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Observed and Estimated Bycatch of Eulachon in 2002–2015 US West Coast Groundfish Fisheries

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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, 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 west coast groundfish fishery from 2002–2015. 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 subpopulations 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 (NMFS 2010). A recent five-year review (Gustafson et al. 2016) resulted in a recommendation and final rule that the DPS remain classified as a threatened species (NMFS 2016, NMFS-WCR 2016).

Across 14 years of observation (2002–2015), a total of 11,968 individual eulachon were estimated to have been caught as bycatch in all groundfish sectors of the U.S. west coast groundfish fishery. About 89% of this bycatch of eulachon occurred during the five year period from 2011–2015, when efforts to identify eulachon in the bycatch of these fisheries became a priority and when other indices of eulachon abundance were highly positive. The Biological Opinion states that take of eulachon in combined LE groundfish bottom trawl and at-sea hake fisheries was not expected to be more than 1,004 fish per year. This level of take was exceeded in 2011, 2013, and 2014 when an estimated bycatch of 1,621; 5,113; and 3,075 eulachon were estimated to have been taken in all observed U.S. west coast groundfish fisheries combined. In 2011, 78% of the bycatch occurred in the catcher-processor sector of the at-sea Pacific hake fishery; in 2013, 81% of the bycatch of eulachon occurred in the shoreside Pacific hake fishery sector; and in 2014, 91% of the eulachon bycatch occurred in the non-hake bottom and midwater groundfish sector.

Several indices of eulachon abundance have shown dramatic increases beginning in 2011, to levels not seen since 2002, which may explain why the BiOp eulachon bycatch take level was exceeded in 2011, 2013, and 2014. The eulachon bycatch take level of 1,004 fish, as articulated in the BiOp, was based on bycatch estimates acquired during 2002–2010 when eulachon abundance was severely depressed. 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. Federal regulations in the commercial groundfish fishery currently mandate 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. Therefore it is likely that most eulachon would readily pass through the mesh openings of groundfish trawl nets and it is difficult to envision how eulachon are retained in groundfish trawl nets unless the codend becomes plugged. Thus the observed eulachon bycatch in the groundfish fishery sectors reported in this document may represent a small fraction of all eulachon encounters with bottom and midwater trawl fishing gear in the groundfish fishery. 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.

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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 2012, p. 127), 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. This documents updates information on eulachon bycatch that was provided in Gustafson et al. (2015a) with the addition of data for the years 2014 and 2015. 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 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 southern eulachon include climate change impacts on ocean and freshwater habitat, bycatch in offshore shrimp trawl fisheries, changes in downstream flow-timing and intensity due to dams and water diversions, and predation. These threats, together with large declines in abundance, indicated to the BRT that the southern DPS of eulachon was at moderate risk of extinction throughout all of its range (Gustafson et al. 2010, 2012). On 18 March 2010, NMFS published a final rule in the Federal Register to list the southern DPS of eulachon as threatened under the ESA (NMFS 2010). A recent five-year review (Gustafson et al. 2016) resulted in a recommendation and final rule that the DPS remain classified as a threatened species (NMFS 2016, NMFS-WCR 2016). 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 onto 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 2011). Over 90 species are listed in the groundfish FMP, including a variety of rockfish, flatfish, roundfish, skates, and sharks. These species are found 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 limited entry permit. The total number of limited entry 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 native tribal commercial fishers in Washington State that have treaty rights to fish groundfish. Tribal fisheries are not included in this report, with the exception of the observed tribal at-sea Pacific hake (*Merluccius productus*) (also known as whiting) sector.

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 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 2011–2014:

- 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 primarily 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 must operate within defined boundaries in waters off northwest Washington. Tribal catch can be delivered to a contracted mothership by catcher vessels for processing or be caught and processed by a contracted catcher-processor.
- Shoreside midwater Pacific hake trawl: 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.

Beginning in 2015 the components of the IFQ fishery previously defined as the midwater non-hake trawl and the shoreside Pacific hake midwater trawl were redefined based on the proportion of Pacific hake in the catch in a trip:

- Shoreside midwater Pacific hake trawl (more than 50% of catch by a vessel on a given day is Pacific hake): Midwater trawl nets are used to catch Pacific hake. Catch is delivered to shore-based processors.
- Shoreside midwater rockfish trawl (less than 50% of catch by a vessel on a given day is Pacific hake): Midwater trawl nets are used to catch rockfish, typically widow and yellowtail. 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.

Open Access (OA) Federal sectors

- 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.

Open Access (OA) state sectors

- OA ocean shrimp[1] (*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 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.

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 Program 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 3-200 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 in the 0-3 mile state territorial zone to carry observers.

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 and ocean shrimp trawl fisheries. The A-SHOP observes the IFQ fishery that delivers Pacific hake at-sea including: catcher-processor, mothership, and tribal catch delivered at sea to motherships. Details on how fisheries observers operate in both the IFQ (aka

[1] *Pandalus jordani* is known as the smooth pink shrimp in British Columbia, ocean pink shrimp or smooth pink shrimp in Washington, pink shrimp in Oregon, and Pacific ocean shrimp in California. Herein we use the common name "ocean shrimp" in reference to *P. jordani* as suggested by the American Fisheries Society (McLaughlin et al. 2005). The common name "pink shrimp" has been assigned to *Farfantepenaeus duorarum*, a commercial species in the South Atlantic and Gulf of Mexico (McLaughlin et al. 2005).

Catch Share) and Non-IFQ (aka Non-Catch Share) sectors can be found online at: http://www.nwfsc.noaa.gov/research/divisions/fram/observation/index.cfm.

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 2002–2015. 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, 2011a; Al-Humaidhi et al. 2012; Gustafson et al. 2015a, b) have provided data on estimated bycatch of eulachon in U.S. west coast commercial fisheries, which were derived from the WCGOP and A-SHOP data. Annual tables of observed bycatch, not extrapolated to the fleetwide level, can also be found online on the NWFSC Fisheries Observation Science website at: https://www.nwfsc.noaa.gov/research/divisions/fram/observation/data_products/sector_products.cfm#obs.

In this document, bycatch ratios for eulachon are reported as weight and as number of individual fish caught per metric ton (mt) of total fish caught 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 2002–2015.

The following commercial groundfish fishery sectors have observed eulachon bycatch during 2002–2015:

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

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. Commercial groundfish fisheries observed by the WCGOP that did not have any observed bycatch of eulachon from 2002–2015 include:

- LE bottom trawl – targeting California halibut
- OA bottom trawl – targeting California halibut
- LE fixed gear primary sablefish
- LE fixed gear non-primary sablefish
- OA fixed gear
- Nearshore fixed gear state-permitted (Oregon and California)

The WCGOP also observes some fisheries that incidentally catch groundfish, including the state permitted ocean shrimp trawl fisheries. The majority of eulachon bycatch off the U.S. west coast occurs in state operated commercial ocean shrimp trawl fisheries in California, Oregon, and Washington. 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 Biological Opinion 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 Biological Opinion, eulachon bycatch in ocean shrimp fisheries is reported in Appendix A; 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 observer. In 2015, exempted fishing permits (EFP) were issued for a subset of the fleet to carry electronic monitoring (EM) systems for compliance and quota management rather than observers; these vessels are still required to carry an observer for additional scientific data collection on ~ 20 to 30% of trips.

Prior to 2011, limited entry groundfish bottom trawl permits were selected for observation using stratified random sampling. Details on the selection process for observer coverage prior to 100% observer implementation in 2011 can be found online at: http://www.nwfsc.noaa.gov/research/divisions/fram/observation/data_products/bottom_trawl.cfm. More background information on the West Coast Groundfish Trawl Catch Share Program and the Fisheries Observation Science Program of the NWFSC (including estimates of observer coverage, observed catch, and a summary of observed fishing depths for each sector) can be found online at: http://www.nwfsc.noaa.gov/research/divisions/fram/observation/index.cfm.

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. Currently, there are three major components to 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 off Washington that uses gear similar to that used in the non-tribal fisheries. The catcher-processor sector "entered into a cooperative agreement (co-op) which split the hake quota into individual fishing quotas by company" in 1997, and "the mothership sector entered into a co-op for the first time as west coast trawl fisheries began operating under a catch shares program" in 2011 (NWFSC 2016). 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 vessels were voluntarily carrying 2 observers for every fishing day. Regulations requiring 2 observers went into effect in 2004.

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; 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 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 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 the shoreside midwater rockfish sector is reported separately. Delivering unsorted catch is necessary to limit handling of the catch and ensure that landed Pacific hake 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 hake functions as a full-retention fishery, 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, a subset of these fleets applied for EFPs 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.

Amount and Extent of Take

The Biological Opinion (BiOp) on Continuing Operation of the Pacific Coast Groundfish Fishery (PCGF) (NMFS 2012, p. 121) 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 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 BiOp language above, 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, Suuronen and Erickson 2010), "collateral mortality" (Broadhurst et al. 2006), "cryptic fishing mortality" (Gilman et al. 2013), or "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). Given that federal regulations in the groundfish fishery mandate 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 (West Coast Region 2016, p. 258), 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). The Magnuson-Stevens Fishery Conservation and Management Reauthorization Act of 2006 defines 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 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 WCGOP training manuals (NWFSC 2017). A-SHOP information and documentation on data collection methods can be found in the A-SHOP observer manual (NWFSC 2016).

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 on the WCGOP Data Processing webpage (http://www.nwfsc.noaa.gov/research/divisions/fram/observation/data_processing.cfm). Data processing was applied prior to the analyses presented in this report. For a complete list of groundfish species defined in the Pacific Coast Groundfish Fishery Management Plan see PFMC (2011).

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. Fish tickets 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 on the WCGOP website under the Data Processing Appendix (https://www.nwfsc.noaa.gov/research/divisions/fram/observation/data_processing.cfm). All data processing steps specific to this report are described in the bycatch estimation methods section below.

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 (2011–2015), (3) IFQ non-hake midwater trawl (2011–2015), (4) IFQ shoreside Pacific hake / rockfish fishery

(2011–2015), (5) at-sea Pacific hake mothership fishery (2002–2015), (6) at-sea Pacific hake catcher-processor fishery (2002–2015), and (7) at-sea Pacific hake tribal mothership fishery (2002–2011, no effort in this sector occurred in 2013–2015, and data for 2012 is confidential as fewer than 3 vessels were observed).

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 2002–2015 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 rockfish for shoreside midwater trawl Pacific hake/rockfish fishery. 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 (a.k.a., bycatch rate) per stratum was computed from observer data as the observed catch (number or weight) of eulachon divided by the observed retained weight of target species (or species groups). Total eulachon bycatch at the 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 over 90 fish species listed in the FMP (PFMC 2011), including over 64 rockfish species, 12 flatfishes, 6 roundfishes, 6 sharks and skates, ratfish, finescale codling, and Pacific rattail grenadier. To maintain the same stratification as in a previous report (Al-Humaidhi et al. 2012), 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 lbs 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

Since 2011, the U.S. West Coast groundfish trawl fishery has been managed under the Catch Share Program, which led to the establishment of Individual Fishing Quotas (IFQs). Under this program, all participating vessels are required to carry a WCGOP observer on all fishing trips, resulting in 100% observer coverage; in 2015, vessels fishing bottom or midwater trawl gear or pot could participate in an EFP and use electronic monitoring rather than an observer. In addition, permit holders with IFQ and a trawl endorsement can fish multiple gear types (although not within the same trip), including bottom or midwater trawl, hook and line, or pot gear. 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 includes midwater non-hake trawl; in 2015, this section includes only bottom trawl, and all shoreside midwater trawl is reported separately.

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 annual, coastwide the unsampled catch was less than 0.7% of the total landed weight of groundfish species during 2011–2015. 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.

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. The eulachon bycatch is reported by year and by each at-sea hake fishery sector: catcher-processors, motherships, and tribal catch delivered at-sea. All vessels fishing in the at-sea hake fishery carry two A-SHOP observers for every fishing day (i.e., 100% coverage).

Though very rare, entire hauls may not be sampled due to unforeseen circumstances (e.g., sickness of observers). These unsampled hauls need to be expanded at the strata level. Typically greater than 99% of hauls are sampled each year, therefore the unsampled portion to be expanded 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 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)

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

Catch shares: IFQ shoreside midwater Pacific hake trawl (2015)

Prior to 2015, this sector was defined as either the shoreside hake or IFQ non-hake midwater trawl fisheries; in 2015, this definition was updated to be consistent with new regulations. This IFQ fishery consists of trips fishing midwater trawl gear landing more than 50% Pacific hake by weight on a landing day. The shoreside midwater trawl fishery functions as a full-retention fishery, so only at-sea discards are observed by WCGOP; additional discards occur on land, so a percent discard is not calculated. All non-EM IFQ vessels carry an observer on every fishing trip.

Catch shares: IFQ shoreside midwater rockfish trawl (2015)

Prior to 2015, this sector was defined as either the shoreside hake or IFQ non-hake midwater trawl fisheries, until the definition was updated to be consistent with new regulations. This IFQ fishery consists of trips fishing midwater trawl gear landing less than 50% Pacific hake by weight on a landing day The shoreside midwater trawl fishery functions as a full-retention fishery, so only at-sea discards are observed by WCGOP; additional discards occur on land, so a percent discard is not calculated. All non-EM IFQ vessels carry an observer on every fishing trip.

