Prepared for the National Oceanic and Atmospheric Association
For NOAA Fisheries Protected Species Conservation and Recovery
Grant No.: NA10NMF4720038

Studies of Eulachon Smelt in Oregon and Washington

Project Completion Report

Prepared by:
Oregon Department of Fish and Wildlife
and
Washington Department of Fish and Wildlife

C. Mallette, editor

September 2014

Studies of Eulachon Smelt in Oregon and Washington

PROJECT COMPLETION REPORT

JULY 2010 – JUNE 2013

Edited by:
Christine Mallette
Oregon Department of Fish and Wildlife

In Cooperation With:
Washington Department of Fish and Wildlife

Prepared For:
National Oceanic and Atmospheric Administration
1401 Constitution Avenue, NW
Room 5128
Washington, DC 20230

For NOAA Fisheries Protected Species Conservation and Recovery
Grant Number NA10NMF4720038

September, 2014

Table of Contents

EXECUTIVE SUMMARY
By Christine Mallette iii

REPORT A. Columbia River Eulachon Spawning Stock Biomass
By James, B.W., O.P. Langness, P.E., Dionne, C.W Wagemann and B.J. Cady .. 1

REPORT B. Freshwater Distribution of Eulachon in Oregon and Washington
By Storch, A.J., E.S. Van Dyke, O.P. Langness, P.E., Dionne, C.W Wagemann and B.J. Cady 60

REPORT C. Marine Life Stage of Eulachon and the Impacts of Shrimp Trawl Operations
By Wargo, L.L., K.E. Ryding, B.W. Speidel and K.E. Hinton 83

Executive Summary

Report A. We report on our progress at developing annual eulachon spawning stock biomass (SSB) estimates for the Columbia River population based on egg and larval production surveys from January 2011 through and including May 2013.

- We sampled the Columbia River 29 days during a 20-week span in 2011 (weeks-of-the-year 3-22), 34 days during a 25-week span in 2011-2012 (weeks 50-21), and 43 days during a 30-week span in 2012-2013 (weeks 48-25).
  - Sample densities, and corresponding egg and larvae outflow estimates, peaked during week 12 (March 13-19) in 2011, during week 12 (March 11-17) in 2012, and during week 18 (Apr. 28 – May 4) in 2013.
- We sampled the Grays River 13 days during a15-week span in 2011(weeks-of-the-year 4-18), 13 days during a 22-week span in 2011/2012 (weeks 51-20), and 19 days during a 20-week span in 2012/2013 (weeks 52-19).
  - In the Grays River, eulachon egg and larvae outflow peaked during week 13 in 2011, during week 16 in 2012, and during week 14 in 2013.
- Mainstem Columbia River SSB was: 3,300,000 pounds (1,500 metric tonnes) in 2011; 3,200,000 pounds (1,500 metric tonnes) in 2011-2012; and 9,650,000 pounds (4,400 metric tonnes) in 2012-2013.
  - These estimates are conservative.
    - If we had assumed there was egg to larvae mortality more females would have been needed to produce the larval production observed.
    - If we had assumed one of the more commonly reported gender ratios favoring males then the observed larval production came from a larger spawner estimate.
  - The main stem Columbia River SSB estimates are many times greater than the corresponding SSB estimates for the Fraser River (31 metric tonnes for 2011; 120 metric tonnes for 2012; and 100 metric tonnes for 2013).
  - The mainstem Columbia River SSB estimate does not capture spawning in Grays River or smaller watersheds like Skamokawa Creek which are downriver of the Clifton Channel/Price Island transect.
- Grays River SSB was 700 pounds (0.3 metric tonne) in 2011; 900 pounds (0.4 metric tonne) in 2011-2012; and 2,300 pounds (1 metric tonne) in 2012-2013.
  - The Grays River SSB estimates are only about 0.02% of the values for the Columbia River.
  - However, the well document variability in eulachon spawning distribution in the Columbia River makes it prudent to continue to monitor the Grays River.
- Having a long-term stock assessment program in the Columbia River would benefit the recovery effort and fisheries management.
  - The egg and larval production needs to be monitored over a 6-month or longer period (if possible starting in November and running through May).

    - Annual collection of adult eulachon in the estuary and lower reaches of the Columbia River is needed to properly parameterize the estimation.

Report B. We report on activities to characterize the freshwater distribution of eulachon eggs and larvae in: (1) the main stem of the Columbia River, (2) known or putative spawning tributaries of the Columbia River and (3) coastal streams in Oregon and Washington. The report summarizes work conducted from January 2011 through and including May 2013.

- Biologists from the Oregon Department of Fish and Wildlife sampled eulachon eggs and larvae at fixed locations in the main stem Columbia River below Bonneville Dam using artificial substrates and ichthyoplankton nets from 10 January–31 May 2011 and 21 November 2011–24 July 2012.
    - The vast majority (93%) of eulachon larvae encountered by ODFW staff were collected during March of 2011 at sites between Cathlamet and Longview, Washington
- Sampling to assess the current freshwater spawning distribution of eulachon also was conducted opportunistically in the Sandy River at several locations between approximately 3 and 5 river kilometers from the confluence with the Columbia River from 27 January–2 June 2011.
    - During the period sampled, two eggs were captured on artificial substrates while six eggs and seven larvae were encountered in oblique ichthyoplankton tows; no eggs or larvae were identified as eulachon.
- District biologists opportunistically conducted 12 artificial substrate sets and 16 larval tows in the Umpqua River during 20 January–8 June 2011.
    - During this effort, no eggs were observed on artificial substrates. One egg and 15 larvae were collected in ichthyoplankton tows; however, none of these specimens were identified as eulachon.
- Biologists from the Oregon Department of Fish and Wildlife set artificial substrates (nine sets) in the Coos River 24 January–28 February 2011.
    - No eggs from any species were encountered.
- Biologists from Washington Department of Fish And Wildlife sampled 41 sites in 21 water bodies in the state of Washington (tributaries of the Columbia River and costal water bodies), and opportunistically at several sites in the main stem Columbia River near the ports of Longview and Kalama during 20 January 2011–7 May 2013.
    - Eulachon larvae and/or eggs were encountered at each site during all sampling events in tributaries of the Columbia River.
    - Eulachon larvae and/or eggs were encountered at 21% of the sites sampled in coastal water bodies.
    - As in tributaries to the Columbia River, eulachon eggs and/or larvae were encountered at each site during opportunistic sampling of the main stem Columbia River.

Report C. We report on our progress from April 2011 through and including October 2012 on determining and evaluating various factors influencing the catch of eulachon (*Thaleichthys* *pacificus*) by Washington ocean pink shrimp (*Pandalus jordani*) trawl vessels, in response to the listing of the southern Distinct Population Segment of eulachon as threatened under the Endangered Species Act. The shrimp trawl fishery was listed second among the severity of threats impacting the recovery of eulachon stocks. With bycatch data lacking for the Washington pink shrimp fleet, the Washington Department of Fish and Wildlife sought and was granted funding to place observers onboard vessels to collect catch composition data at the tow level. We present project results for eulachon; an expanded WDFW technical report (in process) addresses results for other species or categories of species (rockfish and flatfish) encountered during the study.

- In 2011, 24% of trips landing in a Washington port were observed. Following reduced funding in 2012, 16% of trips landed in a Washington port were observed.
- Eulachon bycatch was estimated at 7.8 metric tons (17,132 pounds) in 2011 and 171 metric tons (378,011 pounds) in 2012.
    - During both years, pink shrimp production was comparatively strong.
    - The increase in bycatch in 2012 also occurred at the same time as fishery regulations reduced the allowable bar spacing for fin fish excluders to 0.75 inch (19mm).
    - Results indicate a significant interaction between gear type (excluder bar-spacing) and month and a significant month effect on bycatch.
    - Generally, spatial distribution results point to the co-occurrence of eulachon and pink shrimp. The depth-bycatch relationship was statistically different in each month and overall, but not biologically significant.
    - The average time per tow was approximately 100 minutes. There was no significant interaction between tow time and month and the overall time-bycatch relationship was significant and the same across all months, but not very strong.
- 3,311 total eulachon were randomly sampled at the tow level for length; 2,355 in 2011 and 956 in 2012.
    - Reduced funding and comparatively greater bycatch account for the lesser amount sampled in 2012
    - Eulachon fork length ranged from 74 to 231mm during the two years of observation
        - 2011 had a median fork length of 181mm while 2012 had a median fork length of 127mm.
        - 2011 had a mean fork length of 178 mm while 2012 had a mean fork length of 128mm, suggesting that within year length variation is low.
    - No significant difference in eulachon size by tow depth or by bar spacing are evident.
    - Using the scheme used by Fisheries and Oceans Canada (DFO), we were able to determine that different age ranges were present in 2011 and 2012; age 1+ and age 2+ in 2011 and only predominantly age 1+ in 2012.
- Genetic samples were collected from many length-measured eulachon and, pending funding for analysis, could contribute further to our understanding of eulachon in the

marine environment. These samples are archived with the WDFW Genetics Unit in Olympia.

Accomplishments not Documented in Reports A, B or C

- Beyond preservation of genetic samples, genetic analysis was curtailed due to cuts to the project budget.
- The following genetic sample collections are currently archived at the WDFW Molecular Genetics Laboratory in Olympia, Washington:
  - Cowlitz River (MGL code 09DI) N=108
  - Cowlitz River Tribal Sample (MGL code 13AU) N=62
  - Columbia River Adults (MGL code 13CY) N=69
  - 2011 Washington Trawl (MGL code 11DL) N=769
  - Eulachon by-catch, shrimp fishery (MGL code 12DT) N=435
- Several hundred additional genetic samples collected from larval surveys in the Columbia River and various Coastal rivers are undergoing verification at the WDFW Region 5 Laboratory in Vancouver, Washington. After processing these will be sent to the WDFW Molecular Genetics Laboratory by October 31, 2014 for archiving.
- The WDFW Molecular Genetics Laboratory acquired funding from a Section 6 grant from NOAA and Washington State General Funds to standardize their laboratory to the Canadian Department of Fish and Oceans' Lab.
  - WDFW Molecular Genetics Laboratory obtained 96 Eulachon DNA samples from DFO and genotyped the samples at 14 microsatellite loci. Allele bins were named according to DFO nomenclature such that genotypes developed by WDFW could be compared with original genotypes from DFO for the same individuals. We used this comparison to confirm that allele calls matched between WDFW and DFO.
    - There were 13 differences between genotypes (out of 1392 total) where one agency scored a heterozygote (two different sized alleles) and the other agency scored a homozygote (two same sized alleles). In these cases, one allele was missed in a heterozygote such that it appeared to be a homozygote. This scoring issue is known as "large-allele drop-out" where the larger-sized allele amplifies poorly or not at all, and is missed during scoring. However, these differences constituted less than 1% of the data set.
    - Five Eulachon loci were hyper-variable and had between 50 and 100 alleles per locus.
  - Because the standardization data set included 23% to 73% of the alleles at any single locus, mostly from the center of the allele size distribution, a second round of standardization may be necessary to include alleles that were absent from this data set. This will ensure that allele nomenclature remains standardized throughout allele size ranges.
- The Canadian DFO and Columbia River Inter-Tribal Fish Commission (CRITFC) geneticists have been working to develop some Single Nucleotide Polymorphisms (SNPs) for eulachon.

- WDFW provided the CRITFC genetic laboratory at the Hagerman Fish Culture Experimental Station , Idaho, with 120 samples from the 2013 field work for use in developing the SNPs library.
    - WDFW Molecular Genetics Laboratory will be working toward having their eulachon baseline genotyped with SNPs in addition to microsatellites.
- Under the marine life stage objective, we conducted numerous formal meetings with industry, plus produced the short project highlight video intended for posting to the WDFW website.
- Under the marine life stage objective, the project originally proposed to conduct experiments on gear-related bycatch reduction. This work was accomplished by ODFW through another funding source. The reduced bar spacing modification to the fin fish excluder devices has been adopted by the pink shrimp trawl industry, and research continues to explore further mechanical and operational modifications to the shrimp trawl fleet that reduce eulachon bycatch levels.
- Under the stock assessment objective, the proposed task to determine fecundity, sex, and age on adult samples was hindered by the project budget cuts, and by the closure of fisheries. Through additional NMFS regional funding (and collaboration with the NMFS Point Adams Research Station and the Cowlitz Indian Tribe) adult samples were obtained during 2013 both in estuary and lower main stem reaches of the Columbia River, and in the Cowlitz River. WDFW was able to:
    - Developed a spawning scale to differentiate eulachon gonad morphology,
    - Sent nine unusual gonad samples to the U.S. Fish and Wildlife Service (USFWS) Bozeman Fish Technology Center for histological assessment (all samples confirmed to be from spent fish and not abnormal or infected),
    - Determined that 5% by weight sampling of gonads could yield reasonably accurate and efficient estimates of the true fecundity,
    - Derived an average fecundity value,
    - Confirmed that there was a strong length-fecundity relationship,
    - Discovered that the age composition was overall younger than assumed (2013 run was predominately Age 2, and 3, with some 4; versus the assumed 3, 4 and some Age 5 used in past run predictions), and
    - Observed that the Gonadosomatic Index (GSI) for female eulachon returning in 2013 was consistently 20% throughout all size classes.
- Under the stock assessment objective, one task was to annually compile environmental correlates that may help in the prediction of eulachon adult run strength. Measures of the Pacific Decadal Oscillation (PDO) and Multivariate ENSO Index (MEI; El Nino/ La Nina) were gathered from the internet. In addition, biological information from the Canadian government was obtained such as the eulachon biomass and composition in the West-Coast Vancouver Island (WCVI) shrimp trawl surveys, and Fraser River eulachon SSB estimates.

Presentations have been made at various meetings with regional resource agencies concerning the findings of the project. A presentation summarizing the activities and results of the Section 6 grant project was made at the Washington/British Columbia Chapter of the American Fisheries Society Annual Meeting in Vancouver, Washington on March 26, 2014 (Phillip Dionne presenting, numerous co-authors).

Recommended Citation for a Chapter or Appendix in the Report:
James, B.W., O.P. Langness, P.E. Dionne, C.W. Wagemann and B.J. Cady. 2014. "Columbia River Eulachon Spawning Stock Biomass Estimation." Report A, In C. Mallette (Ed.), *Studies of Eulachon Smelt in Oregon and Washington*, prepared for the National Oceanic and Atmospheric Administration, Washington, DC, by the Oregon Department of Fish and Wildlife and the Washington Department of Fish and Wildlife. Grant No.: NA10NMF4720038.

Report A

Columbia River Eulachon Spawning Stock Biomass Estimation

Brad W. James
Olaf P. Langness
Phillip E. Dionne
Chris W. Wagemann
and
Brad J. Cady

Washington Department of Fish and Wildlife
Fish Program
Region 5
2108 Grand Boulevard
Vancouver, Washington 98661-4624

Final Report to:

National Oceanic and Atmospheric Administration
1401 Constitution Avenue, NW
Room 5128
Washington, DC 20230

For NOAA Fisheries Protected Species Conservation and Recovery
Grant Number NA10NMF4720038

September, 2014

Acknowledgements

We wish to thank numerous individuals for their assistance on various aspects of this project. Jennifer Blaine, Shaffron Shade, Mike Brown, Mike Hill, Mike Wall, and Shay Valentine assisted with the egg and larvae surveys. Over 239,000 eggs and larvae were counted by a crew consisting primarily of Shaffron Shade, Jennifer Blaine, Danielle Rockey, and Laura Lloyd, with help from Cade Roler, Mike Hill, Stephanie Doorly, Shay Valentine, and Maurice Frank.

Jeannette Zamon, Susan Hinton , Paul Bentley, and George McCabe, of the NMFS Point Adams Research Station, Hammond, Oregon, and Craig Olds and staff with the Cowlitz Indian Tribe Natural Resources Department provided us with data and samples of adult eulachon for use in estimating fecundity, sex ratio and other biological parameters. Laura Lloyd conducted most all of the fecundity counts.

This work was supported by funding from NOAA Fisheries Protected Species Conservation and Recovery Grant Award Number NA10NMF4720038.

Table of Contents

Acknowledgements 2
List of Figures 4
List of Tables 6
Abstract 7
Introduction 8
Study Objectives and Report Structure 9
Methods 10
  Study Design 10
  Study Area 10
  Field Data Collection and Laboratory Processing 12
  Data Processing 13
Results and Discussion 14
References 19
Figures 21
Tables 32
Appendix A: Columbia River Discharge 41
Appendix B: Daily Mainstem Columbia River Plankton Net Sampling Effort 47
Appendix C: Lab Counts of Mainstem Columbia River Eulachon Eggs and Larvae 50
Appendix D: Daily and Weekly Columbia River Eulachon Egg and Larvae Sample Densities 53

List of Figures

Figure 1. Lower Columbia River eulachon spawning stock biomass study site showing the location of the larval eulachon sampling transect at Columbia River kilometer 55. Included are the primary tributaries containing eulachon spawning habitat. 11

Figure 2. Map of lower Columbia River with mainstem transect sampling stations indicated by red circles, and USGS gauge station indicated by the blue triangle. 12

Figure 3. Photograph of the plankton net setup deployed to collect eulachon smelt eggs and larvae. Image shows the setup when two General Oceanic flow meters were mounted to the frame. 21

Figure 4. Photographs of plankton net sampling in the Grays River. 22

Figure 5. Photograph of Washington Department of Fish and Wildlife Region 5 laboratory setup to process eulachon larval samples. Scientific Technician Laura Lloyd is viewing a portion of the content of sample 00571 under a 5x lens. A multiple counter is used to separately track eulachon and non-eulachon larvae and eggs. Up to ten eulachon larvae will be taken from a sample and transferred to cryogenic vials containing DNA preservative for future genetic analysis (note pipette and red-capped vial in background). 23

Figure 6. Photograph of a portion of a eulachon larval sample viewed under a 5x lens. Note that the black background facilitates viewing of the thin slightly opaque larvae. This is a very clean sample, without debris, sand and algae. Larvae will cling and become buried in debris and algae, making the task of counting more difficult. 23

Figure 7. Photograph of National Marine Fisheries Service Point Adams Research Station staff bringing in a large haul of adult eulachon near Coffee Pot Island (Columbia River kilometer 68) on March 7, 2013. Small trawls proved to be an efficient way to collect adult eulachon without significant handling mortality. Sampling in the lower reaches of the Columbia River assures a proper representation of the run components, especially sex composition. Photograph courtesy of Jeannette Zamon, NMFS Point Adams Research Station. 24

Figure 8. Photograph of a live male eulachon (top) and female eulachon (bottom) caught during trawling operations in the lower Columbia River in 2013. Biological data collected on the adult run is used to parameterize the estimation of Spawning Stock Biomass (SSB). Photograph courtesy of Jeannette Zamon, NMFS Point Adams Research Station. 25

Figure 9. Weekly eulachon egg and larvae sample densities (values averaged if sampled twice in a week) by site along the Price Island/Clifton Channel transect, for 2011 (weeks 3 through 22), 2011-2012 (weeks 50 through 21), and 2012-2013 (weeks 48 through 25). Charts sized to maintain relatively equal scales. 26

Figure 10. Mean daily Columbia River eulachon egg and larval sample densities collected at the Clifton Channel/Price Island index from January 13, 2011through May26, 2011 (weeks 3 through 22) displayed against the calculated daily Columbia River discharge at Beaver Army Terminal. 27

