years, but is never more than 2.5 mt and is therefore too small to be visible in this figure. Eulachon in the GOA are not part of the Southern DPS of eulachon.

eulachon in the GOA, has ranged from well over 1,000 mt in 2005 and 2008 to under 10 mt in 2017. Combined bycatch of eulachon and "other osmerids" was 63 mt in the GOA in the latest year available, 2019 (Figure 4; Ormseth 2020). According to Ormseth (2020):

> Prior to 2005, species identification by observers was unreliable and many smelt catches were recorded as "other osmerid." While identification has improved since then, smelts in catches are often too damaged for accurate identification and much of the catch is still reported as "other osmerid," so catch reporting here is based on an aggregate osmerid group containing eulachon, capelin [*Mallotus villosus*], surf smelt [*Hypomesus pretiosus*] and "other osmerids"…. Eulachon are the most abundant osmerid in catches, and it is likely that they make up the majority of the "other osmerid" catch. Since 2014, osmerid catches have been well below the 2003–20 mean catch of 336.3 t. Most of the osmerid bycatch occurs in the central GOA, although high-catch years in the central GOA are matched by higher catches [in western and eastern GOA]. (p. 7)

Southeastern Alaska

The Alaska Department of Fish and Game (ADFG 2021, p. 1) reported: "Eulachon smelt spawning runs in the southern portions of Southeast Alaska have had large fluctuations in recent years and continue to show poor returns to many areas with traditional runs of eulachon smelt." In 2021, ADFG closed commercial, personal use, and subsistence eulachon smelt fishing in all waters in Districts 1 (near Ketchikan and Revillagigedo Island, including Unuk River) and 7 (including Bradfield River), and commercial eulachon fishing, but not subsistence fishing, in District 8 (ADFG 2021). Portions of District 1 have been closed since 2005 following collapse of local eulachon populations in 2004 (USDOI 2021). Although federal public waters that flow into ADFG District 1 were closed in 2020 due to anticipated low eulachon returns, the Ketchikan Misty Fjords District Ranger, under authority delegated by the Federal Subsistence Board, opened the Unuk River to the taking of eulachon for subsistence harvest from 1 March to 29 April 2021 (USDOI 2021). Other federal waters in District 1 were closed to eulachon fishing in 2021. According to USDOI (2021):

> Harvest within waters of the Unuk River drainage shall be limited to one five-gallon bucket of whole eulachon per household, and gear is restricted to dip nets and/or cast nets…. Though eulachon appear to be returning to the Unuk River regularly since 2011, the stock sizes within District 1 remain lower than observations prior to the 2004 population collapse. Managers feel that allowing a limited harvest at this time will aid in our efforts to obtain biological data and better assess run sizes, as well as provide federally qualified subsistence users an opportunity to harvest. (pp. 1–2)

Susitna River

The Alaska Department of Fish and Wildlife assessed eulachon SSB in the Susitna River in 2016 (ADFG 2017). The Susitna River flows south into Upper Cook Inlet in south-central Alaska. Eulachon in this river "are targeted by endangered beluga whales and by small-scale commercial and subsistence fishers" (Ormseth 2020, p. 7). Total eulachon SSB was estimated at 48,000 mt (95% confidence interval [CI]: 29,000–127,000 mt) based on larval densities and stream discharge below the confluence of the Yentna and Susitna Rivers from 12 May to 6 July. Other parameters that factored into this estimate were total larval number, estimated egg to larval survival, mean fecundity, mean adult body weight of females, sex ratio, and mean adult body weight of males. The current allowable commercial harvest in Cook Inlet is 100 mt, most of which is taken in the lower Susitna River (Willette and DeCino 2016). Harvest in 2016 was 90.7 mt and the 2016 harvest rate was estimated at "approximately 0.2% (95% CI: 0.1%–0.3%)" (ADFG 2017, p. 1). To the best of our knowledge, the Susitna River eulachon SSB survey has not been repeated.

Updated Status of the Southern DPS of Eulachon

Information on status of eulachon in Canada

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) reviewed the status of eulachon in British Columbia in April 2011 and grouped eulachon populations into three "Designatable Units" (DU) based on their criteria for discreteness and evolutionary significance: 1) Fraser River DU, 2) Central Pacific Coast DU (including all rivers between the Fraser and Skeena Rivers), and 3) Nass/Skeena DU (including the Nass and Skeena Rivers). In May 2011, the Fraser River and Central Pacific Coast DUs were both assessed as endangered and the Nass/Skeena DU was originally assessed as threatened (COSEWIC 2011). COSEWIC reassessed the status of the Nass/Skeena DU as "Special Concern" in May 2013 (COSEWIC 2013). The Fraser River and Central Pacific Coast DUs remain under consideration for listing as endangered under Canada's Species at Risk Act (SARA).

In 2012, DFO published a final version of a Recovery Potential Assessment (RPA) for the three DUs of eulachon in Canada (Levesque and Therriault 2011, Schweigert et al. 2012). Schweigert et al. (2012) stated:

> A lack of consistent long term indices of population abundance made it extremely difficult to determine the recovery potential for these DUs. Indices of in-river abundance were summarized for each DU and examined in relation to time series of putative threats in freshwater and marine environments, at both coastwide and localized scales. No single threat could be identified as most probable for the observed decline in abundances among DUs or in limiting recovery. However, mortality associated with coastwide changes in climate, fishing (direct and bycatch) and marine predation were considered to be greater threats at the DU level, than changes in habitat or predation within spawning rivers. (p. vi)

A summary document of the initial RPA proceedings review of Levesque and Therriault (2011) has been published since the 2016 status review (MacConnachie 2017).

Yearly document sections summarizing status and trends for eulachon in British Columbia have appeared from 2013–20 (McCarter et al. 2014, Boldt et al. 2015, MacConnachie et al. 2016b, 2017, Flostrand et al. 2018, Flostrand 2019, 2020) as part of the annual DFO publication entitled *State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems* (Perry 2014, Chandler et al. 2015, 2016, 2017, 2018, Boldt et al. 2019, 2020b). The latest of these yearly summaries, Flostrand (2020, p. 69) provided these highlights for 2019:

- In 2019, the index of eulachon spawning stock biomass in the Fraser River was estimated to be relatively low (~108 tonnes), similar to or higher than most years from 2004–2017 but lower than estimates for 2015 and 2018.
- Mean eulachon catch per unit effort estimates from an annual spring west coast of Vancouver Island multispecies bottom trawl survey show a moderate increase in 2019 from relatively low levels in 2016 to 2018.

- In the 2019 spring multispecies bottom trawl survey, eulachon standard lengths appeared to have a bi-modal distribution.

In addition, Flostrand (2020, p. 69) stated:

> There are uncertainties associated with the ecology and biology of eulachon stocks as well as the factors affecting eulachon recruitment and survival. For example, it is uncertain what age range comprises the spawning stock each year, the composition of ages by cohort group, and to what degree spawning stocks and cohorts may mix on the spawning grounds and in different areas and seasons of the marine environment.

Ocean surveys of the Southern DPS in Canada

WCVI and QCS small mesh trawl surveys

Fisheries and Oceans Canada no longer uses the west coast Vancouver Island (WCVI) and Queen Charlotte Sound (QCS) multispecies small mesh trawl surveys to calculate biomass indices of juvenile eulachon (Schweigert et al. 2012). However, fishery-independent shrimp surveys are still being conducted each May off WCVI, and CPUE data for eulachon from this survey are available (Flostrand 2020). These trawl surveys were originally designed to survey shrimp populations and they use a randomized design to assign sampling stations in a number of offshore Shrimp Management Areas (SMAs) off WCVI (1972–2019) and in Queen Charlotte Sound (1998–2012, 2016), British Columbia. Eulachon are often taken as bycatch in these surveys. Both the WCVI and QCS indices provided information on pre-spawning juvenile eulachon biomass derived from two to four broodyears at sea. As stated in Schweigert et al. (2012):

> The multispecies small mesh surveys have been conducted consistently with DFO research vessels using a small mesh otter trawl net towed along the bottom with a target duration of 30 min at a depth range of 50–200 m. The surveys are conducted in April to May within the west coast of Vancouver Island (WCVI) region and Central Coast region and in September in the North Coast region (restricted to Chatham Sound)…. The surveys capture eulachon of all age groups although very few young-of-the-year are captured during the spring survey. Usually two distinct size modes are present…. These surveys began in 1973 in the WCVI region, but did not begin until 1998 and 1999 in the North Coast and Central Coast regions, respectively. (p. 3)

Analysis of eulachon data from these multispecies small-mesh bottom trawl surveys showed that the spatial distribution and density of eulachon could vary on an annual basis off WCVI (Hay et al. 1997). Significant mortality likely occurs between when these trawl surveys take place and when adult eulachon return to rivers to spawn, 9–11 months and 18–22 months for the older and younger cohorts, respectively. Perry et al. (2019, 2020) examined biomass anomalies for eulachon and other species in the WCVI small-mesh multispecies bottom trawl surveys. These data consist of “the total biomass over the survey area and are presented as standardised (by the standard deviation) $\log_{10}$-scaled species anomalies from the climatological period 1981–2010" (Perry et al. 2019, p. 85). These data include biomass anomalies of ocean shrimp and several fish species incidentally caught in these surveys, including eulachon from 1973–2019 (Perry et al. 2020, p. 99, their Figure 23-3). According to Perry et al. (2020):

> The survey in May 2019 shows the biomass of *Pandalus jordani* shrimp off central Vancouver Island continued to decline from the record high level observed in 2014, and was now a substantial negative anomaly (although slightly higher than in 2018…). Only three other taxa had negative or near zero biomass anomalies in recent years: lingcod, eulachon, and sea cucumber. (p. 99)

Although biomass indices of juvenile eulachon are no longer being calculated from the WCVI multispecies small mesh survey, this DFO fishery-independent survey is still being conducted each April–May as described above, and CPUE data for eulachon from this survey are calculated. Eulachon CPUE data are available for an aggregate of all WCVI shrimp SMAs (Figure 5). These areas are known as Nootka Grounds (Area 125), Tofino Grounds (Area 124), and Barkley Sound Grounds (Areas 121–123; Perry et al. 2015). All CPUE values were standardized to kilograms of eulachon captured per hour of tow effort (kg/h; Figure 5). In general, high mean CPUE (>100 kg eulachon per hour) occurred during 2001–03 and again from 2013–15 (Figure 5). The highest mean CPUE for eulachon in these surveys across all WCVI SMAs surveyed occurred during 2013, 2014, and 2015, reaching means of 232, 193, and 218 kg of eulachon per hour of tow, respectively (Figure 5). Mean eulachon CPUE across SMAs off WCVI dropped each year from 2016 to 2018, with a low point of about 10 kg/h in 2018 (Figure 5). CPUE rose in 2019 to about 58 kg/h. Flostrand (2020) stated:

> In 2019, the mean eulachon catch per unit effort (CPUE) from the spring WCVI multispecies trawl survey showed a moderate increase in 2019 from relatively low levels in 2016 to 2018. In the 2019 spring multispecies bottom trawl survey, eulachon standard lengths appeared to have a bi-modal distribution with peaks within the ranges of 9–11 cm and 14–17 cm.[4] (p. 70)

Unfortunately, the WCVI multispecies small-mesh survey did not occur in 2020 due to COVID-19 pandemic restrictions on field work. In 2021, the WCVI mean eulachon CPUE across SMAs was about 128 kg of eulachon per hour of tow, the highest it had been since 2016 (Figure 5).

According to DFO (2021b):

> When otter trawl effort shifted to Queen Charlotte Sound (SMA QCSND) in 1996, and observations in 1997 and 1998 showed significant eulachon bycatch, QCSND was closed in 1999 and has remained closed to shrimp trawl.

Calculation of eulachon biomass indices of juvenile eulachon in QCS and off WCVI were discontinued in 2013 due to concerns raised in Schweigert et al. (2012) that the marine biomass indices may have been misleading (DFO 2021a).

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[4] See Figures 2 and 5.

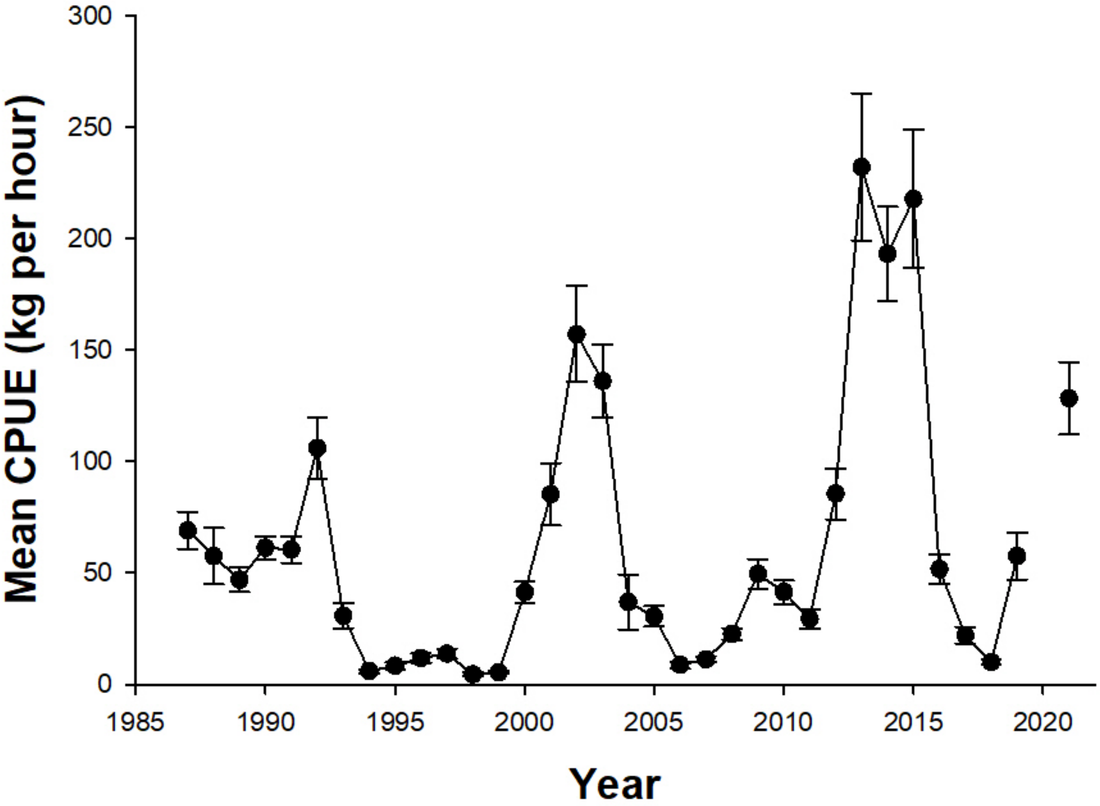

Figure 5. Total mean (± standard error) CPUE (kg/h) of eulachon across all surveyed SMAs off WCVI, 1987–2021. CPUE is based on bycatch of eulachon in multispecies small mesh bottom trawl surveys offshore of WCVI. Data for 2020 are unavailable due to fieldwork restrictions during the COVID-19 pandemic. Data from S. MacConnachie, V. Hodes, and L. Flostrand (DFO, personal communication).

WCVI pelagic ecosystem night trawl survey

Flostrand et al. (2015, p. 93) reported on results of a night-time pelagic trawl survey "used to monitor trends in distribution and relative abundance of pelagic fish species" that has been conducted from 5–15 August off the west coast of Vancouver Island since 2006 (no survey occurred in 2007). Results of the survey for eulachon are reported as mean (± standard error [SE]) CPUE (kg/m^3 or mt/km^3), and as the proportion of positive tows containing eulachon. Flostrand et al. (2015, p. 95) stated: "Eulachon mean CPUE and proportion of positive tows was slightly higher in 2014 compared to previous years." Interpretation of graphical data in Flostrand et al. (2015, their Figure 20-4C) indicates that mean eulachon CPUE (mt/km^3) and percent positive tows increased from about 0.5 mt/km^3 and 20% in 2013 to about 2.0 mt/km^3 and over 40% in 2014, respectively. As Flostrand et al. (2015, p. 97) emphasized: "Eulachon… exhibit both demersal and pelagic behaviour and may not be well sampled by the surface trawl; therefore survey observations for [eulachon]… may be less indicative of actual population dynamics." Although this survey was scheduled to reoccur in 2016 (Flostrand et al. 2015), we have not found descriptions of more recent nighttime pelagic trawl surveys.

September 2015 shrimp trawl survey in Chatham Sound, British Columbia

MacConnachie et al. (2016a) described results of eulachon sampling in a shrimp trawl survey that occurred in Chatham Sound from 13–18 September 2015. All 42 20-minute tows contained some eulachon, ranging in total weight from less than 1 kg to 69 kg. Eulachon lengths were taken from tows containing 50 or more eulachon and a total of 210 fish were sampled for genetic analyzes (MacConnachie et al. 2016a). Eulachon made up nearly 12.5% of the total catch of all species, and analysis of length frequencies indicates a distinct "bimodal size distribution suggesting two cohorts, most likely age-1+ and age-2+ fish based on length" (MacConnachie et al. 2016a, p. 2). Genetic assignments of the 210 eulachon samples based on 14 microsatellite loci suggested that "45.6% of the sampled fish… [originated] from the Nass/Skeena systems and 45.6% from the Central Coast," with the Columbia River contributing 8.2% and only 0.6% assigning to the Fraser River (MacConnachie et al. 2016a, p. 3).

The shrimp trawl net used in this survey was equipped with "a Nordmore separator grate (a fish exclusion device) to emulate the behaviour of the commercial shrimp trawl fishery" (MacConnachie et al. 2016a, p. 1). Nevertheless, MacConnachie et al. (2016a) calculated the CPUE from the survey catch as kg/hr. Presumably, some unknown proportion of eulachon escaped capture during this survey via the Nordmore bycatch reduction device. These CPUE data (1998–2015) were graphically presented as a relative index of abundance. The 2015 CPUE data were characterized as "slightly higher than the earlier years of the time series, but well below the peak of 2009 and 2011" (MacConnachie et al. 2016a, p. 11).

Ocean surveys of the Southern DPS in the United States

West Coast Bottom Trawl Survey (WCBTS)

Starting in 2003, NWFSC's Fishery Resource Analysis and Monitoring (FRAM) Division began combined slope and shelf surveys for groundfish off the U.S. West Coast between the U.S.–Canada border at Cape Flattery, Washington, and the U.S.–Mexico border (Bradburn et al. 2011, Keller et al. 2012). Bottom trawls are fished during the daytime at a nominal tow duration of 15 minutes on the bottom at 4.0 km/h, mainly from late May to late July (early cruise) and again from late August to late October (late cruise). This West Coast Bottom Trawl Survey (WCBTS) is based on a random-grid design, covering the coastal waters at depths of 55–1,280 m. This design uses four industry chartered vessels per year, assigned to a roughly equal number of randomly selected grid cells, and is divided into two "passes" of the coast, which "start operations from Newport, Oregon, heading north to Cape Flattery, Washington, and progress south along the coast, finishing south of San Diego, California" (Bradburn et al. 2011, p. 3).

These groundfish surveys are designed to sample bottom-dwelling species and to sample only over trawlable bottom topography; therefore, they only capture a portion of the whole water column's distribution of eulachon. In addition, the questionable effectiveness of bottom trawls with large mesh nets in catching near-bottom or midwater schooling eulachon limits the usefulness of bottom trawl surveys to assess the eulachon population. It is thus uncertain how an index created from this survey relates to the actual abundance;

however, the trends in this index may be informative. Ward et al. (2015) applied the spatiotemporal tools (delta-generalized linear models with spatial random field) that are used to generate indices of groundfish abundance for stock assessment purposes to an estimated relative biomass index of eulachon derived from the WCBTS for years 2003–13. These data showed an increasing temporal trend in eulachon from 2010–13 (Ward et al. 2015), consistent with other abundance data sources summarized in this document.

Total yearly eulachon catch as weight and numbers in the WCBTS were relatively low from 2003–11 (less than 15 kg and under 350 individual fish; Figure 6). From 2012–14, eulachon catch increased dramatically in the WCBTS to a peak of 206 kg and nearly 6,500 individuals in 2014 (Figure 6). WCBTS eulachon catch was reduced in 2015, but still larger than prior to 2012, at nearly 73 kg and over 4,360 fish. Catch continued to decline in 2016 to about 18 kg and 500 fish and in 2017 to about 11 kg and about 275 fish (Figure 6). WCBTS eulachon increased to nearly 24 kg and over 650 fish in 2019 (Figure 6). These directional trends in eulachon catch in the WCBTS were similar to eulachon abundance trends and indices described by the Columbia River SSB, mean CPUE in the WCVI small mesh trawl survey, and Columbia River larval density estimates. The WCBTS did not occur in 2020 due to COVID-19 restrictions on NOAA field work.

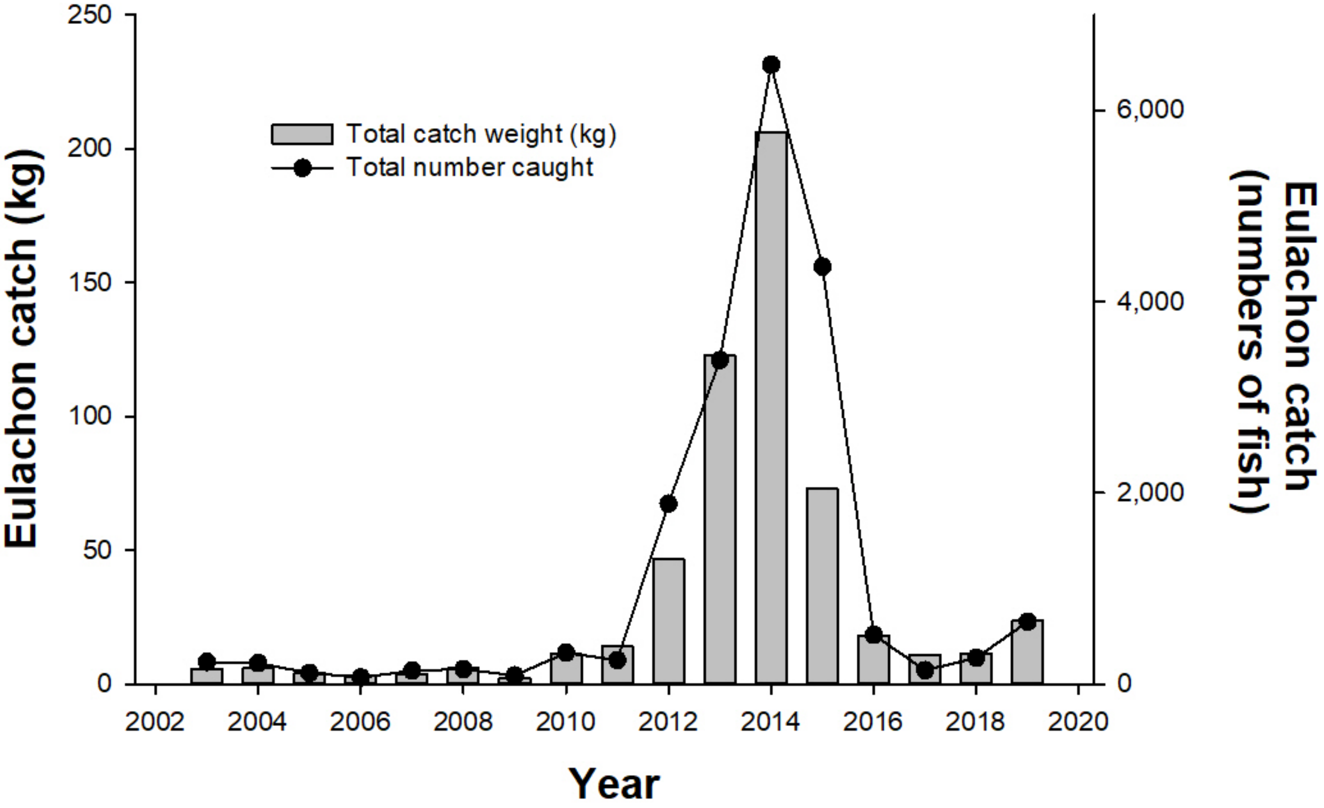

Figure 6. Eulachon incidental catch in the U.S. West Coast Bottom Trawl Survey (WCBTS), 2003–19. Data available on the FRAM Data Warehouse.* The WCBTS was cancelled for 2020 due to the COVID-19 pandemic; data for 2021 have yet to be released.
*https://www.nwfsc.noaa.gov/data/map

Abundance and trends in individual rivers in the Southern DPS

Northern California

The 2010 status review (Gustafson et al. 2010) summarized available information on the status of eulachon in Northern California. Large spawning aggregations of eulachon were reported to have once regularly occurred in the Klamath River (Fry 1979, Moyle et al. 1995, Larson and Belchik 1998, Moyle 2002, Hamilton et al. 2005) and, on occasion, in the Mad River (Moyle et al. 1995, Moyle 2002) and Redwood Creek (Moyle et al. 1995; Figure 1). Small numbers of eulachon have also been reported from the Smith River (Moyle et al. 1995, Moyle 2002).

Klamath River

The 2010 status review (Gustafson et al. 2010) cited numerous sources which reported that large spawning aggregations of eulachon regularly occurred in the Klamath River in the past and on occasion in the Mad River and Redwood Creek in northern California. The 2010 BRT concluded that the available information was most readily interpreted as indicating that noticeable, regularly returning runs of eulachon used to be present in the Klamath River, but had been rare or sporadic for a period of several decades. However, it was noted that they had not been totally absent from this area in recent years. In particular, reports from Yurok Tribe fisheries biologists of a few eulachon being caught incidentally in other fisheries on the Klamath River in 2007 indicated that eulachon still on occasion entered the Klamath River in low numbers.

Since the 2010 status review (Gustafson et al. 2010), there are reports of an estimated seven (McCovey 2011), 40 (McCovey 2012), 112 (McCovey and Walker 2013), and ~1,000 (B. McCovey, Yurok Indian Tribe, personal communication) adult eulachon being sampled by Yurok Tribe biologists in presence/absence surveys using seines and dip nets in the Klamath River in northern California in spring of 2011, 2012, 2013, and 2014, respectively (Gustafson et al. 2016, their Figure 10). Although the Yurok Tribal Fisheries Program has not conducted any official eulachon surveys since 2014, eulachon have been observed in small numbers (no more than two per night, in association with migrating lamprey) at the mouth of the Klamath River every year since then (McCovey, personal communication). In 2020, a single eulachon was seen during night-time lamprey fishing near the mouth of the Klamath River; however, a large run was not observed in 2020 (McCovey, personal communication).

Big, Cummins, and Tenmile Creeks, Oregon

The Oregon Department of Fish and Wildlife (ODFW) collected numerous ichthyoplankton samples from Big Creek ($n = 209$), Cummins Creek ($n = 239$), and Tenmile Creek ($n = 254$) from late December to late April 2014–18 with the intent to produce a eulachon SSB estimation for these coastal Oregon streams (Mallette 2015, Mallette et al. 2018). Eulachon larvae were encountered in only two of the above samples ($n = 702$), both collected in Big Creek on 10 March 2015. Two eulachon larvae were encountered in one sample and seven in the other. Eulachon densities in these samples ranged from 1.06 to 3.93 individuals/m^3

(Mallette 2015, Mallette et al. 2018). An SSB estimate for these streams could not be produced due to lack of eulachon encounters (Mallette et al. 2018). Although larval eulachon were not encountered in Tenmile Creek during 2015–18, adult eulachon were captured in a screw trap in this creek in 2015 (*n* = 26), 2016 (*n* = 1), and 2018 (*n* = 2). Eulachon were not captured in Tenmile Creek in 2017 (Mallette et al. 2018).

Columbia River

The 2010 status review (Gustafson et al. 2010) summarized available information on the status of eulachon in the Columbia River. Adult eulachon spawning occurs in mainstem spawning locations in the Columbia River and on the Cowlitz River (most years). In addition, eulachon are known to spawn in the following lower Columbia River tributaries: Grays River (common use), Skamokawa Creek (infrequent use), Elochoman River (periodic use), Kalama River (common use), Lewis River (common use), and Sandy River (common use in large run years; WDFW and ODFW 2008, Gustafson et al. 2010).

Spawning stock biomass (SSB)

At the time of the 2010 status review (Gustafson et al. 2010), fisheries-independent estimates of SSB of Columbia River eulachon were unavailable. However, since the 2011 run year, WDFW have developed methodologies to provide a yearly retrospective fisheries-independent SSB estimate for Columbia River eulachon, using similar methods to those applied by DFO since 1995 on the Fraser River, to calculate SSB (Hay et al. 2002, James et al. 2014, Langness et al. 2018, 2020a). Since eulachon spawn from November to April in the Columbia River, the spawn year is designated in this document as the year beginning on 1 January. Mean eulachon egg and larval densities (number/m^3) in the Columbia River basin above Grays River are estimated from multiple stationary plankton tows at six stations along a standardized cross-river transect at river kilometer 55 (James et al. 2014, Langness et al. 2018, 2020a). The volume of water (in m^3) filtered through the plankton net is measured with a flowmeter mounted in the mouth of the net. Eulachon egg and larval densities are typically sampled weekly during the tail ends of the outmigration and twice weekly during peak outmigration (James et al. 2014, Langness et al. 2018, 2020a). Plankton net samples are returned to the laboratory and examined using a dissecting microscope for species identification and counting of fish eggs and larvae. Daily estimates of the discharge rate (m^3/day) of the Columbia River are obtained from the U.S. Geological Survey (USGS) stream-gage station located at river kilometer 86.6 (James et al. 2014, Langness et al. 2018, 2020a). The discharge rate and mean egg and larval densities are then used to derive mean daily estimates of larval eulachon plankton outflow from the Columbia River. These plankton outflow data are combined with a mean fecundity of 802.3 eggs/g of female body weight, an assumed egg-to-larval survival of 100%, an assumed sex ratio of 1:1, and a mean fish weight of 40.6 g, to derive SSB and spawner number estimates (James et al. 2014, Langness et al. 2018, 2020a).

Estimates of eulachon SSB and number of spawning fish in the Columbia River basin above Grays River from 2011 to 2021 are presented in Table 1 and Figure 7. Mean SSB increased from about 1,497 mt (95% CI: 916–2,250 mt) in 2011 and 1,451 mt (95% CI: 971–2,050 mt) in 2012 to 4,377 mt (95% CI: 2,581–6,491 mt) in 2013 and 7,257 mt (95% CI: 4,536–10,433 mt) in

Table 1. Estimated SSB, exclusive of fisheries landings, in mt (converted from lb as reported in sources by multiplying by 0.000453592), and equivalent number of adult spawners (as reported in sources) in the Columbia River basin above Grays River, 2011–21. Eulachon spawn from November to April in the Columbia River; however, the spawn year is designated as the year beginning on 1 January. Data as reported in sources listed.

Year	Mean estimated biomass (mt)	Mean estimated number of spawners	Minimum estimated number of spawners	Maximum estimated number of spawners	Source
2011	1,497	36,800,000	17,900,000	69,700,000	James et al. (2014)
2012	1,451	35,700,000	20,000,000	61,400,000	James et al. (2014)
2013	4,377	107,700,000	45,500,000	197,900,000	James et al. (2014)
2014	7,257	180,000,000	80,000,000	320,000,000	James (2014)
2015	5,021	123,582,800	57,525,700	207,570,500	Langness et al. (2018)
2016	2,217	54,556,500	21,654,800	111,991,000	Langness et al. (2018)
2017	744	18,307,100	8,148,600	34,071,100	Langness et al. (2018)
2018	168	4,100,000	1,300,000	9,200,000	Langness et al. (2018)
2019	1,897	46,684,765	19,285,087	89,137,289	Langness et al. (2020a)
2020[a]	1,724	42,560,000	n/a	n/a	JCRMS (2021, 2022)
2021	4,032	100,364,971	34,217,052	198,215,700	JCRMS (2022)

[a] Complete data for 2020 are not available due to COVID-19 pandemic field sampling restrictions. The 2020 estimate for biomass and number of spawning eulachon is derived from twice the estimate of 1,900,000 lb reported in JCRMS (2021, pp. 23–24), which was based on 10 days of truncated larval sampling, and the assumption that there are 11.2 eulachon/lb.

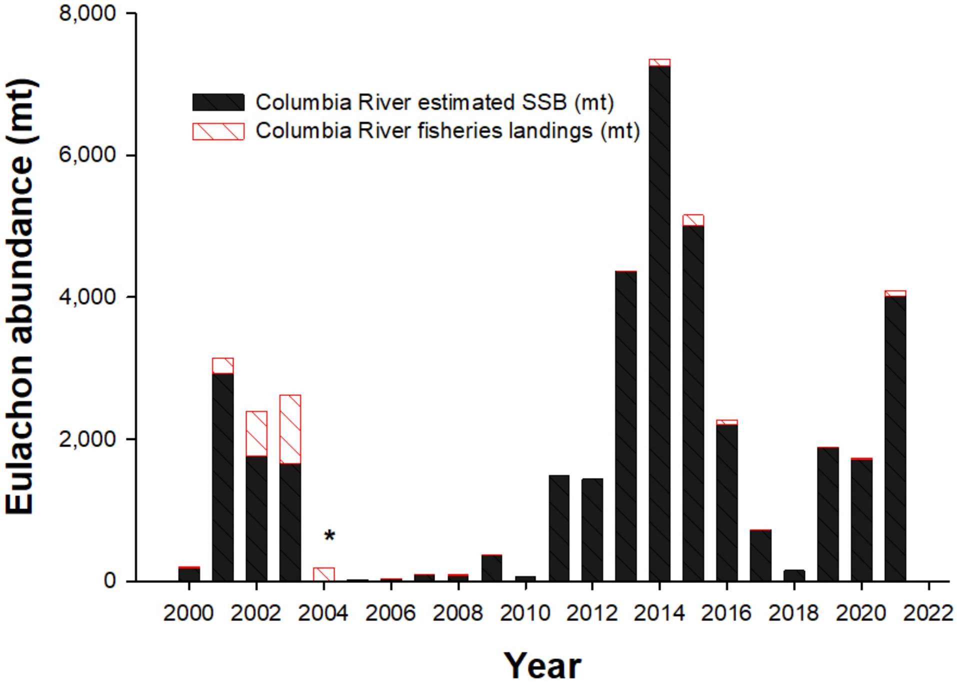

Figure 7. Columbia River eulachon mean estimated SSB and harvest from all fisheries, 2000–21. Commercial catch did not occur in 2011–13 or in 2019, but did occur in 2018; however, landings were too small to be visible on the bar chart. Recreational harvest did not occur in 2006, 2010–13, or 2018–19. Asterisk indicates that a larval survey occurred in 2004; however, SSB data were unavailable and only harvest data are displayed. Complete data for 2020 are not available due to the COVID-19 pandemic and associated field sampling restrictions. The 2020 estimate for biomass is derived from twice the reported minimal estimate of 1,900,000 lb reported in JCRMS (2021, pp. 23–24), which was based on 10 days of truncated larval sampling. Data sources available in Tables 1 and 2.

2014 (James 2014, James et al. 2014). The 2015 Columbia River eulachon SSB was estimated at 5,021 mt (95% CI: 3,225–7,017 mt; Langness 2015, Langness et al. 2018). Estimated Columbia River SSB declined each year from 2015 through 2018 to a low of 168 mt (95% CI: 77–286 mt) in 2018 (Langness et al. 2018). Eulachon SSB increased by an order of magnitude in 2019 to 1,897 mt (95% CI: 1,032–2,910 mt; Langness et al. 2020a; Table 1, Figure 7).