Measures of Uncertainty

As a measure of uncertainty for the estimated bycatch ratio, lower and upper limits of the 95% confidence interval were estimated with a 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 technique 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 that encountered eulachon during 2011–2015, only one confidential stratum occurred, the winter season of 2008 in the Washington LE bottom trawl fishery sector.

Observer Coverage

Reasonable and prudent non-discretionary measures for the ESA Section7(a)(2) 2012 Biological Opinion includes "…identify[ing] goals for minimum [observer] coverage levels to achieve fleet-wide take estimates for eulachon…and a plan for implementation." (p. 124, see also eulachon conservation recommendation, p. 129). Unfortunately, the Biological Opinion provides no guidance on the metrics needed to identify minimum goals for appropriate observer coverage. Observer coverage is directly proportional to sampling effort and thus impacts both the accuracy and precision of bycatch estimates. Therefore, to address the goals for minimum observer coverage, the NWFSC Observer program embarked on a preliminary study of the effect of observer coverage on the accuracy and precision of take estimates (Jannot et al. 2015 preliminary study). The accuracy of an estimate is the difference between the mean of the sample and the true population value, and any difference between those values represents bias. All bycatch estimates are subject to some level of bias that has numerous potential sources (NMFS 2004). In this preliminary work, we only investigate one source of potential bias – the use of a ratio estimator. To the best of our knowledge, NMFS has not tried to identify tolerance level for bias in bycatch estimates. Observer coverage not only influences the magnitude of bycatch estimates, but also the precision of those estimates. Unlike bias, NMFS has a precision goal for bycatch estimates of 20-30% for the coefficient of variation (CV, ratio of the standard error to the estimate itself; NMFS 2004). Lower CVs indicate a more precise estimate.

Non-parametric bootstrap resampling and a ratio estimator were used to estimate the fleet-wide catch weight of eulachon in the IFQ bottom trawl fishery at varying levels of observer coverage. Because there is 100% observer coverage required in the IFQ fishery since 2011, a complete census of the population (vessels) occurs each year. Therefore we know very precisely and accurately the actual fleet-wide eulachon catch weight. We use catch weight rather than count of individuals because this work is part of a larger study examining the influence of observer coverage on fishing mortality in fish, by weight. Work is underway to incorporate similar studies on counts of individuals. The goal of the bootstrapping is to resample vessels within the IFQ fishery at observer coverage rates less than 100% (i.e., 5% to 90% at 5% intervals) to examine the effect on the accuracy and precision of bycatch estimation. Resampling vessels simulates the historical vessel selection process used to randomly select vessels for observation. The target observer coverage rate was based on the number of vessels selected for each bootstrap sample. Observed coverage (i.e., realized coverage rate) is calculated from the amount of landed groundfish in each bootstrap sample (wt. of 'observed'[i.e., sampled] landed groundfish /total wt. of landed groundfish) and therefore is analogous to the WCGOP observer coverage rates which are based on landings at the end of the year, after observation.

For each level of target coverage, we estimated bycatch using the ratio estimator described above. Vessels were randomly drawn 2000 times within each of the year (2011–13) and season (summer = Apr-Oct; winter = Nov-Mar) strata for each specific level of target coverage. The year-season strata match the stratification used in the annual observer groundfish mortality report to estimate bycatch when observer coverage was less than 100% in LE bottom trawl sector (Bellman et al. 2011b). Therefore, strata in this study of observer coverage do not match strata used to estimate bycatch in this report. For each level of coverage, bycatch ratios were constructed from the sampled data (i.e., 'observed' sampled eulachon weight divided by observed landed weight of all groundfish, except Pacific hake), and then multiplied by the total fleet-wide retained catch (all groundfish in the stratum, except Pacific hake) to obtain estimated bycatch within each stratum. This simulates the use of ratio estimators to estimate bycatch by WCGOP. Bycatch weights were then summed across strata to obtain coast-wide estimates of bycatch for each level of target coverage for each year (2011–15). The coast-wide standard deviation of bycatch for each year-stratum-target coverage level was estimated using the bootstrap samples. Bias (|actual - boot|/actual), error statistics, and coverage statistics were calculated for each year-stratum-target coverage level.

Results

Eulachon Bycatch

Eulachon were not observed as bycatch in the LE bottom trawl fishery in Washington from 2002–2010 (Table 2). From 2011 to 2015, a total of 442 individual eulachon were estimated as fleet-wide bycatch in the Washington IFQ non-hake bottom and midwater trawl fishery (Table 3). However, no eulachon were observed or estimated as bycatch in the Washington sector in 2015. Within the Oregon portion of the LE bottom trawl fishery, eulachon bycatch occurred in four of the nine years from 2002–2010 with 80% (783/974) of this estimated bycatch occurring in the year 2002 (Table 4). However, no eulachon bycatch was recorded in the Oregon LE bottom trawl fishery in 2004, 2005, 2006, 2008, or 2010 (Table 4). Between 2011 and 2015, the Oregon IFQ bottom trawl fishery had an estimated eulachon bycatch of 3,972 individual fish with nearly 63% (2,516 individuals) of this total occurring in the year 2014 (Table 5). Eulachon bycatch in the Oregon sector declined from a high point in 2014 to an estimated

641fish during 2015 (Table 5). Eulachon were rarely caught in the California LE bottom trawl fishery; 5 fish in 2004 and 22 fish in 2010 (Table 6). Not a single eulachon was recorded as bycatch in the California IFQ bottom and midwater trawl fishery from 2011–2014. Eulachon bycatch in this California sector in 2015, consisted of an estimated 2 total fish (Table 7).

Eulachon were encountered sporadically in the at-sea Pacific hake fishery as bycatch. The at-sea catcher-processor sector of the Pacific hake fishery has caught more eulachon than other at-sea Pacific hake sectors (Table 8). No eulachon bycatch was reported in the catcher-processor sector from 2002–2005, or in 2010. The estimated eulachon bycatch in the catcher-processor sector was 147; 1,268; and 242 fish in 2006, 2011, and 2014, respectively (Table 8). The bycatch estimate in 2011 amounted to 69% of the total eulachon bycatch estimate of 1,841 fish between 2002 and 2015. In all other years fewer than 40 individual eulachon were observed in the catcher-processor Pacific hake sector as bycatch, except for 2015 when an estimated 56 fish were caught (Table 8).

The non-tribal mothership Pacific hake sector had a total estimated eulachon bycatch of 379 individual fish between 2002 and 2015, with 73% of this bycatch occurring in 2013 (277 fish). No eulachon bycatch occurred in 2002–2006 or in 2010 or 2015, and fewer than 10 individual fish were estimated caught in 2007, 2008, 2009 and 2012 (Table 8). Eulachon bycatch estimate in the tribal mothership Pacific hake fishery was 32 fish in 2009 and 160 fish in 2011. Eulachon bycatch was not observed in this sector from 2002–2008 or in 2010. The tribal mothership sector did not participate in the Pacific hake fishery in 2013–2015, and fewer than three vessels were observed in 2012 (Table 8).

In 2015, the shoreside midwater sector of the IFQ Pacific hake fishery was reported separately as either a midwater Pacific hake sector or as a midwater rockfish 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; when landings were less than 50% hake by weight, the vessel’s landings were reported in the midwater rockfish sector. No recorded eulachon bycatch occurred in either the midwater hake or the midwater rockfish sectors in 2015 (Table 9).

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 2002–2015 is provided in Table 10. From 2002–2015, all groundfish sectors caught an estimated 11,968 individual eulachon. About 89% of this bycatch of eulachon occurred during 2011–2015, when efforts to identify eulachon in the bycatch of these fisheries became a priority and when other indices of eulachon abundance were highly positive (see Table 10 and Discussion).

Observer Coverage

Currently 100% of landings in the IFQ bottom trawl fleet are observed either directly by an observer or through an electronic monitoring system, which also includes LE California halibut tows. In many fisheries, it is not physically or economically feasible to observe all fishing effort and bycatch. For example, prior to 2011 in the LE bottom trawl fleet, target observer coverage was 20–30%, and realized observer coverage rates varied between 14–24% of total landings from 2002–2010 (Somers et al. 2016). As EM has increased in parts of the catch shares fleet, those sectors not fishing using maximized retention are now covered by scientific observers at a target of 20–30% of the landings observed.

Currently there are no national recommendations regarding acceptable levels of bias in bycatch estimation (NMFS 2004). Preliminary results from work conducted by NWFSC scientists indicates that observing 20–30% of the total landings in the bottom trawl fleet might lead to estimates of eulachon bycatch that are relatively unbiased and only slightly larger than the true value (Table 12, Fig. 1; Jannot et al. unpublished work in progress). This preliminary work supports the well-known observation that ratio estimators consistently over-estimate the true value (Pearson 1897), particularly when data are stratified and sample sizes within a stratum are small to moderate (Hutchinson 1971, Rao and Beegle 1967, Williams 1961). Our study suggests that eulachon bycatch estimates are only slightly biased and therefore are reasonable, but likely conservative. Other sources of bias have not been evaluated (NMFS 2004).

The NWFSC Fisheries Observation Science Program is striving to achieve the NMFS recommended precision goal of 20–30% coefficient of variation (CV) around bycatch estimates (NMFS 2004). Preliminary results indicate that achieving this precision goal for eulachon bycatch in the IFQ bottom trawl fishery would be challenging to reach if coverage were to fall to less than 100%. Bootstrapped estimates of CV around eulachon bycatch in the IFQ bottom trawl fishery are estimated to be 40–50% at 90% observer coverage. NMFS recognizes that this is a precision goal for the fishery as a whole and many circumstances might prevent the attainment of this goal. For example, increasing precision requires increasing observer coverage which is costly and might not be the most efficient use of public resources (NMFS 2004). Other issues preventing this goal might include, logistical and safety considerations and other objectives of the NWFSC Fisheries Observation Science Program (NMFS 2004). This work is preliminary and the NWFSC scientists are working to refine these methods and estimates to help guide decisions regarding observer coverage.

The preliminary work on observer coverage presented here is based on the IFQ bottom trawl fleet only. Caution should be used when trying to apply these results to other fishery sectors. The WCGOP is still working to understand how these results might apply to the ocean shrimp fishery and other fishery sectors observed at less than 100%.

Discussion

The Biological Opinion (NMFS 2012, p. 121, a.k.a. BiOp) states that take of eulachon in combined LE groundfish bottom trawl and at-sea hake fisheries was not expected to be more than 1,004 fish per year. In 2011, 1,624 eulachon were estimated caught in these two fisheries, exceeding the recommended take level. Seventy-eight percent of this bycatch occurred in the catcher-processor sector of the at-sea Pacific hake fishery in 2011 (Table 10). Take did not exceed the BiOp take level in 2012 (n = 191) or 2013 (n = 974) in these fishery sectors (Table 10). However, when the shoreside Pacific hake fishery sector is included in the analysis, the BiOp level of eulachon take was again exceeded in 2013, when a total of 5,113 bycaught eulachon were estimated in all U.S. west coast groundfish fisheries combined. The shore-based

Pacific hake fishery accounted for 81% (4,139 eulachon) of the total 2013 bycatch of eulachon (Table 10).

In 2014, the incidental take of eulachon in combined groundfish fisheries of 3,075 fish again exceeded the 1,004 annual take limit as proposed in the BiOp (NMFS 2012). The non-hake bottom and midwater groundfish IFQ sector accounted for 91% of coastwide eulachon bycatch in groundfish fisheries in 2014. Incidental take declined to an estimated 699 eulachon in 2015, and the non-hake bottom and midwater groundfish IFQ sector was responsible for 92% of all eulachon bycatch in the groundfish fisheries (Table 10).

Several indices of eulachon abundance have shown dramatic increases since 2011. Spawning stock biomass (SSB) estimates of eulachon in the Columbia River (Fig. 2) 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. 3) both increased by an order of magnitude between 2010 and 2016. This level of eulachon abundance had not been observed since 2001, before the initiation of the WCGOP program. Increasing eulachon abundance in recent years might partially explain why the eulachon bycatch take level exceeded the BiOp recommended levels in 2011, 2013, and 2014. The previous bycatch peak (783 individuals) occurred in the Oregon portion of the LE bottom trawl fishery in 2002, which coincided with a peak CPUE in the West Coast Vancouver Island small mesh bottom trawl surveys (Fig. 3; Gustafson et al. 2016). Landings in the Columbia River commercial fishery (Gustafson et al. 2010, their fig. 22) and estimates of eulachon SSB (Fig. 3) also previously peaked in 2001–2003, which is also consistent with high offshore abundance of eulachon during 2002.

Eulachon bycatch in U.S. west coast groundfish fisheries appears to be 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 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.

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. Given that federal regulations in the commercial groundfish fishery mandate 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 (West Coast Region 2016, p. 258), 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. This is illustrated by the fact that eulachon appear to easily pass between the ¾ inch wide rigid-grate bars of bycatch reduction devices installed in shrimp trawl nets (see Appendix). Thus the low levels of 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. In fact, it is difficult to imagine how eulachon are retained in groundfish trawl nets unless the codend becomes plugged, because fish the size of eulachon should readily pass through the mesh openings of groundfish trawl nets.

