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Observed and Estimated Bycatch of Eulachon in 2002–2013 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 2002–2013. 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.

Across 12 years of observation (2002–2013), a total of 8,199 individual eulachon were estimated to have been caught as bycatch in all groundfish sectors of the U.S. west coast groundfish fishery. About 88% of this bycatch of eulachon occurred during 2011–2013, 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 when an estimated bycatch of 1,624 eulachon were observed in these two fisheries and in 2013 when a total of 5,115 bycaught eulachon were estimated 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, and in 2013 81% of the bycatch of eulachon occurred in the shoreside Pacific hake fishery 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 and 2013. 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 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.

Acknowledgments

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Introduction and Background

In accordance with the National Marine Fisheries Service (NMFS) Biological Opinion (BiOp) on Continuing Operation of the Pacific Coast Groundfish Fishery (NMFS 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. 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). Eulachon in Canada that overlap the range of the ESA's southern DPS have also been recommended for listing 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 allow for 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:
    - 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.
- 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.
- Shoreside Pacific hake trawl: Midwater trawl nets are used to catch Pacific hake. 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. This component also includes the at-sea processing component of the tribal 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.

- 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.
  - 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.

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

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

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

- OA ocean shrimp[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 bstate permits in Oregon and California. Catch is delivered to shore-based processors or sold live.

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[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).

Northwest Fisheries Science Center Groundfish Observer Programs

The NWFSC Groundfish Observer 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 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 2002–2013. 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) 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.

In this report, we present additional observed eulachon bycatch, both by weight and as number of individual fish caught, for the southern DPS of eulachon. We also report bycatch ratios for eulachon 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 2002–2013.

The following commercial groundfish fishery sectors had observed eulachon bycatch during 2002–2013:

- 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 2002–2013 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 and 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. Trends from the ocean shrimp fishery and comparisons of trends to the fishery-independent NWFSC West Coast Bottom Trawl Survey are reported in Ward et al. (2015). However, 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 and will not be further covered in the body of the current 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 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 coverage.

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 2014, p. 5). 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 Pacific hake fishery

The IFQ shoreside Pacific hake midwater trawl fleet is comprised exclusively of catcher vessels that deliver unsorted catch to shore-based processing plants. 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 are required to carry an observer on 100% of the fishing trips.

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 on 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 2014), 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).

Eulachon Biological Data Collection

Part of the conservation recommendations for eulachon in the Biological Opinion (NMFS 2012, p. 130) included retention of whole eulachon "for stock identification (genetic samples), diet (stomach analysis), sex ratios (examination of gonads), age (Ba:Ca ratios in otoliths), presence (locations of captures), and general morphology measurements." Both the WCGOP Catch Shares (aka IFQ) (NWFSC 2015a) and Non-Catch Shares (aka Non-IFQ) (NWFSC 2015b) training manuals provide instructions to observers that when eulachon are encountered in a trawl, length measurements (fork length) should be obtained from a random selection of five eulachon and that one of these whole body specimens should be individually bagged, the bag barcoded to align with trawl data, and frozen for later analysis. A summary of length frequency data from these biological specimen collections is presented in this document; however, all other biological analyses are waiting for adequate funding to process eulachon specimens for stock identification, diet, sex, and age information.

Methods

Data Sources

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

Observer Data

A list of fisheries, coverage priorities and data collection methods employed by WCGOP in each observed fishery can be found in the Catch Shares (aka IFQ) and Non-Catch Shares (aka Non-IFQ) WCGOP manuals (NWFSC 2015a, b). A-SHOP information and documentation on data collection methods can be found in the A-SHOP observer manual (NWFSC 2014).

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 sales receipts (known as fish tickets) is the 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 format by 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, with state species composition sampling applied, were retrieved from the PacFIN database in March 2014 (for 2011–2013) and November 2012 (for 2002–2010) 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 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

The landed amount of a target species (or species groups) was used as a proxy for fishing effort metric. 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 as bycatch in the following groundfish fishery sectors: (1) LE bottom trawl (2002–2010), (2) IFQ bottom trawl (2011–2013), (3) IFQ non-hake midwater trawl (2011–2013), (4) IFQ shoreside hake fishery (2011–2013), (5) at-sea Pacific hake mothership fishery (2002–2013), (6) at-sea Pacific hake catcher-processor fishery (2002–2013), and (7) at-sea Pacific hake tribal mothership fishery (2002–2011, no effort in this sector occurred in 2013, and data for 2012 is confidential as fewer than 3 vessels were observed).

As mentioned, 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 2002–2013 were: all groundfish species, except Pacific hake, included in the groundfish fishery management plan (FMP) for LE bottom trawl and IFQ trawl sectors, and Pacific hake for shoreside hake and at-sea hake fisheries. For those sectors that encountered eulachon, a ratio estimator was used to estimate the number or weight of eulachon catch per stratum. For a given fishery sector, observer data were stratified by state of landing, year, and season, as applicable and possible given confidentiality rules. 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 various species of rockfishes, flatfishes, skates, etc. 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 removed from the LE bottom trawl data.

Catch shares: non-hake IFQ fishery

Since 2011, the U.S. West Coast groundfish trawl fishery has been managed under the program known as 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 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. To maintain confidentiality standards, bottom and midwater sectors were combined for bycatch estimation. Fleet-wide eulachon bycatch for this sector is almost completely known because all vessels carry an observer (complete census). Bycatch for this fishery was summarized by year and state of landing.

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 the unsampled catch was less than 0.5% of the total landed weight of groundfish species during 2011–2013. 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 any 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 hauls by the proportion of unsampled hauls over the total number of hauls 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 = number of unsampled hauls
T = total number of hauls

Catch shares: shoreside Pacific hake IFQ fishery

The shoreside Pacific hake fishery operates under IFQs as part of the Catch Shares program. Under catch shares regulations, each shoreside hake vessel is required to carry a WCGOP observer at all times, resulting in 100% observer coverage. 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.

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 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 applied 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 2011–2013, 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 study 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 (2011–13). 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); however, during 2011, 2012, and 2013 an estimated 12, 1, and 137 individual eulachon, respectively, were estimated as fleet-wide bycatch in the Washington IFQ bottom trawl fishery (Table 3). 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 2013, the Oregon IFQ bottom trawl fishery had an estimated eulachon bycatch of 816 individual fish with nearly 64% of this total occurring in the year 2013 (Table 5). Eulachon are 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 trawl fishery from 2011–2012; 2013 data cannot be reported in order to satisfy confidentiality requirements (Table 7).

Eulachon appear to be 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 and 1,271 fish in 2006 and 2011, respectively (Table 8). The bycatch estimate in 2011 amounted to 82% of the total eulachon bycatch estimate of 1,547 fish between 2002 and 2013. In all other years, fewer than 40 individual eulachon were observed in the catcher-processor Pacific hake sector as bycatch (Table 8).

The non-tribal mothership Pacific hake sector had an estimated eulachon bycatch of 355 individual fish between 2002 and 2013, with 78% of this bycatch occurring in 2013. No eulachon bycatch occurred in 2002–2006 or in 2010, 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 in 2009 was 32 fish and 160 fish in 2011. Eulachon bycatch was not reported in this sector from 2001–2008 or in 2010. The tribal mothership sector did not participate in the Pacific hake fishery in 2013 and fewer three vessels were observed in 2012 (Table 8). The WCGOP began observing bycatch in the shoreside Pacific hake fishery in 2011 and did not observe eulachon bycatch discarded at-sea in this fishery in 2011 or 2012.

However, 4,139 individual eulachon were estimated to have been landed as bycatch in this fishery in 2013, although effort was similar to the years 2011 and 2012 (Table 9). Bycaught fish are not counted by shore-based catch monitors in this fishery. The 83.5 kg of eulachon recorded by catch monitors was estimated to represent 4,139 individual eulachon based on the average weight of at-sea eulachon that appear as bycatch in other fisheries observed by the WCGOP.

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 2002–2013 is provided in Table 10. From 2002–2013 all groundfish sectors caught an estimated 8,199 individual eulachon. About 88% of this bycatch of eulachon occurred during 2011–2013, 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).

Length Frequency

Length frequency data for eulachon sampled (n = 245) in the 2013 Washington and Oregon IFQ bottom trawl fisheries are presented in Figure 1. Length data were unavailable for other years and other groundfish fishery sectors. Because fish in the same age cohort increase in length throughout the yearly growing season, length frequency data are presented in four separate histograms representative of bycatch during January–February, May–July, August–September, and October–December. It is difficult to identify multiple modes indicative of age classes in these data, although the dominant unimodal peak does show an increasing length over time.

Observer Coverage

Currently 100% of landings are observed in the IFQ bottom trawl fleet which also includes LE California halibut tows. At this point in time, the WCGOP plans to maintain 100% coverage for the foreseeable future. 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 and Jannot 2014). In the unlikely event that observer coverage in the IFQ fleet was reduced, the WCGOP would strive to maintain historic levels of coverage, with 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 Limited Entry bottom trawl fleet might lead to estimates of eulachon bycatch that are relatively unbiased and only slightly larger than the true value (Table 11, Fig. 2; 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 estimates but should be considered to be conservative. Other sources of bias have not been evaluated (NMFS 2004).

The NWFSC Observer 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 Observer 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 = 976) 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 5,115 bycaught eulachon were estimated in all U.S. west coast groundfish fisheries combined. The shore-based Pacific hake fishery accounted for 81% of the total 2013 bycatch of eulachon (Table 10).

Several indices of eulachon abundance have shown dramatic increases since 2011. Spawning stock biomass (SSB) estimates of eulachon in the Columbia River (James et al. 2014), estimates of eulachon larval density in the Columbia River (Fig. 3), and a relative biomass index of eulachon incidental catch in the NWFSC West Coast Bottom Trawl Survey (WCBTS) (Fig. 4), all increased by an order of magnitude between 2010 and 2013. This level of eulachon abundance has 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 and 2013. The previous bycatch peak (783 individuals) occurred in the Oregon portion of the LE bottom trawl fishery in 2002, which coincided with a peak abundance in the West Coast Vancouver Island offshore eulachon biomass index (Gustafson et al. 2010, their fig. 16). Landings in the Columbia River commercial fishery (Gustafson et al. 2010, their fig. 22) and estimates of eulachon eggs-larvae/m^3 and eulachon adult CPUE in the Columbia River (Fig. 3) also previously peaked in 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 2014), 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 in the early years of the two observer programs. 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 (Fig. 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.

Length

Based on recent data summarizing the body size of adult eulachon in the Columbia River (Jen Zamon, NWFSC, pers. comm., March 2013), the mean fork lengths of adult eulachon from multiple collections ranged from 17.2–17.5 cm for males and 16.7– 17.2 cm for females. Data from eulachon collected off the west coast of Vancouver Island indicates that age 1+, 2+, and 3+ juvenile eulachon typically range in standard length (tip of snout to hypural plate) from 6.0-13.0 cm, 10.0-18.0 cm, and 14.0-20.0 cm, respectively (see http://www.pac.dfo-mpo.gc.ca/science/species-especes/pelagic-pelagique/herring-hareng/herspawn/pages/ocean1-eng.html). Using equations to convert standard length to fork length (FL) published in Buchheister and Wilson (2005), age 1+ would range from 6.6–14.1 cm FL, age 2+ would range from 10.9–19.5 cm FL, and, if present, age 3+ eulachon would range from 15.2–21.6 cm FL. Clarke et al. (2007) suggested that eulachon likely spawn after reaching a minimum fork length of 16.0 cm and a body weight greater than 30 g. It is therefore likely that most of the eulachon captured in January–February 2013 and represented in Figure 1 would have been destined to spawn in the spring of 2013, and those collected in August-September and October-December would have likely been either age 2+ or 3+ (based on their modal length) and would have been destined to spawn in the spring of 2014. Multiple modes indicative of age classes are not clearly recognizable in these data, although there is some indication of a bimodal distribution in the August-September and October-December collections, likely corresponding to two age classes.

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), indicating that smaller fish with their poorer swimming ability and endurance may be more likely to suffer greater injury and stress during their escape from trawl gear than larger fish (Broadhurst et al. 2006, Ingólfsson et al. 2007, Suuronen and Erickson 2010, Gilman et al. 2013).

