NOAA Technical Memorandum NMFS-NWFSC-188

https://doi.org/10.25923/3611-ey18

Observed and Estimated Bycatch of Eulachon in the 2002–21 U.S. West Coast Fisheries

December 2023

U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northwest Fisheries Science Center

NOAA Technical Memorandum Series NMFS-NWFSC

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Cover image: Mixed catch of fishes including adult eulachon caught during sea lion prey acoustic trawl surveys in Taku Inlet, Alaska, April 2006. Photograph by J. Page (Vollenweider), NMFS/AFSC.

Reference this document as follows:

Gustafson, R., K. E. Richerson, K. A. Somers, V. J. Tuttle, and J. T. McVeigh. 2023. Observed and Estimated Bycatch of Eulachon in the 2002–21 U.S. West Coast Fisheries. U.S. Department of Commerce, NOAA Technical Memorandum NMFS-NWFSC-188.

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Observed and Estimated Bycatch of Eulachon in the 2002–21 U.S. West Coast Fisheries

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https://doi.org/10.25923/3611-ey18

December 2023

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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.

NOAA Fisheries sets the amount and extent of allowable take of eulachon in federally managed marine waters off the U.S. West Coast. At the Northwest Fisheries Science Center's observer program, we track how many eulachon are incidentally caught each year. Incidentally caught fish, or "bycatch," are usually discarded over the sides of fishing vessels while still at sea—so they are also called "discards." We collect data by direct observation, electronic monitoring, and from fish and shrimp sales information. We estimate total eulachon bycatch every other year, and publish the results in a biennial report. A draft version of the report is shared with the Groundfish Endangered Species Workgroup and the Pacific Fishery Management Council to help them make management decisions.

The observer program monitors eulachon bycatch in fisheries that target ocean shrimp and groundfish on the U.S. West Coast. We present estimates of eulachon bycatch in observed ocean shrimp fisheries on a state-by-state basis and as total eulachon bycatch in the combined shrimp fishery. We also present estimates of eulachon bycatch in federally managed groundfish fisheries in a separate section. The following commercial fishery sectors had observed eulachon bycatch during 2002–21:

- Washington, Oregon, and California ocean shrimp trawl fisheries.
- Limited entry bottom trawl fishery (2002–04, 2007, 2009–10).
- Individual fishing quota bottom and midwater trawl fisheries (2011–21).
- At-sea hake fishery (2006–09, 2011–21).

Definitions of and details on these fisheries can be found throughout this report.

This technical memorandum provides eulachon bycatch estimates for the years 2002 through 2021. Estimates are in numbers of eulachon, weight of eulachon, and ratio of the number and weight of eulachon per metric ton (mt) of shrimp and/or groundfish caught. These estimates are broken out by fishery sector.

Key Takeaways

We present data by fishery sector, as well as by fishery management grouping.

- Most bycatch of eulachon occurs in the ocean shrimp fisheries. No more than 0.3% of total eulachon bycatch occurred in U.S. West Coast groundfish fisheries in any one year from 2010–21.
- The observed bycatch of the Southern DPS of eulachon in state-managed ocean shrimp fisheries over the most recent five years analyzed (2017–21) averaged 12.8 million fish and ranged from 650 thousand to over 22 million fish.
- At the same time, the estimated number of threatened Southern DPS eulachon encountered in the federally managed groundfish sectors for 2017–21 averaged 7,172 fish (range: 56 to 23,820 fish). These bycatch numbers in the groundfish sectors are from fisheries with nearly 100% observer coverage.
- Bycatch of eulachon in U.S. West Coast groundfish fisheries amounted to 23,820 fish in 2021. This is considered a relatively minor threat to eulachon, compared to the bycatch of over 18.5 million eulachon in ocean shrimp fisheries during 2021.

Links used in this section:

- Eulachon: https://www.fisheries.noaa.gov/species/eulachon
- 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
- Observer program: https://www.fisheries.noaa.gov/west-coast/science-data/fisheries-observation-science-west-coast
- Direct observation: https://www.fisheries.noaa.gov/topic/fishery-observers
- Electronic monitoring: https://www.fisheries.noaa.gov/west-coast/resources-fishing/electronic-monitoring-west-coast
- Groundfish Endangered Species Workgroup: https://www.pcouncil.org/navigating-the-council/membership-groups-and-staff/advisory-groups/groundfish-endangered-species-workgroup/#:~:text=The%20Pacific%20Coast%20Groundfish%20and,%2C%20and%20short%2Dtailed%20albatross.
- Pacific Fishery Management Council: https://www.pcouncil.org/

Executive Summary

Eulachon (*Thaleichthys pacificus*) are small-bodied anadromous smelts (Family Osmeridae) that spawn at age-2–5 in the lower portions of rivers that have prominent spring peak-flow events, from northern California to the southeastern Bering Sea coast of Alaska (Hay and McCarter 2000, Willson et al. 2006, Moody and Pitcher 2010). After reaching the ocean as larvae, eulachon spend about 95% of their life in the marine environment over the continental shelf at depths between 50 and 200 m.

In 2010, the National Marine Fisheries Service (NMFS) published a final rule in the Federal Register to list the Southern Distinct Population Segment (DPS) of eulachon as threatened under the Endangered Species Act (USOFR 2010). The Southern DPS of eulachon, which occurs in the northern California Current, is composed of numerous local populations that spawn from the Mad River in northern California to the Skeena River in British Columbia. The recent 2022 five-year status review update resulted in a recommendation and decision that the Southern DPS of eulachon remain classified as a threatened species (Gustafson et al. 2022, NMFS-WCR 2022).

The Biological Review Team for the eulachon status review (Gustafson et al. 2010) scored bycatch in ocean fisheries as a moderate extinction threat in all sub-areas of the Southern DPS of eulachon. The current document provides observed and fleetwide estimates of eulachon bycatch in state-permitted ocean shrimp (*Pandalus jordani*) trawl fisheries from 2004–21 and in federally permitted groundfish fisheries from 2002–21 on the U.S. West Coast. Bycatch observations and estimates are produced by the Northwest Fisheries Science Center's (NWFSC) Fisheries Observation Science Program, which is composed of two units: the West Coast Groundfish Observer Program (WCGOP) and the At-Sea Hake Observer Program (A-SHOP).

From 2004–09, estimated bycatch of eulachon in the Oregon and California ocean shrimp fisheries ranged from about 156,000 fish in 2004 to over 948,000 fish in 2009. Following extension of observer coverage to the fishery in Washington in 2010, estimated eulachon bycatch for all three states combined was nearly 1.1 million fish in 2010 and 606,000 fish in 2011. Estimated eulachon bycatch in ocean shrimp fisheries increased dramatically from 2012–16, reaching nearly 43 million fish in 2012, over 53.3 million fish in 2013, over 73.4 million fish in 2014, and about 60 million fish in 2015. Eulachon bycatch in the combined Washington, Oregon, and California ocean shrimp trawl fishery declined to about 4.4 million fish in 2016 and 649,600 fish in 2017. Coastwide eulachon bycatch in ocean shrimp fisheries was 3.2 million fish in 2018, 19.8 million fish in 2019, and over 22.1 million fish in 2020. Subsequently, estimated eulachon bycatch declined by two-thirds in the Oregon ocean shrimp sector in 2021, but more than doubled in the Washington fishery, resulting in a total coastwide bycatch of over 18.5 million fish in 2021. Ocean shrimp landings did not occur in California in 2021.

Similar to total bycatch, eulachon bycatch ratios (measured as the weight in kg or the number of eulachon per metric ton [mt] of observed ocean shrimp) in Washington and Oregon ocean shrimp fisheries increased dramatically from 2011 to 2012 and remained high in 2013–15. Eulachon bycatch ratios declined in ocean shrimp trawl fisheries from 2015–17. In 2017, bycatch ratios as number of eulachon per mt of shrimp were 145 for Washington, 20 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 per mt of shrimp in 2018 to 1,570 eulachon per mt of shrimp in 2019. In Oregon, the ratio increased from 111 eulachon per mt of shrimp in 2018 to 1,088 eulachon per mt of shrimp in 2019. The eulachon bycatch ratio in the Washington sector declined modestly to 871 eulachon per mt of shrimp in 2020, but increased to 1,494 eulachon per mt of shrimp in 2021. Bycatch ratios declined in the Oregon ocean shrimp sector in 2020 and 2021 to 850 and 296 eulachon per mt of ocean shrimp, respectively.

Sorting-grid bycatch reduction devices (BRDs) are mandated in ocean shrimp trawl fisheries on the U.S. West Coast. Beginning in 2018, Washington and Oregon also mandated the use of light emitting diode (LED) lights on the footrope of each trawl net for bycatch reduction. Similar regulations took effect in California in the 2022–23 season. It is evident that eulachon bycatch ratios in different sectors of ocean shrimp fisheries vary widely from year to year, especially between Oregon and Washington. Many factors influence how eulachon respond to trawl gear illumination, including turbidity, fish density, time of day, groundgear configuration, placement of illumination, and fish fatigue and stress, among others. In addition, it may be that BRDs (both deflecting grids and footrope LEDs) in the ocean shrimp trawl fisheries operate at greatly reduced efficiency when eulachon reach high densities, as they did in 2019–21.

Across 20 years of observation (2002–21), an estimated 45,668 individual eulachon were caught as bycatch in all sectors of the U.S. West Coast groundfish fishery. Eulachon bycatch in combined U.S. West Coast groundfish fisheries increased from an estimated 792 in 2018 and 2,663 in 2019, to an estimated 8,528 eulachon in 2020 and 23,820 eulachon in 2021. The combined 2020 and 2021 estimated bycatch represents about 71% of the 2002–21 total, and the 2021 total is greater than the previous 19 years combined.

Prior to 1 January 2019, federal regulations in the commercial groundfish fishery mandated minimum trawl mesh sizes in the bottom and midwater trawl fisheries of 11.4 cm (4.5 in) and 7.6 cm (3.0 inches), respectively. These mesh size restrictions and several other gear regulations were removed as of 1 January 2019 per a final rule in the Federal Register (USOFR 2018). It was assumed that eliminating mesh size, codend, and chafing gear restrictions for midwater and bottom trawl fisheries would have little impact on eulachon, since participants in the catch share program would likely continue using codends (and other large sections of the trawl net) with mesh sizes similar to those used prior to 1 January 2019 (NMFS 2018). It is unclear what caused eulachon bycatch to greatly increase from 2019 through 2021; however, these increases coincide with elimination of gear restrictions, as detailed in USOFR (2018). Eulachon abundance also increased during this period and the presence of more eulachon in the marine environment likely accounts for some unknown portion of the increased eulachon bycatch in these fisheries.

The vast majority of bycatch of eulachon in U.S. West Coast fisheries occurs in the state-permitted ocean shrimp fisheries, and no more than 0.3% of total eulachon bycatch occurred in U.S. West Coast groundfish fisheries in any one year from 2010–21, when all fisheries with eulachon bycatch were under observation. Bycatch of eulachon in U.S. West Coast groundfish fisheries amounted to 23,820 fish in 2021, and is a relatively minor extinction risk factor for eulachon, compared to the bycatch of over 18.5 million eulachon in ocean shrimp fisheries during 2021.

From a conservation biology perspective, it is important to examine not only observed bycatch and discard mortality, but also the fate of nontarget organisms that escape from trawl nets prior to being hauled aboard fishing vessels. Data on survivability of small pelagic fishes such as eulachon following exclusion by rigid-grate BRDs are scarce. However, Hannah and Jones (2012) used underwater video technology to show that large eulachon were excluded at a higher efficiency than small eulachon when encountering rigid-grate BRDs in an ocean shrimp trawl net. Hannah and Jones (2012, p. 43) noted, "[M]ost eulachon 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." By contrast, 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.

Acknowledgments

The authors gratefully acknowledge the hard work and dedication of observers from the West Coast Groundfish Observer Program and the At-Sea Hake Observer Program, as well as contributions from observer program staff. This document was a joint effort of the Eulachon Bycatch Reporting Team, which has included at various times and in various roles Vanessa Tuttle, Kayleigh Somers, and Kate Richerson (NWFSC/Fishery Resource Analysis and Monitoring Division [FRAM]), Yong-Woo Lee and Jason Jannot (formerly NWFSC/FRAM), Rick Gustafson and Eric Ward (NWFSC/Conservation Biology Division), and Robert Anderson (NMFS/West Coast Region). We also thank James Myers and Shallin Busch for critical reviews of earlier versions of this document.

Abbreviations

ACL	annual catch limit
A-SHOP	At-Sea Hake Observer Program (FRAM)
BRD	biological reduction device
BRT	Biological Review Team
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
DFO	Fisheries and Oceans Canada
DOC	U.S. Department of Commerce
DPS	distinct population segment
DU	designatable unit
EAL	eulachon action level
EFP	exempted fishing permit
EM	electronic monitoring
ESA	Endangered Species Act
FLD	footrope lighting device
FMP	fishery management plan
FRAM	Fishery Resource Analysis and Monitoring Division (NWFSC)
IFMP	integrated fishery management plan
IFQ	individual fishing quota
LE	limited entry
LED	light emitting diode
MSCV	mothership catcher vessel
MSA	Magnuson–Stevens Fishery Conservation and Management Act
NMFS	National Marine Fisheries Service (NOAA)
NOAA	National Oceanic and Atmospheric Administration (DOC)
NWFSC	Northwest Fisheries Science Center (NMFS)
ODFW	Oregon Department of Fish and Wildlife
PFMC	Pacific Fishery Management Council
PSMFC	Pacific States Marine Fisheries Commission
PacFIN	Pacific Fisheries Information Network

SARA	Species at Risk Act (Canada)
SMA	shrimp management area
SSB	spawning stock biomass
USGS	U.S. Geological Survey
WCGOP	West Coast Groundfish Observer Program (FRAM)
WCR	West Coast Region (NMFS)
WCVI	west coast of Vancouver Island
WDFW	Washington Department of Fish and Wildlife

Introduction and Background

This document provides an analysis of observed and fleetwide bycatch estimates of U.S. Endangered Species Act (ESA)-listed eulachon (*Thaleichthys pacificus*, Osmeridae) in ocean shrimp (*Pandalus jordani*)[1] trawl fisheries in Washington from 2010–21, in Oregon and California from 2004–21, and in U.S. West Coast groundfish fishery sectors from 2002–21.

Eulachon is an anadromous smelt that ranges from northern California to the southeastern Bering Sea coast of Alaska (Hay and McCarter 2000, 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 ESA. A eulachon Biological Review Team (BRT)—consisting of federal scientists from the Northwest Fisheries Science Center (NWFSC), Alaska Fisheries Science Center, Southwest Fisheries Science Center, U.S. Fish and Wildlife Service, and U.S. Forest Service—was formed by NMFS, and the team reviewed and evaluated scientific information submitted from state agencies, other interested parties, and from both published and unpublished literature. The BRT identified a Southern distinct population segment (DPS) of eulachon, which occurs in the California Current, and comprises eulachon that spawn in numerous rivers from the Mad River in northern California to the Skeena River in British Columbia. The BRT concluded that major threats to the Southern DPS included: 1) climate change impacts on ocean and freshwater habitat, 2) bycatch in offshore ocean shrimp trawl fisheries, 3) changes in downstream flow timing and intensity due to dams and water diversions, and 4) predation. These threats, together with large declines in abundance, indicated to the 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). Subsequent five-year reviews (Gustafson et al. 2016, 2022, NMFS-WCR 2016, 2022) resulted in recommendations that the DPS remain classified as a threatened species. Eulachon in Canada that overlap the range of the ESA's Southern DPS have also been recommended for listing as endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) under the Canadian Species at Risk Act (SARA; COSEWIC 2011, 2013).

