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Observed and Estimated Bycatch of Eulachon in 2002–2021 U.S. West Coast Groundfish Fisheries

Richard Gustafson[1], Kate Richerson[2], Kayleigh Somers[2], Vanessa Tuttle[2], and Jon McVeigh[2]

[1] Conservation Biology Division
Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112
USA

[2] Fishery Resource Analysis and Monitoring Division
Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112
USA

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Executive Summary

In accordance with the National Marine Fisheries Service (NMFS) Biological Opinion (BiOp) on Continuing Operation of the Pacific Coast Groundfish Fishery (NMFS-NWR 2012, NMFS-WCR 2018), this document provides an analysis of observed bycatch and fleet-wide take estimates of U.S. Endangered Species Act (ESA)-listed eulachon (*Thaleichthys pacificus*) in all sectors of the U.S. West Coast groundfish fishery from 2002–2021. Eulachon is an anadromous smelt (Family Osmeridae) that spawns in freshwater rivers, yet spends 95% of its life in the ocean over the continental shelf and most often at depths between 50 and 200 m. The southern Distinct Population Segment (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 southern DPS of eulachon was listed as threatened under the ESA in 2010 (USOFR 2010). 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 (NMFS-WCR 2022, Gustafson et al. 2022).

Across 19 years of observation (2002–2020), a total of 20,396[1] individual eulachon were estimated to have been caught as bycatch in all observed sectors of the U.S. West Coast groundfish fishery. However, in 2021, an estimated 23,820 eulachon were caught as bycatch in these fisheries, more than in all 19 previous years combined. Eulachon bycatch in all 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 72% of the 2002–2021 total.

The 2012 Groundfish BiOp stated that incidental take of eulachon in combined Limited Entry (LE) groundfish bottom trawl and at-sea hake fisheries was not expected to be more than 1,004 fish per year. However, this threshold of incidental take was exceeded in 2011, 2013, and 2014, which resulted in reinitiation of formal consultation and a revised Groundfish BiOp incidental take statement (ITS) for eulachon (NMFS-WCR 2018). The new ITS takes the fluctuating abundance of eulachon into account, and is based on a comparison of five-year geometric means of both eulachon bycatch in West Coast groundfish fisheries and minimum abundance estimates of Columbia River eulachon (as a proxy for the abundance of southern DPS of eulachon). The yearly bycatch estimate for ITS purposes is estimated as the geometric mean of the most recent year's and the four preceding year's bycatch count estimates in the West Coast groundfish fishery. The abundance proxy for the southern DPS is calculated as the five-year geometric mean from the current year and the preceding four years of the minimum abundance estimates for Columbia River eulachon. Two thresholds for incidental take are calculated from this later number – a precautionary threshold (0.01 percent of the five-year geometric mean of minimum abundance) and a reinitiation threshold (0.02 percent of the five-year geometric mean of minimum abundance) (NMFS-WCR 2018).

Since the previous biennial report on eulachon bycatch (Gustafson et al. 2021), total fleetwide estimated bycatch in U.S. West Coast groundfish fisheries increased from 2,663 total eulachon in

[1] 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).

2019, to 8,528 total eulachon in 2020, and then to 23,820 total eulachon in 2021. Using these eulachon bycatch estimates, the five-year geometric mean of bycatch in the West Coast groundfish fisheries has been determined to be 455 eulachon in 2020 and 567 eulachon in 2021. In 2020, the ITS precautionary and reinitiation thresholds (five year geometric means of 0.01% and 0.02% of minimum Columbia River abundance) were 827 and 1,653, respectively. In 2021, the ITS precautionary and reinitiation thresholds were 932 and 1,865, respectively. Therefore, for the purposes of the Groundfish BiOp, bycatch in 2020 was 42% and 21% of the precautionary and reinitiation thresholds, respectively. In 2021, bycatch was estimated at about 61% of the precautionary and 30% of the reinitiation threshold. Therefore, these thresholds were not exceeded in 2020 or 2021.

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 inches) and 7.6 cm (3.0 inches), respectively. These mesh size restrictions and several other gear regulations were removed as of 1 January 2019 as 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 IFQ-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 increase so dramatically 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.

From a conservation biology perspective, it is important to examine not only observed bycatch and discard mortality but also the fate of non-target organisms that escape from trawl nets prior to being hauled aboard fishing vessels. However, we currently have no direct data to estimate escape or avoidance mortality of eulachon in any sector of the groundfish fishery and we are unaware of any studies that have directly investigated the fate of osmerid smelt species passing through groundfish trawl nets.

Acknowledgments

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Introduction and Background

In accordance with the National Marine Fisheries Service (NMFS) Biological Opinion (BiOp) on Continuing Operation of the Pacific Coast Groundfish Fishery (NMFS-NWR 2012, NMFS-WCR 2018), this document provides an analysis of observed bycatch and fleet-wide take estimates of U.S. Endangered Species Act-listed eulachon (*Thaleichthys pacificus*, Osmeridae) in U.S. West Coast groundfish fishery sectors. The current document updates information on eulachon bycatch in Gustafson et al. (2015, 2017, 2019, 2021), with the addition of data for the years 2020 and 2021.

Eulachon is an anadromous smelt that ranges from northern California to the southeastern Bering Sea coast of Alaska (Willson et al. 2006, Moody and Pitcher 2010). The declining abundance of eulachon in the southern portion of its range led the Cowlitz Indian Tribe to petition (Cowlitz Indian Tribe 2007) the NMFS to list eulachon in Washington, Oregon, and California as a threatened or endangered species under the USA's Endangered Species Act (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 is composed of numerous subpopulations that spawn in 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 climate change impacts on ocean and freshwater habitat, bycatch in offshore shrimp trawl fisheries, changes in downstream flow timing and intensity due to dams and water diversions, and predation. These threats, together with large declines in abundance, indicated to the 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 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 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 et al. 2006). 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 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 3 to 8 weeks depending on temperature. Newly hatched larvae are transparent, slender, and about 4 to 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).

West Coast Groundfish Fishery

The West Coast groundfish fishery (WCGF) is a multi-species fishery that utilizes a variety of gear types. The fishery harvests species designated in the Pacific Coast Groundfish Fishery Management Plan (FMP) and is managed by the Pacific Fishery Management Council (PFMC) (PFMC 2022). Eighty-six species are listed in the groundfish FMP, including a variety of rockfish, flatfish, roundfish, skates, and sharks. These species occur in both federal (> 5.6 km off shore) and state waters (0-5.6 km). Groundfish are both targeted and caught incidentally by trawl nets, hook-&-line gear, and fish pots. Under the FMP, the groundfish fishery consists of four management components:

- The Limited Entry (LE) component encompasses all commercial fishers who hold a federal LE permit. The total number of LE permits available is restricted. Vessels with an LE permit are allocated a larger portion of the total allowable catch for commercially desirable species than vessels without an LE permit.

- The Open Access (OA) component encompasses commercial fishers who do not hold a federal LE permit. Some states require fishers to carry a state-issued OA permit for certain OA sectors.

- The Recreational component includes recreational anglers who target or incidentally catch groundfish species. Recreational fisheries are not covered by this report.

- The Tribal component includes tribal commercial fishers in Washington State that have treaty rights to fish groundfish.

These four components can be further subdivided into sectors based on gear type, target species, permits and other regulatory factors. This report includes data from some of the following sectors:

<u>Limited Entry (LE) sectors</u>

Beginning in 2011, an Individual Fishing Quota (IFQ) program for the LE bottom trawl fleet and the at-sea Pacific hake fleet was implemented, under the West Coast Groundfish Trawl Catch Share Program.

- IFQ fishery (formerly LE bottom trawl and at-sea Pacific hake). The IFQ non-hake sectors consist primarily of bottom trawl, with some midwater trawl and gear-switching (fishing the IFQ permit using fixed gear). This sector is subdivided into the following components due to differences in gear type and target strategy. Components of the IFQ fishery during 2011–2021 were:

    - Bottom trawl: Bottom trawl nets are used to catch a variety of non-hake groundfish species. Catch is delivered to shore-based processors.
    - Midwater non-hake trawl: Midwater trawl nets are used to target midwater non-hake species. Catch is delivered to shore-based processors. Definition of the catch as occurring in this component is based on the captain's target as recorded in the logbook.
    - Pot: Pot gear is used to target groundfish species, primarily sablefish (*Anoplopoma fimbria*). Catch is delivered to shore-based processors.
    - Hook-and-line: Longlines are used to target groundfish species, mainly sablefish. Catch is delivered to shore-based processors.
    - LE California halibut (*Paralichthys californicus*) trawl: Bottom trawl nets are used to target California halibut by fishers holding both a state California halibut permit and an LE federal trawl groundfish permit. Catch is delivered to shore-based processors.
    - At-sea motherships and catcher-processors: Midwater trawl nets are used to catch Pacific hake. Catcher vessels deliver unsorted catch to a mothership. The catch is sorted and processed aboard the mothership. Catcher-processors catch and process at-sea.
    - Tribal at-sea processing component of the Pacific hake sector. The tribal sector operates within the usual and accustomed fishing areas. Tribal catcher vessels deliver catch to contracted motherships for processing.
    - Shoreside midwater Pacific hake trawl (2011–2014): Midwater trawl nets used to catch Pacific hake. Catch is delivered to shore-based processors. Definition of the catch as occurring in this component is based on the captain's target as recorded in the logbook.
    - Shoreside midwater Pacific hake trawl (2015–2021): Midwater trawl nets are used to catch Pacific hake (more than 50% of catch by a vessel on a given day is Pacific hake). Catch is delivered to shore-based processors.
    - Shoreside midwater rockfish trawl (2015–2021): Midwater trawl nets are used to catch rockfish, typically widow and yellowtail (less than 50% of catch by a vessel on a given day is Pacific hake). Catch is delivered to shore-based processors.
- LE fixed gear (non-nearshore): This sector is subdivided into two components due to differences in permitting and management:

    - LE sablefish endorsed season: Longlines and pots are used to target sablefish. Catch is generally delivered to shore-based processors, although a small amount may be sold live.
    - LE sablefish non-endorsed: Longlines and pots are used to target groundfish, primarily sablefish and thornyheads. Catch is delivered to shore-based processors or sold live at the dock.

- Directed Pacific halibut: Longlines are used to target Pacific halibut (*Hippoglossus stenolepis*). The directed commercial Pacific halibut fishery operates south of Point Chehalis, WA and requires a permit from the International Pacific Halibut Commission. Observer coverage in this sector began in 2017.

<u>Open Access (OA) Federal sectors</u>

- OA fixed gear (non-nearshore): Fixed gear, including longlines, pots, fishing poles, stick gear, etc. is used to target non-nearshore groundfish. Catch is delivered to shore-based processors.

<u>Open Access (OA) state sectors</u>

- OA ocean shrimp[2] (*Pandalus jordani*) trawl: Trawl nets are used to target ocean shrimp. Catch is delivered to shore-based processors.
- OA California halibut trawl: Trawl nets are used to target California halibut (*P. californicus*) by fishers holding a state California halibut permit. Catch is delivered to shore-based processors.
- Nearshore fixed gear: A variety of fixed gear, including longlines, pots, fishing poles, stick gear, etc. are used to target nearshore rockfish and other nearshore species managed by state permits in Oregon and California. Catch is delivered to shore-based processors or sold live.
- OA ridgeback prawn trawl (California): Prawn permit issued by the state of California. This fishery uses trawl nets to target ridgeback prawn (*Sicyonia ingentis*) or other prawn/shrimp species. This fishery is defined as occurring only in California, using shrimp or bottom trawl gear, and landing more ridgeback prawn than other species. Observer coverage in this sector began in 2017.

Northwest Fisheries Science Center Fisheries Observation Science Program

The NWFSC Fisheries Observation Science Program's goal 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). The WCGOP was established in May 2001 by NMFS in accordance with the Pacific Coast Groundfish Fishery Management Plan (50 CFR Part 660) (50 FR 20609).This regulation requires all vessels that catch groundfish in the U.S. Exclusive Economic Zone (EEZ) from three to 200 miles offshore to carry an observer when notified to do so by NMFS or its designated agent. Subsequent state rule making has extended NMFS's ability to require vessels fishing within the three-mile state territorial water zone to carry observers.

[2] *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).

The WCGOP and A-SHOP observe distinct sectors of the groundfish fishery. The WCGOP observes the following sectors: IFQ shore-based delivery of groundfish and Pacific hake, LE and OA fixed gear, and state-permitted nearshore fixed gear sectors. The WCGOP also observes several state-managed fisheries that incidentally catch groundfish, including the California halibut trawl, sea cucumber trawl, ridgeback prawn trawl, and ocean shrimp trawl fisheries. The WCGOP also observes the directed Pacific halibut fishery, which is permitted by the International Pacific Halibut Commission. The A-SHOP observes the IFQ fishery that delivers Pacific hake at-sea, including: 1) catcher-processor, 2) mothership catcher vessels, and 3) tribal catch delivered at-sea to motherships. Details on how fisheries observers operate in both the IFQ (aka Catch Share) and Non-IFQ (aka Non-Catch Share) sectors can be found online[3].

Eulachon Bycatch

The primary objective of this report is to provide estimates of bycatch of the ESA-listed southern DPS of eulachon in observed U.S. West Coast federally permitted groundfish fisheries from 2002–2021. In this report, we assume 100% mortality of eulachon incidentally caught and subsequently discarded in these fisheries. A number of previous reports (NWFSC 2009, 2010, Bellman et al. 2008, 2009, 2010, 2011, Al-Humaidhi et al. 2012, Gustafson et al. 2015, 2017, 2019, 2021) have 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.

In this document, bycatch ratios for eulachon are reported as weight in kilograms and as number of individual fish caught per metric ton (mt) of total groundfish retained per haul. These ratios are then used to estimate eulachon bycatch in the fleet in sectors where only a portion of the total hauls were observed. This report includes eulachon bycatch estimates for all groundfish fisheries observed by the WCGOP and A-SHOP from 2002–2021.

The following commercial groundfish fishery sectors had observed eulachon bycatch during 2002–2021:

- LE and IFQ bottom trawl fishery
- IFQ non-hake midwater trawl fishery
- IFQ shoreside midwater Pacific hake trawl
- IFQ shoreside midwater rockfish trawl
- IFQ at-sea Pacific hake catcher-processor fishery
- IFQ at-sea non-tribal Pacific hake mothership-catcher vessel fishery
- Tribal Pacific hake mothership-catcher vessel fishery

Table 1 presents a summary of the permits, gear used, target groups, vessel length range, fishing depth range, and management of fishery sectors and sub-sectors in U.S. West Coast groundfish fisheries that have had documented eulachon bycatch.

The WCGOP also observes some fisheries that incidentally catch groundfish, including the state permitted ocean shrimp trawl fisheries. The majority of observed eulachon bycatch off the U.S.

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

West Coast occurs in state operated commercial ocean shrimp trawl fisheries in California, Oregon, and Washington (Gustafson et al. 2015, 2017, 2019, 2021). However, these non-groundfish trawl fisheries are permitted by the individual states, are not regulated under the Pacific Coast Groundfish FMP, and therefore do not fall under the 2012 (NMFS-NWR 2012) or the reinitiated 2018 (NMFS-WCR 2018) Biological Opinions for eulachon. Eulachon bycatch in these shrimp trawl fisheries is important to understand from the perspective of species conservation. To clearly define the scope of the reporting required under the 2012 and 2018 Biological Opinions, eulachon bycatch in ocean shrimp fisheries is reported in an Appendix to the current report; however, eulachon bycatch in ocean shrimp fisheries will not be further covered in the main body of this document. Recommendations to the PFMC regarding eulachon under the Biological Opinion should not include the ocean shrimp fishery.

Groundfish Fishery Sectors with Eulachon Bycatch

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 and operates year-round off the coasts of Washington, Oregon, and southward to Morro Bay in California. Groundfish trawl vessels deliver their permitted and marketable catch to shore-side processors, and the majority of the portion of their catch which is prohibited by regulations or that is unmarketable is discarded at sea. As mentioned above, an Individual Fishing Quota (IFQ) program for the limited entry shore-based bottom trawl fleet was implemented in 2011, under the West Coast Groundfish Trawl Catch Share Program. This catch shares 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 2011, the LE trawl sector became a catch share program with 100% NMFS-certified observers. In 2015-2021, a subset of the fleet participated in the Pacific Coast Groundfish EM Exempted Fishing Permit (EFP) and carried electronic monitoring (EM) systems for compliance and quota management rather than observers. These vessels were still required to carry an observer for additional scientific data collection on ~ 20 to 30% of trips. More background information on the West Coast Groundfish Trawl Catch Share Program and the Fisheries Observation Science Program of the NWFSC can be found online.[4]

At-sea Pacific hake fishery

This Catch Shares fishery targets Pacific hake off the coasts of Oregon and Washington using midwater trawl nets, primarily from mid-May–November. We report data in this report from three components of the at-sea fishery for Pacific hake: 1) a catcher-processor cooperative, consisting of vessels that harvest with midwater trawl gear and process Pacific hake catch at sea, 2) a mothership cooperative, consisting of catcher vessels that harvest Pacific hake with midwater trawl gear and deliver the catch to a mothership that processes the catch at sea, and 3) a commercial tribal fishery that uses gear similar to that used in the non-tribal fisheries. Data from non-tribal and tribal mothership-catcher vessel sectors have been combined in the current report; however, the commercial tribal fishery has not operated since 2012. The catcher-processor sector

[4] https://www.fisheries.noaa.gov/west-coast/science-data/fisheries-observation-science-west-coast

entered into a cooperative agreement (co-op) which split the Pacific hake quota into individual fishing quotas by company in 1997, and the non-tribal mothership sector entered into a co-op for the first time as West Coast trawl fisheries began operating under a catch shares program[5] in 2011. In each of the at-sea Pacific hake fishery sectors, the portion of the non-hake catch, which is 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.

Shoreside midwater Pacific hake and shoreside midwater rockfish sectors

The IFQ shoreside Pacific hake and rockfish midwater trawl fleet is comprised exclusively of catcher vessels that deliver unsorted catch to shore-based processing plants. From 2011–2014, 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 Pacific hake in a trip. Fishery definitions from 2011–2014 and those in 2015–2021 are not directly comparable, although they are similar. To emphasize this, the WCGOP also altered the name of these fisheries to clarify the difference in 2015–2021 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 2011–2014, all midwater non-hake trips were combined with the bottom trawl sector, but in 2015–2021 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, only at-sea discards are observed by the WCGOP; additional discards occur on shore. All IFQ vessels were required to carry an observer from 2011 to 2014 on 100% of fishing trips. Similar to bottom trawl vessels, in 2015–2021, a subset of these fleets applied for Pacific Coast Groundfish EM Exempted Fishing Permits (EFPs) in order to carry 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 shoreside catch monitoring samples.

Unobserved Mortality

The current document presents WCGOP and A-SHOP observer data describing bycatch mortality of eulachon that is landed on the deck of trawl vessels operating in the various U.S. West Coast groundfish fisheries covered by the Pacific Coast Groundfish Fishery Management Plan. However, data on eulachon "mortalities resulting from encounter[s] with fishing gear," as mentioned in the 2012 BiOp (NMFS-NWR 2012, p. 121), are unavailable. Various terms are used to describe these unobserved but potentially lethal interactions with fishing gear, including: "unaccounted fishing mortality" (Chopin and Arimoto 1995, Suuronen 2005, ICES 2005,

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

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. The components of unaccounted fishing mortality most relevant to the above BiOp language 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). The federal regulations in the groundfish fishery that mandated minimum trawl mesh dimensions in the bottom and midwater trawl fisheries of 11.4 cm (4.5 inches) and 7.6 cm (3.0 inches), respectively were eliminated on 1 January 2019 (USOFR 2018). The Environmental Assessment of these gear changes (NMFS 2018, p. 4-27) reasoned that:

> 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).

If meshes smaller than three inches are not used, it is likely that most eulachon would be able to escape by swimming or falling through codend mesh of this dimension, either during the tow or during haul-back operations. However, we have no information on the level of either escape or avoidance mortality of eulachon in U.S. West Coast groundfish fisheries (see Discussion).

Methods

Data Sources

Data sources for this analysis include onboard observer and electronic monitoring data from the 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[6].

The Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 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 fishermen or dealers. Those data that can only be attributed to two or fewer fishermen 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 2023). A-SHOP information and documentation on data collection methods can be found in the A-SHOP observer manual (NWFSC 2022). The sampling protocol employed by the WCGOP is primarily focused 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. (2022). The sampling protocol employed by the A-SHOP focuses on random samples collected form 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 used as the effort metric. Thus, the retained landing information from fish tickets is crucial information for fleet-wide total bycatch estimation for all sectors of the commercial groundfish fishery 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. Fish ticket and species-composition data are submitted by state agencies to the PacFIN regional database. 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 groundfish fishery. Observer and fish ticket data processing steps are described in detail in Somers et al. (2022). All data processing steps specific to this report are described in the bycatch estimation methods section below.

[6] https://www.fisheries.noaa.gov/west-coast/sustainable-fisheries/west-coast-groundfish-trawl-catch-share-program#ifq-first-receivers-and-catch-monitors

Bycatch Estimation Methods

The landed amount of a target species (or species groups) was used as a proxy for fishing effort. The choice of target species and therefore, the effort metric, depends on the fishery sector. Thus, eulachon bycatch estimation was estimated for each individual fishery sector that encountered eulachon. Eulachon were taken during some years as bycatch in the following groundfish fishery sectors: 1) LE bottom trawl (2002–2010), 2) IFQ bottom trawl (2011–2021), 3) IFQ non-hake midwater trawl (2011–2021), 4) IFQ shoreside Pacific hake fishery (2011–2014), 5) IFQ shoreside midwater Pacific hake fishery (2015–2021), 6) IFQ shoreside midwater rockfish fishery (2015–2021), 7) non-tribal and tribal at-sea Pacific hake mothership fisheries (2002–2021), and 8) at-sea Pacific hake catcher-processor fishery (2002–2021).

As mentioned above, landed catch of target species is used as the effort metric, and target species differ by fishery sector. Target species of those sectors that encountered eulachon during 2002–2021 were: all groundfish species, except Pacific hake, included in the groundfish fishery management plan (FMP) for LE bottom trawl and IFQ trawl sectors, Pacific hake for at-sea hake fisheries, and either Pacific hake or groundfish for shoreside midwater trawl Pacific 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 3 or more active vessels will be reported to protect business interests. A bycatch ratio (aka 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 fleet-wide level was then estimated based on the simple expansion of bycatch ratios by total targeted fish landings as the multiplier for a given strata. The estimation of bycatch ratio and fleet-wide 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)
$\hat{D}$ = fleet-wide total bycatch estimate of eulachon

LE bottom trawl fishery

The LE bottom trawl fishery is a multi-species fishery (2002–2010) that targeted various groundfish species. Since 2011, this fishery has been managed under an Individual Fishing Quota (IFQ) system. Landings for this fishery include all groundfish species defined in the groundfish fishery management plan (FMP), except Pacific hake. There are 86 fish species actively managed under this FMP (PFMC 2022), including 64 rockfish species, 12 flatfishes, 6 roundfishes, and 4 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 of California halibut was 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 40°10' N. latitude. All tows from 2002–2010 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 shares: non-hake 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. Fleet-wide eulachon bycatch for this sector is almost completely known because all vessels not using EM carry an observer. Bycatch for this fishery was summarized by year and state of landing. From 2011–2014, this section included midwater non-hake trawl; however, starting in 2015, this section includes only bottom trawl, and all shoreside midwater trawl is reported separately as IFQ shoreside midwater Pacific hake trawl and IFQ shoreside midwater rockfish trawl.

In the non-EM portion of the fleet, all Catch Shares 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 2011–2021. 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 discard 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
$\hat{U}$ = bycatch estimate of eulachon in unsampled catch

Eulachon bycatch was estimated 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.

Catch Shares 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 Pacific hake fishery

Observed and expanded bycatch data were provided directly from the A-SHOP and incorporated into this report. Eulachon bycatch is reported by year for two at-sea Pacific hake fishery sectors: catcher-processor and motherships delivered at-sea. All vessels fishing in the at-sea Pacific 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 strata 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 strata. The total number of eulachon caught by the at-sea Pacific hake fleet per given 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
T = weight of sampled hauls

Catch shares: shoreside Pacific hake fishery (2011–2014)

Observers in this sector do minimal sampling at sea unless discards occur, as most hauls are retained entirely and the landed catch is sorted and weighed at the plants by catch monitors. At-sea discards and landings data are combined to estimate total catch. Because catch monitors only weigh landed catch, eulachon discard information is available as weight but not counts. Therefore, eulachon bycatch numbers were derived from a 3-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 shares: IFQ shoreside midwater Pacific hake trawl (2015–2021)

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 3-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 shares: IFQ shoreside midwater rockfish trawl (2015–2021)

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 3-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 Exempted Fishing Permits (EFP), 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 State 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, therefore, eulachon bycatch numbers were derived from a 3-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[7] and the Pacific Fisheries Management Council[8].

Measures of Uncertainty

As a measure of uncertainty for the estimated bycatch ratio in sectors without full observer coverage, lower and upper limits of the 95% confidence interval were estimated with a non-parametric 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 fleet-wide 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)].

If there were 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 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 2002–2021, only two confidential strata occurred; the winter season of 2008 in the Washington LE bottom trawl sector, and the 2019–2021 non-EM midwater Pacific hake sector.

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

Results

Eulachon Bycatch[9]

Eulachon were not observed as bycatch in the LE bottom trawl fishery in Washington from 2002–2010 (Table 2). From 2011 to 2019, a total of 19.8 kg of eulachon representing 439 individuals were estimated as fleet-wide bycatch in the Washington IFQ non-hake bottom and midwater trawl fisheries (Tables 3 and 4). 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 2020 are combined with Oregon and reported in Tables 6 and 7. In 2021 nearly 170 kg of eulachon representing 4,392 individual eulachon were estimated from IFQ non-hake bottom and midwater trawl fisheries in Washington (Tables 3 and 4).Within the Oregon portion of the LE bottom trawl fishery, eulachon bycatch occurred in four of the nine years from 2002–2010 with 81% (837/1,034) of this estimated bycatch occurring in the year 2002 (Table 5). However, eulachon bycatch did not occur in the Oregon LE bottom trawl fishery in 2004, 2005, 2006, 2008, or 2010 (Table 5). Between 2011 and 2019, the Oregon IFQ non-hake bottom and midwater trawl fisheries had an estimated eulachon bycatch of 247.3 kg (Table 6) and 5,184 individual fish (Table 7), with 48% (2,511 individuals) of this total occurring in the year 2014 (Table 7). 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 7). 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 7).

Eulachon were rarely caught in the California LE bottom trawl fishery from 2002–2010; 5 fish in 2004 and 21 estimated fish in 2010 (Table 8). A tenth of a kilogram of eulachon representing two bycaught eulachon were recorded in the California IFQ bottom and midwater trawl fisheries in 2015; however, no eulachon occurred as bycatch in this sector from 2011–2014 or from 2016–2021 (Tables 9 and 10).

Eulachon are encountered sporadically in the at-sea Pacific hake fishery as bycatch. Eulachon bycatch was not reported in the Catcher Processor (CP) sector from 2002–2005, or in 2010 (Table 11). Similarly, the Tribal and Non-tribal Mothership Catcher Vessels sector (MSCV) did not report eulachon bycatch from 2002–2006 or in 2010 and 2015 (Table 12).

Between 2002 and 2021 eulachon bycatch in the at-sea Pacific 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 11). In all other years, fewer than 40 individual eulachon were observed in the CP Pacific hake sector as bycatch (Table 11). 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 CP Pacific hake sector. In 2021, the most recent year available, 5,920 eulachon were estimated as bycatch in the at-sea Pacific hake CP sector, representing 66% of all bycatch from 2002–2021 in this sector (Table 11). These

[9] 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).

dramatically higher bycatch levels in 2021 are in contrast to the relatively low bycatch in 2016 of 2 fish and 2017 of 18 fish (Table 11).

The combined non-tribal and tribal mothership-catcher vessels Pacific hake sectors 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 10 individual fish were estimated caught in 2002–2008, 2010, 2012, and 2015–2016 (Table 12). In the most recent years of 2020 and 2021, 198 and 252 eulachon were estimated as bycatch, respectively, in the at-sea mothership-catcher vessels Pacific hake sector (Table 12). The tribal mothership fishery has not operated since 2012.

The WCGOP began observing bycatch in the shoreside Pacific hake fishery in 2011 and did not record any eulachon bycatch in this fishery in 2011, 2012, or 2014 (Table 13). 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 3-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 13). This single estimate of bycatch in 2013 for this sector alone exceeded the 2012 BiOp incidental take threshold of 1,004 fish.

Since 2015, the shoreside midwater sector of the IFQ fishery has been redefined and is now reported separately as the Pacific hake midwater trawl sector and the rockfish midwater trawl sector. When more than 50% of a vessel's landings on a day were Pacific hake, the vessel's landing were reported as midwater hake; however, when landings were less than 50% Pacific 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 are reported in Table 14 and EM data in Table 15. For confidentiality reasons, data for 2019–2021 non-EM midwater hake sector are reported together with EM midwater hake in Table 15. Bycatch in these fisheries are sampled at nearly 100% after being landed and bycatch is weighed by a catch monitor, but counts are not recorded. Therefore, numbers of bycaught eulachon were estimated using a linear weight-count regression and data from a rolling 3-year window of all other catch share eulachon observations. We note that this may result in overestimation or underestimate of true counts if the size of eulachon encountered as bycatch varies across sectors. From 2015–2017 fewer than 10 eulachon per year were estimated as bycatch in either EM of non-EM portions of both the midwater hake and rockfish sectors (Tables 14 and 15). No eulachon bycatch occurred during 2018 in either the non-EM or EM sectors of the midwater Pacific hake fishery (Tables 14 and 15). 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 14 and 15). Subsequently, this sector had an estimated bycatch of 244, 66, and 320 fish in 2019, 2020, and 2021, respectively (Table 14). 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 15).

As mentioned earlier, due to confidentiality considerations, data for the 2019–2021 non-EM and EM portions of the midwater Pacific hake fishery have been combined. Although only seven eulachon were estimated as bycatch in the combined non-EM and EM midwater Pacific hake sectors from 2015–2018, eulachon bycatch amounted to 488, 1,953, and 7,717 fish in 2019, 2020, and 2021, respectively (Tables 14 and 15).

A summary of eulachon bycatch in all U.S. West Coast groundfish fisheries observed by the WCGOP and the A-SHOP that reported eulachon catch from 2002–2021 is provided in Table 16 and Figure 1. Across 20 years of observation (2002–2021), a total of 45,568[10] individual eulachon were estimated to have been caught as bycatch in all groundfish sectors of the U.S. West Coast groundfish fishery (Table 16). About 72% of this bycatch occurred in 2020–2021 (Table 16, Fig. 1).

The previous biennial report on eulachon bycatch (Gustafson et al. 2021), had remarked on the increase in total fleetwide bycatch in U.S. West Coast groundfish fisheries that occurred from a total eulachon bycatch of 58 and 68 fish in 2016 and 2017, to an estimated 792 fish in 2018 and 2,663 total eulachon in 2019 (Table 16, Fig. 1). This increasing bycatch continued in 2020 and 2021, reaching a total of 8,528 fish in 2020 and 23,820 fish in 2021 (Table 16, Fig. 1). 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 16, Fig. 1).

Discussion

The 2012 Biological Opinion (BiOp) on Continuing Operation of the Pacific Coast Groundfish Fishery (PCGF) (NMFS-NWR 2012, p. 121, aka Groundfish BiOp) stated that:

> … the take of threatened southern DPS eulachon will occur as a result of the proposed continued operation of the PCGF. Incidental take of southern DPS eulachon occurs as a result of bycatch and handling in the fisheries, or mortalities resulting from encounter with fishing gear, as a consequence of fishing activity. Take of eulachon in the proposed action is expected to not exceed 1,004 fish per year. This take is expected to occur in the LE groundfish bottom trawl and at-sea hake fisheries.

The reasonable and prudent measures in the 2012 Opinion (NMFS-NWR 2012) state that exceeding the amount or extent of take described in the incidental take statement (ITS) will result in reinitiation of formal consultation if the amount or extent of incidental take is exceeded. As eulachon bycatch exceeded the ITS in 2011, 2013, and 2014 (Gustafson et al. 2015, 2017), "NMFS WCR Sustainable Fisheries Division requested reinitiation with the NMFS WCR Protected Resources Division on April 5, 2016" (NMFS-WCR 2018, p. 1-2). As further stated in NMFS-WCR (2018, p. 1-3):

> Due to wide fluctuations in eulachon abundance, keeping eulachon bycatch under the extent of take described in the 2012 Opinion became difficult when abundance

[10] 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).

> increased, even though impact remained low. Therefore, this new Opinion will consider the effects of the groundfish fishery in terms of eulachon bycatch in light of current information about the fluctuating abundance of eulachon.

2018 Reinitiation of Consultation on the 2012 Biological Opinion for Eulachon

The "amount or extent of take statement" from the 2018 Reinitiation of Consultation for Eulachon of the 2012 Biological Opinion (BiOp) on Continuing Operation of the Pacific Coast Groundfish Fishery (Reinitiation 2018) (NMFS-WCR 2018, p. 2-17 to 2-20) is reproduced below:

> In this biological opinion, NMFS determined that incidental take is reasonably certain to occur as follows:
>
> The proposed groundfish fisheries would result in the capture, harm, and mortality of juvenile and adult eulachon. Eulachon will enter groundfish trawl nets during fishing operations and this can affect eulachon via one of two effect pathways. The first effect pathway is through eulachon being captured in trawl nets but ultimately escaping the nets. Some of those fish may suffer injury as a result of their capture and escape, but there is no way to ascertain whether or how many will suffer minor, sublethal, or lethal effects since those fish are [not] available for observation after their escape. The second effect pathway involves the remaining eulachon being retained as bycatch in groundfish trawl nets, and these fish are expected to die due to crushing and descaling injuries. It is not possible to quantify or monitor the number of eulachon incidentally taken (lethally or otherwise) as a result of the proposed action because an unknown and varying percentage of the eulachon will pass through the trawl nets without detection (the first effect pathway). This percentage will (1) be unknown because the eulachon cannot be counted (the nets are underwater when the eulachon enter and leave the nets) and (2) vary due to gear and environmental variables (i.e. net design, how full the net is, density of fish at capture, fish behavior). Since the eulachon bycatch is the only eulachon take that can be quantified and monitored, this estimate will be used as a surrogate for the total eulachon take in the Pacific coast groundfish fishery. This is appropriate because the proportion of bycatch within the fishery is thought to be a consistent proportion of the total take. In other words, as the total take increases and decreases, the bycatch is assumed to equally change.
>
> As described in the effects analysis, it appears that the bycatch of eulachon fluctuates with eulachon abundance. Thus, to connect take levels to abundance, we describe the extent of take as a proportion of the Columbia River spawner run, as an indicator of the overall abundance within the SDPS [Southern Distinct Population Segment].
>
> The SDPS of eulachon encompasses all populations within the states of Washington, Oregon, and California and extends from the Skeena River in British

Columbia south to the Mad River in Northern California (inclusive). In the ocean, eulachon abundance is difficult to determine since they are dispersed widely along the West Coast; due to their anadromous life history, we can, however, measure their abundance as they migrate as larvae from their fresh water spawning beds to the ocean. There are only two populations where these surveys are currently done [and regularly reported] – the Columbia and Fraser Rivers. The Columbia River eulachon spawning run abundance data are appropriate to use as a representative of eulachon abundance in the groundfish fishery for the following reasons:

(1) The Columbia River has the largest eulachon spawning run within the ESA-threatened SDPS range. A recent study [using genetic signatures to assign fish to their natal river] (2002 to 2015) estimated that 66.8 percent of the eulachon captured off the west coast of Vancouver Island, north of grounds of the Pacific coast groundfish fishery, were of Columbia River origin (Gustafson et al. 2016).
(2) The Pacific coast groundfish fishery is in closest proximity to the Columbia River spawning run. There are no current major eulachon runs south of the Columbia River, and the nearest major spawning run to the north would be in the Fraser River (which is north of the Pacific coast groundfish fishery) (Gustafson et al. 2010).

(3) The Columbia River has a regular eulachon spawning run. No matter how low or high eulachon abundance is, the Columbia River has been observed to have a eulachon spawning run historically (Gustafson et al. 2010). Rivers with smaller eulachon spawning runs often do not occur annually when eulachon abundance is low (Gustafson et al. 2010).

For the above reasons, the minimum estimate for the Columbia River eulachon spawning run will be used as a proxy for the SDPS of eulachon in this Opinion.

To determine the appropriate proportion of the Columbia River spawning run to use as the extent of take, we considered a number of factors. First, we determined it would be best to compare five-year geometric means of the Columbia River spawning run estimates and estimated annual bycatch levels, rather than single year estimates. NMFS will provide annual updates of five-year geometric means from the most recent available data for both eulachon bycatch in the Pacific coast groundfish fishery and the minimum abundance estimate from the annual Columbia River eulachon run. A five-year time-frame will be used for the following reasons:

(1) Eulachon can live up to five years, so this time-frame reasonably reflects one generation.

(2) Longer data sets can more accurately depict abundance and bycatch trends, and provide for the opportunity to consider adjustments to the Pacific coast groundfish fishery, if necessary, in response to a robust data set.

On an annual basis, NMFS will recalculate the five-year geometric mean from the current year and the preceding four years of Columbia River minimum eulachon spawning run data (the proxy for the SDPS). From that number, two thresholds will be calculated – a precautionary (0.01 percent of a five-year geometric mean) and reinitiation (0.02 percent of a five-year geometric mean). For example, the 2016 bycatch thresholds would be (Table 2-4):

- Precautionary threshold = 3,946 eulachon (geometric mean of the Columbia River eulachon spawning run from 2012 to 2016).[11]

- Reinitiation threshold = 7,891 eulachon (geometric mean of the Columbia River eulachon spawning run from 2012 to 2016).[12]

Further, NMFS will combine the most recent year's [i.e., the year previous to the current year] groundfish fishery eulachon bycatch numbers (eulachon bycatch estimates from the Pacific coast groundfish fishery take approximately 9-12 months to obtain following each fishing season) with the bycatch estimates of the four preceding years to calculate a five-year geometric mean for estimated bycatch in the groundfish fishery.

- 2016 Pacific coast groundfish fishery bycatch = 1,277.5 eulachon (geometric mean of bycatch from 2011 to 2015).[13]

For 2016, the Pacific coast groundfish fishery eulachon bycatch estimate (1,277.5 eulachon) was well below the bycatch thresholds described above (Table 2-4) [see Table 13 in current document for revised data]. When analyzing eulachon bycatch and abundance data from 2011 through 2016, the Pacific coast groundfish fishery bycatch was less than a third of the precautionary threshold and less than a sixth of the reinitiation threshold every year.

In summary, the impacts on the SDPS of eulachon by the Pacific coast groundfish fishery will be assessed by using the eulachon retained in the trawl nets as a surrogate for the total take and the Columbia River eulachon spawning run as a proxy for SDPS eulachon abundance. Five-year geometric means for both of those datasets will be used to determine compliance with the analyses within this Opinion.

Two incidental take thresholds will be used:

1. The precautionary threshold is 0.01 percent of the five-year geometric mean of the minimum estimate for the Columbia River eulachon spawner run. This threshold will trigger Term and Condition #2.
2. The reinitiation threshold is 0.02 percent of the five-year geometric mean of the minimum estimate for the Columbia River eulachon spawner run; this is the maximum amount being analyzed for this Opinion. This threshold is based on the existing bycatch levels that have been determined not to jeopardize the

[11] Final eulachon abundance data for the Columbia River (James et al. 2014, James 2014) results in a revised precautionary threshold for 2016 of 3,945 eulachon (see Table 17).
[12] Final eulachon abundance data for the Columbia River (James et al. 2014, James 2014) results in a revised reinitiation threshold for 2016 of 7,889 eulachon (see Table 17).
[13] Updated eulachon bycatch estimates as presented in the current document results in geometric mean of bycatch in 2016 of 1,102 eulachon (see Table 17).

> persistence of the SDPS of eulachon. If eulachon bycatch (measured as a five-year geometric mean) exceeds 0.02 percent of the calculated minimum Columbia River eulachon spawner run abundance (also measured as a five-year geometric mean), then the take limit will be considered to have been exceeded and reinitiation will be triggered.