Figure 11. Mean daily Columbia River eulachon egg and larval sample densities collected at the Clifton Channel/Price Island index from December 6, 2011 through May 21, 2012 (weeks 50 through 21) displayed against the calculated daily Columbia River discharge at Beaver Army Terminal. 27

Figure 12. Mean daily Columbia River eulachon egg and larval sample densities collected at the Clifton Channel/Price Island index from November 28, 2012 through June 21, 2013 (weeks 48 through 25) displayed against the calculated daily Columbia River discharge at Beaver Army Terminal. 28

Figure 13. Box plot of weekly outflow (passive outmigration) of eulachon smelt plankton (eggs and larvae) into the Columbia River estuary at the Clifton Channel/Price Island index for 2011 (weeks 3 through 22), 2011-2012 (weeks 50 through 22), and 2012-2013 (weeks 48 through 25). Dark Blue represents upper (95%) confidence level, the black line separating the boxes represents the mean, and the light blue represents the lower (95%) confidence level. Includes bootstrap generated minimum and maximum estimates. Note the difference in scale between the bottom and top two charts. 29

Figure 14. Comparison of estimated weekly outflow (passive outmigration) of eulachon smelt plankton (eggs and larvae) into the Columbia River estuary at the Clifton Channel/Price Island index for 2011 (weeks 3 through 22), 2011-2012 (weeks 50 through 21), and 2012-2013 (weeks 48 through 25). 30

Figure 15. Comparison of estimated weekly outflow (passive outmigration) of eulachon smelt plankton (eggs and larvae) in the Grays River estuary for 2011 (weeks 4 through 18), 2011-2012 (weeks 51 through 20), and 2012-2013 (weeks 52 through 19). 31

List of Tables

Table 1. Summary of adult eulachon sex ratio data collected for the Columbia and Cowlitz rivers, 2011-2013. 32

Table 2. Eulachon sex ratio published for the Columbia River, tributaries, and for the Fraser River. 33

Table 3. Summary of eulachon fecundity data collected in 2012-2013 from the Cowlitz and Columbia Rivers. 34

Table 4. Parameter values used in estimating Columbia River eulachon spawning stock biomass from 2011 through 2013. 35

Table 5. Estimated Columbia River eulachon mean egg and larvae density, egg and larvae production (smelt plankton outflow), and spawning stock biomass for the period January 9, 2011 through May 28, 2011, including bootstrap generated mean and 95% confidence limit estimates of plankton outflow, numbers of spawners, and SSB in pounds and in metric tons. 36

Table 6. Estimated Columbia River eulachon mean egg and larvae density, egg and larvae production (smelt plankton outflow), and SSB for December 4, 2011 through May 26, 2012, including bootstrap generated mean and 95% confidence limit estimates of plankton outflow, numbers of spawners, and SSB in pounds and in metric tons. 37

Table 7. Estimated Columbia River eulachon mean egg and larvae density, egg and larvae production (smelt plankton outflow), and SSB for November 25, 2012 through June 22, 2013, including bootstrap generated mean and 95% confidence limit estimates of plankton outflow, numbers of spawners, and SSB in pounds and in metric tons. 38

Table 8. Estimated Grays River eulachon mean egg and larvae density and mean and median egg and larvae production (smelt plankton outflow) and SSB, in pounds and in metric tons, for the period January 16, 2011 through May 14, 2011. 39

Table 9. Estimated Grays River eulachon mean egg and larvae density and mean and median egg and larvae production (smelt plankton outflow) and SSB, in pounds and in metric tons, for the period December 18, 2011 through May 19, 2012. 39

Table 10. Estimated Grays River eulachon mean egg and larvae density and mean and median egg and larvae production (smelt plankton outflow) and SSB in pounds and in metric tons, for the period December 23, 2012 through May 11, 2013. 40

Abstract

In 2011, the Oregon Department of Fish and Wildlife and the Washington Department of Fish and Wildlife (WDFW) initiated a three-year monitoring program to assist in tracking coast-wide status and trends in abundance and distribution of the ESA listed southern eulachon smelt distinct population segment (DPS). One objective of this work was for WDFW to develop annual eulachon spawning stock biomass (SSB) estimates for the Columbia River population based on egg and larval production surveys. We developed survey protocols that estimated egg and larvae density (n/m^3) at a transect comprised of six sampling stations crossing the Columbia River just upstream of the estuary. The transect was situated to capture eggs and larvae produced from all Columbia River spawning areas (mainstem and tributaries) except for the Grays River. Separate sampling stations were located on the Grays River. We combined mean weekly egg and larvae densities with estimated river discharge (m^3/s) to estimate the total number of eulachon eggs and larvae produced for specific time periods over three years of eulachon returns to the Columbia River. We converted the estimates of total egg and larvae production into SSB using estimated relative fecundity, sex ratio, and fish weight. We used bootstrapping on the Columbia River data to develop confidence limits for those estimates.

We estimated SSB for the Columbia River from January 9, 2011 through May 28, 2011; December 4, 2011 through May 26, 2012; and November 25, 2012 through June 22, 2013 and from the Grays River for January 16, 2011 through May 14, 2011; December 18, 2011 through May 19, 2012; and December 23, 2012 through May 11, 2013. We estimate that SSB for the Columbia River was 3,300,000 pounds (1,500 metric tonnes) in 2011; 3,200,000 pounds (1,500 metric tonnes) in 2011-2012; and 9,650,000 pounds (4,400 metric tonnes) in 2012-2013. SSB estimates for the Grays River were much smaller, being about 0.02% of the values for the Columbia River.

Introduction

The National Marine Fisheries Service (NMFS) listed the southern distinct Population Segment (DPS) of *Thaleichthys pacificus*, also known as “eulachon,” as threatened under the Endangered Species Act (ESA), effective May 17, 2010 (74 FR 13012; 50 CFR Part 223: 13012-13024; March 18, 2010). The southern DPS consists of all eulachon spawning south of the Dixon Entrance/ Nass River, BC. The Columbia River has been identified as one of the primary spawning rivers of the Southern DPS.

For over a century, the status of the eulachon run to the Columbia River was measured by the number of pounds of fish landed during commercial fisheries. Larval sampling in the Columbia River was first attempted in 1946 (Smith and Saalfeld 1955). A few other eulachon larval sampling events occurred in the decades that followed (Hymer 1994). In 1994, Washington Department of Fish and Wildlife (WDFW) began to consistently monitor the peak outmigration larval density in the Cowlitz River. Over the next few years monitoring was begun in other tributaries of the Columbia River. The first survey in the Grays River was conducted in 1998 (Table 19 in JCRMS 2014). In 1995, eulachon larval sampling was initiated in the mainstem Columbia River downstream from the mouth of the Cowlitz River. In 1997, a transect across the lower Columbia River from navigation marker number 35 at Price Island and across the downstream end of Clifton Channel (near Columbia River kilometer 55) was established as an index to be sampled systematically every year (WDFW and ODFW 2001). Until recently, sampling in the mainstem Columbia River and the tributaries was concentrated around the estimated time of peak larval outflow.

In the “Summary of Scientific Conclusions of the Review of the Status of Eulachon (*Thaleichthys pacificus*) in Washington and Oregon” (Status Review; BRT 2008), the Biological Review Team (BRT) concluded that, “…eulachon are a relatively poorly monitored species….” The spawner biomass estimates established in Canadian rivers were, “regarded by the BRT as constituting the best scientific and commercial data available for recent eulachon abundance in the DPS.” The Canadian approach was to systematically sample the eulachon larval density at multiple mainstem sites throughout the whole period of larval outflow, expand that by the river discharge to obtain an estimation of total season outflow of larvae, and then back calculate how many adults must have produced that larval outflow. This adult equivalent was expressed in metric tonnes (megagrams) and hence referred to as the Spawning Stock Biomass (SSB).

In the Federal Recovery Outline for Eulachon Southern DPS of June 21, 2013, NMFS states that it has been difficult to evaluate the status of eulachon “due to the lack of reliable long term data”, and that available abundance data “are confounded by intermittent reporting, fishery-dependent data, and the lack of directed sampling” (NMFS-NWR 2013). The Federal Recovery Outline for Eulachon Southern DPS, identifies “in-river spawning stock biomass surveys to develop long-term eulachon spawner abundance estimates for all four sub-populations” as the first item in the list of recovery tasks to improve potential for recovery.

Study Objectives and Report Structure

In 2010, the Oregon Department of Fish and Wildlife (ODFW) and WDFW were awarded a National Oceanic and Atmospheric Administration (NOAA) Fisheries Protected Species Conservation and Recovery (Section 6 of the ESA) grant to fund eulachon studies during Federal Fiscal Years (FY) 2010-2013 ("Protected Species Studies of Eulachon Smelt in Oregon and Washington"; Award Number NA10NMF470038).

The goal of this project was to design and implement a monitoring program to track coast-wide status and trends in abundance and distribution to better manage anthropogenic impacts and other threats to recovery of the proposed threatened southern eulachon DPS. The objectives were: 1) to develop and implement an annual eulachon SSB estimate for the Columbia River that will allow managers to better track recovery and manage fishery impacts; 2) to better characterize current eulachon smelt distribution using egg and larvae surveys of known and potential spawning areas in the lower Columbia River, Columbia River tributaries, and coastal river systems of Washington and Oregon, to aid in determination of critical habitat for the DPS; 3) to assess and reduce the impacts of shrimp trawl operations on eulachon smelt by initiating an observer program to estimate the bycatch rates in Washington's ocean shrimp trawl fishery and by developing and testing modifications to ocean shrimp trawl; and 4) to assess the genetic makeup of spatial and temporal components of the Columbia River and Washington/Oregon coastal eulachon smelt runs.

This report presents the work and findings to meet objective 1 stated above (objective 1 is referred to in the project's semiannual progress reports as the" Stock Assessment Objective"). The objective was accomplished by: collecting and enumerating eggs and larvae at sample sites in the lower Columbia River and Grays River each winter/spring (2010-2013); calculating the corresponding river volume for the outmigration periods; expanding the sample egg and larvae densities by the river volume to derive an estimate of annual eulachon plankton production; collecting data on age, sex and fecundity of adults during this period; and, using this information to back calculate the number and pounds of adults needed to produce the observed levels of production—in other words, derive the SSB estimates for each run year.

Ultimately this information will be used to improve the ability of managers to determine stock status, create better run predictions, and hence allow for better fishery management. It is of obvious value to NMFS, who must assess the impacts of various activities (including fisheries), and develop criteria for delisting of the species.

Under Methods, we describe the sample locations, how the samples were collected in the field and processed in the laboratory, and how the data was processed and used to derive the SSB estimates. Results and discussion are combined, and cover the number of days sampled, the period for which the estimates apply, the estimations of SSB for each year and location, and a discussion of factors that may bias our estimations.

Methods

Study Design

Fine-mesh plankton nets have been used sporadically in the lower Columbia River basin since 1946 to collect eulachon smelt larvae. Collection methods and gear were refined and standardized in 1994 for survey of the Cowlitz River (Hymer 1994). Subsequent surveys were expanded to include several other tributaries and the mainstem Columbia River beginning in 1995 (WDFW and ODFW 2001). Further refinements were implemented in 2001 for a study designed to characterize the timing and extent of larval migration in the lower Columbia River as part of an assessment of potential effects on eulachon from a project deepening the Columbia River shipping channel (Howell et al. 2002). One result of this work was establishment of a single standardize sampling transect for the mainstem Columbia River at river kilometer 55 that has since been used by fishery managers to index annual eulachon larvae production for the lower Columbia River and tributaries, excluding the Grays River, which enters the Columbia River downstream of the transect (JCRMS 2014). Separate sampling stations were developed for the Grays River. The methods and sample locations established in these earlier surveys were applied to our 2010-2013 surveys.

Daily egg production method (Parker 1985) has been applied commonly since 1983 using in pelagic fish spawning biomass assessment. Jackson and Cheng (2001) modified the method by using nonlinear regression and bootstrapping techniques to improve estimates of the Shark Bay snapper spawning biomass and Hay et al. (2002) modified it to estimate eulachon smelt SSB in the Fraser River. Their approach expands eulachon egg and larvae sample density data by estimated river discharge to generate SSB estimates. For our study, we expanded upon the existing lower Columbia River eulachon larvae indexing program to implement a SSB estimation survey like that employed by the Canadian Department of Fisheries and Oceans for the Fraser River run (Hay et al. 2002; Hay and McCarter 2003; Therriault and McCarter 2005).

Study Area

Previous studies have documented large spawning concentrations of eulachon in the Cowlitz and Lewis rivers, Washington. During field sampling in 2001, Howell et al. (2002) found the highest densities of out-migrating larvae in the Columbia River downstream of the confluence with the Cowlitz River at Columbia River kilometer 110 (Figure 1). Other major tributaries know to contain eulachon spawning habitat include the Grays, Elochoman, Kalama, Lewis, and Sandy rivers. Spawning was documented in Skamokawa Creek during the 2011 freshwater distribution surveys conducted by WDFW and the Cowlitz Indian Tribe (grant objective 2; see Report B).

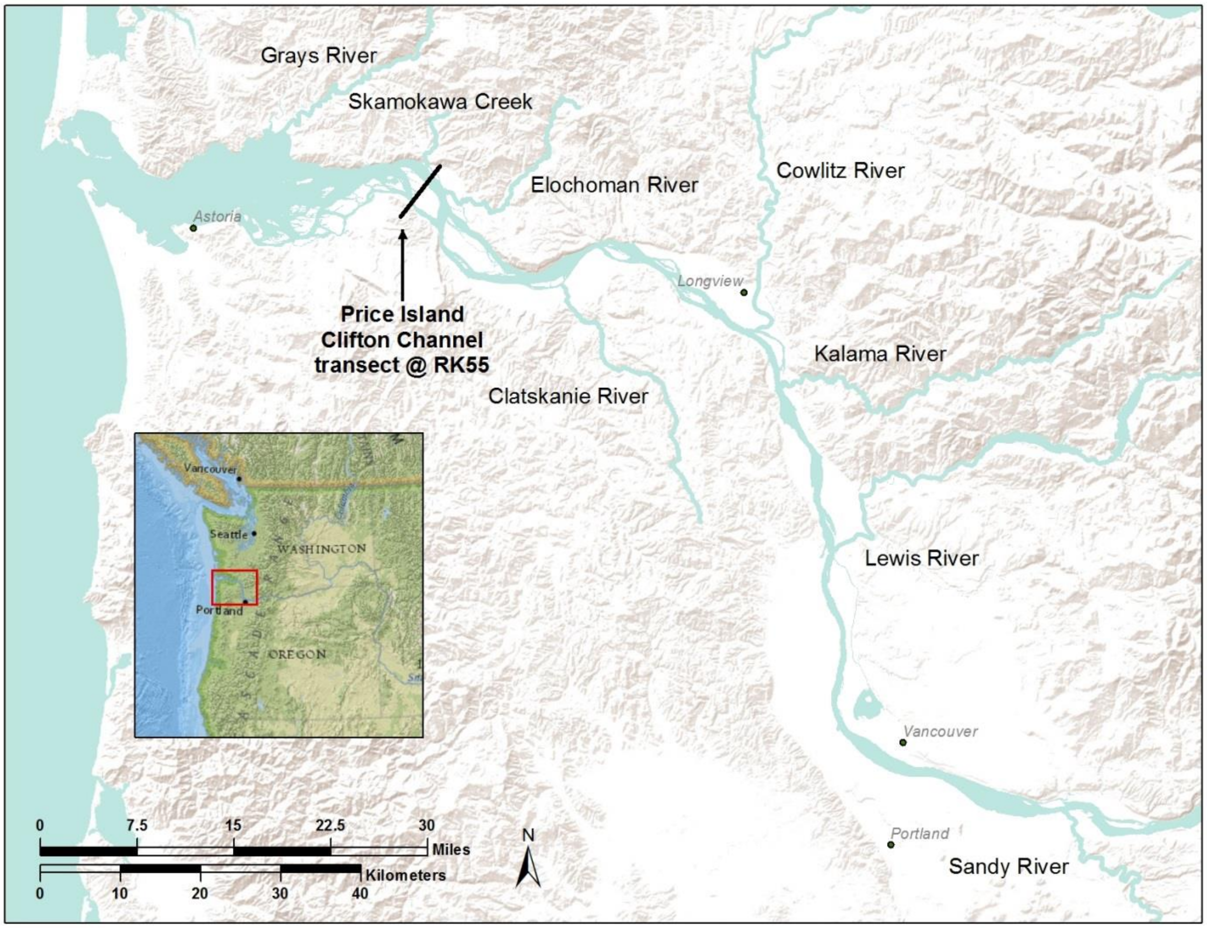

Figure 1. Lower Columbia River eulachon spawning stock biomass study site showing the location of the larval eulachon sampling transect at Columbia River kilometer 55. Included are the primary tributaries containing eulachon spawning habitat.

We sampled the Columbia River at an existing transect (river kilometer 55), the index site for larval eulachon sampling that has been monitored by WDFW since 1997 (WDFW 2001, Howell et al. 2002). The transect position (perpendicular to the river flow) crosses Clifton Channel from the Oregon shore to Tenasillahe Island and then crosses the shipping channel to Price Island on the Washington shore (Figure 2).

Figure 2. Map of lower Columbia River with mainstem transect sampling stations indicated by red circles, and USGS gauge station indicated by the blue triangle.

Field Data Collection and Laboratory Processing

We used a plankton net deployed from an anchored vessel to capture eulachon larvae (Figure 3). The net was a typical ring net design comprising a tapered nylon sock (3.35 m length, 300 μm mesh) lashed to a stainless steel circular frame (0.61 m inside diameter). Samples were collected in an 8.9-cm, two-piece polyvinyl chloride (PVC) collection bucket attached to the end of the sock. Spherical lead weights (2.54 kg, 9.07 kg or both) were attached to the frame base. Water flow was measured with a General Oceanic Model 2030R mechanical flowmeter mounted in the mouth of the net and calibrated to measure the total volume of water in cubic meters that was filtered through the net. Our standard setup was a single flow meter, but we experimented with a two-meter setup in spring 2013.

Sampling the Columbia River involved separate one-to-seven minute stationary plankton tows made for each of six stations situated along the standardized sampling transect located at Columbia River kilometer 55. The transect position (perpendicular to the river flow) crosses Clifton Channel from the Oregon shore to Tenasillahe Island and then crosses the shipping channel to Price Island on the Washington shore (Figure 2).

We sampled during daylight hours on ebb tides for safety and logistical reasons. The vessel was anchored and we recorded water temperature, depth, and turbidity readings. A tow consisted of lowering the plankton net to the river bottom and then retrieving it. Set duration ranged from one to seven minutes depending on river depth. Sample frequency was set to occur twice-weekly during the peak out-migration period and weekly during pre and post peak outmigration.

Sampling the Grays River involved one 3-5 minute stationary plankton tow made at each of two standardized sampling sites located approximately five to eight kilometers upstream from the river's mouth (Figure 4 bottom). Sampling was scheduled to occur weekly during peak outmigration and every other week pre and post peak outmigration.

Contents of the collection bucket were rinsed into separate bar-coded 1-L Nalgene ® screw-cap storage bottles for each sample and fixed with dilute (approximately 70%) ethyl alcohol. Samples were stored in bins and analyzed throughout the season at the WDFW Region 5 laboratory in Vancouver.