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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**	**2011-2013**
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
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		LE permit with trawl endorsement	Midwater trawl	Pacific hake	17–29	Wide range	Same as At-Sea Hake MSCV; electronic monitoring	IFQ; Seasonal; 100% observer coverage of landed catch

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 (2011–2013). Bycatch weights are in kilograms and groundfish landings are in metric tons. Note that catch share fisheries are sampled at close to 100%.

	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	99.4	1,859.6	0.1	1.4	0.6	12
2012	0.0	1	2,189.6	98.6	2,220.9	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

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** (2011–2013). Bycatch weights are in kilograms and groundfish landings are in metric tons. Note that catch share fisheries are sampled at close to 100%.

	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	10,810.0	99.2	10,893.7	4.6	0.2	6.1	127
2012	5.8	163	10,668.6	99.4	10,735.3	3.9	0.1	6.0	167
2013	30.7	507	12,437.6	99.7	12,473.0	15.0	0.9	31.6	522

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** (2011–2013). Bycatch weights are in kilograms and groundfish landings are in metric tons. Note that catch share fisheries are sampled at close to 100%. Asterisks (*) signify strata with fewer than three observed vessels.

	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	4,596.5	99.9	4,601.8	0.0	0.0	0.0	0
2012	0.0	0	4,442.9	99.8	4,451.4	0.0	0.0	0.0	0
2013	*	*	*	99.7	*	0.0	0.0	0.0	0

Table 8. Observed and expanded bycatch (kilograms) and number of eulachon from the at-sea Pacific hake fishery (2002–2013). In 2013 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	99.5	36,333	0.0	0.0	0	0
	2003	766	99.7	41,469	0.0	0.0	0	0
	2004	1,492	99.4	72,859	0.0	0.0	0	0
	2005	1,332	99.6	78,497	0.0	0.0	0	0
	2006	1,488	99.4	78,246	1.5	1.5	145	147
	2007	1,566	99.3	72,898	0.1	0.1	6	6
	2008	1,864	98.8	107,754	2.1	2.1	37	37
	2009	863	99.4	34,591	2.1	2.1	30	30
	2010	1,063	99.5	54,217	0.0	0.0	0	0
	2011	1,530	98.8	71,337	115.6	115.9	1,268	1,271
	2012	1,100	99.4	55,523	1.1	1.1	16	16
	2013	1,439	98.6	78,005	2.9	2.9	39	39
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	99.8	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	278
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	*	*	*	*	0.0	*	0
	2013	na	na	na	na	na	na	na

Table 9. Eulachon bycatch landed (kilograms) and estimated number in the shoreside Pacific hake fishery (2011–2013). Note that this fishery is sampled at 100% after being landed. In this fishery, bycatch weights are landed and weighed by the catch monitor. The counts are then estimated from a count/weight regression.

Year	Total tow numbers	Percent tows sampled	Landed bycatch (kg)	Estimated bycatch numbers
2011	1,701	100	0.0	0.0
2012	1,565	100	0.0	0.0
2013	1,725	100	83.5	4,139

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 2002–2013.

	Non-hake bottom and midwater groundfish fisheries			**Shoreside hake**	**At-sea 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	1,271	1,624
2012	1	167	0	0	0	7	16	191
2013	137	522	0	4,139	na	278	39	5,115
Total	150	1,790	27	4,139	192	355	1,546	8,199

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 2002–2013. 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 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	--	--

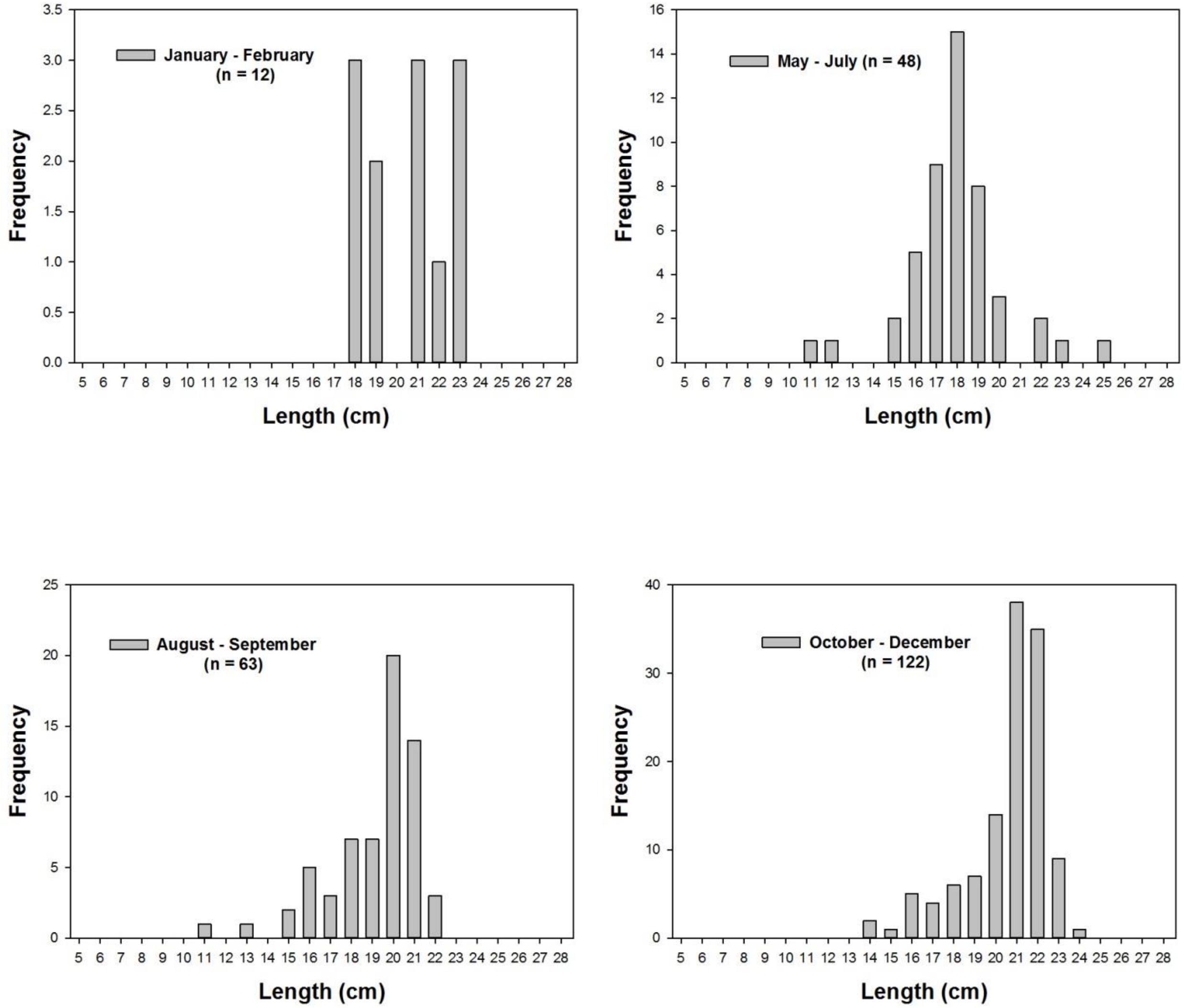

Figure 1. Length frequency histograms of juvenile eulachon caught as bycatch and measured by the WCGOP in IFQ groundfish fisheries off the U.S. West Coast in 2013.

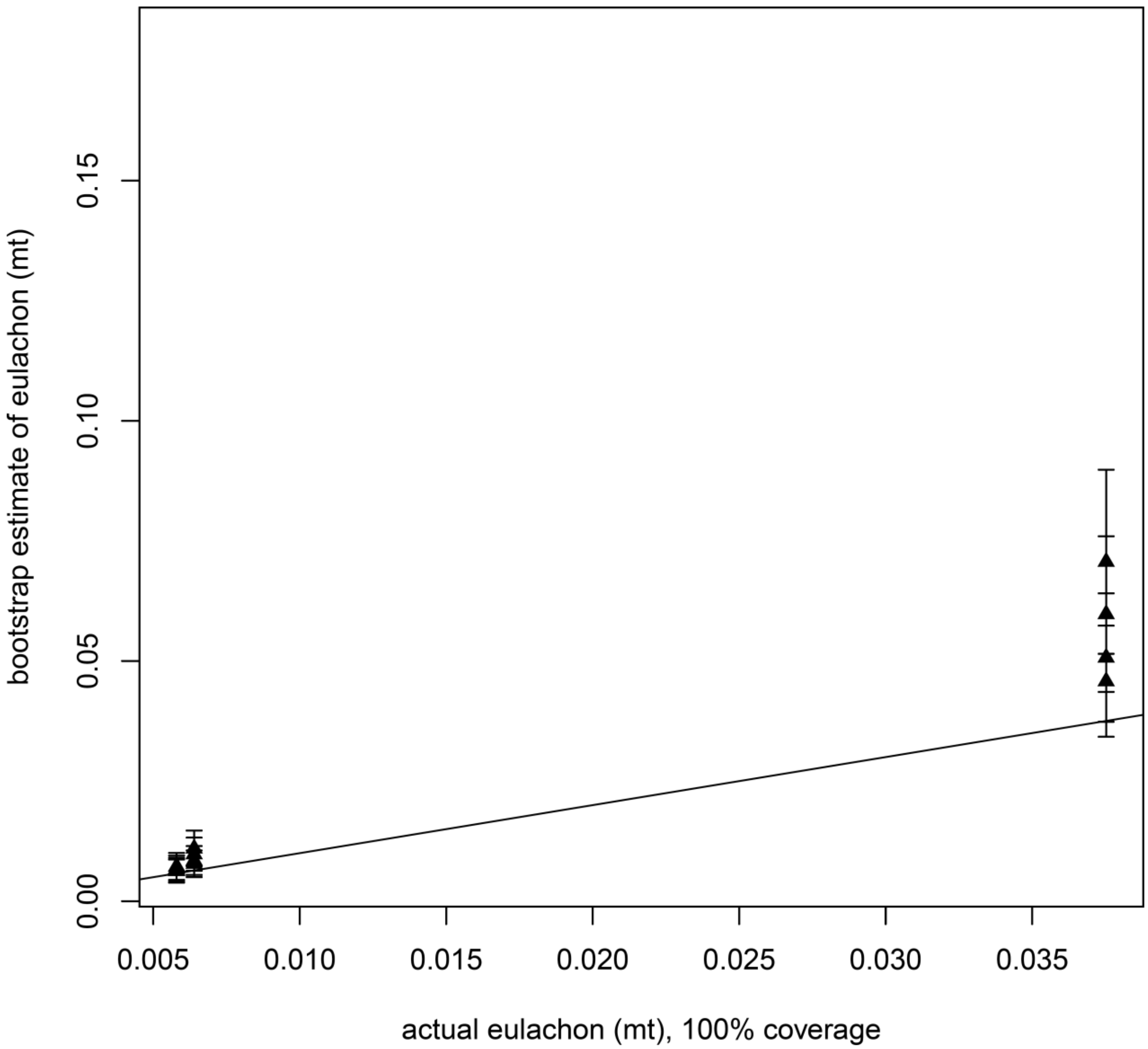

Figure 2. Plot of bootstrapped estimates of eulachon bycatch (mt) as a function of actual eulachon bycatch (mt) for each year of the IFQ bottom trawl fishery (2011–13). The line represents equivalency (slope = 1) where the value of the bootstrap estimate is equal to the actual value. Each of the three 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.