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 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. Other smelt species (Family Osmeridae) occasionally encountered as bycatch in the LE bottom trawl groundfish fishery include surf smelt (*Hypomesus pretiosus*), whitebait smelt (*Allosmerus elongatus*), night smelt (*Spirinchus starksi*), rainbow smelt (*Osmerus mordax*), and capelin (*Mallotus villosus*) (Table 12). Based on WCGOP data available on the NWFSC website (http://www.nwfsc.noaa.gov/research/divisions/fram/observation/data_products/sector_products.cfm), observed but unidentified smelt bycatch in the LE bottom trawl fishery was negligible in most years except for 2002 and 2004, when a respective 0.18 and 0.84 mt of unidentified smelt were observed coastwide (Table 12). Using bycatch ratios calculated by dividing metric tonnage of observed unidentified smelt by observed groundfish landings and multiplying these bycatch ratios by coastwide groundfish landings, an estimated 1.21 and 3.27 mt of unidentified smelt were estimated to have been taken as bycatch coastwide in the LE bottom trawl fishery in 2002 and 2004, respectively.

Very few "unidentified smelt" have been recorded as bycatch in the at-sea Pacific hake trawl fisheries with the exception of 2002, when 1,245 and 156 unidentified smelt were estimated to have been caught in the non-tribal and tribal sectors, respectively (Table 13). 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 the previous period of elevated eulachon abundance (Figs. 2–3). 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.

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 that "… the fact that bycatch does not appear on deck, does not mean that those fish have been released from the gear unimpaired and are capable of surviving." Various terms are used for these unobserved but ultimately lethal interactions with fishing gear, including: "unaccounted fishing mortality" (Chopin and Arimoto 1995, Suuronen 2005, ICES 2005, Suuronen and Erickson 2010); "collateral mortality" (Broadhurst et al. 2006); "cryptic fishing mortality" (Gilman et al. 2013); and "post release mortality" (Raby et al. 2014); among others. Looking beyond mortality, Wilson et al. (2014) have recently 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) recently 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. Thus the observed eulachon bycatch in the groundfish fishery sectors reported in this document may represent a small fraction of all eulachon encounters with bottom and midwater trawl fishing gear in the groundfish fishery.

Trawl-escape mortality studies have been reviewed by Chopin and Arimoto (1995), Suuronen (2005), Broadhurst et al. (2006), Suuronen and Erickson (2010), and most recently by 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 (*Theragra chalcogramma*) 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 et al. 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).

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Table 1. Generalized descriptions of U.S. west coast groundfish fisheries that have had observed bycatch of eulachon.

							Management	
Sector	**Sub-Sector**	**Permits**	**Gear(s)**	**Target(s)**	**Vessel length (m)**	**Depths (m)**	**2002-2010**	**2011-2015**
Limited Entry (LE) Trawl		Federal LE permit with trawl endorsement	Bottom trawl, Midwater trawl	Groundfish assemblage	11–29	Wide range	Cumulative two month trip limits; depth-based closures; 14-23% observer coverage	Individual Fishing Quotas (IFQ); 100% observer coverage or EM
At-Sea Hake	Mothership-Catcher Vessel (MSCV)	LE permit with MSCV endorsement	Midwater trawl	Pacific hake	26–45	53–460	Seasonal quotas for target and bycatch species of concern; 100% observer coverage	IFQ; seasonal; 100% observer
	Catcher-processors (CP)	LE permit with CP endorsement	Midwater trawl	Pacific hake	82–115	60–570	Same as At-Sea Hake MSCV	IFQ; seasonal; 100% observer
	Tribal	(none)	Midwater trawl	Pacific hake		53–460	Tribal; 100% observer coverage	Tribal; 100% observer coverage
Shoreside Hake / Rockfish		LE permit with trawl endorsement	Midwater trawl	Pacific hake	17–29	Wide range	Same as At-Sea Hake MSCV; Some EM	IFQ; Seasonal; 100% observer coverage or EM

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.

		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	318.2	0.00	na na	0.00	na na	23.9	1,322.4	0.0	na na	0	na na
	summer	0.0	0	155.9	0.00	na na	0.00	na na	14.3	1,089.6	0.0	na na	0	na na
2003	winter	0.0	0	132.7	0.00	na na	0.00	na na	9.7	1,371.0	0.0	na na	0	na na
	summer	0.0	0	59.1	0.00	na na	0.00	na na	8.8	674.2	0.0	na na	0	na na
2004	winter	0.0	0	343.3	0.00	na na	0.00	na na	38.3	895.7	0.0	na na	0	na na
	summer	0.0	0	188.5	0.00	na na	0.00	na na	19.7	958.3	0.0	na na	0	na na
2005	winter	0.0	0	174.2	0.00	na na	0.00	na na	17.3	1,004.3	0.0	na na	0	na na
	summer	0.0	0	426.5	0.00	na na	0.00	na na	21.1	2,026.3	0.0	na na	0	na na
2006	winter	0.0	0	92.2	0.00	na na	0.00	na na	17.5	528.0	0.0	na na	0	na na
	summer	0.0	0	304.9	0.00	na na	0.00	na na	23.1	1,317.6	0.0	na na	0	na na
2007	winter	0.0	0	170.9	0.00	na na	0.00	na na	23.6	723.1	0.0	na na	0	na na
	summer	0.0	0	63.6	0.00	na na	0.00	na na	7.2	879.7	0.0	na na	0	na na
2008	winter	*	*	*	0.00	na na	0.00	na na	*	794.0	0.0	na na	0	na na
	summer	0.0	0	324.4	0.00	na na	0.00	na na	34.8	931.2	0.0	na na	0	na na
2009	winter	0.0	0	366.6	0.00	na na	0.00	na na	25.9	1,415.3	0.0	na na	0	na na
	summer	0.0	0	397.0	0.00	na na	0.00	na na	31.2	1,274.0	0.0	na na	0	na na
2010	winter	0.0	0	282.5	0.00	na na	0.00	na na	22.8	1,237.3	0.0	na na	0	na na
	summer	0.0	0	221.9	0.00	na na	0.00	na na	24.9	891.6	0.0	na na	0	na na

Table 3. Observed and fleet-total weights and numbers of eulachon bycatch from IFQ-fishery bottom and midwater trawl vessels that landed their catch in **Washington** (2011–2015). Bycatch weights are in kilograms and groundfish landings are in metric tons. Note that catch share fisheries are sampled at close to 100%. Landings by the EM portion of this fleet are not included here.

	State observed				State fleetwide				
Year	Bycatch (kg of eulachon)	Bycatch (no. of eulachon)	Observed groundfish catch (mt)	Percent landings observed (%)	Fleet groundfish landings (mt)	Unobserved bycatch estimate (kg eulachon)	Unobserved bycatch estimate (no. of eulachon)	Fleet-total bycatch (kg eulachon)	Fleet-total bycatch (no. of eulachon)
2011	0.5	11	1,849.3	99.5	1,859.6	0.1	1.4	0.6	12
2012	0.0	1	2,250.7	98.6	2,281.9	0.0	0.1	0.1	1
2013	7.0	135	1,552.2	99.9	1,554.0	0.1	1.6	7.1	137
2014	11.5	278	883.1	99.7	885.7	0.6	14.3	12.1	292
2015[1]	0.0	0.0	409.2	100.0	409.2	0.0	0.0	0.0	0

1 – Catch and bycatch estimates during 2015 are based on observations of the bottom trawl fishery only.

Table 4. 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.

		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	79	654.1	0.01	0.00 0.03	0.12	0.00 0.41	15.3	4,288.8	40.6	6.2 136.5	515	79 1,778
	summer	2.1	40	538.0	0.00	0.00 0.01	0.07	0.00 0.22	14.8	3,645.4	14.5	2.1 43.4	268	40 798
2003	winter	0.4	10	898.2	0.00	0.00 0.00	0.01	0.00 0.03	19.2	4,667.3	2.2	0.4 6.7	52	10 149
	summer	0.0	0	576.1	0.00	na na	0.00	na na	12.5	4,625.5	0.0	na na	0	na na
2004	winter	0.0	0	1,230.3	0.00	na na	0.00	na na	27.0	4,555.0	0.0	na na	0	na na
	summer	0.0	0	1,032.7	0.00	na na	0.00	na na	18.9	5,449.7	0.0	na na	0	na na
2005	winter	0.0	0	1,268.8	0.00	na na	0.00	na na	26.2	4,850.8	0.0	na na	0	na na
	summer	0.0	0	1,271.9	0.00	na na	0.00	na na	21.8	5,826.4	0.0	na na	0	na na
2006	winter	0.0	0	855.4	0.00	na na	0.00	na na	19.7	4,347.9	0.0	na na	0	na na
	summer	0.0	0	1,215.7	0.00	na na	0.00	na na	18.3	6,644.1	0.0	na na	0	na na
2007	winter	0.0	0	877.4	0.00	na na	0.00	na na	14.2	6,158.9	0.0	na na	0	na na
	summer	0.1	13	1,199.4	0.00	0.00 0.00	0.01	0.00 0.04	18.2	6,598.0	0.5	0.1 1.6	72	13 244
2008	winter	0.0	0	1,401.0	0.00	na na	0.00	na na	17.5	7,999.9	0.0	na na	0	na na
	summer	0.0	0	1,922.9	0.00	na na	0.00	na na	24.4	7,868.0	0.0	na na	0	na na
2009	winter	0.0	0	2,204.7	0.00	na na	0.00	na na	24.4	9,030.6	0.0	na na	0	na na
	summer	0.7	16	1,901.7	0.00	0.00 0.00	0.01	0.00 0.03	23.8	7,984.5	3.1	0.7 9.7	67	16 208
2010	winter	0.0	0	902.7	0.00	na na	0.00	na na	12.1	7,488.3	0.0	na na	0	na na
	summer	0.0	0	1,843.7	0.00	na na	0.00	na na	24.5	7,512.0	0.0	na na	0	na na

Table 5. Observed and fleet-total weights and numbers of eulachon bycatch from IFQ-fishery bottom and midwater trawl vessels that landed their catch in **Oregon** (2011–2015). Bycatch weights are in kilograms and groundfish landings are in metric tons. Note that catch share fisheries are sampled at close to 100%. Landings by the EM portion of this fleet are not included here.

	State observed				**State fleetwide**				
Year	Bycatch (kg of eulachon)	Bycatch (no. of eulachon)	Observed groundfish catch (mt)	Percent landings observed	Fleet groundfish landings (mt)	Unobserved bycatch estimate (kg eulachon)	Unobserved bycatch estimate (no. of eulachon)	Fleet-total bycatch (kg eulachon)	Fleet-total bycatch (no. of eulachon)
2011	5.9	122	10,812.6	99.3	10,893.7	0.2	4.6	6.1	127
2012	5.8	163	10,668.6	99.4	10,735.3	0.1	3.9	6.0	167
2013	30.7	507	12,437.6	99.7	12,473.0	0.9	14.4	31.6	521
2014	116.4	2,473	11,153.7	99.4	11,217.1	2.0	42.6	118.4	2,516
2015[1]	23.9	631	11,036.0	99.6	11,085.7	0.4	9.9	24.3	641

1 – Catch and bycatch estimates during 2015 are based on observations of the bottom trawl fishery only.

Table 6. 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.

		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	480.3	0.00	na na	0.00	na na	12.8	3,758.7	0.0	na na	0	na na
	summer	0.0	0	533.5	0.00	na na	0.00	na na	13.7	3,890.4	0.0	na na	0	na na
2003	winter	0.0	0	342.1	0.00	na na	0.00	na na	11.7	2,925.5	0.0	na na	0	na na
	summer	0.0	0	582.1	0.00	na na	0.00	na na	14.1	4,125.3	0.0	na na	0	na na
2004	winter	0.0	0	742.8	0.00	na na	0.00	na na	33.9	2,193.5	0.0	na na	0	na na
	summer	0.0	1	772.1	0.00	00.0 00.0	0.00	0.00 0.00	21.3	3,621.8	0.2	0.0 0.7	5	1 15
2005	winter	0.0	0	503.4	0.00	na na	0.00	na na	20.2	2,492.0	0.0	na na	0	na na
	summer	0.0	0	596.6	0.00	na na	0.00	na na	19.3	3,086.3	0.0	na na	0	na na
2006	winter	0.0	0	367.9	0.00	na na	0.00	na na	19.1	1,926.7	0.0	na na	0	na na
	summer	0.0	0	607.3	0.00	na na	0.00	na na	20.0	3,030.6	0.0	na na	0	na na
2007	winter	0.0	0	427.8	0.00	na na	0.00	na na	18.0	2,377.5	0.0	na na	0	na na
	summer	0.0	0	703.1	0.00	na na	0.00	na na	19.0	3,705.3	0.0	na na	0	na na
2008	winter	0.0	0	575.6	0.00	na na	0.00	na na	18.1	3,179.3	0.0	na na	0	na na
	summer	0.0	0	663.2	0.00	na na	0.00	na na	19.4	3,415.8	0.0	na na	0	na na
2009	winter	0.0	0	546.4	0.00	na na	0.00	na na	19.3	2,832.3	0.0	na na	0	na na
	summer	0.0	0	637.0	0.00	na na	0.00	na na	18.1	3,518.8	0.0	na na	0	na na
2010	winter	0.0	0	203.8	0.00	na na	0.00	na na	9.5	2,133.8	0.0	na na	0	na na
	summer	0.3	4	565.0	0.00	0.00 0.00	0.01	0.00 0.03	18.5	3,057.8	1.5	0.3 5.8	22	4 81

Table 7. Observed and fleet-total weights and numbers of eulachon bycatch from IFQ-fishery bottom and midwater trawl vessels that landed their catch in **California** (2011–2015). Bycatch weights are in kilograms and groundfish landings are in metric tons. Note that catch share fisheries are sampled at close to 100%. Landings by the EM portion of this fleet are not included here. Asterisks (*) signify strata with fewer than three observed vessels.