We obtained estimates of Columbia River discharge, in cubic feet per second, from data reported for the USGS stream-gage station 14246900 located at Beaver Army Terminal (Columbia River kilometer 86.6; Figure 2). We obtained estimates of Grays River discharge, in cubic feet per second, from data reported for Washington Department of Ecology stream flow monitoring station 25B060 located on the Grays River at the covered bridge (Grays River kilometer 16.9; Figure 4 top). We then estimated daily discharge for each river system in cubic meters per day.

Over 750 samples were collected and brought to the lab to be analyzed. One hundred percent of each sample was examined. Samples were poured into a black dish and we used the 5X lens of an Intertek Model LUX 900 dissecting microscope (with 13W lamp) to count all eggs and larvae (Figures 5 and 6). For species identification of larvae and staging of eggs, we used a Labomed Luxeo 4D (Model 414500) stereozoom microscope.

Up to ten larvae from each sample was placed in 2-ml United Laboratory Plastics cryogenic vials containing DNA preservative solution (100% anhydrous ethanol) and shipped to the WDFW genetic laboratory in Olympia, Washington, for archiving and potential future genetic analyses.

Adult Eulachon samples collected in the lower Columbia River (Figures 7 and 8) collaboratively with the NMFS Point Adams Research Station ("Studies of Eulachon in the Columbia River"; NOAA Award No. NA11NMF4370212), and those collected in the Cowlitz River by the Cowlitz Indian Tribe Natural Resources Department, were processed to obtain data to inform the biological parameters (sex ratios, average weights and lengths, fecundity, etc.) used in the estimation of SSB. Adult processing methods are described in Wagemann (2014).

Data Processing

We estimated eulachon egg and larval eulachon density for each sample based on laboratory counts and the estimated volume of water filtered through the plankton net based on data obtained from the mechanical flowmeter. Water volume calculations were made using only data from the one flow meter used throughout all three years.

Catch rate for larvae was estimated as catch per cubic meter of water filtered in each sample. Expansion of the samples to weekly and annual outflow estimates were done in accordance with the procedures described for the Fraser River (Hay et al. 2002). The cumulative number of eggs and larvae was estimated for each sample week as the product of the weekly mean density of eggs plus larvae (the mean of all six sampling stations for the Columbia River; the mean of the two to four weekly samples for the Grays River) and the river discharge for the week.

Eulachon spawner and SSB estimates were made with the following assumptions: sex ratio = 1:1; fecundity = 32,766 eggs/female; 11.2 eulachon per pound; eggs and larvae are equivalent; and 100% survival from egg to larvae stage (Table 4). We planned to collect annual data on adult eulachon sex ratio, fecundity, and fish weights and lengths by sampling fisheries, but with their elimination following 2010, we obtained samples and data from other sources. The NMFS Point Adams Laboratory provided sex ratio data on 8,031 adult eulachon sampled from the

Columbia River and Cowlitz Indian Tribe Natural Resources Department staff provided us with another 90 adults collected from the Cowlitz River (Table1). We also reviewed literature for sex ratio information (Table 2), but due to the wide range in values reported and concerns about potential biases (Moffitt et al. 2002), decided to follow the example reported in Hay et al. (2002) and concluded that it was valid to use a 1:1 sex ratio.

The NMFS Point Adams Laboratory provided us with 37 adult female eulachon collected from the Columbia River in 2013 for fecundity analysis and Cowlitz Indian Tribe Natural Resources Department staff provided 22 adult females collected in 2012 and 2013 from the Cowlitz River. These fish were examined in our lab and fecundity was estimated from either total counts or from subsampling 5% of each ovary (Wagemann 2014). Weights and lengths were also taken on these fish. Fish weight averaged 40.84 grams (11.1 fish per pound) and length averaged 173 millimeters. From this data (Table 3), we determined a relative fecundity of 802.3 eggs per gram of female for a 173mm fish weighing 40.84 grams, which we applied to all three study years. This compares to a 43.67 gram average (10.4 fish per pound; n=938) for sport-dipped fish collected in 2014 from the Cowlitz River (unpublished data), to a 40.63 gram average (n=2,352) reported in Hays et al. (2002) for the Fraser River, and a 34.6 gram average (13.1 fish per pound; n=2,500) reported for 1953 Columbia River and tributary commercial fisheries (FCO 1954). Due to the range in average weights, we elected to use the 40.63 gram value reported by Hay et al. (2002) to calculate the 11.2 fish per pound used in our SSB modeling.

We employed bootstrapping (Jackson and Cheng 2001) to all raw data for the Columbia River to assess confidence limits around annual egg/larvae production, spawner, and SSB estimates. Bootstrapping was not done on the Grays River data due to the limited number of sampling stations. For each bootstrap sample we let n=1,000 (Table 4). We pooled all bi-weekly density estimates into one-week periods for each station. The bootstrap procedure randomly selected six weekly egg and larvae density values from the pool of six sampling stations, with replacement. The mean and standard deviation were estimated from the 1,000 bootstrap replications for each week. Bootstrap estimates were generated for each sample week and summed for the entire Columbia River egg and larval outdrift period surveyed.

Results and Discussion

Plankton net sampling effort for the Columbia River is summarized in Appendix Tables B1–B3. We sampled the Columbia River 29 days during 19 weeks of a 20-week span in 2011 (weeks-of-the-year 3-22), 34 days during 25 consecutive weeks in 2011-2012 (weeks 50-21), and 43 days during 29 weeks of a 30-week span in 2012-2013 (weeks 48-25). We sampled the Grays River fourteen days in 2011 (weeks 4-18; see footnote Table 8 about 13 days modeled), thirteen days in 2011-2012 (weeks 51-20), and nineteen days in 2012-2013 (weeks 52-19).

Eulachon eggs and/or larvae were present in at least one sample for every day the Columbia River was sampled, except for the final week in 2011-2012 and the final week in 2012-2013 (Appendix Tables C1–C3). Sample densities, and corresponding egg and larvae outflow estimates, peaked during week 12 (March 13-19) in 2011, during week 12 (March 11-17) in 2012, and during week 18 (Apr. 28 – May 4) in 2013 (Figures 9–14; Appendix Tables D1–D3). In the Grays River, eulachon egg and larvae outflow peaked during week 13 in 2011, during week 16 in 2012, and during week 14 in 2013 (Figure 15).

During all three seasons, limited numbers of eggs were taken in the plankton net tows (means of 1.58, 0.68, and 0.40 eggs/m^3 for 2011, 2011-12, and 2012-13, respectively). The mean combined egg and larvae densities (6.64, 4.88, and 14.44 plankton/m^3) were therefore very similar to the mean larvae densities for the given year (5.06, 4.20 and 14.04 larvae/m^3, respectively; Tables 3–5). As a general rule, egg densities peaked earlier than the larvae densities, and fewer were encountered in the Clifton Channel sites than in the Price Island sites. Also, larvae densities were greater over in the Price Island sites (Figure 9; Appendix Tables D1–D3).

The tendency for greater plankton densities at the Price Island sites (Stations 4–6) is thought to be related to the fact that most eulachon spawning tributaries are on the Washington shore (Elochoman, Cowlitz, Kalama, and Lewis rivers). The lack of eggs in the samples is likely due to eulachon spawning further upriver (not in the immediate vicinity of the Clifton Channel/Price Island sampling transect). Most eggs encountered at the sample transect location are in a later stage of development, or are dead.

We estimated SSB for the Columbia River from January 9, 2011 through May 28, 2011; from December 4, 2011 through May 26, 2012; and from November 25, 2012 through June 22, 2013; and for the Grays River from January 16, 2011 through May 14, 2011; from December 18, 2011 through May 19, 2012; and from December 23, 2012 through May 11, 2013. We estimate that SSB for the Columbia River was 3,300,000 pounds (1,500 metric tonnes) in 2011 (Table 5); 3,200,000 pound (1,500 metric tonnes) in 2011-2012 (Table 6); and 9,650,000 pounds (4,400 metric tonnes) in 2012-2013 (Table 7). SSB estimates for the Grays River were much smaller (Tables 8-10), being about 0.02% of the values for the Columbia River.

Before dismissing the Grays River SSB estimates, one needs to consider whether the 2010-2013 results are reflective of what occurs in most years. The larval densities reported for the Grays River in Tables 8-10 average 0.8 larvae/m^3, which is considerably less than the average 29.8 larvae/m^3 reported for ten earlier Grays River surveys (JCRMF 2014). Larval densities in the Grays River have often times not been in sync with the larval densities reported for the mainstem Columbia River or for major spawning tributaries like the Cowlitz River. While the Grays River may never produce the bulk of the larval production, it may at times contribute more to total Columbia River production than is reflected in our 2010-2013 surveys. Smith and Saalfeld (1955) noted that a run has occurred in the main Columbia River every year, while runs in the tributary streams have varied from no fish to those which have individually supported commercial fisheries. They concluded that the irregularity of the runs into the various tributaries virtually precludes the existence of a home tributary influence. This inter-annual variation in where fish spawn within a system has been noted in other systems like the Fraser River Basin (Hay and McCarter 2000) and the Copper River Delta area (Moffitt et al. 2002). Due to this inter-annual variation in spawning, it would be prudent to continue developing SSB estimates for the Grays River.

Accurate eulachon plankton density estimates are dependent upon having correct larvae and egg counts and flow meter measurements. A sticking or slow meter would result in a low estimate of water volume sampled. That would bias the plankton densities high, which subsequently would bias the biomass estimates high. Given the surprisingly high SSB estimates, the use of old flow meters was questioned. Testing the old meter in tandem with a new meter in spring 2013 revealed that two meters performed similarly and, for consistency, we used the readings from just the original meter for all analysis.

Missing eggs and larvae at the beginning and end of a survey will result in an underestimation of the annual plankton production, and consequently introduce negative bias into the SSB estimate (Moffitt et al. 2002). Ideally, one should strive to start and end the season with no eggs or larvae present in the samples. For the mainstem Columbia River (Appendix Tables D1-D3), this was basically achieved for the 2011/12 and 2012/13 surveys; however, during the 2011 survey there was a mean of 0.87 plankton/m^3 on January 1, 2011 (first day of the survey season) and 0.32 plankton/m^3 on May 26, 2011 (the last day of the survey season). The same can be said for our surveys in the Grays River. In Figure 15, the plankton densities in the first survey dates in the 2011 season were high relative to those seen during the rest of the Grays River survey period. The Columbia River eulachon run is known to produce a "pilot run" before the New Year. In some years the "main run" has shown up late. In order to fully capture the whole run, one might consider conducting the larval surveys from November 1 through May 31. This could be a costly adventure. It may be acceptable to consider a slightly abbreviated survey period given that it is unlikely there is significant bias created by not sampling the low-density tails of the run. However, in trimming the survey season one must consider the importance of including the production from the "pilot" component of the run.

As mentioned in the above paragraph, having correct larvae and egg counts is necessary to assure good estimates of plankton density. During the peak of the run we double our sample days per week to improve our confidence intervals. During this time there can be thousands of eggs and larvae to count in a single sample. So, the temptation is to estimate the counts by expansion of a subsample count. If the subsample is not representative, the estimation can be off. We experimented with subsampling, including using a sample splitter device, but found too much variations between the subsamples. As a result, we chose to process the whole sample regardless of the circumstances.

During the past, most measurements of larval and egg density were taken from samples collected around the peak of the outmigration. Because the protocol for this study required us to sample throughout the whole run, samples were taken much earlier and later than normal. It was noted that some larvae and eggs collected in these marginal periods were of different form or size. Subsequently, these larvae and eggs were not included in the eulachon plankton count, but recorded as non-eulachon larvae or eggs. The presence of non-eulachon larvae and eggs were always low, probably never exceeding 5 percent of a sample at any time, and almost never occurring during the peak period for eulachon outmigration. Even if these non-eulachon larvae and eggs were included in the determination of density, they would have created a very minor high bias in the SSB estimate.

River discharge was measured at the Beaver Army Terminal (Columbia River kilometer 86.6) which is some distance above the Clifton Channel/Price Island larval sample transect sites (Columbia River kilometer 55). Two rivers flow into this 31.6 km section of the Columbia River – the Elochoman River (right bank, Columbia River kilometer 62.9) and Clatskanie River (left bank, Columbia River kilometer 80.0). The Elochoman River's mean discharge is 783 ft^3/s, 745 ft^3/s, 549 ft^3/s for January, February, and March respectively (USGS 14247500 data from 1941–1971, http://waterdata.usgs.gov). The Clatskanie River's mean discharge is 349 ft^3/s, 383 ft^3/s, and 212 ft^3/s for January, February and March respectively (USGS 1424700 data from 1950–

1954, http://waterdata.usgs.gov). These two rivers drain approximately 118.8 miles^2, which is only 0.05% of the drainage area above the Beaver Army Terminal gage (256,900 miles^2). Monthly mean discharges for the Beaver Army Terminal site are 301,000 ft^3/s, 244,000 ft^3/s, and 296,000 ft^3/s for January, February and March respectively (USGS 14246900 data from 2011–2013, http://waterdata.usgs.gov). The contribution of these two rivers to the daily discharge at the sampling site during eulachon plankton outflow is minor (<0.05%); however, it does mean that the daily production of eggs and larvae was biased low by that percent (daily production is estimated as the daily discharge (m^3/sec) times the estimated daily larval and egg density (number/m^3)). Not correcting for water inflow downstream of the Beaver Army Terminal biased our estimates of total eulachon egg and larvae production, which subsequently biased our biomass estimates low by <0.05%.

We assume that the larval densities we observed during our daylight sampling are representative of the larval densities throughout the whole day. Some researchers report larger catches of eulachon larvae at night (Levings 1980; Orr 1984). As Moffitt et al. (2002) point out, larger abundance of eulachon larvae migrating at night would bias the biomass estimate low if the samples were only taken during daylight hours. We speculate that diurnal differences in larval densities may be more apparent in smaller and slower bodies of water where the larval collection sites may be closer to the hatching/emergence sites. In larger systems, the passive migrating eulachon larvae are likely to be well mixed and disbursed by the time they arrive at larval collection sites in the lower reaches of the river. Thus the bias may be more of an issue for the SSB estimation in the Grays River than for the SSB estimation in the mainstem Columbia River.

We have assumed that there is no egg to larval mortality. This gives us conservative SSB estimates. Had there been stranding due to dewatering, loss from disease, etc. then it would take more females to produce the egg and larvae seen at the collection site. If some egg retention occurs, or eggs fail to get fertilized, then even more females are needed to account for the observed level of production. In our model we simply divide the number of eggs and larvae produced by the assumed fecundity to derive the estimated number of females.

In the model, we have assumed a sex ratio of 1:1. This assumption may result in a conservative estimate of SSB. Most eulachon studies report a dominance of males in the sample. If we took the weighted average M:F gender ratio from Table 1 of 1.67:1, the estimated number of females would be multiplied by 2.5 rather than doubled to derived the number of spawning smelt. Moffitt et al. (2002) caution that, “all reported sex ratios for eulachon should be interpreted with caution. Eulachon sex ratios in the literature probably vary because of gear selectivity, low sample sizes, and the temporal and spatial scale of sample collections.” Moffitt et al. (2002) explain how gender differences in behavior near and on the spawning grounds may lead to samples dominated by males. It would seem prudent to continue to focus our adult collections in the estuary and lower reaches of the mainstem Columbia River, where the various components of the run are present and mixed together.

Having derived a conservative estimation of spawning smelt, we still need to expand that by an average weight to derive the SSB. Adult size may vary annually (brood strength, condition factor, etc.). By assuming 11.2 fish to a pound, we derive a lower SSB than when we assumed 8.2 fish to a pound in our earlier estimations reported in the project semi-annual progress reports. The fish to a pound value should be adjusted annually to best fit the size/age structure observed.

The SSB estimates for the Fraser River (31 metric tonnes for 2011; 120 metric tonnes for 2012; and 100 metric tonnes for 2013; http://www.pac.dfo-mpo.gc.ca/science/species-especes/pelagic-pelagique/herring-hareng/herspawn/pages/river1-eng.html) are significantly lower than those generated for the Columbia River (1,500 metric tonnes for 2011; 1,500 metric tonnes for 2011/12; and 4,400 metric tonnes for 2012/13). In fact, the highest Fraser River SSB estimate since they began in 1995 was 1,911 metric tonnes for 1996. It is obvious that the Columbia River run is a very significant component of the eulachon southern DPS. Having a long-term stock assessment program in the Columbia River would benefit the recovery effort and fisheries management.

References

BRT (Biological Review Team). 2008. Summary of scientific conclusions of the review of the status of eulachon (Thaleichthys pacificus) in Washington, Oregon, and California. NMFS Northwest Fisheries Science Center. Seattle, WA. 229 p. http://www.nwr.noaa.gov/Other-Marine-Species/upload/Eulachon-Review.pdf

FCO (Fish Commission of Oregon). 1954. 1953 Status Report on Columbia River Fisheries. Fish Commission of Oregon. Portland, Oregon. 2-8.

Hay, D.E., P.B. McCarter. 2000. Status of the eulachon Thaleichthys pacificus, in Canada. Canadian Science Advisory Secretariat. Research Advisory Document 200-145. Fisheries and Oceans Canada, Nanaimo, B.C.

Hay, D.E., P.B. McCarter, R. Joy, M. Thompson and K. West. 2002. Fraser river eulachon biomass assessments and spawning distribution: 1995-2002. PSARC Working Paper P2002-08. 60p.

Hay, D.E. and P.B. McCarter. 2003. Eulachon embryonic egg and larval outdrift sampling manual for ocean and river surveys. Canadian Technical Report of Fisheries and Aquatic Sciences 2451. 35p.

Howell, M.D., M.D. Romano, and T.A. Rien. 2002. Migration timing and distribution of larval eulachon in the lower Columbia River, spring 2001. In Ward, D. L. (Ed.). 2002. Eulachon studies related to Columbia River channel deepening operations. Oregon Dept. of Fish and Wildlife and Washington Dept. of Fish and Wildlife Final Report to U.S. Army Corps of Engineers. Contract No. W66QKZ13237198. 28p.

Hymer, J. 1994. Cowlitz River smelt larvae sampling results, 1994. Columbia River Laboratory Progress Report 94-19. Washington Department of Fish and Wildlife. Battle Ground, Washington. 12p.

Jackson, J. and Cheng, Y.W. 2001. Improving parameter estimation for daily egg production method of stock assessment of pink snapper in Shark Bay, Western Australia, Journal of Agricultural, Biological and Environmental Statistics 6, 243-257.

JCRMF (Joint Columbia River Management Staff). 2014. 2014 Joint Staff Report Concerning Stock Status and Fisheries for Sturgeon and Smelt. Oregon Dept. Fish and Wildlife and Washington Dept. Fish and Wildlife. 47p. http://wdfw.wa.gov/publications/01568/wdfw01568.pdf

Levings, C.D. 1980. Vertical distribution and abundance of epibenthos and macrozooplankton in the lower Fraser Estuary. Department of Fisheries and Oceans, Canadian Data Report of Fisheries and Aquatic Sciences No. 214. (Cited by Orr (1984).

McHugh, J.L. 1939. The eulachon. Fisheries Research Board of Canada Pacific Progress Report 40, 17-22.

Moffitt, S., B. Marston, and M. Miller. 2002. Summary of eulachon research in the Copper River delta, 1998-2002. Report to the Alaska Board of Fisheries. Regional Information Report No. 2A02-34. 64p.

NMFS-NWR (National Marine Fisheries Service Northwest Region). 2013. Federal Recovery Outline: Pacific Eulachon Southern Distinct Population Segment. 24p.