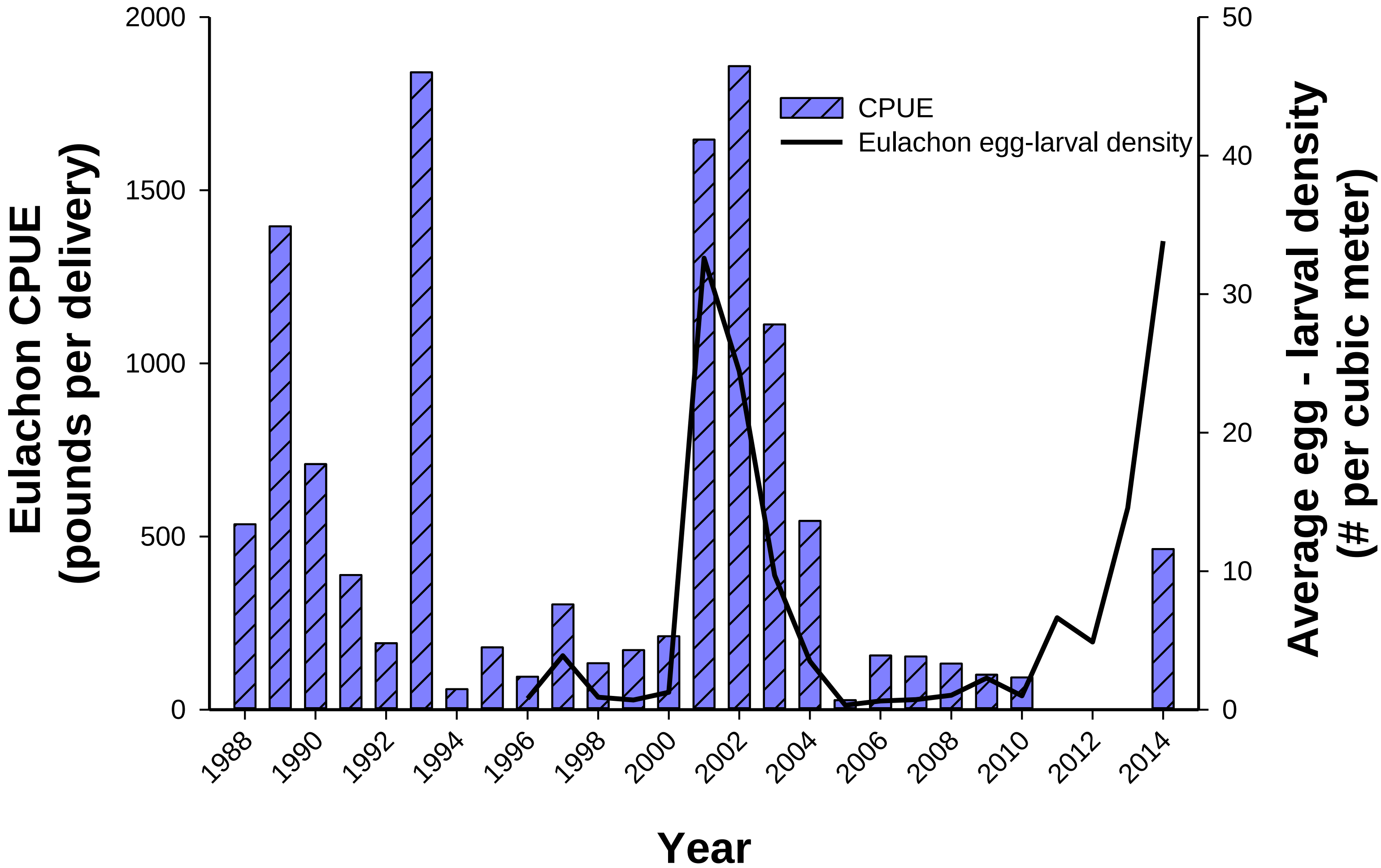

Figure 3. Time series of trends in eulachon CPUE (pounds per delivery) and average eulachon egg - larval density in the mainstem Columbia River. Data from JCRMS (2014, tables 18 and 19) and Olaf Langness (WDFW, pers. commun.). Modified from JCRMS (2014, p. 17, fig. 1).

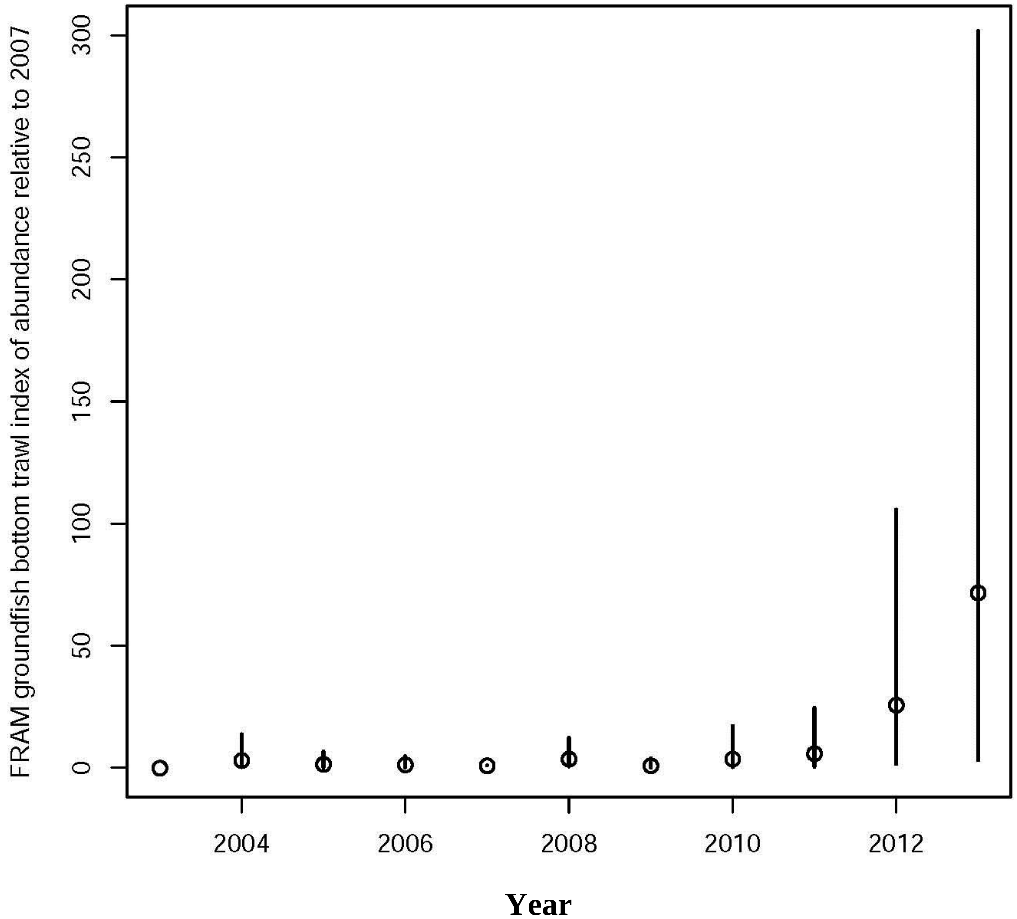

Figure 4. Relative biomass index of eulachon incidental catch (± SE) in the West Coast Bottom Trawl Survey (WCBTS) from 2003–2013. Values are scaled relative to the lowest abundance in 2007, which has been set equal to 1. Figure provided by Dr. Eric Ward (Conservation Biology Division, NWFSC, Seattle, WA). Data source: NOAA Northwest Fisheries Science Center's WCBTS database maintained by the Fisheries Resource Analysis and Monitoring (FRAM) Division.

Appendix A

Observed and Estimated Bycatch of Eulachon in US West Coast Ocean Shrimp Trawl Fisheries From 2004–2013

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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). Eulachon in Canada that overlap the range of the ESA's southern DPS have also been recommended for listing 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 2004–2013.

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). 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, and total coastwide ocean shrimp landings have ranged from a low of 1,888 mt in 1957 to a high of 41,418 mt in 2014 (Fig. A1). The portion of the bycatch that is not marketable or for which regulations prohibit landing is discarded at-sea and 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 2014–2015 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/2015_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 2014-2015, online at https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=88056&inline).

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 Non-Catch Shares (aka Non-IFQ) WCGOP manual (NWFSC 2015).

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 sales receipts (known as fish tickets) is the 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; 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)].

One situation required that 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. Among the federally managed sectors that encountered eulachon during 2011–2013, only one confidential stratum occurred, the winter season of 2008 in the Washington LE bottom trawl fishery sector.

Eulachon biological data collection

The WCGOP Non-Catch Shares (aka Non-IFQ) training manual (NWFSC 2015) provides instructions to observers that when eulachon are encountered in a trawl, length measurements (fork length) should be obtained from a random selection of five eulachon and that one of these whole body specimens should be individually bagged, the bag barcoded to align with trawl data, and frozen for later analysis as described in the Biological Opinion.

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 2007–2013. 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 and the estimated bycatch in terms of weight and numbers of eulachon has increased in each year up to 2013, while the percentage of total shrimp landings observed has fluctuated between just less than 10% to nearly 15% (Table A2). Total estimated bycatch of eulachon in the Washington ocean shrimp fisheries ranged from a low of over 64 thousand (95% CI; 23,361–132,532) fish in 2010 to a high of over 17.2 million (95% CI; 12,077,308–21,444,581) fish in 2013 (Table A2, Fig. A2). Mean estimated total biomass of eulachon bycatch in the Washington fishery during this time period (2010–2013) ranged from 2.1–203.7 mt (Table 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 (the fishery was not observed in 2006); however, estimated bycatch expanded dramatically in 2012 and 2013 to over 28.1 million (95% CI; 17,948,671–39,302,622 million) and 35.1 million (95% CI; 20,316,467–52,991,571), respectively (Table A3, Fig. A2). Similarly, total weight of estimated eulachon bycatch in Oregon increased from 20.5 mt (95% CI; ~14.7–27.4 mt) in 2011 to nearly 428 mt (95% CI; ~285–588 mt) in 2012 and to over 540 mt (95% CI; ~348–759 mt) in 2013.

Bycatch ratios, measured as both kg of eulachon and numbers of fish, per metric ton of ocean shrimp observed also increased dramatically in both the Washington and Oregon ocean shrimp fisheries from 2011 to 2012, and remained high in 2013 (Tables A2–A3, Fig. A2). Bycatch ratios were higher in Washington than in the Oregon fishery in both 2012 and 2013 (Tables A2–A3, Fig. A2).

Eulachon bycatch in the California ocean shrimp fishery has followed a very different trajectory from that observed in Washington and Oregon during the last three years (2011–2013) of available data. Eulachon bycatch in California remained below 25,000 fish prior to 2008 (the fishery was not observed in 2006), rose dramatically in 2010 to over 267,000 (95% CI; 40,040–714,661) fish; fell to its lowest observed level of just 471 (95% CI; 197–826) fish in 2011, increased again dramatically in 2012 to over 337,000 (95% CI; 151,822–616,148) fish, and then fell to just over 16,000 (95% CI; 3,768–33,610) 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). The tonnage of observed ocean shrimp and of fleet-wide landings were relatively stable over the last three to four years, indicating that yearly differences in eulachon distribution, or in the catchability of eulachon, likely contributed to the extreme fluctuations in eulachon bycatch in the California ocean shrimp fishery.

Combined WCGOP estimates of the weight and number of eulachon caught in the Oregon and California ocean shrimp trawl fishery as bycatch from 2004–2013 (except for 2006 when these fisheries were not observed) and in Washington from 2010–2013 are presented in Table A5. Total estimated bycatch of eulachon in the Oregon and California ocean shrimp fisheries ranged from nearly 158,000 fish (95% CI; 11,642–492,844) in 2004 to a high of over 959,000 (95% CI; 238,075–2,147,772) fish in 2009. Estimated eulachon bycatch in the Washington ocean shrimp fishery in 2010 (its first year of observation) was nearly 65,000 fish and the total 2010 estimated eulachon bycatch for all three states combined was over 1,072,000 (95% CI; 532,268–1,891,424). Total three-state eulachon bycatch decreased to about 602,000 (95% CI; 394,343–875,107) fish in 2011 (Table A5). However, as seen earlier, eulachon bycatch increased dramatically in all three states in 2012, topping out at over 42.8 million (95% CI; ~26.9–59.1 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 52.3 million (95% CI; ~32.4–74.5 million) fish (Table A5). Estimated weight of these bycaught eulachon in 2013 was over 744 mt (95% CI; ~498–1,008 mt) (Table A5).