Furthermore, the 2018 Reinitiation of Consultation for Eulachon of the 2012 Biological Opinion (BiOp) on Continuing Operation of the Pacific Coast Groundfish Fishery (Reinitiation 2018) (NMFS-WCR 2018, p. 2-21 to 2-22) stated that:

> Terms and conditions specific to eulachon are modified and updated here to reflect a new set of measures.
>
> 1.a. NMFS shall continue to monitor and report eulachon bycatch numbers and estimate fleetwide mortality incidental to the Pacific coast groundfish fishery.
>
> 1.b. By early fall of each year, the West Coast Groundfish Observer Program shall analyze the most recent year's eulachon bycatch monitoring data and provide this analysis to NMFS Protected Resources Division, NMFS Sustainable Fisheries Division, and the Northwest Fisheries Science Center.
>
> 2. If Pacific coast groundfish fishery catch monitoring indicates eulachon bycatch amounts that surpass 0.01 percent of the calculated minimum Columbia River eulachon run, measured as a five-year geometric mean, the Council's ESA Work Group will address the issues at their next meeting. The ESA Work Group shall examine the Pacific coast groundfish fishery to determine possible reasons for these bycatch amounts, and consider whether possible modifications to the fishery to reduce eulachon bycatch may be necessary. Findings and recommendations of the ESA Work Group shall be reported to the Council.

Precautionary and Reinitiation Incidental Take Levels

The reasonable and prudent measures in the 2012 Opinion (NMFS-NWR 2012) stated that exceeding the amount or extent of take described in the incidental take statement (ITS) will result in reinitiation of formal consultation if the amount or extent of incidental take is exceeded. Reinitiation of consultation for eulachon of the Groundfish BiOp (NMFS-WCR 2018) resulted in a revised ITS, that takes the fluctuating abundance of eulachon into account, and is based on a comparison of five-year geometric means of both eulachon bycatch in West Coast groundfish fisheries and minimum abundance estimates of Columbia River eulachon (as a proxy for the southern DPS of eulachon).

The yearly bycatch estimate for 2018 Reinitiation and ITS purposes is estimated as the geometric mean of the most recent year's and the four preceding year's bycatch count estimates in the West Coast groundfish fishery. The abundance proxy for the southern DPS is calculated as the five-year geometric mean from the current year and the preceding four years of the minimum abundance estimates for Columbia River eulachon (Table 17, Fig. 2).

Since the 2011 run year, Washington Department of Fish and Wildlife (WDFW) has developed methodologies to provide a yearly retrospective fisheries-independent SSB and spawner number estimates for the Columbia River eulachon sub-population of the southern DPS (James et al. 2014, Langness et al. 2020). The rationale for using the minimum spawner number estimates as a proxy for eulachon abundance in the groundfish fishery are reproduced in the above section from the 2018 Reinitiation document (NMFS-WCR 2018, p. 2-17 to 2-20). The SSB is generated from counts of eggs and larvae in plankton tows in the lower Columbia River, combined with river discharge rates, and relative fecundity (eggs produced per gram of eulachon) to estimate metric tons of spawning adults (James et al. 2014, Langness et al. 2020). The relevant assumptions are: "1:1 sex ratio; 40.63 grams average fish weight; 40.84 grams average female fish weight (used in calculating eggs per gram of female fish); 173 millimeters average female fish length; 32,766 average eggs/female; 11.16 eulachon per pound; eggs and larvae are equivalent; and, 100% survival from egg to larvae stage" (Langness et al. 2020, p.7). Six spawning stock biomass estimates are generated from these data; maximum, upper 95% confidence interval, mean, median, lower 95% confidence interval, and minimum estimates (Fig. 2). From these biomass estimates, WDFW calculates eulachon numbers on the basis that there are on average 11.16 (Langness et al. 2020) eulachon to the pound.

The ITS in the 2018 Reinitiation of the BiOp for eulachon (NMFS-WCR 2018) requires the calculation of two thresholds for incidental take from the five-year geometric mean minimum abundance of eulachon in the Columbia River – a precautionary threshold (0.01 percent of the five-year geometric mean of minimum abundance) and a reinitiation threshold (0.02 percent of the five-year geometric mean of minimum abundance) (NMFS-WCR 2018). Analysis of abundance and bycatch data from 2011 to 2016 showed that West Coast groundfish fishery "bycatch was less than a third of the precautionary threshold and less than a sixth of the reinitiation threshold every year" (NMFS-WCR 2018, p. 2-19) (Table 17, Fig. 3).

In 2020, the ITS precautionary and reinitiation thresholds (five year geometric means of 0.01% and 0.02% of minimum Columbia River abundance) were 827 and 1,653, respectively. In 2021, the ITS precautionary and reinitiation thresholds were 932 and 1,865, respectively (Table 17). Using bycatch estimates of eulachon in the current document, the five-year geometric mean of bycatch in the West Coast groundfish fisheries has been determined to be 345 eulachon in 2020 and 567 eulachon in 2021 (Table 17, Fig. 3). Therefore, for the purposes of this BiOp, bycatch in 2020 was 41.8% and 20.9% of the precautionary and reinitiation thresholds, respectively. In 2021, bycatch was estimated at 60.8% of the precautionary and 30.4% of the reinitiation threshold (Table 17, Fig. 3)[14].

NMFS-WCR (2018) chose to establish precautionary and reinitiation thresholds, for comparison to eulachon bycatch, based on the Columbia River abundance estimates, since the Columbia River is the largest subpopulation in the southern DPS and is the only consistently monitored population in the United States. The conservative nature of this decision is explained in the following quotation from NMFS-WCR (2018, p. 2-13):

[14] Eulachon bycatch estimates have been updated in the current document and therefore five-year geometric means of bycatch and percentages of the precautionary and reinitiation thresholds will not always match estimates previously published in Gustafson et al. (2019, 2021).

Since the Columbia River eulachon spawning run only makes up a fraction of the SDPS, this comparison gives us a conservative estimate of the level of impacts of the groundfish fishery. In addition, comparing those impacts to the Columbia River spawning run, as opposed to the overall Columbia River population, is conservative because the fish captured in the proposed action would not be limited to spawners but would be from a variety of age classes: juveniles, subadults, and adults. Due to the high natural mortality rate for eulachon, a large proportion of the eulachon that would be captured by the fishery would not have naturally survived to become spawning adults. Even though the Columbia River eulachon spawning run is being used for analysis, this does not imply that that fishery would be solely impacting the Columbia River spawning run. This proposed action is expected to impact most or all eulachon spawning runs, but none disproportionately.

Eulachon Abundance

Several indices of eulachon abundance showed dramatic increases from 2011–2015, declines from 2016–2018, and subsequent large increases in 2019–2022 (Figs. 4–5). Spawning stock biomass (SSB) estimates of eulachon in the Columbia River (Fig. 4) and mean catch per unit effort (CPUE; kg/h) of eulachon off west coast Vancouver Island (WCVI) as estimated in multispecies small mesh bottom trawl surveys (aka fishery-independent shrimp surveys) (Fig. 5) both increased by an order of magnitude between 2010 and 2015. However, estimates of eulachon SSB in the Columbia River (Fig. 4) and mean CPUE off WCVI (Fig. 5) began declining in 2016, and by 2018, these indices were at less than 3% and 5% of their average 2013–2015 levels, respectively. These declines through 2018 in indices of eulachon abundance parallel declines in estimated bycatch of eulachon in U.S. West Coast groundfish fisheries, especially in 2016 and 2017 (Table 16, Fig. 2). Eulachon abundance increased following 2018 as shown by both indices of abundance—Columbia River SSB (Fig. 4) and mean CPUE off WCVI (Fig. 5)— again paralleling increases in eulachon bycatch in U.S. West Coast groundfish fisheries (Fig. 1).

Mean eulachon SSB in the Columbia River increased more than ten-fold from 2018 to 2019 (JCRMS 2021); however, reliable data for 2020 SSB estimated are not available due to COVID-19 restrictions on fieldwork. Estimated SSB more than doubled from 2020 to 2021and doubled again from 2021 to 2022 to over 8,300 mt (Fig. 4); 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 five-fold from 2018 to 2019 (Fig. 5). Eulachon CPUE data in this survey is 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 (Fig. 5). Again, these increases in Columbia River SSB (Fig. 4) and mean CPUE off WCVI (Fig. 5) parallel increases in eulachon bycatch in U.S. West Coast groundfish fisheries (Fig. 1) from 2018–2021.

The above analysis suggests that eulachon bycatch in 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 non-biological factors, including annual variation in observer coverage rates, trawl duration, trawl depth, trawl location, seasonality, and haul volume coupled with trawl-net mesh size.

Undocumented Bycatch

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 Pacific hake fisheries might have been recorded as “other non-groundfish,” “smelt unidentified,” or “herring/smelt unidentified,” especially from 2002 to 2010.

Observed but unidentified smelt bycatch in the non-hake bottom and midwater groundfish fisheries ranged from about 1,215 kg in 2002 to just under half a kilogram in 2019 (Table 19). Very few “unidentified smelt” have been recorded as bycatch in the at-sea Pacific hake trawl fisheries with the exception of 2002, when an estimated 55 kg of unidentified smelt was observed in this sector (Table 19). As indicated above, the higher level of bycatch of unidentified smelt during the early 2000s in both the LE groundfish and at-sea Pacific hake trawl fisheries corresponds with a period of elevated eulachon (Figs. 4–5) 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 Pacific hake trawl fishery might have consisted of eulachon prior to 2011. It is assumed that after 2010— when extra efforts to identify all eulachon bycatch began— “unidentified smelt” consists of species of non-eulachon smelt (Table 18).

Fate of Eulachon Escaping and Avoiding Groundfish Trawl Nets

From a conservation biology perspective, it is important to examine not only estimated bycatch and discard mortality but also the fate of non-target organisms that escape from trawl nets prior to being hauled aboard fishing vessels. Davis and Ryer (2003) stated “… the fact that bycatch does not appear on deck, does not mean that those fish have been released from the gear unimpaired and are capable of surviving.” Various terms are used for these unobserved but ultimately lethal interactions with fishing gear, including: 1) “unaccounted fishing mortality” (Chopin and Arimoto 1995, Suuronen 2005, ICES 2005, Suuronen and Erickson 2010), 2) “collateral mortality” (Broadhurst et al. 2006), 3) “cryptic fishing mortality” (Gilman et al. 2013), and 4) “post release mortality” (Raby et al. 2014), among others. Looking beyond mortality, Wilson et al. (2014) reviewed the available literature on sub-lethal effects on fitness of individual trawl escapees and classified these as either immediate sub-lethal effects (e.g., physiological impairment, physical injury, and reflex impairment) or delayed sub-lethal effects (e.g., impairment of behavior, growth and reproduction, or immune function). Wilson et al. (2014) argue that sub-lethal effects of encounters with fishing gear may reduce future reproductive output; however, possible fitness consequences have yet to be adequately investigated.

Components of unaccounted fishing mortality most relevant to the present report 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). 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. As mentioned above, 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 several other gear regulations, as of 1 January 2019, have not been analyzed. The observed eulachon bycatch in the groundfish fishery sectors reported in this document may represent a small fraction of all eulachon encounters with bottom and midwater trawl fishing gear in the groundfish fishery.

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 de-scaled, 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).

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).

Regulatory Gear Changes

Based on the overall magnitude of bycatch in U.S. West Coast groundfish fisheries, either there is limited interaction with eulachon in these fisheries or most eulachon encounters result in fish escaping or avoiding trawl gear. 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 11.4 cm (4.5 inches) and 7.6 cm (3.0 inches), 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.

These mesh size restrictions and several other gear regulations were removed as of 1 January 2019 as per a final rule in the Federal Register (USOFR 2018) (Table 19). According to USOFR (2018), this final rule served to remove:

> … the 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 Fisheries 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. [In addition] … this final rule 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, p. 2-2–2-3) stated that:

> 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 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 that:

> 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, p.4-33–4-34) stated that:

> 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 meshes 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, p.4-34–4-36) stated that:

> 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. … under 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, p. 4-43–4-45) stated that:

> It is unlikely that participants in the catch share program would construct and use complete codends with meshes smaller than 3 inches … most 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, p. 4-73–4-77) stated that:

> … the 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^{o} 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^{o} N. latitude …

The real world effects of these regulatory gear changes (Table 19) on eulachon bycatch have yet to be analyzed.

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Table 1. Current descriptions of observed U.S. West Coast groundfish fisheries sectors that have had observed bycatch of eulachon. Modified from summaries available at: https://www.fisheries.noaa.gov/west-coast/fisheries-observers/fishery-sectors-covered-west-coast-groundfish-observer-program-and.

	Sub-Sector	Permits	Gears	Targets	Vessel Length (m)	Fishing Depths (m)	Fishery Management	State or Federal Fishery
Limited Entry (LE) Trawl	LE Trawl	LE permit with trawl endorsement	Bottom Trawl	Groundfish	15-40	10-1600	Individual Fishing Quotas (IFQ); some vessels use electronic monitoring (EM) in lieu of 100% observer coverage	Federal
	Midwater Rockfish	LE permit with trawl endorsement	Midwater Trawl	Midwater Rockfish	15-33	>70	IFQ; some vessels use EM in lieu of 100% observer coverage	Federal
	Midwater Hake	LE permit with trawl endorsement	Midwater Trawl	Pacific hake	17-40	>70	IFQ; some vessels use EM in lieu of 100% observer coverage	Federal
At-Sea Pacific Hake	Mothership-Catcher Vessels (MSCV)	LE permit with MSCV endorsement	Midwater Trawl	Pacific hake	17-40 (catcher vessels)	53-460	IFQ; some vessels use EM in lieu of 100% observer coverage; EM and non-EM catch is sampled by A-SHOP observers; Motherships carry 2 observers for 100% coverage	Federal
	Catcher-processors (CP)	LE permit with CP endorsement	Midwater Trawl	Pacific hake	82-115	60-570	IFQ	Federal
	Tribal	none	Midwater Trawl	Pacific hake	<38	53-460	Tribal management	Tribal

Table 2. Numbers and weight of eulachon observed and bycatch ratios from limited entry bottom trawl vessels that landed their catch in Washington (2002–2010). Bycatch ratios calculated as observed catch of eulachon in both number of fish and weight (in kg) divided by the observed weight (mt) of retained groundfish. Fleet-wide bycatch estimates obtained by multiplying bycatch ratios by fleet-wide groundfish landings. 95% bootstrapped confidence intervals (CI) are provided for the estimates. Winter season is January-April and November-December; summer is May-October. Asterisks (*) signify strata with fewer than three observed vessels. n/a, not applicable.

		State observed								State fleetwide				
Year	Season	Bycatch (kg of eulachon)	Bycatch (no. of eulachon)	Observed groundfish catch (mt)	Bycatch ratio (kg per mt of groundfish)	95% CI	Bycatch ratio (no. per mt of groundfish)	95% CI	Percent landings observed	Fleet groundfish landings (mt)	Bycatch estimate (kg eulachon)	95% CI	Bycatch estimate (no. of eulachon)	95% CI
2002	winter	0.0	0	297.0	0.00	n/a n/a	0.00	n/a n/a	23.3	1,276.5	0.0	n/a n/a	0	n/a n/a
	summer	0.0	0	142.4	0.00	n/a n/a	0.00	n/a n/a	13.8	1,032.7	0.0	n/a n/a	0	n/a n/a
2003	winter	0.0	0	124.3	0.00	n/a n/a	0.00	n/a n/a	9.8	1,265.9	0.0	n/a n/a	0	n/a n/a
	summer	0.0	0	56.4	0.00	n/a n/a	0.00	n/a n/a	8.7	647.9	0.0	n/a n/a	0	n/a n/a
2004	winter	0.0	0	335.7	0.00	n/a n/a	0.00	n/a n/a	38.2	878.8	0.0	n/a n/a	0	n/a n/a
	summer	0.0	0	179.0	0.00	n/a n/a	0.00	n/a n/a	19.8	902.5	0.0	n/a n/a	0	n/a n/a
2005	winter	0.0	0	167.9	0.00	n/a n/a	0.00	n/a n/a	17.2	977.1	0.0	n/a n/a	0	n/a n/a
	summer	0.0	0	408.6	0.00	n/a n/a	0.00	n/a n/a	21.1	1,932.8	0.0	n/a n/a	0	n/a n/a
2006	winter	0.0	0	89.1	0.00	n/a n/a	0.00	n/a n/a	17.4	511.3	0.0	n/a n/a	0	n/a n/a
	summer	0.0	0	276.4	0.00	n/a n/a	0.00	n/a n/a	23.1	1,194.6	0.0	n/a n/a	0	n/a n/a
2007	winter	0.0	0	166.0	0.00	n/a n/a	0.00	n/a n/a	23.7	701.0	0.0	n/a n/a	0	n/a n/a
	summer	0.0	0	60.7	0.00	n/a n/a	0.00	n/a n/a	7.5	813.1	0.0	n/a n/a	0	n/a n/a
2008	winter	*	*	*	0.00	n/a n/a	0.00	n/a n/a	*	767.0	0.0	n/a n/a	0	n/a n/a
	summer	0.0	0	292.1	0.00	n/a n/a	0.00	n/a n/a	35.1	832.7	0.0	n/a n/a	0	n/a n/a
2009	winter	0.0	0	352.0	0.00	n/a n/a	0.00	n/a n/a	26.0	1,355.8	0.0	n/a n/a	0	n/a n/a
	summer	0.0	0	384.0	0.00	n/a n/a	0.00	n/a n/a	32.0	1,200.4	0.0	n/a n/a	0	n/a n/a
2010	winter	0.0	0	280.9	0.00	n/a n/a	0.00	n/a n/a	22.8	1,230.6	0.0	n/a n/a	0	n/a n/a
	summer	0.0	0	221.7	0.00	n/a n/a	0.00	n/a n/a	25.1	882.4	0.0	n/a n/a	0	n/a n/a

Table 3. Observed and fleet-total weight of eulachon bycatch from bottom trawl catch share fishery vessels that landed their catch in Washington (2011–2021). Note that that coverage data (observed and total groundfish landings) includes both bottom and midwater trawl from 2011–2014 for confidentiality. Bycatch weights are in kilograms and groundfish landings are in metric tons. Note that catch share fisheries are sampled at close to 100%. Asterisks (*) signify strata with fewer than three observed vessels. Therefore, Washington and Oregon data were combined in 2020 for confidentiality in Table 6.

Year	Observed bycatch (kg)	Observed groundfish landings (mt)	Fleet-total groundfish landings (mt)	Percent landings observed (%)	Estimated bycatch from unsampled catch (kg)	Landed eulachon (kg)	Fleet-total bycatch (kg)
2011	0.5	2,058.8	2,081.2	98.9	0.1	0.0	0.6
2012	0.0	2,492.0	2,542.7	98.0	0.0	0.0	0.1
2013	7.0	1,682.6	1,695.1	99.3	0.1	0.0	7.1
2014	11.5	1,071.9	1,074.5	99.8	0.5	0.0	12.0
.2015	0.0	434.8	434.8	100.0	0.0	0.0	0.0
2016	0.0	446.7	451.0	99.0	0.0	0.0	0.0
2017	0.0	831.0	834.0	99.6	0.0	0.0	0.0
2018	0.0	747.2	747.2	100.0	0.0	0.0	0.0
2019	0.0	838.4	838.4	100.0	0.0	0.0	0.0
2020	*	*	*	*	*	*	*
2021	141.7	494.3	561.8	88.0	24.5	2.7	168.8

Table 4. Observed and fleet-total number of eulachon bycatch from bottom trawl catch share fishery vessels that landed their catch in Washington (2011–2021). Note that that coverage data (observed and total groundfish landings) includes both bottom and midwater trawl from 2011–2014 for confidentiality. Groundfish landings are in metric tons. Note that catch share fisheries are sampled at close to 100%. Because eulachon landed shoreside (retained) are not counted, landed counts were estimated using a linear weight-count regression and data from a 3-year rolling window of all other catch share eulachon observations. Asterisks (*) signify strata with fewer than three observed vessels. Therefore, Washington and Oregon data were combined in 2020 for confidentiality in Table 7.

Year	Observed bycatch (numbers)	Observed groundfish landings (mt)	Fleet-total groundfish landings (mt)	Percent landings observed (%)	Estimated bycatch from unsampled catch (numbers)	Estimated landed eulachon (numbers)	Fleet-total bycatch (numbers)
2011	11	2,058.8	2,081.2	98.9	1	0	12
2012	1	2,492.0	2,542.7	98.0	0	0	1
2013	135	1,682.6	1,695.1	99.3	2	0	137
2014	278	1,071.9	1,074.5	99.8	11	0	289
2015	0	434.8	434.8	100.0	0	0	0
2016	0	446.7	451.0	99.0	0	0	0
2017	0	831.0	834.0	99.6	0	0	0
2018	0	747.2	747.2	100.0	0	0	0
2019	0	838.4	838.4	100.0	0	0	0
2020	*	*	*	*	*	*	*
2021	3,689	494.3	561.8	88.0	637	66	4,392

Table 5. Numbers and weight of eulachon observed and bycatch ratios from limited entry bottom trawl vessels that landed their catch in Oregon (2002–2010). Bycatch ratios calculated as observed catch of eulachon in both number of fish and weight (in kg) divided by the observed weight (mt) of retained groundfish. Fleet-wide bycatch estimates obtained by multiplying bycatch ratios by fleet-wide groundfish landings. 95% bootstrapped confidence intervals (CI) are provided for the estimates. Winter season is January-April and November-December; summer is May-October. Asterisks (*) signify strata with fewer than three observed vessels. n/a, not applicable.