Reliable SSB estimates for Columbia River eulachon in 2020 are not available due to COVID-19 pandemic restrictions on field sampling (Table 1, Figure 7). The ODFW and WDFW joint Columbia River staff report (JCRMS 2021) stated:

> During the spring of 2020, SSB sampling was truncated due to fieldwork restrictions enacted to comply with COVID-19 precautions as mandated by the Governor of Washington (proclamation 20-25). A total of 10 weeks of sampling were completed but a peak in larval density was unable to be determined as count data appeared to still be on the rise at the time of the shutdown. As a result, an estimate of run size based on the limited sampling that occurred is not reliable. Within the truncated sampling season, approximately 1,900,000 pounds of smelt contributed to the annual run. Conservatively, we can assume that the run size was likely twice that of the estimate produced by larval sampling (or approximately 3,800,000 pounds), but that also assumes the progression of the run size was similar before and after the end of sampling. After the field sampling ceased, we received reports of eulachon adults continuing to migrate into the Columbia River system, indicating that spawning likely continued to occur for several weeks after field sampling ceased. With the available information, we can be reasonably confident that smelt abundance was higher than the observed lows of 2017–2018 and either similar to or slightly higher than the run abundance produced for 2019. (pp. 23–24)

In 2021, Columbia River SSB was estimated at 4,032 mt (JCRMS 2022; Table 1). These SSB estimates have been converted into estimated mean numbers of adult spawners (Table 1), using an average eulachon body weight of 40.6 g and the 11.2 fish/lb estimate used in the WDFW SSB calculations (James et al. 2014, Langness et al. 2018, 2020a). Estimated mean number of spawning eulachon in the Columbia River ranged from a low of 4.1 million in 2018 to a high of 180 million in 2014 (James 2014, James et al. 2014, Langness et al. 2018, 2020a; Table 1). Average eulachon SSB and estimated number of adult spawners in the Columbia River over the first five years of this database (2011–15) were 3,921 mt and 96.8 million fish; over the next five years (2016–20), they were 1,350 mt and 33.3 million fish (Table 1). In 2021, mean number of adult eulachon spawners in the Columbia River was estimated at 100.4 million fish (JCRMS 2022; Table 1).

Retrospective Columbia River SSB

Data from the Columbia River eulachon larval density surveys and water discharge rates have been used by WDFW to generate historical SSB estimates for 2000–10 (B. James and O. Langness, WDFW [retired], unpublished data; Table 2, Figure 7). A survey was conducted in 2004; however, detailed daily larval density data for that year are unavailable. Pre-2011 expansions of historical larval densities have been adjusted for the shorter duration of the pre-2011 surveys (James and Langness, unpublished).

Table 2. Estimated eulachon SSB, harvest biomass, and run size biomass (mt) in the Columbia River basin above Grays River, 2000–21. (Eulachon spawn from November to April in the Columbia River; however, the spawn year is designated as the year beginning on 1 January.) Biomass data reported in original sources in lb were converted to mt by multiplying by 0.000453592. Data from James et al. (2014), Langness et al. (2015, 2018, 2020a), Langness (2015), JCRMS (2020, 2021), and James and Langness (unpublished). Recreational fishery landings (2000–10) assumed roughly equal to tributary commercial dipnet landings. Recreational fishery landings for 2014–21 based on field surveys by WDFW.

Year	Mainstem commercial fishery (mt)	Tributary commercial fishery (mt)	Estimated recreational fishery (mt)	Tribal fisheries (mt)	All fisheries total (mt)	Mean SSB[a] (mt)	Total run biomass (mt)	Total number of fish at 11.2/lb	Exploitation rate (%)
2000	14.06	0.00	0.00	n/a	14.06	207.29	221.35	5,465,600	6.4
2001	72.03	69.99	69.99	n/a	212.01	2,938.46	3,150.47	77,790,720	6.7
2002	26.31	300.82	300.82	n/a	627.95	1,774.73	2,402.68	59,326,400	26.1
2003	31.93	461.08	461.08	n/a	954.08	1,675.98	2,630.06	64,940,792	36.3
2004[b]	7.24	98.07	98.07	n/a	203.37	n/a	n/a	n/a	n/a
2005	0.05	0.05	0.05	n/a	0.14	35.33	35.47	875,930	0.4
2006	5.94	0.00	0.00	n/a	5.94	53.39	59.33	1,464,949	10.0
2007	3.21	0.54	0.54	n/a	4.30	111.58	115.89	2,861,454	3.7
2008	5.16	2.68	2.68	n/a	10.51	99.79	110.31	2,723,627	9.5
2009	2.51	5.49	5.49	n/a	13.49	381.24	394.72	9,746,677	3.4
2010	1.64	0.00	0.00	n/a	1.64	80.24	81.88	2,021,869	2.0
2011[c]	n/a	n/a	n/a	n/a	n/a	1,496.85	1,496.85	36,960,000	0.0
2012[c]	n/a	n/a	n/a	n/a	n/a	1,451.50	1,451.50	35,840,000	0.0
2013[c]	n/a	n/a	n/a	3.39	3.39	4,377.17	4,383.94	108,247,328	0.1
2014	8.42	n/a	92.48	3.16	104.06	7,257.48	7,465.59	184,338,739	1.4
2015	7.51	n/a	131.89	4.72	144.11	5,021.27	5,165.38	127,542,419	2.8
2016	2.19	n/a	63.98	3.88	70.05	2,216.66	2,286.71	56,462,918	3.1
2017	2.28	n/a	0.25	0.86	3.38	743.80	747.18	18,449,312	0.5
2018[c]	0.05	n/a	0.00	0.00	0.05	167.83	167.88	4,145,232	<0.1
2019[c]	n/a	n/a	0.00	10.73	10.73	1,896.81	1,907.54	47,100,637	0.6
2020[d]	4.65	n/a	15.89	10.84	31.39	1,723.65	1,755.04	43,334,984	n/a
2021	4.99	n/a	41.39	25.37	71.75	4,032.44	4,104.19	101,339,694	1.7

[a] SSB estimates from 2000–10 were derived after adjustment for the shorter duration (2–8-week sampling period) of the pre-2011 surveys and using historical Columbia River water discharge rates and expansions of historical larval densities (James and Langness, unpublished).

[b] A larval survey was conducted in 2004; however, detailed daily larval density data and SSB for that year are unavailable.

[c] Columbia River basin commercial and recreational fisheries were closed in 2011–13 and 2019.

[d] Complete Columbia River basin SSB data and number of fish data for 2020 are not available due to COVID-19 sampling restrictions. The reported 2020 estimates of SSB and the number of spawners is twice the reported number based on 10 days of truncated larval sampling (see JCRMS 2021).

These data, when combined with historical commercial, recreational, and tribal fishery landings, provide estimates of total run size and fishery exploitation rate of Columbia River eulachon from 2000–21 (Table 2, Figure 7). These estimates are based on the assumption that historical 2000–10 recreational fishery landings were equal to tributary commercial dip-net landings (James and Langness, unpublished). The 2014–17 and 2020–21 recreational fishery landings (Table 2) are based on field surveys by WDFW (JCRMS 2015, 2017, 2018, 2021).

Columbia River run size

Total run size (SSB plus fisheries catch) of Columbia River eulachon averaged over 2,700 mt (~67 million fish) from 2001–03, which coincides with a previous period of high eulachon marine abundance as seen in the WCVI multispecies small mesh trawl surveys (Figure 5). However, from 2005 to 2010, total run size of eulachon averaged about 133 mt (~3.3 million fish), and fewer than one million eulachon were estimated to have returned to the Columbia River in 2005 (Table 2, Figure 7). For comparison, current SSB methodologies have estimated average run size of Columbia River eulachon from 2011–15 at over 3,993 mt (~98.6 million fish; Table 2, Figure 7) and from 2016–20 at about 1,373 mt (~3.4 million fish; Table 2). In 2021, Columbia River mean eulachon run size was estimated at 4,104 mt, which is equivalent to about 101.3 million fish (Table 2).

Uncertainty of egg and larval identifications used in SSB estimates

Attempts by the WDFW genetics laboratory to characterize population structure of eulachon in the Columbia River basin using microsatellite DNA genotypes of putative eulachon larvae revealed that most of the larvae (94 of 95 individuals) in a sample of the "pilot run" (a.k.a. the early winter run) from the Cowlitz River were not eulachon (Small et al. 2018). These samples were most likely larvae of the longfin smelt (*Spirinchus thaleichthys*), another anadromous osmerid smelt species (Small et al. 2018). To date, clear morphological differences between known eulachon larvae and putative longfin smelt larvae have not been identified. It is unknown how significant a problem misidentification of egg and larval samples may pose to the accuracy of eulachon SSB estimates in the Columbia River basin and elsewhere.

Long-term larval density estimates

A eulachon larval sampling program that measures larval densities (larvae/m^3, averaged across stations and depths at selected index sites) was initiated in 1994 for the Cowlitz River and was expanded to include the Kalama River in 1995, the mainstem Columbia River in 1996, the Elochoman and Lewis Rivers in 1997, and the Grays and Sandy Rivers in 1998 (Figures 8 and 9). JCRMS (2013, p. 43) stated: "Inter-annual comparisons of abundance [i.e., larval density] are tentative as sampling has not been systematic from year to year." JCRMS (2014, p. 17) stated: "Beginning in 2003, multiple collections were conducted at the mainstem Columbia River (Price Island and Clifton Channel) site throughout the outmigration season, which provide the data necessary to identify the peak timing and duration of the outmigration from the bulk of the production area."

Average and adjusted (February–April) eulachon larval densities in the mainstem Columbia River increased in 2013 and 2014 and subsequently declined slightly in 2015, reaching levels not seen since 2001 and 2002 (Figure 8). Columbia River larval density declined to low levels in 2017 (2.8 larvae/m^3) and 2018 (1.1 larvae/m^3), but rose to 15.9 and 13.1 larvae/m^3 in 2019 and

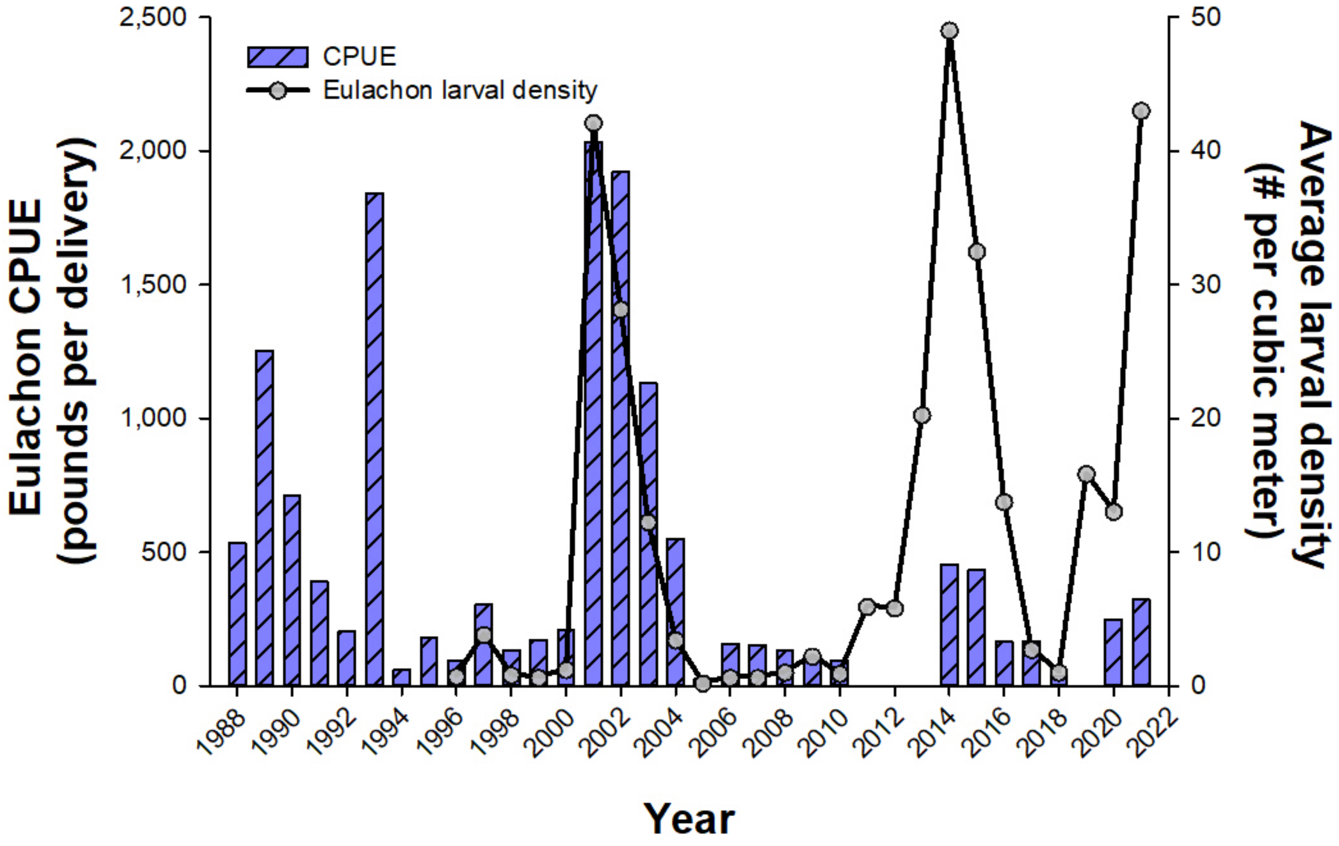

Figure 8. Historical trends in CPUE (lb/delivery) and average larval density in the mainstem Columbia River, 1988–2021. CPUE is lacking for 2011–13 and 2019 due to closure of the commercial fishery. Adjusted density in the mainstem Columbia River from 2011–19 represents average density during February–April for consistency with previous years' methods. Larval density for 2020 represents a 10-week sampling period that was truncated due to COVID-19 early curtailment of field sampling. Data from JCRMS (2014, 2020, 2022). Figure modified from JCRMS (2022, their Figure 3).

2020, respectively. In 2021, eulachon larval densities in the mainstem Columbia River were at the second highest level in the dataset (43.0 larvae/m^3), which began in 1999, only being exceeded by 2014, when larval density was estimated at 49.0 larvae/m^3 (JCRMS 2022; Figure 8).

According to JCRMS (2013):

> For example, 2004–2008 adult returns were poor, despite good larval production during 2000–2003. (p. 20)

Likewise, JCRMS (2021) stated:

> …high larval densities are not necessarily correlated with a strong cohort and subsequently provide little information as to the strength of the returning year class…. Although larval densities will continue to be considered in forecasting run-size estimates, the data here indicate a bottleneck in survival occurs either during the larvae's transition from freshwater to saltwater, or during juvenile rearing in the ocean, prior to their run back to freshwater. (pp. 24–25)

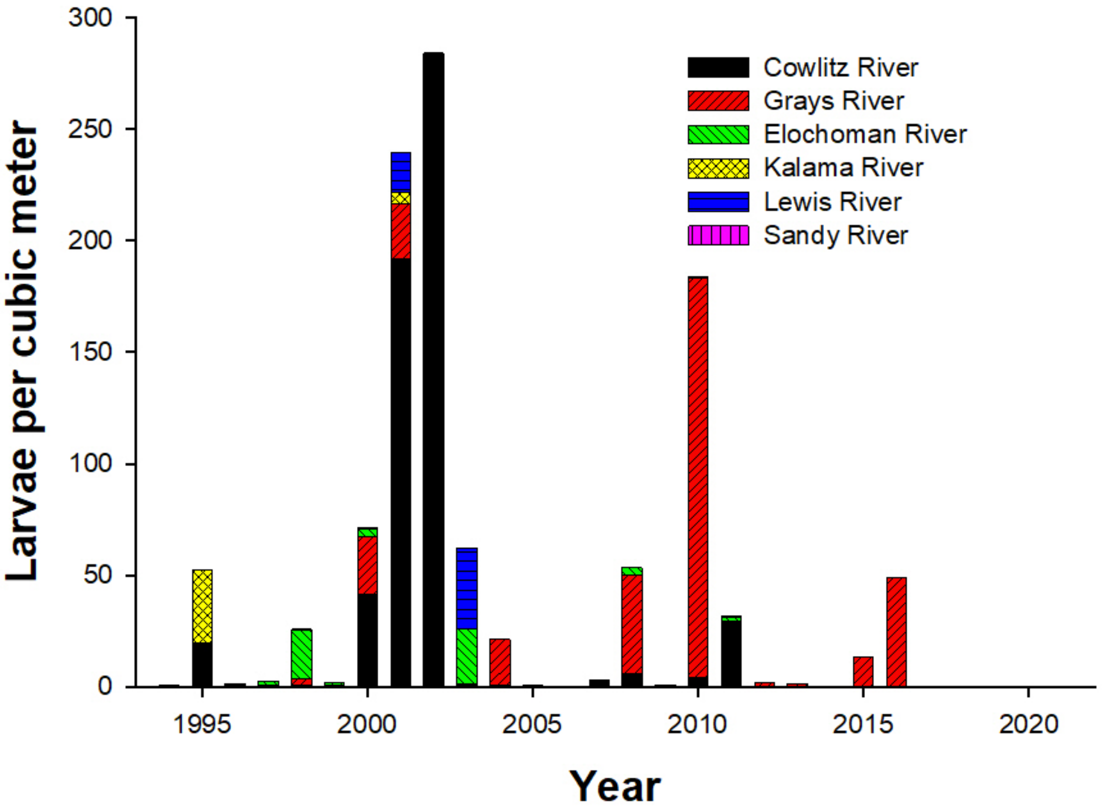

Figure 9. Average eulachon larval density (larvae/m^3) in tributaries to the Columbia River. Interannual comparisons are problematic due to inconsistent effort and methods from year to year. Individual tributaries are not sampled in every year. The last available data were in 2016. Larvae were encountered in the Sandy River in 1998–2000, 2003, and 2011; however, values are too small (0.1 to a trace/m^3) to be evident on the graph. Data from JCRMS (2014, 2021).

WDFW last sampled larval densities in the Cowlitz, Elochoman, Kalama, or Lewis Rivers in 2011 (JCRMS 2021, their Table 21; Figure 9). Average larval density has been observed by the Cowlitz Tribe Natural Resources staff since 2012, but these data are unavailable (JCRMS 2021). Larval density in the Grays River was last estimated in 2016 (JCRMS 2021, their Table 21; Figure 9). Although some larvae were encountered in the Sandy River in 2012, the larval density was not calculated, and additional larval sampling has not occurred since 2012 (JCRMS 2015).

Columbia River CPUE

Historical trends in CPUE (lb/delivery) in the Columbia River commercial eulachon fishery (Figure 8) show similar patterns to both the WCVI small mesh trawl survey juvenile eulachon CPUE (Figure 5) and average eulachon larval density in the Columbia River (Figure 8). Eulachon CPUE increased dramatically in 2001, stayed high in 2002–04, and then dropped to under 200 lb/delivery until the fishery was closed in 2011. No commercial fisheries occurred from 2011–13. Average CPUE in this fishery was approximately 453 lb/delivery in 2014, the highest level since 2004 (Figure 8). However, JCRMS (2014, p. 17) stated: “The modest commercial landings and CPUE… were not consistent with the [high level of] angler success in the sport fishery or with the [high] spawner biomass estimation for 2014.” The commercial fishery CPUE for 2015 was approximately 435 lb/per delivery, only slightly lower than in 2014

(JCRMS 2015, their Table 17; Figure 8). CPUE in the Columbia River commercial fishery in 2016 and 2017 was similar (166 and 167 lb/delivery, respectively), but only about one-third the CPUE levels of 2014 and 2015. In 2018, CPUE (37 lb/delivery) was the lowest since 2005 (when CPUE was 27 lb/delivery), and the Columbia River commercial fishery operated from 1–26 February for two seven-hour periods per week (JCRMS 2019). The commercial fishery was closed in 2019. In 2020, the Columbia River commercial fishery operated during 3–27 February for two 12-hour open periods per week, and CPUE at 250 lb/delivery "was the highest it has been since 2015, and a little over half of the 2014 and 2015 averages" (JCRMS 2021, p. 29). In 2021, the Columbia River commercial fishery operated from 28 January–11 March for two 12-hour open periods per week (Mondays and Thursdays). CPUE came in at 323 lb/delivery, and was "higher than in 2020, and the third highest since 2014" (JCRMS 2022, p. 28; Figure 8).

JCRMS (2021) stated:

> Prior to 2011, annual eulachon larval densities for the mainstem Columbia River site aligned well with the adult CPUE trend from commercial mainstem fisheries…. Strict restrictions imposed on fishing periods during the 2014–2018 commercial fishery altered the fishing effort around the tidal cycle and reduced the relationship between larval density and CPUE. (p. 25)

Grays River

Commercial fishery landings have been recorded since 1936 in the Grays River (Gustafson et al. 2010, their Table 7), and WDFW and ODFW (2008, p. 4) indicated that eulachon "used [Grays River] more frequently than commercial landings would suggest." Because Grays River enters the Columbia River below the mainstem Columbia River SSB index site (Price Island and Clifton Channel), WDFW produced a separate SSB estimate in 2011–13 and 2015–16 for the Grays River (Table S1; James et al. 2014, James 2015, Langness 2015, Langness et al. 2016). Average Grays River SSB from 2011–13 was about 0.6 mt, which represents about 14,500 spawning adults averaged over those three years (Table S1). No SSB estimation was available for the 2014 season in the Grays River due to a funding lapse. Mean eulachon egg and larval production between 11 January and 9 May 2015 was estimated at ~3.0 billion. In 2015, mean SSB was 7.5 mt (Langness 2015, James 2015, Langness et al. 2016), which equates to an estimated 185,400 adult eulachon spawning in the Grays River (Table S1). In 2016, mean Grays River SSB from 3 January to 7 May was estimated at 35.7 mt. This was 4.8 times the 2015 estimate, and representated the equivlent of more than 878,000 adult eulachon. According to Langness et al. (2016, p. 32), Grays River eulachon SSB as a percentage of overall Columbia River SSB ranged from a low of 0.021% in 2011 to a high of 1.58% in 2016. The last Grays River eulachon SSB estimate occurred for the 2016 run year.

Cowlitz River

The Cowlitz Indian Tribe began estimating eulachon spawner abundance in the Cowlitz River in 2015 (N. Reynolds, Cowlitz Indian Tribe, unpublished data).[5] These data are generated from counts of eggs and larvae in ichthyoplankton tows of known water volume in the Cowlitz River (at river kilometer 2), combined with river discharge rates, fecundity

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[5] http://ykfp.org/klickitat/SciCon/SciCon19/ppts/11_Reynolds_Cowlitz_Eulachon_SSB_analysis.pdf

estimates, and estimated sex ratios. The methodology is similar to that applied by DFO since 1995 on the Fraser River, and by WDFW on the Columbia River mainstem since 2011, to calculate SSB. The Cowlitz Indian Tribe spawner estimate uses sex ratios derived from sampling in the Cowlitz River, rather than the assumed 1:1 sex ratio used by DFO and WDFW. Eulachon sex ratios (male:female) specific to the Cowlitz River were determined from adults caught in fyke nets and were 4.33 in 2015 and 3.02 in 2016 (Reynolds, unpublished data).

Abundance of adult eulachon in the Cowlitz River declined >99.9% from over 42 million in 2015 to 310,000 in 2018 (Table S2). A similar dramatic decline in estimated eulachon abundance occurred in the WDFW Columbia River SSB, from a mean of 5,021 mt in 2015 to 168 mt in 2018 (greater than 97% decline; Table 1). The estimated number of eulachon spawners in the Cowlitz River represented 34%, 52%, 16%, and 1% of the total Columbia River basin estimated spawners (Langness et al. 2018) above the Grays River in 2015, 2016, 2017, and 2018, respectively. Cowlitz River spawner abundance data for 2019–21 are unavailable.

The 2010 BRT (Gustafson et al. 2010, p. 41) pointed out that: “Many studies have reported that sex ratios in eulachon are either biased in favor of males or are highly variable depending on time and location of sampling,” and that “All reports of eulachon sex ratio should be viewed with caution, as proportions of male to female eulachon have been reported to vary with fishing gear type, distance upriver, distance from the river shoreline, time of the day, and migration time.” Studies in the Fraser (Hay and McCarter 2000) and Columbia River (Zamon et al. 2021) estuaries have reported sex ratios of 1:1 for eulachon. Use of a 1:1 sex ratio—as adopted by WDFW for mainstem SSB calculations—would significantly reduce estimates of the number of spawning eulachon for 2015–18 in the Cowlitz River.

Naselle River

In 2015–17, WDFW conducted plankton tows in the Naselle River, a tributary of Willapa Bay, to produce a eulachon SSB estimate (Langness 2015, Langness et al. 2018) for this system. Langness et al. (2018) stated:

> Sampling on the Naselle River involved six 1–6 minute plankton tows made at the Naselle River index site located just above the State Highway 401 Bridge … Sampling on the Naselle River occurred once a week during the outmigration period (19 times in 2015, 15 times in 2016, and 12 times in 2017). (p. 20)

Using the same methods described above for estimating the Columbia River SSB, WDFW estimated that mean eulachon egg and larval production in the Naselle River was over 592 million in 2015, and mean estimated SSB amounted to 1.5 mt for the period between 11 January and 23 May 2015 (Table S3; Langness 2015, Langness et al. 2018). An estimated 36,400 eulachon spawned in the Naselle River in 2015 (Table S3; Langness 2015, Langness et al. 2018). Eulachon SSB in the Naselle River was considerably lower in 2016 and 2017, when mean estimates of the number of spawning eulachon were only 600 and 630, respectively (Table S3; Langness et al. 2018). More recent SSB estimates for Naselle River eulachon have not occurred.

Chehalis River

The Quinault Indian Tribe (QIN 2014) sampled for eulachon larvae during 2013 and 2014 in the Chehalis River, a tributary of Grays Harbor, Washington. In 2013 and 2014, 29 and 66 larval eulachon were captured, respectively. Putative eulachon larvae were captured in 5% of samples (19/360) in 2013 and in 9% of samples (34/377) in 2014 (QIN 2014). After normalization of data, QIN (2014) stated:

> …eulachon were present in similar numbers in 2013 and 2014. The mean density of all daytime samples in 2013 was 0.021 larvae/m^3 and in 2014 it was 0.023 larvae/m^3. (p. 24)

In 2015–18, WDFW conducted plankton tows in the Chehalis River to produce a eulachon SSB estimate. This estimate was developed using methods similar to those outlined above for the Columbia River (Langness et al. 2018). Langness et al. (2018) stated:

> Sampling on the Chehalis River index sites involved three plankton tows made at each of two standardized sampling sites…. Sampling… occurred once a week during the outmigration period (20 times in 2015, 18 times in 2016, 16 times in 2016–17, and 4 times in 2018). (p. 20)

The mean eulachon SSB estimates in the Chehalis River in 2015–18 were 11 mt, 28 mt, 8 mt, and 1 mt in 2015, 2016, 2017, and 2018, respectively. At 11.2 fish/lb, these SSB estimates equate to mean numbers of adult spawners of about 272,000, 695,900, 187,300, and 13,400 in 2015, 2016, 2017, and 2018, respectively (Table S4; Langness 2015, Langness et al. 2018). Eulachon abundance was also depressed in the Columbia River in 2018.

Langness et al. (2018) reported on preliminary attempts to detect eulachon eDNA in the Chehalis River and other coastal streams of Washington. Langness et al. (2018) stated:

> Eulachon DNA was identified in the Chehalis, Wishkah and Wynoochee rivers (but not the Satsop River)…. In addition to verifying the presence of eulachon, we detected longfin smelt DNA in the Chehalis and Wishkah rivers, suggesting that some eggs or larvae visually identified as eulachon may actually be longfin smelt. In both the Chehalis and Columbia Rivers, this issue of misidentification is potentially greatest for samples collected early in the season. (p. 29)

Elwha, Lyre, and Dungeness Rivers

Shaffer et al. (2007) reported upon the first formal documentation of eulachon in the Elwha River (58 fish captured from 18 March–28 June 2005). However, anecdotal observations suggested that eulachon "were a regular, predictable feature in the Elwha until the mid-1970s" (Shaffer et al. 2007, p. 80). Small numbers of adult eulachon (usually less than a couple dozen) continued to be captured in the spring during smolt outmigration studies in the mid- to late 2000s (M. McHenry, Lower Elwha Klallam Tribe, personal communication). Over a hundred eulachon were captured in 2012 during two distinct runs, one in January and the other in April (see Gustafson et al. 2016, their Figure 14). During January 2015, hundreds of eulachon were documented in the lower Elwha River during long-term sampling efforts of the lower estuary (A. Shaffer, Coastal Watershed Institute, personal communication).

Shaffer et al. (2017) reported on occurrence of eulachon (and other fishes) in the Elwha River estuary and nearshore environment from January 2008 to November 2015. Although eulachon were present in the Elwha River before the two Elwha River dams were removed, they had not been documented in lower-river side channels or the estuary (Shaffer et al. 2017). However, "eulachon… were observed consistently in the Elwha west estuary… within weeks of initiating dam removal, through dam removal, and post dam removal" (Shaffer et al. 2017, p. 647). They were present "during winter months, primarily in the new habitat and most were gravid, or spent" (Shaffer et al. 2017, p. 647).

Royal (2020, p. 7) reported that the Lower Elwha Klallam Tribe has sampled for eulachon adults and larvae for genetic population studies in the Elwha River, and in the nearby Dungeness and Lyre Rivers, on the north shore of the Olympic Peninsula "using screw traps to capture adults, plankton tow nets to catch larvae, [and] clam guns to collect sediment samples to find eggs…." In 2020, genetic samples (fin clips) were obtained from five adults in the Lyre River, and eulachon larvae were collected in the Elwha (*n* = 25), Dungeness (*n* = 36), and Lyre (*n* = 122) Rivers (R. Paradis, Lower Elwha Klallam Tribe, personal communication).

Fraser River

The 2010 Status Review (Gustafson et al. 2010) summarized available information on the status of eulachon in the Fraser River. Eulachon return on a regular basis to the Fraser River (Figure 1), usually begin to ascend the river at the end of March, and spawning occurs in April until the middle of May (Hay and McCarter 2000, Moody and Pitcher 2010). However, local indigenous knowledge (LFFA 2014, 2015) suggests there may be as many as three separate runs of eulachon in the Fraser River: "an early run near the end of February–beginning of March with smaller fish, followed by a second run in the first week of April with medium sized fish, and lastly a third run at the end of April until about the second week of May with the biggest fish" (LFFA 2014, p. 7). LFFA (2014) stated:

> …the commercial fisheries often focused on the last run of biggest fish…. The only study that DFO undertakes, the egg and larvae study, likely focuses on the later run, missing information for an important component of Fraser River eulachon. (pp. 7–8)

The Fraser River SSB data were derived from the Fraser River Eulachon Egg and Larval Survey, the longest running (since 1995) fisheries-independent abundance estimator of spawning biomass for any river system in the Southern DPS (Table 3, Figure 10). The SSB is generated from counts of eggs and larvae in plankton tows, combined with river discharge rates, fecundity (eggs produced per gram of female eulachon), and an assumed sex ratio of 1:1 to estimate metric tons of spawning adults (Hay et al. 2002, McCarter and Hay 2003). These SSB data are reported both in the yearly Fraser River Eulachon Integrated Fisheries Management Plan (IFMP) and as a yearly section summarizing status and trends for eulachon in British Columbia that has appeared from 2013–20 in the annual

DFO publication, *State of the Physical, Biological and Selected Fishery Resources of Pacific Canadian Marine Ecosystems* (McCarter et al. 2014, Boldt et al. 2015, MacConnachie et al. 2016b, 2017, Flostrand et al. 2018, Flostrand 2019, 2020). The 2021 Fraser River Eulachon IFMP (DFO 2021a) provided the following description of the SSB estimator:

> This survey uses towed, plankton mesh nets to gather samples twice a week from mid-April to early June. The number of eggs and larvae gathered in each tow are counted to calculate density estimates. The density estimates are mathematically integrated to daily mean river discharge water flows to estimate total egg and larvae amounts. The total estimates are then related to a eulachon fecundity estimate (eggs produced per female) to back calculate estimates of SSB by week and to sum across a season. The SSB index is produced in the summer following spawning and provides a relative estimate of how many tonnes of eulachon successfully spawned each year.... Since 2017, there has been exploratory sampling before the start of the standard 7-week

Table 3. Estimated eulachon spawner biomass (mt) in the North and South Arms of the Fraser River and total number of eulachon, assuming a range of 9.9–13.3 eulachon/lb, based on the mean reported weight of eulachon in the Fraser River of 34–46 g. Biomass data based on 7 weeks of egg and larval sampling (DFO 2022).

Year	**South Arm**	**North Arm**	**Total biomass (mt)**	**Total biomass (lb)**	**Number of fish (at 9.9/lb)**	**Number of fish (at 13.3/lb)**
1995	258	44	302	665,796	6,591,381	8,855,087
1996	1,582	329	1,911	4,213,034	41,709,035	56,033,350
1997	57	17	74	163,142	1,615,107	2,169,790
1998	107	29	136	299,829	2,968,304	3,987,721
1999	392	26	418	921,532	9,123,169	12,256,379
2000	76	54	130	286,601	2,837,349	3,811,793
2001	422	187	609	1,342,615	13,291,890	17,856,782
2002	354	140	494	1,089,084	10,781,927	14,484,812
2003	200	66	266	586,430	5,805,653	7,799,514
2004	24	9	33	72,753	720,250	967,609
2005	14	2	16	35,274	349,212	469,144
2006	24	5	29	63,934	632,947	850,323
2007	34	7	41	90,390	894,856	1,202,181
2008	8	2	10	22,046	218,258	293,215
2009	12	2	14	30,865	305,561	410,501
2010	4	<1	4	8,818	87,303	117,286
2011	19	12	31	68,343	676,599	908,966
2012	78	42	120	264,554	2,619,092	3,518,578
2013	59	41	100	220,462	2,182,576	2,932,148
2014	53	13	66	145,505	1,440,500	1,935,218
2015	185	132	317	698,865	6,918,767	9,294,909
2016	32	12	44	97,003	960,334	1,290,145
2017	29	6	35	77,162	763,902	1,026,252
2018	298	110	408	899,486	8,904,912	11,963,164
2019	70	38	108	238,099	2,357,183	3,166,720
2020	404	220	624	1,375,685	13,619,277	18,296,604
2021	64	77	141	310,852	3,077,433	4,134,329

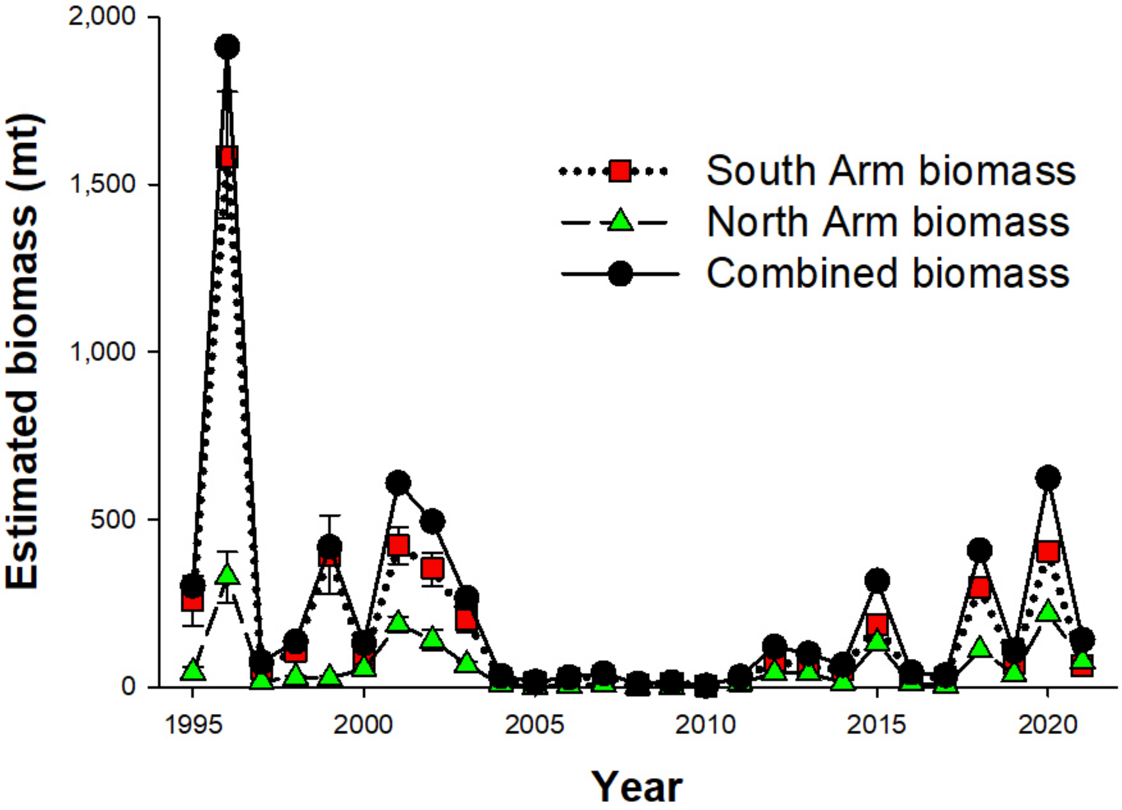

Figure 10. Fraser River eulachon spawning stock biomass (mt), 1995–2021 (estimated from 7-week egg and larval sampling). Data from Table 3 (DFO 2022).