Eulachon Life History

Adult eulachon typically spawn at age-2–5, when they are 160–250 mm in length (fork length). Spawning occurs 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 certain other rivers in their range on an irregular or occasional basis (Hay and McCarter 2000, Willson

[1] *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 to *Farfantepenaeus duorarum*, a commercial species in the South Atlantic and Gulf of Mexico (McLaughlin et al. 2005).

et al. 2006, Moody and Pitcher 2010). The spawning migration typically begins when river temperatures are between 0°C and 10°C, which usually occurs between December and June. Run timing and duration may vary interannually, and multiple temporally separated runs occur in some rivers (Willson et al. 2006). Most eulachon are semelparous. Fecundity ranges from 7,000–60,000 eggs, and individual eggs are approximately 1 mm in diameter. Milt and eggs are released over sand or coarse gravel. Eggs become adhesive after fertilization and hatch in three to eight weeks depending on temperature. Newly hatched larvae are transparent, slender, and about 4–8 mm in total length. Larvae are transported rapidly by spring freshets to estuaries (Hay and McCarter 2000, Willson et al. 2006), and juveniles disperse into waters over the oceanic continental shelf within the first year of life (Hay and McCarter 2000, Gustafson et al. 2010). It has been estimated that eulachon spend about 95% of their life in the ocean (Hay and McCarter 2000), although very little is known about their distribution and behavior in the marine environment. Eulachon have been taken in research trawl surveys over the continental shelf off the U.S. West Coast, most often at depths between 50 and 200 m (NWFSC-EW 2012[2]).

Northwest Fisheries Science Center Fishery Observation Science Program

The goal of the NWFSC Fishery Observation Science Program is to improve estimates of total catch and discard by observing commercial sectors of groundfish fisheries along the U.S. West Coast that target or take groundfish as bycatch. The observer program has two units: the West Coast Groundfish Observer Program (WCGOP) and the At-Sea Hake Observer Program (A-SHOP). WCGOP was established in May 2001 by NMFS in accordance with the Pacific Coast Groundfish Fishery Management Plan.[3] This regulation requires all vessels that catch groundfish in the U.S. Exclusive Economic Zone (EEZ) from 3–200 mi offshore to carry an observer or, for a subset of the fishery, use electronic monitoring (EM) gear. Subsequent rule-making has extended NMFS's ability to require vessels fishing within the three-mile state territorial water zone to carry observers.

WCGOP and A-SHOP observe distinct sectors of the groundfish fishery. WCGOP observes the following sectors: individual fishing quota (IFQ) shore-based delivery of groundfish and Pacific hake (*Merluccius productus*, a.k.a. Pacific whiting, hereafter: "hake"), limited entry (LE) and open access (OA) fixed gear, and state-permitted nearshore fixed gear sectors. WCGOP also observes several state-managed fisheries that incidentally catch groundfish, including ocean shrimp and California halibut (*Paralichthys californicus*) trawl fisheries. In addition, WCGOP observes the directed Pacific halibut (*Hippoglossus stenolepis*) fishery. Details on how fishery observers operate in both the IFQ (a.k.a. catch share) and non-IFQ (a.k.a. non-catch share) sectors can be found on the West Coast Groundfish Trawl Catch Share Observer Program web page.[4] A-SHOP observes the IFQ fishery that catches hake at sea, including catcher–processor (CP) and mothership catcher vessels (MSCV) and tribal catch delivered at sea to motherships.

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[2] Northwest Fisheries Science Center – Eulachon Workgroup. 2012. Potential for development of a marine abundance estimate for the Southern DPS of eulachon (*Thaleichthys pacificus*) based on a summary and analysis of available survey data in 2012. Unpublished manuscript.

[3] https://www.pcouncil.org/groundfish-fishery-management-plan-and-amendments/

[4] https://www.fisheries.noaa.gov/west-coast/fisheries-observers/west-coast-groundfish-trawl-catch-share-observer-program

Eulachon Bycatch

The following commercial fishery sectors had observed eulachon bycatch during 2002–21:

- Washington, Oregon, and California ocean shrimp trawl fisheries.
- LE and IFQ bottom trawl fishery.
- IFQ nonhake midwater trawl fishery.
- IFQ shoreside midwater hake trawl.
- IFQ shoreside midwater rockfish trawl.
- IFQ at-sea hake CP fishery.
- IFQ at-sea nontribal hake MSCV fishery.
- Tribal at-sea hake MSCV fishery.

Table S1 presents a summary of the permits, gear used, target groups, vessel length range, fishing depth range, and management of fishery sectors and subsectors in state-operated ocean shrimp fisheries and U.S. West Coast groundfish fishery sectors that have had documented eulachon bycatch. A number of previous reports (NWFSC 2008, 2009, 2010, Bellman et al. 2008, 2009, 2010, 2011, Al-Humaidhi et al. 2012, Gustafson et al. 2015, 2017, 2019, 2021, 2023) provided data on estimated bycatch of eulachon in U.S. West Coast commercial fisheries, which were derived from the then-current WCGOP and A-SHOP data. Eulachon bycatch count, weight, and ratio estimates are updated in the current document and may not always match estimates previously published in the above documents.

Fishery sectors with eulachon bycatch

Commercial ocean shrimp trawl fisheries in California, Oregon, and Washington

WCGOP observed ocean shrimp trawl fisheries from 2004–21 in Oregon and California (with the exception of 2006), and from 2010–21 in Washington. Bycatch ratios for eulachon are reported as weight in kilograms and as number of individual fish caught per metric ton (mt) of targeted fish (ocean shrimp or groundfish) retained per haul. These ratios are then used to estimate eulachon bycatch in the fleet sectors where only a portion of the total hauls were observed. In this report, we assume 100% mortality of eulachon incidentally caught and subsequently discarded in these 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). Commercial quantities of ocean shrimp occur from Point Arguello, California, north to Queen Charlotte Sound, British Columbia, typically over well defined beds of green mud or green mud and sand (Hannah and Jones 2007, Frimodig et al. 2009). 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 to 140 fathoms) during daylight hours. 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 ft), with an average length of 19.9 m (65 ft), and can use single or double-rigged shrimp trawl gear (Table S1). The ocean shrimp season is open from 1 April through 31 October in all three states, 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 46,409 mt in 2015 (Figure 1). The portion of the catch that is not marketable or for which regulations prohibit landing is discarded at-sea. 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[5] and Oregon.[6]

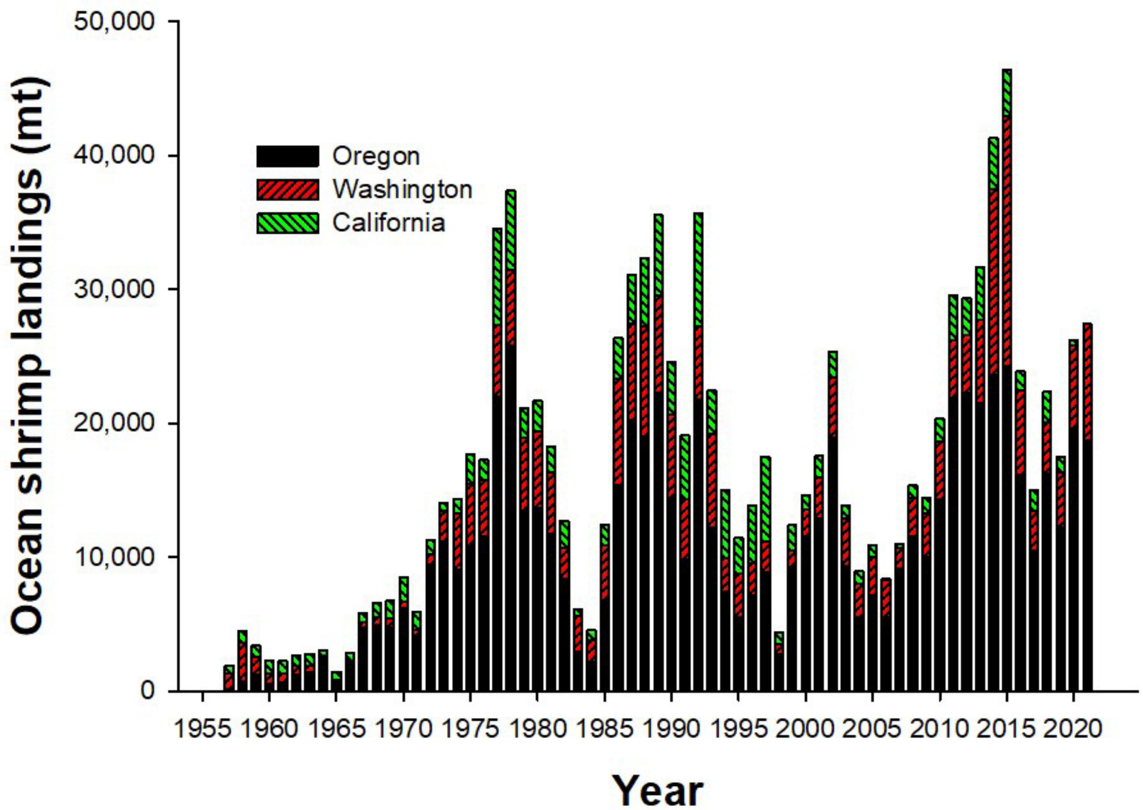

Figure 1. Commercial landings (mt) in ocean shrimp trawl fisheries off the U.S. West Coast through 2021. No landings of ocean shrimp were reported in California in 2020. Data from CDFW (wildlife.ca.gov/Conservation/Marine/Data-Management-Research/MFDE/Commercial-Landings), Saelens (1983), Wargo and Ayres (2016, 2017a, 2018, 2019, 2020), Groth et al. (2017, 2018, 2019, 2021, 2022), Groth and Smith (2020), Wargo et al. (2021, 2022), and Somers et al. (2022)[a].

[a] Somers, K. A., K. E. Richerson, V. J. Tuttle, and J. T. McVeigh. 2022. Fisheries Observation Science Program Coverage Rates, 2002–21. U.S. Department of Commerce, NOAA Data Report NMFS-NWFSC-DR-2022-02. Available: repository.library.noaa.gov/view/noaa/47111 (June 2023).

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

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

Limited entry shore-based bottom trawl fishery

The Pacific Ocean shore-based LE groundfish trawl fishery was established in 1994 for midwater and bottom trawl gear; it operates year-round off the coasts of Washington and Oregon, and southward to Morro Bay in California. Groundfish trawl vessels deliver their permitted and marketable catch to shore-based processors; however, any catch that is prohibited or unmarketable is typically discarded at sea. From 2002–10, observer coverage averaged ~20%. An IFQ program for the LE shore-based bottom trawl fleet was implemented in 2011, with 100% coverage by NMFS-certified observers, under the West Coast Groundfish Trawl Catch Share Observer Program. This catch share system divides the portion of the trawl fisheries' annual catch limits (ACL) for various groundfish stocks and stock complexes into shares controlled by individual fishermen or groups of fishermen (cooperatives), which can be harvested at the fishermen's discretion. In 2015–21, a subset of the fleet participated with Pacific Coast Groundfish Exempted Fishing Permits and carried electronic monitoring (EM) systems, rather than observers, for compliance and quota management. These vessels were still required to carry an observer for additional scientific data collection on ~20–30% of trips. More background information can be found on the West Coast Groundfish Trawl Catch Share Observer Program website.[7]

At-sea hake fishery

This IFQ fishery targets hake off the coasts of Oregon and Washington using midwater trawl nets, primarily from mid-May to November. We report data from three components of the at-sea fishery for hake: 1) the CP cooperative, consisting of vessels that harvest with midwater trawl gear and process hake catch at sea, 2) the MSCV cooperative, consisting of catcher vessels that harvest hake with midwater trawl gear and deliver the catch to motherships that processes the catch at sea, and 3) a commercial MSCV tribal fishery that uses gear similar to that used in the non-tribal fisheries. Data from non-tribal and tribal mothership catcher vessel sectors are combined in the current report. The CP sector entered into a cooperative agreement (co-op) which split the hake quota into individual fishing quotas by company in 1997, and the non-tribal MSCV sector entered into a co-op for the first time as U.S. West Coast trawl fisheries began operating under a catch share program in 2011.[8] In each of the at-sea hake fishery sectors, the portion of the non-hake catch, which is either prohibited by regulations or cannot be processed, is discarded at sea. Observer coverage in the at-sea hake fishery began in the late 1970s. By the early 2000s, the catcher–processors and motherships were each voluntarily carrying two observers for every fishing day. Regulations requiring two observers went into effect in 2004. Starting in 2011, catcher vessels delivering to motherships were also required to have observer coverage for discard accounting, but most have since migrated to electronic monitoring in lieu of 100% observer coverage. Delivered catch is sampled by A-SHOP observers aboard the mothership.

[7] https://www.fisheries.noaa.gov/west-coast/fisheries-observers/west-coast-groundfish-trawl-catch-share-observer-program

[8] https://www.fisheries.noaa.gov/west-coast/sustainable-fisheries/west-coast-groundfish-trawl-catch-share-program

Shoreside midwater hake and shoreside midwater rockfish sectors

The IFQ shoreside hake and rockfish midwater trawl fleet exclusively comprises catcher vessels that deliver unsorted catch to shore-based processing plants. From 2011–14, these sectors were defined based on the captain's target species; however, from 2015 onward, these sectors are defined based on landing half or more of hake in a trip. Fishery definitions from 2011–14 and those in 2015–21 are not directly comparable, although they are similar. To emphasize this, WCGOP also altered the name of these fisheries to clarify the difference in 2015–21 sectors: "shoreside hake" became "shoreside midwater hake", and "midwater non-hake" became "shoreside midwater rockfish." It should also be noted that, in this report, from 2011–14, all midwater non-hake trips were combined with the bottom trawl sector, but in 2015–21 the shoreside midwater rockfish sector is reported separately.

Delivering unsorted catch is necessary to limit handling of the catch and ensure that landed fish are of market quality. One hundred percent of the landed catch from this full-retention fishery is sampled for bycatch by the Catch Monitor Program after being landed and delivered to shore-based facilities. Because shoreside midwater hake and shoreside midwater rockfish function as full-retention fisheries, the at-sea discards observed by WCGOP are typically minimal. However, during sorting and processing, additional "discards" occur on shore. All IFQ vessels were required to carry an observer from 2011–14 on 100% of fishing trips. Similar to bottom trawl vessels, in 2015–21, a subset of these fleets applied for Pacific Coast groundfish EM exempted fishing permits (EFPs) and carried EM for compliance, rather than an observer. This EFP requires maximized retention, so no additional observer coverage is currently required; instead, bycatch estimates rely on EM and shoreside catch monitoring samples.