		State observed								**State fleetwide**				
Year	Season	Bycatch (kg of eulachon)	Bycatch (no. of eulachon)	Observed groundfish catch (mt)	Bycatch ratio (kg per mt of groundfish)	95% CI	Bycatch ratio (no. per mt of groundfish)	95% CI	Percent landings observed	Fleet groundfish landings (mt)	Bycatch estimate (kg eulachon)	95% CI	Bycatch estimate (no. of eulachon)	95% CI
2002	winter	6.2	80	579.8	0.01	0.00 0.04	0.14	0.00 0.46	14.2	4,070.7	43.4	6.2 146.0	562	80 1,892
	summer	2.1	40	490.8	0.00	0.00 0.01	0.08	0.00 0.24	14.5	3,376.9	14.7	2.1 43.5	275	40 812
2003	winter	0.4	10	801.5	0.00	0.00 0.00	0.01	0.00 0.04	19.2	4,177.5	2.2	0.4 6.7	52	10 148
	summer	0.0	0	551.2	0.00	n/a n/a	0.00	n/a n/a	12.6	4,369.5	0.0	n/a n/a	0	n/a n/a
2004	winter	0.0	0	1,181.1	0.00	n/a n/a	0.00	n/a n/a	27.0	4,372.8	0.0	n/a n/a	0	n/a n/a
	summer	0.0	0	989.3	0.00	n/a n/a	0.00	n/a n/a	19.0	5,201.2	0.0	n/a n/a	0	n/a n/a
2005	winter	0.0	0	1,204.2	0.00	n/a n/a	0.00	n/a n/a	25.8	4,669.5	0.0	n/a n/a	0	n/a n/a
	summer	0.0	0	1,179.6	0.00	n/a n/a	0.00	n/a n/a	22.1	5,348.4	0.0	n/a n/a	0	n/a n/a
2006	winter	0.0	0	801.9	0.00	n/a n/a	0.00	n/a n/a	19.7	4,070.1	0.0	n/a n/a	0	n/a n/a
	summer	0.0	0	1,123.5	0.00	n/a n/a	0.00	n/a n/a	18.3	6,151.2	0.0	n/a n/a	0	n/a n/a
2007	winter	0.0	0	851.2	0.00	n/a n/a	0.00	n/a n/a	14.5	5,864.9	0.0	n/a n/a	0	n/a n/a
	summer	0.1	14	1,114.2	0.00	0.00 0.00	0.01	0.00 0.04	18.1	6,147.7	0.5	0.1 1.7	77	14 256
2008	winter	0.0	0	1,335.7	0.00	n/a n/a	0.00	n/a n/a	17.8	7,522.1	0.0	n/a n/a	0	n/a n/a
	summer	0.0	0	1,820.7	0.00	n/a n/a	0.00	n/a n/a	24.7	7,360.1	0.0	n/a n/a	0	n/a n/a
2009	winter	0.0	0	2,167.9	0.00	n/a n/a	0.00	n/a n/a	24.5	8,834.2	0.0	n/a n/a	0	n/a n/a
	summer	0.7	16	1,858.5	0.00	0.00 0.00	0.01	0.00 0.03	23.7	7,846.9	3.1	0.7 9.7	68	16 210
2010	winter	0.0	0	903.9	0.00	n/a n/a	0.00	n/a n/a	12.1	7,445.9	0.0	n/a n/a	0	n/a n/a
	summer	0.0	0	1,850.6	0.00	n/a n/a	0.00	n/a n/a	25.0	7,392.4	0.0	n/a n/a	0	n/a n/a

Table 6. Observed and fleet-total weight of eulachon bycatch from bottom trawl catch share fishery vessels that landed their catch in Oregon (2011–2021). Note that that coverage data (observed and total groundfish landings) includes both bottom and midwater trawl from 2011–2014 for confidentiality. Bycatch weights are in kilograms and groundfish landings are in metric tons. Note that catch share fisheries are sampled at close to 100%. Oregon and Washington data were combined in 2020 for confidentiality.

Year	Observed bycatch (kg)	Observed groundfish landings (mt)	Fleet-total groundfish landings (mt)	Percent landings observed (%)	Estimated bycatch from unsampled catch (kg)	Landed eulachon (kg)	Fleet-total bycatch (kg)
2011	5.9	11,112.6	11,216.4	99.1	0.2	0.0	6.1
2012	5.8	10,992.5	11,081.4	99.2	0.2	0.0	6.0
2013	30.7	12,833.9	12,894.7	99.5	0.9	0.0	31.7
2014	116.4	11,406.0	11,465.6	99.5	1.8	0.0	118.1
.2015	23.9	11,015.8	11,080.8	99.4	0.9	0.0	24.8
2016	1.6	12,003.9	12,101.5	99.2	0.1	0.0	1.7
2017	2.2	12,114.0	12,131.8	99.9	0.0	0.0	2.3
2018	21.1	9,736.0	9,824.5	99.1	1.0	0.0	22.2
2019	31.1	9,651.8	9,714.4	99.4	1.5	1.8	34.4
2020 (WA/ OR)	232.2	7,281.7	7,410.6	98.3	10.9	18.5	261.6
2021	175.6	7,558.5	7,861.2	96.1	13.1	10.9	199.6

Table 7. Observed and fleet-total number of eulachon bycatch from bottom trawl catch share fishery vessels that landed their catch in Oregon (2011–2021). Note that that coverage data (observed and total groundfish landings) includes both bottom and midwater trawl from 2011–2014 for confidentiality. Bycatch weights are in kilograms and groundfish landings are in metric tons. Note that catch share fisheries are sampled at close to 100%. Because eulachon landed shoreside (retained) are not counted, landed counts were estimated using a linear weight-count regression and data from a 3-year rolling window of all other catch share eulachon observations. Oregon and Washington data were combined in 2020 for confidentiality.

Year	Observed bycatch (numbers)	Observed groundfish landings (mt)	Fleet-total groundfish landings (mt)	Percent landings observed (%)	Estimated bycatch from unsampled catch (numbers)	Estimated landed eulachon (numbers)	Fleet-total bycatch (numbers)
2011	122	11,112.6	11,216.4	99.1	5	0	127
2012	164	10,992.5	11,081.4	99.2	4	0	168
2013	510	12,833.9	12,894.7	99.5	16	0	526
2014	2,474	11,406.0	11,465.6	99.5	37	0	2,511
2015	634	11,015.8	11,080.8	99.4	24	0	658
2016	49	12,003.9	12,101.5	99.2	3	0	52
2017	11	12,114.0	12,131.8	99.9	0	0	11
2018	328	9,736.0	9,824.5	99.1	16	0	344
2019	732	9,651.8	9,714.4	99.4	36	19	787
2020 (WA/ OR)	4,485	7,281.7	7,410.6	98.3	211	446	5,142
2021	3,464	7,558.5	7,861.2	96.1	259	264	3,987

Table 8. Numbers and weight of eulachon observed and bycatch ratios from limited entry bottom trawl vessels that landed their catch in California (2002–2010). Bycatch ratios calculated as observed catch of eulachon in both number of fish and weight (in kg) divided by the observed weight

(mt) of retained groundfish. Fleet-wide bycatch estimates obtained by multiplying bycatch ratios by fleet-wide groundfish landings. 95% bootstrapped confidence intervals (CI) are provided for the estimates. Winter season is January-April and November-December; summer is May-October. Asterisks (*) signify strata with fewer than three observed vessels. n/a, not applicable.

		State observed								**State fleetwide**				
Year	Season	Bycatch (kg of eulachon)	Bycatch (no. of eulachon)	Observed groundfish catch (mt)	Bycatch ratio (kg per mt of groundfish)	95% CI	Bycatch ratio (no. per mt of groundfish)	95% CI	Percent landings observed	Fleet groundfish landings (mt)	Bycatch estimate (kg eulachon)	95% CI	Bycatch estimate (no. of eulachon)	95% CI
2002	winter	0.0	0	462.8	0.00	n/a n/a	0.00	n/a n/a	12.4	3,727.6	0.0	n/a n/a	0	n/a n/a
	summer	0.0	0	523.5	0.00	n/a n/a	0.00	n/a n/a	13.4	3,909.3	0.0	n/a n/a	0	n/a n/a
2003	winter	0.0	0	333.4	0.00	n/a n/a	0.00	n/a n/a	11.6	2,875.6	0.0	n/a n/a	0	n/a n/a
	summer	0.0	0	566.9	0.00	n/a n/a	0.00	n/a n/a	13.9	4,068.8	0.0	n/a n/a	0	n/a n/a
2004	winter	0.0	0	734.4	0.00	n/a n/a	0.00	n/a n/a	33.5	2,194.1	0.0	n/a n/a	0	n/a n/a
	summer	0.0	1	756.6	0.00	00.0 00.0	0.00	0.00 0.00	21.3	3,547.4	0.2	0.0 0.7	5	1 15
2005	winter	0.0	0	496.7	0.00	n/a n/a	0.00	n/a n/a	20.1	2,473.1	0.0	n/a n/a	0	n/a n/a
	summer	0.0	0	585.8	0.00	n/a n/a	0.00	n/a n/a	19.4	3,019.9	0.0	n/a n/a	0	n/a n/a
2006	winter	0.0	0	365.4	0.00	n/a n/a	0.00	n/a n/a	19.1	1,911.2	0.0	n/a n/a	0	n/a n/a
	summer	0.0	0	590.8	0.00	n/a n/a	0.00	n/a n/a	20.1	2,935.1	0.0	n/a n/a	0	n/a n/a
2007	winter	0.0	0	424.5	0.00	n/a n/a	0.00	n/a n/a	17.9	2,374.3	0.0	n/a n/a	0	n/a n/a
	summer	0.0	0	694.8	0.00	n/a n/a	0.00	n/a n/a	18.9	3,674.6	0.0	n/a n/a	0	n/a n/a
2008	winter	0.0	0	555.6	0.00	n/a n/a	0.00	n/a n/a	18.0	3,091.9	0.0	n/a n/a	0	n/a n/a
	summer	0.0	0	648.5	0.00	n/a n/a	0.00	n/a n/a	19.3	3,355.9	0.0	n/a n/a	0	n/a n/a
2009	winter	0.0	0	548.4	0.00	n/a n/a	0.00	n/a n/a	19.4	2,825.4	0.0	n/a n/a	0	n/a n/a
	summer	0.0	0	636.6	0.00	n/a n/a	0.00	n/a n/a	18.1	3,513.6	0.0	n/a n/a	0	n/a n/a
2010	winter	0.0	0	203.5	0.00	n/a n/a	0.00	n/a n/a	9.6	2,131.0	0.0	n/a n/a	0	n/a n/a
	summer	0.3	4	581.9	0.00	0.00 0.00	0.01	0.00 0.03	19.1	3,051.5	1.4	0.3 5.5	21	4 81

Table 9. Observed and fleet-total weight of eulachon bycatch from bottom trawl catch share fishery vessels that landed their catch in California (2011–2021). Note that that coverage data (observed and total groundfish landings) includes both bottom and midwater trawl from 2011–2014 for

confidentiality. Bycatch weights are in kilograms and groundfish landings are in metric tons. Note that catch share fisheries are sampled at close to 100%.

Year	Observed bycatch (kg)	Observed groundfish landings (mt)	Fleet-total groundfish landings (mt)	Percent landings observed (%)	Estimated bycatch from unsampled catch (kg)	Landed eulachon (kg)	Fleet-total bycatch (kg)
2011	0.0	4,570.0	4,577.0	99.8	0.0	0.0	0.0
2012	0.0	4,453.2	4,461.7	99.8	0.0	0.0	0.0
2013	0.0	5,059.0	5,072.7	99.7	0.0	0.0	0.0
2014	0.0	4,889.4	4,934.8	99.1	0.0	0.0	0.0
.2015	0.1	4,139.7	4,142.6	99.9	0.0	0.0	0.1
2016	0.0	2,353.2	2,353.2	100.0	0.0	0.0	0.0
2017	0.0	3,101.3	3,109.0	99.8	0.0	0.0	0.0
2018	0.0	2,206.2	2,208.4	99.9	0.0	0.0	0.0
2019	0.0	2,178.3	2,188.5	99.5	0.0	0.0	0.0
2020	0.0	2,231.3	2,248.6	99.2	0.0	0.0	0.0
2021	0.0	2,818.6	2,818.6	100.0	0.0	0.0	0.0

Table 10. Observed and fleet-total number of eulachon bycatch from bottom trawl catch share fishery vessels that landed their catch in California (2011–2021). Note that that coverage data (observed and total groundfish landings) includes both bottom and midwater trawl from 2011–2014 for confidentiality. Bycatch weights are in kilograms and groundfish landings are in metric tons. Note that catch share fisheries are sampled at close to 100%. Because eulachon landed shoreside (retained) are not counted, landed counts were estimated using a linear weight-count regression and data from a 3-year rolling window of all other catch share eulachon observations.

Year	Observed bycatch (numbers)	Observed groundfish landings (mt)	Fleet-total groundfish landings (mt)	Percent landings observed (%)	Estimated bycatch from unsampled catch (numbers)	Estimated landed eulachon (numbers)	Fleet-total bycatch (numbers)
2011	0	4,570.0	4,577.0	99.8	0	0	0
2012	0	4,453.2	4,461.7	99.8	0	0	0
2013	0	5,059.0	5,072.7	99.7	0	0	0
2014	0	4,889.4	4,934.8	99.1	0	0	0
2015	2	4,139.7	4,142.6	99.9	0	0	2
2016	0	2,353.2	2,353.2	100.0	0	0	0
2017	0	3,101.3	3,109.0	99.8	0	0	0
2018	0	2,206.2	2,208.4	99.9	0	0	0
2019	0	2,178.3	2,188.5	99.5	0	0	0
2020	0	2,231.3	2,248.6	99.2	0	0	0
2021	0	2,818.6	2,818.6	100.0	0	0	0

Table 11. Observed and expanded bycatch weight (kilograms) and number of eulachon from the Catcher Processor sector of the at-sea Pacific hake fishery (2002–2021). Sampled weight of hake landing is given in metric tons (mt). Note that this fishery is sampled at close to 100%.

Year	Sampled tows (number)	Percent tows sampled	Sampled hake landings (mt)	Observed bycatch weight (kg)	Expanded fleetwide bycatch weight (kg)	Observed bycatch numbers	Expanded fleetwide bycatch numbers
2002	556	99.5	36,313.5	0.0	0.0	0	0
2003	766	99.7	41,452.4	0.0	0.0	0	0
2004	1,492	99.4	72,839.1	0.0	0.0	0	0
2005	1,332	99.6	78,420.8	0.0	0.0	0	0
2006	1,488	99.4	78,095.5	1.5	1.5	145	147
2007	1,566	99.3	72,799.8	0.1	0.1	6	6
2008	1,864	98.8	107,845.5	2.1	2.1	37	37
2009	863	99.4	34,541.7	2.1	2.1	30	30
2010	1,063	99.5	54,210.3	0.0	0.0	0	0
2011	1,530	98.8	71,282.1	115.6	115.8	1,268	1,270
2012	1,100	99.4	55,457.0	1.1	1.1	16	16
2013	1,439	98.6	77,906.3	2.9	2.9	39	39
2014	1,683	99.2	103,171.6	10.4	10.4	242	242
2015	1,503	98.9	68,435.2	1.8	1.8	56	56
2016	2,188	99.2	108,780.6	0.1	0.1	2	2
2017	2,143	99.3	137,104.5	0.8	0.8	18	18
2018	1,954	99.1	116,005.5	15.9	16.0	259	259
2019	1,936	99.4	116,352.4	46.3	46.5	886	889
2020	1,496	99.4	111,014.6	4.6	4.6	71	71
2021	1,477	97.0	103,260.9	408.0	417.6	5,784	5,920

Table 12. Observed and expanded bycatch weight (kilograms) and number of eulachon from the Tribal and Non-Tribal Mothership Catcher Vessels sector of the at-sea Pacific hake fishery (2002–2021). Sampled weight of hake landing is given in metric tons (mt). Note that this fishery is sampled at close to 100%. Asterisks (*) signify data that cannot be reported due to confidentiality requirements.

Year	Sampled tows (number)	Percent tows sampled	Sampled hake landings (mt)	Observed bycatch weight (kg)	Expanded fleetwide bycatch weight (kg)	Observed bycatch numbers	Expanded fleetwide bycatch numbers
2002	1,198	99.3	48,106.2	0.0	0.0	0	0
2003	1,059	98.4	44,746.2	0.0	0.0	0	0
2004	1,201	99.8	47,508.6	0.0	0.0	0	0
2005	1,670	99.8	72,091.8	0.0	0.0	0	0
2006	1,397	96.8	59,429.5	0.0	0.0	0	0
2007	1,291	99.1	52,335.0	0.2	0.2	4	4
2008	1,726	99.7	72,726.2	0.4	0.4	6	6
2009	1,000	99.6	37,482.4	2.2	2.2	38	38
2010	1,424	100.0	51,926.4	0.0	0.0	0	0
2011	1,474	99.9	56,074.5	17.3	17.3	214	214
2012	*	*	*	*	0.4	*	7
2013	1,249	99.4	52,305.0	12.2	12.2	277	278
2014	1,288	98.5	61,793.8	1.0	1.0	25	25
2015	625	97.7	27,548.8	0.0	0.0	0	0
2016	1,550	99.0	64,597.5	0.3	0.3	4	4
2017	1,287	98.3	65,358.5	0.9	0.9	16	16
2018	1,509	98.3	65,979.1	1.2	1.2	26	26
2019	1,220	99.0	51,829.1	12.7	12.7	198	199
2020	765	99.5	37,260.7	7.2	7.3	197	198
2021	701	97.9	35,506.8	11.7	11.9	246	252

Table 13. Observed eulachon bycatch weight (kilograms) and estimated number of fish in the shoreside Pacific hake fishery (2011–2014). Note that this fishery is sampled at nearly 100% after being landed. Landed weight of Pacific hake is given in metric tons (mt). Number of eulachon are not recorded in this sector and were estimated using a linear weight-count regression and data from a rolling 3-year window of all other catch share eulachon observations.

Year	Total number of tows sampled	Sampled hake landings (mt)	Percent of landings sampled	Landed eulachon bycatch (kg)	Estimated eulachon bycatch (number based on catch shares data)
2011	1,701	90,248.8	100.0	0.0	0
2012	1,564	65,288.0	100.0	0.0	0
2013	1,702	96,867.8	100.0	83.5	1,745
2014	1,679	97,925.2	99.9	0.0	0

Table 14. Observed eulachon bycatch (kilograms) and estimated number of fish in shoreside midwater hake and shoreside midwater rockfish fisheries (2015–2021). Landed weight of Pacific hake and rockfish are given in metric tons (mt). For confidentiality, 2019–2021 midwater hake data are combined with 2019–2021 EM midwater hake data in Table 15. Note that this fishery is sampled at 100% after being landed. Counts are not recorded in this sector and were estimated using a linear weight-count regression and data from a rolling 3-year window of all other catch share eulachon observations. Asterisks (*) signify strata with fewer than three observed vessels.

Year	Total number of tows sampled	Sampled hake landings (mt)	Sampled rockfish landings (mt)	Percent of hake landings sampled	Percent of rockfish landings sampled	Observed bycatch weight (kg)	Estimated eulachon bycatch (number)
2015 midwater hake	282	11,461.4	154.2	100.0	100.0	0.0	0
2016 midwater hake	206	8,970.0	152.4	100.0	100.0	0.0	0
2017 midwater hake	236	10,991.3	211.1	100.0	100.0	0.0	0
2018 midwater hake	180	9,746.0	237.4	100.0	100.0	0.0	0
2019 midwater hake[1]	*	*	*	*	*	*	*
2020 midwater hake[1]	*	*	*	*	*	*	*
2021 midwater hake[1]	*	*	*	*	*	*	*
2015 midwater rockfish	140	15.2	968.5	100.0	100.0	0.0	0
2016 midwater rockfish	40	29.0	319.3	100.0	100.0	0.0	0
2017 midwater rockfish	267	123.3	4,298.0	100.0	100.0	0.5	4
2018 midwater rockfish	365	70.9	6,448.6	100.0	100.0	21.2	163
2019 midwater rockfish	348	52.3	5,311.4	100.0	99.8	23.6	244
2020 midwater rockfish	158	17.7	2,458.6	100.0	100.0	2.7	66
2021 midwater rockfish	200	23.1	3,977.8	100.0	100.0	13.5	320

1 – See Table 15.