	State observed				State fleetwide				
Year	Bycatch (kg of eulachon)	Bycatch (no. of eulachon)	Observed groundfish catch (mt)	Percent landings observed (%)	Fleet groundfish landings (mt)	Unobserved bycatch estimate (kg eulachon)	Unobserved bycatch estimate (no. of eulachon)	Fleet-total bycatch (kg eulachon)	Fleet-total bycatch (no. of eulachon)
2011	0.0	0	4,596.6	99.9	4,601.9	0.0	0.0	0.0	0
2012	0.0	0	4,443.0	99.8	4,451.5	0.0	0.0	0.0	0
2013	0.0	0	5,029.9	99.7	5,043.7	0.0	0.0	0.0	0
2014	0.0	0	4,855.3	99.5	4,880.0	0.0	0.0	0.0	0
2015[1]	0.1	2	4,096.1	99.9	4,098.8	0.0	0.0	0.1	2

1 – Catch and bycatch estimates during 2015 are based on observations of the bottom trawl fishery only.

Table 8. Observed and expanded bycatch (kilograms) and number of eulachon from the at-sea Pacific hake fishery (2002–2015). In 2013-2015 the tribal mothership sector did not participate in this fishery (designated by na). Asterisks (*) signify strata with fewer than three observed vessels.

Sector	Year	Sampled tows (number)	Percent tows sampled	Observed hake (mt)	Observed bycatch weight (kg)	Expanded bycatch weight (kg)	Observed bycatch numbers	Expanded bycatch numbers
Catcher Processor	2002	556	99.8	36,333	0.0	0.0	0	0
	2003	766	99.9	41,469	0.0	0.0	0	0
	2004	1,492	99.7	72,859	0.0	0.0	0	0
	2005	1,332	99.9	78,497	0.0	0.0	0	0
	2006	1,488	99.9	78,246	1.5	1.5	145	147
	2007	1,566	99.7	72,898	0.1	0.1	6	6
	2008	1,864	99.0	107,754	2.1	2.1	37	37
	2009	863	100.0	34,591	2.1	2.1	30	30
	2010	1,063	99.9	54,217	0.0	0.0	0	0
	2011	1,530	98.7	71,337	115.6	115.9	1,268	1,268
	2012	1,100	99.8	55,523	1.1	1.1	16	16
	2013	1,439	99.7	78,005	2.9	2.9	39	39
	2014	1,683	99.9	103,171	10.4	10.4	242	242
	2015	1,503	99.7	68,435	1.8	1.8	56	56
Non-tribal mothership	2002	573	99.8	26,503	0.0	0.0	0	0
	2003	522	97.4	25,333	0.0	0.0	0	0
	2004	569	99.6	24,010	0.0	0.0	0	0
	2005	1,038	99.9	48,601	0.0	0.0	0	0
	2006	1,243	96.9	54,139	0.0	0.0	0	0
	2007	1,135	99.0	47,276	0.2	0.2	4	4
	2008	1,346	99.8	57,687	0.4	0.4	6	6
	2009	597	99.5	24,066	0.3	0.3	6	6
	2010	908	100.0	35,727	0.0	0.0	0	0
	2011	1,246	99.8	49,971	5.2	5.2	54	54
	2012	931	98.1	38,042	0.4	0.4	7	7
	2013	1,249	99.4	52,348	12.2	12.2	277	277
	2014	1,288	98.6	61,794	1.0	1.0	25	25
	2015	625	99.0	27,545	0.0	0.0	0	0

Table 8 (continued). Observed and expanded bycatch (kilograms) and number of eulachon from the at-sea Pacific hake fishery (2002–2015). In 2013-2015 the tribal mothership sector did not participate in this fishery (designated by na). Asterisks (*) signify strata with fewer than three observed vessels.

Sector	Year	Sampled tows (number)	Percent tows sampled	Observed hake (mt)	Observed bycatch weight (kg)	Expanded bycatch weight (kg)	Observed bycatch numbers	Expanded bycatch numbers
Tribal Mothership	2002	625	98.7	21,629	0.0	0.0	0	0
	2003	537	99.4	19,431	0.0	0.0	0	0
	2004	632	100.0	23,511	0.0	0.0	0	0
	2005	632	99.8	23,562	0.0	0.0	0	0
	2006	154	96.3	5,405	0.0	0.0	0	0
	2007	156	100.0	5,129	0.0	0.0	0	0
	2008	380	99.5	14,977	0.0	0.0	0	0
	2009	403	99.8	13,469	2.0	2.0	32	32
	2010	516	100.0	16,206	0.0	0.0	0	0
	2011	228	100.0	6,147	12.1	12.1	160	160
	2012	*	75	*	*	*	*	*
	2013	na	na	na	na	na	0	na
	2014	na	na	na	na	na	0	na
	2015	na	na	na	na	na	0	na

Table 9. Observed eulachon bycatch (kilograms and estimated number of fish) in the shoreside Pacific hake fishery (2011–2014) and shoreside midwater hake and shoreside midwater rockfish fishery (2015). Note that this fishery is sampled at nearly 100% after being landed. In this fishery, eulachon bycatch weights are landed and weighed by the catch monitor. Number of eulachon are then estimated from a count/weight regression. Landed weight of Pacific hake and rockfish are given in metric tons (mt). Landings by the EM portion of these fleets in 2015 are not included here.

Year	Total number of tows sampled	Sampled hake landings (mt)	Sampled rockfish landings (mt)	Percent of landings sampled	Landed eulachon bycatch (kg)	Estimated eulachon bycatch (number)
2011	1,718	90,249	na	100.0	0.0	0
2012	1,602	65,288	na	100.0	0.0	0
2013	1,735	96,868	na	100.0	83.5	4,139
2014	1,726	97,983	na	99.9	0.0	0
2015 midwater hake	289	11,461	154	100.0	0.0	0
2015 midwater rockfish	147	15	968	100.0	0.0	0

Table 10. 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 2002–2015.

	Non-hake bottom and midwater groundfish fisheries [1]			**Shoreside Pacific hake /rockfish**	**At-sea Pacific hake fisheries**			
Year	WA	OR	CA		Tribal Mothership	Non-Tribal Mothership	Catcher Processor	**Total bycatch estimate**
2002	0	783	0	--	0	0	0	783
2003	0	52	0	--	0	0	0	52
2004	0	0	5	--	0	0	0	5
2005	0	0	0	--	0	0	0	0
2006	0	0	0	--	0	0	147	147
2007	0	72	0	--	0	4	6	82
2008	0	0	0	--	0	6	37	43
2009	0	67	0	--	32	6	30	135
2010	0	0	22	--	0	0	0	22
2011	12	127	0	0	160	54	1,268	1,621
2012	1	167	0	0	0	7	16	191
2013	137	521	0	4,139	na	277	39	5,113
2014	292	2,516	0	0	na	25	242	3,075
2015	0	641	2	0	na	0	56	699

1 – Bycatch estimates in non-hake groundfish fisheries from 2002–2010 and 2015 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.

Table 11. Bias and error statistics from a preliminary study examining the effect of variation in observer coverage on estimates of eulachon take (discard weight, mt; Jannot, unpublished work in progress). Note that the strata used in this study were intended to match the annual groundfish mortality report and do not match those used elsewhere in this document. RMSE = root mean squared error; MAE = mean absolute error; RRSE = relative root squared error; RRAE = relative absolute error.

Strata				Bootstrapped Discard Statistics							Bootstrapped Coverage		
Year	Season	Depth	Target Coverage	discard (mt ± 1 SD)	bias	RMSE	MAE	RRSE	RAE	Actual Discard (mt, census)	No. vess. per draw	No. vess. in stratum	Observed Coverage (bootstrap ± 1 SD)
2011	summer	0-125	15%	0.008	0.002	0.006	0.004	1.030	0.986	0.006	3	22	13%
2011	summer	gt250	15%	0.003	0.003	0.001	0.000	2.919	3.407	0.000	5	36	14%
2011	winter	gt250	15%	0.000	0.000	0.000	0.000	3.197	4.562	0.000	7	48	14%
2012	summer	0-125	15%	0.007	0.001	0.006	0.004	1.015	0.944	0.005	4	24	17%
2012	summer	gt250	15%	0.000	0.000	0.000	0.000	2.612	3.155	0.000	5	33	15%
2012	winter	0-125	15%	0.000	0.000	0.000	0.000	6.049	7.033	0.000	2	10	21%
2013	summer	0-125	15%	0.044	0.010	0.044	0.026	1.027	0.964	0.033	3	20	15%
2013	winter	0-125	15%	0.022	0.019	0.023	0.010	1.219	0.968	0.003	2	14	15%
2013	winter	125-250	15%	0.003	0.003	0.001	0.000	2.993	3.528	0.000	6	41	15%
2013	winter	gt250	15%	0.002	0.002	0.001	0.000	1.374	1.166	0.000	6	43	14%
2011	summer	0-125	20%	0.007	0.001	0.006	0.004	1.023	0.995	0.006	4	22	18%
2011	summer	gt250	20%	0.002	0.002	0.001	0.000	2.666	3.293	0.000	7	36	19%
2011	winter	gt250	20%	0.000	0.000	0.000	0.000	3.014	4.231	0.000	10	48	21%
2012	summer	0-125	20%	0.006	0.001	0.005	0.004	1.008	0.961	0.005	5	24	21%
2012	summer	gt250	20%	0.000	0.000	0.000	0.000	2.331	2.886	0.000	7	33	21%
2012	winter	0-125	20%	0.000	0.000	0.000	0.000	5.734	6.544	0.000	2	10	20%
2013	summer	0-125	20%	0.042	0.009	0.038	0.024	1.027	0.966	0.033	4	20	20%
2013	winter	0-125	20%	0.014	0.011	0.017	0.008	1.152	0.905	0.003	3	14	23%
2013	winter	125-250	20%	0.002	0.002	0.001	0.000	2.576	3.314	0.000	8	41	20%
2013	winter	gt250	20%	0.001	0.001	0.001	0.000	1.305	1.107	0.000	9	43	21%
2011	summer	0-125	25%	0.006	0.000	0.004	0.003	1.005	0.993	0.006	6	22	27%
2011	summer	gt250	25%	0.002	0.001	0.001	0.000	2.581	3.138	0.000	9	36	25%
2011	winter	gt250	25%	0.000	0.000	0.000	0.000	2.812	3.890	0.000	12	48	25%
2012	summer	0-125	25%	0.006	0.000	0.005	0.004	1.003	0.978	0.005	6	24	25%
2012	summer	gt250	25%	0.000	0.000	0.000	0.000	2.232	2.875	0.000	8	33	24%
2012	winter	0-125	25%	0.000	0.000	0.000	0.000	5.485	6.388	0.000	2	10	20%
2013	summer	0-125	25%	0.038	0.005	0.029	0.020	1.014	0.979	0.033	5	20	25%
2013	winter	0-125	25%	0.009	0.006	0.012	0.006	1.116	0.885	0.003	4	14	29%
2013	winter	125-250	25%	0.002	0.002	0.001	0.000	2.522	3.155	0.000	10	41	25%
2013	winter	gt250	25%	0.001	0.001	0.001	0.000	1.284	1.167	0.000	11	43	25%
2011	summer	0-125	30%	0.006	0.000	0.004	0.003	1.004	0.995	0.006	7	22	32%
2011	summer	gt250	30%	0.002	0.001	0.001	0.000	2.312	2.826	0.000	11	36	31%
2011	winter	gt250	30%	0.000	0.000	0.000	0.000	2.627	3.515	0.000	14	48	29%
2012	summer	0-125	30%	0.006	0.000	0.005	0.004	1.004	0.981	0.005	7	24	29%
2012	summer	gt250	30%	0.000	0.000	0.000	0.000	2.215	2.729	0.000	10	33	31%
2012	winter	0-125	30%	0.000	0.000	0.000	0.000	3.831	4.329	0.000	3	10	30%
2013	summer	0-125	30%	0.037	0.004	0.026	0.019	1.013	0.983	0.033	6	20	30%
2013	winter	0-125	30%	0.010	0.007	0.013	0.006	1.124	0.881	0.003	4	14	28%
2013	winter	125-250	30%	0.002	0.001	0.001	0.000	2.272	2.766	0.000	12	41	29%
2013	winter	gt250	30%	0.001	0.001	0.001	0.000	1.234	1.134	0.000	13	43	30%
2011	summer	0-125	35%	0.006	0.000	0.004	0.003	1.003	0.997	0.006	8	22	36%
2011	summer	gt250	35%	0.001	0.001	0.001	0.000	2.201	2.715	0.000	13	36	36%
2011	winter	gt250	35%	0.000	0.000	0.000	0.000	2.247	2.920	0.000	17	48	35%
2012	summer	0-125	35%	0.006	0.000	0.004	0.003	1.003	0.985	0.005	8	24	33%
2012	summer	gt250	35%	0.000	0.000	0.000	0.000	2.001	2.429	0.000	12	33	37%
2012	winter	0-125	35%	0.000	0.000	0.000	0.000	3.162	3.576	0.000	4	10	40%
2013	summer	0-125	35%	0.036	0.002	0.022	0.016	1.006	0.988	0.033	7	20	35%
2013	winter	0-125	35%	0.008	0.004	0.009	0.005	1.107	0.879	0.003	5	14	37%
2013	winter	125-250	35%	0.001	0.001	0.001	0.000	2.311	2.859	0.000	14	41	34%
2013	winter	gt250	35%	0.001	0.001	0.001	0.000	1.209	1.171	0.000	15	43	35%

Table 12. Metric tonnage of observed bycatch of unidentified smelt and other non-eulachon species of osmerid smelt in U.S. west coast LE trawl fisheries from 2002–2010. After 2010, in the IFQ groundfish fisheries, efforts were expanded to identify all eulachon to species and unidentified smelt did not likely include eulachon. Double dashes (--) represent zeros or no value. Data from WCGOP website at http://www.nwfsc.noaa.gov/research/divisions/fram/observation/data_products/sector_products.cfm (Excel file labelled "Limited entry (LE) bottom trawl 2002-2010" under Catch Tables by Sector).