Bycatch reduction devices (BRDs)

Deflecting-grate BRDs in ocean shrimp fisheries

Currently, ocean shrimp trawl vessels are required to use BRDs that serve as deflecting grates to guide non-target species toward an escape opening, which is usually on the top of the net. The primary goal of mandatory BRDs is to reduce bycatch of groundfish species and, more recently, protected species such as eulachon. Deflecting-grate 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 in (19.1 mm). In California, approved deflecting-grate 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 in (50.8 mm); 2) soft-panel excluders, usually made of a soft mesh material with individual meshes no larger than 6 in (15.2 cm); and 3) fisheye excluders, which have a forward-facing escape opening that is maintained by a rigid frame. For more information, see the 2023 California Commercial Fishing Regulations Digest.[9]

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

Use of light emitting diodes (LEDs) on the fishing line of each trawl net became mandatory in Washington and Oregon in 2018 and in California as of the 2023 season (see Footrope lighting BRDs in ocean shrimp fisheries). Further details on shrimp BRD requirements and fishery regulations are available online for Washington,[10] Oregon,[11] and California.[12]

Footrope lighting BRDs in ocean shrimp fisheries

The use of LED lights on the footrope or fishing line of ocean shrimp trawl nets to reduce bycatch became mandatory as of 2018 in Washington and Oregon, and 2023 in California. A diagram of a shrimp trawl net depicting the location of the deflecting grid BRD and attachment of LED lights to the trawl footrope is available on the ODFW Commercial Pink Shrimp Fishery website.[13]

Washington regulations as stated in Wargo and Ayres (2018, 2019) 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

[10] https://apps.leg.wa.gov/wac/default.aspx?cite=220-340-500
[11] https://dfw.state.or.us/fish/commercial/docs/2022%20Commercial%20Synopsis.pdf
[12] https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=205932&inline
[13] https://www.dfw.state.or.us/MRP/shellfish/commercial/shrimp/LEDs.asp

Oregon regulations on footrope lights, as stated in Groth et al. (2018, p. 2), are as follows:

> 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.

Groth et al. (2021, p. 10) reported that the "FishTek Marine 'netlight' is now an Oregon legal LED fishing light."

Prior to adoption of regulatory changes on 1 November 2022, footrope lighting devices (FLDs) were used voluntarily in California (CDFW 2022). At its 20–21 April 2022 meeting, the California Fish and Game Commission adopted CDFW's ocean shrimp fishery management plan (FMP; CDFW 2022).[14] This FMP proposed that regulations requiring LEDs to reduce eulachon bycatch be adopted in the California ocean shrimp fishery (CDFW 2022). New regulatory changes were implemented on 1 November 2022 through adoption of the California ocean shrimp FMP as adopted and amended by the California Fish Commission. These regulations[15] stated that:

> Bycatch Reduction Device (BRD) and Footrope Lighting Device (FLD) [are] Required. No shrimp trawl net may be possessed on board a vessel in the commercial pink shrimp fishery that does not include an approved bycatch reduction device BRD and FLD.... All trawl nets used north of Point Conception, Santa Barbara County shall have functional lighting devices attached to the footrope as follows:
>
> (A) Lighting devices shall be blue or green light-emitting diodes that are pressure-rated to a depth of at least 300 meters.
>
> (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 5 lighting devices, spaced at least 4 feet apart in the center of each net.

As part of an ESA Section 6 grant from NOAA to ODFW, WDFW, and CDFW, a year's supply of LED lights was 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

[14] https://wildlife.ca.gov/Conservation/Marine/Invertebrates/Shrimp-Prawn
[15] https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=205932&inline

and distributed to fishers (Groth 2020). These informational sheets are available on the ODFW Marine Resources website.[16] 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).

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

Methods

Data Sources

Sources for this analysis include onboard observer and electronic monitoring data from WCGOP and A-SHOP and landing receipt data, referred to as fish tickets, obtained from the Pacific Fisheries Information Network (PacFIN). In the shorebased IFQ program, each first receiver taking delivery of IFQ species is required to have a certified catch monitor present for the entire duration of the landing. A catch monitor is someone who is land-based at first-receiver facilities and confirms that total landings are accurately sorted, weighed, and recorded on fish tickets. Once verified, catch monitors independently report catch data to the Pacific States Marine Fisheries Commission. More information on onboard observers, first receivers, and catch monitors is available online at the West Coast Groundfish Trawl Catch Share Program website.[17]

The Magnuson–Stevens Fishery Conservation and Management Reauthorization Act of 2006 (MSA) defined information confidentiality requirements such that the government cannot make public any data that can be linked to individual people or businesses. Currently, this is achieved through applying the "Rule of Three," wherein any data presented to the public must have been reported by at least three fishers or dealers. In this study, those data that can only be attributed to two or fewer fishers or dealers are aggregated to a higher level.

Observer data

A list of fisheries, coverage priorities, and data collection methods employed by WCGOP in each observed fishery can be found in the WCGOP training manual (NWFSC 2023a). To date, WCGOP observer data are the main source for discard estimation in the ocean shrimp trawl fishery. The sampling protocol employed by WCGOP primarily focuses on the discarded portion of catch. To ensure that the recorded weights for the retained portion of the observed catch are accurate, haul-level retained catch weights recorded by observers are adjusted based on trip-level fish ticket records. This process is described in further detail in Somers et al. (2023). A-SHOP information and documentation on data collection methods can be found in the A-SHOP observer manual (NWFSC 2023b). The sampling protocol employed by A-SHOP focuses on random samples collected from the total catch. Data processing was applied prior to the analyses presented in this report.

Fish ticket data

For bycatch estimation, the landed amount of a particular fish species or species group is the effort metric. For instance, in the case of the ocean shrimp trawl fishery, bycatch estimation uses the landed amount of ocean shrimp as the effort metric. Thus, the retained landing

[17] https://www.fisheries.noaa.gov/west-coast/sustainable-fisheries/west-coast-groundfish-trawl-catch-share-program

information from fish tickets is crucial for total bycatch estimation for all sectors of the ocean shrimp trawl fishery and commercial groundfish fisheries on the U.S. West Coast. Fish ticket landing receipts are completed by fish-buyers in each port for each delivery of fish by a vessel.

Fish tickets are trip-aggregated sales receipts for market categories that may represent single or multiple species. Fish tickets are issued to fish-buyers by a state agency and must be returned to the agency for processing. They are designed by the individual states (Washington, Oregon, and California) with slightly different formats in each state. In addition, each state conducts shoreside species-composition sampling for numerous market categories that are reported on fish tickets. State agencies submit fish ticket and species-composition data to the PacFIN regional database. In our analyses, annual fish ticket landings data, with state species-composition sampling applied, were retrieved from the PacFIN database and subsequently divided into various sectors of the ocean shrimp fishery and the groundfish fishery. Observer and fish ticket data processing steps are described in detail in Somers et al. (2023). All data processing steps specific to this report are described in the following section.

Bycatch Estimation Methods

The landed amount of a target species (or species group) was used as a proxy for fleetwide fishing effort. The choice of target species and, therefore, the effort metric, depends on the fishery sector. Thus, eulachon bycatch was estimated for each individual fishery sector that encountered eulachon. Eulachon were taken during some years as bycatch in the following fishery sectors:

1. State-operated ocean shrimp trawl (2004–21).
2. LE bottom trawl (2002–10).
3. IFQ bottom trawl (2011–21).
4. IFQ nonhake midwater trawl (2011–21).
5. IFQ shoreside hake (2011–14).
6. IFQ shoreside midwater hake (2015–21).
7. IFQ shoreside midwater rockfish (2015–21).
8. Nontribal and tribal at-sea hake mothership (2002–21).
9. At-sea hake catcher–processor (2002–21).

As mentioned above, landed catch of target species is the effort metric, and target species differ by fishery sector. Target species of those sectors that encountered eulachon during 2002–21 were: 1) ocean shrimp in state-operated ocean shrimp trawl fisheries, 2) all groundfish species, except hake, included in the groundfish FMP for LE bottom trawl and IFQ trawl sectors, 3) hake for at-sea hake fisheries, and 4) either hake or groundfish for shoreside midwater trawl hake/rockfish fisheries. For those sectors that encountered eulachon, a ratio estimator was used to estimate the number or weight of eulachon catch per stratum. For a given fishery sector, observer data were stratified by state of landing, year, and season, as applicable and possible given MSA confidentiality requirements to use the “rule of three”—that only strata with three or more active vessels will be reported, to protect business interests. A bycatch ratio (a.k.a. bycatch rate) per stratum was computed from observer data as the observed catch (number or weight) of eulachon divided by the observed retained weight of target species (or species groups). Total eulachon bycatch at the fleetwide level was then estimated based on the simple expansion of bycatch ratios by total targeted fish landings as the multiplier for a given stratum. The estimations of bycatch ratio and fleetwide expansion were done according to the following equation:

$$\hat{D}_s = \frac{\sum_t d_{st}}{\sum_t r_{st}} \times F_s$$

where:

s = stratum, which is formed by a combination of sector, year, season, state, etc.,
t = individual tows in observer data,
d = observed bycatch count of eulachon,
r = observed retained weight of target species or species group,
F = expansion factor (total weight of landed target species recorded on fish tickets), and
$\hat{D}$ = fleetwide total bycatch estimate of eulachon.

Fishery sectors

Washington, Oregon, and California ocean shrimp trawl fisheries

As described above, fleetwide eulachon bycatch estimates in the Washington, Oregon, and California ocean shrimp trawl fisheries were derived from WCGOP observer data and fish ticket landings data. Annual ocean shrimp fisheries occur from April to October. WCGOP coverage of the Oregon and California ocean shrimp fleets began in 2004 and has continued to the present, with the exception of 2006. Bycatch observation of the Washington ocean shrimp fleet first began in 2010, following revision of Washington regulations allowing federal observers in this state-managed fishery. For analysis purposes, only trips by shrimp vessels landing in a particular state are considered part of that state's ocean shrimp fishery. This definition is consistent with state management.

When necessary to preserve confidentiality, we pooled strata over a three-year time window to estimate bycatch and uncertainty. When there are fewer than three observed vessels in a given stratum, data confidentiality prohibits revealing catch and other associated fishing trip information in that stratum. To overcome this issue, we pooled strata over a three-year time window around the problem stratum; the year before, the year of, and the year after the problem stratum. We then bootstrapped the three-year pooled strata to estimate the bycatch ratio in the confidential stratum. Therefore, this bycatch ratio is a three-year running average.

LE bottom trawl fishery

The LE bottom trawl fishery was a multispecies fishery (2002–10) that targeted various groundfish species. Since 2011, this fishery has been managed under an IFQ system. Landings for this fishery include all groundfish species defined in the groundfish FMP, except hake. There are 86 fish species actively managed under this FMP (PFMC 2022), including 64 rockfish species, 12 flatfishes, six roundfishes, and four sharks and skates. The data were stratified by year, state of landing, and season. LE bottom trawl vessels can hold a California halibut bottom trawl permit and participate in the state-permitted California halibut fishery. California halibut tows can occur on the same trip as tows targeting groundfish and were identified based on the following criteria: 1) the reported tow target was California halibut and more than 150 lb (68 kg) of California halibut were landed, or 2) the tow target was nearshore mix, sand sole, or other flatfish, and the tow took place in less than 30 fathoms and south of lat 40°10′N. All tows from 2002–10 in the observer data that met at least one of these two requirements were defined as LE California halibut and not included in analysis of the LE bottom trawl sector.

Catch share: Nonhake bottom and midwater trawl IFQ fishery

Eulachon were encountered in IFQ bottom and midwater trawl gear sectors. However, fishing activities were very low in the midwater trawl sector in 2011. To maintain confidentiality standards and remain consistent, bottom and midwater sectors were combined for bycatch estimation. Fleetwide eulachon bycatch for this sector is almost completely known because all vessels were monitored by an observer or electronically. Bycatch for this fishery was summarized by year and state of landing. From 2011–14, this section included midwater nonhake trawl. Currently, shoreside midwater trawl is reported separately as IFQ shoreside midwater hake trawl and IFQ shoreside midwater rockfish trawl.

In the non-EM portion of the fleet, all IFQ fishing trips are observed, but a very small number of tows or a small portion of catches from a given tow may be unsampled due to observer illness or other circumstance. Overall, coastwide annual unsampled catch was less than 0.8% of the total landed weight of groundfish species during 2011–21. Three types of unsampled catch categories can occur during observed trips: completely unsorted catch (discards + retained), unsampled discards, and unsampled non-IFQ species. Both completely unsorted catch and unsampled discards could contain both IFQ and non-IFQ species, but unsampled non-IFQ species only contains species that do not belong to the IFQ species list. Estimates of eulachon bycatch are derived from the unsampled portions of the catch for each unsampled category type individually. Estimated bycatch from the unsampled portion of the catch, by stratum, is then added to the observed bycatch amount to obtain the total bycatch estimate. Expansion for the unsampled portion was only needed if eulachon were encountered within a stratum. If no eulachon were encountered in a stratum, then it was assumed that no eulachon were encountered in the unsampled catch. The following equation was used to estimate bycatch in the unsampled portions of the catch in IFQ fisheries:

$$\hat{U}_{sc} = \frac{\sum_{t} d_{st}}{\sum_{t} w_{sct}} \times Z_{sc}$$

where:

s = stratum,
c = category of unsampled catch,
t = individual tows in observer data,
d = observed bycatch count of eulachon,
w = weight of sampled catch,
Z = unsampled weight of catch, and
$\hat{U}$ = bycatch estimate of eulachon in unsampled catch.

We estimated eulachon bycatch within unsorted catch by multiplying the bycatch ratio of the eulachon in a given stratum (i.e., eulachon bycatch numbers or weight divided by the sampled retained + discarded weight of all species) by the weight of unsorted catch of all species per stratum (i.e., expansion factor). Estimations for other unsampled categories were done in the same fashion, but with different denominators for bycatch ratio and different expansion factors. For the unsampled discard category, the denominator was sampled discarded weight of all species and the expansion factor was unsampled discarded weight of all species. For the unsampled non-IFQ category, the denominator was sampled weight of all discarded non-IFQ species and the expansion factor was unsampled weight of discarded non-IFQ species. Data were declared as failed when errors occurred consistently throughout an observer's sampling of a haul or trip. In the case of failed data estimations, the denominator was the sampled weight of target species and the expansion factor was sum of retained weight of target species in failed trips.

IFQ vessels fishing midwater trawl gear function as a maximum retention fishery, with little or no at-sea discard. Catch is sorted on shore, so nearly all protected species catch is discarded shoreside rather than at sea. This can also occur on occasion in bottom trawl sectors.

At-sea hake fishery

Observed and expanded bycatch data were provided directly from A-SHOP and incorporated into this report. We report eulachon bycatch by year for two at-sea hake fishery sectors: catcher–processors, and motherships delivered at sea. All vessels fishing in the at-sea hake fishery carry two A-SHOP observers for every fishing day (i.e., 100% coverage).

Though very rare, entire hauls may not be sampled due to unforeseen circumstances (e.g., observer illness). These unsampled hauls are expanded at the stratum level. Typically, greater than 99% of hauls are sampled each year. Therefore, the expanded unsampled portion is very small.

The eulachon catch in unsampled hauls is estimated by multiplying the eulachon catch from the sampled weight by the proportion of unsampled weight over the total weights per given stratum. This estimated eulachon catch for unsampled hauls is then added to the sum of all eulachon catch in the sampled hauls to produce the total estimated eulachon bycatch per given stratum. The total number of eulachon caught by the at-sea hake fleet, per stratum, was calculated using the following formula:

$$B_s = \sum Y_{st} + \sum Y_{st} \cdot \left(\frac{U_s}{T_s}\right)$$

where:

B = the total estimated eulachon bycatch,
s = individual stratum,
t = individual tow,
Y = number of eulachon caught,
U = weight of unsampled hauls, and
T = weight of sampled hauls.