Table 15. Observed bycatch weights (kilograms) and estimated numbers of eulachon from the electronically-monitored (EM) midwater Pacific hake and midwater rockfish sectors (2015–2021). Landed weight of hake and rockfish are given in metric tons (mt). Counts are not recorded in this sector and were estimated using a linear weight-count regression and data from a rolling 3-year window of all other catch share eulachon observations. For confidentiality, 2019–2021 midwater hake data are combined with 2019–2021 EM midwater hake data.

Year and sector	Observed or monitored hauls	Observed or monitored hake landings (mt)	Observed or monitored rockfish landings (mt)	Observed or monitored eulachon bycatch (kg)	Estimated eulachon bycatch (number)
2015 midwater hake EM	1,178	46,439.8	715.5	0.0	0
2016 midwater hake EM	1,411	76,412.2	942.3	0.0	0
2017 midwater hake EM	2,072	133,153.8	2,697.9	0.9	7
2018 midwater hake EM	1,913	119,402.9	2,791.6	0.0	0
2019 midwater hake EM and non-EM	2,359	143,757.0	3,316.6	47.2	488
2020 midwater hake EM and non-EM	2,762	138,301.2	3,330.8	80.8	1,953
2021 midwater hake EM and non-EM	2,012	125,904.1	2,175.6	318.2	7,717
2015 midwater rockfish EM	81	38.6	794.5	0.0	0
2016 midwater rockfish EM	74	48.4	768.3	0.0	0
2017 midwater rockfish EM	89	157.8	1,568.5	0.0	0
2018 midwater rockfish EM	161	341.7	5,081.0	0.0	0
2019 midwater rockfish EM	179	264.7	4,642.0	5.4	56
2020 midwater rockfish EM	217	413.3	6,891.6	45.4	1,098
2021 midwater rockfish EM	239	131.0	7,654.6	50.8	1,232

Table 16. Estimated bycatch of eulachon (number of individual fish) in U.S. West Coast groundfish fisheries that are part of the Groundfish BiOp and that were observed by the West Coast Groundfish Observer Program (WCGOP) and the At-Sea Hake Observer Program (A- SHOP) from 2002–2021.

Year	Non-hake bottom and midwater groundfish fisheries [1]			At-sea Pacific hake fisheries		Shoreside/ midwater Pacific hake fisheries [2]	Shoreside midwater rockfish fisheries [2]	Electronically monitored midwater Pacific hake fisheries [2]	Electronically monitored midwater rockfish fisheries [2]	Total bycatch estimate
	WA	OR	CA	Catcher Processor	Mothership Catcher Vessels [3]					
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

Table 16 (continued).

Year	Non-hake bottom and midwater groundfish fisheries [1]			At-sea Pacific hake fisheries		Shoreside/ midwater Pacific hake fisheries [2]	Shoreside midwater rockfish fisheries [2]	Electronically monitored midwater Pacific hake fisheries [2]	Electronically monitored midwater rockfish fisheries [2]	Total bycatch estimate
	WA	OR	CA	Catcher Processor	Mothership Catcher Vessels [3]					
2018	0	344	0	259	26	0	163	0	0	792
2019	0	787	0	889	199	n/a [4]	244	488	56	2,663
2020	*	5,142 [5]	0	71	198	n/a [4]	66	1,953	1,098	8,528
2021	4,392	3,987	0	5,920	252	n/a [4]	320	7,717	1,232	23,820

1 – Bycatch estimates in non-hake groundfish fisheries from 2002–2010 and 2015–2021 in Washington, Oregon, and California are based on observations of the bottom trawl fishery only. Estimates in 2011–2014 are based on observations of a combination of the IFQ non-hake bottom and midwater trawl fisheries.
2 – In these fisheries, eulachon bycatch are landed and weighed by the catch monitor. Number of eulachon were estimated using a linear weight-count regression and data from a rolling 3-year window of all other catch share eulachon observations.
3 – Mothership catcher vessels includes both tribal and non-tribal sectors.
4 – Due to confidentiality requirements, EM and non- EM data are combined for the 2019–2021 midwater Pacific hake sector and reported under the EM category.
5 – Due to confidentiality requirements, Washington and Oregon data were combined for the 2020 non-hake bottom and midwater groundfish fisheries.

Table 17. Eulachon minimum abundance in the Columbia River, bycatch totals in the West Coast Groundfish Fishery (WCGF), and calculated precautionary and reinitiation incidental take thresholds based on five-year geometric means of abundance and bycatch (adapted from table 2-4 in NMFS-WCR (2018)). n/a, not applicable.

Year	Minimum Columbia River abundance estimate (number of fish)[1]	Total estimated eulachon bycatch in WCGF (from Table 16)	Five-year geometric mean of bycatch	0.01% of minimum abundance (0.0001 times the minimum number of eulachon)	Five-year geometric mean of 0.01% of minimum abundance (precautionary) threshold)	Five-year mean geometric bycatch as percentage of 0.01% precautionary threshold	0.02% of minimum abundance (0.0002 times the minimum number of eulachon)	Five-year geometric mean of 0.02% of minimum abundance (reinitiation threshold)	Five-year mean geometric bycatch as percentage of 0.02% reinitiation threshold
2006	n/a	147	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2007	n/a	87	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2008	n/a	43	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2009	n/a	136	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2010	n/a	21	n/a	n/a	n/a	n/a	n/a	n/a	n/a
2011	17,900,000	1,623	69	1,790	1,790[2]	3.9%	3,580	3,580[2]	1.9%
2012	20,000,000	192	112	2,000	1,892	5.9%	4,000	3,784	3.0%
2013	45,500,000	2,725	131	4,550	2,535	5.2%	9,100	5,070	2.6%
2014	84,243,100	3,067	300	8,424	3,423	8.8%	16,849	6,845	4.4%
2015	57,525,700	716	559	5,753	3,797	14.7%	11,505	7,594	7.4%
2016	21,654,800	58	1,133	2,165	3,945	28.7%	4,331	7,889	14.4%
2017	8,148,600	56	582	815	3,296	17.6%	1,630	6,592	8.8%
2018	1,300,087	792	455	130	1,619	28.1%	260	3,238	14.0%
2019	19,285,100	2,663	355	1,929	1,205	29.5%	3,857	2,411	14.7%
2020	8,724,800	8,528	345	872	827	41.8%	1,745	1,653	20.9%
2021	39,522,242	23,820	567	3,952	932	60.8%	7,904	1,865	30.4%

1 – Minimum abundance estimates from James et al. (2014), James (2014, revised data), Langness et al. (2020), and L. Heironimus (WDFW, unpublished data).
2 – The first year of available data for minimum eulachon abundance in the Columbia River is 2011, therefore the values for the 2011 five-year geometric means of 0.01% (precautionary threshold) and 0.02% (reinitiation threshold) of minimum Columbia River abundance are the actual values for 2011. Each year thereafter, geometric means for minimum Columbia River abundance are calculated using values from 2011 through that given year until 2015, when an actual moving 5-year geometric mean begins.

Table 18. Observed weight (kg) of "unidentified smelt" and "unidentified herring/smelt" bycatch in non-hake groundfish and in at-sea Pacific hake and shoreside Pacific hake/rockfish trawl fisheries from 2002–2022. After 2010, efforts were expanded to identify all eulachon to species and unidentified smelt did not likely include eulachon. We do not report tribal fishery catch. Double dashes (--) represent zeros or no value. Data available in Groundfish Expanded Mortality Multiyear (GEMM) database at NWFSC/FRAM Data Warehouse - GEMM Fact Layer Metadata, online at: https://www.nwfsc.noaa.gov/data/metadata/observer.gemm_fact.

	Non-hake bottom and midwater groundfish fisheries	**Non-tribal at-sea hake fisheries**		**Shoreside/ midwater Pacific hake fisheries**	**Electronically monitored midwater Pacific hake fisheries**
Year	**Unidentified smelt (kg)**	**Unidentified smelt (kg)**	**Unidentified herring/smelt (kg)**	**Unidentified smelt (kg)**	**Unidentified smelt (kg)**
2002	1,214.89	54.69	--	n/a	n/a
2003	126.98	1.72	--	n/a	n/a
2004	7.92	0.24	--	n/a	n/a
2005	151.53	0.15	--	n/a	n/a
2006	30.02	0.12	--	n/a	n/a
2007	8.27	--	0.61	n/a	n/a
2008	19.75	0.07	36.64	0.45	n/a
2009	4.25	0.34	--	--	n/a
2010	17.77	--	--	--	n/a
2011	27.50	1.42	--	--	n/a
2012	16.25	0.26	--	--	n/a
2013	98.16	0.04	--	87.09	n/a
2014	72.88	0.33	--	39.46	n/a
2015	--	--	--	--	n/a
2016	--	--	--	1.36	0.45
2017	--	--	--	--	--
2018	--	0.30	--	0.45	0.45
2019	0.45	--	--	8.62	--
2020	--	--	--	13.62	--
2021	0.45	2.23	2,180.65	1.82	--

Table 19. Groundfish bottom and midwater trawl gear changes, which may affect eulachon bycatch, and that became effective on 1 January 2019 (USOFR 2018).

Regulation	Old Requirement	New Requirement
Minimum mesh size	Groundfish bottom trawl: - 4.5 inches Midwater trawl: - 3.0 inches - first 20 feet behind footrope or head rope must have bare ropes with 16 inches minimum mesh	Groundfish bottom trawl: - no mesh size restrictions Midwater trawl: - no mesh size restrictions except for the first 20 feet behind footrope or headrope must have bare ropes with 16 inches minimum mesh
Measuring mesh size	- Distance between opposing knots	- Distance between opposing knots or corners in knotless webbing
Codend	- Codends must be single-walled - Chafing gear cannot be used to create a double-walled codend	- Codends may be single-wall or double-wall codends - Chafing gear can be used to create the double-walled codend
Selective flatfish trawl (SFFT)	- SFFT gear must be a two-seamed net. - SFFT is required shoreward of the trawl rockfish conservation area (RCA) north of 40°10′N. lat.	- SFFT gear may be a two-or four-seamed net - SFFT is not required shoreward of the trawl RCA and north of 42°N. lat. But may be used in this area. - SFFT is required shoreward of the trawl RCA between 40°10′ N. lat. And 42°N. lat. And in the Klamath and Columbia River Salmon Conservation Zones.

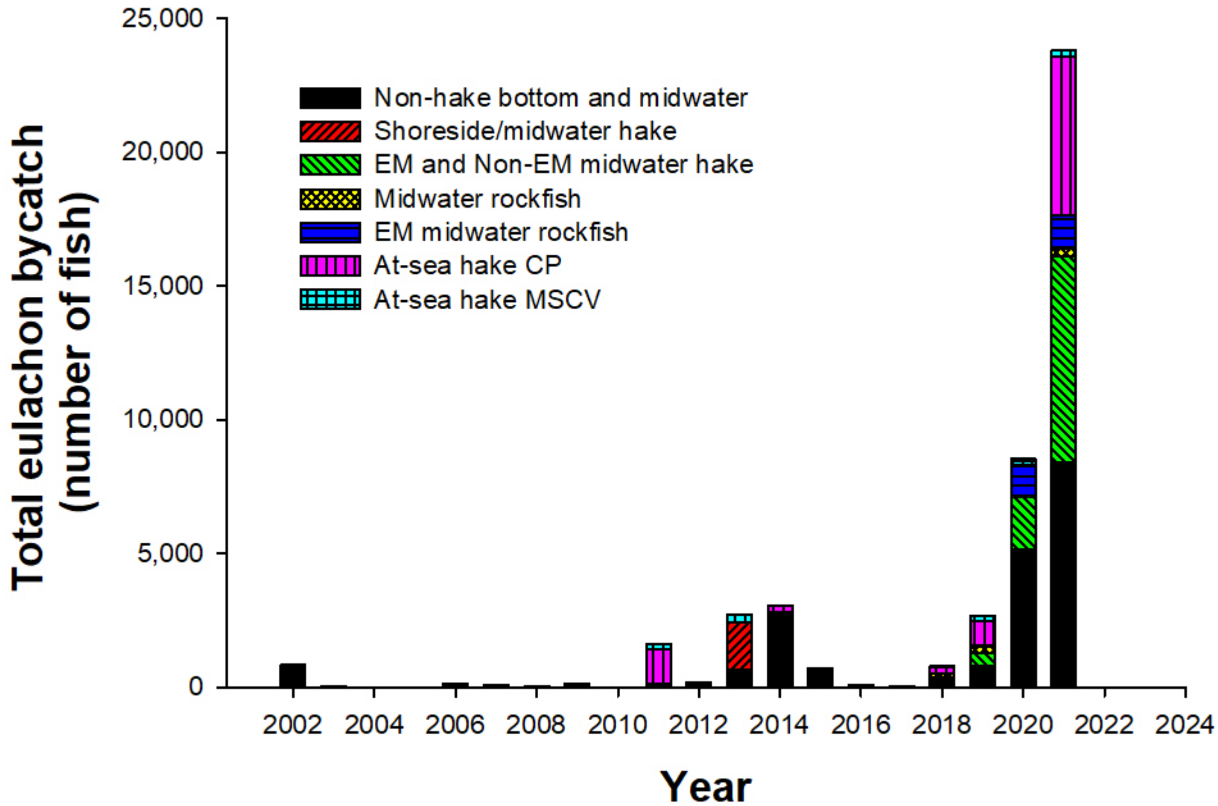

Figure 1. Estimated bycatch of eulachon in U.S. West Coast groundfish fisheries 2002–2021. Data from Table 16. CP, Catcher Processors; MSCV, Mothership Catcher Vessels (combined non-tribal and tribal mothership sectors).

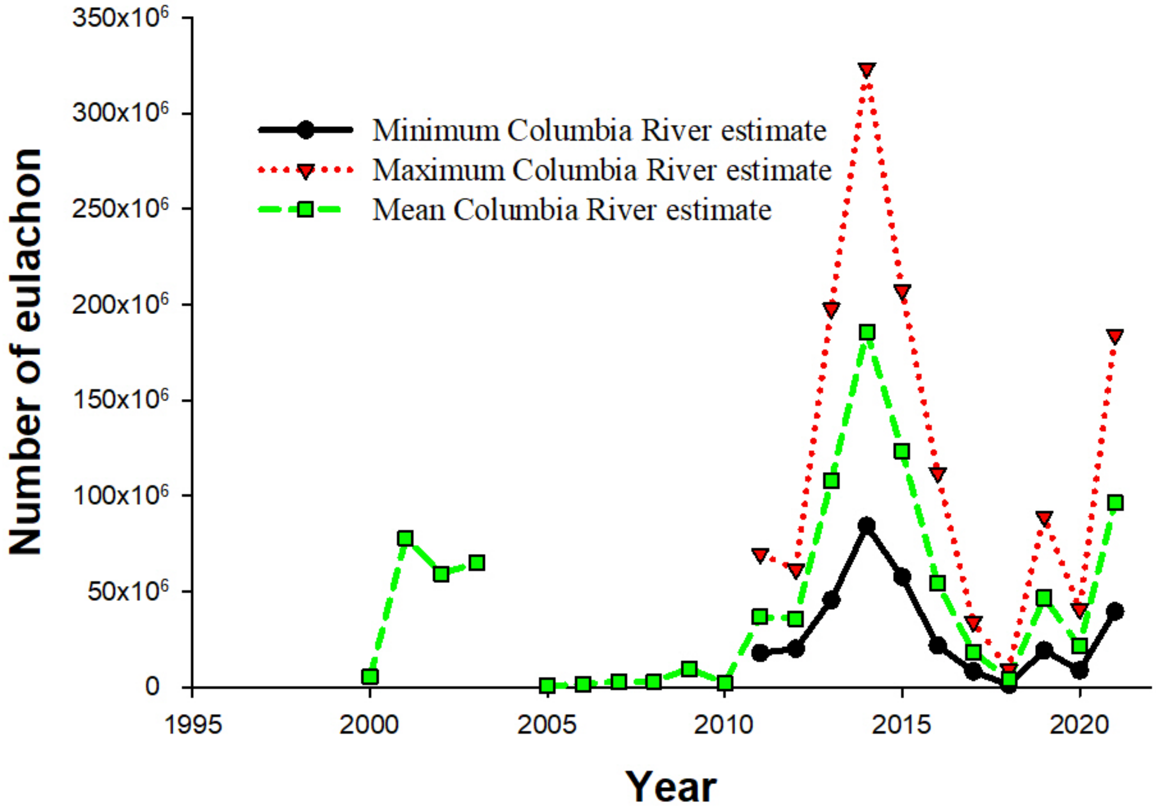

Figure 2. Estimated mean number of adult eulachon spawning in the Columbia River from 2000–2021 (James et al. 2014, James 2014, Langness et al. 2020, JCRMS 2023) and maximum and minimum numbers of eulachon from 2011–2021 (L. Heironimus, WDFW, unpublished data). Minimum abundance is the estimate utilized to derive the precautionary and reinitiation thresholds for eulachon bycatch in the Pacific Coast Groundfish Fishery.

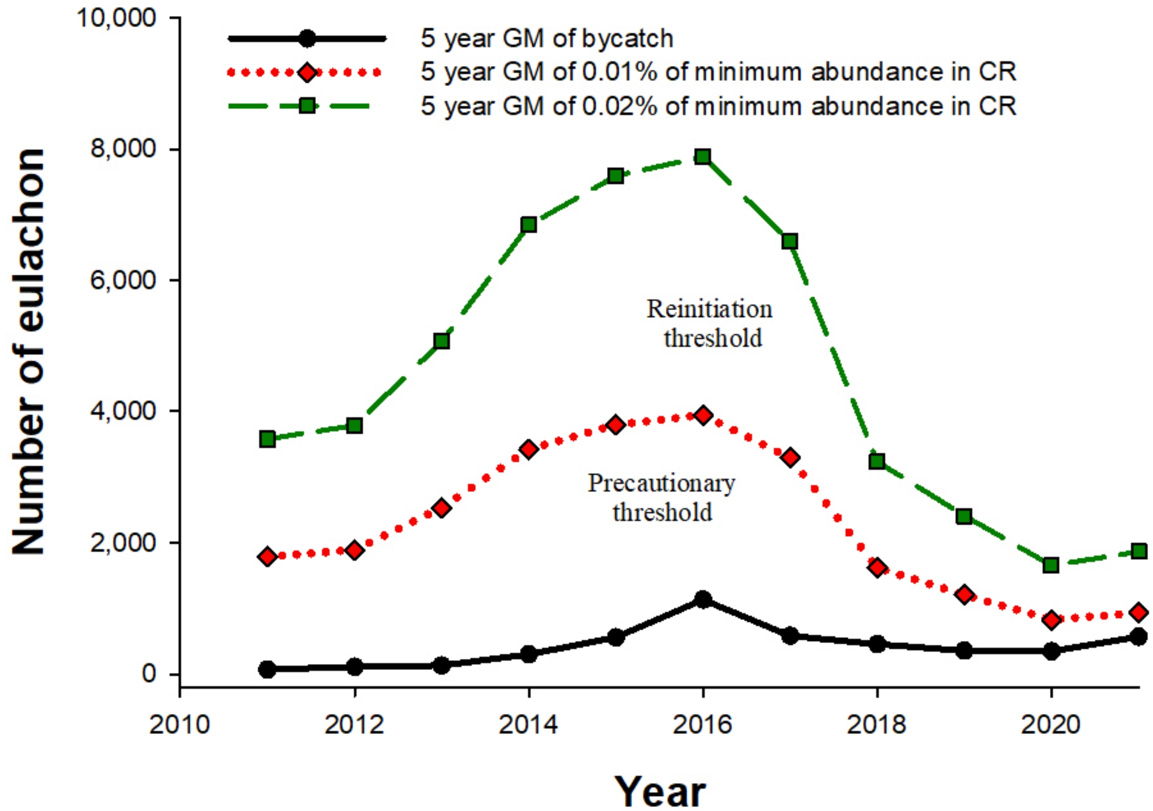

Figure 3. West Coast Groundfish Fishery eulachon bycatch thresholds (0.01 and 0.02 percent of five-year geometric mean of the minimum Columbia River eulachon abundance estimates) compared with the five-year geometric mean of eulachon bycatch (number of individuals) in this fishery [adapted from NMFS-WCR (2018 , their figure 2-1)]. GM, geometric mean; CR, Columbia River. Data from Table 17.