Year	Unidentified smelt	Whitebait smelt	Night smelt	Rainbow smelt	Capelin	Surf smelt
2002	0.18	--	--	--	--	0.03
2003	0.02	--	--	--	--	--
2004	0.84	--	--	--	--	--
2005	0.03	--	--	--	--	--
2006	0.01	--	--	--	--	--
2007	0.00	--	--	--	--	--
2008	0.00	--	--	--	--	--
2009	0.00	0.00	--	--	0.01	0.00
2010	0.00	--	0.00	--	--	--

Table 13. Observed weight (kg) and numbers of "unidentified smelt" and "unidentified herring/smelt" bycatch in at-sea Pacific hake trawl fisheries from 2002–2015. Note that these fishery sectors are 100% sampled. After 2010, efforts were expanded to identify all eulachon to species and unidentified smelt did not likely include eulachon. Double dashes (--) represent zeros or no value. In 2013–2015 the tribal mothership sector did not participate in this fishery (designated by na). Asterisks (*) signify strata with fewer than three observed vessels.

	Tribal at-sea hake fishery		Non-tribal at-sea hake fisheries			
Year	Unidentified smelt (kg)	Unidentified smelt (number)	Unidentified smelt (kg)	Unidentified smelt (number)	Unidentified herring/smelt (kg)	Unidentified herring/smelt (number)
2002	4.10	156	54.38	1,245	--	--
2003	1.17	25	1.70	49	--	--
2004	--	--	0.24	3	--	--
2005	--	--	0.15	6	--	--
2006	--	--	0.12	2	--	--
2007	--	--	--	--	0.61	7
2008	--	--	0.07	5	36.41	605
2009	--	--	0.34	9	--	--
2010	--	--	--	--	--	--
2011	--	--	1.42	14	--	--
2012	*	*	0.26	21	--	--
2013	na	na	0.04	2	--	--
2014	na	na	0.00	0.00	--	--
2015	na	na	--	--	--	--

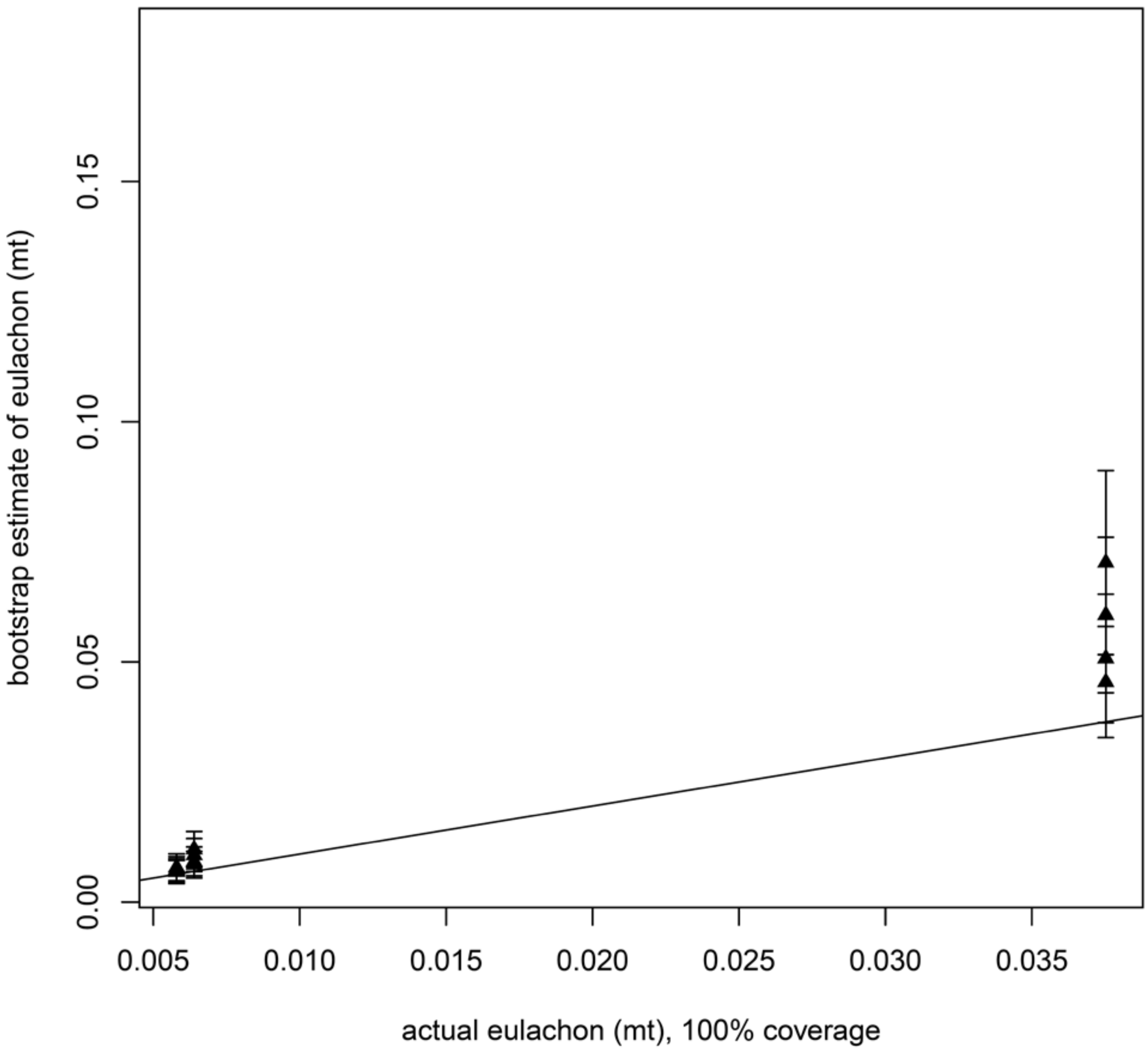

Figure 1. Plot of bootstrapped estimates of eulachon bycatch (mt) as a function of actual eulachon bycatch (mt) for each year of the IFQ bottom trawl fishery (2011–13). The line represents equivalency (slope = 1) where the value of the bootstrap estimate is equal to the actual value. Each of the three sets of points per given actual eulachon bycatch represents a single year of IFQ data. Variation among points within a year represents variation in the number of vessels sampled per bootstrapping run (i.e., observer coverage). For clarity we only show the simulation results for observer coverage between 15–35% which covers the historical (2002–10) range for the LE bottom trawl fishery. Each point is the coastwide mean (± 1 SE) of the bootstrapped bycatch estimate based on 2000 samples for each target sampling rate: 15, 20, 25, 30.

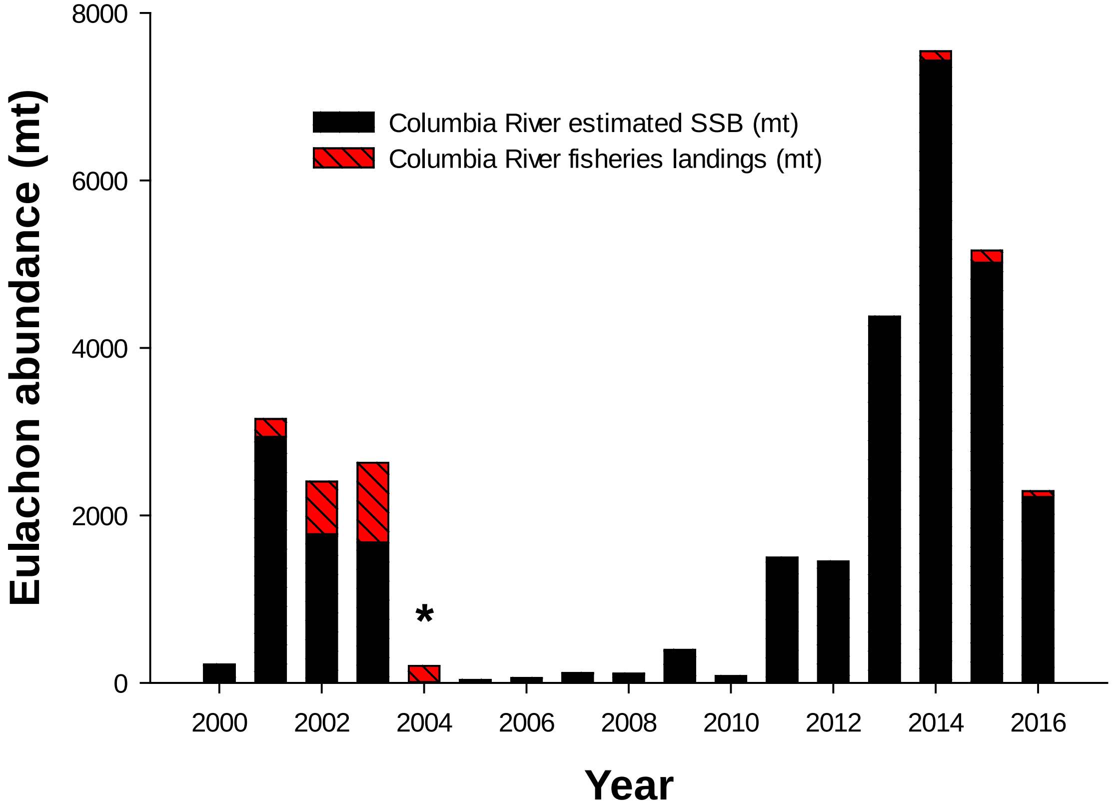

Figure 2. Estimated Columbia River eulachon spawning stock biomass and fisheries landings from 2000–2015. Pre-2011 adjusted SSB estimates are based on historical Columbia River water discharge rates and expansions of historical larval densities adjusted for the shorter duration of the pre-2011 surveys (B. James and O. Langness, WDFW, pers. commun.). 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 is displayed.