> survey period to monitor whether the timing of peak Fraser River spawning eulachon activity may be shifting to earlier in the spring. In 2017, 2018 and 2019, there was 3 weeks of exploratory sampling (10 weeks of sampling in total). In 2020, instead of 3 weeks, there was 2 weeks of exploratory sampling. A week of sampling had to be canceled to accommodate delays related to COVID-19 operating restrictions; resulting in 9 weeks of sampling. (pp. 20–21)

At the time of the 2016 status review, it was noted that Fraser River eulachon SSB had declined from 1994–2010, increased slightly in 2011 and 2012, but biomass was again reduced in 2013 and 2014 (Boldt et al. 2015). In 2015, the Fraser River eulachon SSB rose to an estimated 317 mt, the first time since 2003 that the Fraser River biomass had been above the eulachon action level of 150 mt (MacConnachie et al. 2016b). Mean SSB for the Fraser River from 2011–15 was 127 mt (range 31–317 mt; Table 3, Figure 10).

Since the 2016 status review, the seven-week combined North and South Arm Fraser River SSB (2016–21) has averaged 227 mt (range 35–624 mt; Table 3, Figure 10; McConnachie et al. 2016b, 2017, Flostrand et al. 2018, Flostrand 2019, 2020, DFO 2022). After the highest SSB in 12 years in 2015 (317 mt), Fraser River SSB declined in 2016 and 2017 by an order of magnitude to 44 and 35 mt, respectively. SSB increased again in 2018 to 408 mt, declined to 108 mt in 2019, but increased in 2020 to 624 mt, its highest level since 1996 (Table 3, Figure 10). An additional three weeks of sampling in 2017, 2018, and 2019 and two weeks of sampling in 2020 added 4, 6, 6, and 4 mt, respectively, to the total SSB for those years

(Flostrand 2020, DFO 2021a). In 2021, sampling again continued over a 10-week period, with Fraser River SSB estimated at 141 mt for the standard seven-week period and 156 mt over the full 10 weeks of sampling (Table 3, Figure 10; DFO 2022).

Adult eulachon in the Fraser River are thought to consist of mainly age-3 fish (Clarke et al. 2007, COSEWIC 2011, McAllister 2012). Assuming only a single age class of 3-year-old spawners exists in the Fraser River, and that strays from other populations are minor, it is then possible to calculate a spawner-to-spawner ratio based on the estimated number of spawners in one year compared to the number of spawners returning to the Fraser River three years later. In the Fraser River, this generic productivity metric can be computed as the mean spawner estimate at year *t* divided by the mean total spawner estimate at year *t* – 3. Although the SSB and the estimated numbers of eulachon in the Fraser River were at very low levels from 2008–10, eulachon three years later in 2011, 2012, and 2013 were, respectively, approximately three times, 8.5 times, and 20 times as abundant as the parent broodyears (Figure 11). In 2014 and 2015, Fraser River eulachon were estimated to be about two times and two and a half times as abundant as the parent broodyears, respectively (Figure 11). Spawner to spawner ratios were much reduced in 2016 (0.44) and 2017 (0.53), but subsequently increased in 2018, 2019, and 2020 when eulachon returns were 1.3, 2.5, and 17.8 times as abundant as the parent broodyears (Figure 11). In 2021, Fraser River eulachon were estimated to be 0.35 times as abundant as the 2018 parent broodyear (again assuming all spawners are age-3 fish).

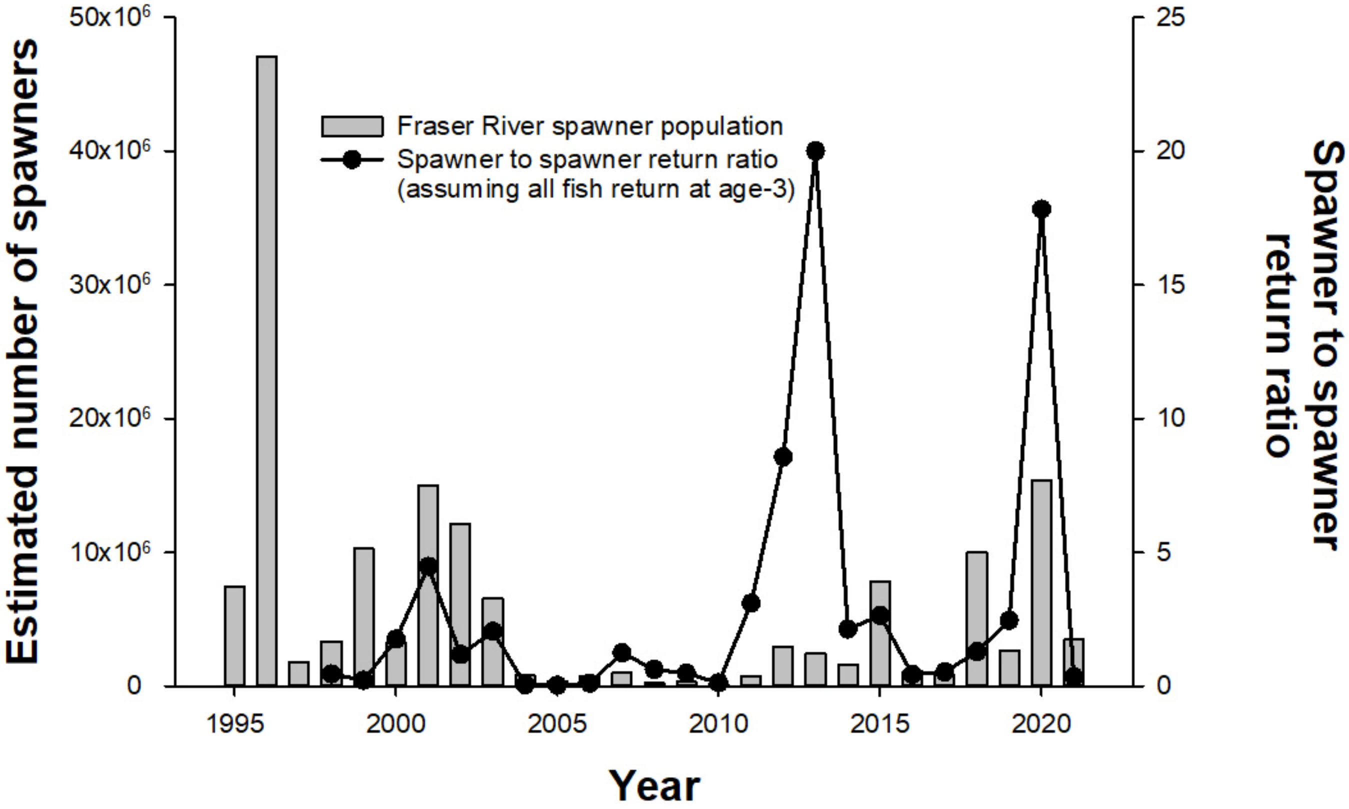

Figure 11. Fraser River estimated number of adult spawning eulachon (based on spawning stock biomass estimates in Table 3 and average weight of 40.6 g/fish), and estimated spawner-to-spawner return ratio, assuming only a single year class of 3-year-old spawners.

Thus, in spite of historically low SSB in the Fraser River, eulachon in this river have recently exhibited high productivity—again assuming minimal straying and all age-3 fish—likely in response to favorable rearing conditions both in the Strait of Georgia and over the nearshore continental shelf. At present, it is not possible to postulate similar spawner-to-spawner ratios for the Columbia River because eulachon returning to this river system apparently represent multiple year classes and no current validated age structure analyses have been applied to these recent broodyears in the Columbia River. From 2000–21, the ratio of Fraser River (based on the seven-week sampling period) to Columbia River eulachon SSB averaged 0.27, with a range of 0.01–2.4. Prior to 2018, the highest ratio of these two stocks had been 0.59 in 2000. In 2018, eulachon were 2.4 times more abundant in the Fraser River than in the Columbia River (Tables 2 and 3, Figure 12).

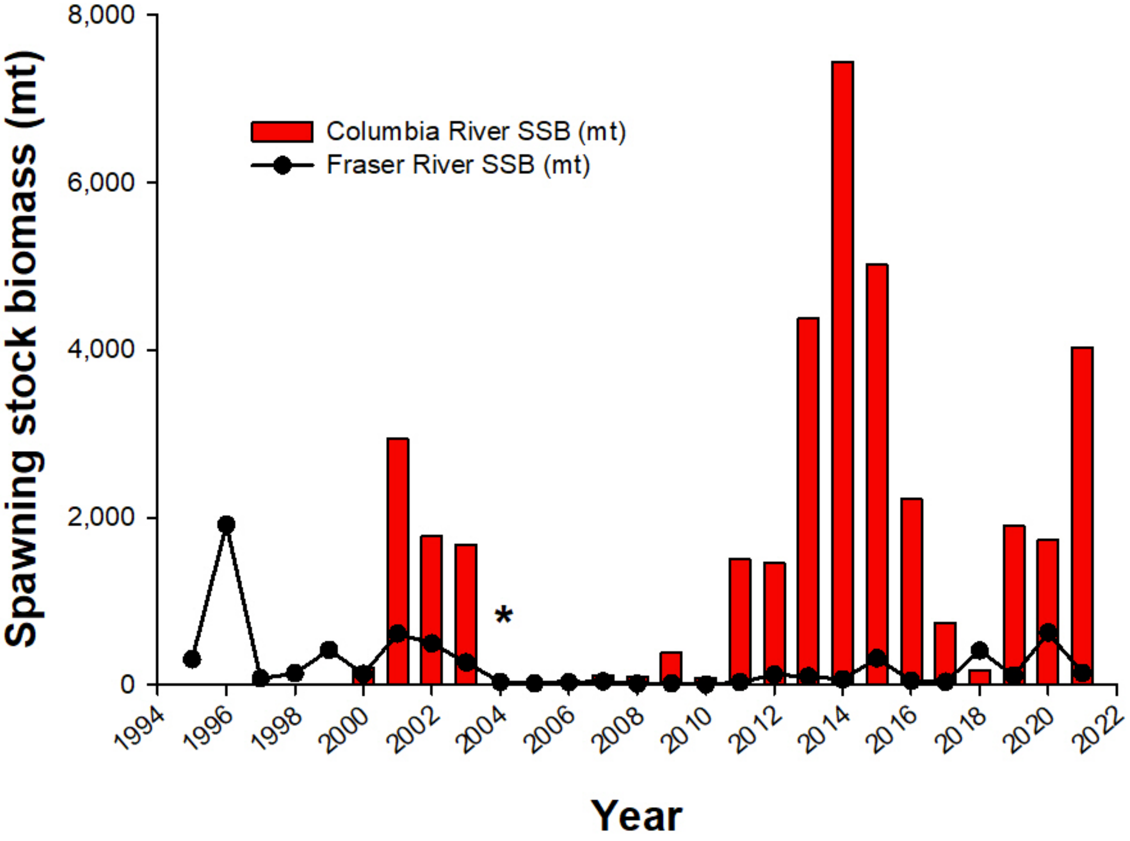

Figure 12. Comparison of Columbia River and Fraser River eulachon SSB estimates. Columbia River data from James (2014), James et al. (2014), Langness et al. (2018, 2020), and JCRMS (2021, 2022). Data for Fraser River from DFO (2022). Columbia River pre-2011 SSB estimates are based on historical water discharge rates and expansions of historical larval densities adjusted for the shorter duration of the pre-2011 surveys (James and Langness, personal communication). Fraser River data from Table 3. Asterisk indicates that a 2004 SSB estimate for the Columbia River is unavailable. The 2020 Columbia River SSB is derived from twice the reported estimate of 1,900,000 lb reported in JCRMS (2021, pp. 23–24), which was based on 10 days of truncated larval sampling due to COVID-19 pandemic field sampling restrictions.

The Lower Fraser Fisheries Alliance[6] (LFFA) was established in 2010 and comprises 30 First Nation communities from the mouth of the Fraser River to the Fraser River Canyon. LFFA's Eulachon Assessment Survey (EAS) began in 2017 to provide an in-season estimation of Fraser River eulachon abundance and is "based on the previous [New Westminster] test fishery methodology" (Fisher 2019, p. 4). The EAS has operated for four years (2017–20; Fisher 2019, DFO 2021a). In 2019, the EAS estimated that 166 mt (95% CI: 95.8–288.4 mt) of adult eulachon returned to the Fraser River (Fisher 2019). By comparison, the Fraser River SSB for 2019 was estimated at 108 mt over the standard 7-week larval survey period (114 mt over the expanded 10-week survey; DFO 2020, 2021a).

According to Fisher (2019):

> The data are showing a strong relationship between the two methodologies [EAS and SSB], and strong potential for use as an in-season indicator. The LFFA plans to continue this important work into the future, to build the capacity within the program to begin use as an in-season indicator for Fraser eulachon FSC [food, social or ceremonial] fisheries and as an important second survey for annual data collection. (p. 4)

DFO (2021a) describes LFFA's EAS as the "LFFA Pilot Survey Project," and stated:

> The Lower Fraser Fisher[ies] Alliance (LFFA) conducted a pilot gillnet survey of returning eulachon on the Fraser River between mid-February and mid-May 2017, with partial funding through the Aboriginal Fund for Species at Risk Program. The survey methodology and location were similar to that used in the 1995–2005 Fraser River (New Westminster) test fishery, with sampling every second day, and additional gear and methodology adjustments to minimize impacts to Fraser River eulachon. Similar survey efforts led by LFFA were also conducted in 2018, 2019 and 2020. Each season, survey efforts have collected information on seasonal relative abundance and run timing, and biological data (fish length, weight, sex, spawn condition). A limited number of samples were also retained for DFO studies, such as for baseline genetics and aging and otolith isotope studies. LFFA intends to continue the survey in 2021 and is seeking funding to continue this work. (p. 24)

In 2020, LFFA's EAS estimated that "107 tonnes [of eulachon] could have returned" to the Fraser River (LFFA 2020, pp. 8–9). DFO (2021a) estimated eulachon SSB in the Fraser River at 624 mt in 2020. Due to several issues with sampling, the EAS and SSB estimates are not comparable for 2020. According to LFFA (2020):

> Normally the program is conducted from early March to mid-May, however, due to funding issues, surveys were conducted from March 8th to April 30th, with a 14-day pause in field surveys and early termination beyond April 30th. Normally, all the data acquired throughout the run… [are] used to estimate

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[6] https://www.lffa.ca/

> in-season run size of eulachon returns, but given the pause in surveys, much of the data for 2020 was infilled and estimated using trends from a previous test fishery dataset (1995–2005) and LFFA EAS (2017–19). Overall, with the infilled data from the analysis and measured data from the field surveys, we estimated that 117 tonnes of eulachon could have returned in 2020. (pp. 8–9)

Johnstone Strait Region

Within the Johnstone Strait Region, eulachon are known to return on either a regular or irregular basis to the Kingcome River (Kingcome Inlet), the Klinaklini and Franklin Rivers (Knight Inlet), the Kakweiken River (Thompson Sound), the Homathko River (Bute Inlet), and the Stafford and Apple Rivers (Loughborough Inlet; Hay and McCarter 2000, Moody and Pitcher 2010). Peak spawn timing in the area occurs about the middle of April (Moody and Pitcher 2010). Regular harvest of eulachon by First Nations fishers reportedly occurs only in the rivers of Kingcome and Knight Inlets (Moody and Pitcher 2010) and therefore harvest and abundance data are available only for the Kingcome and Klinaklini Rivers in this region.

Kingcome River (Johnstone Strait Region)

The 2010 Status Review (Gustafson et al. 2010) summarized available information on the status of eulachon in Kingcome Inlet. Eulachon return on a regular basis to the Kingcome River at the head of Kingcome Inlet on the British Columbia central coast (Hay and McCarter 2000, Moody and Pitcher 2010).

Since Moody's (2008) compilation of information on eulachon abundance, very little additional data on the status of eulachon in the Kingcome River has become available. Eulachon were caught in the Kingcome River in large amounts in late April 2012 (see anecdotal references in Gustafson et al. 2016). Chandler et al. (2018, p. 9) stated that "large returns were observed in Kingcome River during 2015–2017" (Table S5).

Klinaklini River (Johnstone Strait Region)

The 2010 Status Review (Gustafson et al. 2010) summarized available information on the status of eulachon in the Klinaklini River. Eulachon return on a regular basis to the Klinaklini River at the head of Knight Inlet on the British Columbia central coast (Hay and McCarter 2000, Moody and Pitcher 2010). No new information on the status of Klinaklini River eulachon has been located since the 2016 status review; thus, the status of this population is not entirely clear.

Rivers Inlet

The 2010 Status Review (Gustafson et al. 2010) summarized available information on the status of eulachon in Rivers Inlet. Hay and McCarter (2000) reported that an annual run of eulachon return on a regular basis to the Wannock (Wanukv), Chuckwalla, and Kilbella Rivers in Rivers Inlet on the central coast of British Columbia. The Wuikinuxv Nation conducts an annual eulachon monitoring survey for adult distribution, run timing, and egg and larval sampling to determine the status of eulachon in Rivers Inlet. Wuikinuxv Nation (2021) reported that during the annual Eulachon Monitoring:

> A plankton net is deployed in the Wanukv [River] at 4 different locations each day for the two-month study, and the resulting samples are examined with a microscope for eulachon eggs and larvae. Eulachon sampling nets are deployed in the river to detect the presence of adult eulachons, and observations are recorded of eulachon predators like eagles, seals, sea lions, and seagulls. When weather permits, the Kilbala [Kilbella]/Chuckwalla systems are also checked for presence of eulachons. No significant eulachon run has been detected in the territory as of March 30 [2021]. There is still another month of potential for [a] eulachon run to show up according to the run timing knowledge we have available for the territory. (p. 5)

Dean Channel

Hay and McCarter (2000) reported that an annual run of eulachon return on a regular basis to the Bella Coola, Dean, and Kimsquit Rivers in Dean Channel. Recent information on eulachon occurrence in the Bella Coola River occurs below.

Bella Coola River (Dean Channel)

The 2010 Status Review (Gustafson et al. 2010) summarized available information on the status of eulachon in the Bella Coola River. The Nuxalk Fisheries Department conducts annual Bella Coola River eulachon assessments (2001–21). SSB estimates for the Bella Coola River from 2001–04, based on egg and larval surveys similar to those used on the Fraser River, were 0.039 mt (2001), 0.045–0.050 mt (2002), 0.016 mt (2003), and 0.0072 mt (2004; see references in Gustafson et al. 2010). Additional survey data are not available. Eulachon returned in "modest numbers" to the Bella Coola River beginning in 2012, and schools of eulachon were seen in the river in 2013 (MacKinnon 2015). In 2018, newspaper reports[7] indicated that, "[f]or the first time in almost 20 years, there are multiple small schools of eulachon returning to their spawning grounds in the Bella Coola River," and that "since 2012 the run has slowly been coming up." Other newspaper reports[8] indicated that, although there were eulachon in the Bella Coola River in 2018, the run was not large enough to support a First Nations subsistence fishery.

Gardner Canal

Hay and McCarter (2000) reported that eulachon return annually to the Kemano, Kowesas, and Kitlope Rivers in Gardner Canal. A number of drainages in Gardner Canal (Foch, Giltoyees, Kemano, Wahoo, Kowesas, and Kitlope Rivers) were surveyed for eulachon eDNA in 2020 and 2021 by the Haisla Fisheries Commission and EcoFish Research (Victoria, British Columbia; Haisla Nation Council 2021b). Haisla Nation Council (2021b, p. 2) reported "that 9 out of 12 water systems were positive for oolichan presence in 2020" and that results for the 2021 run year will be available in 2022.

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[7] https://www.coastmountainnews.com/news/bella-coola-sees-biggest-run-of-eulachon-in-almost-20-years/

[8] https://www.cbc.ca/news/canada/british-columbia/bella-coola-eulachon-grease-project-revives-tradition-1.4722780

Kemano River (Gardner Canal)

The 2010 Status Review (Gustafson et al. 2010) summarized available information on the status of eulachon in the Kemano River. Hay and McCarter (2000) reported that eulachon return annually to the Kemano River in Gardner Canal and spawn in late March and early April (Moody 2008). Although First Nations catch and CPUE data for the Kemano River were presented in Moody (2008, their Figure 2.16) and this presentation was reviewed by the 2010 BRT (Gustafson et al. 2010), the 2010 BRT did not have access to the actual Kemano River data presented by Moody (2008). Subsequently, these data were presented in a tabular form by COSEWIC (2011, their Table 7 and Figure 14) and were made available in the 2016 Status Review (Gustafson et al. 2016, their Table 9 and Figure 18). A substantial decline in CPUE occurred over the period 1988–2007 (Gustafson et al. 2016). Anecdotal information indicates that very few eulachon returned to the Kemano River from 2008–12 (Gustafson et al. 2016), but a "small run" was noted in 2014 (Haisla Nation Council 2014). In 2015, there was a "conservative estimate of approximately 120 tons" of eulachon in the Kemano River "with about 40 ton[s] taken for food" (Haisla Nation Council 2015, p. 12). The Haisla Fisheries Commission eulachon monitoring program on the Kitimat, Kildala, and Kemano Rivers found eulachon in all three rivers in 2018 (HFC 2019).

Haisla Fisheries Commission (HFC 2019, Haisla Nation Council 2021b) estimated abundance of adult eulachon (short tons) to the Kemano River from 2008–21 (Table 4, Figure 13). Although the river was monitored up to 12 April (Haisla Nation Council 2020), there was no eulachon run on the Kemano River in 2020 (M. Jacobs, Haisla Fisheries Commission, personal communication). In 2021, Haisla Nation Council (2021b) stated:

> Haisla Fisheries have been monitoring Haisla territory river systems since mid February…. The oolichan arrived in Kemano on April 1, 2021 with an estimate run of 40 ton and members harvesting 25 tons. (p. 2)

Table 4. Estimated abundance (mt, original data in short tons) of Kemano River eulachon, 2008–21. Data as presented in Haisla Fisheries Commission Annual Report 2018–19 (HFC 2019).

Year	Estimated return (short tons)	Estimated return (mt)	Source
2008	0	0.00	HFC (2019)
2009	0	0.00	HFC (2019)
2010	10	9.07	HFC (2019)
2011	0	0.00	HFC (2019)
2012	30	27.22	HFC (2019)
2013	162	146.96	HFC (2019)
2014	0	0.00	HFC (2019)
2015	120	108.86	HFC (2019)
2016	190	172.37	HFC (2019)
2017	90	81.65	HFC (2019)
2018	30	27.22	HFC (2019)
2019	n/a	n/a	n/a
2020	0	0.00	Haisla Nation Council (2020)
2021	40	36.29	Haisla Nation Council (2021b)

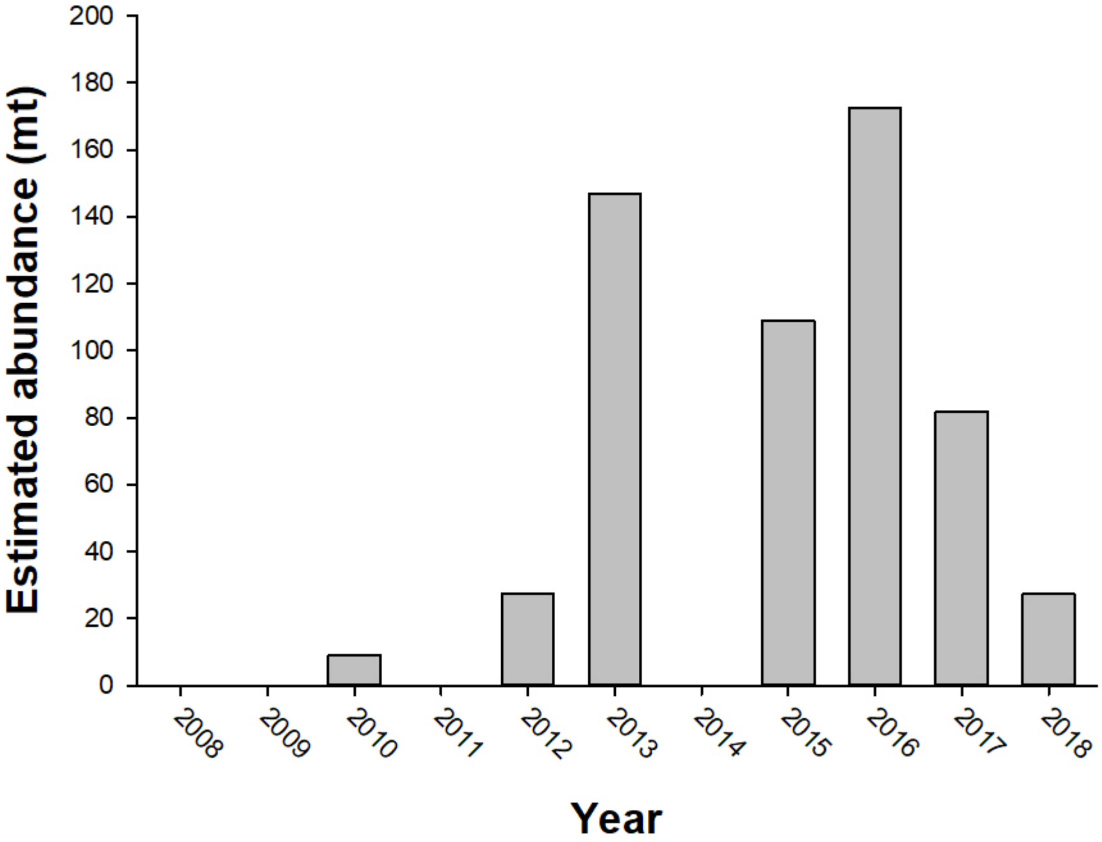

Figure 13. Estimated abundance of adult eulachon returning to the Kemano River, British Columbia, from 2008–18. Data from Haisla Fisheries Commission (2019) and Table 4.

Haisla Nation Council (2020, 2021a,b) reported that Haisla Fisheries Commission, in association with EcoFish Research, surveyed for eulachon eDNA in 12 rivers in Haisla territory (Kemano, Wahoo, Kitlope, Kawasas, Kitimat, Anderson, Wahtl, Moore, Kildala, Dala, Gilloteyse, and Foch) in 2020 and again in 2021. The first four of these systems flow into Gardner Canal and the last four flow into Douglas Channel. Haisla Nation Council (2021b, p. 2) reported "that 9 out of 12 water systems were positive for oolichan presence in 2020" and that results for the 2021 run year will be available in 2022.

Douglas Channel

Hay and McCarter (2000) reported that an annual run of eulachon returns on a regular basis to the Kitimat and Kildala Rivers in Douglas Channel. A number of drainages in Douglas Channel (Kitimat, Dala, and Kildala Rivers, and Anderson, Moore, and Wathl Creeks) were surveyed for eulachon eDNA in 2020 and 2021 by the Haisla Fisheries Commission and EcoFish Research (Haisla Nation Council 2021b). Haisla Nation Council (2021b, p. 2) reported "that 9 out of 12 water systems were positive for oolichan presence in 2020" and that results for the 2021 run year will be available in 2022.

Kitimat River (Douglas Channel)

The 2010 Status Review (Gustafson et al. 2010) summarized available information on the status of eulachon in the Kitimat River. Hay and McCarter (2000) reported that an annual run of eulachon returns on a regular basis to the Kitimat River in Douglas Channel, where spawning peaks in mid- to late March (Moody 2008). Although some First Nations catch and CPUE data for the Kitimat River were presented in Moody (2008, their Figure 2.14) and this presentation was reviewed by the 2010 BRT (Gustafson et al. 2010), the 2010 BRT did not have access to the actual Kitimat River data presented by Moody (2008). Subsequently, these data, as well as additional catch data, were presented in a tabular form in COSEWIC (2011, their Table 6 and Figure 13), and were made available in the 2016 Status Review (Gustafson et al. 2016, their Table 10 and Figure 19). The CPUE data indicate that a steep decline in abundance occurred in the late 1990s, followed by continued low abundance through 2007 (Gustafson et al. 2016). Anecdotal information indicated that small numbers of eulachon returned to the Kitimat River in 2012, 2014, and 2015 (Table S5; Gustafson et al. 2016).

The Haisla Fisheries Commission eulachon monitoring program on the Kitimat, Kildala, and Kemano Rivers found eulachon in all three rivers in 2018 (HFC 2019). In 2020, the Haisla Fisheries Commission monitored the Kitimat and Kildala Rivers and Anderson Creek for adult eulachon. Six eulachon were caught in smelt net sets in Anderson Creek, a small side creek on the Kitimat River delta (Haisla Nation Council 2020). Haisla Nation Council (2021b, p. 2) reported: “Haisla Fisheries have been monitoring Haisla territory river systems since mid-February with the first oolichan caught in the Kitimat River on February 24th [2021].”

Kildala River (Douglas Channel)

The Haisla Fisheries Commission eulachon monitoring program on the Kitimat, Kildala, and Kemano Rivers found eulachon in all three rivers in 2018. According to the Haisla Fisheries Commission Annual Report 2018–19 (HFC 2019, p. 4): “the discovery of Oolichan in the Kildala River was an exciting find, pointing toward a need for continued research, protection and recovery planning.”

Skeena River

The 2010 Status Review (Gustafson et al. 2010) summarized available information on the status of eulachon in the Skeena River. Hay and McCarter (2000) and Moody (2008) reported that an annual run of eulachon returns on a regular basis to the Skeena River and its tributaries. Historically, eulachon returned to the Skeena River around the first week of March, but in the recent past have occasionally returned as early as mid-February (Moody 2008). Anecdotal information indicated that the Skeena River had a “very good run” of eulachon in 2010 and a “good run” in 2011 and 2012 (COSEWIC 2013, p. 11). COSEWIC reassessed the status of the Nass/Skeena Rivers DU in 2013 and reclassified this unit’s status from “Threatened” to “Special Concern” (COSEWIC 2013).

The North Coast Skeena First Nations Stewardship Society (NCSFNSS 2015, p. 3) described the Skeena River eulachon population as “stable” in 2015. However, concerns included the lack of: “stock assessment or management of the fishery; …years of poor returns and harvest in the last two decades; and [the] increasing amount of industrial development being proposed in the Skeena watershed that may pose a threat to the species” (NCSFNSS 2015, p. 3).

NCSFNSS coordinates a Skeena River eulachon catch monitoring survey of the eulachon food fishery. In 2020, the Skeena Eulachon Food, Social, Ceremonial Harvest Monitoring Project ran from 2 February to 13 March and collected data on eulachon catch amounts, location, timing, fishing methods, and biological information on sex ratio and fish size (NCSFNSS 2020). The year 2020 was:

> …the second year of implementing a new survey design for the project that allows for a total estimate of harvested eulachon with a known error. Harvest monitors count the number of fishers, gear types being used, and replicate the methods to determine an estimated catch per unit effort (CPUE)…. In 2019, an estimated 856,000 eulachon (approximately 30.9 tonnes) were harvested from the Skeena River. The program results for 2020 estimated 373,000 eulachon (approximately 13.5 tonnes) was harvested. (p. 11)

Falls River (a.k.a. Big Falls Creek) is a tributary of the Ecstall River, which flows into the lower Skeena River. As part of the Falls River hydroelectric project, Big Falls Creek was dammed in 1930 above a natural waterfall that acted as a barrier to fish migration. Since adult eulachon, but not eggs or larvae, have been observed in the lower Falls River, Sharpe and Butts (2019, p. 7) investigated "eulachon population status and habitat use in the lower Falls River in relation to the Ecstall River" in spring of 2019. Sharpe and Butts (2019) caught adult eulachon in gill nets in the lower Falls River (28 sets, $n = 168$ eulachon) on most sampling days in March 2019, but detected only five eulachon eggs in sediment from one sample out of 28 sampling locations in the lower Falls River. Average catch of eulachon in the Ecstall River was higher than in Falls River. Sharpe and Butts (2019) found that:

> …eulachon are using the Falls River during their freshwater migration, however [they] may only be spawning at the study locations in very low densities. Available spawning substrate was mainly comprised of fine sediment, which is known to be of lower value to spawning eulachon. A potential restoration project could be conducted to introduce additional coarse substrates (sand and gravel), which represents higher value habitat for spawning eulachon. However, maintaining a flow and sediment regime [below the Falls River dam] to support this type of restoration project may be challenging. (p. 2)

Sharpe and Butts (2019, p. 12) cited local Lax Kw'alaams First Nations members for observations that Skeena River eulachon run timing "was earlier than usual [in 2019]… with catch recorded as early as February 16, 2019," and stated "the 2019 eulachon run continued into late March."

Spatial structure

Marine distribution and mixed stock analysis

Analysis of the river of origin of bycaught eulachon in U.S. shrimp and groundfish fisheries would allow scientists to better allocate at-sea risks to eulachon from individual river populations in different regions of the marine environment. A number of studies have attempted to develop a genetic baseline of eulachon river populations and use this baseline to genetically assign at-sea sampled eulachon back to their river of origin using genetic stock identification (GSI) and mixed stock analysis (MSA) methods (Beacham et al. 2005, Candy et al. 2015, Sutherland et al. 2021).

Beacham et al. (2005) used variation at 14 microsatellite DNA loci to examine the stock composition of trawl and research surveys in marine areas off British Columbia. Using a genetic baseline dataset of eulachon populations in eight rivers in Washington and British Columbia, they estimated the proportional composition of three marine-caught samples. A sample of 184 eulachon was collected during a shrimp research survey near Nootka Sound off WCVI in May 2000. The largest proportions of fish were estimated to be from the Columbia River (56.6%, standard deviation [SD] = 10.4) and Fraser River (37.5%, SD = 10.1). Populations in other rivers were estimated to contribute less than 6% to the sample. A sample of 100 eulachon sampled as bycatch in a shrimp trawl fishery near Chatham Sound (off British Columbia's north coast) in March 2001 was estimated to be largely fish from the British Columbia central mainland (51.6%, SD = 13.8) and from the Nass River (37.4%, SD = 10.9). Columbia (1.7%, SD = 2.4) and Fraser (2.1%, SD = 3.6) Rivers contributed a small fraction to the sample. A third sample of 200 fish taken in research shrimp surveys in Queen Charlotte Sound in March 2001 comprised substantial proportions of Columbia River, Fraser River, British Columbia central mainland river, and Skeena River eulachon, all contributing between 22.1% (SD = 5.9) and 27.1% (SD = 6.9).

Beacham et al. (2005) concluded that although eulachon migrations are largely unknown, there is spatial structure to the marine distributions of fish from different rivers. Since the publication of Beacham et al. (2005), additional offshore eulachon samples collected during DFO multispecies small mesh bottom trawl surveys (a.k.a. fishery-independent shrimp surveys) off WCVI have been genetically assigned back to their rivers or populations of origin (Table S6). These percent assignments have been used by DFO scientists to apportion at-sea risks in different regions of the marine environment on a DU-by-DU basis (Schweigert et al. 2012). Schweigert et al. (2012) determined that about 56% of eulachon collected off WCVI could be genetically assigned as originating in the Columbia River. More recent estimates indicate that about two-thirds of the eulachon collected off WCVI could be genetically assigned back to the Columbia River (S. MacConnachie, DFO, unpublished data; Table S6).[9]

Candy et al. (2015) examined eulachon population structure among 12 sampling locations ranging from Washington (Columbia and Cowlitz Rivers) to south-central Alaska (Twentymile and Kenai Rivers in Cook Inlet) by analyzing genetic variation among a panel of 3,911 putatively neutral SNPs and a panel of 193 putatively adaptive SNPs. In MSA tests using these panels, the adaptive SNP panel showed greater assignment success than the neutral SNP panel, and both panels were considerably more powerful than the microsatellite panel used in Beacham et al. (2005).