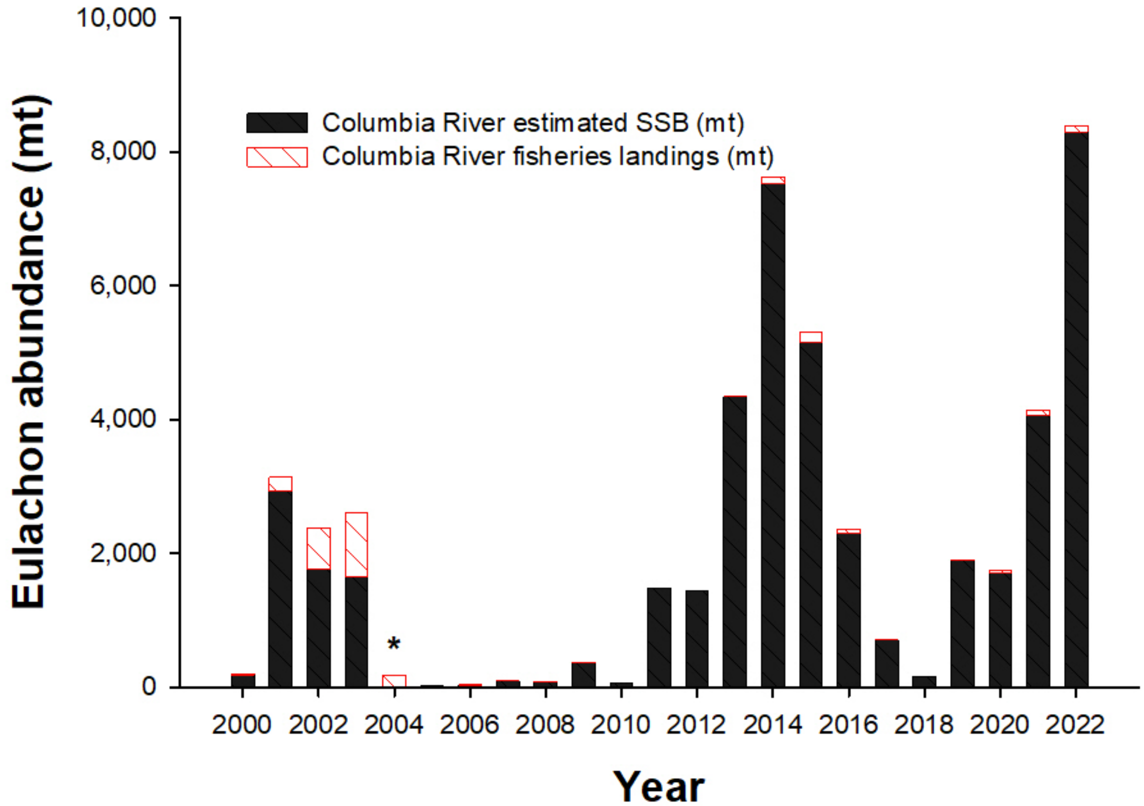

Figure 4. Estimated Columbia River eulachon spawning stock biomass (SSB) and commercial and recreational fisheries landings from 2000–2022. Pre-2011 adjusted SSB estimates based on historical Columbia River water discharge rates and expansions of historical larval densities adjusted for the shorter duration of the pre-2011 surveys (B. James and O. Langness, WDFW, unpublished data). Abundance estimates for 2011–2019 and 2021–2022 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 1,900,000 lb reported in JCRMS (2021, pp. 23–24), which was based on 10 days of truncated larval sampling,

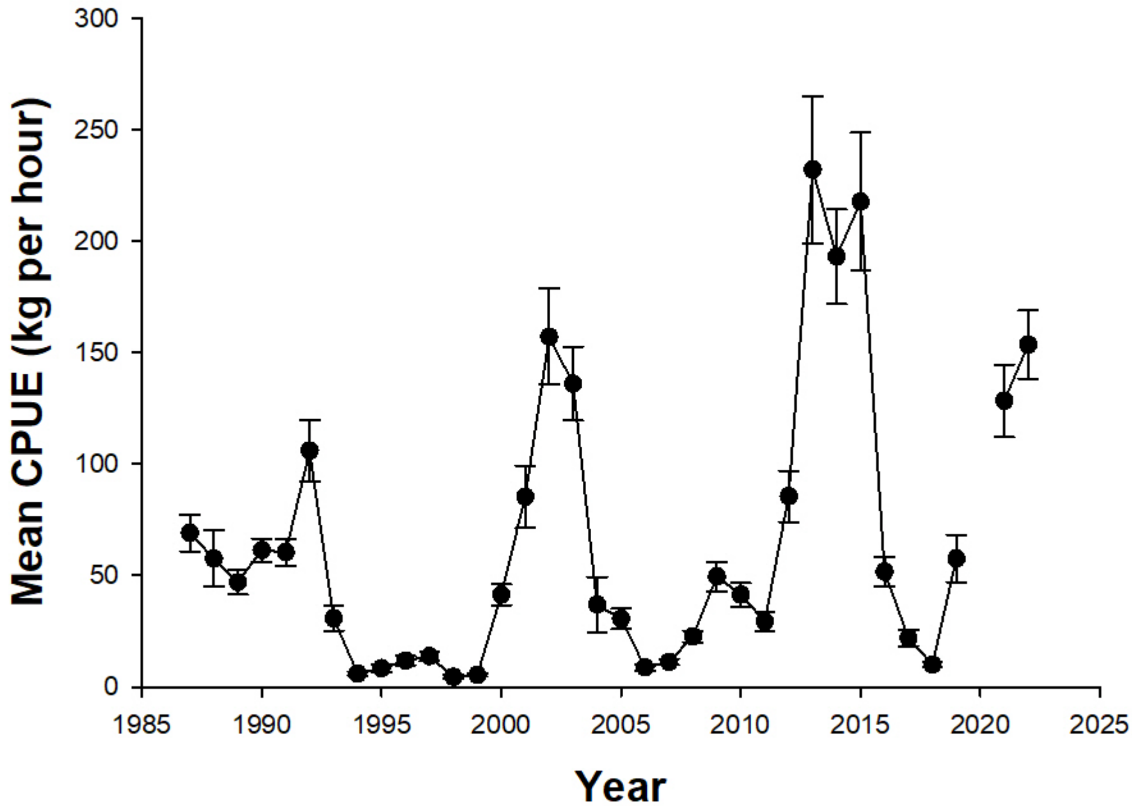

Figure 5. Total mean (± SE) catch per unit effort (CPUE; kg/h) of eulachon across all surveyed Shrimp Management Areas off West Coast Vancouver Island (WCVI) from 1987–2022. Data for 2020 are unavailable due to fieldwork restrictions during the COVID-19 pandemic. CPUE is based on bycatch of eulachon in multispecies small mesh bottom trawl surveys (aka fishery-independent shrimp surveys) offshore of WCVI. Data courtesy of Sean MacConnachie, Vanessa Hodes, and Linnea Flostrand (Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, British Columbia, Canada, pers. commun.,).

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Appendix: Observed and Estimated Bycatch of Eulachon in U.S. West Coast Ocean Shrimp Trawl Fisheries from 2004–2021

Richard Gustafson[1]
Kate Richerson[2]
Kayleigh Somers[2]
Vanessa Tuttle[2]
Jon McVeigh[2]

[1] Conservation Biology Division
Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112
USA

[2] Fisheries Observation Science Program
Fishery Resource Analysis and Monitoring Division
Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112
USA

Introduction

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). This Appendix provides an analysis of observed bycatch and fleet-wide take estimates of U.S. Endangered Species Act-listed eulachon in U.S. West Coast commercial ocean shrimp trawl fisheries from 2004–2021.

Offshore trawl fisheries for ocean shrimp have occurred from Queen Charlotte Sound, British Columbia south to off the west coast of Vancouver Island and to the U.S. West Coast off Cape Mendocino, California (Hannah and Jones 2007). Numerous previous publications have documented eulachon bycatch levels in shrimp trawl fisheries off the coasts of Washington, Oregon, California, and British Columbia (Hay et al. 1999a, 1999b, Olsen et al. 2000, NWFSC 2008, 2009, 2010, Bellman et al. 2011, Al-Humaidhi et al. 2012, Gustafson et al. 2015, 2017, 2019, 2021, DFO 2022a). However, the present document does not specifically cover eulachon bycatch in British Columbia shrimp trawl 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). Ocean shrimp in commercial quantities are found from Point Arguello, California north to Queen Charlotte Sound, British Columbia, typically over well-defined beds of green mud or green mud and sand (Frimodig et al. 2009). 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 feet), with an average length of 19.9 m (65 feet), and can use single or double-rigged shrimp trawl gear (Table A1). 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 (Fig. A1). The portion of the catch that is not marketable or for which regulations prohibit landing is discarded at-sea. In this report, we assume that all discarded eulachon in this fishery results in 100% mortality (see Table A1). 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[15] and Oregon[16].

Deflecting Grid BRDs

Currently, ocean shrimp vessels are required to use bycatch reduction devices (BRDs) that serve as deflecting grids to guide fin-fish towards 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

[15] http://wdfw.wa.gov/fishing/commercial/shrimp/
[16] http://www.dfw.state.or.us/MRP/shellfish/commercial/shrimp/index.asp

2003. Current regulations in Washington and Oregon, adopted by both states in 2012, require ocean shrimp trawl fishery BRDs to consist of a rigid panel or grate of narrowly spaced bars (usually constructed of aluminum) with no gaps between the bars exceeding 0.75 inches (19.1 mm). Use of LED (Light Emitting Diode) lights 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 below). Further details on shrimp BRD requirements and fishery regulations are available online for Washington[17], Oregon[18], and California[19].

In California, approved deflecting grid BRDs for use in the ocean shrimp fishery include: 1) rigid or semi-rigid grate excluders consisting of vertical bars with no gaps between the bars exceeding 2 inches (50.8 mm); 2) soft-panel excluders, usually made of a soft mesh material with individual meshes no larger than 6 inches; and 3) fisheye excluders, which have a forward-facing escape opening that is maintained by a rigid frame. For more information, see the 2022 California Commercial Fishing Regulations Digest.[20]

Although data on survivability of rigid-grate BRDs by small pelagic fishes such as eulachon are scarce, many studies on trawl net escape mortality for other fishes indicate that "among some species groups, such as small-sized pelagic fish, mortality may be high" and "the smallest escapees often appear the most vulnerable" (Suuronen 2005, p. 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:

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

[17] https://apps.leg.wa.gov/wac/default.aspx?cite=220-340-500
[18] https://www.dfw.state.or.us/fish/commercial/docs/2020_Commercial_Synopsis.pdf
[19] https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=205932&inline
[20] https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=191712&inline

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.

Footrope Lighting BRDs

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. 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

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 Pink (Ocean) Shrimp, *Pandalus jordani*, Fishery Management Plan[21] (FMP) (CDFW 2022). 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 Pink (Ocean) Shrimp FMP as adopted and amended by the California Fish Commission. These regulations[22] 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 were distributed to all fishers in the state-regulated ocean shrimp trawl fisheries on the U.S. West Coast (Groth 2020). In addition, six laminated informational sheets relating to species identification of shrimp trawl bycatch and species life history were produced and distributed to fishers (Groth 2020). These informational sheets are available on the ODFW Marine Resources website.[23] 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).

[21] https://wildlife.ca.gov/Conservation/Marine/Invertebrates/Shrimp-Prawn
[22] https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=205932&inline
[23] https://www.dfw.state.or.us/MRP/shellfish/commercial/shrimp/news_publications.asp

Methods

Data Sources

Data sources for this analysis include onboard observer data from the WCGOP and landing receipt data, Shorebased IFQ Program referred to as fish tickets, obtained from the Pacific Fisheries Information Network (PacFIN).

Observer Data

To date, observer data are the main source for discard estimation in the ocean shrimp trawl fishery. Coverage priorities and data collection methods employed by WCGOP in the ocean shrimp trawl fishery can be found in the WCGOP observer-training manual (NWFSC 2023). The sampling protocol employed by the WCGOP is primarily focused 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. (2022a) and was conducted prior to the analyses presented in this report.

Fish Ticket Data

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 information from fish tickets is crucial information for fleet-wide total bycatch estimation for all sectors of the ocean shrimp trawl fishery 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. In this case, fish tickets are trip-aggregated sales receipts for ocean shrimp. 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 a slightly different format for each state. In addition, each state conducts species-composition sampling at the ports for numerous market categories that are reported on fish tickets. Fish ticket and species-composition data are submitted by state agencies to the PacFIN regional database. Annual fish ticket landings data for ocean shrimp were retrieved from the PacFIN database. Observer and fish ticket data processing steps are described in detail in Somers et al. (2022a). All data processing steps specific to this report are described in the bycatch estimation methods section below.

Bycatch Estimation Methods

Fleet-wide 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 continued to the present with the exception of 2006; whereas, 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.

Bycatch ratios for these fisheries were calculated by dividing the observed bycatch of eulachon (number of fish and weight of fish in kilograms) by the observed retained weight (in metric tons) of ocean shrimp. The fleet landed weight of ocean shrimp was then used as a multiplier to expand observed eulachon bycatch ratios to the fleet. The estimation of bycatch ratio and fleet-wide 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 year and state, etc.
t = individual tows in observer data
d = observed bycatch count of eulachon
r = observed retained weight of ocean shrimp
F = expansion factor (weight of landed ocean shrimp recorded on fish tickets)
$\hat{D}$ = fleet-wide bycatch estimate of eulachon

Measures of Uncertainty

As a measure of uncertainty for the estimated bycatch ratio, upper and lower limits of the 95% confidence interval were estimated with a non-parametric bootstrap procedure for the strata that were not 100% observed (i.e., non-IFQ fisheries). 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 fleet-wide 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 technique 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 necessary to preserve confidentiality, we pooled strata over a three-year time window to estimate bycatch and uncertainty. If there were 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. This bycatch ratio can be viewed as a three-year running average.

Results

Eulachon Bycatch

Observer data from the ocean shrimp trawl fishery were received from the West Coast Groundfish Observer Program (WCGOP) at the NWFSC[24]. These data contained all observed tows for the years 2004, 2005, and 2007–2021. The observed tows were in waters between 80 and 250 m in depth. The ocean shrimp trawl fishery did not carry WCGOP observers in 2006. 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 A2 and A3 (Washington,) A4 and A5 (Oregon), A6 and A7 (California) and compiled for the entire U.S. West Coast in Table A8.

The WCGOP began observing eulachon bycatch in the Washington ocean shrimp fishery in 2010. Since 2010, the percentage of total shrimp landings observed has fluctuated between about 5 and 19.5% (Table A2). The estimated Washington sector bycatch in terms of weight (Table A2) and numbers of eulachon (Table A4) increased dramatically beginning in 2012, and remained elevated relative to 2010–2011 through 2015 (Fig. A2). Eulachon bycatch and bycatch ratios declined significantly through 2017, increased in 2018 through 2019, declined somewhat in 2020, but increased again in 2021 (Tables A2 and A3, Figs. A2 and A3). Estimated fleetwide eulachon bycatch numbers in 2018 were more than three times the 2017 level and 2019 numbers were more than four and a half times the 2018 numbers. Washington fleetwide bycatch and bycatch ratios remained elevated in 2020, but estimated bycatch numbers more than doubled from 2020 to 2021 (Tables A2 and A3, Figs. A2 and A3).

Total estimated bycatch of eulachon in the Washington ocean shrimp fisheries ranged from a low of 67 thousand (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 A3, Fig. A2). 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 thousand), 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 A3, Fig. A2).

Mean estimated total biomass of eulachon bycatch in the Washington fishery during this time period (2010–2021) ranged from 2.1–231.4 mt (Table A2). 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 2012–2013 to 5.0 kg/mt in 2016 and 3.8 kg/mt in 2017 (Table A2, Fig. A3); 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 A2, Fig. A3).

Eulachon bycatch in the Oregon ocean shrimp fishery was estimated at well under a million individual fish (range of 146–845 thousand) from 2004–2011 (although the fishery was not

[24] 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).

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 A5, Fig. A2). 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 A4). 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 A4 and A5). 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 thousand fish (95% CI: 49,871–401,489) and 3.9 mt (95% CI: ~0.9–7.7 mt) in 2017 (Tables A4 and A5). These improving trends did not continue into the 2018–2020 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 A4 and A5, Fig. A2). 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 A4 and A5).

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) also increased dramatically from 2011 to 2012, and remained high in 2013–2015 (Tables A3 and A4, Fig. A3). 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 A4 and A5, Fig. A3). 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 A3 and A4, Fig. A3). 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 A3 and A4, Fig. A3).

The eulachon bycatch estimate in the California ocean shrimp sector remained below 23 thousand fish from 2004 to 2008 (the fishery was not observed in 2006), rose dramatically in 2010 to over 267 thousand 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 thousand fish (95% CI: 151,938–601,147), and then fell to less than 17 thousand fish (95% CI: 3,794–33,971) in 2013 (Table A7). Biomass of eulachon bycatch and bycatch ratios showed similar fluctuations over the time period from 2010–2013 (Tables A6 and A7). Eulachon bycatch again increased from 2014–2015 in the California ocean shrimp trawl sector. Estimated bycatch was over 602 thousand 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 A6 and A7). The tonnage of observed ocean shrimp and of fleet-wide landings were relatively stable over the period from 2011–2015, 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 A6 and A7). 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 thousand 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 A7). Ocean shrimp landings in the California fishery were down by about 60% in 2016–2017 compared to the 2011–2015 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 3.5 thousand 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 A7, Fig. A3). 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 thousand fish (95% CI: 3,472–13,463) with a bycatch ratio of about 23 eulachon/mt of shrimp (Table A7). Ocean shrimp landings did occur in the California sector during 2021.

Bycatch ratios were higher in Washington than in the Oregon fishery in both 2012 and 2013 (Tables A2–A5, Fig. A3). In 2015, bycatch ratios declined in the Oregon sector but rose in both the Washington and California sectors of the ocean shrimp trawl fishery (Tables A2–A7, Fig. A3). Eulachon bycatch and bycatch ratios continued to decline in all three state ocean shrimp fisheries from 2015 to 2016 to 2017. However, declines in bycatch and bycatch ratios were most dramatic in Oregon and California over this time period. In 2017 comparative bycatch ratios as number of eulachon per metric ton of shrimp were 145.4 (95% CI: 99.3–212.1) for Washington, 19.9 (95% CI: 4.7–38.4) for Oregon, and nearly zero (95% CI: 0.0–0.1) for California (Tables A3, A5, A7). Although the bycatch ratio as number of eulachon per metric ton of shrimp increased modestly in California to 1.5 fish (95% CI: 1.0–2.1) in 2018 and declined to 0.8 fish (95% CI: 0.3–1.3) in 2019, this ratio increased by an order of magnitude from 2018 to 2019 in both Washington and Oregon (Tables A3 and A5). In Washington, the bycatch ratio as number of eulachon per metric ton of shrimp increased from 145 in 2017 to 367 fish (95% CI: 175–692) in 2018 and to 1,576 fish (95% CI: 1,155–2,064) in 2019 (Table A3). Similarly, the bycatch ratio as number of eulachon per metric ton of shrimp increased in Oregon from about 20 fish in 2017 to 111 fish (95% CI: 22–233) in 2018 and to 1,092 fish (95% CI: 756–1,441) in 2019. Eulachon bycatch ratios remained negligible in the California ocean shrimp sector during 2017–2020, and no ocean shrimp were landed in California in 2021. The eulachon bycatch ratio as number of eulachon per metric ton of ocean shrimp in the Washington sector declined modestly to 871 fish (95% CI: 505–1,076) in 2020, but increased to 1,494 fish (95% CI: 486–2,828) in 2021 (Table A3). Bycatch ratios declined in the Oregon ocean shrimp sector in 2020 and 2021 to 850 (95% CI: 304–1,453) and 296 (95% CI: 152–482) eulachon per metric ton of ocean shrimp, respectively (Table A5).