Catch share: Shoreside hake fishery (2011–14)

Observers in this sector did minimal sampling at sea unless discards occurred, as most hauls were retained entirely and the landed catch was sorted and weighed at the plants by catch monitors. At-sea discards and landings data were combined to estimate total catch. Because catch monitors only weighed landed catch, eulachon discard information is available as weight but not counts. Therefore, eulachon bycatch numbers were derived from a three-year rolling window regression fit of count and weight information based on all catch share data for shoreside hake, midwater hake, and midwater rockfish.

Catch share: IFQ shoreside midwater hake trawl (2015–21)

The shoreside midwater trawl fishery functions as a full-retention fishery, so only at-sea discards are observed by WCGOP; however, additional discards occur on land, so a percent discard is not calculated. All non-EM IFQ vessels carry an observer on every fishing trip. Because catch monitors only weigh landed catch, eulachon discard information is available as weight but not counts. Therefore, eulachon bycatch numbers were derived from a three-year rolling window regression fit of count and weight information based on all catch share data for shoreside hake, midwater hake, and midwater rockfish.

Catch share: IFQ shoreside midwater rockfish trawl (2015–21)

The shoreside midwater trawl fishery functions as a full-retention fishery, so only at-sea discards are observed by WCGOP; however, additional discards occur on land, so a percent discard is not calculated. All non-EM IFQ vessels carry an observer on every fishing trip. Because catch monitors only weigh landed catch, eulachon discard information is available as weight but not counts. Therefore, eulachon bycatch numbers were derived from a three-year rolling window regression fit of count and weight information based on all catch share data for shoreside hake, midwater hake, and midwater rockfish.

Electronically monitored shore-based IFQ sectors

As indicated above, a portion of the IFQ fishery has been covered by EM under EFPs since 2015. Under the current EM EFPs, vessel captains are required to complete detailed logbooks and the logbook is the primary catch reporting device for the program. Video review is performed by the Pacific States Marine Fisheries Commission (PSMFC), and the EM video system is then used to audit the logbook and ensure proper recording of all discards. This program has partial WCGOP observer coverage at sea and full video coverage that has been reviewed for the presence of eulachon. Eulachon must be retained on EM vessels, and on-shore catch monitors record weights. Since counts of eulachon are not recorded in EM fisheries, eulachon bycatch numbers were derived from a three-year rolling window regression fit of count and weight information based on all catch share data for shoreside hake, midwater hake, and midwater rockfish. More information on the IFQ EM EFP fishery can be found online at the websites of NOAA's West Coast Region[18] and the Pacific Fishery Management Council.[19]

Measures of uncertainty

As a measure of uncertainty for the estimated bycatch ratio, lower and upper limits of the 95% confidence interval were estimated with a nonparametric bootstrap procedure for the fisheries strata that were not 100% observed. The bootstrap procedure randomly selects vessels that were observed within a stratum, with replacement. The number of vessels randomly selected is the same as the total number of observed vessels in the stratum. Random selection of vessels is intended to approximate the WCGOP vessel selection process. The bycatch ratio was estimated for each of 10,000 bootstrapped data sets to obtain a bootstrapped distribution of bycatch ratio estimates. The lower (2.5% percentile) and upper (97.5% percentile) confidence limits of the bycatch ratio were calculated from the bootstrapped distribution. The 95% confidence interval was also estimated for the fleetwide bycatch estimate per stratum by multiplying the confidence limits of the bycatch ratio by total landed weight of the target species in a given stratum. Lower confidence bound of total bycatch estimate was truncated at the observed bycatch amount if the estimated lower bound was less than the observed bycatch amount. One limitation with this method is that we underestimate the true uncertainty because we can only estimate the portion of uncertainty resulting from observer sampling. We have no information about uncertainty related to landings data; see Shelton et al. (2012).

When there are fewer than three observed vessels in a given stratum, data confidentiality prohibits revealing catch and other associated fishing trip information in that stratum. To overcome these issues, we estimated bycatch by pooling strata over a three-year time window around the problem stratum: the year before, the year of, and the year after the problem stratum. We then bootstrapped the three-year pooled strata to estimate the

[18] https://www.fisheries.noaa.gov/action/fisheries-west-coast-states-pacific-coast-groundfish-fishery-electronic-monitoring-program
[19] https://www.pcouncil.org/managed_fishery/electronic-monitoring/

bycatch ratio in the confidential stratum. This bycatch ratio can be viewed as a three-year running average. Among the federally managed sectors considered in this report that encountered eulachon during 2002–21, only three confidential strata occurred: the winter season of 2008 in the Washington LE bottom trawl sector, the 2019–21 non-EM midwater hake sector, and the 2020 Washington IFQ nonhake bottom and midwater trawl fisheries.

Results

Eulachon Bycatch in Ocean Shrimp Fisheries

Numerous previous publications have documented eulachon bycatch levels in ocean shrimp trawl fisheries off the coasts of Washington, Oregon, California, and British Columbia (Hay et al. 1999a,b, Olsen et al. 2000, NWFSC 2008, 2009, 2010, Bellman et al. 2011, Al-Humaidhi et al. 2012, Gustafson et al. 2015, 2017, 2019, 2021, 2023, DFO 2023a,b). However, the present document does not specifically cover eulachon bycatch in British Columbia shrimp trawl fisheries.

We received ocean shrimp trawl fisheries observer data from WCGOP.[20] These data contained all observed tows for the years 2004, 2005, and 2007–21. The ocean shrimp trawl fishery did not carry WCGOP observers in 2006. WCGOP first began observing the Washington ocean shrimp trawl fishery in 2010. All observed tows were in waters between 80 and 250 m in depth. Weight and numbers of observed eulachon bycatch, bycatch ratios, and estimated fleet-total bycatch weights and numbers of eulachon from ocean shrimp fisheries are presented by state in Tables S2 and S3 (Washington), Tables S4 and S5 (Oregon), and Tables S6 and S7 (California), and are compiled for the entire U.S. West Coast in Table 1.

Since 2010, the percentage of observed landings in the Washington ocean shrimp fishery has fluctuated between about 5 and 19.5% (Table S2). Estimated number of bycaught eulachon in the Washington ocean shrimp fisheries ranged from a low of 67,000 (95% CI: 24,723–140,986) fish in 2010 to a high of 22.3 million (95% CI: 16,832,276–28,913,245) fish in 2015 (Table S3, Figure 2). The state fleetwide bycatch count estimates of eulachon in the Washington ocean shrimp fishery were much lower in 2016 (~1.5 million) and 2017 (~442,000), but increased to about 1.4 million (95% CI: 670,990–2,651,935) in 2018 and to more than 6.5 million (95% CI: 4,810,078–8,597,092) in 2019. Estimated bycatch in the Washington ocean shrimp sector was over 5.4 million (95% CI: 3,172,204–6,766,075) in 2020, and more than doubled to over 13 million (95% CI: 4,230,963–24,637,980) in 2021 (Table S3, Figure 2).

Mean estimated total biomass of eulachon bycatch in the Washington fishery during this time period (2010–21) ranged from 2.1–231.4 mt (Table S2). The Washington sector bycatch ratio, measured as kilograms of eulachon per metric ton of retained shrimp, was highest during 2012 (37.0 kg/mt) and 2019 (33.6 kg/mt) and lowest in 2010 (0.5 kg/mt) and 2011 (1.3 kg/mt). This bycatch ratio had declined from high levels in 2012–13 to 5.0 kg/mt in 2016 and 3.8 kg/mt in 2017 (Table S2, Figure 3); however, this ratio increased to 8.4 kg/mt in 2018 and markedly increased to 33.6 kg/mt in 2019. The Washington sector ocean shrimp bycatch ratio remained elevated in 2020 (21.6 kg/mt) and 2021 (26.6 kg/mt; Table S2, Figure 3).

The Washington ocean shrimp fishery was 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

[20] Eulachon bycatch count and weight estimates have been updated in the current document and may not always match estimates previously published in Gustafson et al. (2015, 2017, 2019, 2021, 2023).

Table 1. Total estimated bycatch of eulachon (metric tons [mt] and number of individuals) in ocean shrimp fisheries observed by the West Coast Groundfish Observer Program (WCGOP), 2004–21. Ocean shrimp fisheries were not observed in 2006. Dashes (—) signify years when the sector was not observed.

	Eulachon bycatch (mt)				Eulachon bycatch (number of fish)			
Year	**WA**	**OR**	**CA**	**Coastwide**	**WA**	**OR**	**CA**	**Coastwide**
2004	—	2.88	0.20	3.08	—	146,379	9,745	156,124
2005	—	4.95	0.18	5.13	—	207,878	8,437	216,315
2006	—	—	—	—	—	—	—	—
2007	—	3.90	0.16	4.06	—	198,054	11,194	209,248
2008	—	10.33	0.32	10.65	—	390,056	22,744	412,800
2009	—	8.71	1.01	9.72	—	845,473	102,782	948,255
2010	2.13	13.69	2.45	18.28	67,205	740,552	267,080	1,074,837
2011	5.68	20.45	0.03	26.16	123,741	481,880	475	606,096
2012	156.69	427.94	6.88	591.52	14,282,792	28,379,097	337,437	42,999,326
2013	202.83	540.06	0.72	743.61	17,097,607	36,207,414	16,705	53,321,726
2014	144.02	618.70	6.56	769.29	13,635,062	59,329,960	602,169	73,567,191
2015	218.09	361.53	32.34	611.96	22,307,542	35,582,198	2,234,225	60,123,965
2016	31.79	66.17	1.96	99.91	1,499,284	2,866,306	51,688	4,417,278
2017	11.50	3.93	0.00	15.43	442,022	207,577	31	649,630
2018	32.32	26.88	0.05	59.26	1,405,326	1,793,646	3,503	3,202,475
2019	139.93	300.16	0.02	441.10	6,565,150	13,300,628	938	19,866,716
2020	135.72	433.01	0.15	568.88	5,477,469	16,624,798	8,083	22,110,350
2021	231.39	120.95	n/a	352.34	13,017,493	5,530,881	n/a	18,548,374

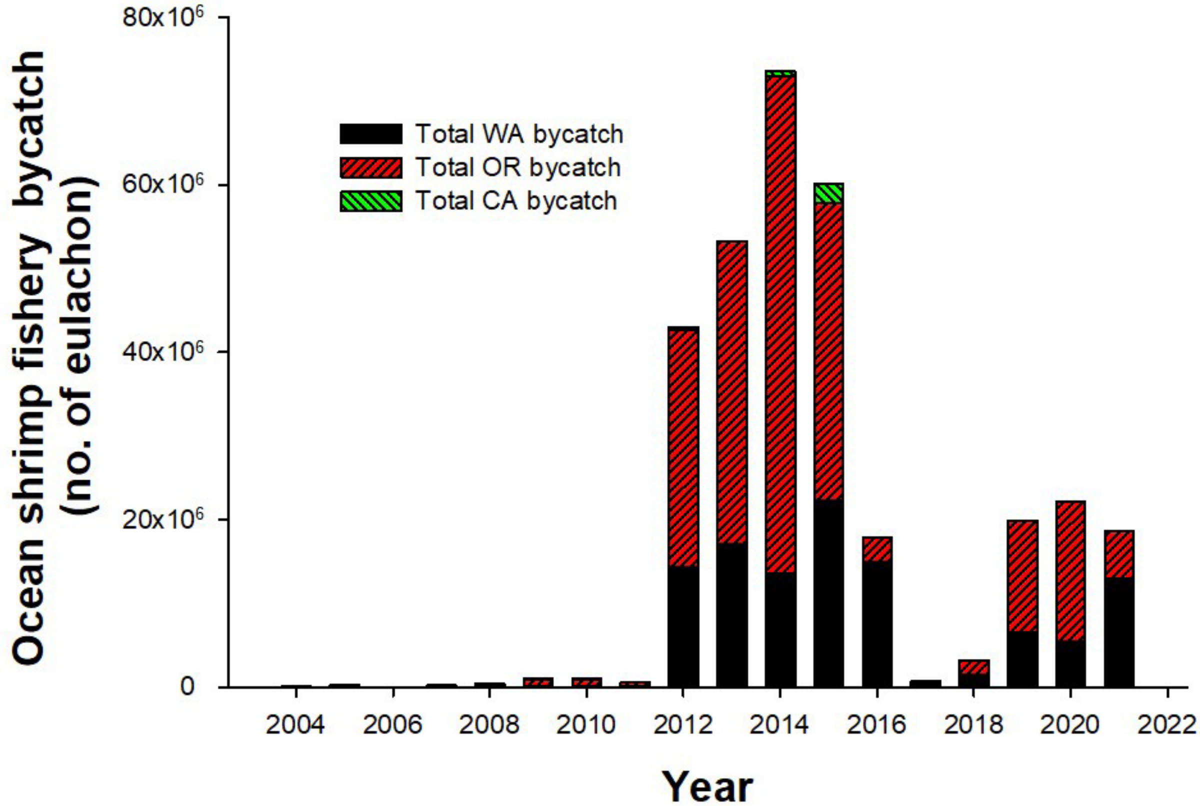

Figure 2. Estimated total mean bycatch of eulachon in the California, Oregon (2004–21), and Washington (2010–21) ocean shrimp trawl fisheries. Ocean shrimp fisheries were not observed in 2006.

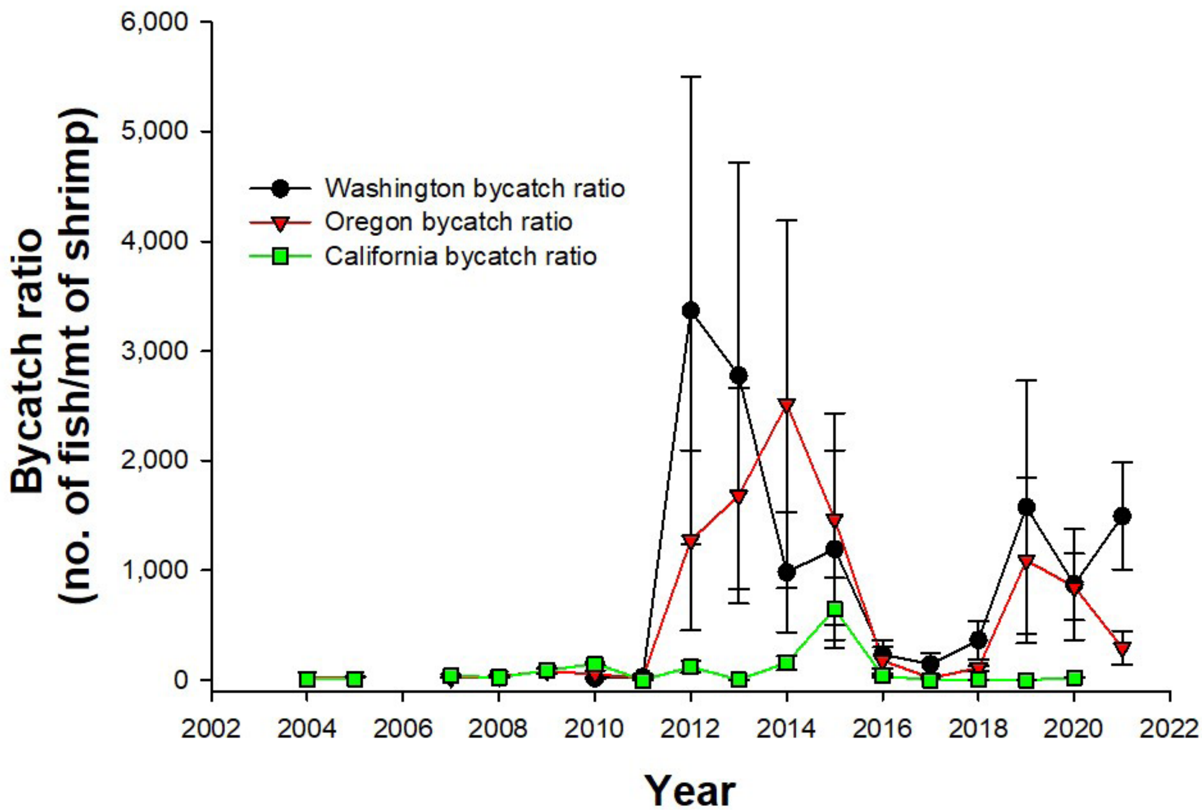

Figure 3. Estimated bycatch ratios of eulachon in the California, Oregon (2004–21), and Washington (2010–21) ocean shrimp trawl fisheries. 95% bootstrapped CIs are provided for the estimates. Ocean shrimp fisheries were not observed in 2006.