Orr, U. 1984. 1983 Eulachon sampling on the Lower Nass River in relation to log handling. Fisheries and Oceans Draft Report, June 1984. Department of fisheries and Oceans, North Coast Habitat Management, Prince Rupert, British Columbia.

Parker, K. (1985). Biomass model for the egg production method In: Lasker R (Ed.) An egg production method for estimating spawning biomass of pelagic fish: application to the northern anchovy *Engraulis mordax*. NOAA Technical Report No. 36, NMFS, 5-6.

Royal, L.A. 1932. Unpublished data. Washington Department of Fisheries (as reported in Smith and Saalfeld 1955).

Smith, W.E. and R.W. Saalfeld. 1955. Studies on Columbia River smelt *Thaleichthys pacificus* (Richardson). WDF Fisheries Research Papers 1 (3): 3-26.

Therriault, T.W. and P.B. McCarter. 2005. Using an Eulachon Indicator Framework to Provide Advice on Fraser River Harvest Opportunities for 2006. Dept. of Fisheries and Oceans, Canadian Science Advisory Secretariat Research Document 05/77. 15p.

Wagemann, C. 2014. Progress report for the reporting period of July 1, 2013 – December 31, 2013. Studies of Eulachon in the Columbia River, NOAA Award No. NA11NMF4370212. 9p.

WDFW (Washington Department of Fish and Wildlife) and ODFW (Oregon Department of Fish and Wildlife). 2001. Washington and Oregon eulachon management plan. WDFW and ODFW. 33p. http://wdfw.wa.gov/fish/creel/smelt/wa-ore_eulachonmgmt.pdf.

Figures

Figure 3. Photograph of the plankton net setup deployed to collect eulachon smelt eggs and larvae. Image shows the setup when two General Oceanic flow meters were mounted to the frame.

Figure 4. Photographs of plankton net sampling in the Grays River.

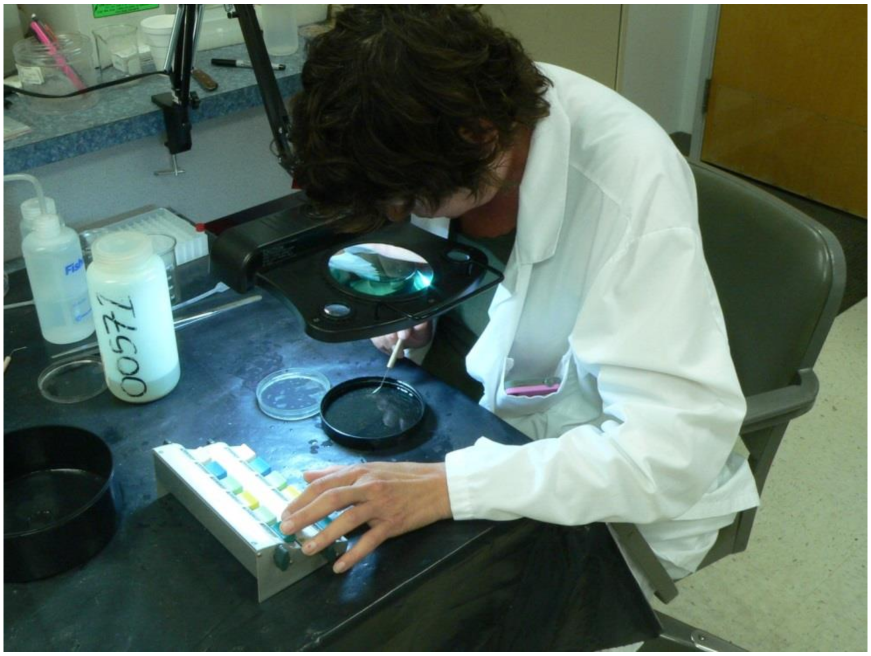

Figure 5. Photograph of Washington Department of Fish and Wildlife Region 5 laboratory setup to process eulachon larval samples. Scientific Technician Laura Lloyd is viewing a portion of the content of sample 00571 under a 5x lens. A multiple counter is used to separately track eulachon and non-eulachon larvae and eggs. Up to ten eulachon larvae will be taken from a sample and transferred to cryogenic vials containing DNA preservative for future genetic analysis (note pipette and red-capped vial in background).

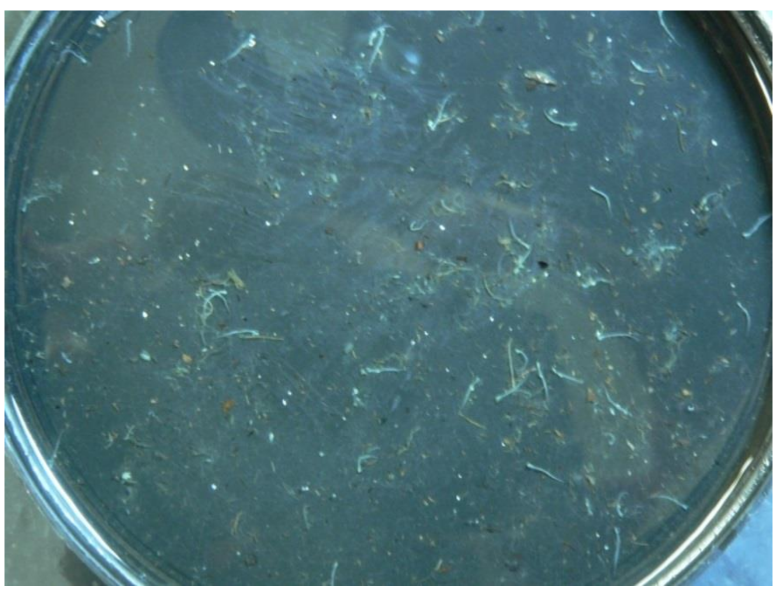

Figure 6. Photograph of a portion of a eulachon larval sample viewed under a 5x lens. Note that the black background facilitates viewing of the thin slightly opaque larvae. This is a very clean sample, without debris, sand and algae. Larvae will cling and become buried in debris and algae, making the task of counting more difficult.

Figure 7. Photograph of National Marine Fisheries Service Point Adams Research Station staff bringing in a large haul of adult eulachon near Coffee Pot Island (Columbia River kilometer 68) on March 7, 2013. Small trawls proved to be an efficient way to collect adult eulachon without significant handling mortality. Sampling in the lower reaches of the Columbia River assures a proper representation of the run components, especially sex composition. Photograph courtesy of Jeannette Zamon, NMFS Point Adams Research Station.

Figure 8. Photograph of a live male eulachon (top) and female eulachon (bottom) caught during trawling operations in the lower Columbia River in 2013. Biological data collected on the adult run is used to parameterize the estimation of Spawning Stock Biomass (SSB). Photograph courtesy of Jeannette Zamon, NMFS Point Adams Research Station.

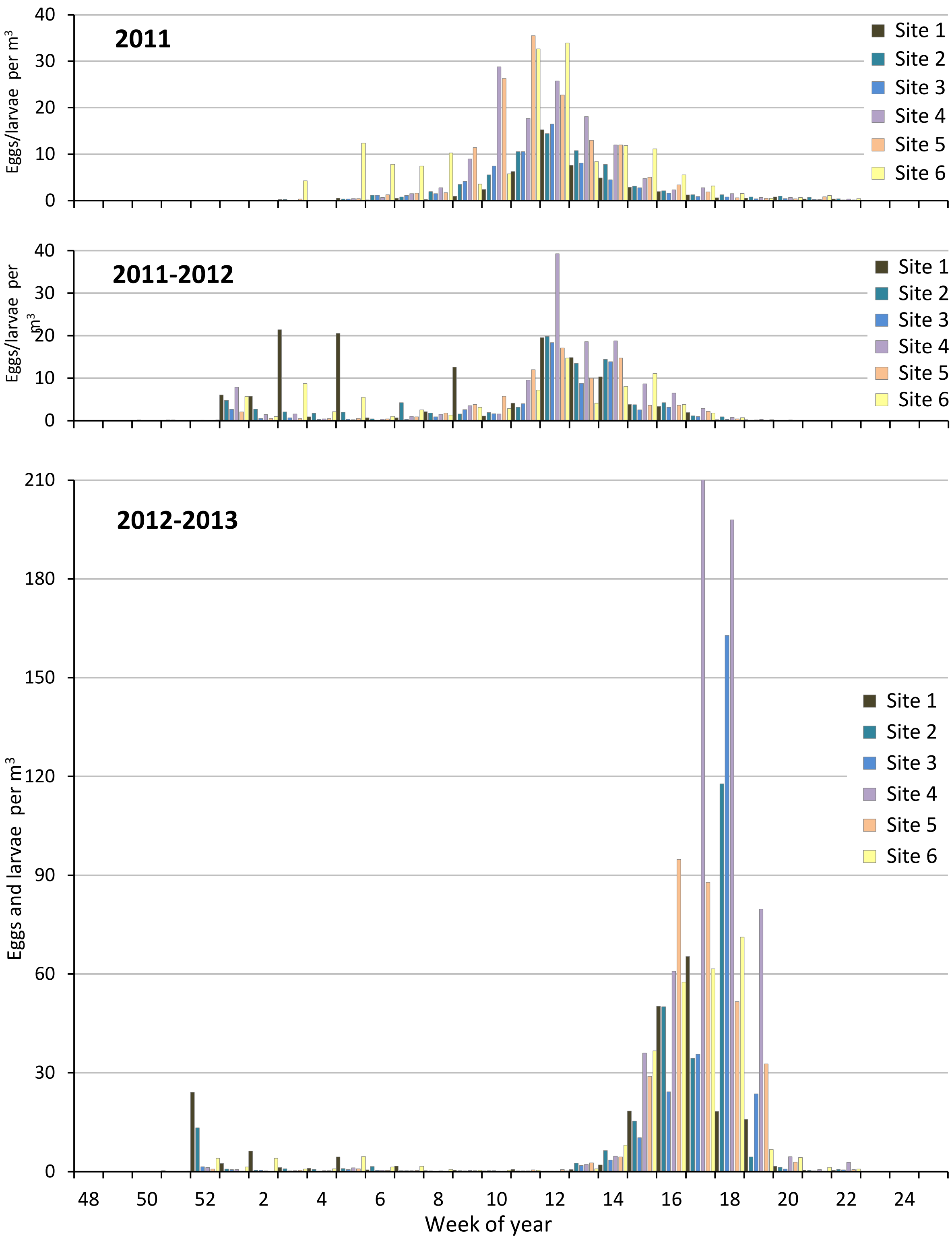

Figure 9. Weekly eulachon egg and larvae sample densities (values averaged if sampled twice in a week) by site along the Price Island/Clifton Channel transect, for 2011 (weeks 3 through 22), 2011-2012 (weeks 50 through 21), and 2012-2013 (weeks 48 through 25). Charts sized to maintain relatively equal scales.

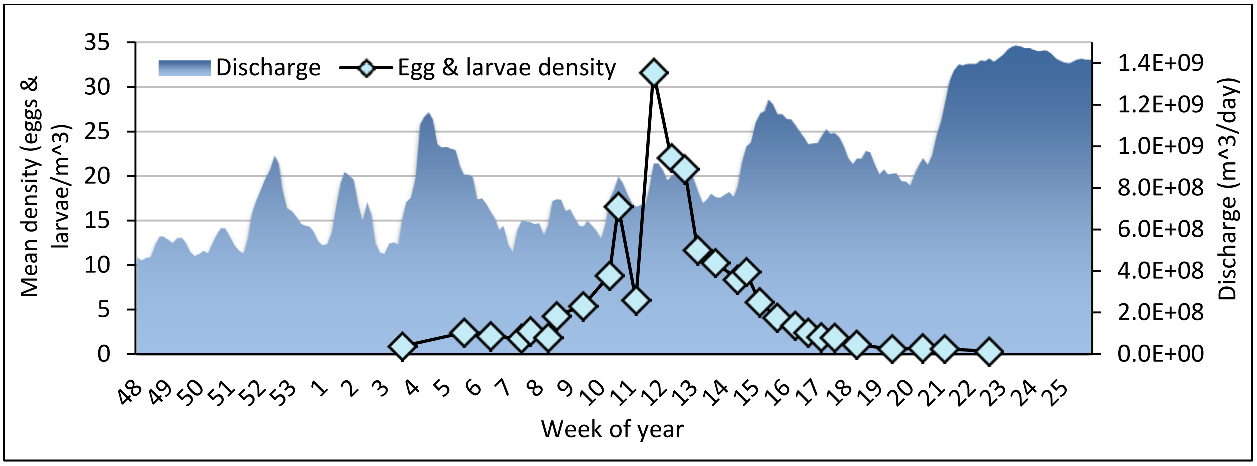

Figure 10. Mean daily Columbia River eulachon egg and larval sample densities collected at the Clifton Channel/Price Island index from January 13, 2011through May26, 2011 (weeks 3 through 22) displayed against the calculated daily Columbia River discharge at Beaver Army Terminal.

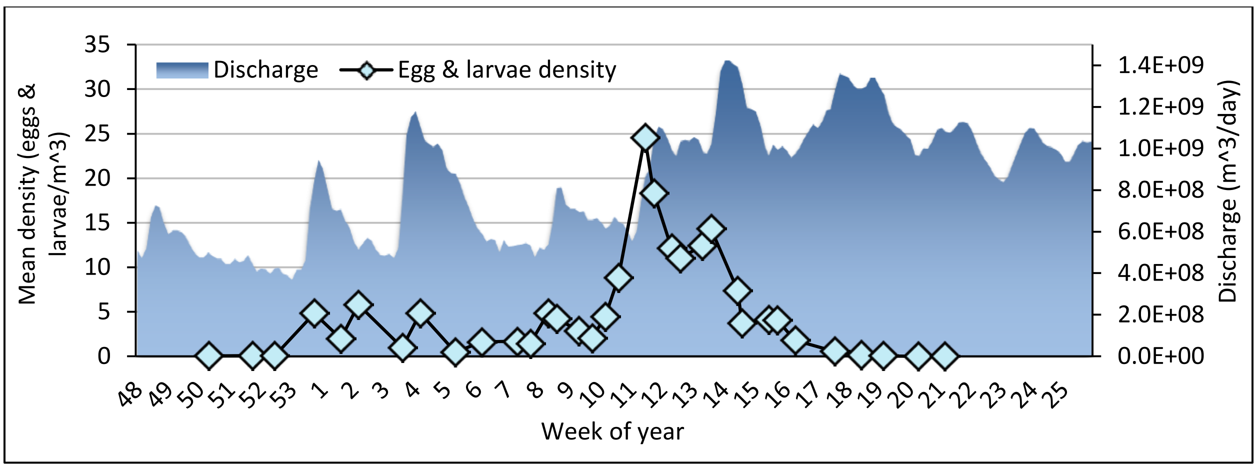

Figure 11. Mean daily Columbia River eulachon egg and larval sample densities collected at the Clifton Channel/Price Island index from December 6, 2011 through May 21, 2012 (weeks 50 through 21) displayed against the calculated daily Columbia River discharge at Beaver Army Terminal.

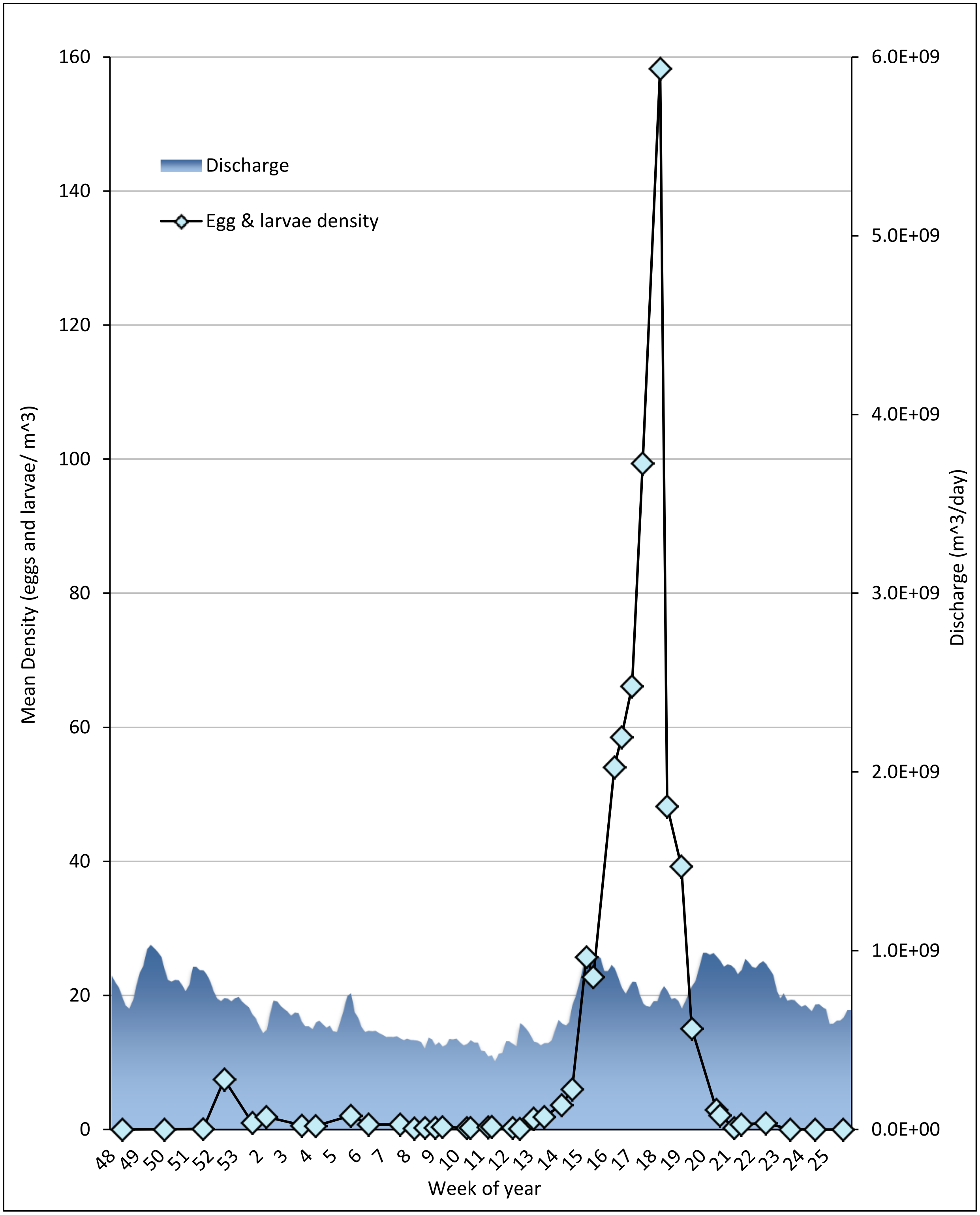

Figure 12. Mean daily Columbia River eulachon egg and larval sample densities collected at the Clifton Channel/Price Island index from November 28, 2012 through June 21, 2013 (weeks 48 through 25) displayed against the calculated daily Columbia River discharge at Beaver Army Terminal.