According to Candy et al. (2015), the percent correct assignment for leave-one-out tests of individual assignment back to population and region of origin:

> …for the neutral panel ranged from 6% to 94% (mean = 53%) for assignment to population and 89% to 100% (mean = 98%) for assignment to region…. Percent correct assignment for the adaptive panel ranged from 22% to 71% (mean = 64%) for assignment to population and 97% to 100% (mean = 99%) for assignment to region. (p. 9)

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[9] https://www.nwcouncil.org/sites/default/files/3_s-macconnachie_0.pdf

The Beacham et al. (2005) microsatellite panel performed "…considerably poorer, ranging from 10% to 47% (mean = 19%) for assignment to population and from 47% to 80% (mean = 67%) for assignment to region" (Candy et al. 2015, p. 9).

Sutherland et al. (2021) developed an improved eulachon genetic baseline of 521 variant SNP loci, genotyped in 1,989 individuals from 14 populations ranging from south-central Alaska (Twentymile River) to Northern California (Klamath River). Although some aspects of this research are still in development, the ultimate goal of these studies is to "develop an improved baseline with highly resolving markers, large sample sizes, and multiple sampling years, providing more accurate estimates for MSA and GSI" (Sutherland et al. 2021, p. 79).

Columbia River tributaries

The Cowlitz Indian Tribe (2014) examined spawning distribution, run timing, and presence/absence of eulachon in numerous tributaries to the lower Columbia River during 2011–13. Eulachon eggs and/or larvae were reportedly found up to 10 miles (16.1 km) upstream on both the Grays and Elochoman Rivers and up to 5 miles (8 km) upstream on Skamokawa Creek in 2011–13. Eggs and larvae were found up to 1 mile (1.6 km) upstream in Mill Creek in 2011–12, but not in 2013. In 2011–12, eulachon eggs or larvae were seen up to 2 miles (3.2 km) upstream in Abernathy Creek and up to 1 mile (1.6 km) upstream in Germany Creek (Cowlitz Indian Tribe 2014). Eulachon eggs or larvae were found in the Kalama River in 2011–13 up to 8 miles (12.9 km) upstream of the mouth. Eggs and larvae were found in the North Fork Lewis River up to 7 miles (11.3 km) upstream in 2011–12, and in the East Fork Lewis River in 2011 at 6 miles (9.7 km) upstream. And finally, eulachon eggs or larvae were found in the Washougal River in 2011–12 up to 6 miles (9.7 km) upstream and in the Sandy River in 2011–12 at 5 miles (8 km) upstream (Cowlitz Indian Tribe 2014).

In 2011, WDFW sampled Skamokawa Creek and the Elochoman, Cowlitz, Kalama, and Lewis Rivers for presence/absence of eulachon and detected eulachon eggs or larvae in all locations sampled (Storch et al. 2014, their Table 2). Eulachon eggs or larvae were also detected in all samples collected in the mainstem Columbia River and Grays River during 2011–13 (Storch et al. 2014, their Tables 1 and 2). As mentioned above, clear morphological differences between known eulachon larvae and putative longfin smelt larvae have not been identified. It is unknown how significant a problem misidentification of egg and larval samples may pose to the accuracy of eulachon presence/absence studies. Larval eulachon were collected from the Grays River to calculate SSB in 2011–13, 2015, and 2016 (Table S1; James et al. 2014, Langness et al. 2016), and adult eulachon were sampled in the Grays River in 2019 (P. E. Dionne, WDFW, personal communication) for genetic analyses.

Cowlitz River and tributaries

The Cowlitz Indian Tribe (2014) examined presence/absence of eulachon eggs and larvae during 2011–13 in the Cowlitz River and two of its tributaries, the Coweeman and Toutle Rivers. Putative eulachon larvae were reported in the Cowlitz River 41–45 miles (66–72.4 km) upstream in 2011, 46–50 miles (74–80.5 km) upstream in 2012, and no higher than 1–5 miles

(1.6–8.0 km) upstream in 2013 (Cowlitz Indian Tribe 2014). Putative eulachon larvae were encountered 1 mile (1.6 km) and 2 miles (3.2 km) upstream in the Coweeman River in 2011 and 2012, respectively. Cowlitz Indian Tribe (2014) reportedly found eulachon larvae in the Toutle River 6 miles (9.7 km) and 3 miles (4.8 km) upstream in 2011 and 2013, respectively. However, presence/absence plankton surveys did detect eulachon eggs and larvae in the Toutle River in 2012 (Cowlitz Indian Tribe 2014). As mentioned above, clear morphological differences between known eulachon larvae and putative longfin smelt larvae have not been identified. It is unknown how significant a problem misidentification of egg and larval samples may pose to the accuracy of eulachon presence/absence studies.

Washington coastal streams

Storch et al. (2014, their Table 3) summarized WDFW sampling efforts for presence/absence of eulachon eggs and larvae in 15 Washington state locations during either 2011 or 2012:

- The Big Quilcene, Little Quilcene, and Tahuya Rivers in Hood Canal.
- The Clallam and Elwha Rivers along the Strait of Juan de Fuca.
- The Moclips, Clearwater, Hoh, and Quillayute Rivers and Goodman Creek on the Washington coast.
- The Humptulips and Chehalis Rivers draining into Grays Harbor.
- The Naselle and Bear Rivers and the north fork of the Willapa River draining into Willapa Bay.

Eulachon eggs and larvae were detected in the Naselle, Bear, Willapa, and Chehalis Rivers (Storch et al. 2014, p. 72), but not in the other systems listed, perhaps because surveys "typically consisted of only a single plankton tow." Efforts by WDFW to estimate spawning stock biomass of eulachon in the Naselle and Chehalis Rivers are summarized in Abundance and trends in individual rivers in the Southern DPS. Larval eulachon were successfully sampled in 2015–17 from the Naselle River and in 2015–18 from the Chehalis River (Langness et al. 2018).

The Quinault Indian Tribe (QIN 2014) demonstrated the presence of eulachon larvae in the Chehalis River in both 2013 (*n* = 29) and 2014 (*n* = 66), during January–April. One eulachon larva was obtained in the tributary Wishkah River in 2013, and 17 were obtained in the Hoquiam River in 2014 (QIN 2014). No eulachon larvae were detected during 2013 in the Hoquiam or Wynoochee Rivers, or during 2014 in the Wishkah River (QIN 2014). Langness et al. (2018) detected low numbers of eulachon eggs and/or larvae in each of 16 plankton samples from the Chehalis River from 5 December 2016 to 20 April 2017. Eulachon larvae were also detected during one of 18 plankton surveys in the Wynoochee River and four of 17 plankton surveys on the Wishkah River between 29 December 2016 and 24 April 2017. However, eulachon were not detected in the Satsop River during any of the 17 plankton surveys conducted during this same period (Langness et al. 2018). As mentioned above, clear morphological differences between known eulachon larvae and putative longfin smelt larvae have not been identified. It is unknown how significant a problem misidentification of egg and larval samples may pose to the accuracy of eulachon presence/absence studies.

Royal (2020, p. 7) reported that the Lower Elwha Klallam Tribe has sampled for eulachon adults and larvae for genetic population studies in the Elwha, Dungeness, and Lyre Rivers on the north shore of the Olympic Peninsula "using screw traps to capture adults, plankton tow nets to catch larvae, [and] clam guns to collect sediment samples to find eggs." In 2020, genetic samples (fin clips) were obtained from five adults in the Lyre River and putative eulachon larvae were collected in the Elwha (*n* = 25), Dungeness (*n* = 36), and Lyre (*n* = 122) Rivers (Paradis, personal communication). Genetic identification of these latter samples has not been completed.

Oregon coastal streams

In 2011, ODFW opportunistically sampled for eulachon eggs and larvae in the Umpqua and Coos Rivers; however, none of the specimens collected were identified as eulachon (Storch et al. 2014). Over a four-year period from winter 2014 to spring 2018, ODFW monitored three creeks—Big Creek, Cummins Creek, and Tenmile Creek—on the Oregon coast for eulachon egg and larval production. These three creeks were sampled 352 times and 702 ichthyoplankton collections were made. According to Mallette et al. (2018),

> …we observed little evidence of spawning in Big, Cummins, or Tenmile creeks during the entire four year sampling period. Use of these creeks and the associated habitat appears very limited. The only two ichthyoplankton samples that contained eulachon were taken from Big Creek on the same day, which indicates that at best, there is evidence for one spawning event in Big Creek that occurred prior to March 10, 2015. These results imply that these creeks may not support substantial amounts of eulachon production. The negligible number of eulachon larvae and eggs observed preclude any calculation of SSB for the duration of the study across all three streams. (pp. 12–13)

ODFW sampled nine eulachon larvae in Big Creek on the Oregon coast on 10 March 2015 (Mallette 2015, Mallette et al. 2018). As mentioned above, clear morphological differences between known eulachon larvae and putative longfin smelt larvae have not been identified. It is unknown how significant a problem misidentification of egg and larval samples may pose to the accuracy of eulachon presence/absence studies. Mallette et al. (2018) further noted:

> …26 adult eulachon were observed in a screw trap in Tenmile Creek [in 2015], which is operated by the ODFW Salmonid Life Cycle Monitoring Project…. In 2016, they observed one adult eulachon and in 2017 and 2018 they observed zero and two eulachon in this screw trap, respectively. (p. 14)

Northern California coastal streams

Two larval eulachon were captured in the lower Mad River on 10 February 2020, during ichthyoplankton surveys for longfin smelt larvae. These two specimens were genetically identified as eulachon (M. Gilroy, California Department of Fish and Wildlife [CDFW], personal communication). On 6 March 2020, a single adult eulachon was captured in a screw trap about 5.6 km upstream of the ocean and released on the Little River in Humboldt County, California (Gilroy, personal communication).

Environmental indices and eulachon abundance trends

Since the 2016 status review, three separate non-peer-reviewed studies have attempted to provide statistical correlations between temporal estimates of eulachon abundance and oceanographic and/or freshwater environmental indices: Sharma et al. (2017), Montgomery (2020), and D. E. Hay and J. F. Schweigert (DFO [retired], unpublished data).

Sharma et al. (2017) examined the relationship between eulachon abundance and environmental conditions to determine the impact of potential future climate change on eulachon in the Columbia River. This study's "methods of analysis included statistical models using empiric data, and G.I.S. [Geographic Information System]-based approaches coupled with regional climate change projections" (Sharma et al. 2017, p. 1). Eulachon "abundance" data in this report were described as: 1) Eulachon Trawl Bycatch Index (2003–12) derived from the WCBTS, 2) SSB estimates for the Fraser (2005–14) and Columbia (2005–14) Rivers, and 3) short-term catches in the Fraser and Columbia Rivers (1960–96) and longer-term catches in the Columbia River (1938–2010). The WCBTS was not specifically designed to enumerate eulachon, and the eulachon caught were incidental to the goals of the survey and represent only a small and erratic portion of the distribution of eulachon. In addition, the questionable effectiveness of bottom trawls with large mesh nets in catching near-bottom or midwater-schooling eulachon limits the usefulness of this bottom trawl survey to assess the eulachon population (see West Coast Bottom Trawl Survey). In addition, it is inappropriate to assume that estimated catches for eulachon are "directly proportional to abundance" in the Columbia River basin, as was done in Sharma et al. (2017). There is ample evidence that eulachon landings within the Columbia River basin cannot be equated with eulachon abundance over the time period analyzed (Craig and Hacker 1940, Smith and Saalfeld 1955, WDFW and ODFW 2008, JCRMS 2014). For example, Craig and Hacker (1940, p. 209) stated: "The total yearly catch… [is] not an index of the abundance or availability of the smelt… [it] is more of an index of the demand for smelt than of abundance." Therefore, results in Sharma et al. (2017) based upon eulachon "catches" in the Columbia River and its tributaries are not reviewed in the present document.

Environmental indices analyzed in Sharma et al. (2017, p. 34) for eulachon included: 1) sea surface temperature (SST) for April to July "from geographical stations closest to the river mouth," 2) ocean upwelling indices (UPI) for April to July, 3) Pacific Decadal Oscillation (PDO) for April to June, 4) El Niño–Southern Oscillation (ENSO) for April to June, and 5) historic seasonal river flow records as a freshwater indicator. April to July environmental data were chosen as these were "assumed to be the primary months of larval eulachon ocean entry" and correlational analyses of SSB abundance with SST, UPI, PDO, and ENSO were done with lags of one, two, or three years (Sharma et al. 2017, p. 24).

Correlational analysis of Columbia River eulachon SSB data (Sharma et al. 2017) showed:

> …the month of May (SST2 and SST3) to be correlated with higher abundance when the SST is lower. In addition, in July, upwelling indices are positively correlated with abundance on either 1, or 2 year lags for the month of July. Finally, the large scale indicators are negatively correlated by a 2 to 3 year lag for PDO in May/June…. (p. 109)

In conclusion, Sharma et al. (2017) stated:

> …eulachon will likely be negatively affected by increases in Sea Surface Temperature and lower upwelling conditions the year before they show up to the river…. [E]arly life stage survivals are highly dependent on ocean conditions during their outmigration from the freshwater to the marine environment. In general, the timing of the spring transition and the magnitude of the upwelling and reductions in sea surface temperature that accompany it indicate larger survival and abundances… than contrary conditions of less upwelling and higher temperatures. (p. 124)

Sharma et al. (2017) also regressed eulachon data from the WCBTS "trawl survey index" (Ward et al. 2015) from the preceding year against Columbia River SSB for the following year.

Sharma et al. (2017, p. 111) stated: "Based on this relationship, an extremely good estimate on what may be expected to return in the Columbia is possible using trawl survey data from the [WCBTS] lagged by one year." Sharma et al. (2017) had access to the WCBTS eulachon "trawl survey index" for 2003–14 and Columbia River SSB data from 2005–14. Although we do not have access to the trawl survey index after 2014, it appears from comparing eulachon WCBTS eulachon catch in Figure 6 with Columbia River SSB shown in Figure 7 that this correlation remains positive after an additional five years of data.

It is apparent from discussion sections that Sharma et al. (2017) confused the two spatial data sets used in Ward et al. (2015): fishery-independent catch of eulachon from the WCBTS (Bradburn et al. 2011) and estimated bycatch of eulachon in the ocean shrimp trawl fisheries (Al-Humaidhi et al. 2012). Installation of bycatch reduction devices (LED lights on trawl-net footropes) mentioned in Sharma et al. (2017) that make the fishery bycatch temporal data set unusable after 2015 refer only to the shrimp trawl fisheries and not to the fishery-independent WCBTS, as assumed by Sharma et al. (2017, p. 111). The WCBTS survey methodology has remained the same since 2003, and this survey data remains as an "independent measure of abundance" for eulachon (Ward et al. 2015, Sharma et al. 2017 [p. 111]). Unfortunately, WCBTS data are not released until at least one year-class of eulachon encountered in the ocean survey would have already spawned in freshwater.

Montgomery (2020) used multivariate analyses to examine correlations between WDFW's estimation of eulachon SSB in the Columbia River (2000–17) and 16 ocean ecosystem indicators[10] (2000–17) from NWFSC's Estuarine and Ocean Ecology Program that were developed to study how ocean conditions impact Pacific salmon survival off Oregon and Washington. A principle components analysis (PCA) summarized the ocean indicators into principle components (PCs), "which are uncorrelated new axes, where the first axis summarizes the dominant trends in variation and the second axis accounts for residual variance not accounted for by the first axis, and so on for additional axes" (Montgomery 2020, p. 10). Five regression analyses were performed on Columbia River

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[10] https://www.fisheries.noaa.gov/west-coast/science-data/ocean-ecosystem-indicators-pacific-salmon-marine-survival-northern

eulachon SSB, and PC scores for the first and second axes of the ocean indicators—with time lags of zero, one, two, three, and four years prior to the year the SSB were measured. Results (Montgomery 2020) indicated that:

> …ocean conditions in the three years prior to return are predictive of eulachon abundance; data from two years and three prior have a stronger and more significant relationship than one year prior which suggests dominant life history strategies in the Columbia River. One of the interesting results from this analysis is that indicators related to bottom-up processes and large-scale oceanic drivers such as the status of the PDO are important to eulachon abundance…. Bottom-up biological indicators like copepod biomass and abundance, as well as major climatic/ocean indices… are likely key drivers of patterns in eulachon abundance in the Columbia River. (p. 16)

Correlations between and among eulachon abundance datasets such as Fraser River SSB, Columbia River SSB, and CPUE of eulachon catch off WCVI, and environmental indices such as the PDO and the Northern Copepod Anomaly (NCA), have also been examined (Hay and Schweigert, unpublished). Fraser River SSB (1995–2017) was not significantly correlated with the NCA or PDO when zero-, one-, or two-year lags were applied to the data. However, Columbia River SSB (2000–18) was significantly correlated with PDO in the same year and when lagged two years, and with the NCA when data were lagged by two years (Hay and Schweigert, unpublished). The WCVI CPUE (1990–2018) was also significantly correlated with both PDO and NCA when lagged by one or two years. Among the abundance data, Columbia SSB and WCVI eulachon CPUE were significantly correlated in the same year and when lagged by one year. However, untransformed Fraser River SSB data were not significantly correlated with either Columbia River SSB or WCVI CPUE (Hay and Schweigert, unpublished). When these analyses were repeated using log values of Fraser River SSB, significant correlations were seen with Columbia River SSB in the same year and with the NCA data lagged by two years (Hay and Schweigert, unpublished). It is probable that the NCA responds to changes in sea surface temperature, which is a main component of the PDO index, such that when the PDO is positive (warm conditions) the NCA is negative and vice versa. Eulachon depend on copepods during their transition from larvae to juveniles. When the PDO is negative and the NCA is positive, nutritious northern copepods increase in abundance, and eulachon respond in a year or two by increasing in abundance both offshore and eventually in the Columbia and Fraser Rivers (Hay and Schweigert, unpublished).

Qualitative Threats Assessment (2010 BRT)

The 2010 BRT examined the potential roles that 16 identified threats (list in Gustafson et al. 2010) may have played in the decline of the Southern DPS of eulachon, and scored the severity of these threats from one to five in four subareas of the Southern DPS: the Klamath, Columbia, and Fraser Rivers, and that portion of the Southern DPS along the mainland coast of British Columbia. The severity of each threat was qualitatively scored as follows: 1 = very low, 2 = low, 3 = moderate, 4 = high, and 5 = very high. The results of the 2010 BRT's analysis of the severity of threats to eulachon were presented in the 2010 status review report (Gustafson et al. 2010) by rank order from most severe to least severe for each geographical subset, as determined by the mean 2010 BRT threat scores. Also presented were the standard deviation about the mean threat scores, the modal score, the range of scores, and the number of 2010 BRT members scoring the threat (Gustafson et al. 2010, their Tables 15–18). In the present report, the modal scores of the 2010 BRT's analysis of the severity of threats to eulachon were used to present the results of the 2010 BRT's qualitative threats analysis (Table S7).

The 2010 BRT categorized climate change impacts on ocean conditions as the most serious threat to persistence of eulachon in all four subareas of the Southern DPS: Klamath River, Columbia River, Fraser River, and British Columbia coastal rivers south of the Nass River. Climate change impacts on freshwater habitat and eulachon bycatch in offshore shrimp fisheries were also ranked in the top four threats in all subareas of the Southern DPS. Dams and water diversions in the Klamath and Columbia Rivers and predation in the Fraser River and British Columbia coastal rivers filled out the last of the top-four threats. In most categories, some portion of the 2010 BRT felt that insufficient data were available to score the threat severity (thereby marking the threat severity as unknown).

Update of Selected Threats Information

New information has become available for two threats that were classified as of moderate to high severity in the eulachon 2010 status review (Gustafson et al. 2010): climate change impacts on ocean conditions, and eulachon bycatch in ocean fisheries. New information related to these two threats is reviewed in the following section. New information on commercial and recreational fisheries, which were viewed as low to very low threats by the 2010 BRT, is presented in the following section.

In British Columbia, the recovery potential assessment (RPA) of eulachon (Schweigert et al. 2012) stated that:

> No single threat could be identified as most probable for the observed decline in abundances among [eulachon] DUs or in limiting recovery. However, mortality associated with coastwide changes in climate, fishing (direct and bycatch) and marine predation were considered to be greater threats at the DU level, than changes in habitat or predation within spawning rivers. (p .vii)

In addition, Schweigert et al. (2012, p. 1) stated: "Some existing threats (e.g., food, social and ceremonial fisheries, marine mammal predation, and degradation of freshwater habitat) are unlikely to have been responsible for the recent widespread declines in abundance, but may now be preventing recovery from low abundance in some DUs."

Environmental Factors

This section provides an overview, with a particular emphasis on recent and predicted future changes, in environmental factors that are important to eulachon productivity and survival.

Observed and predicted future ocean conditions

The marine distribution of the Southern DPS of eulachon encompasses the Northern California Current Ecosystem (CCE), which is part of one of the four major Eastern Boundary Upwelling Systems (EBUS) in the world's oceans (these are the California, Humboldt, Canary, and Benguela Currents). Primary productivity in the Northern CCE is fueled by wind-driven upwelling of cold, nutrient-rich, deep waters to the surface (Bakun 1990, Chan et al. 2008). Along the coasts of British Columbia, Washington, and Oregon, ocean upwelling depends on strong coastal northerly or equatorward winds, which drive warm surface waters offshore and induce upwelling of deep waters (Bakun 1990, Bograd et al. 2009, Checkley and Barth 2009). Upwelling-favorable winds are more frequent in the spring and summer, but do not occur uniformly even at those times. Ocean upwelling off California is much more consistent, less seasonal, and stronger on average than in areas farther north. Winter winds in the CCE typically blow from the southwest or poleward direction and create downwelling conditions. These alongshore winds shift during the spring transition to blow predominately from the northwest or equatorward direction, creating upwelling conditions (Bograd et al. 2009, Checkley and Barth 2009).

Harvey et al. (2021a) stated that the average peak of upwelling occurs in late April off San Diego (around lat 33°N) and mid-June off Point Arena, California (at lat 39°N). Within the range of eulachon marine distribution north of approximately lat 40°N, the average peak of upwelling occurs "in late July at 45°N (off Newport, Oregon)" (Harvey et al. 2021a, p. 5). The amount of upwelled nutrients delivered in the form of nitrate "at 39°N is an order of magnitude greater than at 45°N or 33°N" (Harvey et al. 2021a, p. 5).

As eulachon are rarely found in marine waters south of about lat 40°N, the majority of the following summary of upwelling conditions and other regional ocean indices is confined to information centered on conditions at lat 45°N, in the vicinity of Newport, Oregon. Much of this information comes from oceanographic sampling along the Newport Hydrographic Line, which has occurred on a biweekly basis (weather permitting) since 1996 at seven stations (from one to 25 nautical miles off Newport, Oregon). Sampling includes CTD (conductivity, temperature, and depth) profiles and long-running measures of chlorophyll, nutrients, phytoplankton, copepods, krill, ichthyoplankton, pteropods, and invertebrate larvae (Peterson et al. 2014).

Our primary sources for recent observed ocean conditions in the CCE are: 1) NOAA's California Current Integrated Ecosystem Assessment (CCIEA) Status Reports (Harvey et al. 2020, 2021a,b,c), 2) recent reports on the state of the California Current (Thompson et al. 2019, Weber et al. 2021), and 3) reports on the state of the physical, biological, and other fishery resources of Pacific Canadian marine ecosystems (Chandler et al. 2015, 2016, 2017, 2018, Boldt et al. 2019, 2020b). Primary sources for recent and predicted future global ocean conditions are the Intergovernmental Panel on Climate Change's (IPCC) Special Report on Ocean and Cryosphere in a Changing Climate (SROCC; Bindoff et al. 2019) and Chapters 5 (Canadell et al. 2021) and 9 (Fox-Kemper et al. 2021) in "Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change" (IPCC 2021).

El Niño–Southern Oscillation

Under normal weather conditions in the equatorial tropical Pacific Ocean, warm surface water along the coast of South America is carried offshore to the west along the equator by trade winds.[11] This warm water is replaced by cold, upwelled water that provides nutrients to the Humboldt Current System. These normal conditions are often interrupted by the opposing hot and cold climate patterns in the tropical Pacific termed El Niño and La Niña, respectively. These cyclic equatorial SST phenomena have been termed the El Niño–Southern Oscillation (ENSO) cycle. The ENSO can be described by the Oceanic Niño Index (ONI; Figure 14), which is based on three-month running-mean SST anomalies in the Niño 3.4 region (between lat 5°N and 5°S and long 120–170°W). El Niño is characterized by a positive ONI greater than or equal to +0.5°C and La Niña is characterized by a negative ONI less than or equal to –0.5°C. These threshold SST anomalies in the Niño 3.4 region must also last for at least five consecutive overlapping three-month periods in order to be classified as either a full-fledged El Niño or La Niña. Warmer, less productive conditions off the Pacific Northwest are associated with the El Niño phase of ENSO, which occurs on average every two to seven years and may last from six to 18 months (see Climate Prediction Center[12]).

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[11] https://oceanservice.noaa.gov/facts/tradewinds.html

[12] https://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/enso.shtml

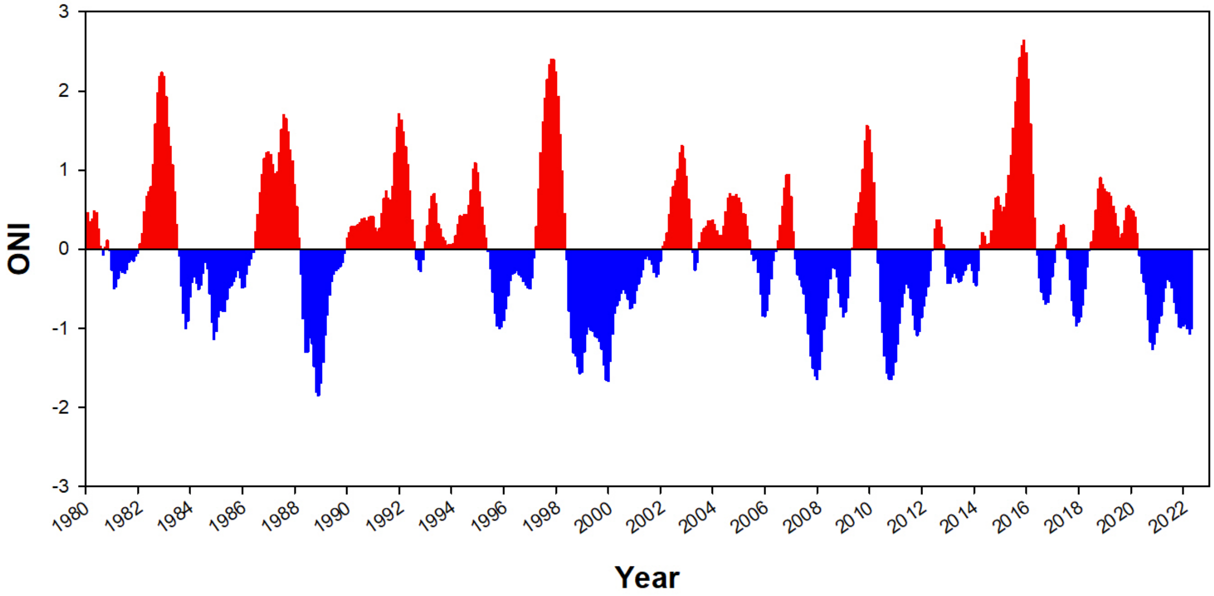

Figure 14. Time series of the monthly ONI from December 1980 through May 2022. Data source: www.integratedecosystemassessment.noaa.gov/regions/california-current/california-current-iea-indicators.

A very strong El Niño occurred from November 2015–April 2016 when ONI values up to +2.6°C were recorded (Figure 14). Weak La Niña conditions occurred from August–December 2016 and October 2017–April 2018. A weak El Niño occurred from October 2018–June 2019. Negative ONI values were reported by June 2020 (Figure 14; Harvey et al. 2021a), and La Niña conditions occurred in most months from August 2020–May 2022 (Figure 14). The current status of ENSO (as of 14 July 2022), from Climate Prediction Center, is:

> La Niña is present. Equatorial sea surface temperatures (SSTs) are below average across most of the Pacific Ocean. The tropical Pacific atmosphere is consistent with La Niña. La Niña is favored to continue through 2022 with the odds for La Niña decreasing into the Northern Hemisphere late summer (60% chance in July–September 2022) before increasing through the Northern Hemisphere fall and early winter 2022 (62–66% chance).

How various environmental factors individually influence fitness and survival of eulachon is largely unknown; however, La Niña conditions are usually associated with high productivity in the CCE, which should provide eulachon with positive growth conditions in the near term.

Pacific Decadal Oscillation

The Pacific Decadal Oscillation (PDO) index is an indicator of the ocean–atmosphere variation for the North Pacific whose opposite regimes, characterized by a positive and negative PDO, typically last for 20–30 years (Mantua et al. 1997, Mantua and Hare 2002; Figure 15). The main driver of the PDO index is variability in anomalies of monthly SST in the North Pacific (poleward of lat 20°N; Mantua et al. 1997). Negative PDO values are associated with relatively cool ocean temperatures in the Northern CCE, and positive values

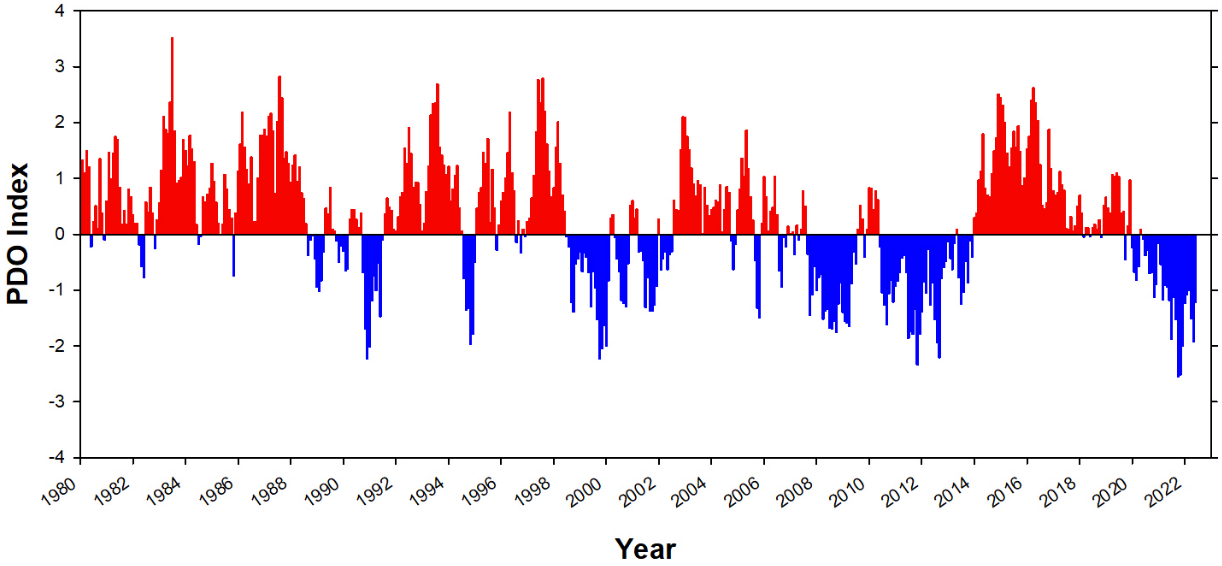

Figure 15. Monthly values for the PDO index from January 1980 through June 2022, based on SST anomalies in the North Pacific Ocean, poleward of lat 20°N. In the CCE, negative PDOs are associated with cold, productive ocean conditions and positive PDO values are associated with warm conditions. Changes in PDO regimes occur at roughly decadal scales. The PDO has remained negative since January 2020. Data source: https://oceanview.pfeg.noaa.gov/erddap/tabledap/cciea_OC_PDO.htmlTable?time,PDO.

are associated with warmer, less productive conditions. Changes in regional patterns of the PDO have been associated with variation in the abundance of numerous species in the ocean off the Pacific Northwest, including copepods (Fisher et al. 2015), forage fish (Lindegren et al. 2013), Pacific salmon (Mantua et al. 1997), and Pacific hake (McFarlane et al. 2000).

The PDO was mostly positive from January 2014 to fall 2019, indicative of poor upwelling conditions in the northern CCE (Figure 15). However, the PDO has been mostly negative since January 2020. A similar string of consecutive negative PDO values (25 months to date) has not occurred since before the beginning of the 2013–16 marine heatwave (see Marine heatwaves). This string of negative PDO values indicates “that greater upwelling of nutrient-rich deep waters to the surface occurred in the northern CCE than in the previous several years (Di Lorenzo et al. 2008)” (Weber et al. 2021, p. 5). How various environmental factors individually influence fitness and survival of eulachon is largely unknown; however, a negative PDO is associated with high productivity in the CCE, which should provide eulachon with positive growth conditions in the near term.

North Pacific Gyre Oscillation

The North Pacific Gyre Oscillation (NPGO) is a basin-scale climate index representing the second leading mode in sea surface height anomalies in the northeast Pacific Ocean as driven by variations in the circulation of the North Pacific Subtropical Gyre and Alaskan Gyre (Di Lorenzo et al. 2008). Positive NPGO values usually indicate increased equatorward flow in the California Current and are associated with increased nutrients, chlorophyll-*a*, and surface salinities (Harvey et al. 2020, Weber et al. 2021). Negative NPGOs are associated

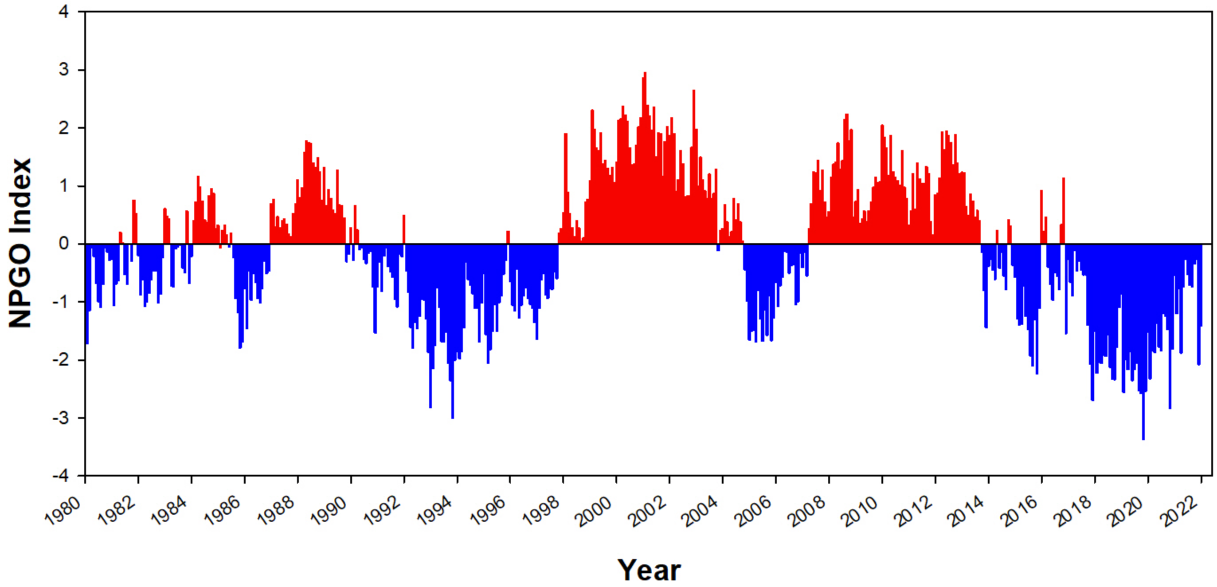

Figure 16. Monthly values for the NPGO index from January 1980 through January 2022. The NPGO is a measure of low-frequency variation of sea surface height, which relates to the source waters for the California Current Ecosystem (CCE). Negative NPGO values are usually associated with low productivity in the CCE, and positive NPGO values indicate periods of high CCE productivity. However, the CCE has been experiencing high productivity since 2020 in spite of the NPGO remaining negative. Data source: oceanview.pfeg.noaa.gov/erddap/tabledap/cciea_OC_NPGO.htmlTable?time,NPGO.

with decreased nutrients, chlorophyll-*a*, and surface salinities, “implying less subarctic source water and generally lower productivity” (Harvey et al. 2020, p. 8). The NPGO has been negative since December 2016 (Figure 16), which historically would indicate a decrease in equatorward flow in the CCE (Weber et al. 2021; Figure 16). Paradoxically, the NPGO, PDO, and ONI are all currently negative, and have been since June 2020 (Figures 14–16).