"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 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 S2). 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 S2).

Eulachon bycatch in the Oregon ocean shrimp fishery was estimated at well under a million individual fish (range of 146,000–845,000) from 2004–11 (although the fishery was not observed in 2006). However, estimated bycatch expanded dramatically in 2012 and 2013 to nearly 28.4 million (95% CI: 18,284,056–39,987,990) and 36.2 million (95% CI: 21,219,261–54,766,425), respectively (Table S5, Figure 2). Similarly, total weight of estimated eulachon bycatch in Oregon increased from 20.5 mt (95% CI: ~14.8–27.1 mt) in 2011 to nearly 427.9 mt (95% CI: ~284.0–592.1 mt) in 2012, and to over 540.1 mt (95% CI: ~349.5–765.5 mt) in 2013 (Table S4). Subsequently, estimated eulachon bycatch remained high in the Oregon ocean shrimp trawl sector, reaching over 59.3 million fish (95% CI: 39,501,596–84,044,933) and 618.7 mt (95% CI: ~434.9–823.7 mt) in 2014, and over 35.5 million fish (95% CI: 23,481,100–50,648,622) and 361.5 mt (95% CI: ~257.5–484.6 mt) in 2015 (Tables S4 and S5). Eulachon bycatch numbers and weights were down in the subsequent two years to about 2.9 million fish (95% CI: 1,969,417–4,024,904) and 66.2 mt (95% CI: ~48.3–88.9 mt) in 2016, and about 207,000 fish (95% CI: 49,871–401,489) and 3.9 mt (95% CI: ~0.9–7.7 mt) in 2017 (Tables S4 and S5). These improving trends did not continue into the 2018–20 seasons. Eulachon bycatch numbers and weights in the Oregon sector increased to 1.8 million fish (95% CI: 374,603–3,772,282) and 26.9 mt (95% CI: ~6.4–56.7 mt) in 2018, to over 13.3 million fish (95% CI: 9,211,602–17,554,549) and 300.2 mt (95% CI: ~214.8–396.3 mt) in 2019, and to 16.6 million fish (95% CI: 5,946,644–28,427,219) and 433.1 mt (95% CI: ~191.6–689.0 mt) in 2020 (Tables S4 and S5, Figure 2). Eulachon bycatch declined in the Oregon ocean shrimp sector in 2021 to an estimated 5.5 million fish (95% CI: 2,856,020–9,016,669) and a weight of 120.9 mt (95% CI: ~67.8–189.6 mt; Tables S4 and S5).

As in the Washington sector, bycatch ratios in the Oregon sector (measured as both kilograms and numbers of eulachon per metric ton of retained ocean shrimp observed) increased dramatically from 2011 to 2012, and remained high in 2013–15 (Tables S4 and S5, Figure 3). Observed bycatch ratios were at their highest in 2014 (26.2 kg/mt and 2,517 eulachon/mt). In 2015, the Oregon sector bycatch ratios declined to 14.9 kg/mt and 1,466 eulachon/mt. Further declines in bycatch ratios continued in 2016 and 2017, reaching 4.1 kg/mt and 178 eulachon/mt in 2016 and 0.4 kg/mt and 20 eulachon/mt in 2017 (Tables S4 and S5, Figure 3). These declining trends in the bycatch ratios did not continue in 2018 and 2019. Bycatch ratios in the Oregon sector increased in 2018 and 2019, reaching 1.7 kg/mt and 111 eulachon/mt in 2018 and 24.7 kg/mt and 1,092 eulachon/mt in 2019 (Tables S4 and S5, Figure 3). Bycatch ratios in the Oregon ocean shrimp sector declined to 22.1 kg/mt and 850 eulachon/mt in 2020, and to 6.5 kg/mt and 296 eulachon/mt in 2021 (Tables S4 and S5, Figure 3).

The eulachon bycatch estimate in the California ocean shrimp sector remained below 23,000 fish from 2004 to 2008 (the fishery was not observed in 2006), rose dramatically in 2010 to over 267,000 fish (95% CI: 40,047–701,036), fell to its second lowest observed level of just 475 fish (95% CI: 203–838) in 2011, increased again dramatically in 2012 to over 337,000 fish (95% CI: 151,938–601,147), and then fell to less than 17,000 fish (95% CI: 3,794–33,971) in 2013 (Table S7). Biomass of eulachon bycatch and bycatch ratios showed similar fluctuations from 2010–13 (Tables S6 and S7). Eulachon bycatch again increased from 2014–15 in the California ocean shrimp trawl sector. Estimated bycatch was over 602,000 fish (95% CI: 243,639–1,067,945) and 6.5 mt (95% CI: ~2.7–11.6 mt) in 2014 and increased to over 2.2 million fish (95% CI: 971,606–4,050,448) and 32.3 mt (95% CI: ~15.0–57.9 mt) in 2015 (Tables S6 and S7). The tonnages of observed ocean shrimp and of fleetwide landings were relatively stable over the period from 2011–15, 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. 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 both kilograms and numbers of eulachon per metric ton of retained ocean shrimp observed) increased from 1.7 to 9.4 kg/mt shrimp and from 157 to 647 eulachon/mt shrimp between 2014 and 2015 (Tables S6 and S7). 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. Fleetwide bycatch was over 51,000 fish (95% CI: 16,976–111,195) with a bycatch ratio of about 38 eulachon/mt of shrimp in 2016. Bycatch consisted of 31 fish (95% CI: 5–128) with a bycatch ratio of 0.02 eulachon/mt of shrimp in 2017 (Table S7). Ocean shrimp landings in the California fishery were down by about 60% in 2016–17 compared to the 2011–15 period, which may explain a portion of the reduction in eulachon bycatch evident in the 2017 values, although reduced eulachon abundance is also a likely factor. Unlike Washington and Oregon, California ocean shrimp fishery eulachon bycatch and bycatch ratios in 2018 and 2019 remained at relatively low levels. Fleetwide bycatch was about 3,500 fish (95% CI: 2,392–4,745) with a bycatch ratio of about 1.5 eulachon/mt of shrimp in 2018. Fleetwide California bycatch consisted of 938 fish (95% CI: 342–1,477) with a bycatch ratio of 0.83 eulachon/mt of shrimp in 2019 (Table S7, Figure 3). Although ocean shrimp landings in California in 2020 were less than a third of average landings over the previous five years, eulachon bycatch was elevated to over 8,000 fish (95% CI: 3,472–13,463) with a bycatch ratio of about 23 eulachon/mt of shrimp (Table S7). Ocean shrimp landings did occur in the California sector during 2021.

Total coastwide estimated bycatch of eulachon in the Oregon and California ocean shrimp fisheries ranged from 156,000 fish in 2004 to a high of 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 over 1 million. Coastwide eulachon bycatch decreased to about 606,000 fish in 2011 (Table 1). However, as seen earlier, 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 1). Estimated weight of these bycaught eulachon in 2013 was 743.6 mt (Table 1).

Coastwide eulachon bycatch in ocean shrimp trawl fisheries again increased in 2014 to an all-time high of over 73.5 million fish and 769.3 mt. 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 1). Estimated coastwide bycatch in 2015 amounted to over 60.1 million fish and 612.0 mt (Table 1). Coastwide eulachon bycatch in ocean shrimp trawl fisheries declined by two orders of magnitude from 2015 to 2017, declining from 60.1 million fish in 2015 to 4.4 million fish in 2016 and to 649,000 fish in 2017 (Table 1). However, 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 over 19.8 million fish in 2019 (Table 1). These increases in coastwide bycatch were mostly due to increased bycatch in both Washington and Oregon. Coastwide eulachon bycatch remained elevated in 2020 at over 22.1 million fish and 568.9 mt. Subsequently, estimated eulachon bycatch declined by two-thirds in the Oregon ocean shrimp sector in 2021, but more than doubled in the Washington sector, resulting in a total coastwide bycatch of over 18.5 million fish in 2021. Eulachon were not landed in California during 2021.

Degree of observer coverage in ocean shrimp fisheries

Observer coverage in ocean shrimp trawl fisheries from 2010–19 has ranged from 9–16% of ocean shrimp landings on a coastwide basis (Table S8; Somers et al. 2022[21]). Percent of ocean shrimp landings over the most recent two years, 2020 and 2021, saw a reduction to 5% and 6%, respectively, due to COVID-19 pandemic restrictions on observers, and to respond to shifting coverage priorities. Observer coverage data for Washington and California are available only for 2010–19 (Table S8). Prior California data cannot be reported for confidentiality reasons, and the Washington shrimp trawl sector was not observed by WCGOP before 2010. Since 2004, observer coverage in the Oregon ocean shrimp fishery has ranged from a low of 5.6% to a high of 15.3% of total shrimp landings (Table S3). During 2010–19, observer coverage in Washington, Oregon, and California averaged 13.4%, 12.5%, and 14.7% of total shrimp landings, respectively (Tables S2–S7; Somers et al. 2022). No ocean shrimp trawl fishery landings were observed in 2006.

Unidentified smelt bycatch in ocean shrimp trawl fisheries

Due to sampling conditions, time constraints, and other priorities, not all smelt were identified to the species level in the ocean shrimp trawl fishery observer database from 2004–15, and thus a portion of the bycatch in these fisheries was recorded as "smelt unidentified." Beginning in 2011 an effort was made to identify all eulachon encountered, and an additional category of "non-eulachon smelt" was added. Prior to 2011, a large portion of observed bycatch categorized as "smelt unidentified" might have consisted of eulachon. Other osmerid smelt species occasionally encountered as bycatch in the commercial ocean

[21] Somers, K. A., K. E. Richerson, V. J. Tuttle, and J. T. McVeigh. 2022. Fisheries Observation Science Program Coverage Rates, 2002–21. U.S. Department of Commerce, NOAA Data Report NMFS-NWFSC-DR-2022-02. Available: repository.library.noaa.gov/view/noaa/47111 (June 2023).

shrimp fisheries include surf smelt (*Hypomesus pretiosus*), whitebait smelt (*Allosmerus elongatus*), night smelt (*Spirinchus starksi*), longfin smelt (*S. thaleichthys*), rainbow smelt (*Osmerus mordax*), and capelin (*Mallotus villosus*; Table S9). Combined observations of unidentified smelt and other non-eulachon osmerid smelt species bycatch in Oregon and California (2004–10) and Oregon, California, and Washington (2011–21) ocean shrimp trawl fisheries are presented in Table S9. The percentage of this unidentified smelt category from 2004–10 that consisted of eulachon is unknown. Bycatch observation did not begin in the Washington ocean shrimp fishery until 2010, and starting in 2011 an effort was made by observers to record all eulachon observed, so fish categorized as unidentified smelt in the database from 2011–21 likely consist of other osmerid smelt species besides eulachon.

Eulachon Bycatch in Groundfish Fisheries[22]

LE bottom trawl fishery

Eulachon were not observed as bycatch in the LE bottom trawl fishery in Washington from 2002–10 (Table S10). Within the Oregon portion of the LE bottom trawl fishery, eulachon bycatch occurred in four of the nine years from 2002–10, with 81% of this estimated bycatch occurring in 2002 (Table S11). However, eulachon bycatch did not occur in the Oregon LE bottom trawl fishery in 2004, 2005, 2006, 2008, or 2010 (Table S11). Eulachon were rarely caught in the California LE bottom trawl fishery from 2002–10; five fish in 2004 and 21 estimated fish in 2010 (Table S12).

IFQ nonhake bottom and midwater trawl fisheries

From 2011 to 2019, a total of 19.8 kg of eulachon (calculated to be equivalent to 439 individual fish) were estimated as fleetwide bycatch in the Washington IFQ nonhake bottom and midwater trawl fisheries (Tables S13 and S14). Eulachon were not observed or estimated as bycatch in the Washington sector from 2015 to 2019. For confidentiality reasons, weight and counts of eulachon bycatch in Washington during 2020 are combined with Oregon and reported in Tables S15 and S16. In 2021, nearly 170 kg of eulachon representing 4,392 individual fish were estimated from IFQ nonhake bottom and midwater trawl fisheries in Washington (Tables S13 and S14). Between 2011 and 2019, the Oregon IFQ nonhake bottom and midwater trawl fisheries had an estimated eulachon bycatch of 247.3 kg (Table S15) and 5,184 individual fish (Table S16), with 48% (2,511 individuals) of this total occurring in 2014 (Table S16). Eulachon bycatch in the Oregon sector declined from a high point in 2014 to an estimated 11 fish during 2017; however, this trend reversed in 2018 and 2019, with estimated bycatch increasing to 344 fish in 2018 and 787 fish in 2019 (Table S16). More recent bycatch significantly increased to 5,142 fish in 2020 (Oregon and Washington data combined for confidentiality reasons) and 3,987 fish in 2021 (Table S16). A tenth of a kilogram of eulachon representing two bycaught eulachon was recorded in the California IFQ bottom and midwater trawl fisheries in 2015; however, no eulachon occurred as bycatch in this sector from 2011–14 or from 2016–21 (Tables S17 and S18).

[22] Eulachon bycatch count and weight estimates have been updated in the current document and may not always match estimates previously published in Gustafson et al. (2015, 2017, 2019, 2021, 2023).

At-sea hake fishery

Bycatch of eulachon occurs sporadically in the at-sea hake fishery. Eulachon bycatch was not reported in the hake CP sector from 2002–05, or in 2010 (Table S19). Similarly, the combined hake tribal and nontribal MSCV sector did not report eulachon bycatch from 2002–06 or in 2010 and 2015 (Table S20).

Between 2002 and 2021, eulachon bycatch in the at-sea hake CP sector exceeded an estimated 50 fish in 2006 (147 fish), 2011 (1,270 fish), 2014 (242 fish), 2015 (56 fish), 2018 (259 fish), 2019 (889 fish), 2020 (71 fish), and 2021 (5,920 fish; Table S19). In all other years, fewer than 40 individual eulachon were observed in the hake CP sector as bycatch (Table S19). The bycatch estimate in 2011 of 1,270 fish amounted to 41% of the total eulachon bycatch estimate of 3,083 fish between 2002 and 2020 in the hake CP sector. In 2021, the most recent year available, 5,920 eulachon were estimated as bycatch in the at-sea hake CP sector, representing 66% of all bycatch from 2002–21 in this sector (Table S19). These dramatically higher bycatch levels in 2021 are in contrast to the relatively low bycatch in 2016 of two fish and 2017 of 18 fish (Table S19).