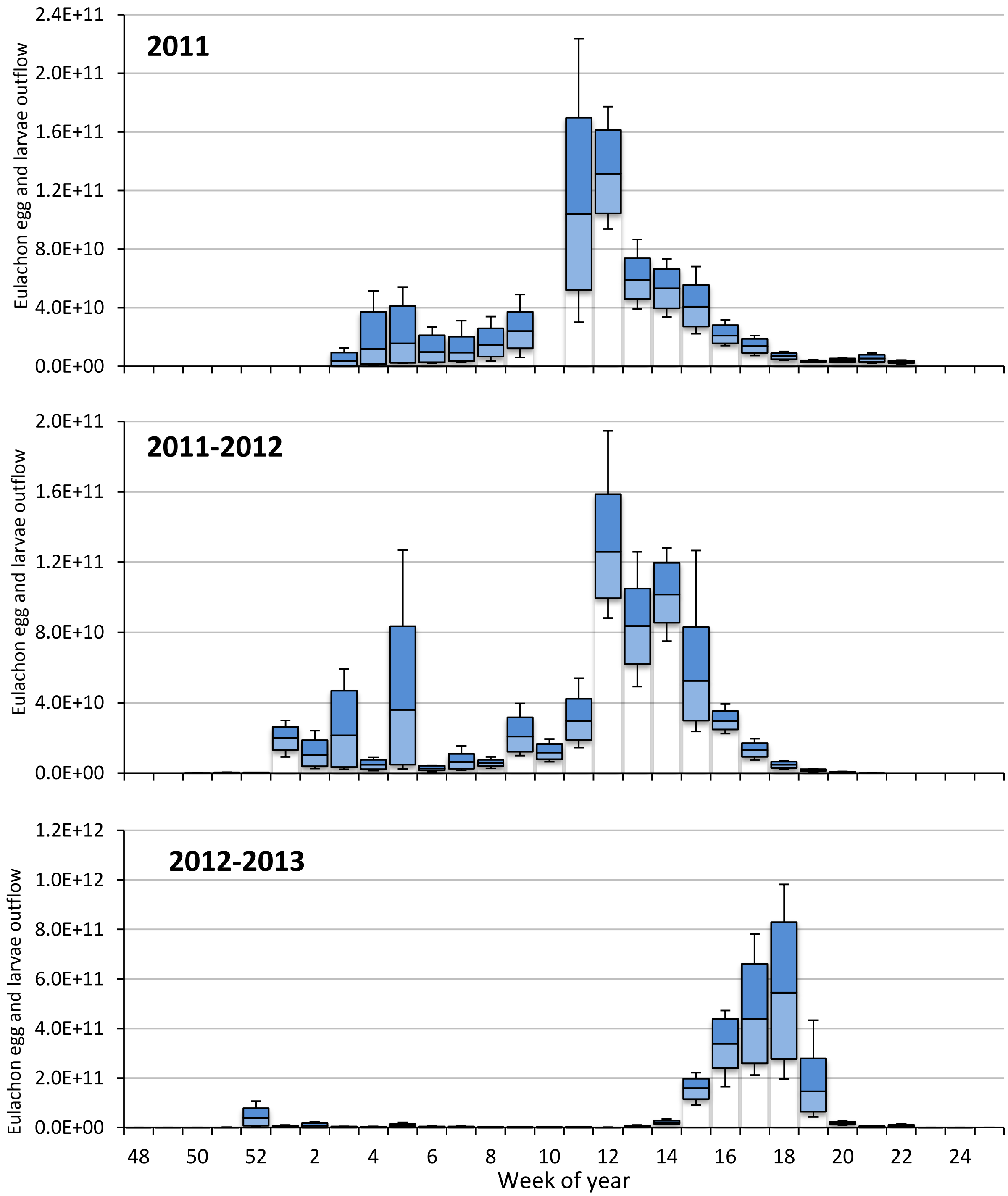

Figure 13. Box plot of weekly outflow (passive outmigration) of eulachon smelt plankton (eggs and larvae) into the Columbia River estuary at the Clifton Channel/Price Island index for 2011 (weeks 3 through 22), 2011-2012 (weeks 50 through 22), and 2012-2013 (weeks 48 through 25). Dark Blue represents upper (95%) confidence level, the black line separating the boxes represents the mean, and the light blue represents the lower (95%) confidence level. Includes bootstrap generated minimum and maximum estimates. Note the difference in scale between the bottom and top two charts.

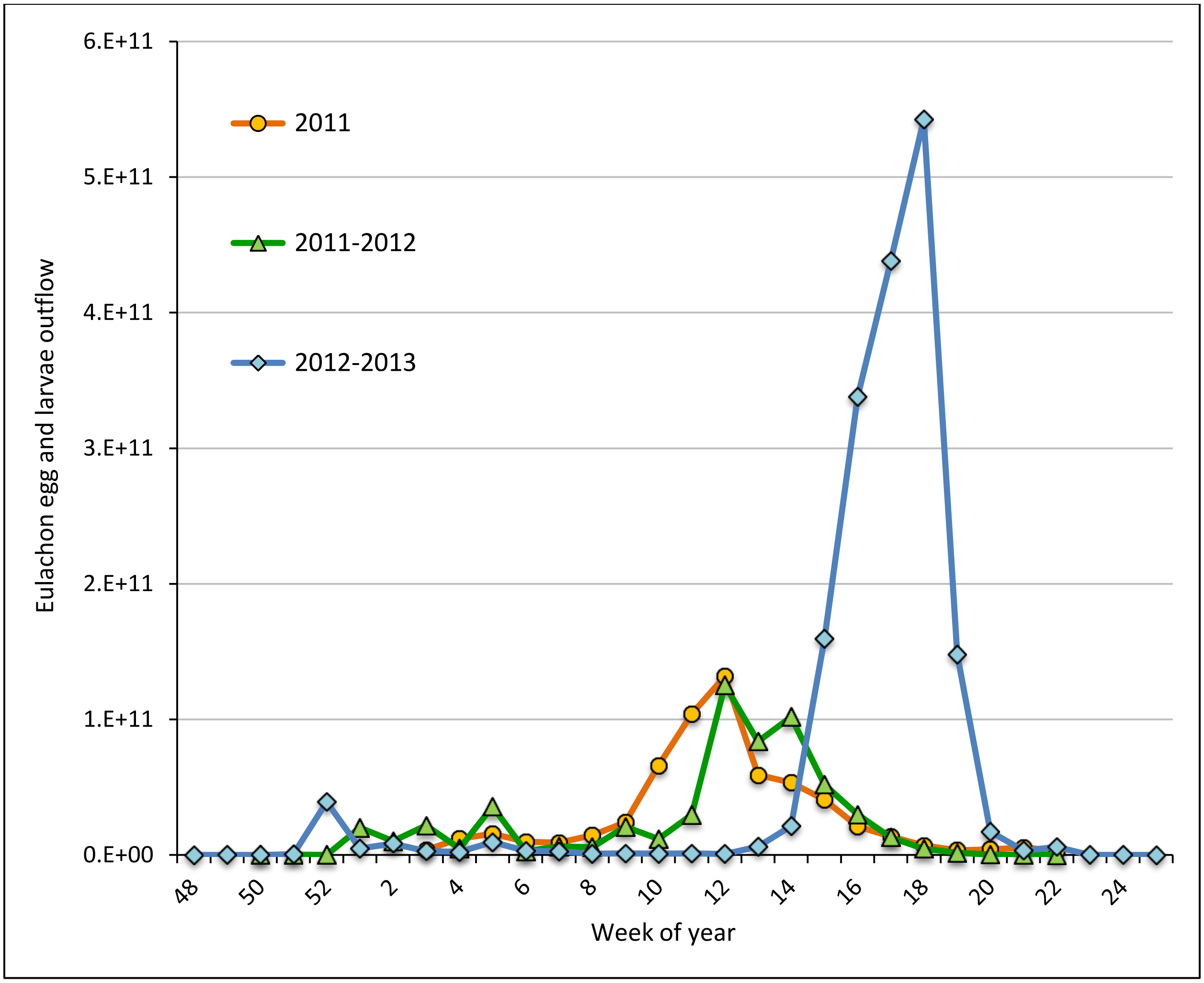

Figure 14. Comparison of estimated weekly outflow (passive outmigration) of eulachon smelt plankton (eggs and larvae) into the Columbia River estuary at the Clifton Channel/Price Island index for 2011 (weeks 3 through 22), 2011-2012 (weeks 50 through 21), and 2012-2013 (weeks 48 through 25).

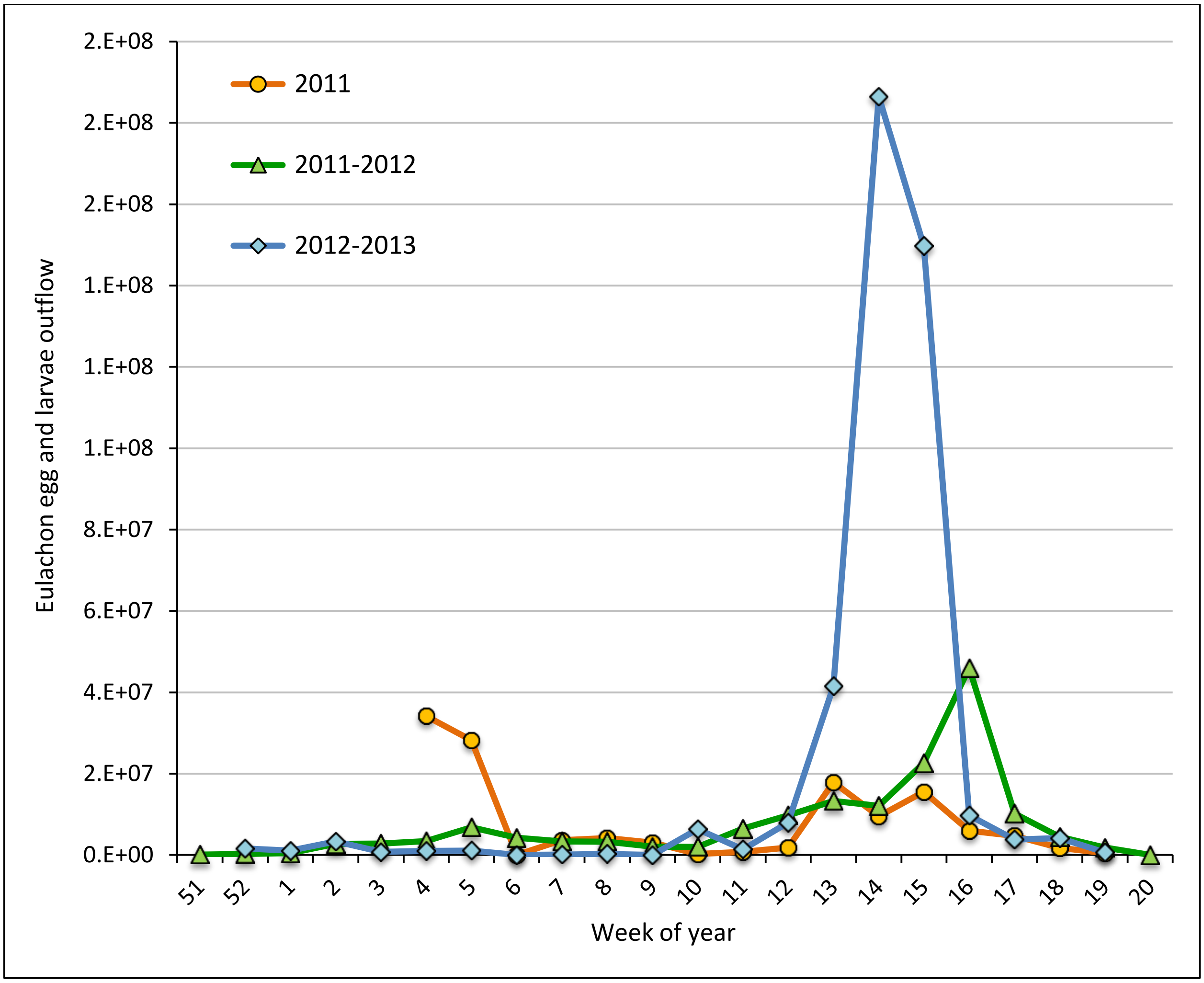

Figure 15. Comparison of estimated weekly outflow (passive outmigration) of eulachon smelt plankton (eggs and larvae) in the Grays River estuary for 2011 (weeks 4 through 18), 2011-2012 (weeks 51 through 20), and 2012-2013 (weeks 52 through 19).

Tables

Table 1. Summary of adult eulachon sex ratio data collected for the Columbia and Cowlitz rivers, 2011-2013.

Date	Source	Study	Collection gear	Number examined	Gender ratio (M:F)
2011-2012	Cowlitz River	Cowlitz Tribe	Fyke net	60	0.32:1
2012-2013	Cowlitz River	Cowlitz Tribe	Fyke net	30	0.33:1
2013 Feb 25	Columbia River	NMFS Pt. Adams	trawl	126	0.64:1
2013 Mar 5	Columbia River	NMFS Pt. Adams	gillnet	1,230	n/a
2013 Mar 7	Columbia River	NMFS Pt. Adams	trawl	6,480	1.86:1
2013 Mar 11	Columbia River	NMFS Pt. Adams	trawl	173	0.57:1
2013 Mar 12	Columbia River	NMFS Pt. Adams	trawl	22	0.05:1
			Total	6,801	
				Range	0.32–1.86:1
				Daily average	0.78:1
				Weighted average	1.67:1

Table 2. Eulachon sex ratio published for the Columbia River, tributaries, and for the Fraser River.

Year	Source	Reference	Collection gear	Number examined	Gender ratio (M:F)
1930's	Columbia River	Royal (1932) [1]	commercial gillnet		6.8:1
1930's	Cowlitz River	Royal (1932) [1]	commercial dip net		3.2:1
1930's	Lewis River	Royal (1932) [1]	commercial dip net		12.3:1
				Mean	4.5:1
1946	Cowlitz River	Smith and Saalfeld (1955)	commercial dip net	1,465	10.5:1
1946	Sandy River	Smith and Saalfeld (1955)	commercial dip net	992	2.8:1
1946	Cowlitz River	Smith and Saalfeld (1955)	dipnet		3.0:1
				1930's – 1946 Range	2.8-12.3:1
1939	Fraser River	McHugh (1939)	commercial gillnet	1,066	1.73:1
1995	Fraser River	Hay et al. (2002)	commercial gillnet	663	0.88
1996	Fraser River	Hay et al. (2002)	commercial gillnet	459	1.11
1997	Fraser River	Hay et al. (2002)	commercial gillnet	513	0.98
1998	Fraser River	Hay et al. (2002)	commercial gillnet	416	1.67
2000	Fraser River	Hay et al. (2002)	commercial gillnet	201	1.16
2001	Fraser River	Hay et al. (2002)	commercial gillnet	100	1.00
			Total	2,352	
				1995-2001 Range	0.88-1.67:1
				1995-2001 Average	1.09:1

[1] As reported in Smith and Saalfeld (1955).

Table 3. Summary of eulachon fecundity data collected in 2012-2013 from the Cowlitz and Columbia Rivers.

Fish		Fecundity		Fish		Fecundity	
Length (mm)	Weight (g)	Total	Relative	Length (mm)	Weight (g)	Total	Relative
147	24.0	23,559	982.0	172	36.5	36,705	1,006.4
149	22.0	18,276	831.7	172	30.3	26,020	858.5
150	27.7	19,716	711.5	172	39.5	33,745	855.4
151	25.1	24,640	980.9	173	37.3	30,639	821.6
152	22.7	21,962	969.6	174	34.3	7,032	205.3
152	27.5	18,868	685.9	175	37.3	30,532	818.6
155	25.3	30,846	1,220.2	175	39.3	29,866	759.6
155	26.9	27,940	1,037.5	177	50.5	34,451	682.7
160	33.8	40,087	1,185.7	177	44.8	36,277	809.6
160	33.8	27,071	800.0	177	42.1	36,405	865.5
160	34.6	23,438	677.0	180	46.8	29,561	631.4
161	33.8	32,356	958.1	181	50.1	30,330	605.4
161	30.2	24,381	808.5	182	52.2	33,970	651.0
162	33.1	26,723	806.4	183	47.6	45,010	945.0
162	30.8	23,307	757.0	183	50.8	35,149	692.3
163	36.9	31,911	865.7	183	54.5	37,216	682.5
164	37.7	27,754	736.2	184	54.0	47,508	879.9
164	33.7	28,745	852.2	184	40.2	39,913	992.4
166	37.2	32,140	863.5	185	48.9	30,305	620.0
166	29.5	28,729	975.2	185	51.2	49,817	972.8
167	33.8	27,666	819.7	190	54.4	42,126	775.1
168	31.9	29,349	921.5	190	55.0	40,466	735.4
168	31.5	31,311	992.7	191	60.5	43,535	719.4
168	37.2	37,503	1,008.4	191	52.4	38,967	743.7
168	36.6	26,722	731.1	202	64.7	50,002	772.6
168	39.1	35,120	897.3	205	60.6	36,865	608.5
169	34.3	29,840	870.7	207	71.7	51,685	721.1
170	39.2	29,710	757.5	209	66.0	46,087	698.3
170	41.0	37,655	918.4	215	82.4	59,487	721.9
171	34.3	32,637	952.6				

Table 4. Parameter values used in estimating Columbia River eulachon spawning stock biomass from 2011 through 2013.

Parameter	Value
Biological	
sex ratio	1:1
mean female length (mm)	173
mean female weight (gram)	40.84
eggs/gram female	802.3
eggs/ female	32,766
mean fish weight (gram)	40.6
fish/pound	11.2
egg to larvae survival	100%
Bootstrap	
iterations	1,000
alpha	0.05
Confidence Level	0.95

Table 5. Estimated Columbia River eulachon mean egg and larvae density, egg and larvae production (smelt plankton outflow), and spawning stock biomass for the period January 9, 2011 through May 28, 2011, including bootstrap generated mean and 95% confidence limit estimates of plankton outflow, numbers of spawners, and SSB in pounds and in metric tons.

Cumulative values for:		Plankton outflow	Number of spawners	SSB (pounds)	SSB (megagram)
Days Sampled	29				
n (per sample day)	6				
Mean egg density	1.58				
Mean larvae density	5.06				
Mean egg & larvae density	6.64				
Point estimate		602,000,000,000			
Bootstrap results					
Maximum		1,135,000,000,000	69,700,000	6,240,000	2,800
Upper CI		902,000,000,000	55,400,000	4,960,000	2,200
Mean		599,000,000,000	36,800,000	3,300,000	1,500
Median		587,000,000,000	36,000,000	3,220,000	1,500
Lower CI		369,000,000,000	22,600,000	2,020,000	900
Minimum		291,000,000,000	17,900,000	1,600,000	700

Table 6. Estimated Columbia River eulachon mean egg and larvae density, egg and larvae production (smelt plankton outflow), and SSB for December 4, 2011 through May 26, 2012, including bootstrap generated mean and 95% confidence limit estimates of plankton outflow, numbers of spawners, and SSB in pounds and in metric tons.

Cumulative values for:		Plankton outflow	Number of spawners	SSB (pounds)	SSB (megagram)
Days Sampled	34				
n (per sample day)	6				
Mean egg density	0.68				
Mean larvae density	4.20				
Mean egg & larvae density	4.88				
Point estimate		582,000,000,000			
Bootstrap results					
Maximum		1,001,000,000,000	61,400,000	5,500,000	2,500
Upper CI		823,000,000,000	50,500,000	4,520,000	2,100
Mean		582,000,000,000	35,700,000	3,200,000	1,500
Median		575,000,000,000	35,300,000	3,160,000	1,400
Lower CI		389,000,000,000	23,900,000	2,140,000	1,000
Minimum		326,000,000,000	20,000,000	1,790,000	800

Table 7. Estimated Columbia River eulachon mean egg and larvae density, egg and larvae production (smelt plankton outflow), and SSB for November 25, 2012 through June 22, 2013, including bootstrap generated mean and 95% confidence limit estimates of plankton outflow, numbers of spawners, and SSB in pounds and in metric tons.