Lack of stationarity in basin-scale climate indices

As Harvey et al. (2020) stated:

> Positive ONI and PDO values and negative NPGO values usually denote conditions that lead to low CCE productivity, whereas negative ONI and PDO values and positive NPGO values are associated with periods of high CCE productivity. (p. 7)

However, Litzow et al. (2020a) have shown that:

> …the physical and ecological conditions mapping onto the Pacific Decadal Oscillation (PDO) index and North Pacific Gyre Oscillation (NPGO) index have changed over multidecadal timescales. These changes apparently began around a 1988/1989 North Pacific climate shift that was marked by abrupt northeast Pacific warming, declining temporal variance in the Aleutian

> Low (a leading atmospheric driver of the PDO), and increasing correlation between the PDO and NPGO patterns…. Since the late 1980s, both indices have become less relevant to physical–ecological variability in regional ecosystems from the Bering Sea to the southern California Current. Users of these climate indices should be aware of nonstationary relationships with underlying climate variability within the historical record, and the potential for further nonstationarity with ongoing climate change. (p. 1)

Both the PDO and NPGO indices are defined using analyses for a fixed time period, 1900–93 for the PDO and 1950–2004 for the NPGO. More recent values of these indices are derived by applying the original statistical patterns onto subsequent observations (Litzow et al. 2020a). However, this "assumes a stationary relationship between evolving patterns of ocean climate variability and the patterns identified by the original statistical definitions" (Litzow et al. 2020a, p. 1). Litzow et al. (2020a) showed that variability in the PDO and NPGO might have limited ability to predict climate conditions when applied to different time periods. An example of this is the loss of either positive or neutral correlations between PDO and Pacific salmon production that obtained during previous decades (Mantua and Hare 2002), so that PDO and Pacific salmon production are now, unlike in the recent past, negatively correlated (Litzow et al. 2020b).

Marine heatwaves

A marine heatwave (MHW) is defined as "a prolonged discrete anomalously warm water event that can be described by its duration, intensity, rate of evolution, and spatial extent" (Hobday et al. 2016, p. 227), or, more simply, as "a discrete period of prolonged anomalously warm [sea] water at a particular location" (Oliver et al. 2021, p. 314). Hobday et al. (2016) suggested that definitions of "discrete," "prolonged," and "anomalously warm" could be quantified. Discrete MHW events would have "well-defined start and end times" and could not have cool gaps of more than two days between warm events. Prolonged would generally indicate that the event "needs to persist for at least five days." Anomalously warm would be characterized relative to a high anomalous percentile threshold above the climatological value (e.g., above 90% of climatological values; Hobday et al. 2016, pp. 230–231). In the North Pacific, major MHWs are classified when daily interpolated standardized sea-surface temperature anomalies (SSTa), are greater than 1.29 times the standard deviation from normal and the minimum areal extent of the heatwave is at least 400,000 km^2 (California Current Marine Heatwave Tracker[13]).

One of the largest MHWs ever recorded began in late 2013 in the northeastern Pacific Ocean off Alaska during the boreal winter of 2013–14 and lasted into 2016. Because of its size and persistence, this patch of anomalously warm water came to be nicknamed "the Blob" (Bond et al. 2015, Di Lorenzo and Mantua 2016, Jacox et al. 2018a, Thompson et al. 2019). Peak SST anomalies were greater than 2.5°C by February 2014 in the main Blob patch (Bond et al. 2015, Di Lorenzo and Mantua 2016). During 2014, the blob continued to grow in size to the south and reached Baja California in the Southern CCE by late 2014 (Bond et al. 2015, Di Lorenzo and Mantua 2016, Gentemann et al. 2017, Jacox et al. 2018a). Some warm-water patches of the blob were greater than 4.5 million km^2 in area and persisted for over six months.

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[13] https://www.integratedecosystemassessment.noaa.gov/regions/california-current/cc-projects-blobtracker

Various hypotheses have been put forward as to what caused the 2013–16 MHW in the Northeast Pacific. Bond et al. (2015) stated:

> …these anomalies were caused by lower than normal rates of the loss of heat from the ocean to the atmosphere and of relatively weak cold advection in the upper ocean. Both of these mechanisms can be attributed to an unusually strong and persistent weather pattern featuring much higher than normal sea level pressure over the waters of interest [during the period of October 2013 through January 2014]. (p. 3414)

Thompson et al. (2019, p. 2) stated: "The warming began in the Gulf of Alaska in late 2013 when slack winds resulted in strong stratification and anomalous heating of surface waters." Di Lorenzo and Mantua (2016) combined observations and an ensemble of climate model simulations to show that:

> …teleconnections between the North Pacific and the weak 2014/2015 El Niño linked the atmospheric forcing patterns of this event. These teleconnection dynamics from the extratropics to the tropics during winter 2013/14, and then back to the extratropics during winter 2014/15, are a key source of multi-year persistence of the North Pacific atmosphere. (p. 1042)

The warm Blob reached the Northern CCE in mid-September of 2014, then subsided during spring 2015 in response to strong upwelling, only to return when upwelling weakened later in 2015 (Peterson et al. 2017, Gentemann et al. 2017). The strong El Niño of 2015–16 enhanced this coastal MHW (Jacox et al. 2016, Thompson et al. 2019). SSTs during January 2014 to August 2016 were anomalously warm along the entire U.S. West Coast, "reaching a maximum SST anomaly of 6.2°C off Southern California" (Gentemann et al. 2017, p. 312). Although the three-year period from 2014–16 was the warmest since 1920, when records began (Jacox et al. 2018a, Thompson et al. 2019), the coastal MHW in the CCE had dissipated by September of 2016 (Gentemann et al. 2017).

The coastal MHW of 2013–16 (a.k.a. the Blob) had a dramatic effect on the California Current Ecosystem (Cavole et al. 2016, Peterson et al. 2017, Cheung and Frölicher 2020). According to Peterson et al. (2017):

> At least 14 species of copepods occurred which had never been observed in shelf/slope waters off Oregon, some of which are known to have NP Gyre affinities, indicating that the source waters of the coastal "Blob" were likely of both offshore (from the west) and subtropical/tropical origin…. Impacts to the lower trophic levels were unprecedented and include a novel plankton community composition resulting from increased copepod, diatom, and dinoflagellate species richness and increased abundance of dinoflagellates. Additionally, the multiyear warm anomalies were associated with reduced biomass of copepods and euphausiids, high abundance of larvaceans and doliolids (indictors of oligotrophic ocean conditions), and a toxic diatom bloom (*Pseudo-nitzschia*) throughout the California Current in 2015, thereby changing the composition of the food web that is relied upon by many commercially and ecologically important species. (p. 7267)

Besides copepods, many other groups experienced dramatic shifts in both distribution and abundance in response to the anomalously warm waters from 2014–16, including other members of the plankton community, pelagic red crabs, pelagic fish, forage fish, seabirds, and marine mammals (Cavole et al. 2016, Peterson et al. 2017). In addition, an extensive and long-lasting harmful algal bloom (HAB) of the toxic diatom *Pseudo-nitzschia* coincided with the coastal MHW that began "nearly synchronously along the entire coast in late spring/early summer (April–June), with the onset of seasonal upwelling, and endured through the end of 2015" (Bates et al. 2018, p. 16).

A new MHW (known as NEP19 or Blob 2.0) began in mid-May 2019 in the Gulf of Alaska, and by late August 2019 had extended to the CCE off Washington to Central California (Amaya et al. 2020, Chen et al. 2021). Amaya et al. (2020) stated:

> …the 2019 Blob 2.0 primarily resulted from a weakened North Pacific High, which reduced the strength of the surface winds, resulting in reduced evaporative cooling and wind-driven upper ocean mixing in the Northeast Pacific. Consequently, strong downward surface heat fluxes were mixed over a record minimum mixed layer depth, producing surface warming in excess of 2.5°C above normal. (p. 6)

At its greatest extent, NEP19 covered about 8.5 million km^2 and lasted for 239 days. By January 2020, NEP19 had "shrunk to an area less than 100,000 km^2 and receded to a region far offshore in the Gulf of Alaska, with SST in the region mostly falling below the threshold for classification as a heatwave" (Harvey et al. 2021b, p. S-11). A new MHW formed in February 2020 (NEP20a) and covered 4.6 million km^2 at its peak in April. By June 2020, NEP20a had weakened and since "this heatwave remained >1,500 km from the coast… [it] likely had little impact on the CCE" (Harvey et al. 2021b, p. S-11).

A new MHW (NEP20b) formed in May–June 2020 (Harvey et al. 2021a) and expanded to its maximum size of 9.1 million km^2 by late September 2020. Moderate to strong upwelling apparently kept NEP20b from impacting the CCE until late September, although: "During this peak period, the second 2020 heatwave covered over 50% of the CCE… particularly in waters off central and northern California, Oregon, and Washington" (Harvey et al. 2021b, p. S-11). By 4 April 2021, NEP20b had shrunk to less than 400,000 km^2 (the area threshold for a large MHW) after lasting for 309 days. The California Current Marine Heatwave Tracker stated that "NEP20b was the 2nd largest MHW (by a slight margin) seen in this region since satellite monitoring and analysis began in 1982."

Soon after the decline of NEP20b, a new MHW (NEP21A) began to form in late April 2021 and had grown to 4.5 million km^2 by September 2021. The California Current Marine Heatwave Tracker stated that NEP21A "fell below the area threshold (400,000 km^2) for large marine heatwave classification in December 2021" and "lasted 236 days, qualifying it as the 6th longest heatwave on record."

By mid-February 2022, another MHW (NEP22A) had developed in the eastern North Pacific and covered an area of 3 million km^2. As of 14 June 2022, the California Current Marine Heatwave Tracker stated that:

> NEP22A has reached the U.S. West Coast. During May 5–19, May 22–28, and June 3–11, there were major reversals in the typical southern pattern of winds which drive upwelling along the coast, which likely allowed NEP22A to reach the coast from offshore…. Whether strong upwelling will resume and reduce the potential impacts of this 2022 MHW on the coast [is] unknown at this time.

Frölicher et al. (2018, p. 360) used earth system models and satellite data to show that MHWs "have already become longer-lasting and more frequent, extensive and intense in the past few decades" and that the number of MHW days doubled between 1982 and 2018. How MHWs influence fitness and survival of eulachon is largely unknown. Conclusions and expectations for eulachon presents some speculative associations between past MHWs and observed eulachon abundance.

Upwelling indices

Three major indices of upwelling strength in the CCE are available: 1) the Bakun Index, 2) the Coastal Upwelling Transport Index (CUTI), and 3) the Biologically Effective Upwelling Transport Index (BEUTI; Jacox et al. 2018b). Various versions of the Bakun Index are available beginning in 1946 (Bakun 1973, Schwing et al. 1996); however, from 1988 onward, the CUTI and BEUTI are the preferred indices for the U.S. West Coast from lat 31–47°N. The CUTI provides estimates of the physical vertical transport of either upwelled or downwelled water, whereas the BEUTI estimates the vertical flux of nitrate that is either upwelled or downwelled and is more relevant when analyzing biological systems (Jacox et al. 2018b). Additional information concerning these upwelling indices can be found in Jacox et al. (2018b) and at the SWFSC Environmental Research Division website.[14] See Harvey et al. (2021c, their Figure 2-7) for graphs of CUTI and BEUTI daily data for 2020, smoothed with a 10-day running mean, and presented relative to average climatological values for 1986–2019 at lat 45°N, 39°N, and 33°N.

Strong winter upwelling occurred in 2020 that "preceded the start of an average to above-average upwelling season" (Harvey et al. 2021a, p. 5). Harvey et al. (2021a, p. 5) noted that in 2020, frequent upwelling events occurred at "45°N, with peaks ≥1 SD above the mean, that were usually followed by relaxation events," and that: "When upwelling events are followed by relaxation, as occurred in 2020, the upwelled nutrients may be more likely to be retained and spur coastal production" (Harvey et al. 2021a, p. 5).

Pierce and Barth, physical oceanographers at Oregon State University, have calculated the dates of spring transition to northerly winds (the upwelling season) and fall transition to southerly winds (the downwelling season) in the CCE at lat 45°N since 1985. Spring and fall transition (Huyer et al. 1979) dates are derived from the alongshore wind stress record. Pierce

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[14] https://oceanview.pfeg.noaa.gov/products/upwelling/intro.

and Barth calculated that 2021 had the earliest date of spring transition (22 March) since 1990. A number of additional methods for estimating dates of spring and fall transition in the CCE are summarized on the University of Washington Columbia Basin Research website.[15]

How various environmental factors individually influence fitness and survival of eulachon is largely unknown; however, early and prolonged upwelling in the CCE would likely have a positive effect on eulachon growth and survival.

Copepod anomalies

Larval and juvenile eulachon are planktivorous and commonly feed upon copepods during the critical transition period between these two life stages (Gustafson et al. 2010). Osgood et al. (2016) examined historical stomach content records from the 1960s in the Strait of Georgia and found that calanoid copepods accounted for 73% of individual larval and juvenile eulachon stomach contents. There are two main suites or assemblages of copepod species over the continental shelf off the west coast of North America: a lipid-rich boreal shelf assemblage (e.g., *Calanus marshallae*, *Pseudocalanus mimus*, and *Acartia longiremis*) that normally occurs from central Oregon to the Bering Sea, and a southern assemblage (e.g., *Paracalanus parvus*, *Mesocalanus tenuicornis*, *Clausocalanus* spp., and *Ctenocalanus vanus*) that is lower in nutritional quality and usually most abundant along the California coast (Mackas et al. 2001, 2007, Fisher et al. 2015). Northern copepods are normally the dominant species off Newport, Oregon, at lat 45°N in summertime, whereas in winter, southern copepod species dominate.

Changes in the relative abundance and distribution of these copepod assemblages co-vary with oceanographic conditions (Roemmich and McGowan 1995, Mackas et al. 2001, Peterson and Keister 2003, Zamon and Welch 2005, Hooff and Peterson 2006, Mackas et al. 2007, Fisher et al. 2015). When warm conditions prevail, as during an El Niño year or when the PDO is positive, the distribution of zooplankton communities shifts to the north and the southern assemblage of copepods becomes dominant in the Northern CCE (Mackas et al. 2007, Fisher et al. 2015). The presence of these southern copepod species indicates onshore or poleward transport of water from the subtropics, whereas the presence of northern lipid-rich copepods indicates that subarctic waters are flowing equatorward (Fisher et al. 2015).

Variations in the normal seasonal cycles of northern and southern copepods are illustrated via anomalies in the abundance of northern copepods (Figure 17). Harvey et al. (2021a) noted:

> In 2020, northern copepods continued an overall increasing trend since the extreme lows during the 2014–2016 heatwave. They were >1 SD above the mean in spring/summer 2020 before their regular seasonal decline in the fall.... The spring-summer anomaly was among the highest of the time series. Southern copepods were below-average for much of 2020, continuing a decline since the heatwave.... These values suggest above-average feeding conditions for pelagic [planktivorous] fishes off central Oregon in 2020, with late-spring/summer copepod ratios the most favorable observed since before the 2014–2016 heatwave, and in nearly a decade. (p. 9)

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[15] http://www.cbr.washington.edu/status/trans

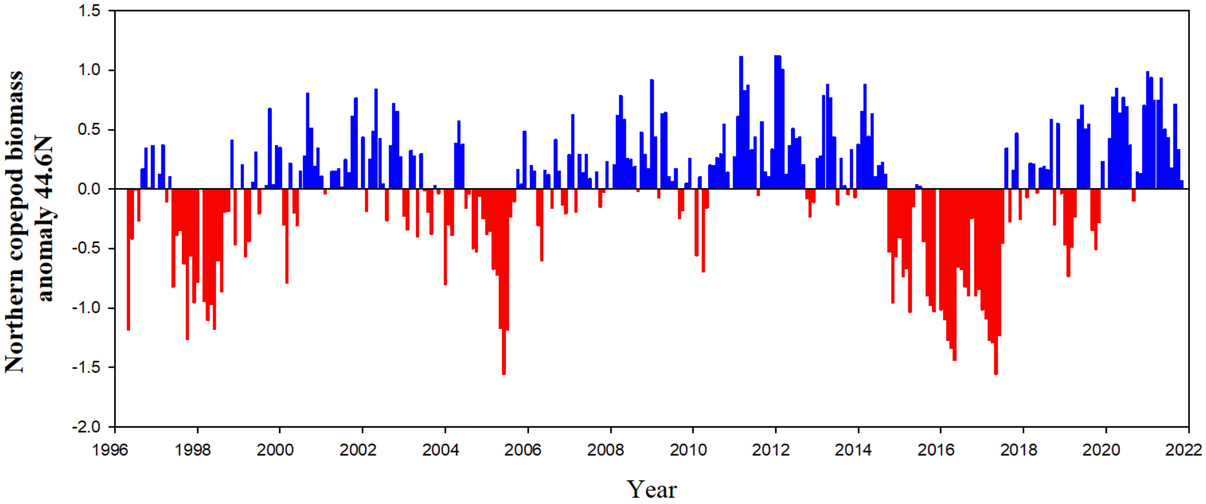

Figure 17. Monthly northern copepod biomass anomaly from station NH05 off Newport, OR (lat 44.6°N), June 1996–November 2021. Data source: oceanview.pfeg.noaa.gov/erddap/tabledap/cciea_EI_COP.htmlTable?time,northern_copepod_biomass_anomaly.

The recently released Ocean Indicators Summary for 2021 (NOAA Fisheries website[16]) stated:

> Throughout 2021, northern copepods continued an increasing trend that began in 2020 after prolonged negative biomass anomalies from 2015–2017. The biomass anomalies remained strongly positive throughout the year, with the spring–summer anomalies ranking the highest in the 24-year time series…. The transition from a warm-water lipid-deplete winter copepod community to a cold-water summer community occurred on April 16 in 2021. The past two years mark the earliest transition dates since before 2014.

As noted in Environmental indices and eulachon abundance trends, both Montgomery (2020) and Hay and Schweigert (personal communication) found significant correlations between the presence of an abundance of northern copepods in the CCE and trends in eulachon abundance, two and three years later, in the Columbia River. The current abundance of northern copepods and depressed numbers of southern copepods in the CCE would be expected to result in increased eulachon survival, and suggest that eulachon returns to the Columbia River may remain relatively elevated, at least in the near term.

Krill abundance

Euphausiids (a.k.a. krill), principally *Thysanoessa spiniferia,* are the principle prey item of juvenile eulachon in the open ocean (Hay 2002). Therefore, the following discussion is centered on *T. spinifera*. In the CCE near Newport, Oregon, the numerically dominant euphausiids are *Euphausia pacifica* and *T. spinifera* (Gómez-Gutiérrez et al. 2005). These two species are most abundant during summer, but are present throughout the year. According to Fisher et al. (2020):

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[16] https://www.fisheries.noaa.gov/west-coast/science-data/ocean-indicators-summary-2021#zooplankton

> …*E. pacifica* is the most abundant species of euphausiid in the NCC [Northern California Current], but *T. spinifera* has a higher potential energetic content due to its larger body size and higher lipid density…. *E. pacifica* are generally found offshore of or along the shelf break…. *T. spinifera* are concentrated closer to shore, mostly inhabiting the continental shelf…. *T. spinifera* had significantly higher total lipid density ($p < 0.001$; 40.65 ± 2.89 μg/mg) compared to *E. pacifica* (total lipids: 18.97 ± 1.85 μg/mg)…. Future warming events might disrupt the availability of *T. spinifera* as they are more associated with cool ocean conditions.

Cimino et al. (2020) regressed environmental data and ocean model output to quantify the habitat associations of *T. spinifera.* This species was associated with shallow areas with cold water and high levels of chlorophyll, suggesting "an affinity for coastal upwelling environments" (Cimino et al. 2020, p. 1546). *Thysanoessa spinifera* declined dramatically during the Blob. During this period, negative *T. spinifera* anomalies "along the coast were almost twice the magnitude of El Niño anomalies" (Cimino et al. 2020, p. 1546). Models for *T. spinifera* "predicted warm El Niño (cool La Niña) conditions resulted in lower (higher) than average krill abundances along much of the U.S. West Coast" (Cimino et al. 2020, p. 1546).

Hypoxia

Although hypoxia (defined here as dissolved oxygen ≤1.4 mL/L) occurs off the CCE in an Oxygen Minimum Zone (OMZ) on the continental slope below about 600 m, hypoxia in inner continental shelf waters of the CCE (in depths less than 50 m) was unknown until 2002 (Chan et al. 2008, 2019). Since reports of crab mortality in 2002 in the Dungeness crab (*Metacarcinus magister*) fishery, severe hypoxic water conditions (defined here as dissolved oxygen ≤0.5 mL/L) on the continental shelf have become a recurring phenomenon, "despite the absence of such low values in the previous five decades of observations in the system" (Chan et al. 2019, p. 64). These low dissolved oxygen (DO) levels in shelf waters are likely to negatively impact many near-bottom species of invertebrates and fishes, including eulachon. Shelf hypoxia in the CCE is driven by upwelling, which brings nutrient-rich water of low DO content and low pH to the surface. This nutrient-rich water fuels blooms of plankton, which provide food for many organisms. However, when these plankton blooms die and sink to the ocean bottom, their decomposition consumes oxygen, often leading to hypoxia of near-bottom waters. The link is strong between the start of upwelling and emergence of hypoxic conditions over the continental shelf (Chan et al. 2019). Hypoxia in shelf portions of the CCE is most apparent in late summer and early fall (Feely et al. 2016), until the fall transition causes mixing of shelf waters.

Hypoxia now occurs regularly in the CCE over the continental shelf in summer and fall months (Adams et al. 2013, Peterson et al. 2013, Chan et al. 2019). Along the Newport Hydrographic Line near lat 45°N in summer 2020, DO levels were "above the hypoxia threshold at each station, though the seasonal mean at NH25 was close to the threshold and was at the threshold in July" (Harvey et al. 2021b, p. S-13). Hypoxic waters do not usually impact the nearshore waters of the CCE until mid-June to July; however, in 2021, the early onset of the spring transition in March (see Upwelling indices) led to hypoxic conditions over the continental shelf as early as April.

The NOAA Research News website[17] stated:

> A NOAA Fisheries survey off Washington and Oregon in late May found large phytoplankton blooms and hypoxic conditions on the continental shelf in the area of Grays Harbor, Washington. At about the same time, beachgoers reported large numbers of dead crabs washing ashore in the area of Ocean Shores, Washington. In early June and again in July, samples along the Newport Line, a long-term monitoring transect off Newport, Oregon, also showed hypoxic waters.

How eulachon respond to hypoxic water events is unknown; however, as eulachon occupy near-benthic habitats of the continental shelf at depths of 50–200 m, it is likely that hypoxic events would, at a minimum, affect their distribution in the water column. Since eulachon are very mobile, they would likely move away from areas of hypoxia.

Ocean acidification

Global increases in atmospheric CO_2 have caused an increase in the amount of CO_2 absorbed by the oceans. As Canadell et al. (2021) stated:

> Once dissolved in seawater, CO_2 reacts with water and forms carbonic acid. In turn carbonic acid dissociates, leading to a decrease in the concentration of carbonate (CO_3^{-2}) ions, and increasing both bicarbonate (HCO_3^-) and hydrogen (H+) ion concentration, which… [causes] a shift in the carbonate chemistry towards a less basic state, commonly referred to as ocean acidification. (p. 5-48)

According to the SROCC (Bindoff et al. 2019):

> Multiple datasets and models show that the rate of ocean uptake of atmospheric CO_2 has continued to strengthen in the recent two decades in response to the increasing concentration of CO_2 in the atmosphere. The *very likely* range for ocean uptake is between 20–30% of total anthropogenic emissions in the recent two decades. (p. 450)

As a consequence:

> The ocean is continuing to acidify in response to ongoing ocean carbon uptake. The open ocean surface water pH is observed to be declining (*virtually certain*) by a *very likely* range of 0.017–0.027 pH units per decade since the late 1980s across individual time series observations longer than 15 years…. These changes in pH have reduced the stability of mineral forms of calcium carbonate due to a lowering of carbonate ion concentrations….(p. 450)

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[17] https://research.noaa.gov/News/ArtMID/451/ArticleID/2779/Low-oxygen-waters-off-Washington-Oregon-coasts-risk-becoming-large-%e2%80%9cdead-zones%e2%80%9d

Since publication of the SROCC (Bindoff et al. 2019), Canadell et al. (2021) stated:

> …continued observations of seawater carbonate chemistry at ocean time series stations and compiled shipboard studies providing temporally resolved and methodologically consistent datasets have further strengthened the evidence of the progress of acidification across all regions of the oceans (p. 5-51).

Feely et al. (2016) emphasized the linkage between hypoxia and ocean acidification (OA) in the CCE. Much of the nutrient-rich, low-oxygen upwelled water that fuels productivity in the CCE also is relatively low in pH. Aragonite is a form of calcium carbonate, whose saturation state in seawater can be used as a measurement of seawater carbon dioxide concentration. An aragonite saturation state of less than 1.0 "…indicates corrosive conditions that have been shown to be stressful for many CCE species, including oysters, crabs, and pteropods" (Harvey et al. 2021c, p. 19). Since upwelled water is hypoxic and acidified relative to surface waters, "…aragonite saturation levels tend to be lowest during and following upwelling in the spring and summer, and highest during the winter" (Harvey et al. 2021c, p. 19). Aragonite saturation is measured at Stations NH05 and NH25 along the Newport Line, and Harvey et al. (2021c) stated:

> Generally, at NH05, the waters from about 15 m to the bottom become corrosive [aragonite saturation <1.0] in summer and fall, and the entire water column is above the saturation value in winter and into spring. Offshore, at NH25, waters below about 140 m remain corrosive year-round, and the annual variability is between ~50–140 m. (p. 19)

Exposure of eulachon to OA would occur during the juvenile and adult pre-spawning stages; however, as experiments on the sensitivity of various life stages of eulachon to OA have not been performed, it is uncertain how eulachon will respond to increasing OA.

Predicted changes in the California Current Ecosystem

Many of the climate modelling studies in the following section refer to two climate change scenarios, RCP 2.6 and RCP 8.5. RCP stands for "representative concentration pathways" that characterize greenhouse gas concentration trajectories used by the IPCC in their fifth Assessment Report in 2015. RCP 2.6 represents a very stringent scenario in which greenhouse gases peak in the mid-20th century and then decline over time, and RCP 8.5 represents a scenario where greenhouse gases continue to steadily increase through the end of the century (a.k.a. "business as usual," but actually a worst-case emissions outcome). In the future, the CCE is predicted to experience more frequent and intense MHWs, regional increases in wind-forced upwelling, and worsening acidification and hypoxia, which are all forecast to increase with anthropogenic climate change (Rykaczewski and Dunne 2010, Feely et al. 2016, Somero et al. 2016, Brady et al. 2017, Joh and DiLorenzo 2017, Frölicher et al. 2018, Xiu et al. 2018, Buil et al. 2021, Siedlecki et al. 2021).

In regards to MHWs, model projections of future conditions—out to the year 2100 under the IPPC climate warming scenario RCP 8.5—indicate that there will be "more prolonged multiyear warm events (>1°C) with larger spatial coverage (~18%) and higher maximum amplitude (~0.5°C for events >2°C) over the Northeast Pacific" (Joh and DiLorenzo 2017, p. 11663).

Additional model simulations by Frölicher et al. (2018) indicate that the number of MHW days:

> …is projected to further increase on average by a factor of 16 for global warming of 1.5 degrees Celsius relative to preindustrial levels and by a factor of 23 for global warming of 2.0 degrees Celsius…. [M]odels project an average increase in the probability of MHWs by a factor of 41…. However, current national policies for the reduction of global carbon emissions are [by the end of the twenty-first century, for global warming of 3.5°C]…. At this level of warming, MHWs have an average spatial extent that is 21 times bigger than in preindustrial times, last on average 112 days and reach maximum sea surface temperature anomaly intensities of 2.5 degrees Celsius. (p. 360)

Bakun (1990, p. 198) stated that coastal, upwelling-favorable winds are generated by the "pressure gradient between a thermal low-pressure cell that develops over the heated land mass and the higher barometric pressure over the cooler ocean." Bakun (1990) hypothesized that climate warming will intensify these thermal land–sea differences, since land areas are predicted to warm twice as fast as the oceans, and should lead to more intense coastal upwelling in the CCE. Numerous studies (García-Reyes et al. 2013, Sydeman et al. 2014, Brady et al. 2017, Xiu et al. 2018, Howard et al. 2020, Quilfen et al. 2021, Siedlecki et al. 2021) have attempted to test the Bakun hypothesis by examining changes in coastal winds and upwelling intensity.

Most analyses of historical observations suggest that winds have intensified in the CCE (García-Reyes and Largier 2010, Sydeman et al. 2014, Quilfen et al. 2021); however, the mechanism behind this intensification is debatable, and therefore the Bakun "hypothesis has increasingly been challenged" (Fox-Kemper et al. 2021, p. 9-39). In regards to regional changes in upwelling intensity, Fox-Kemper et al. (2021, p. 9-39) stated that of the four eastern boundary upwelling systems, "only the California Current system has experienced large-scale upwelling-favorable wind intensification over the period 1982–2010 albeit with regional differences (García-Reyes and Largier 2010, Seo et al. 2012)." An early global simulation (Rykaczewski and Dunne 2010) using an earth system model (ESM) projected decreases in DO and increases in nutrients, productivity, and acidification in the CCE during the 21st century.

More recently, Brady et al. (2017, p. 5044) used a climate model ensemble to simulate changes in upwelling from 1920 to 2100 in the CCE and projected that CCE "upwelling will become more intense in the spring and less intense in the summer as a result of anthropogenic climate change." However, these changes will only begin to "emerge primarily in the second half of the [21st] century." Brady et al. (2017, p. 5049) argued that earlier studies (e.g., García-Reyes and Largier 2010, Sydeman et al. 2014) that attributed "observed historical trends in CCS upwelling… [to] anthropogenic climate change" were unlikely to be able to distinguish natural climate variability from anthropogenic forcing.

Xiu et al. (2018) applied a high-resolution coupled physical–biological model to the CCE from 1970 to 2049 under the RPC 8.5 greenhouse gas scenario. The results indicated an "increased upwelling intensity associated with stronger alongshore winds in the coastal region," accompanied by increased nutrient transport and a likely decrease in DO and increase in future hypoxic events (Xiu et al. 2018, p. 1). However, these impacts are predicted to vary across the CCE, with an increase in upwelling in the north and a decrease in the south.

Howard et al. (2020) utilized five dynamically downscaled earth system models to project future CCE physical and biogeochemical variables out to 2100. Results showed that global and downscaled models agreed "on significant increases in temperature and decreases in oxygen in the coastal Northeast Pacific" (Howard et al. 2020, p. 12). However, changes in upwelling, primary productivity, and nutrients were less certain. Howard et al. (2020, p. 13) concluded that basin-scale processes were "more important than the local wind changes in driving the climate response" and that "despite the substantial body of research focused on testing the Bakun hypothesis and evaluating changes in winds, shifting winds are likely not the dominant or decisive factor controlling changes in the key biogeochemical variables in the coastal CCS that have long motivated study of the sensitivity of wind-driven upwelling to climate change."

Buil et al. (2021) produced climate projections for the CCE under the high-emission scenario (RCP 8.5) by application of a regional ocean circulation model together with a biogeochemical model to downscale global earth system models. Buil et al. (2021, p. 1) found that "all models agree in the direction of the future change in offshore waters: an intensification of upwelling favorable winds in the northern CCS, an overall surface warming, and an enrichment of nitrate and corresponding decrease in dissolved oxygen below the surface mixed layer." Siedlecki et al. (2021) also utilized multiple models downscaled to the CCE to project future trajectories of temperature, O_2, pH, CO_2, and carbonate saturation state. Siedlecki et al. (2021, p. 2871) found that "projected changes for the CCS are consistent with the directional trends indicated by the global model for scenario RCP 8.5—warmer, more acidified, higher carbon content, and lower oxygen concentration." These changes are expected to be most intense in the northern CCE (Siedlecki et al. 2021), similar to the findings of Xiu et al. (2018).

Recently, Quilfen et al. (2021) examined estimated trends in upwelling winds using satellite wind analyses and atmospheric model reanalyses in the CCE for 1996–2018. The start and end years were chosen because they are not influenced by particular positive or negative phases of the ENSO, PDO, or NPGO. Results show a 25% increase in winter and spring upwelling-favorable winds within the Central CCE (Cape Blanco, Oregon, to Point Conception, California), which "is associated with a local increase of more than 25% in the seasonal upwelling transport index, as found with satellite products" (Quilfen et al. 2021, p. 14).

Predicted changes for coastal British Columbia eulachon

Weatherdon et al. (2016) employed a dynamic bioclimate envelope model (DBEM) to predict changes in abundance, distribution, and catch potential of species of commercial and cultural importance to coastal British Columbia First Nations under both the lower (RCP 2.6) and higher (RCP 8.5) greenhouse gas emission scenarios. For eulachon, changes in relative abundance were projected to decline from 2000–50 by 26.4% and 35.7% under the lower and upper scenarios, respectively (Weatherdon et al. 2016). Projected poleward range shifts for eulachon from 2000–50 on the British Columbia coast were estimated at 32.9 km/decade under RCP 2.6 and 39.5 km/decade under RCP 8.5 (Weatherdon et al. 2016). Change in catch potential for eulachon from 2000–50 declined by 22.7% and 37.1% under RCP 2.6 and 8.5, respectively (Weatherdon et al. 2016). Although two other models, AquaMaps and Maxent, corroborated eulachon catch declines, these models gave significantly more conservative estimates of 5.0% and 6.8% declines, respectively (Weatherdon et al. 2016).

Observed and predicted future freshwater conditions

Predicted changes for Columbia River eulachon

Sharma et al. (2017) modelled historic conditions and future climate change scenarios for monthly runoff in the lower Columbia River and its major eulachon spawning tributaries. Sharma et al. (2017) also modelled historic and future climate change scenarios for mean monthly (January, February, March) water temperatures in the lower Columbia River below Bonneville Dam. Results (Sharma et al. 2017) of the modelled monthly flow under several climate change scenarios indicated:

> The March freshet was projected to increase or remain steady in all hydrologic units, as overall increases in winter precipitation in future climate change scenarios compensate for a smaller snowpack. Notably, early and mid-winter flows are significantly higher for hydrologic units with headwaters in snow-dominant areas, presumably because more precipitation in future climate change scenarios falls as rain and less as snow, leading to earlier runoff. In the Cowlitz River Basin… December–February combined runoff is projected to increase 26% from the baseline historic period to the 2040s, and 44% from the baseline historic period to the 2080s. Similar, but less dramatic increases are projected to occur in the Sandy and Lewis basins…. The lower basins (Skamokawa, Elochoman, Kalama and Grays…) experience only small increases in early–mid-winter runoff, because they are historically rain-dominant. These projections suggest that a reduction in the March freshet, which would likely be detrimental to the outmigration of future eulachon runs, may not be a concern in the lower Columbia tributaries, but a shift to earlier peak flows may change run timing (or protract the outmigration period). (p. 114)

Although management of dams and reservoirs acts to control and smooth out flows in the Columbia River, “Increasing rainfall and less snowfall in the Upper Columbia River Basin is projected to cause the peak in available discharge to occur earlier in the spring, and likely increase the overall water supply during the winter months while decreasing it during the late spring and summer months” (Sharma et al. 2017, p. 117).