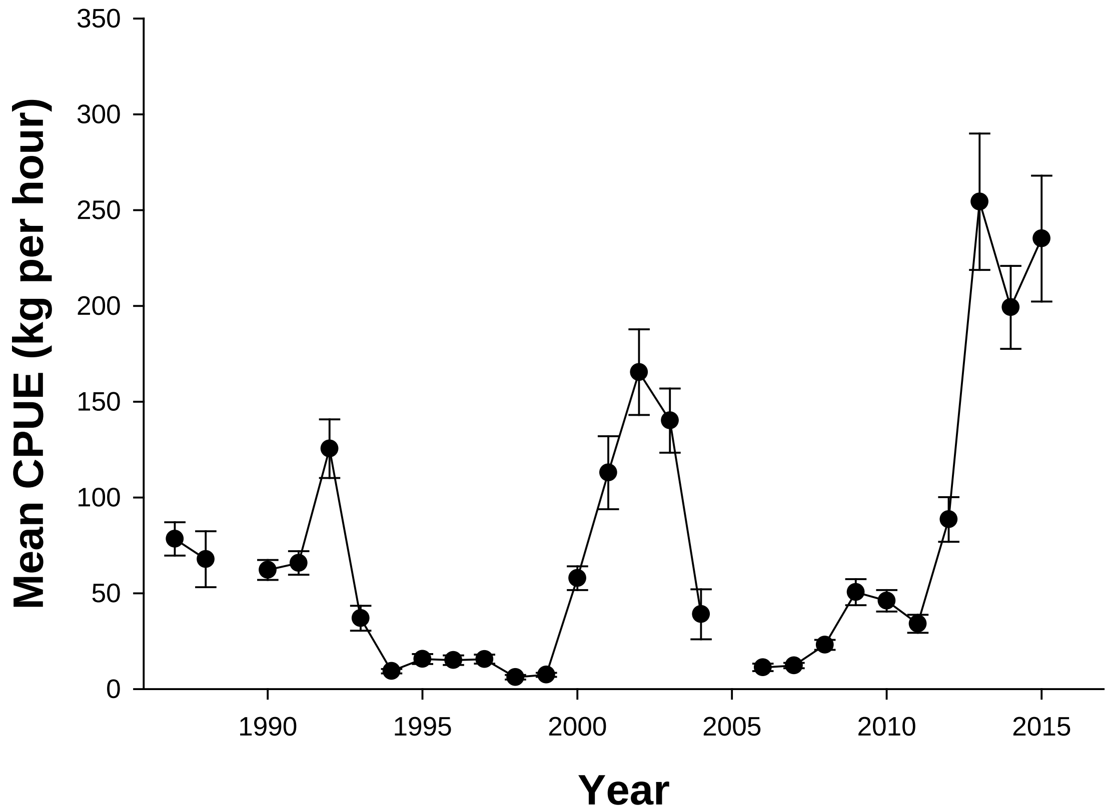

Figure 3. Total mean (± SE) catch per unit effort (CPUE; kg/h) of eulachon across all surveyed Shrimp Management Areas (125 OFF, 124 OFF, 23 OFF, 21 OFF, and 21 IN) off West Coast Vancouver Island (WCVI). CPUE is based on bycatch of eulachon in multispecies small mesh bottom trawl surveys (aka, fishery-independent shrimp surveys) offshore of WCVI. Data courtesy of Sean MacConnachie (Fisheries and Oceans Canada, Pacific Biological Station, Nanaimo, BC, Canada, pers. commun., 3 September 2015).

Appendix A

Observed and Estimated Bycatch of Eulachon in US West Coast Ocean Shrimp Trawl Fisheries From 2004–2015

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Introduction and Background

Eulachon (*Thaleichthys pacificus*, Osmeridae) is an anadromous smelt that ranges from northern California to the southeastern Bering Sea coast of Alaska (Willson et al. 2006, Moody and Pitcher 2010). The declining abundance of eulachon in the southern portion of its range led the Cowlitz Indian Tribe to petition (Cowlitz Indian Tribe 2007) the National Marine Fisheries Service (NMFS) to list eulachon in Washington, Oregon, and California as a threatened or endangered species under the USA's Endangered Species Act (ESA). A eulachon Biological Review Team (BRT)—consisting of 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 compiled by NMFS staff from both published and unpublished literature. The BRT identified a southern Distinct Population Segment (DPS) of eulachon—that 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 southern eulachon include climate change impacts on ocean and freshwater habitat, bycatch in offshore shrimp trawl fisheries, changes in downstream flow-timing and intensity due to dams and water diversions, and predation. These threats, together with large declines in abundance, indicated to the BRT that the southern DPS of eulachon was at moderate risk of extinction throughout all of its range (Gustafson et al. 2010, 2012). On 18 March 2010, NMFS published a final rule in the Federal Register to list the southern DPS of eulachon as threatened under the ESA (NMFS 2010). A recent five-year review (Gustafson et al. 2016) resulted in a recommendation and final rule that the DPS remain classified as a threatened species (NMFS 2016, NMFS-WCR 2016). 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). This document provides an analysis of observed bycatch and fleet-wide take estimates of U.S. Endangered Species Act-listed eulachon in U.S. west coast offshore commercial ocean shrimp trawl fisheries from 2004–2015.

Eulachon Life History

Adult eulachon typically spawn at age 2–5, when they are 160–250 mm in length (fork length), in the lower portions of rivers that have prominent spring peak flow events or freshets (Hay and McCarter 2000, Willson et al. 2006). Many rivers within the range of eulachon have consistent yearly spawning runs; however, eulachon may appear in other rivers only on an irregular or occasional basis (Hay and McCarter 2000, Willson et al. 2006). The spawning migration typically begins when river temperatures are 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 length (total length). Larvae are transported rapidly by spring freshets to estuaries (Hay and McCarter 2000, Willson et al. 2006) and juveniles disperse onto 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 and most often at depths between 50 and 200 m (NWFSC-EW 2012).

Ocean Shrimp Trawl Fisheries

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). Offshore trawl fisheries for ocean shrimp occur from the west coast of Vancouver Island 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). However, this document does not specifically cover eulachon bycatch in the 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 April 1 through October 31 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 46,494 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). Information on ocean shrimp fisheries can be found for Washington online at http://wdfw.wa.gov/fishing/commercial/shrimp/, for Oregon online at http://www.dfw.state.or.us/MRP/shellfish/commercial/shrimp/index.asp, and for California in Frimodig et al. (2007, 2009).

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. BRDs became mandatory in California in 2002 (Frimodig 2008, Frimodig et al. 2009) and in Washington and Oregon in 2003. Current 2017 regulations in Washington and Oregon, adopted by both states in 2012, require ocean shrimp trawl fishery BRDs to consist of a rigid panel or grate of narrowly spaced bars (usually constructed of aluminum) with no gaps between the bars exceeding 0.75 inches (19.1 mm). Further details on shrimp BRD requirements and fishery regulations for Washington can be found at http://apps.leg.wa.gov/wac/default.aspx?cite=220-52-050; and for Oregon at http://www.dfw.state.or.us/fish/commercial/docs/2017_commercial_synopsis.pdf. Approved BRDs for use in the ocean shrimp fishery in California 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 large than 6 inches;” and (3) fisheye excluders, which have a forward facing escape opening that is maintained by a rigid frame (see California Fishing Regulations Commercial Digest 2015-2016, online at https://nrm.dfg.ca.gov/Search.aspx?q=California+Fishing+Regulations+Commercial+Digest+).

Methods

Data Sources

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

Observer data

To date, observer data is 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 2017).

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 on the WCGOP Data Processing webpage (http://www.nwfsc.noaa.gov/research/divisions/fram/observation/data_processing.cfm) 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. Fish tickets 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 on the WCGOP website under Data Processing Appendix (http://www.nwfsc.noaa.gov/research/divisions/fram/observer/data_processing.cfm/). 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 method is that we underestimate the true uncertainty because we can only estimate the portion of uncertainty resulting from observer sampling. We have no information about uncertainty related to landings data [see Shelton et al. (2012)].

When 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

Observer data from the ocean shrimp trawl fishery were received from the West Coast Groundfish Observer Program (WCGOP) at the NWFSC. These data contained all tows observed for the years 2004, 2005, and 2007–2015. The observed tows were in waters shallower than 250 m and deeper than 80 m. The ocean shrimp trawl fishery did not carry WCGOP observers in 2006.

The WCGOP began observing eulachon bycatch in the Washington ocean shrimp fishery in 2010. The estimated Washington sector bycatch in terms of weight and numbers of eulachon increased dramatically beginning in 2012, and has remained elevated relative to 2010–2011, while the percentage of total shrimp landings observed has fluctuated between about 7 and 16% (Table A2). Total estimated bycatch of eulachon in the Washington ocean shrimp fisheries ranged from a low of over 64 thousand (95% CI; 23,950–132,532) fish in 2010 to a high of over 22.4 million (95% CI; 16,809,929–28,991,135) fish in 2015 (Table A2, Fig. A2). Mean estimated total biomass of eulachon bycatch in the Washington fishery during this time period (2010–2015) ranged from 2.1–219.8 mt (Table A2). The Washington sector bycatch ratio, on a kg of eulachon per metric ton of retained shrimp basis, was highest during 2012 (37.9 kg/mt) and 2013 (32.9 kg/mt) and lowest in 2010 (0.5 kg/mt) and 2011 (1.3 kg/mt). Recently, this bycatch ratio has somewhat declined from high levels in 2012–2013 to 10.2 kg/mt in 2014 and 11.7 kg/mt in 2015 (Table A2, Fig. A2).

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 observed in 2006); however, estimated bycatch expanded dramatically in 2012 and 2013 to over 28.1 million (95% CI; 18.0–39.3 million) and 34.7 million (95% CI; 19.9–52.5 million), respectively (Table A3, Fig. A2). Similarly, total weight of estimated eulachon bycatch in Oregon increased from 20.4 mt (95% CI; ~16.3–22.8 mt) in 2011 to nearly 428 mt (95% CI; ~387–497 mt) in 2012 and to over 540 mt (95% CI; ~430–736 mt) in 2013. Subsequently, estimated eulachon bycatch has remained high in the Oregon ocean shrimp trawl sector, reaching over 54.7 million fish (95% CI; 37.6–74.1 million) and 636 mt (95% CI; ~510–770 mt) in 2014 and over 35.3 million fish (95% CI; 23.1–50.4 million) and 361 mt (95% CI; ~271–380 mt) in 2015 (Table A3, Fig. A2). As in the Washington sector, bycatch ratios in the Oregon sector, (measured as both kg 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, Fig. A2). Observed bycatch ratios were at their highest in 2014 (27.0 kg/mt and 2,232 eulachon/mt). In 2015, the Oregon sector bycatch ratios declined to 14.9 kg/mt and 1,458 eulachon/mt.

Eulachon bycatch in the California ocean shrimp fishery followed a very different trajectory from that observed in Washington and Oregon during 2011–2013. Eulachon bycatch in California remained below 25 thousand fish from 2004 to 2008 (the fishery was not observed in 2006), rose dramatically in 2010 to over 267 thousand (95% CI; 40,040–702,623) fish; fell to its lowest observed level of just 471 fish (95% CI; 198–827) in 2011, increased again dramatically in 2012 to over 337 thousand (95% CI; 148,647–606,034) fish, and then fell to just over 16 thousand (95% CI; 3,816–33,998) fish in 2013 (Table A4, Fig. A2). Biomass of eulachon bycatch and bycatch ratios have shown similar fluctuations over the time period from 2010–2013 (Table A4). Eulachon bycatch again increased from 2014–2015 in the California ocean shrimp trawl sector; estimated bycatch was over 611 thousand fish (95% CI; 241,491–1,063,825) and 6.6 mt in 2014 and increased to over 2 million fish (95% CI; 960,061–3,567,063) and 32.3 mt in 2015 (Table A4, Fig. A2). The tonnage of observed ocean shrimp and of fleet-wide landings were relatively stable over 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 kg and numbers of eulachon per metric ton of retained ocean shrimp observed) increased from 1.7 to 9.7 kg/mt shrimp and from 159 to 594 eulachon/mt shrimp between 2014 and 2015 (Table A4).

Combined WCGOP estimates of the weight and number of eulachon caught in the Oregon and California ocean shrimp trawl fishery as bycatch from 2004–2015 (except for 2006 when these fisheries were not observed) and in Washington from 2010–2015 are presented in Table A5. Total estimated bycatch of eulachon in the Oregon and California ocean shrimp fisheries ranged from nearly 158 thousand fish (95% CI; 11,642–492,887) in 2004 to a high of nearly 959 thousand (95% CI; 237,377–2,169,745) fish in 2009. Estimated eulachon bycatch in the Washington ocean shrimp fishery in 2010 (its first year of observation) was nearly 65 thousand fish, and the total 2010 estimated eulachon bycatch for all three states combined was over one million (95% CI; 540,065–1,889,846). Coastwide eulachon bycatch decreased to about 605 thousand (95% CI; 397,957–876,346) fish in 2011 (Table A5). However, as seen earlier, eulachon bycatch increased dramatically in all three states in 2012, topping out at over 42.6 million (95% CI; ~26.8–58.8 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 51.8 million fish (95% CI; ~31.8–73.9 million) (Table A5). Estimated weight of these bycaught eulachon in 2013 was over 743 mt (95% CI; ~603–967 mt) (Table A5). Coastwide eulachon bycatch in ocean shrimp trawl fisheries again increased in 2014 to an all-time high of 68.8 million fish (95% CI; ~45.2–97.0 million) and 785 mt (95% CI; ~589–966 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 A5). Estimated coastwide bycatch in 2015 amounted to 59.8 million fish (95% CI; ~40.9–83.0 million) and 613 mt (95% CI; ~482–716 mt) (Table A5). Bycatch ratios were higher in Washington than in the Oregon fishery in both 2012 and 2013 (Tables A2–A3, Fig. A2). 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–A4, Fig. A2).

Degree of observer coverage

Observer coverage in ocean shrimp trawl fisheries over the past three years has ranged from 10–14% of ocean shrimp landings on a coastwide basis. Since 2004, observer coverage in the Oregon ocean shrimp fishery has ranged from a low of 5.6% to a high of 13.6% of total shrimp landings (Table A3). Observer coverage data for Washington and California are available only for 2010–2015; prior California data cannot be reported for confidentiality reasons, and the Washington shrimp trawl sector was not observed by the WCGOP prior to 2010. During 2010–2015, observer coverage in Washington and California averaged 11.6% and 12.4% of total shrimp landings, respectively (Tables A2, A4). No ocean shrimp trawl fishery landings were observed in 2006.