A mapped representation of the spatial distribution of eulachon bycatch risk and areas of highest bycatch encounters in the state ocean shrimp trawl fisheries from 2002–2013 is provided in Figures A3 and A4, respectively. Methods describing the calculations behind these methods are provided in Ward et al. (2015). To summarize the methods, bycatch risk (calculated as eulachon density / ocean shrimp density) was calculated for each year as a function of effort, fishing depth, and sea surface temperature. Hotspots of density for each species (eulachon, shrimp) were allowed to be autoregressive, so that a hotspot one year may be useful in predicting density the next year. Bycatch risk from this analysis is shown in Figure A3 is calculated as estimated eulachon biomass/ shrimp biomass and hot spots of eulachon bycatch are depicted in orange-red colors showing an increasing risk in 2012 and 2013 compared to earlier years. In Figure A4 the areas of highest bycatch risk are depicted as the top 10% of observed bycatch values in red. These areas represent the consistent hotspots of bycatch (eulachon to shrimp density) found across all years. There areas of high risk may represent feeding aggregations of eulachon, or large densities for other reasons. A more complete description of the methodology and results can be found in Ward et al. (2015).

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 2010–2013; 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 2010–2013, observer coverage in Washington and California averaged 12.8% and 12.4% of total shrimp landings, respectively (Table A2, A4). No ocean shrimp trawl fishery landings were observed in 2006. See Fisheries Observation Science, Sector Data Products website (http://www.nwfsc.noaa.gov/research/divisions/fram/observation/data_products/sector_products.cfm#ob) for ocean shrimp fishery observer coverage data by state sector.

Length frequency

Length frequency data of eulachon sampled in the 2009 (n = 76), 2010 (n = 50), and 2011 (n = 262) Oregon ocean shrimp trawl fisheries are presented in Figure A5. Length frequency data of 2012 bycaught eulachon in Washington (n = 2,045), Oregon (n = 6,799) and California (n = 489) are presented in Figures A6, A7 and A8, respectively. Likewise, Figures A9, A10, and A11 present 2013 length frequency data for Washington (n =2,768), Oregon (n = 5,644) and California (n = 309), respectively. Because fish of the same age increase in length throughout the yearly growing season, length frequency data are presented in separate histograms representative of monthly bycatch throughout the open ocean shrimp trawl season from April to October, to better track age cohorts.

Discussion

The previously depressed and currently increasing abundance of the southern DPS of eulachon (James et al. 2014; Fig. 2) are likely contributing to the increased levels of eulachon bycatch reported in this document for 2012 and 2013. 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.

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. (2012, 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; Hannah and Jones 2000, 2003, 2007, 2012; Frimodig et al. 2009) and great progress has been made in reducing bycatch, particularly of 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).

"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 2004–2013 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 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 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 we believe that fish categorized as unidentified smelt in the database from 2011–2013 would likely consist of other osmerid smelt species besides eulachon.

Length

Based on recent data summarizing the body size of adult eulachon in the Columbia River (Jen Zamon, NWFSC, pers. comm., March 2013), the mean fork lengths of adult eulachon from multiple collections ranged from 17.2–17.5 cm for males and 16.7– 17.2 cm for females. Data from eulachon collected off the west coast of Vancouver Island indicates that age 1+, 2+, and 3+ juvenile eulachon, typically range in standard length (tip of snout to hypural plate) from 6.0-13.0

cm, 10.0-18.0 cm, and 14.0-20.0 cm, respectively (see http://www.pac.dfo-mpo.gc.ca/science/species-especes/pelagic-pelagique/herring-hareng/herspawn/pages/ocean1-eng.html). Using equations to convert standard length to fork length (FL) published in Buchheister and Wilson (2005), age 1+ would range from 6.6–14.1 cm FL, age 2+ would range from 10.9–19.5 cm FL, and if present age 3+ eulachon would range from 15.2–21.6 cm FL. Clarke et al. (2007) suggested that eulachon likely spawn after reaching a minimum fork length of 16.0 cm and a body weight greater than 30 g.

Length frequency data of bycaught eulachon appear unimodal in 2012 (Figs. A6–A8), without a clear indication of more than one age class. In contrast, several monthly samples of bycaught eulachon in the 2013 ocean shrimp fisheries in both Washington and Oregon (Figs. A9–A10), but not California Fig. A11), illustrate a bimodal size frequency distribution. Similarly, Wargo et al. (2014) found an apparent unimodal distribution of length frequencies of bycaught eulachon measured in the 2012 Washington ocean shrimp trawl fishery. A weak bimodal length frequency distribution indicative of two age classes was detected among eulachon sampled from the 2011 Washington ocean shrimp fishery (Wargo et al. 2014).

Conservation implications and the promise of lighted trawl nets

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 have shown great promise for significantly reducing bycatch of eulachon (Hannah and Jones 2014, 2015; Hannah et al. 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. 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 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. (2014) stated that “How the addition of artificial light is causing these changes in fish behavior and bycatch reduction is not known,” but “the addition of artificial light appears to have greatly increased the passage of fishes through restricted spaces (between BRD bars and the open space between trawl fishing line and groundline) that they typically would avoid under normal seafloor ambient light conditions.” Winger et al. (2012, p. 89), in a review of fish behavior near bottom trawls stated that:

> It is well known that most species of fish have well developed and efficient visual systems that are particularly well adapted to detect very small differences in contrast in the generally monochromatic underwater environment in which they exist … Where water clarity is good and light intensity is high, fish may see an approaching net from afar and may react to its approach by rising in the water column and allowing the net to pass underneath, thus avoiding capture. Conversely, in dark or turbid conditions, visible range may be very short and fish may have little time to react to the approaching net.

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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**	**2011-2013**
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** (2010–2013). 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	0.2 0.9	15.1	5.4 30.9	9.6	4,295.6	2,062.9	774.9 3,818.2	64,735	23,361 132,532
2011	917.7	19,976	697.2	1.3	0.8 2.1	28.7	16.4 46.9	16.6	4,211.9	5,543.8	3,347.6 8,871.6	120,671	68,949 197,747
2012	23,135.3	2,118,790	626.0	37.0	24.4 48.7	3,384.9	2,086.4 4,514.7	14.8	4,242.3	156,797.2	103,668.0 206,687.5	14,359,862	8,851,034 19,152,683
2013	20,646.3	1,740,333	626.8	32.9	24.3 40.1	2,776.4	1,953.3 3,468.2	10.1	6,183.1	203,660.0	150,472.6 247,703.8	17,167,047	12,077,308 21,444,581

Appendix Table A3. Numbers and weight of eulachon observed and bycatch ratios from ocean shrimp trawl vessels that landed their catch in **Oregon** (2010–2013). 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 81.9	7.7	5,537.0	2,875.3	221.8 8,401.9	146,338	11,291 453,313
2005	278.7	11,669	402.9	0.7	0.1 1.4	29.0	3.3 58.6	5.6	7,159.4	4,953.3	771.3 10,176.3	207,362	21,457 419,649
2006	--	--	--	--	-- --	--	-- --	0.0	5,531.8	--	-- --	--	-- --
2007	277.8	14,084	650.0	0.4	0.0 1.1	21.7	1.0 58.8	7.1	9,128.6	3,901.7	277.8 10,241.2	197,807	14,084 537,063
2008	600.3	22,634	672.5	0.9	0.2 1.9	33.7	9.1 63.4	5.8	11,575.9	10,332.6	2,405.2 21,740.3	389,604	104,816 734,031
2009	650.9	63,175	751.2	0.9	0.2 1.9	84.1	21.8 181.8	7.5	10,048.7	8,707.4	2,155.0 19,468.4	845,081	219,174 1,827,136
2010	1,635.3	88,373	1,705.4	1.0	0.7 1.3	51.8	32.8 73.1	11.9	14,290.4	13,702.6	9,783.4 17,865.3	740,501	468,866 1,044,231
2011	2,786.7	65,524	2,986.0	0.9	0.7 1.2	21.9	14.8 30.9	13.6	21,915.1	20,452.9	14,665.0 27,351.1	480,907	325,197 676,531
2012	57,865.9	3,804,855	3,014.2	19.2	12.8 26.4	1,262.3	805.2 1,763.1	13.5	22,291.6	427,946.2	285,016.6 588,501.9	28,138,728	17,948,671 39,302,622
2013	58,004.9	3,773,026	2,313.2	25.1	16.1 35.2	1,631.1	943.3 2,460.4	10.7	21,537.8	540,062.9	347,564.8 759,024.6	35,129,318	20,316,467 52,991,571

Appendix Table A4. Numbers and weight of eulachon observed and bycatch ratios from ocean shrimp trawl vessels that landed their catch in **California** (2010–2013). 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	*	*	*	0.2	0.0 0.5	11.4	0.0 39.7	*	996.8	212.4	14.6 541.9	11,403	351 39,531
2005	*	*	*	0.2	0.0 0.5	11.4	0.0 40.7	*	860.6	183.4	0.0 455.5	9,788	0 35,051
2006	--	--	--	--	-- --	--	-- --	--	63.6	--	-- --	--	-- --
2007	*	*	*	0.5	0.0 1.2	40.0	0.0 86.3	*	289.1	157.6	13.0 334.1	11,548	978 24,943
2008	*	*	*	0.4	0.0 0.9	26.4	0.0 66.0	*	945.5	341.4	82.9 835.7	24,962	5,908 62,402
2009	*	*	*	0.9	0.2 2.5	96.3	16.0 270.9	*	1,183.5	1,102.0	242.8 2,907.0	113,983	18,902 320,635
2010	367.9	40,040	265.5	1.4	0.2 3.5	150.8	16.1 403.5	15.0	1,771.0	2,454.0	397.0 6,121.8	267,057	40,040 714,661
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	10.3 59.8	471	196 830
2012	857.2	42,018	347.6	2.5	1.2 4.8	120.9	54.4 220.8	12.5	2,790.7	6,882.0	3,350.3 13,485.8	337,344	151,822 616,148
2013	65.8	1,533	359.8	0.2	0.0 0.4	4.3	1.0 8.8	9.4	3,829.8	700.3	170.8 1,393.5	16,320	3,768 33,610

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 2004–2013. 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.

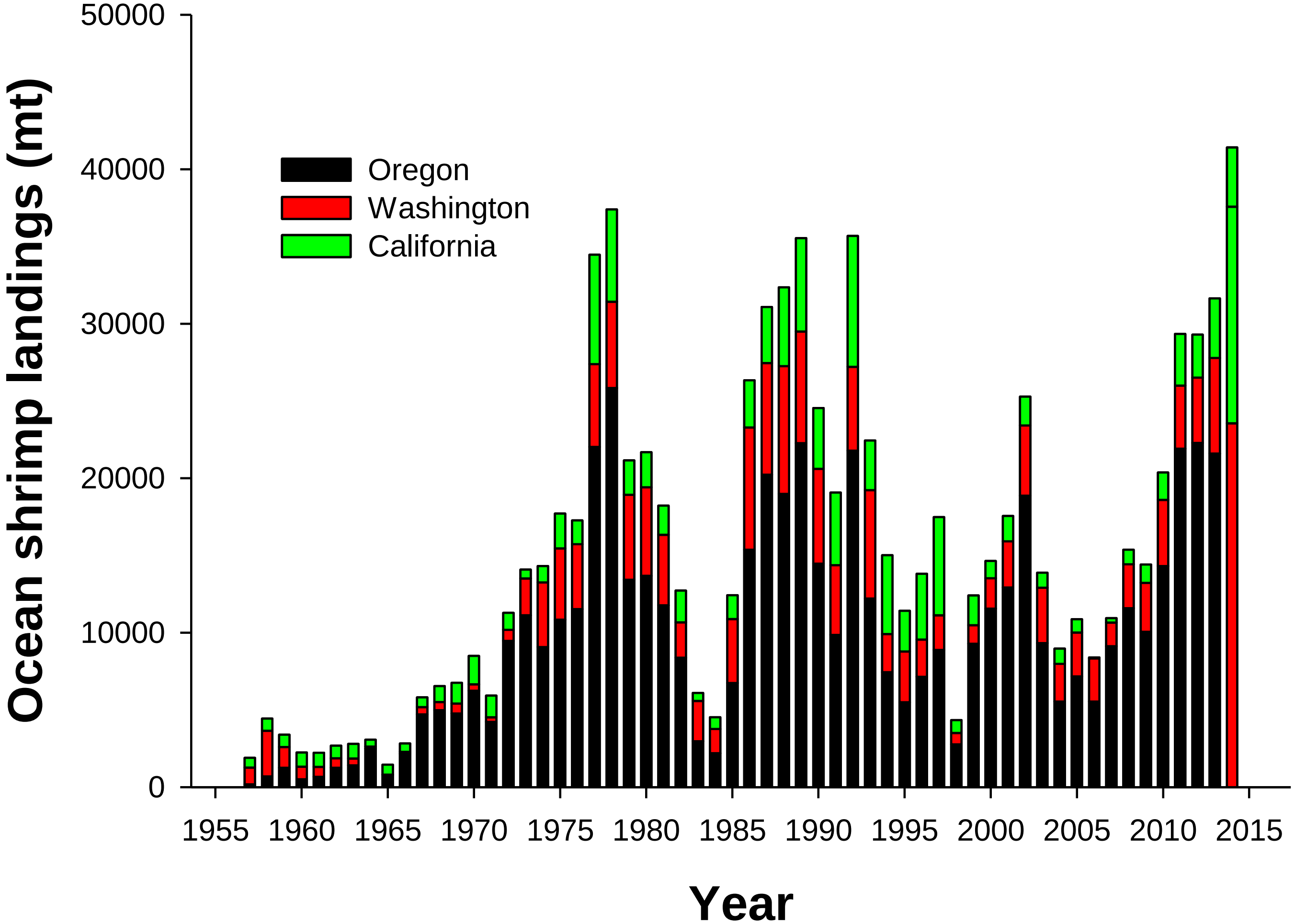
	Eulachon bycatch (mt)					Eulachon bycatch (numbers of fish)				
Year	Washington	Oregon	California	Coastwide bycatch	95% CI	Washington	Oregon	California	Coastwide bycatch	95% CI
2004	--	2.88	0.21	3.09	0.24 8.94	--	146,388	11,403	157,742	11,642 492,844
2005	--	4.95	0.18	5.14	0.77 10.63	--	207,362	9,788	217,150	21,457 454,700
2006	--	--	--	--	-- --	--	--	--	--	-- --
2007	--	3.90	0.16	4.06	0.29 10.58	--	197,807	11,548	209,355	15,062 562,006
2008	--	10.33	0.34	10.67	2.49 22.58	--	389,604	24,962	414,566	110,723 796,433
2009	--	8.71	1.10	9.81	2.40 22.38	--	845,081	113,983	959,065	238,075 2,147,772
2010	2.06	13.70	2.45	18.22	10.96 27.81	64,735	740,501	267,057	1,072,294	532,268 1,891,424
2011	5.54	20.45	0.03	26.03	18.02 36.28	120,671	480,907	471	602,049	394,343 875,107
2012	156.80	427.95	6.88	591.63	392.03 808.68	14,359,862	28,138,728	337,344	42,835,935	26,951,527 59,071,452
2013	203.66	540.06	0.70	744.42	498.21 1,008.12	17,167,047	35,129,318	16,320	52,312,685	32,397,543 74,469,761