Since water temperatures and water temperature models for the winter months are not available for the lower Columbia River, Sharma et al. (2017) projected:

> …air temperature increases (January–March) from the ensemble climate change scenarios… onto the historical water temperature record of the Columbia River at Bonneville. In order to do this, it was necessary to convert air temperature increases to water temperature increases…. Morrill et al. (2005) examined the historic water temperature of a group of disparate streams and rivers, and found an average ratio of increase of +0.7°C water temperature for each increase of +1.0°C air temperature. We applied this 0.7:1.0 ratio increase to projected air temperature increases for future climate

> change scenarios to the historical water temperature record. As part of this process, it was also necessary to adjust for the difference between the climate change scenarios baseline period (1916–2006) and the period of the Columbia River temperature data (1965–2014). To do this, we used the Pacific Northwest Index…. We then summarized the mean water temperature in the Lower Columbia River by month for the historic and future scenarios. (p. 119)

Smith and Saalfeld (1955) reported that eulachon are present in the Columbia River when water temperatures are between 2°C and 10°C, and delay migration into spawning tributaries until temperatures at the Bonneville Dam forebay are above 4.4°C (WDFW and ODFW 2001). However, Sharma et al. (2017) stated:

> …under all future climate change scenarios, a 4.4°C water temperature threshold appears irrelevant, as winter water temperatures will rarely dip below this mark, if at all. For in-migrating eulachon adults, it may mean that this will allow earlier migration into the system, as warmer water temperatures may be hospitable throughout the winter for spawning. This effect could potentially be beneficial to eulachon, in that it could allow for a longer spawning period, and different life cycle strategies to take advantage of this. However, higher water temperatures in coldwater fish during rearing causes a faster development but smaller size at hatch. Without adequate food sources, these fish are disadvantaged in their growth and development. There is also a potential for ill effects on out-migrating larvae, if they leave their natal rivers earlier in the winter, and their arrival in the ocean is mismatched with spring upwelling periods off of Oregon and Washington, which usually don't begin until April, and usually peak in early summer…. Further complicating matters, changes to the intensity and period of upwelling off the NE Pacific coast (i.e. the California Current) are uncertain under future climate conditions…. (p. 120)

Vulnerability of eulachon to climate change

Moyle et al. (2013) evaluated potential climate change effects on 164 freshwater fish species in California, including eulachon, through application of expert knowledge by four scientists to score each fish species across ten metrics for vulnerability to impacts of future climate change. Each of the ten ecological, physiological, or behavioral characteristics of each species were given scores of 1–3 or 1–4, with lower scores indicating that the characteristic gave the species a greater vulnerability to climate change. Species were classified into five categories based on their climate change vulnerability (Vc) scores (in parentheses): critically vulnerable (<17), highly vulnerable (18–22), less vulnerable (23–27), least vulnerable (28–32), and likely to benefit from climate change (>32). Total climate change vulnerability (Vc) scores could potentially range from 10 for critically vulnerable to 35 for likely to benefit from climate change (Moyle et al. 2013). The mean Vc score for eulachon in this exercise was 18.8, with a range of 15–20, indicating that eulachon in California are "highly vulnerable" to climate change and that "[t]he species is on the path towards extinction as the result of climate change" (Moyle et al. 2013, their Tables 2 and 4).

Moyle et al. (2013) classified fully 83% of native freshwater fishes in California as either critically or highly vulnerable to climate change using their expert knowledge framework. According to Moyle et al. (2013):

> Predicted climate change effects on freshwater environments in California will dramatically change the fish fauna. Principally, most native fishes will become more restricted in their distributions and many will ultimately be driven to extinction if present trends continue. (p. 10)

McClure et al. (in preparation) have initiated a California Current fish stock climate vulnerability assessment following the methodology developed by NMFS and described in Morrison et al. (2015) and Hare et al. (2016). Crucial steps in this vulnerability assessment include expert scoring for: 1) climate exposure variables impact on each species (e.g., mean SST, phenology of upwelling, etc.), 2) biological and ecological sensitivity attributes of each species (e.g., habitat specificity, population growth rate, etc.), 3) the quality of data used in the assessment, and 4) the directional effect of climate change for each species (whether negative, neutral, or positive on the species). Experts scored each climate exposure variable and sensitivity attribute as low, moderate, high, or very high using a five-tally scoring system, where each expert had five points or tallies to distribute across four bins (low, moderate, high, very high) depending on their level of certainty. To score the anticipated directional effect of climate change on a species, experts had four tallies to distribute across three bins (negative, neutral, or positive). Further methodological details are in Morrison et al. (2015) and Hare et al. (2016).

The Southern DPS of eulachon had an overall climate vulnerability ranking of "moderate," with a 79% certainty from bootstrap analysis (McClure et al. in preparation). Eulachon had a "high" overall climate exposure score. Primary drivers of the climate exposure score included ocean acidification (mean = 3.8) and mean sea surface temperature (mean = 3.2). The primary drivers of eulachon's moderate biological sensitivity score were: complexity in reproductive strategy (mean = 3.1), spawning cycle (mean = 2.9), other stressors (mean = 2.6), and early life-history survival and settlement requirements (mean = 2.5). It was noted that eulachon spawn timing is temperature-dependent and thus sensitive to climate change. Eulachon larval use of estuarine environments and post-larval dependence on the presence of preferred prey organisms at the time of ocean entry also highlight eulachon's sensitivity to climate change. McClure et al. (in preparation) noted that estuarine environments and upwelling conditions are especially susceptible to environmental change. These analyses indicate that climate change is likely to have a negative effect on the Southern DPS of eulachon. McClure et al. (in preparation) noted:

> Significant changes in southern eulachon spawning distribution were observed, with decadal gaps in spawning occurrence and/or very low spawner abundance. These changes were linked to warming temperatures. (p. 244)

Conclusions and expectations for eulachon

Climate change effects on ocean conditions remains the greatest cause for concern regarding population recovery of the Southern DPS of eulachon. From late 2013 to mid-2017, the CCE experienced both a severe MHW in the form of the Blob (2013–16) and a strong El Niño event (2015–16). The period from 2014–16 "was the warmest 3-year period on record, with mean SSTa of 1.3°C, 3.1… [SD] above the mean of all 3-year periods from 1920–2016" (Jacox et al. 2018a, p. S29). The impact of the Blob on eulachon abundance is likely reflected in the 2018 Columbia River SSB estimate of slightly more than four million fish, the lowest estimate since 2010 (Table 2, Figure 7). Eulachon returning to the Columbia River in 2018 were mostly from the broodyears 2015 or 2016, which would have entered the CCE in spring or summer of those years when both the Blob and the strong El Niño of 2015–16 were active. These anomalously warm oceanographic conditions had a strong effect on the quality of the zooplankton prey community forming the base of the food web in the ocean. The Estuarine and Ocean Ecology Program[18] at NWFSC describes the biological spring transition in the coastal ocean as the date the copepod community switches "from a winter (warm water) community to a summer (cold-water) community." In 2015 and 2016, the biological spring transition never occurred, as lipid-rich northern copepods were absent from surveys along the Newport Hydrographic Line during both years. In addition, Brodeur et al. (2019) stated:

> The community of taxa in both 2015 and 2016 was significantly different from the previously sampled years. Crustacean plankton densities (especially Euphausiidae) were extremely low in both of these years, and the invertebrate composition became dominated mostly by gelatinous zooplankton. (p. 1)

Since euphausiids are the primary prey of juvenile and adult eulachon in the CCE, these low densities of euphsiids during the Blob likely had long-lasting negative impacts on eulachon growth and survival.

Another MHW developed in May 2019 that was as large and intense as the Blob, but did not extend as deep into the water column and diminished in the fall. This MHW came ashore from Washington to Central California by late August, but few data are available to assess its ecological impact on the Northern CCE (Harvey et al. 2020). Nevertheless, Harvey et al. (2021c, p. 29) noted: "Biological and ecological survey data suggest average to above-average feeding conditions in 2020 in much of the CCE, although… [these data] should be interpreted with care: survey effort was reduced in 2020 due to COVID-19, and many samples have yet to be processed."

Two additional MHWs were observed in the North Pacific in 2020 and 2021, but mostly stayed offshore. Whether the current MHW in the eastern North Pacific (NEP22A) will similarly stay offshore of the CCE is uncertain. Although a weak El Niño event occurred from late 2018 into 2019, it had minimal impact on the CCE. ENSO-neutral conditions prevailed for the second half of 2020 and first half of 2021. La Niña conditions prevailed from August 2020–May 2021, redeveloped in October 2021, and are forecast to persist into the Northern Hemisphere in winter 2022–23 (Figure 14).

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[18] https://www.fisheries.noaa.gov/west-coast/science-data/estuarine-and-ocean-ecology-pacific-northwest

From 2014 to late 2019, the PDO index was mostly positive, while the NPGO index was mostly negative (Figures 15 and 16), both of which indicate warm, low-productivity conditions in the CCE. The PDO switched to a negative state in 2020 and remained negative at the time of this writing in July 2022 (Figure 15). Paradoxically, the NPGO index did not similarly switch states in 2020 and has remained in a negative state since 2016 (Figure 16).

Both a negative PDO and La Niña conditions are associated with high productivity in the CCE, which should provide eulachon with positive growth conditions. Other indications of the presence of good ocean conditions for eulachon are the northern copepod biomass anomaly, which was mostly positive in 2020 and remained positive throughout 2021 (Figure 17). Early and strong upwelling in 2020 and 2021 fueled very productive conditions in the CCE. However, this high level of primary production likely led to the widespread near-bottom hypoxia on the continental shelf off Washington and Oregon in 2021. How eulachon respond to these hypoxic water events is unknown.

The near-term outlook for eulachon productivity in the CCE is positive, based on the presence of good ocean conditions for the most-recent three years. The productivity potential, as indicated by life-history characteristics such as low age-at-maturity, small body size, planktonic larvae, and perhaps their high fecundity, confers eulachon with some resilience to environmental perturbations, as they retain the ability to rapidly respond to favorable ocean conditions.

Eulachon Bycatch

Eulachon bycatch in U.S. West Coast groundfish fisheries, 2002–19

Several previous reports (Gustafson et al. 2015, 2017, 2019, 2021) have provided data on estimated bycatch of eulachon in U.S. West Coast commercial groundfish fisheries. Data for these reports were derived from the West Coast Groundfish Observer Program (WCGOP) and the At-Sea Hake Observer Program (A-SHOP), both of which are administered by the Fisheries Observation Science Program in NWFSC's FRAM Division.

Most recently, Gustafson et al. (2021) estimated eulachon bycatch for each individual U.S. West Coast federal groundfish fishery sector that encountered eulachon during 2002–19. The following commercial federal groundfish fishery sectors were active and observed for eulachon bycatch from 2002–19:

- Individual Fishery Quota (IFQ) bottom trawl (2011–19).
- IFQ non-hake midwater trawl (2011–14).
- IFQ shoreside Pacific hake (*Merluccius productus*) (2011–14).
- IFQ shoreside midwater Pacific hake (2015–19).
- IFQ shoreside midwater rockfish (2015–19).
- At-sea Pacific hake catcher–processor fishery (2002–19).
- At-sea Pacific hake non-tribal mothership fishery (2002–19).
- At-sea Pacific hake tribal mothership fishery (2002–12).
- Limited entry (LE) bottom trawl (2002–10).

Table S8 presents a summary of the permits, gear used, target groups, vessel lengths, fishing depths, and management of these fishery sectors. Gustafson et al. (2021) reported bycatch ratios for eulachon as weight (kg) and as number of individual fish caught/mt of total groundfish or Pacific hake or groundfish retained per haul. These ratios were then used to estimate eulachon bycatch in the fleet sectors where only a portion of the total trips were observed. Data sources and bycatch estimation methods for eulachon bycatch in U.S. West Coast groundfish fisheries in 2002–19 are provided in Gustafson et al. (2021).

Catch share: Non-hake bottom and midwater trawl IFQ fishery bycatch

Since 2011, the U.S. West Coast groundfish trawl fishery has been managed under the Catch Share Program, which led to the establishment of IFQs. Under this program, all participating vessels were required to carry a WCGOP observer on all fishing trips, resulting in 100% observer coverage. Bycatch estimation data were combined for the bottom and midwater sectors from 2011–14 to maintain confidentiality standards despite very low activity in the non-hake midwater trawl sector in that year. Starting in 2015, this sector includes only bottom trawl, and all shoreside non-hake midwater trawl is reported separately as IFQ shoreside midwater rockfish trawl. Beginning in 2015, vessels fishing bottom or midwater trawl gear could apply for a Pacific Coast Groundfish EM Exempted Fishing Permit and use electronic monitoring (EM) rather than an observer for monitoring of IFQ and some protected species. Fleetwide eulachon bycatch for this sector is almost completely known because all vessels were required to use EM or an observer. Rarely, entire hauls may not be sampled due to unforeseen circumstances (e.g., sickness of observers). Bycatch estimation methods for these rare events were detailed in Gustafson et al. (2021). Bycatch data for these fisheries were summarized by year and state of landing (Gustafson et al. 2021).

From 2011–14, 439 individual eulachon were estimated as fleetwide bycatch in the Washington IFQ non-hake bottom and midwater trawl fisheries (Table S9). However, no eulachon were observed or estimated as bycatch in the Washington sector from 2015–19. Between 2011 and 2019, the Oregon IFQ non-hake bottom and midwater trawl fisheries had an estimated eulachon bycatch of 5,127 individual fish, with 49% (2,510 individuals) of this total occurring in the year 2014 (Table S10). Eulachon bycatch in the Oregon sector declined from this high point in 2014 to an estimated 11 fish during 2017; however, this trend reversed in 2018 and 2019, with estimated bycatch increasing to 334 fish in 2018 and 760 fish in 2019 (Table S10). Two bycaught eulachon were recorded in the California IFQ non-hake bottom and midwater trawl fisheries in 2015; however, no eulachon occurred as bycatch in this sector either before or after 2015 (Table S11).

At-sea Pacific hake fishery bycatch

Eulachon bycatch in the at-sea Pacific hake fishery was reported by year and by two subsectors: catcher–processors (CP) and mothership–catcher vessels (MSCV). Gustafson et al. (2021) reported combined non-tribal and tribal MSCV data, and the current report does likewise. All vessels fishing in the at-sea Pacific hake fishery carry two A-SHOP observers for every fishing day (i.e., 100% coverage). Rarely, entire hauls may not be sampled due to unforeseen circumstances (e.g., observer illness). Bycatch estimation methods for these rare events were detailed in Gustafson et al. (2021).

Eulachon are encountered sporadically in the at-sea Pacific hake fishery as bycatch. The at-sea CP sector of the Pacific hake fishery has caught more eulachon than other at-sea Pacific hake sectors (Gustafson et al. 2021). However, no eulachon bycatch was observed in the CP sector from 2002–05, or in 2010 (Table S12). Between 2002 and 2019, eulachon bycatch in the at-sea CP Pacific hake fishery exceeded an estimated 50 fish in 2006 (147 fish), 2011 (1,268 fish), 2014 (242 fish), 2015 (56 fish), 2018 (259 fish), and 2019 (889 fish; Table S12). In all other years, fewer than 40 individual eulachon were observed in the CP Pacific hake sector (Table S12). The bycatch estimate in 2011 of 1,268 fish amounted to 42% of the total estimate of 3,009 fish from 2002–19. In the most recent years of 2018 and 2019, 259 and 889 eulachon were estimated as bycatch in the at-sea Pacific hake CP sector, respectively (Table S12). These bycatch levels represent 9% (2018) and 30% (2019) of the 2002–19 total bycatch, and are in contrast to the relatively low bycatch in 2016 of 2 fish and in 2017 of 18 fish (Table S12).

The combined non-tribal and tribal MSCV Pacific hake sector had a total estimated eulachon bycatch of 816 individual fish from 2002–19, with 34% of this bycatch occurring in 2013 (277 fish) and 24% in 2019 (199 fish). The tribal mothership fishery has not operated since 2012. No eulachon bycatch occurred in 2002–06 or in 2010 or 2015, and fewer than 10 individual fish were caught in 2007, 2008, 2012, or 2016 in this sector (Table S13). In the most recent years of 2018 and 2019, 26 and 199 eulachon were estimated as bycatch in the at-sea Pacific hake MSCV sector, respectively (Table S13).

Catch share: Shoreside Pacific hake fishery bycatch, 2011–14

The shoreside Pacific hake fishery operated under an IFQ system as part of the Catch Share Program and was defined as shoreside catcher vessels fishing midwater trawl and targeting Pacific hake according to the captain's logbook. Under catch share regulations, each shoreside hake vessel is required to carry a WCGOP observer, resulting in 100% compliance monitoring. Observers do minimal sampling at sea unless discards occur, as most hauls are retained entirely and the landed catch is sorted and weighed at the plants by catch monitors. At-sea discards and landings data are combined to estimate total catch. Because catch monitors only weigh landed catch, shoreside eulachon discard information is available as weight but not counts. Therefore, eulachon bycatch numbers were estimated from weight information using a regression fit to count and weight data from discard in other groundfish fishery sectors.

WCGOP began observing bycatch in the shoreside Pacific hake fishery in 2011, and did not record any eulachon bycatch in this fishery in 2011, 2012, or 2014 (Table S14). However, in 2013, shore-based catch monitors recorded the bycatch of 83.5 kg of eulachon in this fishery. Since bycaught fish are weighed but not counted in this fishery, a linear weight–count regression based on data from other catch share fishery sectors was used to estimate that 83.5 kg of eulachon was equivalent to 1,393 individual eulachon (Table S14).

Catch share: IFQ shoreside midwater Pacific hake trawl and rockfish trawl bycatch, 2015–19

Prior to 2015, this sector was defined as either the shoreside hake or IFQ non-hake midwater trawl fishery. Since 2015, the shoreside midwater sector of the IFQ fishery has been redefined and is now reported separately as the Pacific hake midwater trawl sector and the rockfish midwater trawl sector. The Pacific hake fishery consists of trips fishing midwater trawl gear landing more than 50% Pacific hake by weight on a landing day. The rockfish fishery consists of trips fishing midwater trawl gear landing more than 50% midwater rockfish by weight on a landing day. All non-EM IFQ vessels carry an observer on every fishing trip, and WCGOP only observes discards that occur at sea. The EM portions of these sectors function as full-retention fisheries, and nearly 100% of bycatch in these fisheries is sampled and weighed by catch monitors after being landed. Therefore, numbers of bycaught eulachon were estimated using a linear weight–count regression based on data from all other catch share eulachon discard observations. Non-EM and EM eulachon bycatch data for these two sectors have been combined in this report (Table S15); however, when confidentiality rules allowed, non-EM data and EM data were reported independently in Gustafson et al. (2021).

No recorded eulachon bycatch occurred in either the midwater hake or the midwater rockfish sectors in 2015 or 2016 (Table S15). In 2017, 0.5 kg of eulachon bycatch was recorded in the midwater rockfish sector, equivalent to eight individual eulachon (Table S15), and 0.9 kg of eulachon bycatch was recorded in the midwater Pacific hake fishery, equivalent to 15 individual eulachon (Table S15). No eulachon bycatch occurred during 2018 in the midwater Pacific hake fishery (Table S15); however, an estimated 163 eulachon were incidentally caught in the 2018 midwater rockfish fishery (Table S15). Bycatch increased in 2019 to an estimated 788 and 485 eulachon in the midwater Pacific hake and the midwater rockfish sectors, respectively (Table S15).

Limited entry bottom trawl fishery bycatch

The LE bottom trawl fishery was a multispecies fishery (2002–10) that targeted various groundfish species. The data were stratified by year, state of landing, and season in Gustafson et al. (2021). Since 2011, this fishery has been managed under an IFQ system, and those more recent data are reported in the above non-hake bottom and midwater trawl section. Eulachon were not observed as bycatch in the LE bottom trawl fishery in Washington from 2002–10 (Table S16). Within the Oregon portion of the LE bottom trawl fishery, eulachon bycatch occurred in four of the nine years from 2002–10, with 81% (837/1,034 fish) of this estimated bycatch occurring in the year 2002 (Table S16). However, eulachon bycatch was not recorded in the Oregon LE bottom trawl fishery in 2004, 2005, 2006, 2008, or 2010 (Table S16). Eulachon were rarely caught in the California LE bottom trawl fishery from 2002–10, with only an estimated five fish in 2004 and 21 estimated fish in 2010 (Table S16; Gustafson et al. 2021).

Summary of eulachon bycatch in U.S. West Coast groundfish fisheries

Across 18 years of observation (2002–19), a total of 13,305 individual eulachon were estimated to have been caught as bycatch in all federal groundfish sectors of the U.S. West Coast groundfish fishery (Table S16, Figure 18; Gustafson et al. 2021).[19] About 60% of this bycatch occurred during the five-year period from 2011–15, when efforts to identify eulachon in the bycatch of these fisheries became a priority and when other indices of eulachon abundance were highly positive. Total fleetwide bycatch in U.S. West Coast federal groundfish fisheries has increased from an estimated 56 total eulachon in 2016 and 68 total eulachon in 2017, to an estimated 782 total eulachon in 2018 and 3,121 total eulachon in 2019 (Table S16, Figure 18; Gustafson et al. 2021).

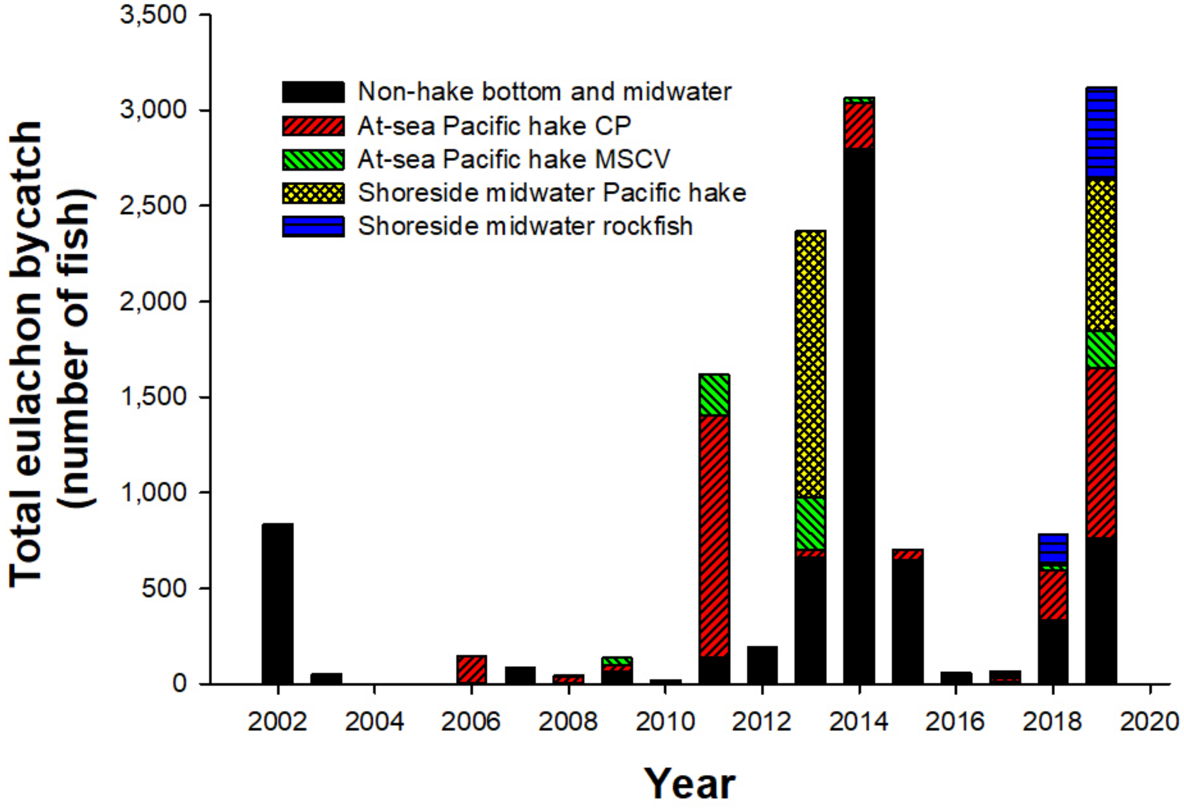

Figure 18. Estimated bycatch of eulachon in U.S. West Coast groundfish fisheries, 2002–19. Data from Table S16. CP = catcher–processors, MSCV = mothership catcher vessels (combined non-tribal and tribal mothership sectors).

From a conservation biology perspective, it is important to examine not only estimated bycatch and discard mortality but also the fate of non-target organisms that escape from trawl nets prior to being hauled aboard fishing vessels. Davis and Ryer (2003, p. 8) stated: "…the fact that bycatch does not appear on deck, does not mean that those fish have been released from the gear unimpaired and are capable of surviving." Various terms are used for these unobserved, but ultimately lethal interactions with fishing gear: "unaccounted

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[19] Eulachon bycatch count and weight estimates were updated in Gustafson et al. (2021) and may not always match estimates previously published in Gustafson et al. (2015, 2017, 2019).

fishing mortality" (Chopin and Arimoto 1995, Suuronen 2005, Suuronen and Erickson 2010), "collateral mortality" (Broadhurst et al. 2006), "cryptic fishing mortality" (Gilman et al. 2013), and "post release mortality" (Raby et al. 2014), among others. Looking beyond mortality, Wilson et al. (2014) reviewed the available literature on sublethal effects on fitness of individual trawl escapees and classified these as either immediate sublethal effects (e.g., physiological impairment, physical injury, and reflex impairment) or delayed sublethal effects (e.g., impairment of behavior, growth, reproduction, or immune function). Wilson et al. (2014) argue that sublethal effects of encounters with fishing gear may reduce future reproductive output; however, possible fitness consequences have yet to be adequately investigated.

Currently, we have no direct data to estimate escape or avoidance mortality of eulachon in any sector of the groundfish fishery, and we are unaware of any studies that have directly investigated the fate of osmerid smelt species passing through groundfish trawl nets. Although data on survivability of passing through trawl nets by small forage fishes such as eulachon are scarce, results of several studies have shown a direct relationship between fish length and survival of various fish species escaping trawl nets through the codend mesh (Sangster et al. 1996, Suuronen et al. 1996a,b, Ingólfsson et al. 2007), indicating that smaller fish with their poorer swimming ability and endurance may be more likely to suffer greater injury and stress during their escape from trawl gear than larger fish (Broadhurst et al. 2006, Ingólfsson et al. 2007, Suuronen and Erickson 2010, Gilman et al. 2013).

Eulachon bycatch in groundfish trawl fisheries in Canada

The most recent Integrated Fisheries Management Plan (IFMP) for Fraser River eulachon (DFO 2022) indicated that bycatch of eulachon in the groundfish trawl fishery is typically low. Since 2007, eulachon bycatch in Canadian groundfish fisheries has been estimated at 0.7 mt or less, with the exception of 2012 (1.7 mt), 2013 (1.8 mt), and 2014 (4.2 mt; DFO 2022). Bycatch of eulachon in these fisheries was last estimated at less than 0.1 mt in 2021 (DFO 2022).

The IFMP (DFO 2022) stated:

> The groundfish bottom trawl fishery has been subject to 100% mandatory at-sea observer coverage for all fishing activities since 1996. Due to the ongoing global pandemic, at-sea observer services were temporarily suspended to help protect the health of observers and fishers from the spread of COVID-19. The groundfish trawl fishery continues to be subject to 100% at-sea and dockside monitoring and an emergency electronic monitoring (EM) program is being deployed as an alternative mitigating management measure for all Option A groundfish trawl vessels. (pp. 34–35)

The IFMP (DFO 2022) also stated:

> Current management measures in place for the groundfish trawl fishery include:
>
> 1. Groundfish trawl licences specifically prohibit the fishing for and retention of eulachon.
> 2. The groundfish trawl fishery is subject to 100% at-sea monitoring of all fishing events and 100% dockside monitoring of catch.

3. DFO has implemented a minimum mesh size of 76 mm (approximately three inches) in any part of a bottom trawl or mid-water trawl net, including the cod-end, for all waters of the Pacific Ocean, except for specific areas where more restrictive rules are in place as outlined in the groundfish IFMP.
4. On April 2, 2012, DFO implemented a groundfish bottom trawl closure that "froze the bottom trawl footprint on the west coast of Canada" and implemented the industry agreed upon habitat conservation measures for protection of corals and sponges in the Pacific Region groundfish trawl fishery. A benefit for eulachon of this closure was removal of current and future fishing activities in the shallow water habitat where eulachon are known to be found.
5. DFO and the groundfish trawl industry will be developing encounter protocols for eulachon that will require groundfish trawl harvesters to adjust their fishing activities when eulachon are incidentally encountered. Encounter protocols are rapid-response procedures that could include bio sampling, enhanced monitoring and reporting requirements, immediate modification to vessel/fleet fishing activity and/or implementation of spatial/temporal closures. (pp. 35–36)

Eulachon bycatch in ocean shrimp trawl fisheries

Ocean shrimp (*Pandalus jordani*) in commercial quantities are found from Point Arguello, California, north to Queen Charlotte Sound, British Columbia, typically over well defined beds of green mud or green mud and sand (Frimodig et al. 2009). *Pandalus jordani* is known as the smooth pink shrimp in British Columbia, ocean pink shrimp or smooth pink shrimp in Washington, pink shrimp in Oregon, and Pacific ocean shrimp in California. Herein we use the common name "ocean shrimp" in reference to *P. jordani* as suggested by the American Fisheries Society (McLaughlin et al. 2005). The common name "pink shrimp" has been assigned by the American Fisheries Society to *Farfantepenaeus duorarum*, a commercial species in the South Atlantic and Gulf of Mexico (McLaughlin et al. 2005). Because ocean shrimp undergo a vertical diel migration, dispersing into surface waters during nighttime hours and returning to near-bottom aggregations in the daytime (Zirges and Robinson 1980, Frimodig et al. 2009), ocean shrimp vessels generally trawl in depths ranging from 91–256 m (50–140 fathoms) during daylight hours. Previous publications have documented eulachon bycatch levels in shrimp trawl fisheries off the coasts of California, Oregon, Washington, and British Columbia (Hay et al. 1999a,b, Olsen et al. 2000, Rutherford et al. 2013, Gustafson et al. 2015, 2017, 2019, 2021).

Bycatch regulations in Canada

Following recognition that large numbers of eulachon were occurring as bycatch in Queen Charlotte Sound shrimp fisheries (Hay and McCarter 2000, Olsen et al. 2000) and of a concurrent decline in central coast British Columbia eulachon stocks, DFO closed the Queen Charlotte Sound shrimp trawl fishery in 1999, which has remained closed (DFO 2021b). In addition, concerns over eulachon bycatch in offshore west coast Vancouver Island shrimp trawl fisheries also led DFO to set eulachon bycatch action levels for WCVI. Bycatch reduction gear has been mandatory since 2000.

DFO's Shrimp Trawl Integrated Fisheries Management Plan for 2021–22 (DFO 2021b) stated:

> The incidental bycatch of [eulachon]… is of concern to First Nations since the returns of eulachon to many of the Central Coast rivers and the Fraser River have declined. Various First Nations organizations in the North Coast, Central Coast, and Fraser River have requested that the shrimp trawl fishery be closed to avoid eulachon bycatch. The Department is working with the shrimp trawl industry to minimize eulachon bycatch. Area closures, seasonal closures, and the EAL [Eulachon Action Level]… with an at-sea observer program were implemented to monitor eulachon bycatch in WCVI. Bycatch reduction devices (including rigid grates, and footrope lighting devices) are mandatory coast wide. (p. 19)

DFO (2021b, their Appendix 1) also stated that bycatch reduction devices (BRDs) consist of:

> …exclusion grate (or Nordmore grate) inserted into the forward end of the cod end of the trawl net at an angle so that it entirely blocks access to the cod end, except for the spaces between the bars. A maximum spacing of 31.75 mm (1.25 inches) on the rigid grate has been implemented as a Condition of Licence for all fishing areas other than 21OFF, 23OFF, 124OFF, 125OFF, and 27OFF. Within SMA 21OFF, 23OFF, 124OFF, 125OFF, and 27OFF the maximum spacing is 19 mm. The netting directly above the grate shall have a triangular opening (escape hole) the full width of the grate. (p. 42)

See DFO (2021b) for a description of individual SMAs. DFO (2021b, their Appendix 1) stated:

> Specific management measures for eulachon bycatch have been developed for WCVI SMAs. An at-sea observer program is funded by active industry vessel owners. The primary goal of the observer program is to monitor eulachon bycatch in WCVI SMAs. Observers are deployed by the service provider when the vessel master obtains a hail number to go fishing. The observer travels with the vessel when fishing and records information on all species in the catch, the configuration of the gear and specific tow location and duration. This information is used to monitor the eulachon-to-shrimp ratio and the eulachon catch rates…. An EAL is set annually for WCVI… to encourage active shrimp trawl harvesters to adjust their gear to minimize eulachon bycatch…. There will be no in-season adjustment to the EAL based on the WCVI surveys as in previous years. Eulachon bycatch cannot be retained. (p. 15)

Furthermore, DFO (2021b, their Appendix 1, p. 16) stated: "In the event the estimate of eulachon bycatch in a given WCVI area reaches the EAL the commercial fishery will likely close in that area." New management changes and highlights for 2021–22 relevant to eulachon bycatch issues in the DFO shrimp trawl fisheries management plan (DFO 2021b, their Appendix 1) include:

> 1.1. Mandatory Use of LED Lights
>
> Vessels fishing for shrimp by trawl must use footrope lighting devices (LEDs) on their trawl nets in all shrimp trawl management areas of the coast.

…1.5. Eulachon Action Level for West Coast Vancouver Island (WCVI)

The Eulachon Action Level (EAL) for the WCVI remains set at 4 tonnes (t). The WCVI EAL is further divided into two (2) portions, with an EAL of 2 t set for SMAs 124OFF and 125OFF combined, and 2 t set for SMAs 23OFF & 21OFF and 23IN combined.

1.6. Individual Vessel Eulachon Bycatch Limit

An individual vessel eulachon bycatch limit pilot program for SMAs 124OFF and 125OFF will be in place for the 2021/22 season. A maximum of 250 lb. of eulachon bycatch will be authorized under this pilot for each "S" and "FS" vessel fishing within SMAs 124OFF and 125OFF during the licence year. Each vessel's eulachon bycatch will be monitored by an independent at-sea observer for 100% of fishing effort.

1.7. Individual Vessel Eulachon Bycatch Limit Overage Adjustment

An individual vessel eulachon bycatch overage adjustment provision for SMAs 124OFF and 125OFF will be in place for the 2021/22 licence year. Individual vessels fishing within SMAs 124OFF and 125OFF that exceed their individual vessel eulachon bycatch limit for the 2021/22 season will have the overage amount deducted from their 2022/23 individual vessel bycatch limit. SMAs 124OFF and 125OFF will close effective 23:59 hours on February 28, 2022 even if these SMAs have remaining shrimp quota available. This closure is to allow the Department time prior to licence renewal to calculate any individual vessel eulachon overages, and prepare unique individual vessel licence conditions for the following season.

1.8. At-Sea Observer Coverage

At-sea observer coverage will be required on all fishing trips for SMA 124OFF and 125OFF during the 2021/22 season (100% observer coverage). Within SMAs 23OFF & 21OFF and 23IN coverage will be required at a rate of 25% of each vessel's fishing days in these areas during the season.

…1.11. Skeena River Estuary Area Seasonal Closure

A new seasonal closure in Pacific Fisheries Management Area 4-12 and 4-15. Those waters that include Area 4-15 and that portion of Area 4-12 in that lies south of a boundary formed by two submarine cables that cross Inverness Passage about 0.8 miles South East of Hicks Point, and then beginning 2 miles north of Hazel Point on Smith island and following the line of the two submarine cables that cross Marcus Passage and Malacca Passage, to the North end of Lawyer Island and the Ashore to Porcher Island one mile south of Hunter Point, will be closed February 15th, 2022 to March 31st, 2022 to help avoid the risk of interactions with eulachon returning to spawn. (pp. 3–4)

In regards to the mandatory use of LEDs on shrimp trawl gear, DFO (2021b, their Appendix 1) stated:

> The vessel master shall ensure that vessels fishing for shrimp by trawl use footrope lighting devices (LEDs) on their trawl nets in all shrimp trawl management areas of the coast. At all times when the trawl net is in the water;
>
> (a) the lighting devices must be operational;
>
> (b) lighting devices are emitting a green colour;
>
> (c) lighting devices are securely attached within 6 inches (15.24 cm) of the forward leading edge of the bottom panel of trawl netting; and
>
> (d) each trawl net has a minimum of five (5) lighting devices spaced 4 feet (1.22 m) apart in the central 16 feet (4.88 m) of each net. (p. 7)

Bycatch ratios in British Columbia shrimp trawl fisheries

Rutherford et al. (2013) summarized catch composition and weight of target shrimp catch and incidental bycatch, including kilograms of eulachon, for observed tows in the British Columbia commercial shrimp trawl fishery from 2002–11. A bycatch monitoring program conducted by an independent third party at-sea observer program provided annual observer coverage, which ranged from <1.0–3.4% of total coastwide shrimp tow hours. Rutherford et al. (2013) defined target shrimp catch as consisting of six species: sidestripe shrimp (*Pandalopsis dispar*), smooth pink shrimp (*Pandalus jordani*), spiny pink shrimp (*Pandalus borealis*), flexed pink shrimp (*Pandalus goniurus*), coonstripe shrimp (*Pandalus danae*), and humpback shrimp (*Pandalus hypsinotus*). Since 2002, bycatch reduction devices have been mandatory in these fisheries. Rutherford et al. (2013) did not explore the suitability of these data for estimating total and species-specific bycatch; however, we have used these data to estimate eulachon bycatch ratios from the observed portions of these fisheries as kg of observed eulachon/mt of observed target shrimp (Table S17). Annual observed catch of target shrimp and eulachon bycatch data were reported separately for each SMA and trawl type, since beam and otter trawls “have significantly different fishing characteristics” (Rutherford et al. 2013, p. 1).