The combined hake nontribal and tribal MSCV sector had a total estimated eulachon bycatch of 1,267 individual fish between 2002 and 2021, with 22% of this bycatch occurring in 2013 (278 fish) and 20% in 2021 (252 fish). Fewer than ten estimated eulachon were caught in 2002–08, 2010, 2012, and 2015–16 (Table S20). In the most recent years of 2020 and 2021, 198 and 252 eulachon were estimated as bycatch, respectively, in the at-sea hake MSCV sector (Table S20). The tribal mothership fishery has not operated since 2012.

Shoreside hake fishery

WCGOP began observing bycatch in the shoreside hake fishery in 2011, and did not record any eulachon bycatch in this fishery in 2011, 2012, or 2014 (Table S21). However, in 2013 catch monitors recorded the bycatch of 83.5 kg of eulachon in this fishery. Since bycaught fish are weighed but not counted by shore-based catch monitors in this fishery, a linear weight–count regression based on data from a rolling three-year window of all other catch share eulachon observations was used to estimate that 83.5 kg of eulachon was equivalent to 1,745 individual eulachon (Table S21).

Shoreside midwater hake and shoreside midwater rockfish sectors

Since 2015, the shoreside midwater sector of the IFQ fishery has been redefined and is now reported separately as the hake midwater trawl sector and the rockfish midwater trawl sector. When more than 50% of a vessel's landings on a day were hake, the vessel's landings were reported as midwater hake; however, when landings were less than 50% hake by weight, the vessel's landings were reported in the midwater rockfish sector. Non-EM and EM eulachon bycatch data for these two sectors are reported separately in this report, non-EM data in Table S22 and EM data in Table S23, with the exception of the

2019–21 non-EM midwater hake sector, which is reported in Table S23 together with EM midwater hake for reasons of confidentiality. Bycatch in these fisheries is sampled at nearly 100% after being landed, and bycatch is weighed by a catch monitor. Therefore, numbers of bycaught eulachon were estimated using a linear weight–count regression and data from a rolling three-year window of all other catch share eulachon observations. We note that this may result in overestimation or underestimation of true counts if the size of eulachon encountered as bycatch varies across sectors. From 2015–17, fewer than ten eulachon per year occurred as bycatch in either EM or non-EM portions of both the midwater hake and rockfish sectors (Tables S22 and S23). No eulachon bycatch occurred during 2018 in either the EM or non-EM sectors of the midwater hake fishery (Tables S22 and S23). Likewise, no eulachon bycatch occurred in the 2018 EM midwater rockfish sector; however, an estimated 163 eulachon were incidentally caught in the 2018 non-EM portion of the midwater rockfish fishery (Tables S22 and S23). Subsequently, this sector had an estimated bycatch of 244, 66, and 320 fish in 2019, 2020, and 2021, respectively (Table S22). Meanwhile, the EM portion of the midwater rockfish fishery reported 56, 1,098, and 1,232 bycaught eulachon in 2019, 2020, and 2021, respectively (Table S23). Due to confidentiality considerations, data for the 2019–21 EM and non-EM portions of the midwater hake fishery have been combined. Although only seven eulachon were estimated as bycatch in the combined EM and non-EM midwater hake sectors from 2015–18, eulachon bycatch amounted to 488, 1,953, and 7,717 fish in 2019, 2020, and 2021, respectively (Tables S22 and S23).

Combined U.S. West Coast groundfish fisheries

A summary of eulachon bycatch in all U.S. West Coast groundfish fisheries observed by WCGOP and A-SHOP that reported eulachon catch from 2002–21 is provided in Table 2 and Figure 4. Across 20 years of observation (2002–21), an estimated 45,216 individual eulachon were caught as bycatch in all groundfish sectors of the U.S. West Coast groundfish fishery (Table 2).[23] Total fleetwide bycatch in U.S. West Coast groundfish fisheries increased from a total eulachon bycatch of 58 and 68 fish in 2016 and 2017, to an estimated 792 fish in 2018 and 2,663 fish in 2019 (Table 2, Figure 4). This increasing bycatch continued in 2020 and 2021, reaching 8,528 fish in 2020 and 23,820 fish in 2021 (Table 2, Figure 4). Estimated eulachon bycatch in all U.S. West Coast groundfish fisheries was greater in the single year 2021 than in the previous 19 years of observation combined (Table 2, Figure 4).

Undocumented bycatch in groundfish fisheries

Coincident with the advent of the IFQ fisheries in 2011, WCGOP and A-SHOP observers were instructed to make an extra effort to identify all eulachon and other osmerid bycatch to species in the groundfish fisheries. Prior to that time (due to sampling conditions, time constraints, and other priorities), it is likely that some portion of observed eulachon bycatch in the LE bottom trawl and at-sea hake fisheries was recorded as "other nongroundfish," "smelt unidentified," or "herring/smelt unidentified," especially from 2002–10.

[23] Eulachon bycatch count and weight estimates have been updated in the current document and may not always match estimates previously published in Gustafson et al. (2015, 2017, 2019, 2021, 2023).

Table 2. Estimated bycatch of eulachon (number of individual fish) in U.S. West Coast groundfish fisheries and that were observed by WCGOP and A-SHOP, 2002–21. *CP* = catcher–processor, *MSCV* = mothership catcher vessel, *SS* = shoreside, *MW* = midwater, *EM* = electronic monitoring.

Year	Nonhake bottom and midwater groundfish fisheries[a]			At-sea hake fisheries		SS/MW hake fisheries[b]	SS/MW rockfish fisheries[b]	EM MW hake fisheries[b]	EM MW rockfish fisheries[b]	Total bycatch estimate
	WA	OR	CA	CP	MSCV[c]					
2002	0	837	0	0	0	—	—	—	—	837
2003	0	52	0	0	0	—	—	—	—	52
2004	0	0	5	0	0	—	—	—	—	5
2005	0	0	0	0	0	—	—	—	—	0
2006	0	0	0	147	0	—	—	—	—	147
2007	0	77	0	6	4	—	—	—	—	87
2008	0	0	0	37	6	—	—	—	—	43
2009	0	68	0	30	38	—	—	—	—	136
2010	0	0	21	0	0	—	—	—	—	21
2011	12	127	0	1,270	214	0	—	—	—	1,623
2012	1	168	0	16	7	0	—	—	—	192
2013	137	526	0	39	278	1,745	—	—	—	2,725
2014	289	2,511	0	242	25	0	—	—	—	3,067
2015	0	658	2	56	0	0	0	0	0	716
2016	0	52	0	2	4	0	0	0	0	58
2017	0	11	0	18	16	0	4	7	0	56
2018	0	344	0	259	26	0	163	0	0	792
2019	0	787	0	889	199	n/a[d]	244	488	56	2,663
2020	*	5,142[e]	0	71	198	n/a[d]	66	1,953	1,098	8,528
2021	4,392	3,987	0	5,920	252	n/a[d]	320	7,717	1,232	23,820

[a] Bycatch estimates in nonhake groundfish fisheries from 2002–10 and 2015–21 in Washington, Oregon, and California are based on observations of the bottom trawl fishery only. Estimates in 2011–14 are based on observations of a combination of the IFQ nonhake bottom and midwater trawl fisheries.
[b] In these fisheries, eulachon bycatch is landed and weighed by catch monitors. Numbers of eulachon were estimated using a linear weight–count regression and data from a rolling three-year window of all other catch share eulachon observations.
[c] *MSCV* includes both tribal and nontribal sectors.
[d] Due to confidentiality requirements, EM and non-EM data are combined for the 2019–21 midwater hake sector and reported under the EM category.
[e] Due to confidentiality requirements, Washington and Oregon data were combined for the 2020 nonhake bottom and midwater groundfish fisheries.

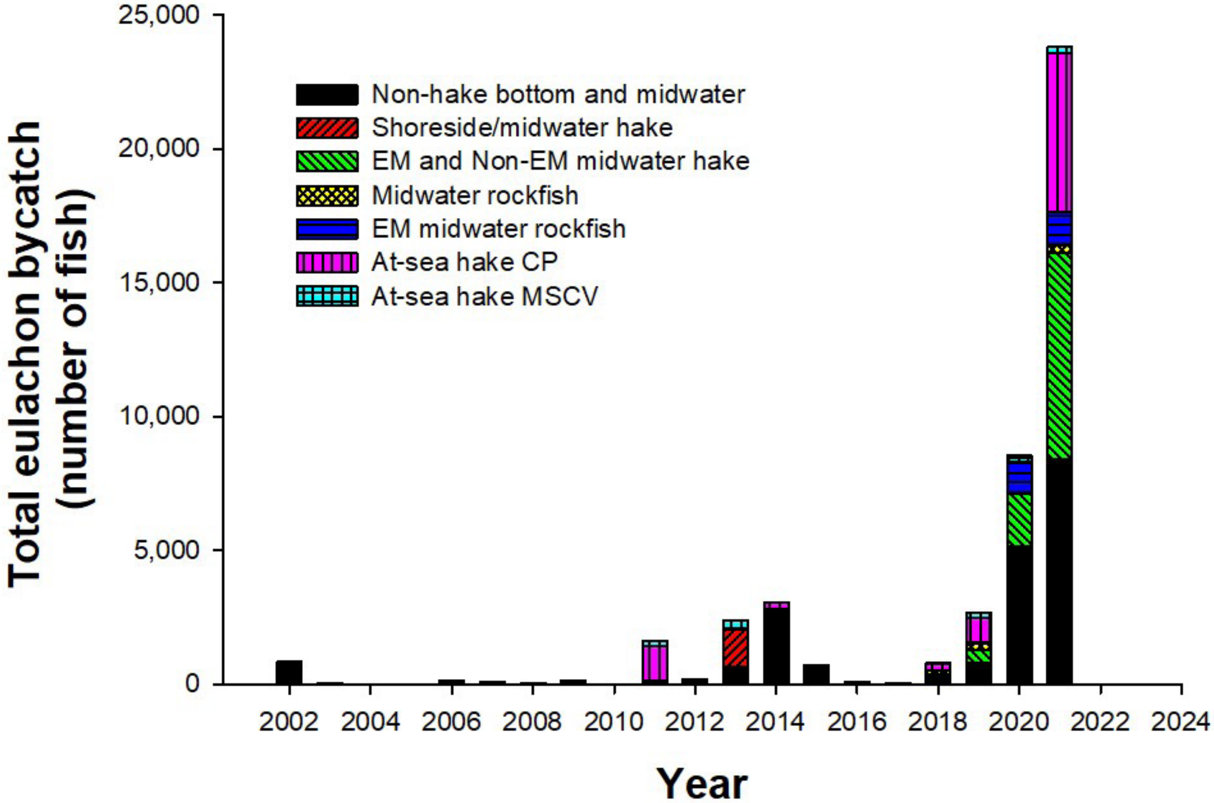

Figure 4. Estimated bycatch of eulachon in U.S. West Coast groundfish fisheries, 2002–21. Data from Table S25. *CP* = catcher–processors, *MSCV* = mothership catcher vessels (combined tribal and nontribal mothership sectors).

Observed but unidentified smelt bycatch in the nonhake bottom and midwater groundfish fisheries ranged from about 1,215 kg in 2002 to just under half a kilogram in 2019 (Table S24). Very few "smelt unidentified" have been recorded as bycatch in the at-sea hake trawl fisheries with the exception of 2002, when an estimated 55 kg of unidentified smelt was observed in this sector (Table S24). As indicated above, the higher level of bycatch of unidentified smelt during the early 2000s in both the LE groundfish and at-sea hake trawl fisheries corresponds with a period of elevated eulachon (Figure 5, Figure 6) and other forage fish abundance. It is unknown what portion of this unidentified smelt bycatch in either the LE groundfish trawl fishery or the at-sea hake trawl fishery might have consisted of eulachon prior to 2011. After 2010, when extra efforts to identify all eulachon bycatch began, "smelt unidentified" likely consists of species of non-eulachon smelt (Table S24).

Comparison of Eulachon Bycatch in Ocean Shrimp Fisheries and Groundfish Fisheries

Since 2010, both WCGOP and A-SHOP have provided estimates of eulachon bycatch in all three state-operated ocean shrimp fisheries and in all federally permitted U.S. West Coast groundfish fisheries. Over the 12-year period from 2010–21, bycatch of eulachon individuals in all U.S. West Coast groundfish fisheries ranged from 0.001% to 0.267% of total bycatch in

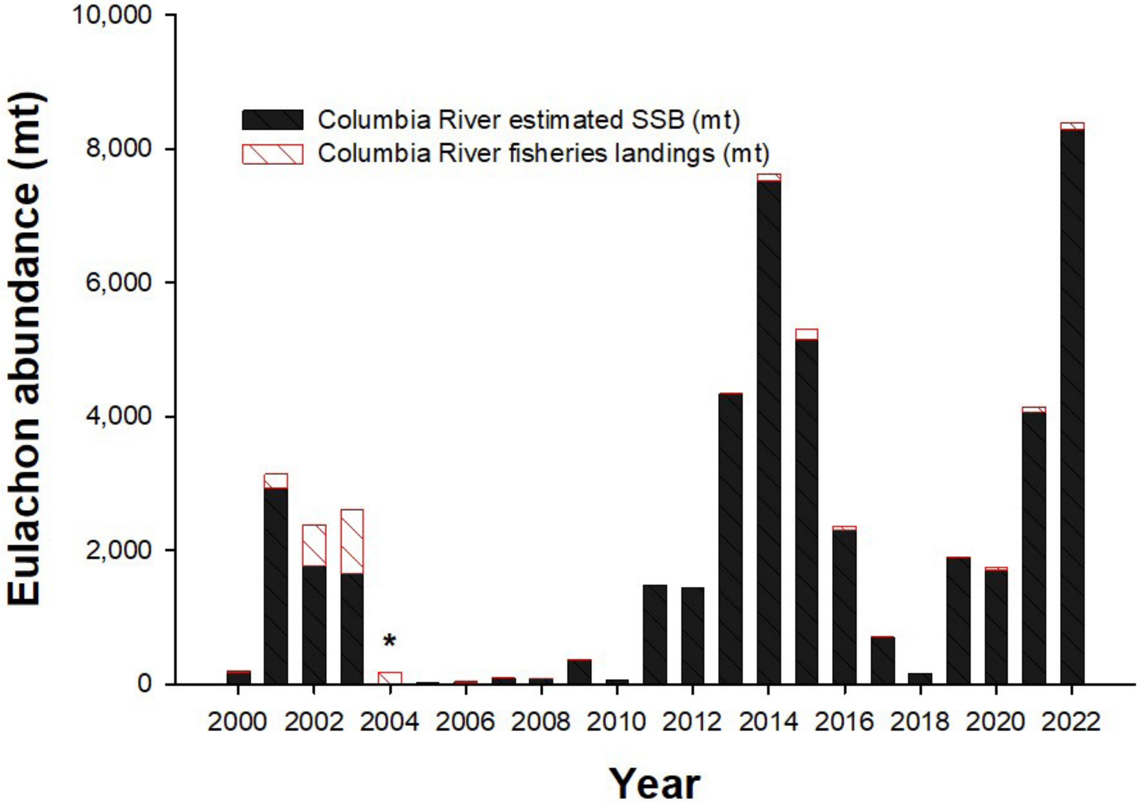

Figure 5. Estimated Columbia River eulachon spawning stock biomass (SSB) and commercial and recreational fisheries landings, 2000–22. Pre-2011 adjusted SSB estimates based on historical Columbia River water discharge rates and expansions of historical larval densities adjusted for the shorter duration of the pre-2011 surveys (B. James and O. Langness, WDFW, unpublished data). Abundance estimates for 2011–19 and 2021–22 from JCRMS (2023, their Table 20). Single asterisk (*) indicates that a survey was conducted in 2004; however, detailed daily larval density data for that year are unavailable and only harvest data for that year are displayed. Complete data for 2020 are not available due to COVID-19 pandemic field sampling restrictions. The 2020 SSB estimate is derived from twice the estimate of 1.9 million lb reported in JCRMS (2021, pp. 23–24), which was based on 10 days of truncated larval sampling.

all fisheries. In 2021, when total estimated eulachon bycatch in U.S. West Coast groundfish fisheries was 23,820 fish, this amounted to just 0.128% of total estimated eulachon bycatch in all fisheries, which was over 18.5 million fish. A breakdown of the relative proportion of total estimated yearly eulachon bycatch in the Washington, Oregon, and California ocean shrimp fisheries and coastwide groundfish fisheries (Figure 7) amply illustrates the relatively minor impact of bycatch in groundfish fisheries as an extinction risk factor, compared to eulachon bycatch in the ocean shrimp fisheries.