Appendix Table A6. Ocean shrimp trawl observer coverage rates, 2004-2013. 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 WCGOP online observer coverage rate spreadsheet file labelled “Observer Coverage Rates 2002-2013” at http://www.nwfsc.noaa.gov/research/divisions/fram/observation/data_products/sector_products.cfm.

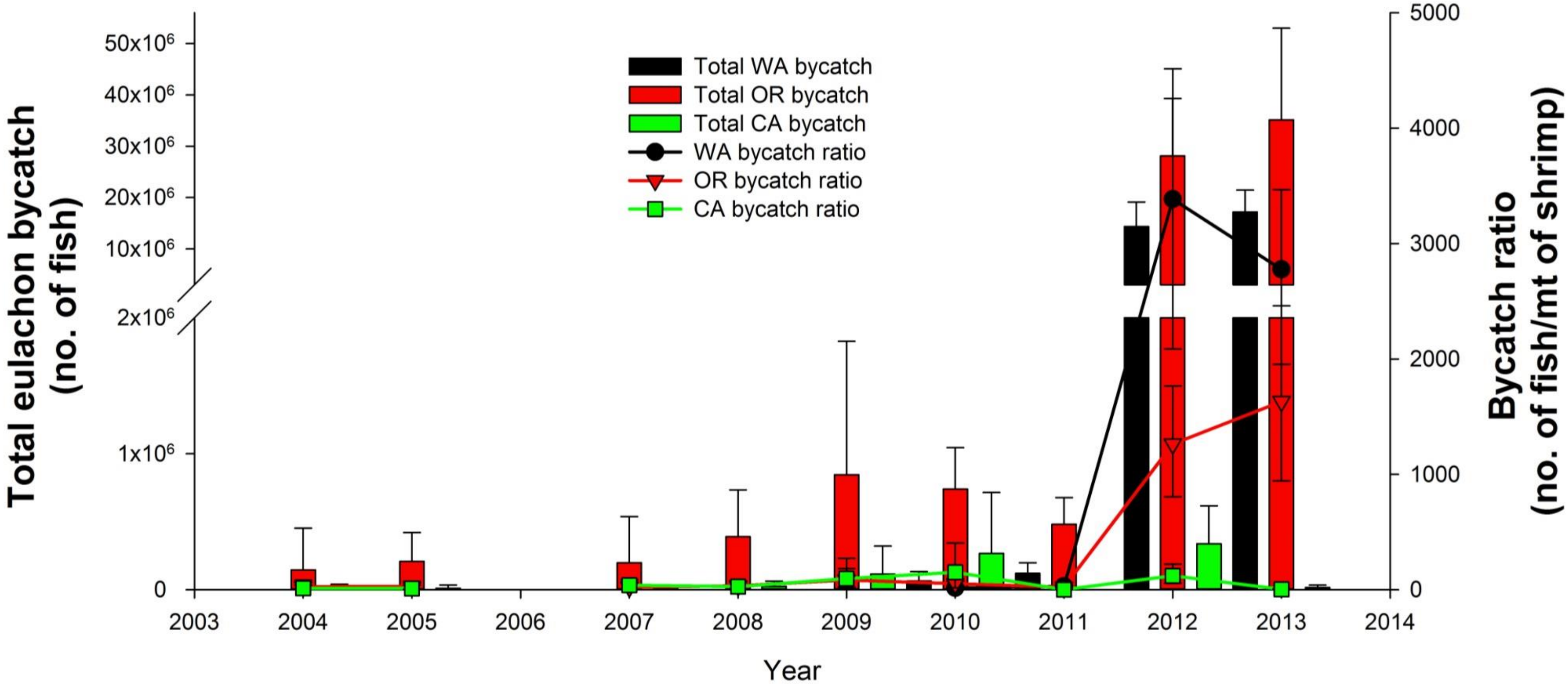
	Observed				**Fleetwide Total**	**Coverage Rate**
Year	Number of vessels	Number of trips	Number of tows	Observed ocean shrimp landings (mt)	Ocean shrimp landings (mt)	Percent ocean shrimp landings observed
2004	*	*	*	*	8,974.3	7%
2005	*	*	*	*	10,861.9	4%
2006					8,399.8	
2007	*	*	*	*	10,935.0	6%
2008	*	*	*	*	15,374.6	5%
2009	*	*	*	*	14,412.2	6%
2010	51	126	1,654	2,383.3	20,357.0	12%
2011	57	186	2,579	4,103.8	29,459.9	14%
2012	64	200	2,731	3,987.8	29,324.6	14%
2013	69	153	1,916	3,299.8	31,550.7	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 2004–2013. Shrimp fisheries were not observed in 2006. Data from WCGOP online database file labelled "Shrimp trawl" at http://www.nwfsc.noaa.gov/research/divisions/fram/observation/data_products/sector_products.cfm.

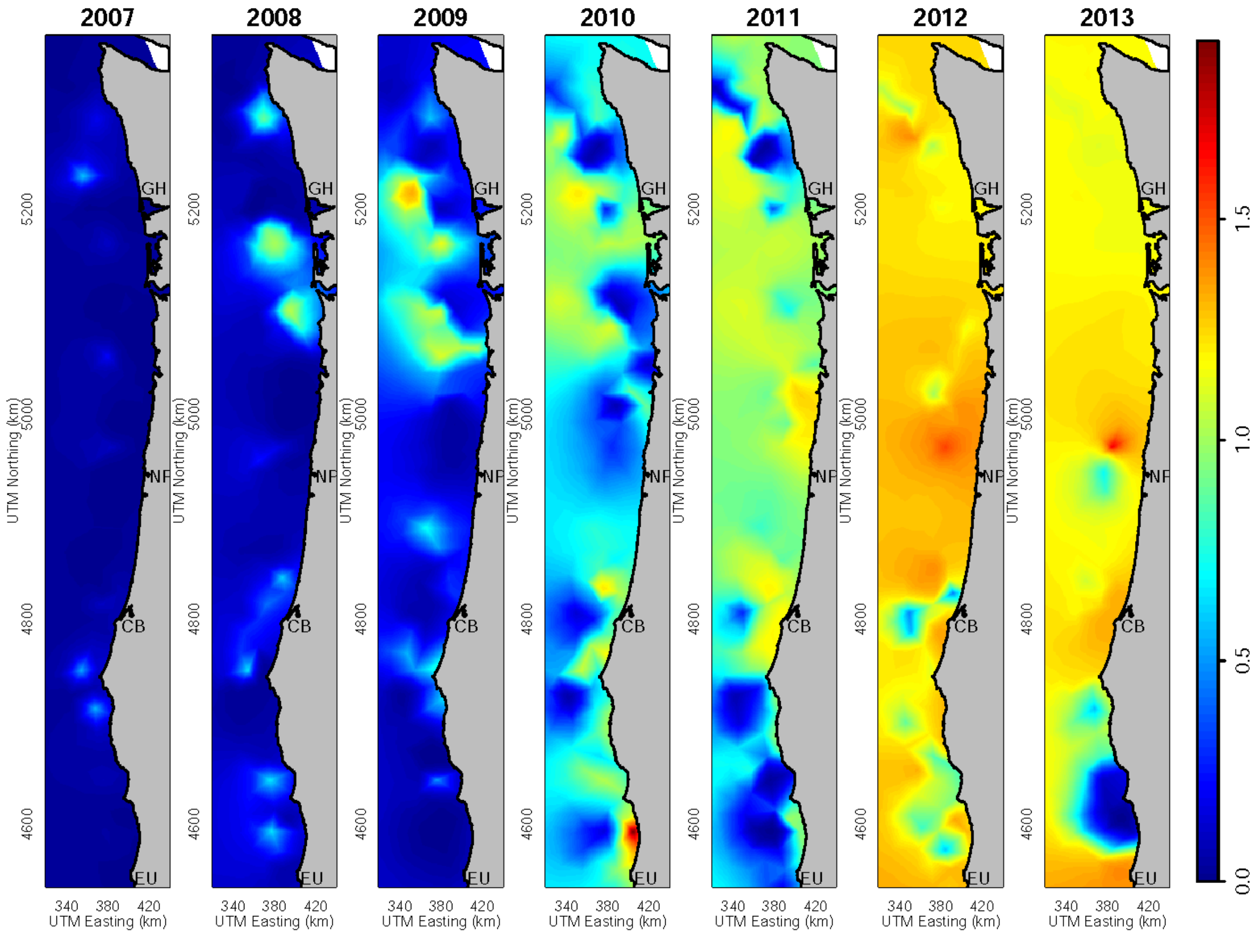
	Unidentified smelt	**Unidentified non-eulachon smelt**	**Whitebait smelt**	**Night smelt**	**Rainbow smelt**	**Capelin**	**Surf smelt**	**Observed shrimp landings**	**Unidentified smelt bycatch ratio**	**Fleetwide shrimp landings**	**Fleetwide unidentified smelt bycatch**
2004	3.92	--	0.04	0.05	--	--	--	518.13	0.0076	6,533.80	49.48
2005	0.86	--	0.06	0.00	--	--	0.07	424.70	0.0020	8,020.00	16.18
2007	0.39	--	0.00	0.20	--	0.00	--	672.69	0.0006	9,417.70	5.48
2008	1.43	--	0.00	0.00	--	--	0.01	805.78	0.0018	12,521.40	22.23
2009	0.03	--	0.41	0.05	0.04	--	--	876.57	0.0000	11,232.20	0.44
2010	0.30	--	0.41	0.06	--	--	0.00	2,383.30	0.0001	20,357.00	2.53
2011	2.01	0.06	2.78	1.37	--	--	0.00	4,103.80	0.0005	29,460.00	14.43
2012	3.26	4.14	9.64	0.00	--	--	--	3,987.80	0.0008	29,324.60	23.96
2013	2.10	4.27	3.34	0.00	--	--	0.00	3,299.80	0.0006	31,550.70	20.09