Cumulative values for:		Plankton outflow	Number of spawners	SSB (pounds)	SSB (megagram)
Days Sampled	43				
n (per sample day)	6				
Mean egg density	0.40				
Mean larvae density	14.16				
Mean egg & larvae density	14.56				
Point estimate		1,759,000,000,000			
Bootstrap results					
Maximum		3,224,000,000,000	197,900,000	17,730,000	8,000
Upper CI		2,602,000,000,000	159,700,000	14,310,000	6,500
Mean		1,755,000,000,000	107,700,000	9,650,000	4,400
Median		1,732,000,000,000	106,300,000	9,520,000	4,300
Lower CI		1,034,000,000,000	63,500,000	5,690,000	2,600
Minimum		741,000,000,000	45,500,000	4,080,000	1,900

Table 8. Estimated Grays River eulachon mean egg and larvae density and mean and median egg and larvae production (smelt plankton outflow) and SSB, in pounds and in metric tons, for the period January 16, 2011 through May 14, 2011.

Cumulative values for:		Plankton outflow	Number of spawners	SSB (pounds)	SSB (megagram)
Days Sampled	13[1]				
n (per sample day)	2 to 4				
Mean egg density	0.12				
Mean larvae density	0.19				
Mean egg & larvae density	0.31				
Point estimate		133,100,000	8,200	700	0.3

[1] Two nearly consecutive days were averaged for one week, so modeled as 13 days rather than the 14 days sampled.

Table 9. Estimated Grays River eulachon mean egg and larvae density and mean and median egg and larvae production (smelt plankton outflow) and SSB, in pounds and in metric tons, for the period December 18, 2011 through May 19, 2012.

Cumulative values for:		Plankton outflow	Number of spawners	SSB (pounds)	SSB (megagram)
Days Sampled	13				
n (per sample day)	2 to 4				
Mean egg density	0.31				
Mean larvae density	1.22				
Mean egg & larvae density	1.53				
Point estimate		158,100,000	9,700	900	0.4

Table 10. Estimated Grays River eulachon mean egg and larvae density and mean and median egg and larvae production (smelt plankton outflow) and SSB in pounds and in metric tons, for the period December 23, 2012 through May 11, 2013.

Cumulative values for:		Plankton outflow	Number of spawners	SSB (pounds)	SSB (megagram)
Days Sampled	19				
n (per sample day)	2 to 4				
Mean egg density	0.66				
Mean larvae density	0.95				
Mean egg & larvae density	1.61				
Point estimate		420,900,000	25,800	2,300	1.0

Appendix A: Columbia River Discharge

Table A1. Columbia River discharge, in cubic feet per second reported for the USGS gauging station at Beaver Army Terminal, and daily discharge in cubic meters per day, January 9, 2011 through May 28, 2011. Included is river temperature measured during sampling of the Price Island/Clifton Channel transect.

Date	Discharge		Temp.
	(ft^3/sec)	(m^3/day)	(^oC)
2011/01/09	198,000	484,422,000	
2011/01/10	218,000	533,353,000	
2011/01/11	221,000	540,693,000	
2011/01/12	216,000	528,460,000	
2011/01/13	264,000	645,896,000	5°
2011/01/14	300,000	733,973,000	
2011/01/15	308,000	753,545,000	
2011/01/16	347,000	848,962,000	
2011/01/17	452,000	1,105,852,000	
2011/01/18	468,000	1,144,997,000	
2011/01/19	476,000	1,164,570,000	
2011/01/20	461,000	1,127,871,000	
2011/01/21	413,000	1,010,436,000	
2011/01/22	406,000	993,310,000	
2011/01/23	408,000	998,203,000	
2011/01/24	404,000	988,417,000	
2011/01/25	402,000	983,523,000	
2011/01/26	371,000	907,680,000	
2011/01/27	354,000	866,088,000	5°
2011/01/28	354,000	866,088,000	
2011/01/29	349,000	853,855,000	
2011/01/30	304,000	743,759,000	
2011/01/31	307,000	751,099,000	
2011/02/01	296,000	724,186,000	
2011/02/02	281,000	687,488,000	5°
2011/02/03	268,000	655,682,000	
2011/02/04	245,000	599,411,000	
2011/02/05	253,000	618,984,000	
2011/02/06	217,000	530,907,000	
2011/02/07	201,000	491,762,000	
2011/02/08	245,000	599,411,000	
2011/02/09	263,000	643,449,000	4°
2011/02/10	262,000	641,003,000	
2011/02/11	260,000	636,110,000	4°
2011/02/12	256,000	626,323,000	
2011/02/13	258,000	631,216,000	
2011/02/14	235,000	574,945,000	
2011/02/15	255,000	623,877,000	4°
2011/02/16	302,000	738,866,000	
2011/02/17	305,000	746,206,000	4°
2011/02/18	304,000	743,759,000	
2011/02/19	282,000	689,934,000	
2011/02/20	286,000	699,721,000	
2011/02/21	269,000	658,129,000	
2011/02/22	253,000	618,984,000	
2011/02/23	252,000	616,537,000	4°
2011/02/24	263,000	643,449,000	
2011/02/25	254,000	621,430,000	
2011/02/26	243,000	594,518,000	
2011/02/27	228,000	557,819,000	
2011/02/28	256,000	626,323,000	
2011/03/01	308,000	753,545,000	3°
2011/03/02	324,000	792,690,000	
2011/03/03	350,000	856,301,000	3°
2011/03/04	336,000	822,049,000	
2011/03/05	316,000	773,118,000	
2011/03/06	298,000	729,080,000	
2011/03/07	290,000	709,507,000	4°
2011/03/08	295,000	721,740,000	
2011/03/09	295,000	721,740,000	
2011/03/10	325,000	795,137,000	
2011/03/11	376,000	919,912,000	5°
2011/03/12	375,000	917,466,000	
2011/03/13	362,000	885,660,000	
2011/03/14	342,000	836,729,000	
2011/03/15	352,000	861,195,000	6°
2011/03/16	355,000	868,534,000	
2011/03/17	370,000	905,233,000	
2011/03/18	373,000	912,573,000	6°
2011/03/19	364,000	890,554,000	
2011/03/20	345,000	844,069,000	
2011/03/21	319,000	780,458,000	7°
2011/03/22	297,000	726,633,000	
2011/03/23	304,000	743,759,000	
2011/03/24	316,000	773,118,000	
2011/03/25	309,000	755,992,000	6°
2011/03/26	308,000	753,545,000	
2011/03/27	314,000	768,225,000	
2011/03/28	319,000	780,458,000	
2011/03/29	310,000	758,438,000	
2011/03/30	331,000	809,817,000	7°
2011/03/31	379,000	927,252,000	
2011/04/01	409,000	1,000,649,000	8°
2011/04/02	417,000	1,020,222,000	
2011/04/03	456,000	1,115,638,000	
2011/04/04	474,000	1,159,677,000	8°
2011/04/05	478,000	1,169,463,000	
2011/04/06	501,000	1,225,734,000	
2011/04/07	492,000	1,203,715,000	7°
2011/04/08	472,000	1,154,784,000	
2011/04/09	472,000	1,154,784,000	
2011/04/10	463,000	1,132,764,000	
2011/04/11	462,000	1,130,318,000	
2011/04/12	451,000	1,103,406,000	8°
2011/04/13	439,000	1,074,047,000	
2011/04/14	427,000	1,044,688,000	
2011/04/15	413,000	1,010,436,000	8°
2011/04/16	415,000	1,015,329,000	
2011/04/17	415,000	1,015,329,000	
2011/04/18	431,000	1,054,474,000	7°
2011/04/19	443,000	1,083,833,000	
2011/04/20	434,000	1,061,814,000	
2011/04/21	435,000	1,064,260,000	8°
2011/04/22	427,000	1,044,688,000	
2011/04/23	409,000	1,000,649,000	
2011/04/24	386,000	944,378,000	
2011/04/25	374,000	915,019,000	
2011/04/26	386,000	944,378,000	9°
2011/04/27	384,000	939,485,000	
2011/04/28	400,000	978,630,000	
2011/04/29	398,000	973,737,000	
2011/04/30	374,000	915,019,000	
2011/05/01	354,000	866,088,000	
2011/05/02	364,000	890,554,000	
2011/05/03	354,000	866,088,000	
2011/05/04	355,000	868,534,000	10°
2011/05/05	356,000	870,981,000	
2011/05/06	341,000	834,282,000	
2011/05/07	340,000	831,836,000	
2011/05/08	332,000	812,263,000	
2011/05/09	355,000	868,534,000	
2011/05/10	372,000	910,126,000	
2011/05/11	386,000	944,378,000	10°
2011/05/12	373,000	912,573,000	
2011/05/13	391,000	956,611,000	
2011/05/14	431,000	1,054,474,000	
2011/05/15	460,000	1,125,425,000	
2011/05/16	501,000	1,225,734,000	11°
2011/05/17	538,000	1,316,258,000	
2011/05/18	558,000	1,365,189,000	
2011/05/19	569,000	1,392,102,000	
2011/05/20	568,000	1,389,655,000	
2011/05/21	571,000	1,396,995,000	
2011/05/22	571,000	1,396,995,000	
2011/05/23	571,000	1,396,995,000	
2011/05/24	578,000	1,414,121,000	
2011/05/25	576,000	1,409,228,000	
2011/05/26	582,000	1,423,907,000	12°
2011/05/27	575,000	1,406,781,000	
2011/05/28	582,000	1,423,907,000	

Table A2. Columbia River discharge, in cubic feet per second reported for the USGS gauging station at Beaver Army Terminal, and daily discharge in cubic meters per day, December 4, 2011 through May 26, 2012. Included is river temperature measured during sampling of the Price Island/Clifton Channel transect.

Date	Discharge		Temp.	Date	Discharge		Temp.	Date	Discharge		Temp.
	(ft^3/sec)	(m^3/day)	(^oC)		(ft^3/sec)	(m^3/day)	(^oC)		(ft^3/sec)	(m^3/day)	(^oC)
2011/12/04	195,000	477,082,000		2012/01/21	471,000	1,152,337,000		2012/03/09	261,000	638,556,000	
2011/12/05	195,000	477,082,000		2012/01/22	482,000	1,179,249,000		2012/03/10	247,000	604,304,000	
2011/12/06	205,000	501,548,000	8°	2012/01/23	452,000	1,105,852,000	6°	2012/03/11	227,000	555,373,000	
2011/12/07	198,000	484,422,000		2012/01/24	425,000	1,039,795,000		2012/03/12	248,000	606,751,000	
2011/12/08	193,000	472,189,000		2012/01/25	418,000	1,022,669,000		2012/03/13	308,000	753,545,000	
2011/12/09	193,000	472,189,000		2012/01/26	412,000	1,007,989,000		2012/03/14	354,000	866,088,000	6°
2011/12/10	182,000	445,277,000		2012/01/27	419,000	1,025,115,000		2012/03/15	367,000	897,893,000	
2011/12/11	182,000	445,277,000		2012/01/28	406,000	993,310,000		2012/03/16	429,000	1,049,581,000	7°
2011/12/12	193,000	472,189,000		2012/01/29	370,000	905,233,000		2012/03/17	452,000	1,105,852,000	
2011/12/13	186,000	455,063,000		2012/01/30	360,000	880,767,000		2012/03/18	446,000	1,091,173,000	
2011/12/14	189,000	462,403,000		2012/01/31	359,000	878,321,000	6°	2012/03/19	428,000	1,047,134,000	
2011/12/15	200,000	489,315,000		2012/02/01	340,000	831,836,000		2012/03/20	405,000	990,863,000	7°
2011/12/16	184,000	450,170,000	6°	2012/02/02	316,000	773,118,000		2012/03/21	394,000	963,951,000	
2011/12/17	168,000	411,025,000		2012/02/03	296,000	724,186,000		2012/03/22	423,000	1,034,901,000	7°
2011/12/18	173,000	423,258,000		2012/02/04	271,000	663,022,000		2012/03/23	426,000	1,042,241,000	
2011/12/19	172,000	420,811,000		2012/02/05	252,000	616,537,000		2012/03/24	424,000	1,037,348,000	
2011/12/20	164,000	401,238,000		2012/02/06	241,000	589,625,000	6°	2012/03/25	432,000	1,056,921,000	
2011/12/21	174,000	425,704,000	6°	2012/02/07	226,000	552,926,000		2012/03/26	426,000	1,042,241,000	
2011/12/22	175,000	428,151,000		2012/02/08	232,000	567,606,000		2012/03/27	402,000	983,523,000	8°
2011/12/23	163,000	398,792,000		2012/02/09	229,000	560,266,000		2012/03/28	399,000	976,184,000	
2011/12/24	160,000	391,452,000		2012/02/10	205,000	501,548,000	5°	2012/03/29	417,000	1,020,222,000	8°
2011/12/25	151,000	369,433,000		2012/02/11	229,000	560,266,000		2012/03/30	479,000	1,171,910,000	
2011/12/26	171,000	418,364,000		2012/02/12	216,000	528,460,000		2012/03/31	561,000	1,372,529,000	
2011/12/27	171,000	418,364,000		2012/02/13	217,000	530,907,000		2012/04/01	581,000	1,421,460,000	
2011/12/28	191,000	467,296,000		2012/02/14	220,000	538,247,000	5°	2012/04/02	581,000	1,421,460,000	
2011/12/29	289,000	707,060,000		2012/02/15	221,000	540,693,000		2012/04/03	574,000	1,404,334,000	
2011/12/30	342,000	836,729,000	6°	2012/02/16	224,000	548,033,000		2012/04/04	568,000	1,389,655,000	8°
2011/12/31	387,000	946,825,000		2012/02/17	219,000	535,800,000	6°	2012/04/05	535,000	1,308,918,000	8°
2012/01/01	369,000	902,786,000		2012/02/18	196,000	479,529,000		2012/04/06	490,000	1,198,822,000	
2012/01/02	330,000	807,370,000		2012/02/19	215,000	526,014,000		2012/04/07	487,000	1,191,482,000	
2012/01/03	291,000	711,953,000		2012/02/20	211,000	516,227,000		2012/04/08	481,000	1,176,803,000	
2012/01/04	287,000	702,167,000		2012/02/21	221,000	540,693,000	6°	2012/04/09	454,000	1,110,745,000	
2012/01/05	290,000	709,507,000	7°	2012/02/22	266,000	650,789,000		2012/04/10	414,000	1,012,882,000	
2012/01/06	269,000	658,129,000		2012/02/23	332,000	812,263,000	6°	2012/04/11	395,000	966,397,000	9°
2012/01/07	255,000	623,877,000		2012/02/24	333,000	814,710,000		2012/04/12	416,000	1,017,775,000	
2012/01/08	226,000	552,926,000		2012/02/25	300,000	733,973,000		2012/04/13	407,000	995,756,000	9°
2012/01/09	211,000	516,227,000	6°	2012/02/26	291,000	711,953,000		2012/04/14	414,000	1,012,882,000	
2012/01/10	223,000	545,586,000		2012/02/27	291,000	711,953,000		2012/04/15	404,000	988,417,000	
2012/01/11	234,000	572,499,000		2012/02/28	284,000	694,827,000	6°	2012/04/16	391,000	956,611,000	
2012/01/12	228,000	557,819,000		2012/02/29	286,000	699,721,000		2012/04/17	400,000	978,630,000	10°
2012/01/13	211,000	516,227,000		2012/03/01	269,000	658,129,000		2012/04/18	411,000	1,005,543,000	
2012/01/14	200,000	489,315,000		2012/03/02	269,000	658,129,000	5°	2012/04/19	429,000	1,049,581,000	
2012/01/15	199,000	486,869,000		2012/03/03	272,000	665,469,000		2012/04/20	443,000	1,083,833,000	
2012/01/16	203,000	496,655,000		2012/03/04	264,000	645,896,000		2012/04/21	457,000	1,118,085,000	
2012/01/17	194,000	474,636,000		2012/03/05	252,000	616,537,000	6°	2012/04/22	449,000	1,098,512,000	
2012/01/18	215,000	526,014,000		2012/03/06	259,000	633,663,000		2012/04/23	462,000	1,130,318,000	
2012/01/19	311,000	760,885,000	4°	2012/03/07	275,000	672,808,000		2012/04/24	484,000	1,184,143,000	
2012/01/20	435,000	1,064,260,000		2012/03/08	265,000	648,343,000	7°	2012/04/25	486,000	1,189,036,000	

Table A2 (cont.). Columbia River discharge, in cubic feet per second reported for the USGS gauging station at Beaver Army Terminal, and daily discharge in cubic meters per day, December 4, 2011 through May 26, 2012. Included is river temperature measured during sampling of the Price Island/Clifton Channel transect.

Date	Discharge		Temp.	Date	Discharge		Temp.	Date	Discharge		Temp.
	(ft^3/sec)	(m^3/day)	(^{o}C)		(ft^3/sec)	(m^3/day)	(^{o}C)		(ft^3/sec)	(m^3/day)	(^{o}C)
2012/04/26	523,000	1,279,559,000	11^o	2012/05/07	514,000	1,257,540,000	13^o	2012/05/18	423,000	1,034,901,000	
2012/04/27	556,000	1,360,296,000		2012/05/08	482,000	1,179,249,000		2012/05/19	445,000	1,088,726,000	
2012/04/28	552,000	1,350,510,000		2012/05/09	460,000	1,125,425,000		2012/05/20	449,000	1,098,512,000	
2012/04/29	548,000	1,340,723,000		2012/05/10	451,000	1,103,406,000		2012/05/21	442,000	1,081,386,000	14^o
2012/04/30	534,000	1,306,471,000		2012/05/11	445,000	1,088,726,000		2012/05/22	440,000	1,076,493,000	
2012/05/01	526,000	1,286,899,000	12^o	2012/05/12	435,000	1,064,260,000		2012/05/23	447,000	1,093,619,000	
2012/05/02	526,000	1,286,899,000	12^o	2012/05/13	427,000	1,044,688,000		2012/05/24	460,000	1,125,425,000	
2012/05/03	531,000	1,299,132,000		2012/05/14	397,000	971,291,000		2012/05/25	461,000	1,127,871,000	
2012/05/04	547,000	1,338,277,000		2012/05/15	394,000	963,951,000	14^o	2012/05/26	458,000	1,120,532,000	
2012/05/05	548,000	1,340,723,000		2012/05/16	410,000	1,003,096,000					
2012/05/06	529,000	1,294,238,000		2012/05/17	409,000	1,000,649,000					

Table A3. Columbia River discharge, in cubic feet per second reported for the USGS gauging station at Beaver Army Terminal, and daily discharge in cubic meters per day, November 25, 2012 through June 22, 2013. Included is river temperature measured during sampling of the Price Island/Clifton Channel transect.