Total coastwide estimated bycatch of eulachon in the Oregon and California ocean shrimp fisheries ranged from 156 thousand fish in 2004 to a high of 948 thousand fish in 2009. Estimated eulachon bycatch in the Washington ocean shrimp fishery in 2010 (its first year of observation) was over 67 thousand fish, and the total 2010 estimated eulachon bycatch for all three states combined was over 1 million. Coastwide eulachon bycatch decreased to about 606 thousand fish in 2011 (Table A8). 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 A8). Estimated weight of these bycaught eulachon in 2013 was 743.6 mt (Table A8). 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 A8). Estimated coastwide bycatch in 2015 amounted to over 60.1 million fish and 612.0 mt (Table A8). 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 649 thousand fish in 2017 (Table A8). 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 A8). 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

Observer coverage in ocean shrimp trawl fisheries from 2010–2019 has ranged from 9–16 % of ocean shrimp landings on a coastwide basis (Table A9) (Somers et al. 2022b). 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. Observer coverage data for Washington and California are available only for 2010–2019 (Table A9). Prior California data cannot be reported for confidentiality reasons, and the Washington shrimp trawl sector was not observed by the 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 A3). During 2010–2019, observer coverage in Washington, Oregon, and California averaged 13.4%, 12.5%, and 14.7% of total shrimp landings, respectively (Tables A2–A7) (Somers et al. 2022b). No ocean shrimp trawl fishery landings were observed in 2006.

Discussion

The fluctuating relative abundance of the southern DPS of eulachon (Figs. 4, 5) likely influences the high eulachon bycatch from 2012–2015, the subsequent decrease in bycatch in 2016 to 2018, and increased bycatch observed in 2019 to 2021 in West Coast ocean shrimp trawl fisheries, as reported in the current document. These patterns are also likely influenced by the orientation and degree to which artificial LED lighting has been used since 2015 to illuminate portions of trawl nets in different sectors of these fisheries. LED lighting of ocean shrimp trawl footropes became mandatory in both Oregon and Washington during the 2018 and 2019 seasons (Wargo and Ayres 2018, 2019, Groth et al. 2018). The potential impact of lighted trawl net footropes on bycatch ratios and overall bycatch is an active area of research and is further discussed below.

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).

The Washington ocean shrimp fishery was also observed separately in 2011 and 2012 by a team of state-deployed fishery bycatch observers (Wargo et al. 2014, 2016). Wargo et al. (2016, p. 28) reported a fleetwide eulachon bycatch in the Washington state ocean shrimp fishery of "7.8 mt (17,132 pounds) for 2011 and 171 mt (378,011 pounds) for 2012." These bycatch estimates are approximately 30% and 10% greater than the estimates for the Washington ocean shrimp fishery as reported in the present document 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 the WCGOP observed 16.2% of the total ocean shrimp landings (Table A2). 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 the WCGOP (Table A2).

Bycatch Reduction Devices

Prior to the mandated use of bycatch reduction devices (BRDs), 32–61% of the total catch in the Oregon ocean shrimp fishery consisted of non-shrimp 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 fin fish 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 (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 10 green LED lights were placed along the trawl fishing line of ocean shrimp trawl nets with rigid-grate BRDs with 0.75 inch (19.1 mm) bar spacing installed and then were compared with identical trawls 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 that "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 that, "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, p. 9 and 12) emphasized "that proper installation of LEDs is key to bycatch reduction" and that research efforts in 2017 "will further examine use of LEDs in bycatch reduction." As mentioned above, LED lighting of ocean shrimp trawl footropes became mandatory in both Oregon and Washington starting with the 2018 season (Wargo and Ayres 2018, 2019, Groth et al. 2018).

Lomeli et al. (2018) examined the effect on eulachon bycatch of placing 5, 10, and 20 LED lights along the footrope of ocean shrimp trawl nets. Catch efficiencies between the three LED lighting configurations were compared with one another and with paired unilluminated trawls. According to Lomeli et al. (2018, p. 2230), the unilluminated trawl caught 81, 60, and 47% more eulachon than the 5-, 10-, and 20-LED configurations, respectively" and "these differences in average catch efficiency were significant." These results indicate that "light emitted by the 5-LED configuration provided sufficient illumination for most fishes to perceive the contrast between the trawl fishing line and the seabed and thus avoid capture, and that use of more illumination provides no clear added bycatch reduction benefit (Lomeli et al. 2018, p. 2232). These bycatch benefits were 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 showed that 5 LEDs worked better than 10 or 20 … [Lomeli et al. 2020]) and a rule was adopted accordingly …
>
> 2. How are LEDs placed along 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 (Figs. 4 and 5) and eulachon bycatch by state (Figs. A2 and A3) 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 A8). 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 2017–2021, respectively (Tables A3, A5, A7). 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 A3 and A5). Although an average of about 6% of total shrimp landings from 2017–2021 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) (Tables A2–A8). 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 A7). 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), 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, amongst others (Lomeli et al. 2020, p. 52–53).

Oregon and Washington Ocean Shrimp FMPs

Both the Washington (Wargo and Ayres 2017b, p. 6) and Oregon (Hannah et al. 2018, p. 7) ocean shrimp fisheries management plans, list developing methods to reduce bycatch (especially of eulachon) as high on their prioritized list of research needs. Although both plans list “action levels” that trigger management actions to restrict or curtail shrimp catch when shrimp catch-per-trip levels reach certain low counts, neither state’s FMP has management action levels related to amount of eulachon bycatch taken. By comparison, in British Columbia the shrimp trawl Integrated Fisheries Management Plan (IFMP) has implemented a Eulachon Action Level (EAL) in response to incidental eulachon by-catch in the shrimp trawl fishery (DFO 2022a, b). When an EAL is reached in specific trawl areas, they are then closed to shrimp harvest for the season. According to this plan (DFO 2022b, p. 4):

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

Bycatch Hotspots

Ward et al. (2015) applied spatiotemporal models to both fishery-dependent observations of eulachon bycatch and eulachon fisheries-independent survey data to (1) estimate population trends of eulachon, (2) understand eulachon bycatch risk in shrimp fisheries, and (3) identify persistent bycatch hotspots that may be used in future management actions to reduce eulachon bycatch rates. Two spatial data sets for the period from 2007–2012 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 fisheries-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 4–5) 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.

"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 2004–2015 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 shrimp fisheries include surf smelt (*Hypomesus pretiosus*), whitebait smelt (*Allosmerus elongatus*), night smelt (*Spirinchus starksi*), rainbow smelt (*Osmerus mordax*), longfin smelt (*Spirinchus thaleichthys*), and capelin (*Mallotus villosus*) (Table A10). Combined observations of unidentified smelt and other non-eulachon smelt osmerid species bycatch in Oregon and California (2004–2010) and Oregon, California, and Washington (2011–2019) ocean shrimp trawl fisheries are presented in Table A10. The percentage of this unidentified smelt category from 2004–2010 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 2011–2019 likely consist of other osmerid smelt species besides eulachon.

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Table A1. Generalized descriptions of U.S. West Coast ocean shrimp fisheries that have had observed bycatch of eulachon.

Sector	Sub-Sector	Permits	Gear(s)	Target(s)	Vessel length (m)	Depths (m)	Management 2002-2010	Management 2011-2021
Ocean Shrimp (aka pink shrimp)		WA, OR, or CA state ocean shrimp permit	Shrimp trawl	Ocean shrimp (*Pandalus jordani*)	11.5–33	91–256	WA, OR, or CA state ocean shrimp regulations; Bycatch Reduction Devices and LED lights required; trip limits on groundfish landed; 4-16% observer coverage	

Table A2. Weight of observed eulachon bycatch, bycatch ratios, and estimated fleet-total bycatch weights of eulachon from ocean shrimp trawl vessels that landed their catch in Washington (2010–2021). Bycatch ratios were calculated for each year by dividing the observed catch of eulachon (kg) by the observed weight (mt) of retained ocean shrimp. A fleet-wide bycatch estimate was obtained by multiplying the bycatch ratios by fleet-wide ocean shrimp landings. 95% bootstrapped confidence intervals (CI) are provided for the estimates.

Year	**Bycatch (kg of eulachon)**	**Retained eulachon (kg)**	**Observed ocean shrimp landings (mt)**	**Bycatch ratio (kg per mt of ocean shrimp)**	**95% CI**	**Percent landings observed**	**Fleet total ocean shrimp landings (mt)**	**Fleet total bycatch estimate (kg)**	**95% CI**
2010	198.0	0.0	399.5	0.50	0.17 0.95	9.3	4,295.6	2,129.3	750.3 4,078.8
2011	917.7	0.0	697.2	1.32	0.80 2.09	16.2	4,312.1	5,675.7	3,431.5 8,996.6
2012	23,135.3	0.0	626.0	36.96	24.74 48.38	14.8	4,239.4	156,689.3	104,877.3 205,087.3
2013	20,646.3	0.0	626.8	32.94	24.33 40.25	10.2	6,157.9	202,827.6	149,877.3 205,087.3
2014	10,043.2	0.0	967.6	10.38	5.43 17.88	7.0	13,876.2	144,021.2	75,389.2 248,166.2
2015	24,961.4	0.0	2,183.3	11.67	9.00 14.90	11.4	18,682.3	218,088.6	168,127.7 278,321.6
2016	5,505.9	0.0	1,107.8	4.97	2.66 7.97	17.3	6,395.9	31,788.7	17,013.6 51,000.6
2017	2,241.0	0.0	592.6	3.78	2.54 5.16	19.5	3,040.6	11,497.8	7,726.4 15,703.8
2018	5,244.1	0.0	621.9	8.43	3.94 16.26	16.2	3,832.8	32,319.6	15,103.5 62,322.1
2019	17,621.0	0.0	524.6	33.59	22.02 48.09	12.6	4,166.1	139,928.1	91,742.3 200,359.5
2020	8,133.1	0.0	376.8	21.58	11.75 27.63	6.0	6288.2	135,715.4	73,903.9 173,718.7
2021	12,158.9	0.0	457.8	26.56	9.26 50.28	5.3	8711.8	231,389.7	80,709.9 438,064.5

Table A3. Numbers of observed eulachon bycatch, bycatch ratios, and estimated fleet-total bycatch numbers of eulachon from ocean shrimp trawl vessels that landed their catch in Washington (2010–2021). Bycatch ratios were calculated for each year by dividing the observed catch of eulachon (numbers) by the observed weight (in mt) of retained ocean shrimp. A fleet-wide bycatch estimate (number of fish) was obtained by multiplying the bycatch ratios by fleet-wide ocean shrimp landings. 95% bootstrapped confidence intervals (CI) are provided for the estimates. Any missing counts were estimated using a year-specific linear weight-count regression and data from all other eulachon observations in the pink shrimp fishery.

Year	Bycatch (numbers)	Retained eulachon (numbers)	Observed ocean shrimp landings (mt)	Bycatch ratio (number per mt of ocean shrimp)	95% CI	Percent landings observed	Fleet total ocean shrimp landings (mt)	Fleet total bycatch estimate (numbers)	95% CI
2010	6,250	0.0	399.5	15.65	5.76 32.82	9.3	4,295.6	67,205	24,723 140,986
2011	20,008	0.0	697.2	28.70	16.62 46.15	16.2	4,312.1	123,741	71,664 199,025
2012	2,108,868	0.0	626.0	3,369.06	2,129.15 4,469.90	14.8	4,239.4	14,282,792	9,026,318 18,949,701
2013	1,740,405	0.0	626.8	2,776.55	1,943.74 3,494.98	10.2	6,157.9	17,097,607	11,969,243 21,521,585
2014	950,829	0.0	967.6	982.62	548.28 1,592.54	7.0	13,876.2	13,635,062	7,608,043 22,098,505
2015	2,553,221	0.0	2,138.3	1,194.04	900.97 1,547.62	11.4	18,682.3	22,307,542	16,832,276 28,913,245
2016	259,680	0.0	1,107.8	234.41	126.86 357.79	17.3	6,395.9	1,499,284	811,348 2,288,380
2017	86,151	0.0	592.6	145.37	99.34 212.09	19.5	3,040.6	442,022	302,068 644,901
2018	228,025	0.0	621.9	366.66	175.07 691.91	16.2	3,832.8	1,405,326	670,990 2,651,935
2019	826,741	0.0	524.6	1,575.84	1,154.56 2,063.56	12.6	4,166.1	6,565,150	4,810,078 8,597,092
2020	328,250	0.0	376.8	871.07	504.47 1,075.99	6.0	6,288.2	5,477,469	3,172,204 6,766,075
2021	684,031	0.0	457.8	1,494.25	485.66 2,828.13	5.3	8,711.8	13,017,493	4,230,963 24,637,980

Table A4. Weight of observed eulachon bycatch, bycatch ratios, and estimated fleet-total bycatch weights of eulachon from ocean shrimp trawl vessels that landed their catch in Oregon (2004–2021). Bycatch ratios were calculated for each year by dividing the observed catch of eulachon (kg) by the observed weight (mt) of retained ocean shrimp. A fleet-wide bycatch estimate was obtained by multiplying the bycatch ratios by fleet-wide ocean shrimp landings. 95% bootstrapped confidence intervals (CI) are provided for the estimates. Double dashes (--) signify unobserved strata.

Year	Bycatch (kg of eulachon)	Retained eulachon (kg)	Observed ocean shrimp landings (mt)	Bycatch ratio (kg per mt of ocean shrimp)	95% CI	Percent landings observed	Fleet total ocean shrimp landings (mt)	Fleet total bycatch estimate (kg)	95% CI
2004	221.8	0.0	427.2	0.52	0.00–1.55	7.7	5,537.0	2,875.3	221.8–8,583.8
2005	278.7	0.0	402.9	0.69	0.11–1.43	5.6	7,159.4	4,953.3	785.3–10,266.9
2006	--	--	--	--	-- – --	0.0	5,531.8	--	-- – --
2007	277.8	0.0	650.0	0.43	0.01–1.11	7.1	9,128.6	3,901.7	277.8–10,153.3
2008	600.3	0.0	672.5	0.89	0.21–1.89	5.8	11,575.9	10,332.6	2,384.9–21,919.3
2009	650.9	0.0	751.2	0.87	0.22–1.93	7.5	10,048.7	8,707.4	2,177.4–19,438.1
2010	1,635.3	1.5	1,706.8	0.96	0.68–1.24	11.9	14,290.4	13,692.8	9,776.0–17,972.3
2011	2,786.7	0.0	2,986.0	0.93	0.68–1.24	13.6	21,915.1	20,452.8	14,813.9–27,089.4
2012	57,865.9	0.0	3,014.2	19.20	12.74–26.56	13.5	22,291.6	427,944.1	283,967.3–592,130.2
2013	58,004.8	0.0	2,313.2	25.08	16.23–35.54	10.7	21,537.8	540,062.5	349,460.7–765,452.2
2014	59,631.8	0.0	2,272.0	26.25	18.45–34.94	9.6	23,573.3	618,701.6	434,861.9–823,678.1
2015	33,828.5	0.0	2,267.0	14.89	10.61–19.96	9.3	24,273.6	361,525.7	257,482.2–484,559.5
2016	9,467.7	0.0	2,305.9	4.11	3.00–5.52	14.3	16,115.6	66,167.4	48,310.0–88,942.1
2017	546.9	0.0	1,454.9	0.38	0.09–0.74	13.9	10,458.6	3,931.7	901.7–7,708.7

Table A4 (Continued).

Year	Bycatch (kg of eulachon)	Retained eulachon (kg)	Observed ocean shrimp landings (mt)	Bycatch ratio (kg per mt of ocean shrimp)	95% CI	Percent landings observed	Fleet total ocean shrimp landings (mt)	Fleet total bycatch estimate (kg)	95% CI
2018	3,522.8	0.0	2,124.4	1.66	0.40 3.50	13.1	16,212.4	26,884.5	6,432.5 56,715.2
2019	45,827.3	47.6	1,853.7	24.72	17.64 32.54	15.2	12,179.9	301,155.3	214,821.7 396,283.3
2020	14,554.5	0.0	657.6	22.13	9.79 35.22	3.4	19,564.9	433,009.8	191,555.2 689,040.7
2021	7,443.7	9.1	1,151.5	6.46	3.62 10.14	6.2	18,708.7	120,948.4	67,781.0 189,638.0

Table A5. Numbers of observed eulachon bycatch, bycatch ratios, and estimated fleet-total bycatch numbers of eulachon from ocean shrimp trawl vessels that landed their catch in Oregon (2004–2021). Bycatch ratios were calculated for each year by dividing the observed catch of eulachon (numbers) by the observed weight (in mt) of retained ocean shrimp. A fleet-wide bycatch estimate (number of fish) was obtained by multiplying the bycatch ratios by fleet-wide ocean shrimp landings. 95% bootstrapped confidence intervals (CI) are provided for the estimates. Any missing counts were estimated using a year-specific linear weight-count regression and data from all other eulachon observations in the pink shrimp fishery.

Year	Bycatch (number)	Retained eulachon (number)	Observed ocean shrimp landings (mt)	Bycatch ratio (number per mt of ocean shrimp)	95% CI	Percent landings observed	Fleet total ocean shrimp landings (mt)	Fleet total bycatch estimate (number)	95% CI
2004	11,294	0	427.2	26.44	0.00 81.32	7.7	5,537.0	146,379	11,294 450,288
2005	11,698	0	402.9	29.04	3.09 58.34	5.6	7,159.4	207,878	22,107 417,672
2006	--	--	--	--	-- --	0.0	5,531.8	--	-- --
2007	14,102	0	650.0	21.70	0.12 57.77	7.1	9,128.6	198,054	14,102 527,394
2008	22,660	0	672.5	33.70	9.29 63.09	5.8	11,575.9	390,056	107,486 730,368
2009	63,204	0	751.2	84.14	21.97 183.07	7.5	10,048.7	845,473	220,802 1,839,590
2010	88,447	37	1,706.8	51.82	33.30 74.16	11.9	14,290.4	740,552	475,899 1,059,728
2011	65,657	0	2,986.0	21.99	15.08 30.59	13.6	21,915.1	481,880	330,541 670,344
2012	3,837,380	0	3,014.2	1,273.09	820.22 1,793.86	13.5	22,291.6	28,379,097	18,284,056 39,987,990
2013	3,888,818	0	2,313.2	1,681.11	985.21 2,542.81	10.7	21,537.8	36,207,414	21,219,261 54,766,425
2014	5,718,348	0	2,272.0	2,516.83	1,675.69 3,565.26	9.6	23,573.3	59,329,960	39,501,596 84,044,933
2015	3,329,763	0	2,267.0	1,465.88	967.43 2,086.57	9.3	24,273.6	35,582,198	23,483,100 50,648,622
2016	410,130	0	2,305.9	177.86	122.21 249.75	14.3	16,115.6	2,866,306	1,969,417 4,024,904
2017	28,876	0	1,454.9	19.85	4.77 38.39	13.9	10,458.6	207,577	49,871 401,489

Table A5 (Continued).

Year	Bycatch (no. of eulachon)	Retained eulachon (numbers)	Observed ocean shrimp landings (mt)	Bycatch ratio (number per mt of ocean shrimp)	95% CI	Percent landings observed	Fleet total ocean shrimp landings (mt)	Fleet total bycatch estimate (number)	95% CI
2018	235,027	0	2,124.4	110.63	23.11 232.68	13.1	16,212.4	1,793,646	374,603 3,772,282
2019	2,024,011	1,898	1,853.7	1,091.86	756.30 1,441.28	15.2	12,179.9	13,300,628	9,211,602 17,554,549
2020	558,801	0	657.6	849.72	303.94 1,452.97	3.4	19,564.9	16,624,798	5,946,644 28,427,219
2021	340,388	557	1,151.5	295.60	152.50 481.95	6.2	18,708.7	5,530,881	2,856,020 9,016,669

Table A6. Weight of observed eulachon bycatch, bycatch ratios, and estimated fleet-total bycatch weights of eulachon from ocean shrimp trawl vessels that landed their catch in California (2004–2021). Bycatch ratios were calculated for each year by dividing the observed catch of eulachon (kg) by the observed weight (mt) of retained ocean shrimp. A fleet-wide bycatch estimate was obtained by multiplying the bycatch ratios by fleet-wide ocean shrimp landings. 95% bootstrapped confidence intervals (CI) are provided for the estimates. Double dashes (--) signify unobserved strata. Asterisks (*) signify strata with fewer than three observed vessels.