Discussion

The previously depressed and currently high relative abundance of the southern DPS of eulachon (Figs. 2–3) are likely contributing to the increased levels of eulachon bycatch reported in this document for 2012–2015. It is unclear why bycatch ratios were highest in the Washington, intermediate in the Oregon, and lowest in the California sectors of the ocean shrimp trawl fishery in 2012 and 2013. The dramatic increases in the level of eulachon bycatch in both the Washington and Oregon ocean shrimp trawl fisheries in 2012 and 2013 occurred in spite of regulations, enacted in 2012, requiring the use of BRDs with a minimum 19 mm (0.75 inch) bar spacing. In 2014, eulachon bycatch ratios declined in Washington, but increased in both the Oregon and California sectors of the ocean shrimp trawl fishery (Tables A2–A4). In 2015, both eulachon bycatch ratios and overall bycatch increased in both the Washington and California sectors of the ocean shrimp trawl fishery, but declined in the Oregon sector (Tables A2–A4). Some of these patterns may be influenced by the degree to which artificial lights have been used to illuminate portions of trawl nets in different sectors of these fisheries. The potential impact of lighted trawl nets on bycatch ratios and overall bycatch is an active area of research and is further discussed below.

Although speculative, it may be that BRDs 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.

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). Wargo et al. (2014) 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 5.5 and 156.8 mt in 2011 and 2012, respectively. In the 2011 Washington ocean shrimp trawl fishery 24% of trips were observed by the state observers (Wargo et al. 2014), whereas the WCGOP observed 16.6% of the total ocean shrimp landings (Table A2). In 2012, 16% of trips were observed by the state observer program (Wargo et al. 2014) and 14.8% of shrimp landings were observed by the WCGOP (Table A2).

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

Prior to the mandated use of bycatch reduction devices (BRDs), 32–61% of the total catch in the Oregon ocean shrimp fishery consisted of 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; Frimodig et al. 2009) 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 and 2003 in Washington and Oregon has 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.

None of the shrimp trawl BRDs in use today eliminate all incidental catch, and residual bycatch of fish (Hannah et al. 2011), especially of eulachon, remains a problem. Recent experimentation with artificial light to illuminate portions of trawl nets in the Oregon ocean shrimp fishery has shown great promise for significantly reducing bycatch of eulachon (Hannah and Jones 2014, 2015; Hannah et al. 2015; Groth et al. 2017). In 2014, researchers 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).

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.” Hannah and Jones (2016) also discussed several technical developments concerning types of lights that have been used and lighting configurations that are being tried to increase eulachon avoidance of shrimp trawl nets. Although use of LED lights on ocean shrimp trawl nets is not currently regulated in U.S. waters, Hannah and Jones (2016, p. 9) proposed regulations in Oregon be imposed to require use of footrope lighting devices such as the “Lindgren-Pitman Electralume Light Emitting Diode (LED) lights” or “other footrope lighting devices that are deemed by the Department to have comparable or greater total illumination may be approved for use, on a case-by-case basis, through issuance of an Experimental Gear Permit (EGP).”

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." According to Groth et al. (2017, p. 9), ODFW experiments planned for up to 16 days at sea in 2017, in collaboration with the Pacific States Marine Fisheries Commission:

> … will further test the use of LEDs and determine how catches of eulachon, darkblotched rockfish, other fishes, and ocean shrimp are affected by 1) altering the number of lights attached along the central portion of the trawl fishing line, and 2) attaching lights along the fishing line of the trawl wings as opposed to the central portion. The goal of this work is to understand the most efficient way to use LEDs for reducing bycatch.

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*), and capelin (*Mallotus villosus*) (Table A7). Based on Somers et al. (2016), observed but unidentified smelt bycatch in the Oregon and California ocean shrimp trawl fishery ranged from a high of 3.92 mt in 2004 to a low of 0.03 mt in 2009 (Table A7). Bycatch ratios for unidentified smelt were calculated by dividing metric tons of observed unidentified smelt by observed shrimp landings. Expansion of these observed levels of bycatch to a fleetwide level of yearly unidentified smelt bycatch was done by multiplying these bycatch ratios by the fleetwide landings in metric tons of ocean shrimp (Table A7). Fleetwide bycatch of unidentified smelt ranged from a high of 49.48 mt in 2002 to a low of 0.44 mt in 2009 (Table A7). The percentage of this unidentified smelt category 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 2011–2015 likely consist of other osmerid smelt species besides eulachon.

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

							Management	
Sector	**Sub-Sector**	**Permits**	**Gear(s)**	**Target(s)**	**Vessel length (m)**	**Depths (m)**	**2002-2010**	**2011-2015**
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 required; trip limits on groundfish landed; 4-14% observer coverage	

Appendix Table A2. Numbers and weight of eulachon observed and bycatch ratios from ocean shrimp trawl vessels that landed their catch in **Washington** (2010–2015). Bycatch ratios were calculated for each year by dividing the observed catch of eulachon (in numbers of eulachon and in kg of eulachon) by the observed weight (in mt) of retained ocean shrimp. A fleet-wide bycatch estimate (in both weight and 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.

	State observed								State fleetwide				
Year	Bycatch (kg of eulachon)	Bycatch (no. of eulachon)	Observed ocean shrimp catch (mt)	Bycatch ratio (kg per mt of ocean shrimp)	95% CI	Bycatch ratio (no. per mt of ocean shrimp)	95% CI	Percent landings observed	Fleet ocean shrimp landings (mt)	Bycatch estimate (kg eulachon)	95% CI	Bycatch estimate (no. of eulachon)	95% CI
2004	--	--	--	--	-- --	--	-- --	0.0	2,440.5	--	-- --	--	-- --
2005	--	--	--	--	-- --	--	-- --	0.0	2,841.8	--	-- --	--	-- --
2006	--	--	--	--	-- --	--	-- --	0.0	2,804.4	--	-- --	--	-- --
2007	--	--	--	--	-- --	--	-- --	0.0	1,517.4	--	-- --	--	-- --
2008	--	--	--	--	-- --	--	-- --	0.0	2,853.3	--	-- --	--	-- --
2009	--	--	--	--	-- --	--	-- --	0.0	3,180.0	--	-- --	--	-- --
2010	198.0	6,214	412.4	0.5	0.3 0.8	15.1	5.6 30.9	9.6	4,295.6	2,062.9	1,321.7 3,341.2	64,735	23,950 132,532
2011	917.7	19,976	697.2	1.3	1.0 1.6	28.7	16.6 46.6	16.2	4,312.1	5,675.7	4,112.2 6,989.5	123,543	71,620 200,806
2012	23,135.3	2,099,376	626.0	37.0	27.3 45.6	3,353.9	2,053.7 4,461.5	14.8	4,239.4	156,689.4	115,871.7 193,403.4	14,218,507	8,706,595 18,914,078
2013	20,646.3	1,740,163	626.8	32.9	27.9 37.2	2,776.2	1,930.9 3,480.7	10.2	6,157.9	202,827.8	171,874.1 229,367.1	17,095,225	11,890,427 21,433,552
2014	10,053.1	948,397	980.9	10.2	5.5 14.2	966.9	529.7 1,568.9	7.1	13,876.2	142,222.1	76,530.4 196,539.5	13,417,079	7,350,640 21,770,031
2015	25,127.9	2,559,825	2,151.1	11.7	10.2 15.2	1,190.0	893.5 1,540.9	11.4	18,814.3	219,779.6	191,465.8 286,177.6	22,389,318	16,809,929 28,991,135

Appendix Table A3. Numbers and weight of eulachon observed and bycatch ratios from ocean shrimp trawl vessels that landed their catch in **Oregon** (2010–2015). Bycatch ratios were calculated for each year by dividing the observed catch of eulachon (in numbers of eulachon and in kg of eulachon) by the observed weight (in mt) of retained ocean shrimp. A fleet-wide bycatch estimate (in both weight and 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.

	State observed								**State fleetwide**				
Year	Bycatch (kg of eulachon)	Bycatch (no. of eulachon)	Observed ocean shrimp catch (mt)	Bycatch ratio (kg per mt of ocean shrimp)	95% CI	Bycatch ratio (no. per mt of ocean shrimp)	95% CI	Percent landings observed	Fleet ocean shrimp landings (mt)	Bycatch estimate (kg eulachon)	95% CI	Bycatch estimate (no. of eulachon)	95% CI
2004	221.8	11,291	427.2	0.5	0.0 1.5	26.4	0.0 82.8	7.7	5,537.0	2,875.3	221.8 8,260.2	146,338	11,291 458,456
2005	278.7	11,669	402.9	0.7	0.4 2.2	29.0	3.0 58.4	5.6	7,159.4	4,953.3	2626.5 15,780.6	207,362	21,542 418,275
2006	--	--	--	--	-- --	--	-- --	0.0	5,531.8	--	-- --	--	-- --
2007	277.8	14,084	650.0	0.4	0.1 1.3	21.7	0.1 57.5	7.1	9,128.6	3,901.7	643.8 11,720.1	197,807	14,084 525,035
2008	600.3	22,634	672.5	0.9	0.5 1.2	33.7	9.4 63.4	5.8	11,575.9	10,332.6	5,598.7 13,703.9	389,604	108,426 734,054
2009	650.9	63,175	751.2	0.9	0.3 2.3	84.1	21.7 184.1	7.5	10,048.7	8,707.4	3,461.3 23,250.9	845,081	218,424 1,849,900
2010	1,635.3	88,373	1,705.4	1.0	0.6 1.1	51.8	33.3 73.8	11.9	14,290.4	13,702.6	8,686.2 15,632.0	740,501	476,074 1,054,691
2011	2,786.7	65,524	2,986.0	0.9	0.7 1.0	21.9	14.9 30.8	13.6	21,915.1	20,452.9	16,312.7 22,755.2	480,907	326,139 674,713
2012	57,865.9	3,794,927	3,014.2	19.2	17.4 22.3	1,259.0	806.4 1,763.4	13.5	22,291.6	427,946.2	387,937.7 496,644.5	28,065,308	17,975,466 39,308,140
2013	58,004.9	3,725,425	2,313.2	25.1	20.0 34.2	1,610.5	922.1 2,436.5	10.7	21,537.8	540,062.9	430,973.7 736,470.9	34,686,116	19,859,260 52,476,489
2014	61,855.3	5,320,324	2,291.3	27.0	21.6 32.2	2,321.9	1,595.4 3,145.1	9.7	23,573.3	636,365.9	509,709.9 759,788.9	54,735,346	37,608,999 74,140,221
2015	34,028.1	3,326,275	2,282.1	14.9	11.2 15.7	1,457.6	954.1 2,081.6	9.4	24,226.1	361,234.5	270,858.0 380,036.3	35,310,975	23,113,342 50,428,497

Appendix Table A4. Numbers and weight of eulachon observed and bycatch ratios from ocean shrimp trawl vessels that landed their catch in **California** (2010–2015). Bycatch ratios were calculated for each year by dividing the observed catch of eulachon (in numbers of eulachon and in kg of eulachon) by the observed weight (in mt) of retained ocean shrimp. A fleet-wide bycatch estimate (in both weight and 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.

	State observed								**State fleetwide**				
Year	Bycatch (kg of eulachon)	Bycatch (no. of eulachon)	Observed ocean shrimp catch (mt)	Bycatch ratio (kg per mt of ocean shrimp)	95% CI	Bycatch ratio (no. per mt of ocean shrimp)	95% CI	Percent landings observed	Fleet ocean shrimp landings (mt)	Bycatch estimate (kg eulachon)	95% CI	Bycatch estimate (no. of eulachon)	95% CI
2004	*	*	*	0.3	0.1 0.7	11.5	0.0 40.6	*	996.8	311.1	108.9 711.6	11,442	351 40,431
2005	*	*	*	0.3	0.0 0.5	11.4	0.0 40.7	*	860.6	225.9	25.1 404.7	9,848	0 35,051
2006	--	--	--	--	-- --	--	-- --	--	63.6	--	-- --	--	-- --
2007	*	*	*	0.6	0.3 0.9	39.6	0.0 86.3	*	289.1	168.4	86.8 272.0	11,450	978 24,943
2008	*	*	*	0.3	0.0 0.5	26.2	0.0 66.0	*	945.5	251.5	82.9 517.8	24,793	5,908 62,402
2009	*	*	*	0.6	0.3 1.2	96.2	16.0 270.3	*	1,183.5	740.6	405.2 1,399.5	113,815	18,953 319,844
2010	367.9	40,040	265.5	1.4	0.4 2.2	150.8	16.0 396.7	15.0	1,771.0	2,454.0	718.6 3,927.1	267,057	40,040 702,623
2011	3.7	59	420.6	0.0	0.0 0.0	0.1	0.1 0.2	12.6	3,333.0	29.6	15.2 33.0	471	198 827
2012	857.2	42,018	347.6	2.5	1.4 5.3	120.9	53.3 217.2	12.5	2,790.7	6,882.0	4,023.3 14,793.4	337,344	148,647 606,034
2013	65.8	1,533	359.8	0.2	0.1 0.3	4.3	1.0 8.7	9.2	3,915.4	715.9	221.5 1,295.2	16,684	3,816 33,998
2014	1,020.2	94,976	597.5	1.7	0.8 2.4	158.9	62.8 276.7	15.5	3,845.0	6,564.9	2,901.4 9,327.7	611,152	241,491 1,063,825
2015	3,134.5	198,759	334.7	9.4	5.9 14.7	593.9	278.0 1,033.0	9.7	3,453.0	32,341.9	20,503.8 50,622.0	2,050,791	960,061 3,567,063

Appendix Table A5. Total estimated bycatch of eulachon (number of individuals and mt) in ocean shrimp fisheries observed by the West Coast Groundfish Observer Program (WCGOP) from 2004–2015. Ocean shrimp fisheries were not observed in 2006. Italicized bycatch estimates result from bootstrapping due to fewer than three observed vessels in those strata. Dashes (--) signify years when the sector was not observed.