Date	Discharge		Temp.
	(ft^3/sec)	(m^3/day)	(°C)
2012/11/25	352,000	861,195,000	
2012/11/26	337,000	824,496,000	
2012/11/27	323,000	790,244,000	
2012/11/28	303,000	741,312,000	10°
2012/11/29	284,000	694,827,000	
2012/11/30	277,000	677,701,000	
2012/12/01	296,000	724,186,000	
2012/12/02	330,000	807,370,000	
2012/12/03	358,000	875,874,000	
2012/12/04	376,000	919,912,000	
2012/12/05	413,000	1,010,436,000	
2012/12/06	422,000	1,032,455,000	
2012/12/07	416,000	1,017,775,000	
2012/12/08	407,000	995,756,000	
2012/12/09	395,000	966,397,000	
2012/12/10	366,000	895,447,000	9°
2012/12/11	343,000	839,175,000	
2012/12/12	339,000	829,389,000	
2012/12/13	343,000	839,175,000	
2012/12/14	342,000	836,729,000	
2012/12/15	331,000	809,817,000	
2012/12/16	316,000	773,118,000	
2012/12/17	331,000	809,817,000	
2012/12/18	373,000	912,573,000	
2012/12/19	373,000	912,573,000	
2012/12/20	365,000	893,000,000	
2012/12/21	364,000	890,554,000	7°
2012/12/22	354,000	866,088,000	
2012/12/23	339,000	829,389,000	
2012/12/24	317,000	775,564,000	
2012/12/25	300,000	733,973,000	
2012/12/26	294,000	719,293,000	
2012/12/27	302,000	738,866,000	7°
2012/12/28	300,000	733,973,000	
2012/12/29	293,000	716,847,000	
2012/12/30	301,000	736,419,000	
2012/12/31	304,000	743,759,000	
2013/01/01	293,000	716,847,000	
2013/01/02	286,000	699,721,000	
2013/01/03	280,000	685,041,000	
2013/01/04	263,000	643,449,000	5°
2013/01/05	254,000	621,430,000	
2013/01/06	237,000	579,838,000	
2013/01/07	220,000	538,247,000	
2013/01/08	229,000	560,266,000	5°
2013/01/09	266,000	650,789,000	
2013/01/10	295,000	721,740,000	
2013/01/11	293,000	716,847,000	
2013/01/12	282,000	689,934,000	
2013/01/13	276,000	675,255,000	
2013/01/14	271,000	663,022,000	
2013/01/15	261,000	638,556,000	
2013/01/16	268,000	655,682,000	
2013/01/17	267,000	653,236,000	
2013/01/18	248,000	606,751,000	4°
2013/01/19	237,000	579,838,000	
2013/01/20	237,000	579,838,000	
2013/01/21	230,000	562,712,000	
2013/01/22	245,000	599,411,000	4°
2013/01/23	249,000	609,197,000	
2013/01/24	241,000	589,625,000	
2013/01/25	234,000	572,499,000	
2013/01/26	239,000	584,732,000	
2013/01/27	225,000	550,480,000	
2013/01/28	223,000	545,586,000	
2013/01/29	250,000	611,644,000	
2013/01/30	277,000	677,701,000	
2013/01/31	306,000	748,652,000	
2013/02/01	312,000	763,332,000	5°
2013/02/02	269,000	658,129,000	
2013/02/03	255,000	623,877,000	
2013/02/04	236,000	577,392,000	
2013/02/05	223,000	545,586,000	
2013/02/06	226,000	552,926,000	6°
2013/02/07	225,000	550,480,000	
2013/02/08	226,000	552,926,000	
2013/02/09	221,000	540,693,000	
2013/02/10	217,000	530,907,000	
2013/02/11	212,000	518,674,000	
2013/02/12	213,000	521,121,000	
2013/02/13	212,000	518,674,000	
2013/02/14	214,000	523,567,000	
2013/02/15	209,000	511,334,000	6°
2013/02/16	205,000	501,548,000	
2013/02/17	209,000	511,334,000	
2013/02/18	206,000	503,995,000	
2013/02/19	205,000	501,548,000	6°
2013/02/20	204,000	499,101,000	
2013/02/21	201,000	491,762,000	
2013/02/22	185,000	452,616,000	6°
2013/02/23	211,000	516,227,000	
2013/02/24	207,000	506,441,000	
2013/02/25	193,000	472,189,000	6°
2013/02/26	201,000	491,762,000	
2013/02/27	190,000	464,849,000	6°
2013/02/28	194,000	474,636,000	
2013/03/01	208,000	508,888,000	
2013/03/02	207,000	506,441,000	
2013/03/03	209,000	511,334,000	
2013/03/04	200,000	489,315,000	
2013/03/05	193,000	472,189,000	
2013/03/06	196,000	479,529,000	7°
2013/03/07	205,000	501,548,000	7°
2013/03/08	200,000	489,315,000	
2013/03/09	200,000	489,315,000	
2013/03/10	181,000	442,830,000	
2013/03/11	180,000	440,384,000	
2013/03/12	168,000	411,025,000	7°
2013/03/13	171,000	418,364,000	8°
2013/03/14	156,000	381,666,000	
2013/03/15	174,000	425,704,000	
2013/03/16	176,000	430,597,000	
2013/03/17	203,000	496,655,000	
2013/03/18	203,000	496,655,000	
2013/03/19	197,000	481,975,000	8°
2013/03/20	191,000	467,296,000	
2013/03/21	244,000	596,964,000	8°
2013/03/22	238,000	582,285,000	
2013/03/23	230,000	562,712,000	
2013/03/24	217,000	530,907,000	
2013/03/25	202,000	494,208,000	9°
2013/03/26	200,000	489,315,000	
2013/03/27	193,000	472,189,000	
2013/03/28	199,000	486,869,000	10°
2013/03/29	199,000	486,869,000	
2013/03/30	205,000	501,548,000	
2013/03/31	228,000	557,819,000	
2013/04/01	251,000	614,090,000	
2013/04/02	243,000	594,518,000	10°
2013/04/03	239,000	584,732,000	
2013/04/04	246,000	601,858,000	
2013/04/05	285,000	697,274,000	10°
2013/04/06	308,000	753,545,000	
2013/04/07	340,000	831,836,000	
2013/04/08	375,000	917,466,000	
2013/04/09	388,000	949,271,000	10°
2013/04/10	401,000	981,077,000	
2013/04/11	395,000	966,397,000	11°
2013/04/12	397,000	971,291,000	
2013/04/13	391,000	956,611,000	
2013/04/14	362,000	885,660,000	
2013/04/15	362,000	885,660,000	
2013/04/16	377,000	922,359,000	
2013/04/17	369,000	902,786,000	10°

Table A3 (cont.). Columbia River discharge, in cubic feet per second reported for the USGS gauging station at Beaver Army Terminal, and daily discharge in cubic meters per day, November 25, 2012 through June 22, 2013. Included is river temperature measured during sampling of the Price Island/Clifton Channel transect.

Date	Discharge (ft^3/sec)	Discharge (m^3/day)	Temp. (°C)
2013/04/18	348,000	851,408,000	
2013/04/19	324,000	792,690,000	11°
2013/04/20	311,000	760,885,000	
2013/04/21	325,000	795,137,000	
2013/04/22	339,000	829,389,000	11°
2013/04/23	338,000	826,943,000	
2013/04/24	309,000	755,992,000	
2013/04/25	288,000	704,614,000	12°
2013/04/26	283,000	692,381,000	
2013/04/27	281,000	687,488,000	
2013/04/28	294,000	719,293,000	
2013/04/29	294,000	719,293,000	
2013/04/30	315,000	770,671,000	12°
2013/05/01	328,000	802,477,000	
2013/05/02	316,000	773,118,000	12°
2013/05/03	299,000	731,526,000	
2013/05/04	302,000	738,866,000	
2013/05/05	295,000	721,740,000	
2013/05/06	277,000	677,701,000	15°
2013/05/07	295,000	721,740,000	
2013/05/08	315,000	770,671,000	
2013/05/09	328,000	802,477,000	15°
2013/05/10	342,000	836,729,000	
2013/05/11	373,000	912,573,000	
2013/05/12	405,000	990,863,000	
2013/05/13	405,000	990,863,000	
2013/05/14	400,000	978,630,000	
2013/05/15	404,000	988,417,000	
2013/05/16	394,000	963,951,000	
2013/05/17	385,000	941,932,000	15°
2013/05/18	373,000	912,573,000	
2013/05/19	378,000	924,806,000	
2013/05/20	376,000	919,912,000	
2013/05/21	369,000	902,786,000	15°
2013/05/22	355,000	868,534,000	
2013/05/23	365,000	893,000,000	14°
2013/05/24	390,000	954,164,000	
2013/05/25	382,000	934,592,000	
2013/05/26	373,000	912,573,000	
2013/05/27	370,000	905,233,000	
2013/05/28	380,000	929,699,000	
2013/05/29	385,000	941,932,000	
2013/05/30	379,000	927,252,000	14°
2013/05/31	367,000	897,893,000	
2013/06/01	353,000	863,641,000	
2013/06/02	317,000	775,564,000	
2013/06/03	300,000	733,973,000	
2013/06/04	312,000	763,332,000	
2013/06/05	295,000	721,740,000	
2013/06/06	297,000	726,633,000	17°
2013/06/07	296,000	724,186,000	
2013/06/08	288,000	704,614,000	
2013/06/09	281,000	687,488,000	
2013/06/10	285,000	697,274,000	
2013/06/11	278,000	680,148,000	
2013/06/12	271,000	663,022,000	
2013/06/13	286,000	699,721,000	17°
2013/06/14	287,000	702,167,000	
2013/06/15	280,000	685,041,000	
2013/06/16	276,000	675,255,000	
2013/06/17	242,000	592,071,000	
2013/06/18	243,000	594,518,000	
2013/06/19	250,000	611,644,000	
2013/06/20	250,000	611,644,000	
2013/06/21	256,000	626,323,000	19°
2013/06/22	274,000	670,362,000	

Appendix B: Daily Mainstem Columbia River Plankton Net Sampling Effort

Table B1. Daily plankton net sampling effort to collect eulachon eggs and larvae, in minutes and water volume (cubic meters) sampled, for the six sites situated along the Columbia River Price Island/Clifton Channel transect, January 13, 2011 through May 26, 2011.

Sample		Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
Week	Date	Min.	Volume	Min.	Volume	Min.	Volume	Min.	Volume	Min.	Volume	Min.	Volume
1	2011-01-13	1:57	19.4	2:31	24.3	3:13	36.9	2:18	17.4	3:15	49.4	2:44	16.8
2	2011-01-27	1:26	18.5	1:36	19.2	1:59	30.8	1:20	11.7	4:08	69.7	2:47	24.5
3	2011-02-02	2:35	16.8	2:43	18.6	2:45	28.0	1:51	13.7	2:53	33.3	4:30	25.9
4	2011-02-09	2:03	18.1	2:36	21.7	2:27	28.6	1:50	12.6	3:24	54.5	4:03	29.2
	2011-02-11	4:01	42.7	5:16	43.6	4:53	53.4	3:16	23.4	3:30	56.4	5:07	8.9
5	2011-02-15	2:45	22.5	4:42	43.0	4:43	51.8	3:16	26.9	2:53	41.2	5:10	48.4
	2011-02-17	3:16	41.9	5:04	64.2	5:57	93.8	3:00	30.1	7:20	141.3	4:47	62.7
6	2011-02-23	4:00	51.8	5:06	55.3	5:08	67.4	3:38	33.0	5:10	78.4	4:50	51.9
7	2011-03-01	2:51	43.5	4:35	44.5	4:45	61.5	3:36	28.7	3:32	59.0	4:35	45.0
	2011-03-03	4:05	46.6	5:05	63.8	5:11	78.7	3:58	38.8	5:01	103.3	4:29	54.7
8	2011-03-07	5:09	52.2	5:22	52.1	4:49	56.9	2:46	23.5	5:15	67.7	4:55	50.8
	2011-03-11	4:37	62.8	5:08	70.3	5:40	79.1	3:37	34.7	4:05	79.8	6:00	62.3
9	2011-03-15	4:02	45.7	4:44	57.1	5:00	67.0	3:53	36.5	4:09	76.6	4:19	45.4
	2011-03-18	4:27	49.3	4:49	63.4	4:54	77.9	3:52	44.2	3:56	73.4	4:19	45.9
10	2011-03-21	4:19	36.1	4:57	39.7	4:31	52.3	5:07	44.7	4:54	58.4	4:37	35.3
	2011-03-25	4:04	45.0	4:43	53.8	4:54	62.3	3:57	37.2	4:05	72.7	4:02	36.3
11	2011-03-30	3:41	36.9	4:32	49.6	4:32	62.6	4:10	39.8	4:18	80.1	3:58	36.9
	2011-04-01	3:28	40.4	4:30	46.1	4:47	49.2	4:14	39.6	4:56	68.7	4:03	40.3
12	2011-04-04	4:07	50.9	4:48	60.8	4:52	55.1	4:58	46.1	5:04	65.6	4:55	47.6
	2011-04-08	3:41	61.2	3:50	64.6	3:02	56.4	2:15	28.7	4:05	100.7	3:04	35.2
13	2011-04-12	4:06	47.9	5:10	53.9	4:50	66.4	4:13	29.3	3:40	41.1	4:23	24.7
	2011-04-15	3:58	63.8	4:24	58.1	4:40	71.9	4:40	45.4	2:55	38.0	3:59	28.9
14	2011-04-18	5:24	90.0	5:13	73.9	5:29	77.0	5:06	31.4	5:05	48.2	5:00	30.4
	2011-04-21	4:06	47.4	5:55	62.5	6:09	110.7	4:03	51.3	4:56	107.3	4:15	49.6
15	2011-04-26	4:04	56.4	4:24	57.2	4:32	55.5	3:57	34.1	2:52	44.0	4:52	33.6
16	2011-05-04	3:31	47.8	4:07	49.1	4:09	45.3	3:35	28.7	2:33	25.4	3:59	19.2
17	2011-05-11	5:25	75.2	5:54	59.5	5:17	62.8	4:35	22.4	5:18	70.0	4:43	40.2
18	2011-05-16	4:53	76.3	4:51	57.5	5:24	62.3	4:57	42.5	4:35	79.3	5:37	58.3
19	2011-05-26	5:03	79.8	5:19	71.8	5:20	71.5	4:49	54.5	3:51	75.3	4:56	50.6

Table B2. Daily plankton net sampling effort to collect eulachon eggs and larvae, in minutes and water volume (cubic meters) sampled, for the six sites situated along the Columbia River Price Island/Clifton Channel transect, December 6, 2011 through May 21, 2012.

Sample		Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
Week	Date	Min.	Volume	Min.	Volume	Min.	Volume	Min.	Volume	Min.	Volume	Min.	Volume
1	2011-12-06	3:21	29.2	4:07	30.6	4:29	39.8	3:58	26.1	2:56	44.4	4:25	35.8
2	2011-12-16	3:44	31.8	4:19	34.3	4:37	41.1	3:39	22.8	2:47	34.1	4:25	29.6
3	2011-12-21	3:28	30.1	4:10	36.5	4:20	45.7	3:27	17.6	3:00	46.6	4:03	25.8
4	2011-12-30	4:03	55.5	4:53	56.6	4:50	60.9	3:43	31.4	3:07	56.4	3:25	30.1
5	2012-01-05	3:23	34.1	3:08	32.3	3:45	39.5	2:54	24.5	1:37	31.4	3:11	19.5
6	2012-01-09	3:22	16.0	3:30	24.7	3:35	33.6	3:28	29.2	1:07	20.0	3:31	23.6
7	2012-01-19	3:26	37.0	3:48	46.5	3:55	57.3	3:25	35.1	1:58	41.8	3:25	28.8
8	2012-01-23	3:23	44.3	3:17	39.5	3:15	47.6	3:04	34.2	2:28	55.5	3:38	40.9
9	2012-01-31	3:45	46.0	3:50	27.1	3:47	48.1	4:15	32.0	4:13	79.6	3:39	34.5
10	2012-02-06	3:36	34.9	4:27	43.5	4:35	57.9	4:13	38.7	3:15	52.3	4:35	37.2
11	2012-02-14	3:30	33.4	4:58	44.4	4:47	50.9	3:52	28.3	3:27	52.2	4:02	24.3
	2012-02-17	3:49	39.2	4:40	37.8	4:47	53.6	3:50	27.8	2:59	41.5	4:00	23.2
12	2012-02-21	3:55	19.2	4:22	29.8	4:26	38.7	4:46	39.7	2:46	35.8	4:35	28.3
	2012-02-23	5:00	23.1	4:42	33.3	4:37	45.9	4:18	33.3	3:13	44.2	3:36	13.5
13	2012-02-28	4:01	40.2	4:47	45.0	5:06	54.7	3:31	26.2	3:51	61.7	4:20	35.3
	2012-03-02	3:53	26.2	4:19	29.2	4:22	38.1	3:46	20.9	2:54	31.9	4:08	18.8
14	2012-03-05	4:00	40.0	4:17	44.6	4:28	53.4	4:10	36.8	3:29	58.7	4:16	26.1
	2012-03-08	3:46	24.6	4:29	34.3	4:33	47.1	3:52	27.8	2:50	36.4	3:47	21.2
15	2012-03-14	3:40	57.3	4:40	69.1	4:39	59.8	4:30	40.6	5:42	125.2	4:24	50.1
	2012-03-16	2:21	28.5	3:22	36.2	3:20	42.0	2:19	20.0	4:23	71.5	2:50	28.0
16	2012-03-20	2:40	33.1	3:31	41.6	3:46	51.9	2:46	29.9	4:46	88.9	2:27	20.9
	2012-03-22	3:48	54.3	3:44	54.5	3:17	51.9	3:22	42.5	4:57	96.2	3:23	42.2
17	2012-03-27	2:49	36.2	3:42	50.2	3:31	58.4	2:30	19.1	5:04	91.2	2:38	24.1
	2012-03-29	2:11	25.5	3:00	37.6	3:08	42.4	2:03	21.7	4:18	62.2	2:07	19.0
18	2012-04-04	2:08	32.9	2:44	40.7	3:19	57.7	1:30	18.7	4:49	95.4	2:02	21.7
	2012-04-05	1:48	24.9	2:30	32.8	2:31	40.2	1:44	22.1	3:11	57.9	1:49	15.8
19	2012-04-11	2:13	28.2	3:31	44.1	3:43	56.9	2:33	24.7	4:45	90.7	2:42	27.8
	2012-04-13	2:24	33.0	3:33	40.1	3:22	50.9	2:02	18.7	4:18	82.2	2:42	23.2
20	2012-04-17	2:48	30.3	3:19	34.7	3:21	42.4	2:35	23.5	3:54	65.7	2:44	26.4
21	2012-04-26	3:12	49.2	3:51	58.0	3:58	44.4	3:05	34.7	5:24	103.0	3:11	29.9
22	2012-05-02	3:18	36.2	3:27	57.2	3:14	53.1	3:29	45.3	4:33	79.7	3:48	30.6
23	2012-05-07	3:01	34.4	3:42	55.1	4:27	82.9	2:48	27.1	5:07	98.8	2:50	29.8
24	2012-05-15	2:40	27.0	3:16	31.0	3:12	38.5	2:28	18.2	3:25	51.7	2:39	18.1
25	2012-05-21	N/A	40.9	N/A	40.6	N/A	54.6	N/A	29.4	N/A	65.0	N/A	28.7

Table B3. Daily plankton net sampling effort to collect eulachon eggs and larvae, in minutes and water volume (cubic meters) sampled, for the six sites situated along the Columbia River Price Island/Clifton Channel transect, November 28, 2012 through June 21, 2013.