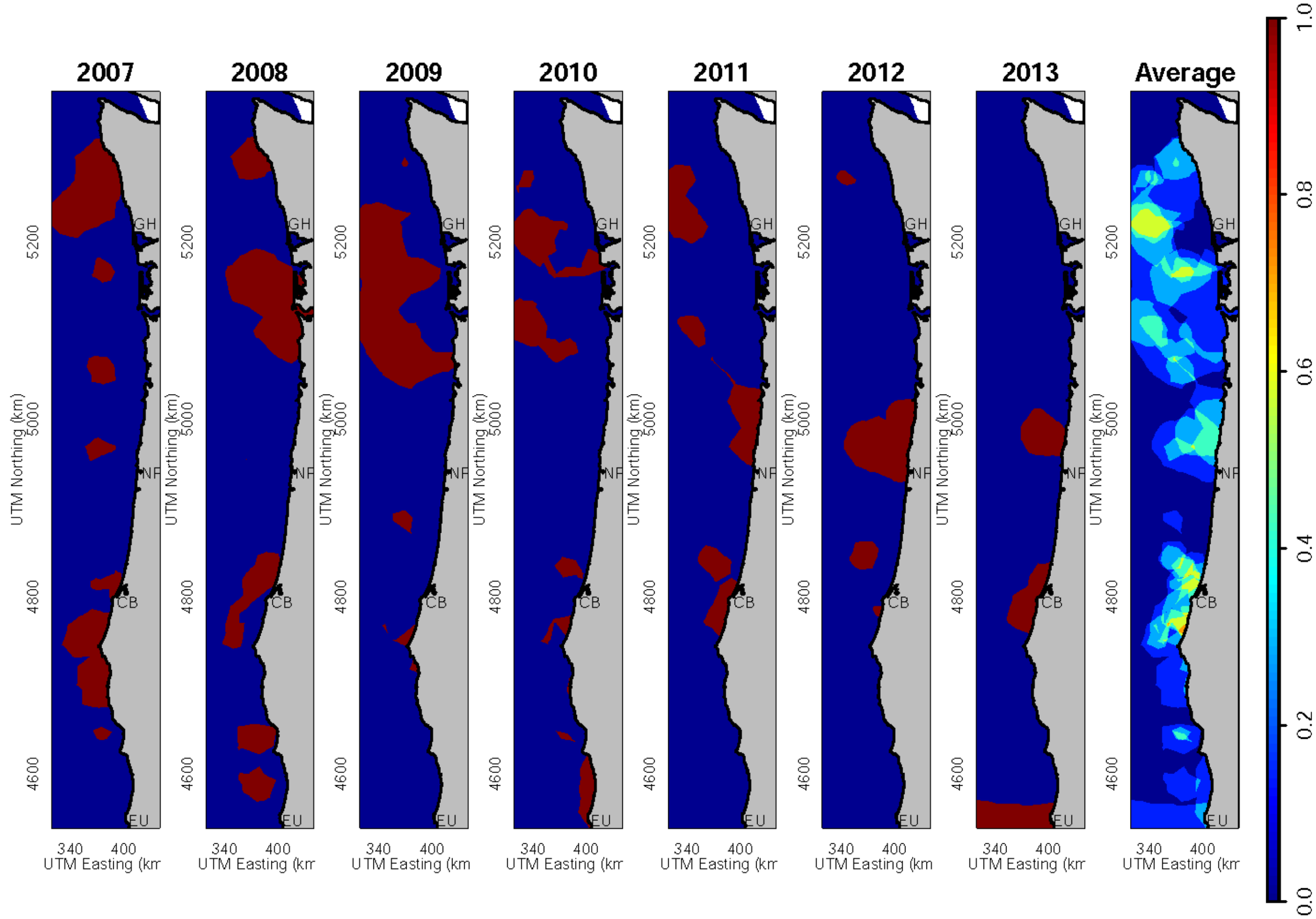
Appendix Figure A1. Commercial landings in ocean shrimp trawl fisheries off the U.S. west coast. Data from PACFIN (http://pacfin.psmfc.org/pacfin_pub/woc.php), CDFW (http://www.dfg.ca.gov/marine/fishing.asp), WDFW (http://wdfw.wa.gov/fishing/commercial/shrimp/), and Saelens (1983).



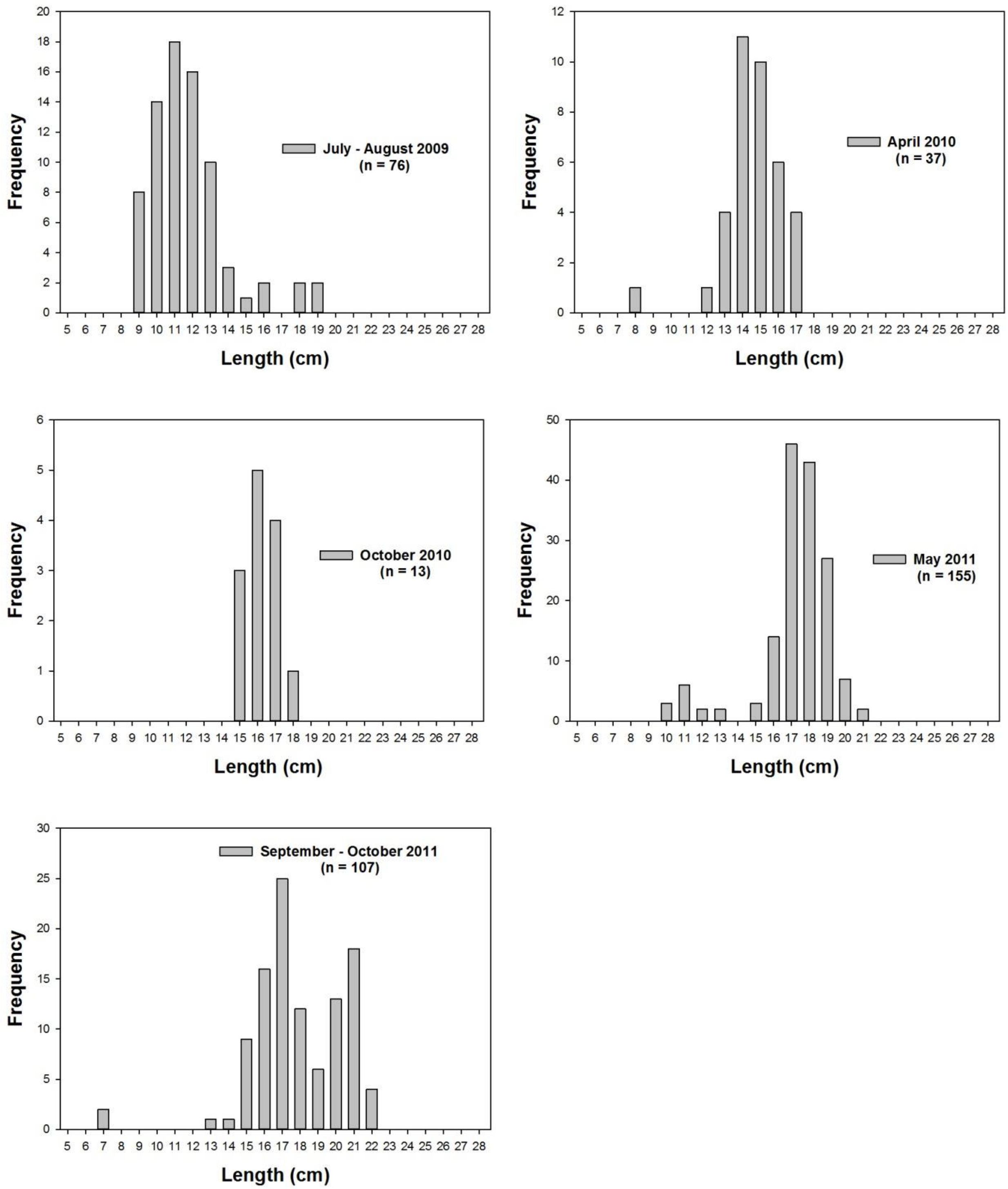
Appendix Figure A2. Estimated total bycatch and bycatch ratios of eulachon in the California, Oregon (2004–2013), and Washington (2010–2013) ocean shrimp trawl fisheries. Ocean shrimp fisheries were not observed in 2006.



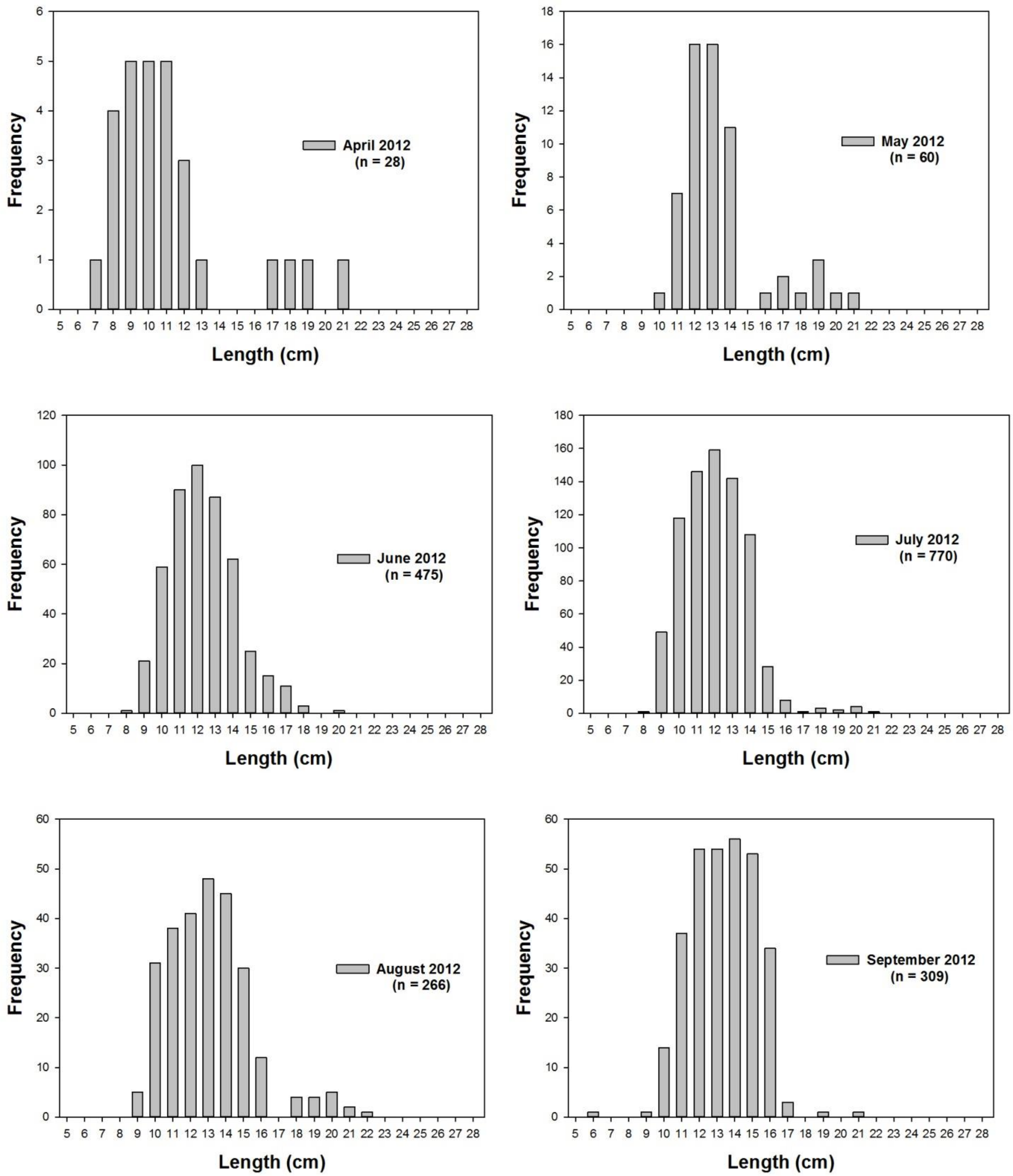
Appendix Figure A3. Estimated bycatch risk, projected from the posterior predictive distribution on a 1 km grid. Bycatch risk is calculated as estimated eulachon biomass / shrimp biomass (so the scale is unitless). Orange / red areas represent relative hot spots of eulachon bycatch; blue areas represent areas of low risk. All years are shown on the same scale to show the increasing trend in eulachon / shrimp biomass. In all cases, only modeled output is shown, which went through further smoothing and binning procedures to satisfy confidentiality requirements.