Year	Bycatch (kg of eulachon)	Retained eulachon (kg)	Observed ocean shrimp landings (mt)	Bycatch ratio (kg per mt of ocean shrimp)	95% CI	Percent landings observed	Fleet total ocean shrimp landings (mt)	Fleet total bycatch estimate (kg)	95% CI
2004	*	*	*	0.20	0.00 0.54	*	992.3	202.6	14.6 539.4
2005	*	*	*	0.20	n/a n/a	*	859.1	175.4	n/a n/a
2006	--	--	--	--	-- --	--	63.5	--	-- --
2007	*	*	*	0.54	0.16 1.21	*	288.9	155.9	47.4 349.3
2008	*	*	*	0.33	0.05 1.03	*	945.5	316.7	82.9 977.2
2009	*	*	*	0.85	n/a n/a	*	1,183.5	1,008.2	n/a n/a
2010	367.9	0.0	265.5	1.39	0.23 3.46	15.0	1,770.9	2,453.8	398.8 6,133.7
2011	3.7	0.0	420.6	0.01	0.00 0.02	12.6	3,332.9	29.6	10.4 59.0
2012	857.2	0.0	347.6	2.47	1.21 4.79	12.5	2,790.6	6,881.8	3,386.9 13,372.8
2013	65.8	0.0	359.8	0.18	0.04 0.37	9.2	3,915.3	715.9	163.2 1,448.6
2014	1,020.2	0.0	597.5	1.71	0.71 3.03	15.5	3,845.0	6,564.9	2,729.6 11,643.8
2015	3,134.5	0.0	334.7	9.37	4.33 16.77	9.7	3,452.9	32,341.2	14,957.1 57,921.9
2016	445.1	0.0	311.7	1.43	0.44 3.14	22.7	1,370.2	1,956.6	597.8 4,306.9
2017	0.2	0.0	241.8	0.00	0.00 0.00	16.0	1,510.0	1.5	0.2 4.9

Table A6 (Continued).

Year	Bycatch (kg of eulachon)	Retained eulachon (kg)	Observed ocean shrimp landings (mt)	Bycatch ratio (kg per mt of ocean shrimp)	95% CI	Percent landings observed	Fleet total ocean shrimp landings (mt)	Fleet total bycatch estimate (kg)	95% CI
2018	8.3	0.0	365.2	0.02	0.02 0.03	16.0	2,288.4	52.0	35.8 72.1
2019	3.8	0.0	204.2	0.02	0.01 0.03	18.0	1,133.4	21.0	8.1 32.7
2020	66.3	0.0	152.7	0.43	0.02 0.73	43.0	355.6	154.3	66.3 258.1
2021	n/a	n/a	n/a	n/a	n/a n/a	n/a	0.0	n/a	n/a n/a

Table A7. Numbers of observed eulachon bycatch, bycatch ratios, and estimated fleet-total bycatch numbers of eulachon from ocean shrimp trawl vessels that landed their catch in California (2004–2021). Bycatch ratios were calculated for each year by dividing the observed catch of eulachon (numbers) by the observed weight (in mt) of retained ocean shrimp. A fleet-wide bycatch estimate (number of fish) was obtained by multiplying the bycatch ratios by fleet-wide ocean shrimp landings. 95% bootstrapped confidence intervals (CI) are provided for the estimates. Asterisks (*) signify strata with fewer than three observed vessels. Double dashes (--) signify unobserved strata. Any missing counts were estimated using a year-specific linear weight-count regression and data from all other eulachon observations in the pink shrimp fishery.

Year	Bycatch (number)	Retained eulachon (number)	Observed ocean shrimp landings (mt)	Bycatch ratio (number per mt of ocean shrimp)	95% CI	Percent landings observed	Fleet total ocean shrimp landings (mt)	Fleet total bycatch estimate (number)	95% CI
2004	*	*	*	9.82	0.00 40.74	*	992.3	9,745	352 40,425
2005	*	*	*	9.82	n/a n/a	*	859.1	8,437	n/a n/a
2006	--	--	--	--	-- --	--	63.5	--	-- --
2007	*	*	*	38.75	11.66 90.37	*	288.9	11,194	3,368 26,107
2008	*	*	*	24.06	3.45 77.25	*	945.5	22,744	5,910 73,038
2009	*	*	*	86.85	n/a n/a	*	1,183.5	102,782	n/a n/a
2010	40,047	0	265.5	150.82	15.41 395.87	15.0	1,770.9	267,080	40,047 701,036
2011	60	0	420.6	0.14	0.06 0.25	12.6	3,332.9	475	203 838
2012	42,031	0	347.6	120.92	54.45 215.42	12.5	2,790.6	337,437	151,938 601,147
2013	1,535	0	359.8	4.27	0.97 8.68	9.2	3,915.3	16,705	3,794 33,971
2014	93,580	0	597.5	156.61	62.85 277.75	15.5	3,845.0	602,169	241,639 1,067,945
2015	216,541	0	334.7	647.05	281.38 1,173.04	9.7	3,452.9	2,234,225	971,606 4,050,448
2016	11,759	0	311.7	37.72	12.39 81.15	22.7	1,370.2	51,688	16,976 111,195
2017	5	0	241.8	0.02	0.00 0.08	16.0	1,510.0	31	5 128

Table A7 (Continued).

Year	Bycatch (number)	Retained eulachon (number)	Observed ocean shrimp landings (mt)	Bycatch ratio (number per mt of ocean shrimp)	95% CI	Percent landings observed	Fleet total ocean shrimp landings (mt)	Fleet total bycatch estimate (number)	95% CI
2018	559	0	365.2	1.53	1.04 2.08	16.0	2,288.4	3,503	2,392 4,745
2019	169	0	204.2	0.83	0.30 1.30	18.0	1,133.4	938	342 1,477
2020	3,472	0	152.7	22.73	1.01 37.86	43.0	355.6	8,083	3,472 13,463
2021	n/a	n/a	n/a	n/a	n/a n/a	n/a	0.0	n/a	n/a n/a

Table A8. Total estimated bycatch of eulachon (mt and number of individuals) in ocean shrimp fisheries observed by the West Coast Groundfish Observer Program (WCGOP) from 2004–2021. Ocean shrimp fisheries were not observed in 2006. Dashes (--) signify years when the sector was not observed.

	Eulachon bycatch (mt)				Eulachon bycatch (numbers of fish)			
Year	Washington	Oregon	California	Coastwide bycatch	Washington	Oregon	California	Coastwide bycatch
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

Table A8 (Continued).

	Eulachon bycatch (mt)				Eulachon bycatch (numbers of fish)			
Year	**Washington**	**Oregon**	**California**	**Coastwide bycatch**	**Washington**	**Oregon**	**California**	**Coastwide bycatch**
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

Table A9. Ocean shrimp trawl observer coverage rates, 2004–2021. Total trips, tows, vessels and ocean shrimp landings (mt) observed in the ocean shrimp trawl fishery. Coverage rates are computed as the observed proportion of total ocean shrimp landings, summarized from fish ticket landing receipts. Asterisks (*) represent confidential data. Double dashes (--) represent unobserved years. Data from Somers et al. (2022b) and Tables A2–A4.

	Observed				Fleetwide Total	Coverage Rate
Year	Number of vessels	Number of trips	Number of tows	Observed ocean shrimp landings (mt)	Ocean shrimp landings (mt)	Percent ocean shrimp landings observed
2004	*	*	*	*	8,969.7	*
2005	*	*	*	*	10,860.3	*
2006	--	--	--	--	8,399.7	--
2007	*	*	*	*	10,934.9	*
2008	*	*	*	*	15,374.6	*
2009	*	*	*	*	14,412.2	*
2010	54	126	1,708	2,371.9	20,356.8	12%
2011	60	186	2,673	4,103.8	29,560.1	14%
2012	69	200	2,819	3,987.8	29,321.6	14%
2013	69	153	1,977	3,299.8	31,611.0	10%
2014	66	176	2,176	3,837.2	41,294.5	9%
2015	75	254	3,761	4,740.0	46,408.9	10%
2016	82	244	3,843	3,725.4	23,881.7	16%
2017	73	180	2,793	2,282.6	15,009.3	15%
2018	79	207	3,493	3,113.4	22,335.5	14%
2019	81	204	3,416	2,590.9	17,479.4	15%
2020	32	70	920	1,187.2	26,208.8	5%
2021	34	77	908	1,609.3	27,420.4	6%

Table A1020. Observed bycatch weight (mt) by year of unidentified smelt, and osmerid smelt species other than eulachon in U.S. West Coast ocean shrimp fisheries (WA, OR, and CA combined) from 2004–2021. Shrimp fisheries were not observed in 2006. Asterisks (*) represent confidential data. Data available in Groundfish Expanded Mortality Multiyear (GEMM) database at NWFSC/FRAM Data Warehouse - GEMM Fact Layer Metadata, online at: https://www.nwfsc.noaa.gov/data/metadata/observer.gemm_fact. Shrimp landings available in Somers et al. (2022b).

	Unidentified smelt	Unidentified non-eulachon smelt	Whitebait smelt	Night smelt	Rainbow smelt	Longfin smelt	Capelin	Surf smelt	Observed shrimp landings	Percent ocean shrimp landings observed	Fleetwide shrimp landings
2004	60.277	--	0.687	0.754	--	--	--	--	*	*	8,969.7
2005	21.914	--	1.659	--	--	--	--	1.828	*	*	10,860.3
2006	--	--	--	--	--	--	--	--	--	--	8,399.7
2007	6.367	--	0.001	3.222	--	--	0.022	--	*	*	10,934.9
2008	27.298	--	0.048	--	--	--	--	0.196	*	*	15,374.6
2009	0.565	--	6.659	0.793	0.696	--	--	--	*	*	14,412.2
2010	2.545	--	3.421	0.498	--	--	--	0.002	2,371.9	12%	20,356.8
2011	15.216	0.370	20.117	10.072	--	--	--	0.007	4,103.8	14%	29,560.1
2012	23.864	30.609	71.513	--	--	--	--	--	3,987.8	14%	29,321.6
2013	19.576	40.150	31.917	--	--	--	--	0.002	3,299.8	10%	31,611.0
2014	16.733	101.482	125.257	--	--	--	--	--	3,837.2	9%	41,294.5
2015	4.192	30.398	9.387	--	--	0.001	--	--	4,740.0	10%	46,408.9
,2016	0.063	5.267	1.141	--	--	--	--	0.004	3,725.4	16%	23,881.7
2017	--	1.045	--	--	--	--	--	--	2,289.3	15%	15,009.3
2018	0.098	3.981	--	0.078	--	--	--	--	3,113.4	14%	22,333.6
2019	0.335	14.493	--	--	--	--	--	0.001	2,582.6	15%	17,479.4
2020	--	53.046	--	--	--	--	--	--	1,187.2	5%	26,208.8
2021	0.221	13.782	0.002	--	--	--	--	--	1,609.3	6%	27,420.4

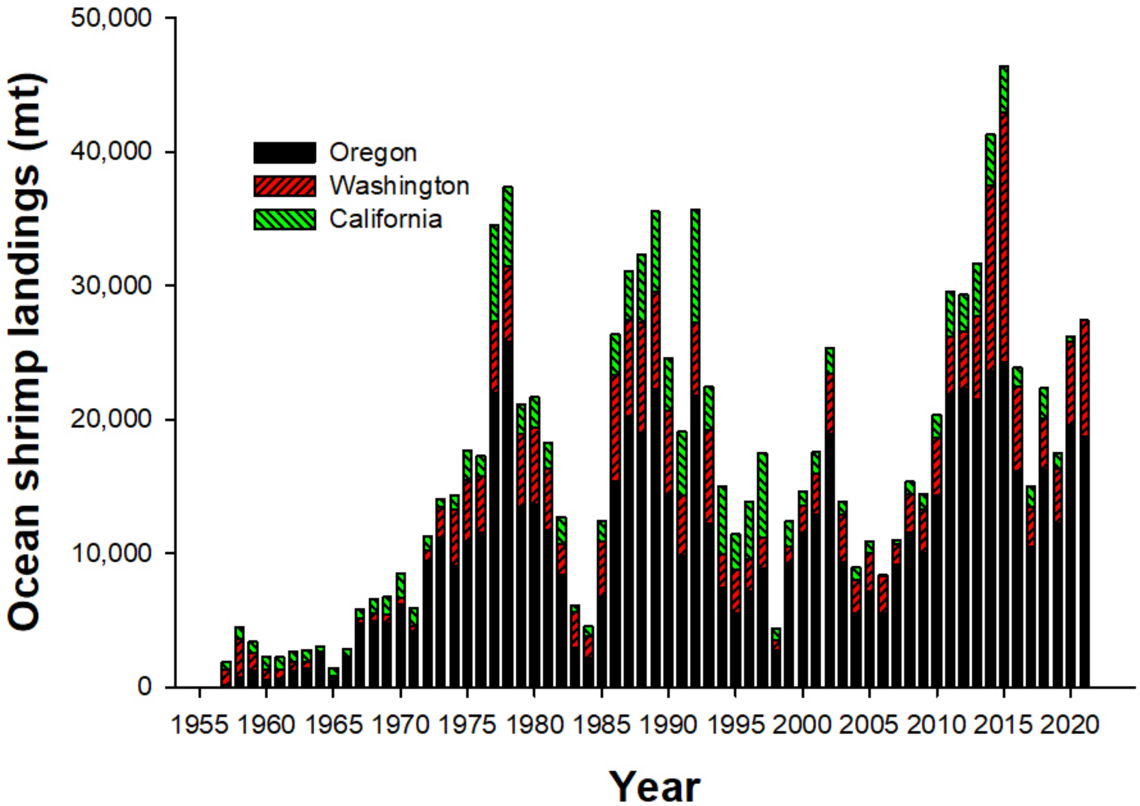

Figure A1. Commercial landings (mt) in ocean shrimp trawl fisheries off the U.S. West Coast through 2021. No landings of ocean shrimp were reported in California in 2020. Data from CDFW (www.wildlife.ca.gov/Fishing/Commercial/Landings), Saelens (1983), Wargo and Ayres (2016, 2017a, 2018, 2019, 2020), Groth et al. (2017, 2018, 2019, 2021, 2022), Groth and Smith (2020), Wargo et al. (2021, 2022), and Somers et al. (2022b).

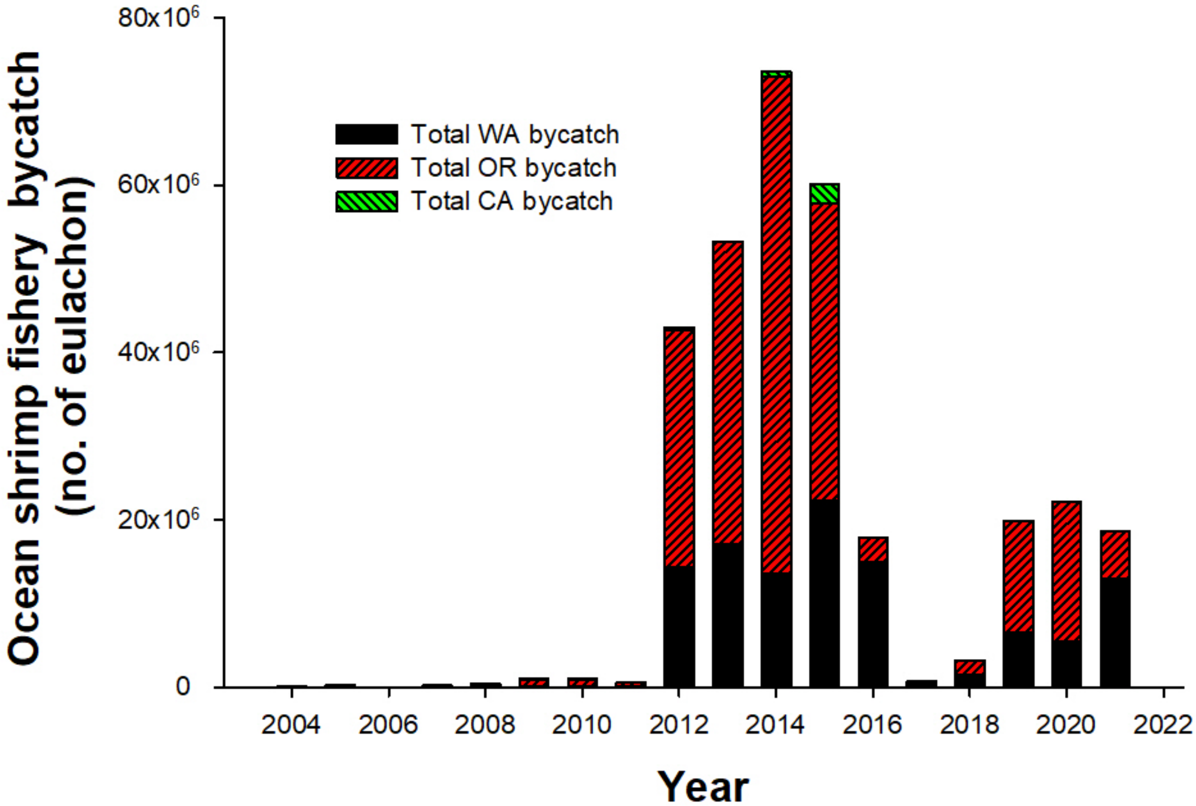

Figure A2. Estimated total mean bycatch of eulachon in the California, Oregon (2004–2021), and Washington (2010–2021) ocean shrimp trawl fisheries. Ocean shrimp fisheries were not observed in 2006.

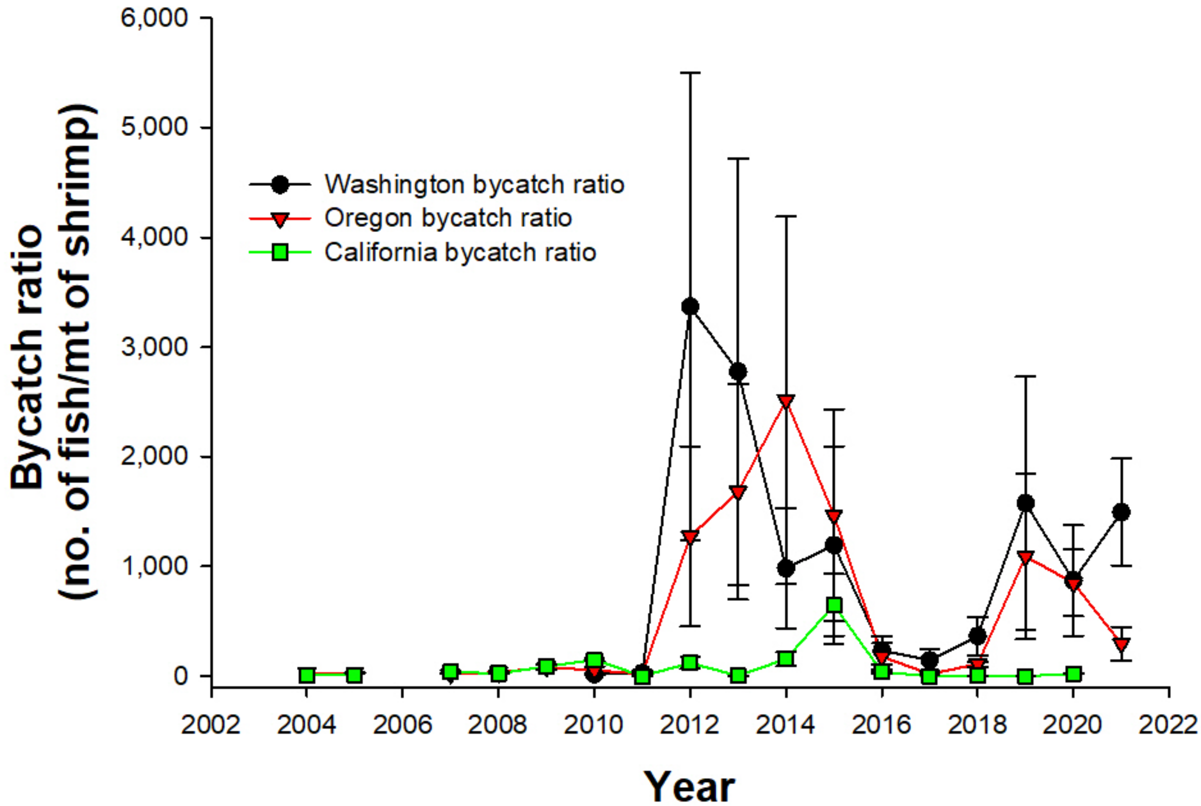

Figure A3. Estimated bycatch ratios of eulachon in the California, Oregon (2004–2021), and Washington (2010–2021) ocean shrimp trawl fisheries. 95% bootstrapped confidence intervals (CI) are provided for the estimates. Ocean shrimp fisheries were not observed in 2006.