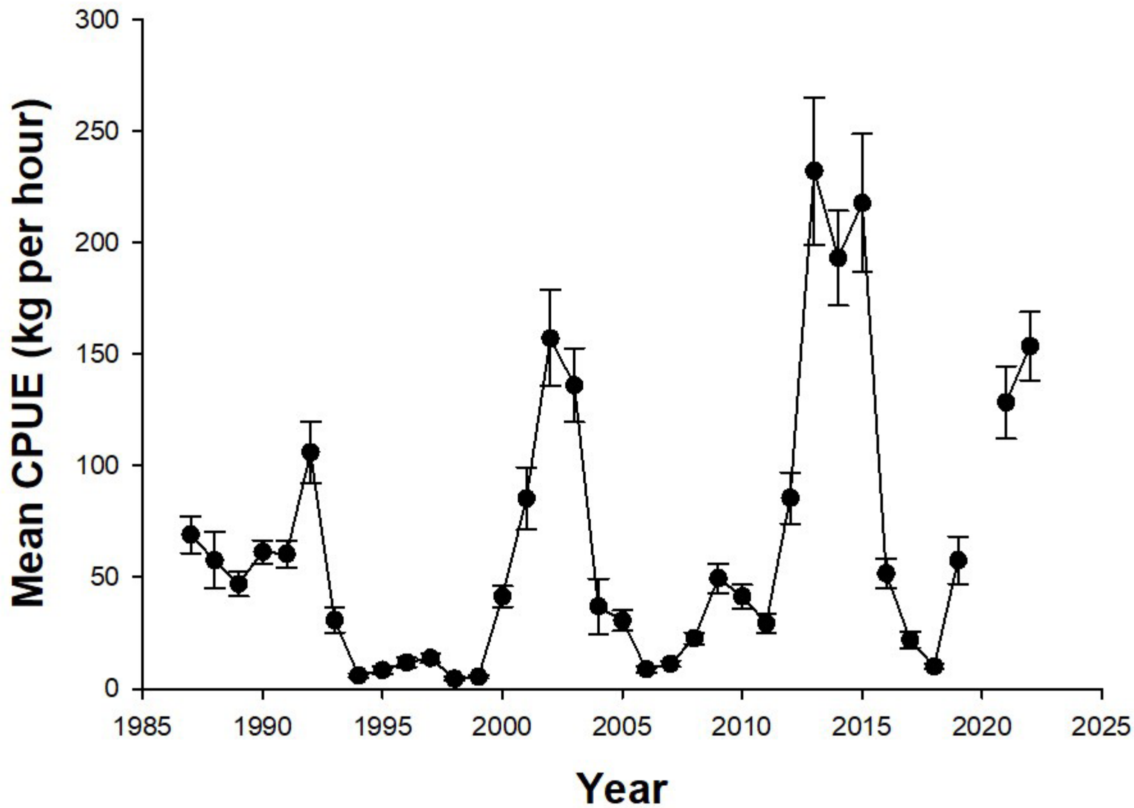

Figure 6. Total mean (±SE) catch per unit effort (CPUE; kg/h) of eulachon across all surveyed shrimp management areas off the west coast of Vancouver Island (WCVI), 1987–22. Data for 2020 are unavailable due to fieldwork restrictions during the COVID-19 pandemic. CPUE is based on bycatch of eulachon in multispecies small-mesh bottom trawl surveys (a.k.a. fishery-independent shrimp surveys) offshore of WCVI. (Data courtesy of S. MacConnachie, V. Hodes, and L. Flostrand, Fisheries and Oceans Canada, personal communication.)

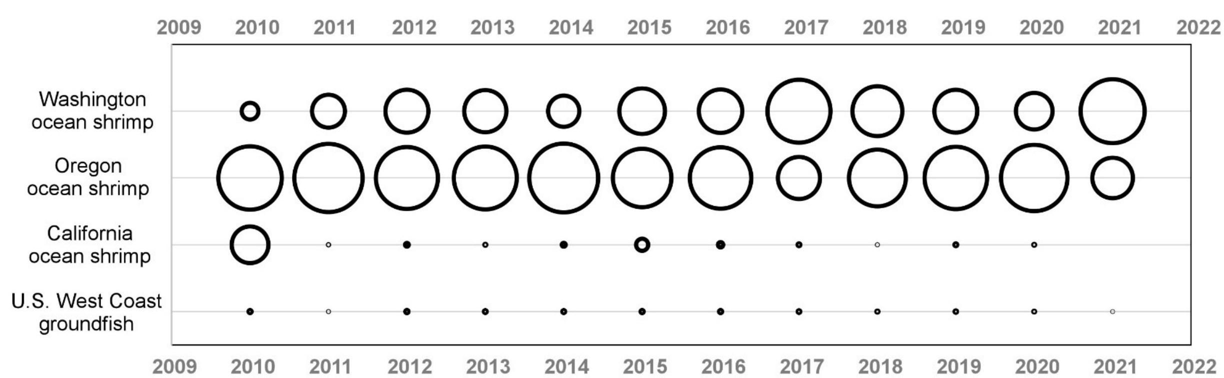

Figure 7. Bubble plot showing relative proportion of total eulachon bycatch per year, 2010–21, attributed to the Washington ocean shrimp, Oregon ocean shrimp, California ocean shrimp, and all U.S. West Coast groundfish fisheries. Surface area of each bubble represents the percent of total bycatch for each year attributed to that particular fishery.

Discussion

Eulachon Abundance

Several indices of eulachon abundance showed dramatic increases from 2011–15, declines from 2016–18, and subsequent large increases in 2019–22 (Figure 5, Figure 6). Spawning stock biomass (SSB) estimates of eulachon in the Columbia River (Figure 5) and mean CPUE (kg/h) of eulachon off the west coast of Vancouver Island (WCVI), as estimated in multispecies small-mesh bottom trawl surveys (a.k.a. fishery-independent shrimp surveys; Figure 6) both increased by an order of magnitude between 2010 and 2015. However, estimates of eulachon SSB in the Columbia River (Figure 5) and mean CPUE off WCVI (Figure 6) began declining in 2016, and by 2018, these indices were at less than 3% and 5% of their average 2013–15 levels, respectively. These declines through 2018 in indices of eulachon abundance parallel declines in estimated bycatch of eulachon in U.S. West Coast ocean shrimp (Table 1, Figure 2) and groundfish fisheries (Table 2, Figure 4), especially in 2016 and 2017. Eulachon abundance increased following 2018 as shown by both indices of abundance—Columbia River SSB (Figure 5) and mean CPUE off WCVI (Figure 6)—again paralleling increases in eulachon bycatch in U.S. West Coast ocean shrimp (Figure 2) and groundfish fisheries (Figure 4). Mean eulachon SSB in the Columbia River increased more than tenfold from 2018 to 2019 (JCRMS 2021); however, reliable data for 2020 estimated SSB are not available due to COVID-19 restrictions on fieldwork. Estimated SSB more than doubled from 2021 to 2022 to over 8,300 mt (Figure 5), which is "the highest [estimated abundance in the Columbia River] since the SSB was first calculated in 2011" (JCRMS 2023, p. 23). Mean CPUE of eulachon in small-mesh bottom trawl surveys off WCVI increased fivefold from 2018 to 2019 (Figure 6). Eulachon CPUE data in this survey are unavailable for 2020, again due to COVID-19 restrictions on fieldwork. However, CPUE more than doubled from 2019 to 128 kg/h in 2021 and increased again in 2022 to over 153 kg/h (Figure 6). Again, these increases in Columbia River SSB (Figure 5) and mean CPUE off WCVI (Figure 6) parallel increases in eulachon bycatch in U.S. West Coast ocean shrimp (Figure 2) and groundfish fisheries (Figure 4) from 2018–21.

The above analysis suggests that eulachon bycatch in state-operated ocean shrimp trawl fisheries and U.S. West Coast groundfish fisheries is likely driven by both eulachon distribution and cyclic abundance. Evidence from some surveys (NWFSC-EW 2012) indicates that the latitudinal and longitudinal range of eulachon likely expands in years of high abundance, perhaps leading to an increase in bycatch in peripheral portions of its geographic range. In addition, point estimates of bycatch might fluctuate due to a number of nonbiological factors, including annual variation in observer coverage rates, trawl duration, trawl depth, trawl location, seasonality, haul volume, and trawl net mesh size.

Bycatch Reduction Devices in Ocean Shrimp Fisheries

In addition to eulachon abundance, patterns of fluctuating levels of eulachon bycatch in ocean shrimp trawl fisheries are also likely influenced by the 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 (Groth et al. 2018, Wargo and Ayres 2018, 2019), and in California in 2023 (CDFW 2022, Groth et al. 2023). 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.

Many early exploratory surveys of ocean shrimp distribution and abundance off the U.S. West Coast commented upon the species of bycatch taken during these cruises (Pruter and Harry 1952, Schaefers and Johnson 1957, Tegelberg and Smith 1957, Alverson et al. 1960, Ronholt and Magill 1961, Robinson 1966), but few attempted to quantify bycatch biomass. Tegelberg and Smith (1957, p. 28) found eulachon to be "common in some catches" during exploratory shrimp cruises off the Washington coast in 1955 and 1956. Alverson et al. (1960) reported that osmerid smelt, along with eelpouts (Zoarcidae) and small sole, "dominated incidental catches of fish in numbers and were taken in most drags" off Washington and Oregon in 1958. Ronholt and Magill (1961) listed eulachon as among the numerous species incidentally taken during a 1960 exploratory shrimp cruise off central Oregon. Robinson (1966, p. 3) also reported that, in addition to several other species taken as bycatch, "in a few tows considerable numbers of smelt… were captured" off Oregon in March 1966 during studies of abundance and distribution of ocean shrimp (Robinson 1966, p. 3).

Prior to the mandated use of bycatch reduction devices (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, p. 2) evaluated bycatch in this fishery and stated that:

> 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….

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 at a time (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, Lomeli et al. 2018, 2020, Groth and Smith 2020).

Hannah et al. (2015) compared bycatch levels over 42 paired trials between lighted and unlighted trawl nets using double-rigged vessels that could tow paired shrimp trawl nets (Hannah et al. 2015). When ten 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," but 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, p. 9):

> 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.

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 (Light Emitting Diode) lights when trawling" and that "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) and in California in 2023 (CDFW 2022, Groth et al. 2023).

Lomeli et al. (2018) examined the effect on eulachon bycatch of placing five, ten, 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 five-, ten-, 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 also 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) examined the "degree that eulachon across all length classes (and other fishes) are escaping trawl entrainment in response to the illumination," by using trawl nets without rigid sorting grid BRDs installed. 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 [*Sebastes 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" and that "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" (Lomeli et al. 2020, p. 53). 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) stated that both of these groundgear configurations are commonly used in the ocean shrimp fishery and that "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).

Bancroft and Groth (2021) and Groth et al. (2022) reported upon a survey of the Oregon shrimp fleet in 2019 that asked questions on the use of bycatch reduction methods. Groth et al. (2022, p. 2) presented the questions asked and the results as follows:

> 1. How many LEDs do you use?
>
> On average, shrimpers used 7 LEDs per net, 2 more than required by rule. Prior to LED rule adoption the average was closer to 10. In 2019, research [Lomeli et al. 2020] showed that 5 LEDs worked better than 10 or 20… and a rule was adopted accordingly….

2. How are LEDs placed along the footrope?

Most shrimpers used the maximum of 4 foot spacing required by rule (for the central portion of the net), however some used wider spacing and more LEDs. Our research has shown that the 5 LEDs at 4 foot spacing in the central portion of the fishing line minimized bycatch, with no benefit from extra LEDs. In addition, we have found that LEDs placed in other areas of the net (headrope, BRD, wings, etc.) may have a negative effect, likely since they attract fish…. [Hannah et al. 2015]

3. How high is your fishing line off the bottom?

As Fishing Line Height (FLH) is lowered, bycatch increases. Since LEDs allow bycatch escapement under the net, FLH may have an even stronger effect on modern bycatch exclusion rates. The fleet appears to have adjusted to this, recognizing that higher FLHs mean less sorting of bycatch and more time fishing.

Mean FLH was 20 inches, a good height for minimizing bycatch and not affecting shrimp catch. However, this varies greatly depending on the footrope style (Hannah and Jones 2003). Modifying shrimp nets to catch fewer eulachon and not affect shrimp catch is a high priority goal of scientists and industry. While LEDs are highly effective, modifications of the net's groundline has a strong effect on eulachon bycatch and is an area where more research is needed…. [Hannah et al. 2011]

4. Why do you change the FLH?

Most often people change FLH when bycatch is higher. Many skippers look for signs that the footrope is positioned correctly and adjust droppers accordingly.

5. How many LEDs are working?

While we were collecting this survey data, we also poked around to see how many LEDs were working and to understand how they are operating and the details of working with them. We found 73% of the LEDs in place working…. Maintaining functioning LEDs is required by rule and critical to clean fishing, which allows more time towing and less time picking.

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. However, 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 5, Figure 6) and eulachon bycatch by state (Figure 2) 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, p. 91) stated that:

> 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.

Comparison of Bycatch and Bycatch Ratios by State Sector

Although the Washington State sector of the ocean shrimp fishery accounted for only 20%, 17%, 24%, 24%, and 32% of total coastwide shrimp landings in 2017, 2018, 2019, 2020, and 2021, respectively, it accounted for 68%, 44%, 33%, 25%, and 70% of total coastwide eulachon bycatch in the same respective five years (Table 1). This disproportionate level of bycatch is also reflected in the bycatch ratios—as eulachon per metric ton of shrimp landed—which averaged 893, 474, and 5 in Washington, Oregon, and California for the five years 2017–21, respectively (Tables S3, S5, and S7). Eulachon bycatch ratios in the Oregon sector decreased from 850 to 296 eulachon per metric ton of shrimp between 2020 and 2021, but increased in the Washington sector from 871 in 2020 to 1,494 eulachon per metric ton of shrimp in 2021 (Tables S3 and S5). Although an average of about 6% of total shrimp landings from 2017–21 occurred in the California sector, only an estimated total of 12,555 eulachon were caught in this sector during this entire five-year period (less than 0.02% of the coastwide total; Table 1 and Tables S2–S7). 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, 0.83, and 22.7 eulachon caught per metric ton of shrimp landed in California in 2017, 2018, 2019, and 2020, respectively (Table S7). Eulachon were not landed in California in 2021.