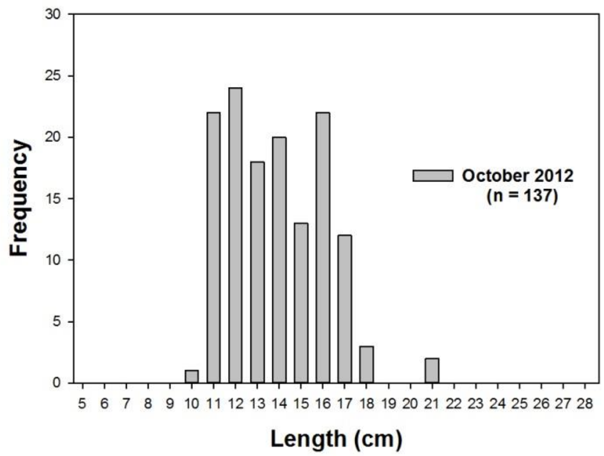
Appendix Figure A4. Estimated areas of highest bycatch risk, projected from the posterior predictive distribution on a 1 km grid. For any year, bycatch risk is defined as the top 10% of values (shown in red); to show consistent areas across time, averages are calculated over all years, 2007–2013. In all cases, only modeled output is shown, which went through further smoothing and binning procedures to satisfy confidentiality requirements. North to south: GH = Grey's Harbor, WA, NP = Newport, OR, CB = Coos Bay, OR, EU = Eureka, CA.



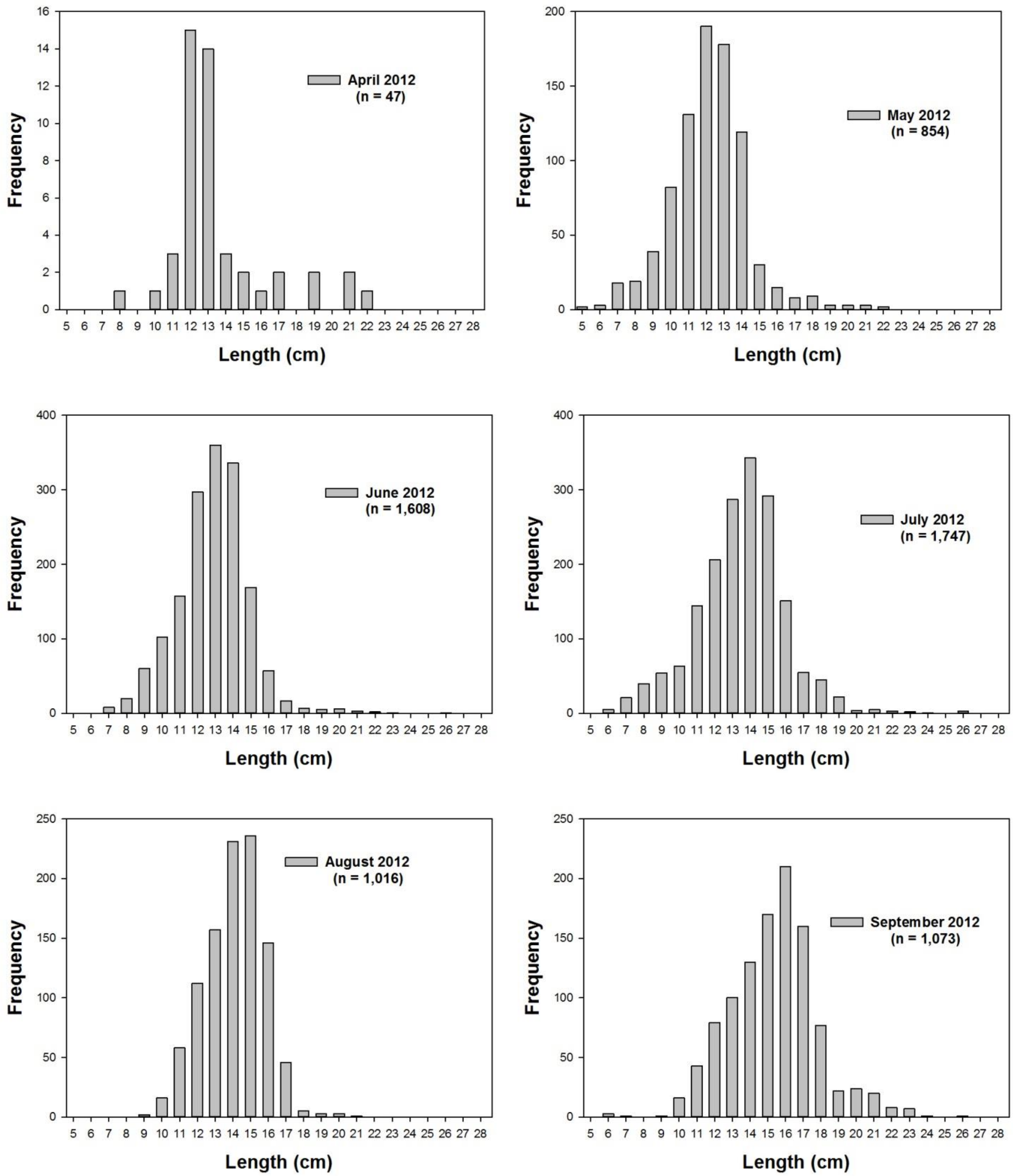
Appendix Figure A5. Length frequency histograms of juvenile eulachon caught as bycatch and measured by the WCGOP in the Oregon ocean shrimp trawl fishery in 2009–2011.



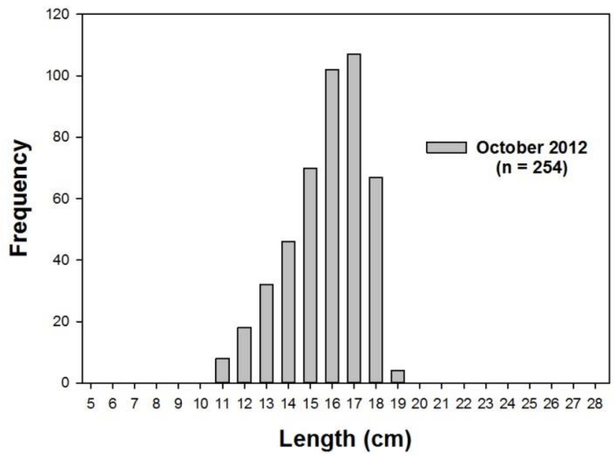
Appendix Figure A6. Length frequency histograms of juvenile eulachon caught as bycatch and measured by the WCGOP in the Washington ocean shrimp trawl fishery in 2012.



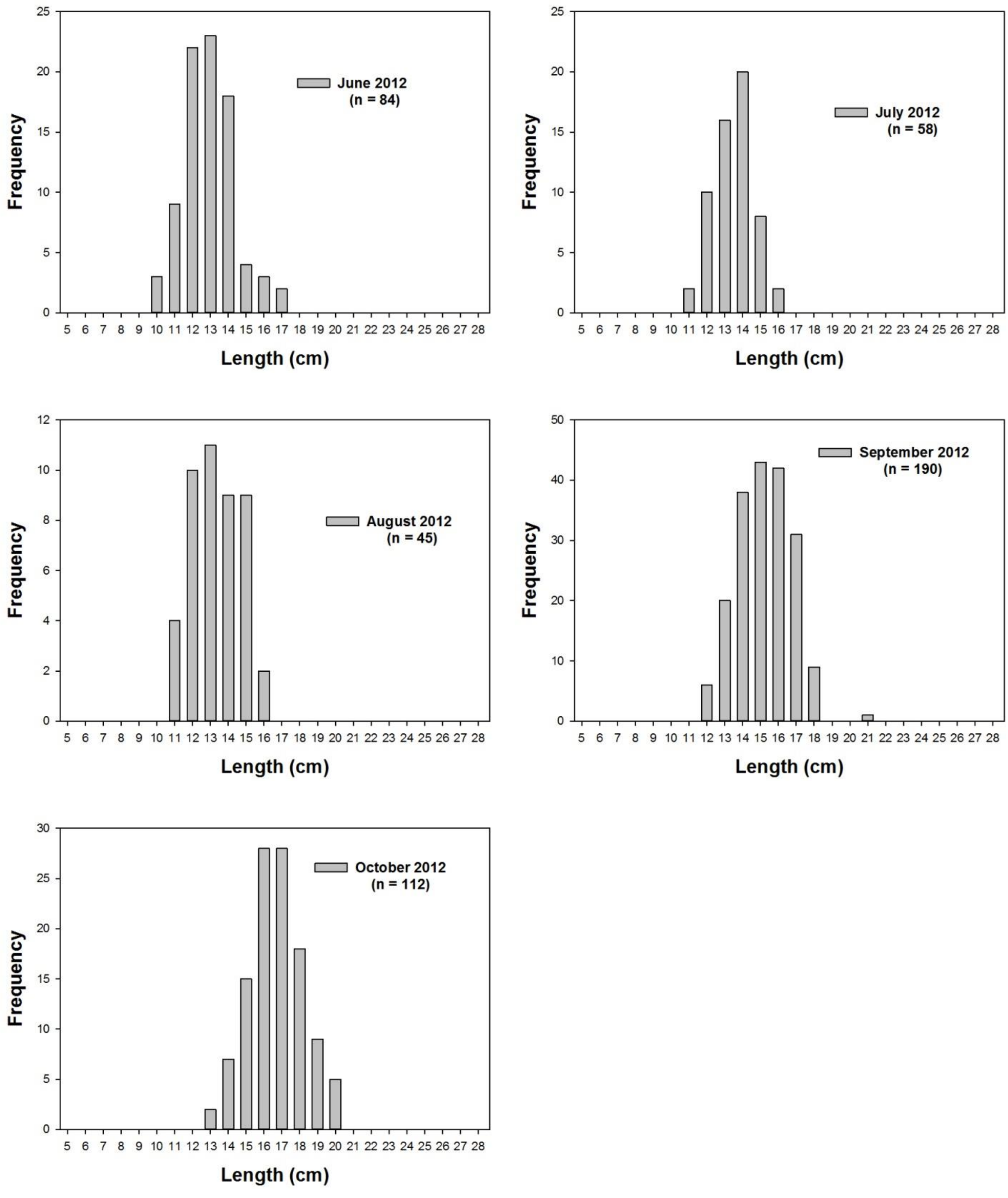
Appendix Figure A6 (continued). Length frequency histograms of juvenile eulachon caught as bycatch and measured by the WCGOP in the Washington ocean shrimp trawl fishery in 2012.