Bycatch ratios expressed as observed eulachon catch (kg/mt of target shrimp) ranged from a high of 41.38 in SMA PRD in 2002 to a low of 0.09 in SMA 19 in 2008 for beam trawls, and a high of 116.38 in SMA 124OFF in 2002 and a low of 0.18 in SMA 14 in 2006 for otter trawls (Table S17). No obvious trends in eulachon bycatch ratios or correlations between SMAs or trawl types are discernible with these data.

Bycatch regulations in U.S. West Coast ocean shrimp fisheries

Ocean shrimp fisheries began in California in 1952 and expanded into Oregon and Washington by the mid- to late 1950s (Frimodig et al. 2009). Vessels that currently operate in the state-permitted ocean shrimp trawl fisheries in Washington, Oregon, and California range in size from 11.6–32 m (38–105 feet), with an average length of 19.9 m (65 feet), and can use single- or double-rigged shrimp trawl gear (Table S8).

The ocean shrimp season is open 1 April through 31 October in Washington, Oregon, and California, and vessels deliver catch to shore-based processors. Total coastwide ocean shrimp landings have ranged from a low of 1,888 mt in 1957 to a high of 46,494 mt in 2015 (Figure 19; Gustafson et al. 2021, their appendix). The portion of the bycatch that is not marketable or for which regulations prohibit landing is discarded at sea, and all discarded eulachon in this fishery results in 100% mortality. Additional information on ocean shrimp fisheries for California can be found in Frimodig et al. (2007, 2009) and online at the respective state agency websites for Washington[20] and Oregon.[21]

Currently, ocean shrimp vessels are required to use BRDs that serve as deflecting grids to guide finfish toward an escape opening, usually on the top of the net. The primary goal of mandatory deflecting grid BRDs is to reduce bycatch of groundfish species and, more recently, protected species such as eulachon. BRDs became mandatory in California in 2002 (Frimodig 2008, Frimodig et al. 2009) and in Washington and Oregon in 2003. Current regulations in Washington and Oregon, adopted by both states in 2012, require ocean shrimp trawl fishery BRDs to consist of a rigid panel or grate of narrowly spaced bars (usually constructed of aluminum) with no gaps between the bars exceeding 0.75 inches (19.1 mm). Further details on shrimp BRD requirements and fishery regulations for Washington[22] and Oregon[23] are online.

In California, approved deflecting grid BRDs for use in the ocean shrimp fishery include: 1) rigid or semi-rigid grate excluders consisting of vertical bars with no gaps between the bars exceeding 2 inches (50.8 mm); 2) soft-panel excluders, usually made of a soft mesh material with individual meshes no larger than 6 inches; and 3) fisheye excluders, which have a forward-facing escape opening that is maintained by a rigid frame. For more information, see the 2022 California Commercial Fishing Regulations Digest.[24]

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[20] http://wdfw.wa.gov/fishing/commercial/shrimp/

[21] http://www.dfw.state.or.us/MRP/shellfish/commercial/shrimp/index.asp

[22] https://apps.leg.wa.gov/wac/default.aspx?cite=220-340-500

[23] https://www.dfw.state.or.us/fish/commercial/docs/2020_Commercial_Synopsis.pdf

[24] https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=191712&inline

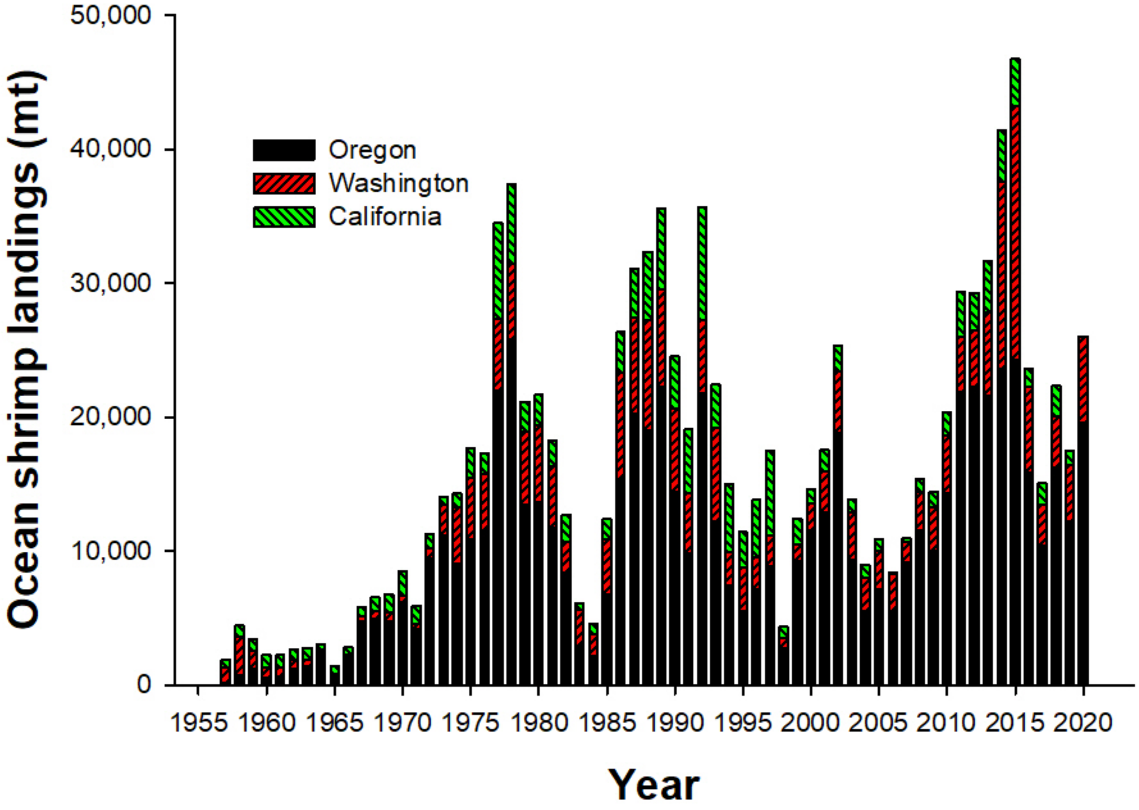

Figure 19. Commercial landings (mt) in ocean shrimp trawl fisheries off the U.S. West Coast through 2020. No landings of ocean shrimp were reported in California in 2020. Data from PacFIN (reports.psmfc.org/pacfin/f?p=501:1000::::::), CDFW (www.wildlife.ca.gov/Fishing/Commercial/Landings), Saelens (1983), Wargo and Ayres (2016, 2017a, 2018, 2019, 2020), Groth et al. (2017, 2018, 2019, 2021), Groth and Smith (2020), and Wargo et al. (2021).

As of 2018, Washington and Oregon also mandated the use of LED lights on the footrope of each trawl net. Washington regulations as stated in Wargo and Ayres (2018) are as follows:

> Washington Administrative Code 220-340-500 Commercial ocean pink shrimp trawl fishery—Coastal waters.
>
> (7) It is unlawful to fish with trawl gear for pink shrimp for commercial purposes unless footrope lighting devices that have been approved by the department are used in each net. A list of approved footrope lighting devices is available from the department.
>
> Footrope lighting devices must meet the following criteria:
>
>> (a) Lighting devices must be operational;
>>
>> (b) Lighting devices must be securely attached within six inches of the forward leading edge of the bottom panel of trawl netting; and
>>
>> (c) Each trawl net must have a minimum of five lighting devices, spaced four feet apart in the central sixteen feet of each net.

> (8) It is unlawful to modify footrope lighting devices or device placement on the footrope in any way inconsistent with subsection (7)(c) of this section, except as provided by special gear permit as described in subsection (9) of this section.
>
> (9) Testing of footrope lighting devices or placement on the footrope is allowed by special gear permit only, consistent with the terms and conditions of the permit.
>
> Three lighting devices are approved for use in 2018:
>
> 1. Lindgren-Pitman "LP Electrolume Light" – Green
>
> 2. Catch All Tackle "Deep Drop LED Fishing Light" – Green
>
> 3. Rock-engineering "LED Rope Light" – Green (p. 11)

Groth et al. (2021, p. 10) reported: "FishTek Marine 'netlight' is now an Oregon legal LED fishing light." Oregon regulations on footrope lights, as stated in Groth et al. (2018), are:

> Oregon Administrative Rule 635-005-0630;
>
> 3) It is unlawful to fish with trawl gear for pink shrimp for commercial purposes unless footrope lighting devices that have been approved by the Department are used in each net. A list of approved footrope lighting devices is available from the Department. Footrope lighting devices must meet the following criteria:
>
> (a) Lighting devices must be operational;
>
> (b) Lighting devices must be securely attached within 6 inches of the forward leading edge of the bottom panel of trawl netting; and
>
> (c) Each trawl net must have a minimum of five lighting devices, spaced 4 feet apart in the central 16 feet of each net. (p. 2)

Footrope lighting devices (FLDs), are currently being used voluntarily in California (CDFW 2022). At its 20–21 April 2022 meeting, the California Fish and Game Commission adopted CDFW's *Pink (Ocean) Shrimp*, Pandalus jordani, *Fishery Management Plan* [FMP] (CDFW 2022). This FMP proposed that regulations requiring FLDs to reduce eulachon bycatch be adopted in the California ocean shrimp fishery (CDFW 2022). An adoption hearing for implementing FLD regulations as outlined in the Pink (Ocean) Shrimp Fishery Management Plan[25] will occur in June 2022.

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[25] https://wildlife.ca.gov/Conservation/Marine/Invertebrates/Shrimp-Prawn

As part of an ESA Section 6 grant from NOAA to ODFW, WDFW, and CDFW, a year's supply of LED lights were distributed to all fishers in the state-regulated ocean shrimp trawl fisheries on the U.S. West Coast (Groth 2020). In addition, six laminated informational sheets relating to species identification of shrimp trawl bycatch and species life history were produced and distributed to fishers (Groth 2020). These informational sheets are available on the ODFW Marine Resources website.[26] One of these informational sheets illustrates identifying characteristics of typical roundfishes, including eulachon, which may occur as bycatch in the ocean shrimp trawl fisheries (Bancroft and Groth 2019). Another of these informational sheets describes and illustrates the chronological development of bycatch reduction devices in U.S. West Coast ocean shrimp trawl fisheries (Groth and Bancroft 2019).

Estimated eulachon bycatch in U.S. West Coast ocean shrimp fisheries, 2004–19

Gustafson et al. (2021, their appendix) reported observed and estimated bycatch of eulachon in ocean shrimp trawl fisheries for the years 2004, 2005, and 2007–19. The observed tows were in waters shallower than 250 m and deeper than 80 m. WCGOP did not observe the ocean shrimp trawl fishery in 2006. Data sources and bycatch estimation methods for eulachon bycatch in U.S. West Coast ocean shrimp fisheries in 2004–19 are detailed in Gustafson et al. (2021, their appendix). The following bycatch summary for U.S. West Coast ocean shrimp fisheries is based on data from Gustafson et al. (2021, their appendix), which contains additional detailed bycatch information. Bycatch in this report is presented as number of eulachon, and bycatch ratios are presented as number of eulachon caught/mt of shrimp. See Gustafson et al. (2021, their appendix) for data on bycatch weight (kg of eulachon) and bycatch ratios presented as kg of eulachon/mt of shrimp.

WCGOP began observing the Washington ocean shrimp fishery in 2010. The estimated Washington sector bycatch in terms of numbers of eulachon increased dramatically beginning in 2012, and remained elevated relative to 2010–11 through 2015. Eulachon bycatch and bycatch ratios declined significantly after 2015, only to rise again in 2018 and 2019. Estimated eulachon bycatch numbers in both 2016 and 2017 in this sector were each about an order of magnitude lower than they had been in the previous year. Total estimated bycatch of eulachon in the Washington ocean shrimp fisheries ranged from a low of over 67,000 fish in 2010 to a high of nearly 22.3 million fish in 2015 (Table S18, Figure 20). The state fleetwide bycatch count estimate of eulachon in the Washington ocean shrimp fishery declined to about 1.5 million fish in 2016 and to 442,000 in 2017. However, bycatch increased in 2018 and 2019 to over 1.4 million and 6.5 million fish, respectively (Table S18).

The Washington sector bycatch ratio, measured as number of eulachon per metric ton of retained ocean shrimp observed, was highest during 2012 (3,369 eulachon/mt shrimp) and 2013 (2,777 eulachon/mt shrimp) and lowest in 2010 (16 eulachon/mt shrimp) and 2011 (29 eulachon/mt shrimp). The high bycatch ratios of 2012–15 declined to 234 eulachon/mt shrimp in 2016 and 145 eulachon/mt shrimp in 2017 (Table S18, Figure 20); however, this ratio rose in 2018 and 2019 to 367 and 1,570 eulachon/mt shrimp, respectively (Table S18).

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[26] https://www.dfw.state.or.us/MRP/shellfish/commercial/shrimp/news_publications.asp

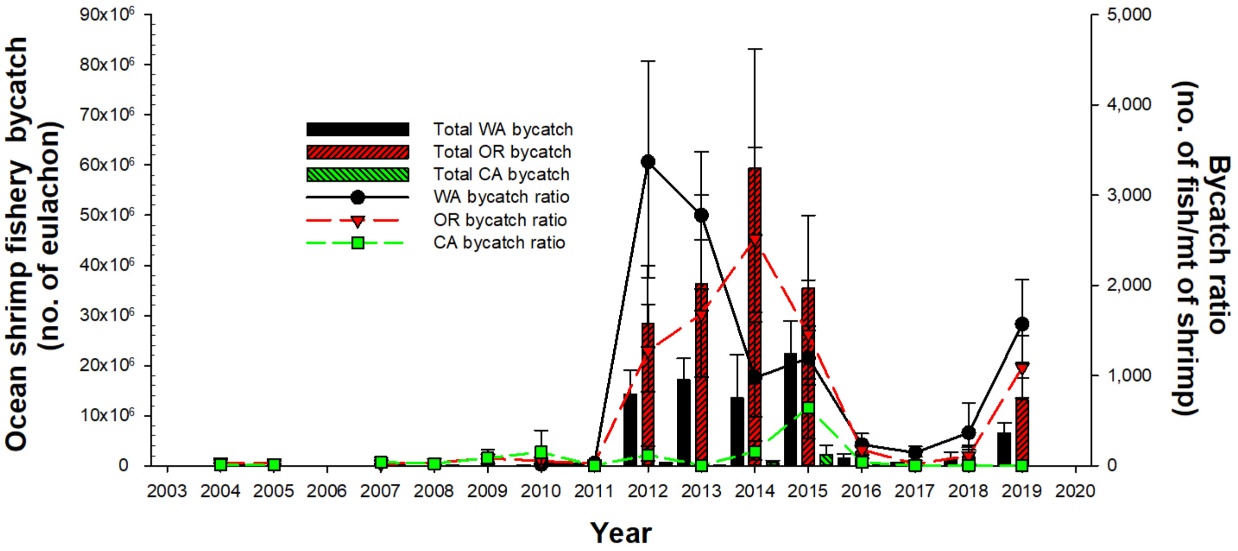

Figure 20. Estimated total bycatch and bycatch ratios of eulachon in the CA, OR (2004–19), and WA (2010–19) ocean shrimp trawl fisheries. Ocean shrimp fisheries were not observed in 2006. Error bars represent upper and lower 95% confidence intervals.

Washington bycatch ratios measured as kg of eulachon/mt of retained ocean shrimp observed are available in Gustafson et al. (2021, their Table A2). From 2010–19, the percent of total ocean shrimp landings observed by WCGOP observers fluctuated between a low of 7% (2007) and a high of 19.5% (2017) in the Washington sector (Table S18).

Eulachon bycatch in the Oregon ocean shrimp fishery was estimated at well under a million individual fish (range of about 146,000–845,000) from 2004–11 (although the fishery was not observed in 2006); however, estimated bycatch increased dramatically in 2012 and 2013 to nearly 28.4 million and 36.2 million, respectively (Table S19, Figure 20). Subsequently, estimated eulachon bycatch remained high in the Oregon ocean shrimp trawl sector, reaching over 59.3 million fish in 2014 and over 35.4 million fish in 2015 (Table S19, Figure 20). Eulachon bycatch numbers were down in the subsequent two years to about 2.8 million fish in 2016, and about 208,000 fish in 2017 (Table S19). These declines in bycatch from 2015–17 did not continue into 2018 and 2019. Eulachon bycatch numbers increased to about 1.8 million fish in 2018, and over 13.2 million fish in 2019 (Table S19).

As in the Washington sector, bycatch ratios in the Oregon sector (measured as numbers of eulachon/mt of retained ocean shrimp observed) also increased dramatically from 2011 to 2012, remained high in 2013–15, declined through 2017, but then began increasing again in 2018 through 2019 (Table S19, Figure 20). Observed bycatch ratios were at their highest in 2014 (2,517 eulachon/mt shrimp) and declined to 1,460 eulachon/mt shrimp in 2015. Further declines in bycatch ratios continued in 2016 and 2017, reaching 178 eulachon/mt shrimp in 2016 and 20 eulachon/mt shrimp in 2017 (Table S19, Figure 20). From the low point of 2017, eulachon bycatch ratios have increased by an order of magnitude in both 2018 and 2019 to 111 and 1,088 eulachon/mt shrimp, respectively (Table S19, Figure 20). Oregon bycatch ratios measured as kg of eulachon/mt of retained ocean shrimp observed are available in Gustafson et al. (2021, their Table A3). From 2004–19, the percent of total ocean shrimp landings observed by WCGOP observors fluctuated between a low of 6% (2005 and 2008) and a high of 15% (2019) in the Oregon sector (Table S19).

Eulachon bycatch in the California ocean shrimp fishery followed a very different trajectory from that observed in Washington and Oregon during 2011–13 and again from 2016–19. Eulachon bycatch in California remained below 23,000 fish from 2004–08 (the fishery was not observed in 2006), rose in 2009 to over 102,000 fish, and then rose again to over 267,000 fish in 2010. In 2011, eulachon estimated bycatch fell to a low of just 475 fish, but then increased dramatically in 2012 to over 337,000 fish, and subsequently fell to just under 17,000 fish in 2013 (Table S20, Figure 20). Bycatch ratios (Table S20) showed similar fluctuations from 2010–13. By 2014, estimated eulachon bycatch in the California ocean shrimp trawl sector was over 602,000 fish in 2014 and increased to over 2.2 million fish in 2015 (Table S20). Like Washington, but unlike Oregon, the bycatch ratio of eulachon increased from 2014 to 2015 in the California sector of the ocean shrimp trawl fishery. The bycatch ratios in the California sector (measured as numbers of eulachon/mt of retained ocean shrimp observed) increased from 157 to 647 eulachon/mt shrimp between 2014 and 2015 (Table S20). California ocean shrimp fishery eulachon bycatch and bycatch ratios in 2016, and especially in 2017, were down to levels not seen since prior to 2010 (Table S20). California fleetwide bycatch was over 51,000 fish with a bycatch ratio of nearly 38 eulachon/mt of shrimp in 2016, and further declined in 2017 to only 31 fish and a bycatch ratio of 0.02 eulachon/mt of shrimp (Table S20, Figure 20). Eulachon bycatch and bycatch ratios in California rose moderately to 3,503 fish and 1.5 eulachon individuals/mt of shrimp in 2018, and declined in 2019 to 938 fish and 0.8 eulachon/mt of shrimp (Table S20). The tonnage of observed ocean shrimp and of fleetwide ocean shrimp landings was relatively stable from 2011–19 (Table S20), indicating that yearly differences in eulachon distribution, or in the catchability of eulachon, likely contributed to the extreme fluctuations in eulachon bycatch in the California ocean shrimp fishery.

Combined WCGOP estimates of the number of eulachon caught in the Oregon and California ocean shrimp trawl fishery as bycatch from 2004–19 (except for 2006 when these fisheries were not observed) and in Washington from 2010–19 are presented in Table 5. Total estimated bycatch of eulachon in the Oregon and California ocean shrimp fisheries from 2004–09 ranged from nearly 156,000 fish in 2004 to a high of over 948,000 fish in 2009. Estimated eulachon bycatch in the Washington ocean shrimp fishery in 2010 (its first year of observation) was over 67,000 fish, and the total 2010 estimated eulachon bycatch for all three states combined was nearly 1.1 million fish (Table 5). Coastwide eulachon bycatch decreased to about 606,000 fish in 2011 (Table 5). However, as described above, eulachon bycatch increased dramatically in all three states in 2012, topping out at nearly 43 million individual eulachon. Bycatch increased again in Washington and Oregon, but not California, in 2013, resulting in an estimated total eulachon bycatch for all three states combined of over 53.3 million fish (Table 5, Figure 20).

Coastwide eulachon bycatch in ocean shrimp trawl fisheries again increased in 2014 to an all-time high of over 73.4 million fish. In 2015, coastwide bycatch declined relative to 2014 due to declining bycatch in the Oregon ocean shrimp sector; however, bycatch increased in both the Washington and the California sectors in 2015 (Table 5, Figure 20). Estimated coastwide bycatch in 2015 amounted to nearly 60 million fish. Coastwide eulachon bycatch in ocean shrimp trawl fisheries declined by two orders of magnitude from 2015–17, from 60 million in 2015 to about 4.4 million fish in 2016 and 649,600 fish in 2017 (Table 5, Figure 20). Coastwide eulachon bycatch in ocean shrimp trawl fisheries increased by an order of magnitude from 2017 to 2018, and another order of magnitude to 2019. Coastwide bycatch was 3.2 million fish in 2018 and 19.8 million fish in 2019 (Table 5, Figure 20). These increases in coastwide bycatch were mostly due to increased bycatch in both Washington and Oregon.

Table 5. Total WA, OR, CA, and coastwide estimated bycatch of eulachon (number of individual fish) in ocean shrimp fisheries observed by WCGOP, 2004–19. Methods detailed in Gustafson et al. (2021, their appendix). Ocean shrimp fisheries were not observed in 2006.

Year	WA bycatch (numbers)	OR bycatch (numbers)	CA bycatch (numbers)	Coastwide bycatch (numbers)	Lower 95% CI of bycatch	Upper 95% CI of bycatch
2004	n/a	146,379	9,745	156,124	11,646	481,658
2005	n/a	207,878	8,437	216,315	n/a	n/a
2006	n/a	n/a	n/a	n/a	n/a	n/a
2007	n/a	198,054	11,194	209,248	17,470	560,460
2008	n/a	390,056	22,744	412,800	112,796	808,671
2009	n/a	845,473	102,782	948,255	n/a	n/a
2010	67,205	740,552	267,080	1,074,837	540,720	1,885,302
2011	123,741	481,880	475	606,096	397,617	878,247
2012	14,282,792	28,379,097	337,437	42,999,326	27,215,256	59,543,786
2013	17,097,607	36,207,414	16,705	53,321,726	33,238,823	75,461,066
2014	13,515,720	59,329,960	602,169	73,447,849	47,867,587	106,385,340
2015	22,292,347	35,445,296	2,234,225	59,971,868	41,121,997	82,972,192
2016	1,499,088	2,862,045	51,688	4,412,821	2,768,978	6,390,508
2017	442,022	207,577	31	649,630	350,299	1,050,269
2018	1,405,326	1,793,646	3,503	3,202,475	1,039,965	6,388,117
2019	6,540,749	13,254,945	938	19,796,632	13,899,886	26,169,417

Eulachon bycatch and bycatch ratios declined in all three state ocean shrimp fisheries from 2015–17. However, declines in bycatch and bycatch ratios were most dramatic in Oregon and California over this time period. In 2017, comparative bycatch ratios as number of eulachon/mt of shrimp were 145.4 for Washington, 19.9 for Oregon, and nearly zero for California (Tables S18–S20, Figure 20). The bycatch ratio remained at very low levels during 2018 and 2019 in California; however, the ratio increased in Washington from 367 eulachon/mt of shrimp in 2018 to 1,570 eulachon/mt of shrimp in 2019 and in Oregon from 111 eulachon/mt of shrimp in 2018 to 1,088 eulachon/mt of shrimp in 2019 (Tables S18–S20). Bycatch ratios in Washington and Oregon, reported as number of eulachon/mt of observed shrimp, followed similar trajectories from 2010–19, starting at relatively low levels in 2010–11 (less than 30), increasing dramatically in 2012–15 (thousands of fish), falling to moderate levels during 2016–17 (tens to low hundreds of fish), and increasing by 2019 to 1,000 fish in Oregon and 1,500 fish in Washington (Tables S18–S20, Figure 20). Bycatch ratios for the Washington, Oregon, and California ocean shrimp sectors measured as kg of eulachon/mt of observed ocean shrimp are available in Gustafson et al. (2021, their Tables A2–A4).

The Washington ocean shrimp fishery was also observed separately in 2011 and 2012 by a team of state-deployed fishery bycatch observers (Wargo et al. 2014, 2016). Wargo et al. (2016, p. 28) reported a fleetwide eulachon bycatch in the Washington state ocean shrimp fishery of "7.8 mt (17,132 pounds) for 2011 and 171 mt (378,011 pounds) for 2012." These bycatch estimates are approximately 30% and 10% greater than the estimates for the Washington ocean shrimp fishery, as reported in the present document (Table S18) and in Gustafson et al. (2021, their appendix), of 5.7 and 156.7 mt in 2011 and 2012, respectively. In the 2011 Washington ocean shrimp trawl fishery, 24% of trips or 26% of observed ocean shrimp landings were observed by the state observers (Wargo et al. 2014, 2016), whereas

WCGOP observed 16.2% of the total ocean shrimp landings (Table S18). In 2012, 16% of trips or 14% of observed ocean shrimp landings were observed by the state observer program (Wargo et al. 2014, 2016), and 14.8% of shrimp landings were observed by WCGOP (Table S18).

The fluctuating relative abundance of the Southern DPS of eulachon likely influenced high eulachon bycatch from 2012–15, the subsequent decrease in bycatch in 2016 and 2017, and increased bycatch observed in 2018 and 2019 in U.S. West Coast ocean shrimp trawl fisheries, as reported in Gustafson et al. (2021, their appendix). Bycatch ratios, particularly in Washington and Oregon (Tables S18 and S19, Figure 20), also appear to wax and wane in concert with increases and decreases in eulachon abundance. These patterns are also likely influenced by the orientation and degree to which artificial LED lighting has been used since 2015 to illuminate portions of trawl nets in different sectors of these fisheries. LED lighting of ocean shrimp trawl footropes became mandatory in both Oregon and Washington during the 2018 and 2019 seasons (Wargo and Ayres 2018, 2019, Groth et al. 2018). The potential impact of lighted trawl net footropes on bycatch ratios and overall bycatch is an active area of research and is further discussed below.

Bycatch reduction devices

Prior to the mandated use of BRDs, 32–61% of the total catch in the Oregon ocean shrimp fishery consisted of nonshrimp biomass, including various species of smelt (Hannah and Jones 2007). Krutzikowsky (2001) evaluated bycatch in this fishery and stated:

> Bycatch discards in this fishery can range from relatively low to very high levels that can affect the efficiency and, possibly, the value of the fishery. Bycatch of Pacific whiting, *Merluccius productus*, in particular, can become high enough on the shrimp grounds to preclude efficient shrimping…. The majority of bycatch is discarded, such as… smelt Osmeridae sp. (p. 2)

Reducing bycatch in this fishery has long been an active field of research (Hannah et al. 1996, 2003, 2011, 2015, Hannah and Jones 2000, 2003, 2007, 2012, 2013, Frimodig et al. 2009, Lomeli et al. 2018, 2020) and great progress has been made in reducing bycatch, particularly for larger-bodied fishes. Use of BRDs in offshore shrimp trawl fisheries, which was mandated beginning in 2002 in California (rigid or semi-rigid grate or soft-panel excluders) and 2003 in Washington and Oregon (rigid grate BRDs) substantially reduced bycatch of finfish in these fisheries (Hannah and Jones 2007, Frimodig et al. 2009). As of 2005, following required implementation of BRDs, the total bycatch by weight had been reduced to about 7.5% of the total catch, and osmerid smelt bycatch was reduced to an estimated average of 0.73% of the total catch across all BRD types (Hannah and Jones 2007). However, some of these studies were done in the mid-2000s, when eulachon were at a historically low level of abundance.

Beginning in 2014, researchers (Hannah and Jones 2014, 2015, Hannah et al. 2015) began experimentation with LED lights to illuminate portions of trawl nets in the Oregon ocean shrimp fishery in an effort to provide additional bycatch reduction. Additional studies have continued to show the efficacy of lighted trawl net fishing lines in significantly reducing bycatch of eulachon (Groth et al. 2017, 2018, 2019, 2021, Lomeli et al. 2018, 2020, Groth and Smith 2020).

Hannah et al. (2015) compared bycatch levels over 42 paired trials of lighted and unlighted trawl nets using double-rigged vessels that could tow paired shrimp trawl nets (Hannah et al. 2015). When 10 green LED lights were placed along the trawl fishing line of ocean shrimp trawl nets with rigid-grate BRDs with 0.75-inch (19.1-mm) bar spacing installed, and then were compared with identical trawl nets without lights, the bycatch of eulachon was reduced by 91%, with little or no effect on shrimp catch. Hannah et al. (2015, p. 60) stated: "How the addition of artificial light is causing these changes in fish behavior and bycatch reduction is not known." However, the authors speculated that illumination of the trawl fishing line may possibly allow the fish to see the approaching net sooner and react in time to avoid being entrained, and "likely encouraged some species to also move downwards, perhaps exploiting a natural tendency to move towards the seafloor when threatened" (Hannah et al. 2015, p. 66). As noted by the Oregon Pink Shrimp Fisheries Management Plan (Hannah et al. 2018):

> An important benefit of this new bycatch reduction technology is that most eulachon now do not even enter the trawl but escape under the trawl net. Relative to entering the trawl net and then being excluded via the BRD, this technology should reduce physical stress on eulachon from their encounter with the trawl. (p. 9)

Hannah and Jones (2016, p. 6) stated that, to their knowledge, "all shrimpers that fished in 2015 [in the Oregon ocean shrimp fishery] used LED… lights when trawling" and "all said they used lights and were happy with the resulting bycatch reduction." According to Groth et al. (2017, p. 11): "NMFS observer data from 2015 showed that of the 2,137 hauls observed [in the Oregon sector]: 1,466 used LEDs, 66 did not use LEDs, and on the 605 remaining hauls, this data was not reported." Thus, a minimum of about 69% of hauls in Oregon had some form of lights installed on the trawl nets in 2015. Furthermore, Groth et al. (2017, p. 11) stated: "In 2016, we talked to 66 vessels landing shrimp into Oregon; of these, 57 vessels reported using LEDs 100% of the time, 7 reported using them sometimes (depending on bycatch rates, deferred maintenance cost, etc.), and 2 reported not using them at all." Groth et al. (2017, pp. 9 and 12) emphasized "that proper installation of LEDs is key to bycatch reduction" and that research efforts in 2017 "will further examine use of LEDs in bycatch reduction." As mentioned above, LED lighting of ocean shrimp trawl footropes became mandatory in both Oregon and Washington starting with the 2018 season (Wargo and Ayres 2018, 2019, Groth et al. 2018).

Lomeli et al. (2018) examined the effect on eulachon bycatch of placing 5, 10, and 20 LED lights along the footrope of ocean shrimp trawl nets. Catch efficiencies between the three LED lighting configurations were compared with one another and with paired unilluminated trawls. According to Lomeli et al. (2018, p. 2230), "the unilluminated trawl caught 81, 60, and 47% more eulachon than the 5-, 10-, and 20-LED configurations, respectively" and "these differences in average catch efficiency were significant." These results indicate that "light emitted by the 5-LED configuration provided sufficient illumination for most fishes to perceive the contrast between the trawl fishing line and the seabed and thus avoid capture, and that use of more illumination provides no clear added bycatch reduction benefit" (Lomeli et al. 2018, p. 2232). These bycatch benefits were achieved without a reduction in ocean shrimp catches.

All of the above studies showing bycatch reduction with lighted trawl fishing lines were conducted with rigid sorting grids (19.1-mm bar spacing) installed in both lighted and unlighted nets. Lomeli et al. (2020, p. 45) used trawl nets without rigid sorting grid BRDs installed to examine the "degree that eulachon across all length classes (and other fishes) are escaping trawl entrainment in response to the illumination." Lomeli et al. (2020) compared catch efficiency for shrimp, eulachon, rockfishes, and flatfishes across 42 paired simultaneous tows conducted with one illuminated and one unilluminated net. Illuminated nets were equipped with five green LED lights installed in the central fishing line area. Catch efficiency of ocean shrimp did not differ significantly between nets with and without lights; however, on average, 66% more eulachon in the size range of 12.5–16.5 cm were caught in unilluminated versus illuminated nets (Lomeli et al. 2020). Fewer yellowtail rockfish (*Sebastes flavidus*) were also caught in illuminated trawls; however, over the common length ranges encountered, "the illuminated trawl on average caught 3.6, 3.5, 2.8, 4.4, and 2.7 times more stripetail rockfish [*S. saxicola*], other rockfishes, arrowtooth flounder [*Atheresthes stomias*], slender sole [*Lyopsetta exilis*], and other flatfishes, respectively, than the unilluminated trawl" (Lomeli et al. 2020, p. 50). These results showed that sorting-grid BRDs are still necessary in illuminated trawls, since "the illuminated trawl caught several size classes of fishes that the sorting grids would have released if present" (Lomeli et al. 2020, p. 53). Furthermore, Lomeli et al. (2020, p. 53) stated: "the combined use of footrope illumination and sorting grids (as is required in Oregon and Washington fisheries) is the most effective means for reducing bycatch across a larger suite of species and sizes." The trawl nets used in this study "differed from the prior studies [Hannah et al. 2015, Lomeli et al. 2018] in that the central portion of the groundgear consisted of just drop chains as opposed to a continuous ground line" (Lomeli et al. 2020, p. 51). Lomeli et al. (2020, p. 51) stated that both of these groundgear configurations are commonly used in the ocean shrimp fishery, and "trawls with central ground line sections removed have been shown to reduce the overall level of bycatch compared with trawls with continuous ground lines." Therefore, "further research investigating how changes in groundgear configuration may affect the efficacy of illumination along ocean shrimp trawl fishing lines is needed" (Lomeli et al. 2020, p. 51).

Although these controlled at-sea studies showed that eulachon bycatch in ocean shrimp trawl fisheries can be reduced by nearly 70% with LEDs alone (Groth and Smith 2020), and by 81% (Lomeli et al. 2018) to 91% (Hannah et al. 2015) when LEDs and rigid grate deflecting grids (19.1-mm bar spacing) are used in combination, significant eulachon bycatch continues to occur in these fisheries, particularly when overall eulachon abundance is high. Even with these reductions in percentage of eulachon bycatch, it is evident that bycatch amounts are likely to increase and decrease in concert with increasing and decreasing eulachon abundance. A comparison of graphs of eulachon abundance (Figure 7) and eulachon bycatch by state (Figure 20) supports this supposition.