At this point, 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, pp. 52–53), 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).

Oregon, Washington, and California Ocean Shrimp FMPs

The Washington (Wargo and Ayres 2017b, p. 6) and Oregon (Hannah et al. 2018, p. 7) ocean shrimp FMPs list developing methods to reduce bycatch (especially of eulachon) as high on their prioritized lists of research needs. The Washington (Wargo and Ayres 2017b), Oregon (Hannah et al. 2018), and California (CDFW 2022) FMPs all list "action levels" that trigger management actions to restrict or curtail shrimp catch when shrimp catch-per-trip levels reach certain low counts. However, these FMPs do not have management action levels that would restrict shrimp catch in response to elevated levels of eulachon bycatch. By comparison, in British Columbia the shrimp trawl integrated fisheries management plan (IFMP) has implemented a eulachon action level (EAL) in response to incidental eulachon bycatch in the shrimp trawl fishery (DFO 2023a,b). When an EAL obtains in a specific trawl area, that area is then closed to shrimp harvest for the season. According to this plan (DFO 2023b, Appendix 1, p. 3):

> The Eulachon Action Level (EAL) for the WCVI remains set at 4 tonnes (t).[24] The WCVI EAL is further divided into two (2) portions, with an EAL of 2 t set for SMAs [Shrimp Management Area] 124OFF and 125OFF combined, and 2 t set for SMAs 23OFF & 21OFF and 23IN combined.

Bycatch Hotspots in Ocean Shrimp Trawl Fisheries

Ward et al. (2015) applied spatiotemporal models to both fishery-dependent observations of eulachon bycatch and eulachon fishery-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 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 fishery-independent survey dataset over the duration of the datasets. The later dataset also suggested that eulachon density was "substantially higher in 2012 than in any recent period" (Ward et al. 2015). 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, their Figures 4 and 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.

Recent Regulatory Gear Changes in Bottom and Midwater Trawl Fisheries

Based on the overall magnitude of bycatch in U.S. West Coast groundfish fisheries prior to 2020, either there was limited interaction with eulachon in these fisheries or most eulachon encounters resulted in fish escaping or avoiding trawl gear. Prior to 1 January 2019, federal regulations in the commercial groundfish fishery required minimum trawl mesh sizes in the bottom and midwater trawl fisheries of 4.5 in (11.4 cm) and 3.0 in (7.6 cm), respectively. It is likely that most eulachon would be able to escape trawl nets by swimming or falling through mesh of this dimension, either during the tow or during haul-back operations.

[24] One tonne (t) is the same as one metric ton (mt).

These mesh size restrictions and several other gear regulations were removed as of 1 January 2019 per a final rule in the Federal Register (USOFR 2018; Table S25). Diagrams depicting the components of bottom trawl gear and chafing gear on a midwater trawl codend are available in the Groundfish Trawl Gear Small Entity Compliance Guide.[25] According to USOFR (2018), this final rule served to remove:

> [T]he minimum mesh size requirement of 4.5 inches (11.4 cm) for groundfish bottom trawl nets and revise[d] the minimum mesh size requirements for midwater trawl gear. Midwater trawl gear nets are no longer required to have a minimum mesh size of 3.0 inches (7.6 cm)…. However, the [Pacific Fishery Management] Council did not recommend revising the restriction on the minimum mesh size restriction for the first 20 feet (6.51 m) behind the footrope or head-rope for midwater trawl gears because it is essential to the definition of midwater trawl gear. As such, nets must still be configured so that the first 20 feet (6.51 m) immediately behind the footrope or head-rope is constructed with bare ropes or mesh with a minimum size of 16 inches (40.64 cm)…. [The final rule also redefined] minimum mesh size as the smallest distance allowed from opposing knots or corners. In addition, this final rule revises the definition for measuring minimum mesh size to include knotless nets, as well as redefining the approach for measuring mesh size as the opening between opposing corners…. [T]his final rule [also] eliminates the prohibition on double-walled codends and restrictions on the use of chafing gear. Removing these restrictions will allow vessel operators flexibility in how they use chafing gear to protect nets and codends, fish relative to the seafloor, and strategically use mesh sizes to enhance fishing operations (i.e., herding smaller fish through the net)…. This final rule [also] revises the definition of selective flatfish trawl, a type of small footrope trawl gear, to allow for a two or four-seamed net with no more than four riblines, while retaining all other existing restrictions related to configuration of this gear…. Revising the definition of selective flatfish trawl to allow for use of a fourseam net will provide for better flow and improved selectivity compared to a two-seam net. A four-seam net has more open meshes for smaller fish to escape…. The final rule also eliminate[d] the requirement that vessels use selective flatfish trawl gear shoreward of the trawl RCA [Rockfish Conservation Area] north of 42°N lat. Instead, trawl vessels are allowed to use any type of small footrope trawl gear, including selective flatfish trawl gear, shoreward of the trawl RCA north of 42°N lat.

The Environmental Assessment of these mesh size changes (NMFS 2018, pp. 2-2–2-3) stated:

> The intent of eliminating the minimum mesh size requirements is to provide fishermen with more flexibility to configure their trawl gear to improve efficiency for catching target species, while reducing catch of unwanted species. Strategic use of smaller mesh sizes may facilitate the use or construction

[25] https://media.fisheries.noaa.gov/dam-migration/compliance_guide_chafing_gear_2014.pdf

> of excluder devices (e.g., flexible grates). For instance, small meshes may be needed to herd or guide fish, as well as to reinforce the net where the excluder or guiding panels are attached to reduce wear on the net meshes.

Furthermore, the Environmental Assessment (NMFS 2018, p. 4-27) stated:

> Midwater or bottom trawl fishermen would not likely purchase codends and intermediates that consist entirely of meshes smaller than 3 inches. Midwater trawling is generally species-selective; catch and discard of small fish while using 3-inch mesh in the midwater trawl fishery is generally low…. Reducing the mesh size of the midwater codend to something smaller than 3 inches could increase catch and discard of small fish. In addition, reducing codend and intermediate mesh size (throughout the sections) could increase drag and decrease flow…, subsequently decreasing fishing efficiency…. Based on this reasoning, it is unlikely that fishermen would use meshes smaller than 3 inches throughout midwater (or bottom) trawls. They may, however, strategically use meshes that are smaller than 3 inches in specific locations of the net to improve size or species selectivity (e.g., for the installation of selective devices).

In regards to the codend changes, the Environmental Assessment of these gear changes (NMFS 2018, pp. 4-33–4-34) stated:

> Allowing entire double-wall codends may reduce the effective mesh size through masking codend meshes and could increase the catch of small fish…, if the entire codend were constructed of double meshes…. Reasons for not building complete double-wall codends may be similar to the reasons that most fishermen would not use mesh sizes much smaller than current practices… which include various disincentives such as economics, cost, increased drag, increased fuel consumption, decreased flow, increased catch of small and unmarketable fish, decreased fishing efficiency, loss of MSC certification, and individual accountability…. While it is unlikely that many (or any) participants in the catch share program would build and use complete double-wall codends (see above), participants may strategically use double-wall mesh in the codends to reduce wear in specific areas of the net (e.g., under restraining straps)…, improve function of selective devices to reduce catch of unwanted species, or provide strength and rigidity to specific sections of the net for attaching underwater cameras…. There are numerous business disincentives for using complete double-wall codends…. Thus, eliminating codend requirements for midwater and bottom trawl would likely result in no change in impact on target and non-target groundfish….

In regards to the chafing gear changes, the Environmental Assessment of these gear changes (NMFS 2018, pp. 4-34–4-36) stated:

> Increasing chafing gear coverage… could raise the catch of small fish… by increasing the number of meshes that might be blocked (or masked) by chafing gear…. However, studies suggest that if chafing gear meshes are larger than codend meshes, and if chafing gear is hung relatively loosely over codend meshes (i.e., chafing gear is wider than the codend panel and is not attached at the terminal end), then chafing gear may not have a measurable effect on codend selectivity. Therefore, it would not likely increase retention of undersized fish due to blocked meshes…. Most fishermen would be unlikely to build chafing gear with small meshes (e.g., chafing gear mesh size equal to codend mesh size) that would lay tight to the codend meshes, or chafing gear that might cover more of the codend than necessary, because doing so could decrease flow, increase drag…, and increase the catch of undersized fish…. [U] nder the trawl catch share program, vessels have various incentives to avoid the catch of small, unmarketable groundfish for which quota is required…. For each pound of these fish caught, fishermen must use a pound of quota, forgoing their opportunity to use that quota to cover catch for which they can get paid. The effect of catching small fish that must be covered with quota is a reduction of vessel revenue (i.e., no payment will be made for undersized fish), as well as additional sorting time (workload) for the vessel's crew and processor's employees…. On this basis, regardless of the amount and continuity of chafing gear allowed on a codend, fishermen's incentive is to configure the gear and select fishing locations to avoid catching undersized groundfish. Thus, they may not use the maximum amount of chafing gear, minimum mesh size, etc. to the degree allowed under any particular alternative.

In regards to the impact on eulachon of no mesh size, codend, or chafing gear restrictions, the Environmental Assessment of these gear changes (NMFS 2018, pp. 4-43–4-45) stated:

> It is unlikely that participants in the catch share program would construct and use complete codends with meshes smaller than 3 inches…. [M]ost fishermen would likely continue using codends (and other large sections of their trawl) with mesh sizes similar to those currently used… with the exception of strategically placed small meshes that may benefit the installation and functionality of selective devices. Use of smaller meshes may allow for the development of selective devices that could reduce the catch of small fish, such as eulachon…. As such…, [no mesh size restrictions] would likely have no change in impact (if excluder use or function is not improved) to low positive change in impact (if excluder use or function is improved) for eulachon…. [In addition,] because there are numerous disincentives for using complete double-wall codends, and considering the mitigation measures available to reduce catch of non-groundfish species if a conservation concern emerges…, eliminating codend requirements for bottom and midwater trawl likely would result in no change in impact for non-target non-groundfish species…. [In addition, no chafing gear restrictions]… likely would have no change in impact for non-groundfish….

The Environmental Assessment of the redefinition of selective flatfish trawl (SFFT) to allow for a two- or four-seamed net (NMFS 2018, pp. 4-73–4-77) stated:

> [T]he SFFT definition would be modified to allow a two-seam or a four-seam net, while retaining the other gear restrictions…. However, the area restrictions north of 40°10′N latitude would be eliminated, with the exception of groundfish bottom trawling within the Klamath and Columbia River Conservation Zones where the SFFT would be required to reduce trawl impacts on ESA-listed salmon…. Groundfish trawl vessels would be allowed to use any small footrope trawl shoreward of the trawl RCA…. Eulachon entering the trawl likely would more readily escape trawl meshes from a four-seam SFFT… than from a two-seam SFFT… due to differences in open meshes and flow. The level of this improved escapement is uncertain, however, because the amount of improvement to flow in a four-seam net compared to a two-seam net is uncertain…. Although escapement may increase through more open meshes, the fate of eulachon escaping trawls is uncertain…. Mortality of eulachon would not likely increase measurably under [these redefinitions of the SFFT]…. However, an impact up to low-negative would be assumed because of the likelihood of some unaccounted mortality (i.e., escape mortality)…. If low-negative impacts were to occur, they would be most pronounced north of 42°N latitude because most fishing effort shoreward of the trawl RCA during the summer season occurs in the northern area…. In addition, eulachon density is highest north of 42°N latitude….

The real-world effects of these regulatory gear changes (Table S25) on eulachon bycatch have yet to be analyzed.

Fate of Eulachon Escaping and Avoiding Capture

From a conservation biology perspective, it is important to examine not only estimated bycatch and discard mortality but also the fate of nontarget organisms that escape from trawl nets prior to being hauled aboard fishing vessels. Davis and Ryer (2003, pp. 7–8) stated that "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." The components of unobserved mortality most relevant to the above include: 1) escape mortality (i.e., mortality of fish escaping from trawl nets prior to the net being brought on deck) and 2) avoidance mortality (i.e., direct or indirect mortality of fish resulting from the stress and fatigue of avoiding a trawl net; ICES 2005, Broadhurst et al. 2006). Various terms are used for these unobserved but ultimately lethal interactions with fishing gear, including: "unaccounted fishing mortality" (Chopin and Arimoto 1995, Suuronen 2005, ICES 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. ICES (2005) also identified post-trawl mortalities resulting from predation or infection of physically or behaviorally impaired fish as subcomponents of escape and avoidance mortality. Raby et al. (2014) reviewed the role of predation on mortality of fish escaping or avoiding trawl gear.

Trawl-escape mortality studies have been reviewed by Chopin and Arimoto (1995), Suuronen (2005), Broadhurst et al. (2006), Suuronen and Erickson (2010), and Gilman et al. (2013). Experimental field studies of escape mortality from trawl nets have typically used cages to surround the trawl codend and capture escapees. These cages are subsequently detached from the trawl gear and held at depth or in the water column to observe the fate of escaped fish. Because of the expense and technical difficulties of performing such research, escape mortality has been evaluated for only a few species and fisheries (Gilman et al. 2013), but it is evident that different species exhibit a wide range of sensitivities to contact with trawl gear. Gadoid species such as Baltic cod (*Gadus morhua*) and saithe (*Pollachius virens*) appear relatively robust, and these species—as well as many flatfishes—generally suffer less than 10% mortality from passage through towed trawl net meshes; see references reviewed in Suuronen and Erickson (2010) and Gilman et al. (2013). Mortality of whiting (*Merlangus merlangus*) and haddock (*Melanogrammus aeglefinus*) has generally been less than 25%; however, walleye pollock (*Gadus chalcogrammus*) can suffer 50% mortality following passage through trawl nets. On the other hand species such as Baltic herring (*Clupea harengus*), which are easily descaled, may suffer from 30–80% mortality subsequent to passage through trawl codends (Suuronen et al. 1996a,b, Suuronen and Erickson 2010, Gilman et al. 2013). It has been acknowledged that some of the above studies may suffer from bias caused by collection, transportation, and holding of trawl escapees (Suuronen and Erickson 2010, Gilman et al. 2013) and might overestimate escape mortality. In addition, few of these studies have included control groups of fish, although more recent studies have included control fish (Suuronen 2005). On the other hand, many studies have evaluated escape mortality using experiments that have not always simulated true commercial fishing conditions in terms of tow duration, catch volume, season, and depth, and have likely underestimated true escape mortality (Suuronen and Erickson 2010).

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 and 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.

Fate of eulachon escaping ocean shrimp trawl nets

Although data on survivability of encounters with 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, p. 39) 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.

Hannah and Jones (2012, p. 43) concluded:

> [D]ata 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.

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.

Fate of eulachon escaping and avoiding groundfish trawl nets

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). These studies indicate 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).

As mentioned in Recent Regulatory Gear Changes in Bottom and Midwater Trawl Fisheries, unless the codend of a trawl net becomes plugged with larger fish, most eulachon should be able to escape through the codend mesh of trawl nets used in the U.S. West Coast groundfish fisheries. However, the impact on eulachon bycatch of removal of mesh size restrictions and other gear regulations as of 1 January 2019 has yet to be analyzed. Given the likelihood that most eulachon encountering groundfish trawls would escape through the mesh, the level of eulachon bycatch reported in this document may represent a small fraction of all eulachon encounters with bottom and midwater trawl fishing gear in the U.S. West Coast groundfish fishery.

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