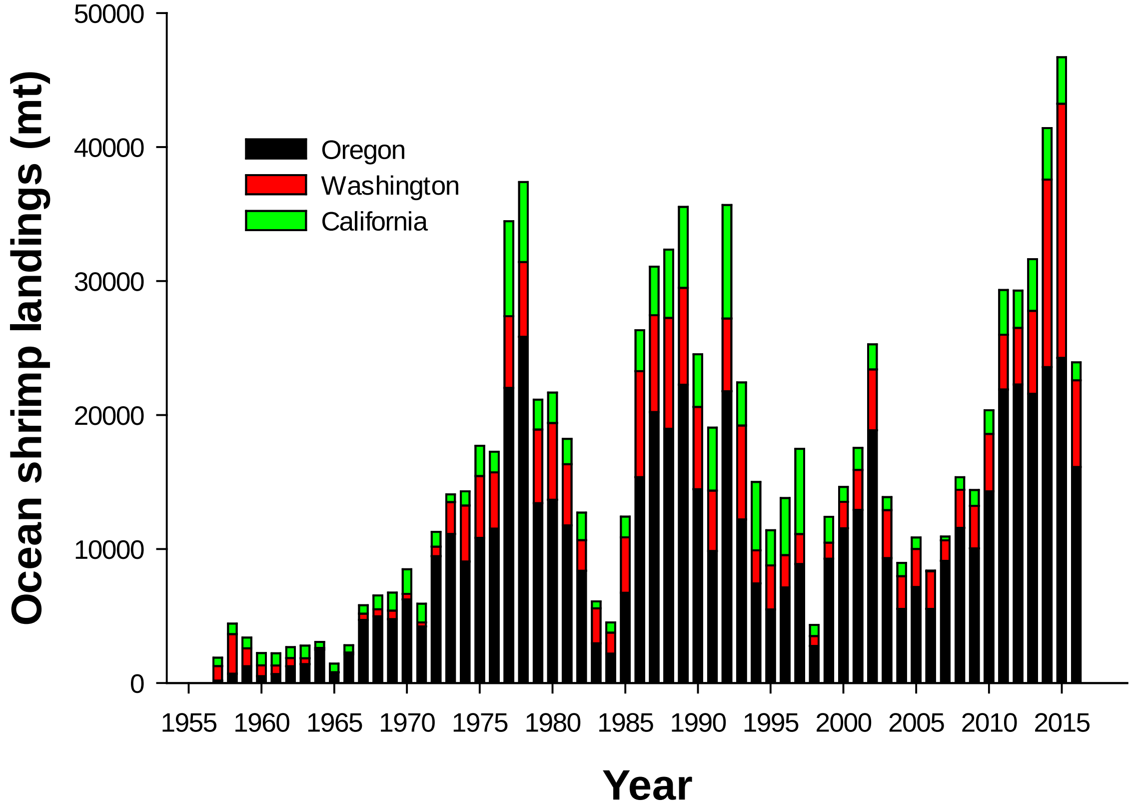
	Eulachon bycatch (mt)					**Eulachon bycatch (numbers of fish)**				
Year	Washington	Oregon	California	Coastwide bycatch	95% CI	Washington	Oregon	California	Coastwide bycatch	95% CI
2004	--	2.88	0.31	3.19	0.33 8.97	--	146,388	11,442	157,780	11,642 498,887
2005	--	4.95	0.23	5.18	2.65 16.19	--	207,362	9,848	217,210	21,542 453,326
2006	--	--	--	--	-- --	--	--	--	--	-- --
2007	--	3.90	0.17	4.07	0.73 11.99	--	197,807	11,450	209,257	15,062 549,978
2008	--	10.33	0.25	10.58	5.68 14.22	--	389,604	24,793	414,397	114,334 796,455
2009	--	8.71	0.74	9.45	3.87 24.65	--	845,081	113,815	958,896	237,377 2,169,745
2010	2.06	13.70	2.45	18.22	10.73 22.90	64,735	740,501	267,057	1,072,294	540,065 1,889,846
2011	5.68	20.45	0.03	26.16	20.44 29.78	123,543	480,907	471	604,921	397,957 876,346
2012	156.69	427.95	6.88	591.52	507.83 704.84	14,218,507	28,065,308	337,344	42,621,159	26,830,708 58,828,252
2013	202.83	540.06	0.72	743.61	603.07 967.13	17,095,225	34,686,116	16,684	51,798,025	31,753,502 73,944,039
2014	142.22	636.37	6.56	785.15	589.14 965.66	13,417,079	54,735,346	611,152	68,763,577	45,201,130 96,974,077
2015	219.78	361.23	32.34	613.36	482.83 716.84	22,389,318	35,310,975	2,050,791	59,751,084	40,883,332 82,986,695

Appendix Table A6. Ocean shrimp trawl observer coverage rates, 2004-2015. 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. Blank cells represent unobserved years. Data from [Somers, K.A., Y.-W. Lee, J.E. Jannot, & J. McVeigh. 2016. FOS coverage rates, 2002-2015. Last updated: 16 August 2016. NOAA Fisheries, NWFSC Observer Program, 2725 Montlake Blvd E., Seattle, WA 98112. http://www.nwfsc.noaa.gov/research/divisions/fram/observation/data_products/sector_products.cfm#ob]

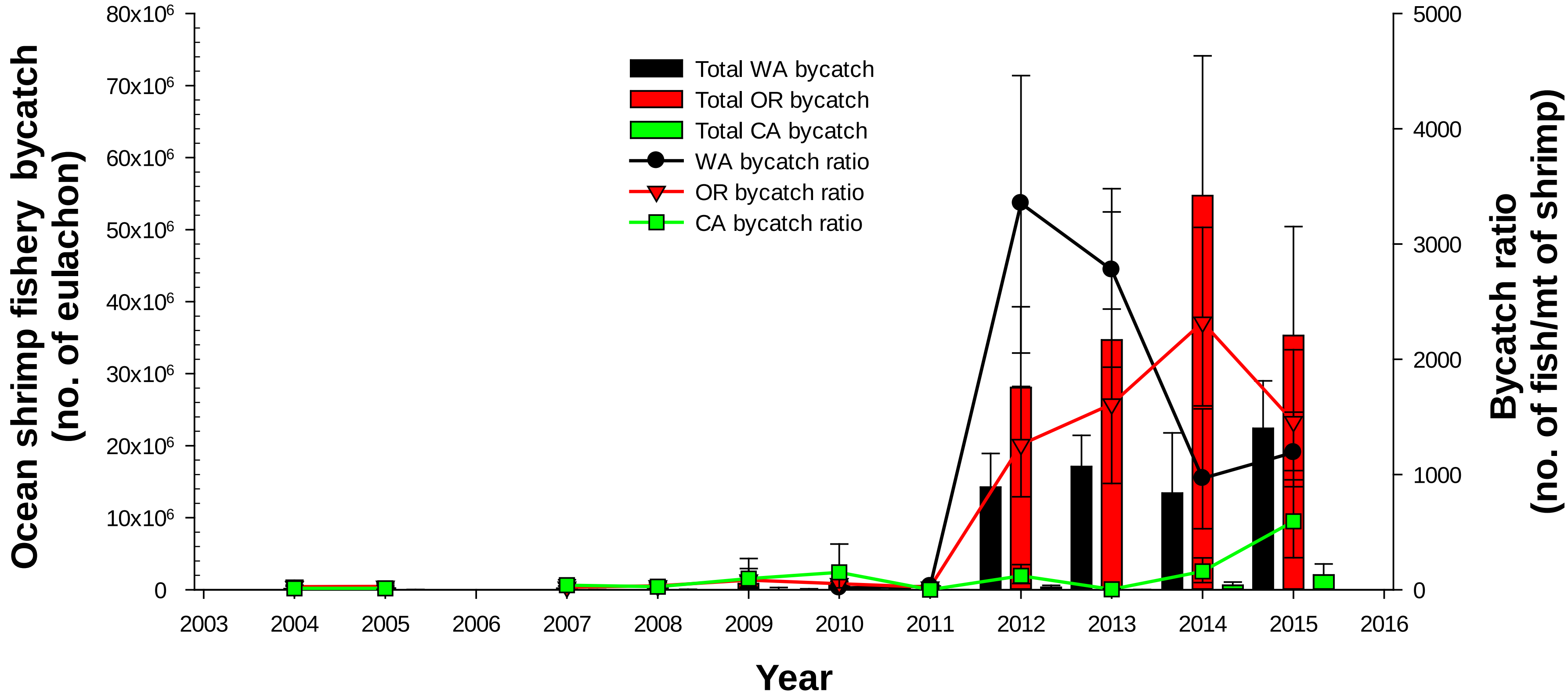
	Observed				**Fleetwide Total**	**Coverage Rate**
Year	Number of vessels	Number of trips	Number of tows	Observed ocean shrimp landings (mt)	Ocean shrimp landings (mt)	Percent ocean shrimp landings observed
2004	*	*	*	*	8,974.3	*
2005	*	*	*	*	10,861.9	*
2006					8,399.8	
2007	*	*	*	*	10,935.0	*
2008	*	*	*	*	15,374.6	*
2009	*	*	*	*	14,412.2	*
2010	54	126	1,711	2,383.3	20,357.0	12%
2011	60	186	2,674	4,103.8	29,560.2	14%
2012	69	200	2,825	3,987.8	29,321.8	14%
2013	69	153	1,983	3,299.8	31,611.0	10%
2014	66	176	2,207	3,869.7	41,294.5	9%
2015	75	254	3,784	4,767.5	46,493.5	10%

Appendix Table A7. Metric tonnage of observed and fleetwide bycatch of unidentified smelt, and observed bycatch of other osmerid smelt species in U.S. west coast ocean shrimp fisheries (WA, OR and CA combined) from 2004–2015. Shrimp fisheries were not observed in 2006. Data from WCGOP online database [Somers, K.A., Y.-W. Lee, J.E. Jannot, & J. McVeigh. 2016. Catch tables by sector: Pink shrimp trawl, 2004-2015. Last updated: 1 August 2016. NOAA Fisheries, NWFSC Observer Program, 2725 Montlake Blvd E., Seattle, WA 98112. http://www.nwfsc.noaa.gov/research/divisions/fram/observation/data_products/sector_products.cfm#obs].

	Unidentified smelt	**Unidentified non-eulachon smelt**	**Whitebait smelt**	**Night smelt**	**Rainbow smelt**	**Capelin**	**Surf smelt**	**Observed shrimp landings**	**Unidentified smelt bycatch ratio**	**Fleetwide shrimp landings**	**Fleetwide unidentified smelt bycatch**
2004	3.92	--	0.04	0.05	--	--	--	518.13	0.0076	8,974.30	68.20
2005	0.86	--	0.06	0.00	--	--	0.07	424.70	0.0020	10,861.90	21.72
2007	0.39	--	0.00	0.20	--	0.00	--	672.69	0.0006	10,935.00	6.56
2008	1.43	--	0.00	0.00	--	--	0.01	805.78	0.0018	15,374.60	27.67
2009	0.03	--	0.41	0.05	0.04	--	--	876.57	0.0000	14,412.20	0.00
2010	0.30	--	0.41	0.06	--	--	0.00	2,383.30	0.0001	20,357.00	2.04
2011	2.01	0.06	2.78	1.37	--	--	0.00	4,103.80	0.0005	29,560.20	14.78
2012	3.26	4.14	9.64	0.00	--	--	--	3,987.80	0.0008	29,321.80	23.46
2013	2.10	4.27	3.33	0.00	--	--	0.00	3,286.22	0.0006	31,611.00	18.97
2014	1.55	8.84	11.01	--	--	--	--	3,869.73	0.0004	41,294.50	16.54
2015	0.40	3.10	0.91	--	--	--	--	4,758.63	0.0001	46,493.50	3.91



Appendix Figure A1. Commercial landings in ocean shrimp trawl fisheries off the U.S. west coast through 2016. Data from PACFIN (http://pacfin.psmfc.org/pacfin_pub/woc.php), CDFW (https://www.wildlife.ca.gov/Fishing/Commercial), WDFW (http://wdfw.wa.gov/fishing/commercial/shrimp/), and Saelens (1983).



Appendix Figure A2. Estimated total bycatch and bycatch ratios of eulachon in the California, Oregon (2004–2015), and Washington (2010–2015) ocean shrimp trawl fisheries. Ocean shrimp fisheries were not observed in 2006.