Although speculative, it may be that BRDs (both deflecting grids and LED lighted footropes) in the ocean shrimp trawl fisheries operate at greatly reduced efficiency when eulachon reach high densities. Winger et al. (2010) stated:

> Fish density is also expected to affect the performance of BRDs installed within the net. When large pulses of fish are encountered, devices such as selection windows, sorting grids, or separator panels may be temporarily masked by

> neighboring conspecifics. This reduces the probability of fish encountering the devices and thus reduces the potential sorting efficiency. (p. 91)

Although data on survivability of rigid-grate BRDs by small pelagic fishes such as eulachon are scarce, many studies on trawl net escape mortality for other fishes indicate that "among some species groups, such as small-sized pelagic fish, mortality may be high" and "the smallest escapees often appear the most vulnerable" (Suuronen 2005, pp. 13–14). A workshop (Pickard and Marmorek 2007) to determine research priorities for eulachon in Canada recommended the need to research the effectiveness of BRDs and the need to estimate mortality, not just bycatch. Partly in response to these concerns, Hannah and Jones (2012) used underwater video technology to examine behavior of eulachon when encountering rigid-grate BRDs in an ocean shrimp trawl net. The purpose of this research was to determine fish condition and survival following exclusion by the BRDs and the effectiveness of these types of BRDs at reducing mortality rates. Hannah and Jones (2012) stated:

> Almost 80% of the large eulachon maintained an upright vertical orientation throughout their escape and exited the trawl in a forward-swimming orientation. Large eulachon maintained distance from the deflecting grid better than the other species encountered ($p < 0.001$) and typically showed no contact or only minimal contact with it (63%). Only about 20–30% of the large eulachon showed behaviors indicating fatigue, such as laying on or sliding along the grid. (p. 39)

Hannah and Jones (2012) concluded:

> …data on behavior of large eulachon escaping from a shrimp trawl show that most have enough residual swimming ability to minimize their physical contact with the deflecting grid, maintain their vertical orientation and to continue actively swimming in a forward direction as they exit. This suggests that the use of deflecting grids in the ocean shrimp fishery is likely reducing eulachon mortality rates, as well as bycatch. (p. 43)

Hannah and Jones (2012) also noted that large eulachon are excluded at a higher efficiency than are small eulachon. Behavior of eulachon in this study, both large and small, may have been influenced by the use of artificial video lighting.

Comparison of bycatch and bycatch ratios by state sector

Although the Washington state sector of the ocean shrimp fishery accounted for only 20%, 17%, and 24% of total coastwide shrimp landings in 2017, 2018, and 2019, respectively, it disproportionately accounted for 68%, 44%, and 33% of total coastwide eulachon bycatch in the same respective three years (Tables S18–S20). This is also reflected in the average 2017–19 bycatch ratios—as eulachon/mt of shrimp landed—of 694, 406, and 1 in Washington, Oregon, and California, respectively (Tables S18–S20). Eulachon bycatch ratios in the Oregon sector show a similar pattern to the Washington sector, increasing in each of the last two years, from a low point of about 20 eulachon/mt of shrimp in 2017, to about 111 and 1,088 eulachon/mt of shrimp in 2018 and 2019, respectively (Table S19). The bycatch ratio in the Washington sector was about 145 eulachon/mt of shrimp in 2017, increasing to about 367 and 1,570 eulachon/mt of shrimp in 2018 and 2019, respectively. Although an average of about 9% of total coastwide shrimp landings from 2017–19 occurred in the California sector, only an estimated total of 4,472 eulachon were caught in this sector during this entire three-year period (less than 0.02% of the coastwide total). The scarcity of eulachon in the California sector over this period is also reflected in the relatively low bycatch ratios of 0.02, 1.53, and 0.83 eulachon caught per mt of shrimp landed in California in 2017, 2018, and 2019, respectively (Table S20).

It is unclear why eulachon bycatch ratios in various sectors of ocean shrimp fisheries vary to the degree they do, especially between Oregon and Washington. As was pointed out by Lomeli et al. (2020), many factors likely "…have a considerable effect on how some fishes respond to illumination on trawl gear." These include turbidity, fish density, time of day, groundgear configuration, placement of illumination, and fish fatigue and stress, among others (Lomeli et al. 2020, pp. 52–53).

Oregon and Washington ocean shrimp fishery management plans

Developing methods to reduce bycatch (especially of eulachon) is high on the prioritized lists of research needs in both the Washington (Wargo and Ayres 2017b) and Oregon (Hannah et al. 2018) ocean shrimp FMPs. Although both plans list "action levels" that trigger management actions to restrict or curtail shrimp catch when shrimp catch-per-trip levels reach certain low counts, neither state's FMP has management action levels related to amount of eulachon bycatch taken. By comparison, in British Columbia, the shrimp trawl IFMP has implemented the Eulachon Action Level (EAL) in response to incidental eulachon bycatch in the shrimp trawl fishery (DFO 2021a,b). When an EAL is reached in specific trawl areas, they are then closed to shrimp harvest for the season. According to this plan (DFO 2021b):

> The Eulachon Action Level (EAL) for the WCVI remains set at 4 tonnes (t). The WCVI EAL is further divided into two (2) portions, with an EAL of 2 t set for SMAs 124OFF and 125OFF combined, and 2 t set for SMAs 23OFF & 21OFF and 23IN combined. (p. 3)

Bycatch hotspots in ocean shrimp fisheries

Ward et al. (2015) applied spatiotemporal models to both fishery-dependent observations of eulachon bycatch and eulachon fisheries-independent survey data to: 1) estimate population trends of eulachon, 2) understand eulachon bycatch risk in shrimp fisheries, and 3) identify persistent bycatch hotspots that may be used in future management actions to reduce eulachon bycatch rates. Two spatial data sets for the period from 2007–12 were examined: WCGOP catch data of shrimp and eulachon in the California, Oregon, and Washington ocean shrimp trawl fisheries, and fishery-independent incidental eulachon catch in the U.S. West Coast Bottom Trawl Survey (Ward et al. 2015). Ward et al. (2015) found support for a greater than 40% annual increase in eulachon density based on the bycatch dataset and a greater than 55% annual increase based on the fisheries-independent survey dataset over the duration of the datasets. The latter dataset also suggested that eulachon density was “…substantially higher in 2012 than in any recent period” (Ward et al. 2015, p. 2204). These data also imply “…that increases in bycatch [are] not due to an increase in incidental targeting of eulachon by fishing vessels, but likely because of an increasing population size of eulachon” (Ward et al. 2015, p. 2198). Ward et al. (2015, their Figures 4–5) also presented mapped representations of both the spatial distribution of eulachon bycatch risk and areas of highest bycatch encounters. Ward et al. (2015) found that the coastal areas just south of Coos Bay, Oregon—between the Columbia River and Grays Harbor, Washington—and just south of La Push, Washington, were consistent hotspots of eulachon bycatch across years.

Commercial, Recreational, and Subsistence Fisheries

California

The California 2021–22 Freshwater Sport Fishing Regulations[27] state: “Candlefish or eulachon may not be taken or possessed.” They were current through 28 February 2022.

Oregon and Washington

Fishery landings

Commercial fishery landings of eulachon in the Columbia River basin were first recorded by state and federal fisheries agencies in 1888, although newspaper records show that commercial fisheries for eulachon were in operation by 1866. Eulachon commercial fishery landings data from 1888–2009 are available in Gustafson et al. (2010, their Table 7) and from 1995–2021 in Table S21. The full record of landings in metric tons is graphically presented in Figure 21. Oregon and Washington jointly regulate and manage the commercial eulachon fishery in the Columbia River, as proscribed in the Columbia River Compact, approved by the U.S. Congress. Commercial and recreational eulachon fisheries in the tributaries are individually managed by Oregon and Washington within their state boundaries (WDFW and ODFW 2001). There are no commercial fisheries that target eulachon in marine waters of Canada or the U.S. West Coast.

Commercial and recreational eulachon fisheries continued to operate in the 2009–10 season; however, all commercial and recreational fisheries in the Columbia River and its tributaries were closed for the three years following ESA listing (i.e., from 2011–13; JCRMS 2014). Since 2014, consultations between WCR, WDFW, and ODFW have resulted in commercial and, on occasion, recreational eulachon fisheries in the Columbia River basin. However, limited landings occurred in 2018 and all fisheries were closed in 2019. These limited fishing opportunities were designed to take no more than 1% of the spawning stock biomass. It was expected that a limited eulachon fishery would benefit eulachon recovery efforts by:

- Providing essential context for interpreting historical harvest data to better understand trends and variability in eulachon abundance.

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[27] https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=190456&inline

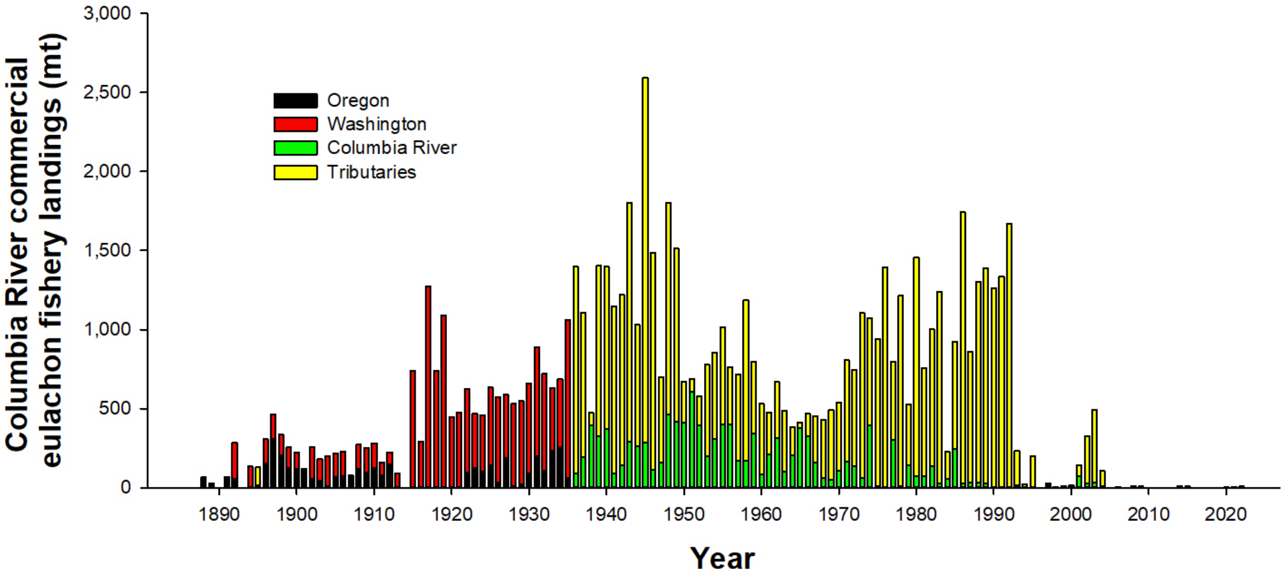

Figure 21. Commercial eulachon fishery landings in the Columbia River and tributaries, 1888–2021. Landings occurred in 1890; however, values are too small to be evident on the graph. Landings occurred in 1893 and 1914, based on newspaper and periodical sources (see Gustafson et al. 2010), but official records have not been located. Data sources are listed in Gustafson et al. (2010, their Table 7) and in Tables 6 and S21.

- Filling critical information gaps such as the length and age structure of spawning eulachon, as well as the temporal and spatial distribution of the run.
- Supporting the cultural traditions of northwest tribes who relied on eulachon as a seasonally important food source and valuable trade item.
- Providing a limited public and commercial opportunity for eulachon harvest to maintain a connection between people and the eulachon resource. This connection is important to sustaining public engagement in eulachon conservation and recovery.

A commercial gillnet fishery opening occurred in the mainstem Columbia River on Mondays and Thursdays for seven hours each day from 10 February to 6 March in 2014, from 2–26 February in 2015, from 1–25 February in 2016, and from 2–27 February in 2017, for a total opening each year of 56 hours (JCRMS 2014, 2015, 2017, 2018, 2019, 2020, 2021, ODFW 2015, 2016). Approximately 8.4, 7.5, 2.2, and 2.3 mt of eulachon were commercially harvested in 2014, 2015, 2016, and 2017, respectively (Table 6; ODFW 2014, 2015, 2016, 2017). Commercial harvest was again open for 8 days in 2018 on Mondays and Thursdays for 7 hours per day for a total of 56 hours, but only 0.05 mt (100 pounds) were landed (JCRMS 2019). No commercial eulachon fishery occurred in 2019 due to a prediction of low returns, similar to 2018; however, returns were better than expected (JCRMS 2020). In 2020, a Columbia River mainstem commercial eulachon fishery occurred on Mondays and Thursdays for 12 hours each day from 3–27 February for a total of eight days or 96 hours. About 4.6 mt of eulachon were landed in 2020 (JCRMS 2021). In 2021, nearly five mt of eulachon were caught by commercial mainstem fishers, again fishing on Mondays and Thursdays for 12 hours per day, from 28 January to 11 March, for a total of 13 days and 156 hours.

Table 6. Estimated eulachon catch from the Columbia River and tributary commercial, sport, and tribal fisheries, in mt (converted from lb as reported in sources by multiplying by 0.000453592) and numbers of fish, 2014–21. Source: ODFW (2014–21) and JCRMS (2015, 2017–22). Number of eulachon in the catch calculated using an average of 11.2 eulachon/lb as suggested by James et al. (2014) and Langness et al. (2018).

	Mainstem commercial		Cowlitz sport		Sandy sport		Tribal catch	
Year	(mt)	(number)	(mt)	(number)	(mt)	(number)	(mt)	(number)
2014	8.42	207,850	89.77	2,216,480	2.72	66,978	3.16	78,064
2015	7.51	185,315	131.89	3,256,624	<0.05	<1,116	4.72	116,480
2016	2.19	54,006	63.98	1,579,760	closed	closed	3.88	95,872
2017	2.28	56,213	0.25	6,059	closed	closed	0.86	21,280
2018	0.05	1,232	closed	closed	closed	closed	0.00	0
2019	closed	closed	closed	closed	closed	closed	10.73	264,992
2020	4.65	114,856	15.89	392,448	closed	closed	10.84	267,680
2021	4.99	123,166	41.39	1,022,000	closed	closed	25.37	626,528

Catch records were not maintained for eulachon recreational fisheries in the Columbia River basin prior to 2014, although, in the past, recreational harvest had been estimated at times to equal the historical commercial catch (WDFW and ODFW 2001). Recreational sport fisheries were permitted on the Cowlitz and Sandy Rivers in 2014, where an estimated 89.8 and 2.7 mt were harvested, respectively (Table 6; JCRMS 2016). Likewise, recreational dip-net fisheries operated on the Cowlitz and Sandy Rivers in 2015. The Cowlitz River recreational dip-net fishery, which was open for two Saturdays in February 2015, harvested an estimated 131.9 mt of eulachon (Table 6; JCRMS 2017). Less than 100 lb of eulachon were dipped in the recreational fishery in the Sandy River during 2015. Recreational harvest was estimated at about 64 mt in the single-day opening of the recreational (a.k.a. sport) fishery on the Cowlitz River in 2016 (Table 6). Eulachon did not enter the Sandy River from 2016–21 in sufficient numbers to allow a sport fishery opening (Table 6). A one-day five-hour recreational fishery opening occurred on 25 February 2017 in the Cowlitz River; however, eulachon were scarce and only an estimated 0.25 mt (541 pounds) were harvested (Table 6; JCRMS 2018). No recreational fisheries were opened in either 2018 or 2019 on the Cowlitz River due to low commercial catch in 2018 and predicted low returns in 2019 (JCRMS 2019, 2020). In 2020, recreational fishers on the Cowlitz River harvested nearly 16 mt during two separate five-hour fishery openings on 14 and 26 February (Table 6; JCRMS 2021). In 2021, nearly 41.4 mt of eulachon were harvested by an estimated 9,873 recreational fishers on the Cowlitz River during a single five-hour opening on 2 March (JCRMS 2022).

Records of tribal subsistence and ceremonial fishery landings on the Cowlitz River have been maintained since 2014 (Table 6; JCRMS 2015, 2017–22). These include harvest by the Yakima Tribes, Warm Spring Tribes, Umatilla Tribes, and the Cowlitz Tribe (Table 6). In 2021, "[t]he estimated tribal harvest of 55,940 pounds was approximately two times the [tribal] harvest that occurred during 2019 or 2020" (JCRMS 2022, p. 29; Table 6).

British Columbia

Commercial fishery landings of eulachon in the Fraser River were first recorded by the federal Department of Marine and Fisheries in 1881, although newspaper records show that commercial fisheries for eulachon were in operation by 1868 (Gustafson et al. 2010). During the period from 1936–95, yearly eulachon landings on the Fraser River averaged about 11% of landings in the same year on the Columbia River (range of 1–58%). However, since 1997, the Fraser River commercial fishery for eulachon has essentially been closed, opening only briefly in 2002 and 2004, when 5.76 and 0.44 mt were landed, respectively (see Gustafson et al. 2010). In regards to eulachon fishing opportunities on the Fraser River, DFO IFMPs (DFO 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021a) indicate that there were no recreational or commercial fisheries for eulachon on the Fraser River in 2005–20. From 1995 to 2005 (with the exception of 1999), a test fishery for eulachon on the Fraser River operated in the vicinity of New Westminster, British Columbia; however, this fishery has not operated since 2006 (DFO 2013, 2021a).

In regards to indigenous fisheries, the IFMP for Fraser River eulachon (DFO 2020) stated:

> In 2019, Indigenous peoples' access to eulachon for food, social and ceremonial (FSC) purposes was managed through communal Aboriginal fishing licences on the Fraser River. In 2019, harvest opportunities were provided on a case-by-case basis per Band up to the maximum harvest level target of 9,652 lb (4.38 t) total; the total eulachon harvest in 2019 was 7,847 lb (3.56 t). (p. 55)

Similarly, in 2020, the maximum FSC harvest-level target was set at 10,538 lb (4.78 t) total and the actual FSC harvest was 10,332 lb (4.69 t; DFO 2021a). Maximum harvest targets and actual harvest of Fraser River eulachon in these First Nations indigenous fisheries are available from 2013–20 (Table S22, Figure 22).

Recreational fishing for eulachon with dip nets, gillnets, minnow nets, or cast nets in freshwater is prohibited throughout British Columbia[28] (DFO 2021a). Recreational harvest of eulachon is also prohibited in all marine areas of British Columbia due to conservation concerns. Additional recent landings and effort statistics for most First Nations fisheries within the Southern DPS of eulachon are unavailable.

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[28] http://www-ops2.pac.dfo-mpo.gc.ca/xnet/content/fns/index.cfm?pg=view_notice&lang=en&DOC_ID=115494&ID=r

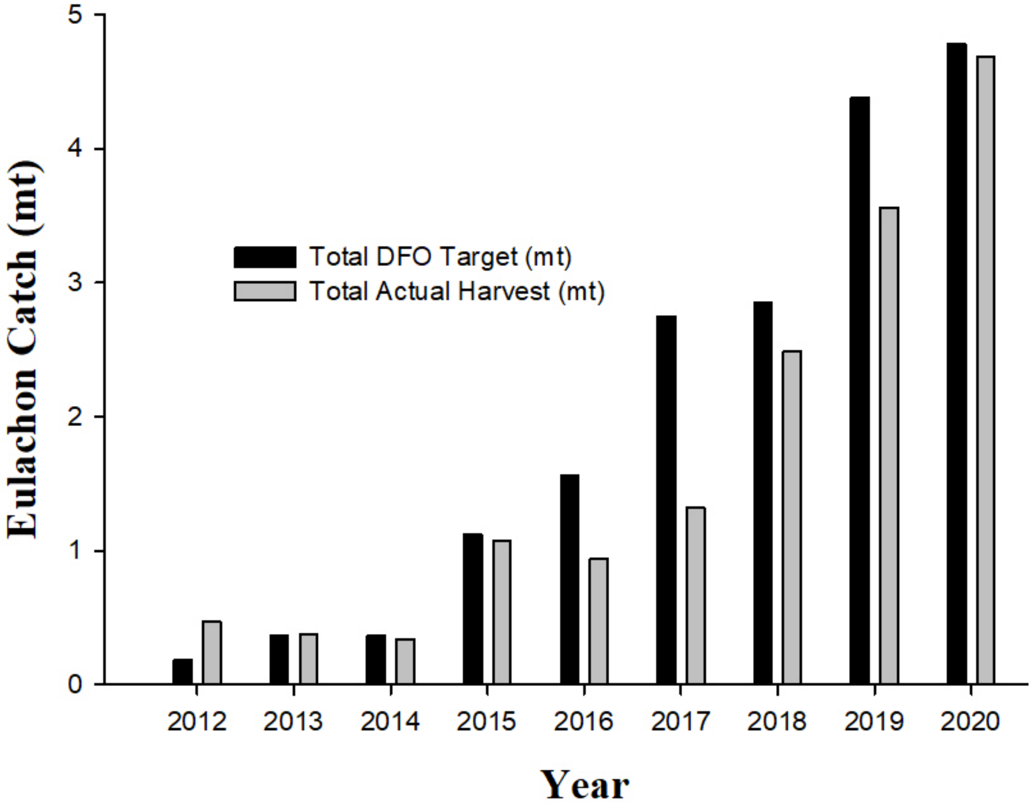

Figure 22. DFO target catch and actual catch in the First Nations Fraser River FSC eulachon fishery, 2012–20 (DFO 2013–20, 2021a).

Risk Summary

2010 Status Review

The 2010 BRT determination of overall risk to the Southern DPS of eulachon, as reported in the 2010 status review (Gustafson et al. 2010), used these categories: at "high risk of extinction," at "moderate risk of extinction," or "not at risk of extinction." The 2010 BRT adopted a 100-year time frame as the period over which it had confidence in evaluating risk, similar to what other quantitative and qualitative conservation assessments for other species have used in their extinction risk evaluations (Morris et al. 1999, McElhany et al. 2000). The 2010 BRT assessment was guided by the results of a risk matrix analysis that integrated information about demographic risks with expectations about likely interactions with threats and other factors.

The 2010 BRT's scores for overall risk to the Southern DPS, throughout all of its range, were heavily weighted to moderate risk, with this category receiving 60% of the likelihood points. High risk received 32% of the likelihood points, and not at risk received 8% of the points. The likelihood methodology was described in Gustafson et al. (2010). The 2010 BRT was concerned that, although eulachon were a relatively poorly monitored species, most of the available information indicated that the Southern DPS had experienced an abrupt decline in abundance throughout its range. The 2010 BRT was particularly concerned that two large spawning populations—in the Columbia and Fraser Rivers—had declined to what appeared to be historically low levels in the Fraser River and nearly so in the Columbia River. The 2010 BRT was also concerned that there was very little monitoring data available for Northern California eulachon, but determined that the available information suggested that eulachon in Northern California had experienced an abrupt decline several decades prior to when the 2010 BRT met. The 2010 BRT was also concerned that attempts to estimate actual spawner abundance in some rivers in British Columbia that were known to have supported significant First Nations fisheries in the past had resulted in very low estimates of spawning stock.

In addition, the 2010 BRT was concerned that the then-current abundance of the many individual populations within the Southern DPS was sufficiently low to be an additional risk factor, even for populations (such as the Columbia and Fraser) where the absolute population size seemed large compared to many other at-risk fish populations. Indeed, the 2010 BRT considered a central question to be whether a DPS or stock may be at risk of extinction when there may be hundreds of thousands or perhaps millions of individuals remaining in the population. In evaluating this issue, the 2010 BRT concluded that eulachon (and other similar forage fishes; see Dulvy et al. 2004) may be at significant risk at population sizes that are a fraction of their historical levels but are still large compared to what would be considered normal for other ESA-listed species.

The 2010 BRT also had concerns about risks related to spatial structure and distribution. In particular, the BRT was concerned that if formerly significant populations in Northern California, such as the Klamath River, become extirpated, there would be less opportunity for successful recolonization , potentially resulting in contraction of the southern portion of the Southern DPS's range. In terms of threats related to diversity, the 2010 BRT was also concerned about the apparently very low abundance of the Klamath River eulachon, which might be expected to have unique adaptations to conditions at the southernmost extent of the range. The 2010 BRT also noted that several populations that used to support significant First Nations fisheries on the British Columbia coast had declined to very low levels (e.g., Bella Coola and Wannock Rivers). The 2010 BRT noted some positive signs, including observations that eulachon continued to display variation in spawn timing, age-at-maturity, and spawning locations, and a high degree of biocomplexity (i.e., many spawning locations and spawn-timing variation) in the Columbia River, which may buffer this stock from freshwater environmental perturbations.

The 2010 BRT was concerned that climate change may have contributed to a mismatch between timing of ocean entry of eulachon larvae and availability of crucial prey species. However, the ability of the Columbia River eulachon stock to respond rapidly to the good ocean conditions of the late-1999–early-2002 period illustrated the species' resiliency, and the 2010 BRT viewed this resiliency as providing the species with a buffer against future environmental perturbations. Cold ocean conditions in the California Current Ecosystem in the fall of 2007 and spring–summer of 2008 were considered to be favorable for eulachon, and the 2010 BRT postulated that this indicated that elevated levels of eulachon were expected to return starting with the 2011 run year (Gustafson et al. 2010). In fact, the year 2011 is when elevated eulachon abundance was first detected in several indices of abundance reviewed in the current document. However, the 2010 BRT was concerned that these changes in the ocean, favorable to eulachon larval survival, might be of short-term duration, similar to the late-1998–early-2002 period.

2016 Status Review Update

At the time of the 2016 status review update (Gustafson et al. 2016), adult spawning abundance of the Southern DPS of eulachon had clearly increased since the listing occurred in 2010. A number of data sources, including 1) SSB estimates in the Columbia and Fraser Rivers, 2) CPUE in small-mesh bottom trawl surveys off WCVI, 3) incidental catch in the WCBTS, and 4) estimated bycatch in ocean shrimp trawl fisheries, indicated that eulachon abundance in some areas of the Southern DPS was substantially higher during 2011–15 compared to indications of very low abundance from 2005–10. The improvement in estimated abundance in the Columbia River at the time, relative to the time of listing, reflected both changes in biological status and improved monitoring. The documentation of eulachon returning to the Naselle, Chehalis, Elwha, and Klamath Rivers from 2011–15 likely indicated both changes in biological status and improved monitoring.

The 2016 status review update (Gustafson et al. 2016), noted that compared to the situation at the time of the 2010 status review (Gustafson et al. 2010), monitoring of annual abundance of eulachon in several areas of the Southern DPS had increased substantially. Annual monitoring of SSB had continued in the Fraser River (1995–2015) and had expanded to the Columbia (2011–15), Grays (2011–13, 2015), Cowlitz (2015), Naselle (2015), and Chehalis (2015) Rivers. Mean SSB over the five-year period from 2011–15 was estimated at 127 mt in the Fraser River and 4,007 mt in the Columbia River. This was a considerable improvement over the previous five-year period (2006–10) immediately prior to the 2010 BRT's analysis, when mean SSB was estimated at 20 mt in the Fraser River and 153 mt in the Columbia River.

At the time of the 2016 status review update (Gustafson et al. 2016), the situation in the Klamath River was more positive than it had been at the time of the 2010 status review (when either very few or no eulachon had been seen for the previous 20 years), with adult eulachon presence being documented in the Klamath River in the spawning seasons of 2011–14. However, very little additional data on the status of eulachon in coastal rivers north of the Fraser River was available in 2016 (Gustafson et al. 2016). At the time, newly obtained CPUE estimates for the Kemano and Kitimat Rivers suggested substantial recent declines without apparent recovery (COSEWIC 2011). Anecdotal observations as reported in several First Nations' newsletters and in annual environmental reports indicated that the Skeena (2010–15), Kemano (2015), and Kingcome (2012) Rivers had supported substantial runs of spawning eulachon in recent years; however, eulachon in the Kitimat River (2012, 2014) were reportedly at low levels. The 2016 status review update (Gustafson et al. 2016) suggested that the existing poor ocean conditions at the time and the likelihood that these conditions would persist into the near future indicated that population declines might become widespread in the upcoming return years.

Updated Risk Summary

Since the 2016 status review update (Gustafson et al. 2016), annual SSB monitoring has continued in the Fraser (1995–2021) and Columbia (2011–21) Rivers, and continued sporadically in the Grays (2011–13, 2015–16), Cowlitz (2015–18), Naselle (2015–17), and

Chehalis (2015–18) Rivers. However, lack of funding has precluded more recent monitoring of eulachon SSB in the Grays, Naselle, and Chehalis Rivers. The SSB methodology likely underestimates the actual biomass of eulachon required to produce the observed larval production, since it does not account for egg and larval mortality upstream of the sampling site (JCRMS 2022). In addition, it is unclear how significant a problem misidentification of egg and larval samples between eulachon and longfin smelt may pose to the accuracy of eulachon SSB estimates in the Columbia River basin, and elsewhere.

Adult eulachon abundance in Columbia River SSB surveys plus fishery harvest (i.e., run size) declined precipitously from a mean of 5,672 mt (~12.5 million lb) in 2013–15, to a mean run size of 1,067 mt (~2.3 million lb) in 2016–18. Subsequently, Columbia River eulachon run size increased to a mean of 2,522 mt (~5.6 million lb) in 2019–21.[29] Over this nine-year period, Columbia River abundance was highest in 2014 (7,466 mt, or ~16.5 million lb) and lowest in 2018 (168 mt, or ~370,000 lb). Run size of Columbia River eulachon in 2018 was only 2% of the 2014 run size (Tables 1 and 2, Figure 7). Other measures of eulachon abundance in the Southern DPS followed a similar trajectory over this time period, with the exception of the Fraser River eulachon SSB (Figure 12). Although Fraser River SSB was relatively elevated in 2015 at 317 mt, it declined in 2016 (44 mt) and 2017 (35 mt), as did Columbia River SSB; however, in 2018, when Columbia River SSB was at a ten-year low, Fraser River SSB increased to 408 mt and was nearly 2.5 times higher than Columbia River SSB in 2018 (Table 3, Figures 10 and 12). As Columbia River SSB increased dramatically in 2019, Fraser River SSB declined to 108 mt. Data comparisons for 2020 are incomplete due to COVID-19 limitations on field work in the Columbia River; however, in 2020, abundance in the Fraser River increased dramatically to 624 mt. Fraser River Eulachon SSB had not been so high since 2001 (Table 3, Figure 10). In 2021, Fraser River SSB (over the standard seven-week sampling period) was 141 mt, compared to an SSB of 4,104 mt in the Columbia River. The two measures of offshore eulachon abundance—CPUE in small-mesh bottom trawl surveys off WCVI (Figure 5), and incidental catch in the WCBTS (Figure 6)—show similar trends since 2015 to the Columbia River run size (i.e., rapid decline to 2018 and subsequent rebound; Figure 7).

In 2016, the situation in the Klamath River was more positive than it had been at the time of the 2010 status review (Gustafson et al. 2010), when either very few or no eulachon had been seen for the previous 20 years. Adult eulachon presence was documented in the Klamath River in the spawning seasons of 2011–14 (Gustafson et al. 2016). However, besides a few anecdotal reports of small numbers of eulachon seen on occasion in the Klamath River after 2014, very little new information on eulachon in the Klamath River has become available since the 2016 status review update. The Yurok Tribe is monitoring eulachon presence/absence with eDNA in 2021–22 in the Klamath and Mad Rivers and Redwood Creek. Results are not available at this time.

Anecdotal observations, as reported in several First Nations' newsletters, newspapers, and other sources (Table S5; Gustafson et al. 2016), indicate that the Skeena (2018–20), Bella Coola (2013, 2018), Kemano (2015, 2018–19, 2021), and Kingcome (2015–17) Rivers have

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[29] Reliable SSB estimates for Columbia River eulachon in 2020 are not available due to COVID-19 pandemic restrictions on field sampling. The estimate for 2020 run size used in these calculations (3,869,195 lb, or 1,755 mt) is twice the mean value calculated from the shortened 10-week survey, as conservatively suggested in JCRMS (2021).

apparently supported substantial runs of spawning eulachon in recent years; however, eulachon in the Kitimat River (2014–15, 2018, 2020–21) have reportedly remained at low levels (Table S5; Gustafson et al. 2016). Substantial returns have occurred in some years on the Kemano River (2010, 2012–13, 2015–18, 2021), although the Kemano River reportedly had no eulachon run in 2020 (Table S5; Gustafson et al. 2016, HFC 2019).

Based on the overall magnitude of bycatch in U.S. West Coast groundfish fisheries, either there is limited interaction with eulachon in these fisheries or most eulachon encounters result in fish escaping or avoiding trawl gear. In recent years, total fleetwide estimated bycatch in U.S. West Coast groundfish fisheries increased by one and then two orders of magnitude, from 68 total eulachon in 2017, to 782 in 2018 and 3,121 in 2019. It is difficult to envision how eulachon are retained in groundfish trawl nets unless the codend becomes plugged. Thus, the observed eulachon bycatch in the groundfish fishery sectors reported may represent a small fraction of all eulachon encounters with bottom and midwater trawl fishing gear in the groundfish fishery. It is important to examine not only observed bycatch and discard mortality, but also the fate of non-target organisms that escape from trawl nets prior to being hauled aboard fishing vessels. However, we currently have no direct data to estimate escape or avoidance mortality of eulachon in any sector of the groundfish fishery, and we are unaware of any studies that have directly investigated the fate of osmerid smelt species passing through groundfish trawl nets.

The fluctuating relative abundance of the Southern DPS of eulachon (Figures 5 and 7) likely influences the high eulachon bycatch from 2012–15, the subsequent decrease in bycatch in 2016 and 2017, and increased bycatch observed in 2018 and 2019 in U.S. West Coast ocean shrimp trawl fisheries. Coastwide eulachon bycatch in ocean shrimp trawl fisheries increased by an order of magnitude from 2017 to 2018, and another order of magnitude to 2019. Coastwide bycatch was 3.2 million fish in 2018 and 19.8 million fish in 2019 (Table 5). These increases in coastwide bycatch were mostly due to increased bycatch in both Washington and Oregon. More recent data are unavailable. These patterns are also likely influenced by the orientation and degree to which artificial LED lighting has been used to illuminate portions of trawl nets in different sectors of these fisheries. LED lighting of ocean shrimp trawl footropes became mandatory in Oregon and Washington in 2018 and in British Columbia in the 2021–22 season.

At-sea scientific studies showed that eulachon bycatch in ocean shrimp trawl fisheries can be reduced by nearly 70% with LEDs installed on the footrope of shrimp trawl nets, and by 81–91% when LEDs and rigid grate deflecting grids are used in combination. Even so, significant eulachon bycatch continues to occur in ocean shrimp fisheries, particularly when overall eulachon abundance is high. Even with these reductions in percent bycatch, it is evident that bycatch amounts are likely to increase and decrease in concert with increasing and decreasing eulachon abundance.

There are indications, perhaps in response to warming conditions or altered stream flow timing, that adult eulachon are returning earlier in the season to several rivers within the Southern DPS, including the Bella Coola (Moody and Pitcher 2010), the Kemano (Pickard and Marmorek 2007), and the Columbia (Gustafson et al. 2010) Rivers. Since almost all rivers that support eulachon populations are fed by extensive snowmelt or glacial runoff, elevated temperatures, changes in snowpack, and changes in the timing and intensity of stream flow will likely have impacts on eulachon (Sharma et al. 2017). In most rivers, eulachon typically spawn well before the spring freshet, near the seasonal flow minimum, and this strategy typically results in egg-hatch coinciding with peak spring river discharge. The expected alteration in stream flow timing may result in eulachon spawning earlier, or in larvae being flushed out of spawning rivers at an earlier date. Early emigration may result in a mismatch between entry of larval eulachon into the ocean and coastal upwelling, which could have a negative impact on marine survival of eulachon during this critical transition period. Warmer ocean conditions may be expected to contribute to a mismatch between eulachon ocean-entry timing and presence of preferred prey species. However, strong early-spring upwelling has occurred in the CCE during the last two seasons (2020 and 2021), which may well provide the match with earlier larval emigration timing and northern copepod prey abundance that appears crucial for strong eulachon survival (Sharma et al. 2017, Montgomery 2020; Hay and Schweigert, personal communication).

A number of data sources, including 1) SSB in the Columbia and Fraser Rivers, 2) CPUE in small-mesh bottom trawl surveys off WCVI, 3) incidental catch in the WCBTS, and 4) estimated bycatch in ocean shrimp trawl fisheries, indicate that eulachon abundance increased in the most recent three years (2019–21). Every indication is that ocean conditions continue to be the primary driver of eulachon abundance. Recent improvements in ocean conditions in the Northern California Current Ecosystem, beginning in 2020 (Harvey et al. 2021a), suggest that in the absence of MHWs impinging on the CCE, eulachon abundance should continue at moderately high levels in the near future.

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