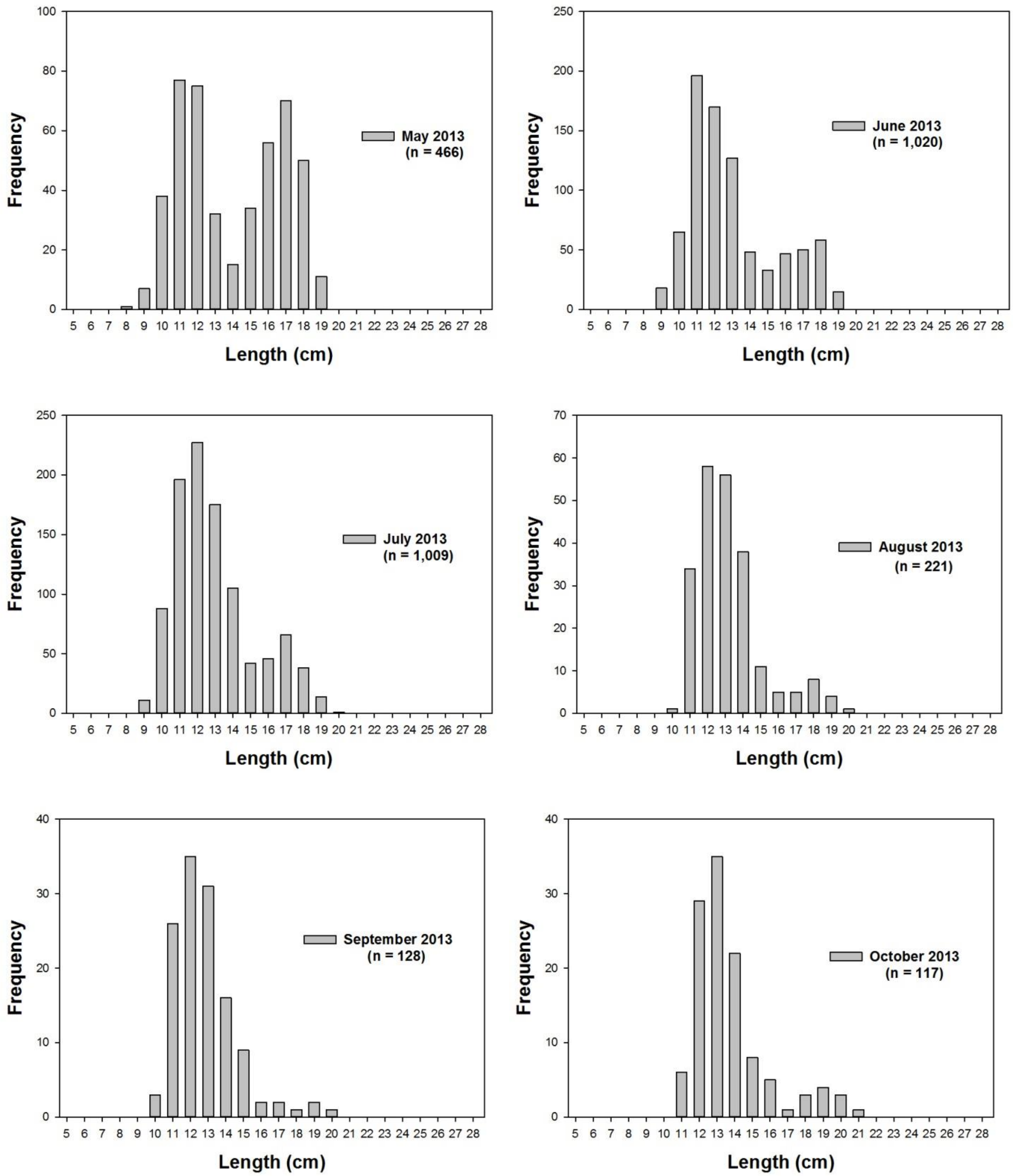
Appendix Figure A7. Length frequency histograms of juvenile eulachon caught as bycatch and measured by the WCGOP in the Oregon ocean shrimp trawl fishery in 2012.



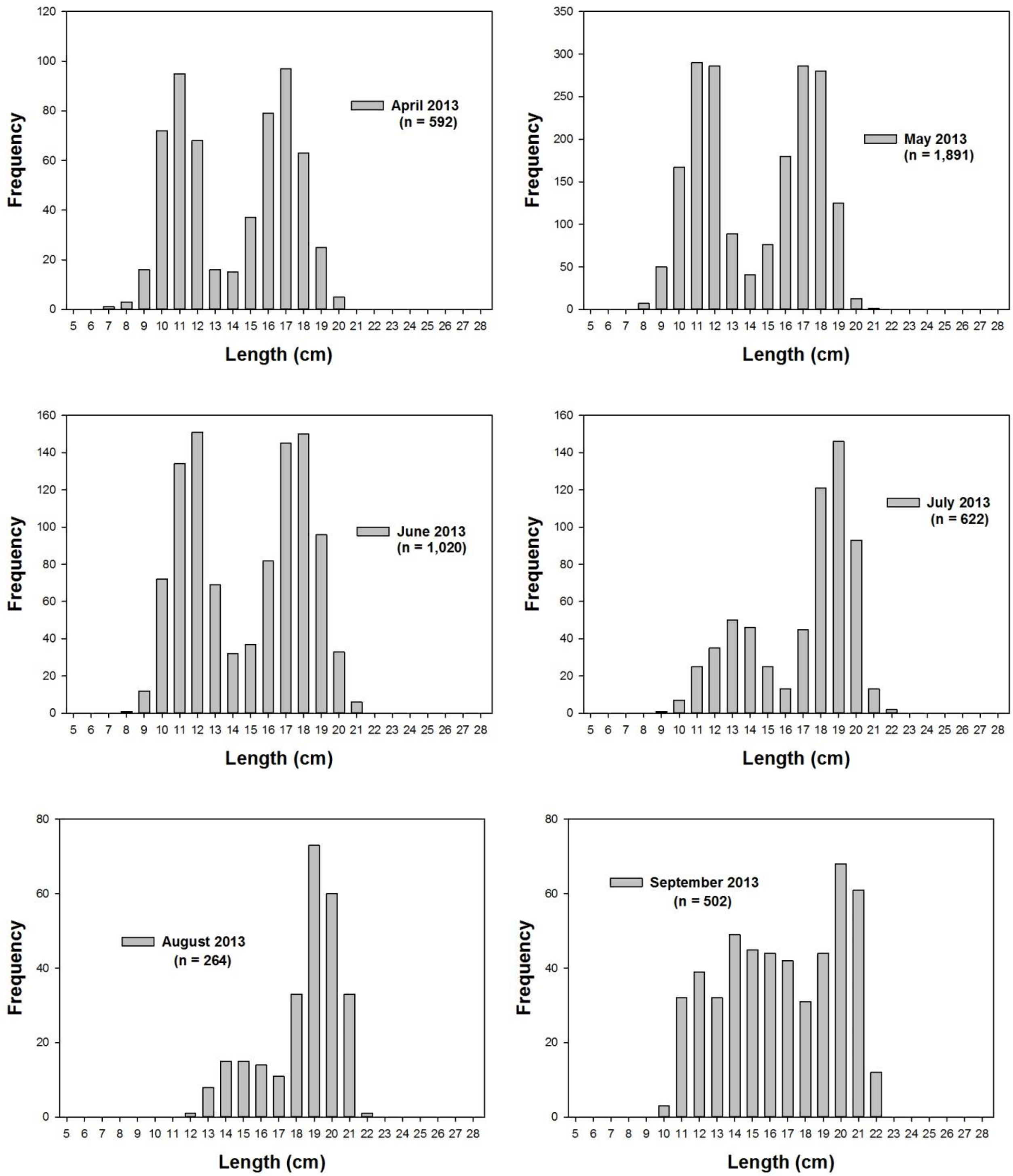
Appendix Figure A7 (continued). Length frequency histograms of juvenile eulachon caught as bycatch and measured by the WCGOP in the Oregon ocean shrimp trawl fishery in 2012.



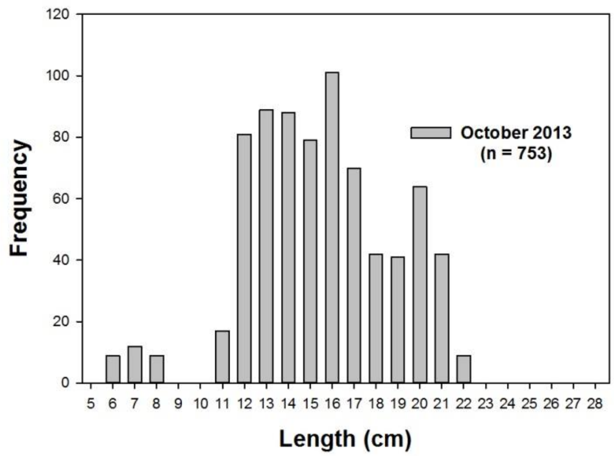
Appendix Figure A8. Length frequency histograms of juvenile eulachon caught as bycatch and measured by the WCGOP in the California ocean shrimp trawl fishery in 2012.



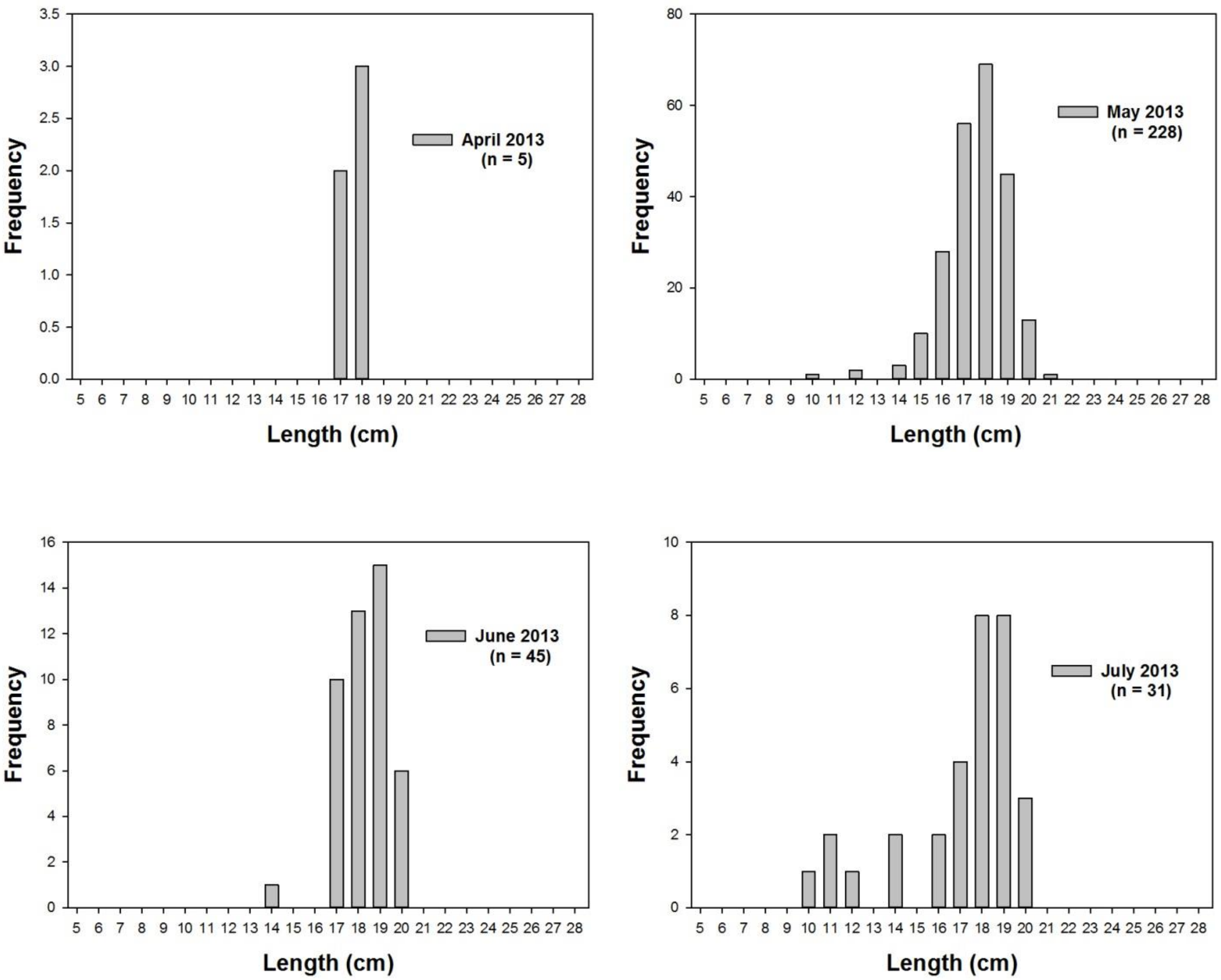
Appendix Figure A9. Length frequency histograms of juvenile eulachon caught as bycatch and measured by the WCGOP in the Washington ocean shrimp trawl fishery in 2013.



Appendix Figure A10. Length frequency histograms of juvenile eulachon caught as bycatch and measured by the WCGOP in the Oregon ocean shrimp trawl fishery in 2013.



Appendix Figure A10 (continued). Length frequency histograms of juvenile eulachon caught as bycatch and measured by the WCGOP in the Oregon ocean shrimp trawl fishery in 2013.



Appendix Figure A11. Length frequency histograms of juvenile eulachon caught as bycatch and measured by the WCGOP in the California ocean shrimp trawl fishery in 2013.