Sample		Site 1		Site 2		Site 3		Site 4		Site 5		Site 6	
Week	Date	Min.	Volume	Min.	Volume	Min.	Volume	Min.	Volume	Min.	Volume	Min.	Volume
1	2012-11-28	4:49	51.2	4:29	52.6	4:26	52.1	4:50	47.4	4:30	74.0	4:34	47.5
2	2012-12-10	3:09	45.6	4:40	64.4	5:05	82.4	3:16	37.2	5:00	113.3	4:15	41.6
3	2012-12-21	4:30	57.1	4:32	61.4	4:55	78.1	4:56	53.5	5:03	100.5	4:26	49.9
4	2012-12-27	5:26	31.1	4:41	38.1	4:44	49.5	4:03	30.9	3:35	54.5	3:44	19.3
5	2013-01-04	4:02	48.0	4:44	48.5	5:12	57.9	4:09	37.0	3:58	72.1	4:07	34.4
6	2013-01-08	4:53	71.3	5:06	66.9	5:34	71.8	4:03	32.0	3:02	31.4	4:18	10.7
7	2013-01-18	4:00	41.3	5:05	56.3	5:04	59.7	4:17	28.5	4:14	77.9	3:58	26.3
8	2013-01-22	4:17	42.2	5:11	45.9	4:54	56.4	4:40	41.2	3:55	64.4	4:32	28.9
9	2013-02-01	4:56	71.7	5:22	70.3	5:20	76.6	4:28	39.8	5:14	108.0	4:51	46.1
10	2013-02-06	4:05	40.0	4:41	49.5	4:47	53.5	3:59	33.1	3:56	68.0	3:43	27.7
11	2013-02-15	3:32	43.3	3:56	34.2	3:48	36.6	3:16	16.7	3:18	32.7	4:21	14.8
12	2013-02-19	4:09	24.2	5:51	34.4	5:25	38.6	3:44	20.6	3:05	36.4	3:55	16.8
	2013-02-22	4:08	46.1	4:51	45.9	4:36	46.0	4:23	29.3	2:57	24.8	4:41	14.3
13	2013-02-25	4:02	51.2	4:51	50.9	4:38	58.8	4:09	36.2	3:56	68.5	4:26	36.1
	2013-02-27	3:54	28.2	4:37	37.8	4:30	52.4	4:02	34.9	3:10	42.1	4:08	23.8
14	2013-03-06	4:15	35.7	5:01	49.2	4:53	46.2	4:00	31.9	3:47	59.7	4:21	34.9
	2013-03-07	4:01	36.4	5:55	49.7	4:35	44.1	4:07	34.8	3:33	52.9	4:01	21.9
15	2013-03-12	4:10	36.1	5:04	44.8	4:58	59.5	4:10	33.0	3:59	60.2	4:36	31.9
	2013-03-13	3:55	32.2	4:56	40.6	4:43	51.4	4:36	36.9	3:49	49.5	4:12	23.2
16	2013-03-19	3:50	26.0	4:32	33.7	4:33	34.1	4:31	25.2	3:18	45.7	4:16	26.0
	2013-03-21	4:27	31.7	4:43	34.8	4:40	40.9	4:43	35.5	4:15	72.0	4:20	28.0
17	2013-03-25	4:00	35.3	4:38	37.8	4:55	45.7	4:24	33.3	3:36	51.2	4:29	29.1
	2013-03-28	3:55	35.0	4:51	43.3	4:32	46.0	4:08	29.3	3:34	56.1	3:44	20.2
18	2013-04-02	4:03	26.7	5:00	28.4	4:33	35.9	3:58	19.2	4:07	62.6	4:05	22.3
	2013-04-05	4:37	39.6	5:13	34.5	5:08	46.4	4:11	13.5	5:07	85.2	4:07	27.6
19	2013-04-09	3:20	32.9	3:47	34.7	3:52	50.1	3:23	28.5	2:18	50.8	3:45	39.8
	2013-04-11	3:30	47.1	3:36	42.7	3:35	55.9	2:39	29.0	5:24	111.3	2:27	22.0
20	2013-04-17	3:07	36.4	4:07	46.0	4:30	59.4	3:19	29.5	4:30	94.5	4:02	34.5
	2013-04-19	3:00	34.2	2:38	29.2	3:07	35.2	3:07	29.3	4:30	83.4	3:05	23.4
21	2013-04-22	3:05	39.0	3:13	38.1	3:39	45.9	2:47	20.5	4:37	84.0	3:29	26.6
	2013-04-25	2:02	11.5	3:09	25.2	3:00	32.4	2:33	24.7	3:46	52.7	2:47	16.6
22	2013-04-30	2:36	26.2	3:17	30.5	3:14	39.4	2:49	24.3	5:38	108.8	2:35	21.5
	2013-05-02	1:43	18.6	2:44	32.3	2:56	37.2	1:41	15.9	4:03	77.3	1:41	10.0
23	2013-05-06	1:56	19.3	2:40	25.9	2:37	29.3	1:46	11.4	3:56	61.6	2:08	11.9
	2013-05-09	2:06	24.4	2:41	34.2	2:55	40.1	2:05	16.7	3:11	27.1	2:55	15.1
24	2013-05-16	1:49	22.2	2:43	34.6	2:40	37.7	2:08	20.9	4:59	97.5	2:10	19.7
	2013-05-17	2:03	24.1	2:57	33.4	3:08	42.0	1:55	17.2	4:54	93.1	2:15	16.6
25	2013-05-21	2:04	32.9	2:42	35.6	2:50	39.0	2:08	19.6	3:50	54.4	1:41	8.6
	2013-05-23	2:05	29.0	3:00	36.7	2:55	44.7	1:50	19.2	5:05	95.8	2:10	18.4
26	2013-05-30	1:25	18.9	2:46	41.3	2:47	44.1	1:57	26.7	5:26	114.4	2:03	22.7
27	2013-06-06	4:07	47.4	3:58	43.6	4:45	58.1	4:06	38.1	4:31	79.9	3:10	24.4
28	2013-06-13	4:23	54.4	4:00	51.6	4:08	56.5	4:12	39.5	3:48	79.9	3:44	26.4
29	2013-06-21	4:12	47.3	4:20	46.9	5:04	57.7	4:18	33.0	5:00	82.1	4:22	23.3

Appendix C: Lab Counts of Mainstem Columbia River Eulachon Eggs and Larvae

Table C1. Daily numbers of eulachon eggs and larvae collected during plankton net sampling of the six sites along the Columbia River Price Island/Clifton Channel transect, January 13, 2011 through May 26, 2011.

Sample		Site 1		Site 2		Site 3		Site 4		Site 5		Site 6		Totals	
Week	Date	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae
1	2011-01-13	0	4	0	7	0	2	0	1	5	11	0	72	5	97
2	2011-01-27	0	10	1	6	1	9	1	4	11	20	1	302	15	351
3	2011-02-02	0	3	0	22	2	30	1	8	16	26	1	202	20	291
4	2011-02-09	0	7	1	18	3	29	5	19	50	51	0	123	59	247
	2011-02-11	1	26	5	26	20	42	1	24	28	50	0	94	55	262
5	2011-02-15	0	2	10	62	20	38	32	16	21	19	1	267	84	404
	2011-02-17	10	6	66	73	82	92	92	23	268	84	44	897	562	1,175
6	2011-02-23	16	32	65	129	246	33	272	25	869	26	52	131	1,520	376
7	2011-03-01	11	8	91	17	206	36	176	13	1,847	169	25	221	2,356	464
	2011-03-03	147	55	478	78	718	144	1,867	111	1,654	243	111	223	4,975	854
8	2011-03-07	20	30	35	121	82	127	31	147	739	373	29	214	936	1,012
	2011-03-11	33	693	200	1,071	204	1,175	173	793	728	3,624	28	3,743	1,366	11,099
9	2011-03-15	13	549	50	910	75	1,061	227	817	168	2,036	12	1,296	545	6,669
	2011-03-18	71	829	114	646	81	1,162	102	910	265	958	50	1,745	683	6,250
10	2011-03-21	0	335	32	497	19	344	92	954	180	457	5	219	328	2,806
	2011-03-25	19	247	22	417	36	538	91	383	278	813	13	370	459	2,768
11	2011-03-30	5	107	13	324	21	261	144	495	171	711	23	309	377	2,207
	2011-04-01	4	267	50	351	24	195	29	283	443	448	32	561	582	2,105
12	2011-04-04	6	125	41	238	23	170	85	242	157	210	30	526	342	1,511
	2011-04-08	61	135	24	83	25	93	21	51	121	336	18	357	270	1,055
13	2011-04-12	11	78	39	107	16	95	4	62	25	136	3	168	98	646
	2011-04-15	7	123	8	79	4	104	10	101	20	88	0	122	49	617
14	2011-04-18	13	53	13	70	2	37	13	117	28	109	1	63	70	449
	2011-04-21	6	73	14	75	11	130	1	71	10	96	2	209	44	654
15	2011-04-26	0	35	1	71	2	42	5	47	2	25	1	51	11	271
16	2011-05-04	0	28	0	39	0	19	2	18	2	11	0	10	4	125
17	2011-05-11	3	56	0	61	0	27	0	15	3	23	0	26	6	208
18	2011-05-16	0	26	0	41	0	19	0	10	0	67	1	64	1	227
19	2011-05-26	0	27	0	29	0	14	0	17	0	13	0	24	0	124
	Totals	457	3,969	1,373	5,668	1,923	6,068	3,477	5,777	8,109	11,233	483	12,609	15,822	45,324

Table C2. Daily numbers of eulachon eggs and larvae collected during plankton net sampling of the six sites along the Columbia River Price Island/Clifton Channel transect, December 6, 2011 through May 21, 2012.

Sample		Site 1		Site 2		Site 3		Site 4		Site 5		Site 6		Totals	
Week	Date	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae
1	2011-12-06	0	0	3	1	0	0	1	0	1	0	1	0	6	1
2	2011-12-16	0	0	4	1	3	4	0	1	0	0	0	0	7	6
3	2011-12-21	0	0	0	0	1	4	0	0	0	1	2	2	3	7
4	2011-12-30	0	335	2	268	0	160	1	246	2	111	2	169	7	1,289
5	2012-01-05	0	196	1	86	0	20	0	35	0	17	0	19	1	373
6	2012-01-09	0	341	0	50	0	21	0	45	1	8	0	206	1	671
7	2012-01-19	1	31	0	80	0	15	0	14	2	18	0	61	3	219
8	2012-01-23	0	910	1	76	0	16	1	7	1	29	0	224	3	1,262
9	2012-01-31	4	25	6	5	2	2	1	10	18	15	0	35	31	92
10	2012-02-06	0	23	1	183	2	15	4	36	1	46	0	93	8	396
11	2012-02-14	0	126	1	57	2	39	0	61	21	56	1	13	25	352
	2012-02-17	0	17	5	79	8	46	1	21	41	44	0	48	55	255
12	2012-02-21	1	283	0	23	35	41	122	47	84	72	9	72	251	538
	2012-02-23	0	240	9	69	17	128	5	87	55	86	6	40	92	650
13	2012-02-28	23	41	72	49	62	34	34	11	373	53	0	88	564	276
	2012-03-02	0	14	11	21	24	32	4	25	40	106	0	59	79	257
14	2012-03-05	11	119	53	91	85	80	172	187	108	182	3	58	432	717
	2012-03-08	1	121	39	64	78	150	94	167	167	523	4	250	383	1,275
15	2012-03-14	107	1,473	66	1,413	110	1,100	286	1,441	555	1,936	40	754	1,164	8,117
	2012-03-16	1	326	10	647	30	661	148	574	241	782	11	370	441	3,360
16	2012-03-20	21	490	31	432	41	361	102	604	227	823	0	71	422	2,781
	2012-03-22	30	742	104	752	62	447	162	418	376	411	21	184	755	2,954
17	2012-03-27	39	253	90	528	45	702	129	288	288	822	13	163	604	2,756
	2012-03-29	4	316	13	608	19	617	30	312	49	1,028	1	167	116	3,048
18	2012-04-04	18	99	35	149	7	81	109	115	47	188	58	383	274	1,015
	2012-04-05	7	92	13	84	36	104	46	71	45	230	1	28	148	609
19	2012-04-11	8	60	9	160	10	178	54	108	101	285	3	118	185	909
	2012-04-13	5	135	28	158	16	134	34	84	10	230	0	76	93	817
20	2012-04-17	3	55	1	37	8	32	10	58	50	93	0	48	72	323
21	2012-04-26	6	6	17	35	5	7	11	16	8	30	3	18	50	112
22	2012-05-02	2	6	2	4	2	7	2	11	5	2	0	6	13	36
23	2012-05-07	0	2	0	1	1	0	1	3	0	0	0	1	2	7
24	2012-05-15	0	0	1	0	0	0	0	0	0	1	0	0	1	1
25	2012-05-21	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Totals	292	6,877	628	6,211	711	5,238	1,564	5,103	2,917	8,228	179	3,824	6,291	35,481

Table C3. Daily numbers of eulachon eggs and larvae collected during plankton net sampling the six sites along the Columbia River Price Island/Clifton Channel transect, November 28, 2012 through June 21, 2013.

Sample		Site 1		Site 2		Site 3		Site 4		Site 5		Site 6		Totals	
Week	Date	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae	Eggs	Larvae
1	2012-11-28	0	0	1	0	1	0	0	0	0	0	1	0	3	0
2	2012-12-10	1	0	2	0	1	0	0	0	0	0	2	1	6	1
3	2012-12-21	1	16	1	4	1	3	1	1	0	0	0	6	4	30
4	2012-12-27	0	751	0	505	0	73	0	37	0	41	0	78	0	1,485
5	2013-01-04	2	117	2	36	0	34	0	23	0	7	1	47	5	264
6	2013-01-08	2	441	0	30	1	30	0	6	0	2	1	42	4	551
7	2013-01-18	0	50	3	43	0	14	1	8	1	34	0	20	5	169
8	2013-01-22	1	42	1	29	1	7	0	11	2	17	1	24	6	130
9	2013-02-01	5	311	3	63	1	42	1	44	2	91	3	208	15	759
10	2013-02-06	0	22	0	76	0	19	0	15	0	23	0	38	0	193
11	2013-02-15	2	70	1	10	1	10	0	5	4	7	2	22	10	124
12	2013-02-19	0	3	1	9	0	2	0	4	1	4	0	8	2	30
	2013-02-22	0	24	0	3	0	3	2	3	0	1	0	13	2	47
13	2013-02-25	0	14	2	18	1	5	1	16	2	29	0	2	6	84
	2013-02-27	1	14	0	8	0	19	1	10	0	3	2	18	4	72
14	2013-03-06	1	10	5	8	7	6	4	2	2	4	1	7	20	37
	2013-03-07	0	6	9	9	7	5	3	2	4	1	4	12	27	35
15	2013-03-12	3	17	3	5	4	12	2	3	18	3	3	15	33	55
	2013-03-13	1	24	1	7	1	10	1	10	28	7	0	9	32	67
16	2013-03-19	0	1	0	3	2	2	0	4	45	0	2	4	49	14
	2013-03-21	0	0	3	4	3	0	4	1	5	7	3	4	18	16
17	2013-03-25	3	2	39	12	93	8	71	6	172	10	6	8	384	46
	2013-03-28	17	18	134	32	42	27	45	14	95	4	10	15	343	110
18	2013-04-02	12	70	29	99	38	58	32	20	234	58	39	60	384	365
	2013-04-05	10	28	44	243	41	160	64	26	204	158	35	285	398	900
19	2013-04-09	13	769	149	506	256	508	237	754	574	717	37	1,414	1,266	4,668
	2013-04-11	42	569	110	390	54	249	224	854	560	3,064	6	804	996	5,930
20	2013-04-17	2	456	39	2,122	58	2,200	12	1,932	213	8,452	11	2,382	335	17,544
	2013-04-19	4	3,000	12	1,543	0	366	14	1,625	43	8,128	1	1,069	74	15,731
21	2013-04-22	9	2,009	8	825	12	881	6	3,129	71	5,106	6	2,366	112	14,316
	2013-04-25	0	906	1	1,182	4	1,674	4	6,690	19	5,990	1	562	29	17,004
22	2013-04-30	0	517	2	5,804	10	11,027	6	6,854	30	7,678	0	2,284	48	34,164
	2013-05-02	0	312	0	1,466	0	1,688	0	1,802	0	2,504	0	360	0	8,132
23	2013-05-06	0	185	0	137	2	1,323	8	1,518	0	2,102	0	94	10	5,359
	2013-05-09	0	539	0	123	1	77	0	436	0	849	0	82	1	2,106
24	2013-05-16	0	41	0	42	2	33	0	124	1	272	0	97	3	609
	2013-05-17	0	33	1	43	3	20	0	54	0	270	0	60	4	480
25	2013-05-21	0	0	0	19	0	11	0	3	0	8	0	3	0	44
	2013-05-23	0	27	0	7	0	4	0	20	0	8	0	43	0	109
26	2013-05-30	0	7	0	28	0	22	0	74	0	66	0	17	0	214
27	2013-06-06	0	0	0	3	0	2	0	0	0	2	0	0	0	7
28	2013-06-13	0	1	0	2	0	0	0	0	0	3	0	0	0	6
29	2013-06-21	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Totals	132	11,422	606	15,498	648	20,634	744	26,140	2,330	45,730	178	12,583	4,638	132,007

Appendix D: Daily and Weekly Columbia River Eulachon Egg and Larvae Sample Densities

Table D1. Daily and weekly Columbia River eulachon egg and larval sample densities collected from the six sites situated along the Price Island/Clifton Channel transect, January 13 through May 26, 2011.

Sample		Site 1			Site 2			Site 3			Site 4			Site 5			Site 6			Mean		
Week	Date	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.
1	2011-01-13	0.00	0.21	0.21	0.00	0.29	0.29	0.00	0.05	0.05	0.00	0.06	0.06	0.10	0.22	0.32	0.00	4.29	4.29	0.02	0.85	0.87
2	2011-01-27	0.00	0.54	0.54	0.05	0.31	0.37	0.03	0.29	0.32	0.09	0.34	0.43	0.16	0.29	0.44	0.04	12.33	12.37	0.06	2.35	2.41
3	2011-02-02	0.00	0.18	0.18	0.00	1.18	1.18	0.07	1.07	1.14	0.07	0.58	0.66	0.48	0.78	1.26	0.04	7.78	7.82	0.11	1.93	2.04
4	2011-02-09	0.00	0.39	0.39	0.05	0.83	0.88	0.10	1.01	1.12	0.40	1.51	1.91	0.92	0.94	1.85	0.00	4.21	4.21	0.24	1.48	1.73
	2011-02-11	0.02	0.61	0.63	0.11	0.60	0.71	0.37	0.79	1.16	0.04	1.03	1.07	0.50	0.89	1.38	0.00	10.62	10.62	0.18	2.42	2.60
																					weekly mean	2.16
5	2011-02-15	0.00	0.09	0.09	0.23	1.44	1.67	0.39	0.73	1.12	1.19	0.59	1.78	0.51	0.46	0.97	0.02	5.52	5.54	0.39	1.47	1.86
	2011-02-17	0.24	0.14	0.38	1.03	1.14	2.17	0.87	0.98	1.85	3.06	0.76	3.82	1.90	0.59	2.49	0.70	14.31	15.01	1.30	2.99	4.29
																					weekly mean	3.07
6	2011-02-23	0.31	0.62	0.93	1.18	2.33	3.51	3.65	0.49	4.14	8.24	0.76	9.00	11.08	0.33	11.41	1.00	2.53	3.53	4.24	1.18	5.42
7	2011-03-01	0.25	0.18	0.44	2.05	0.38	2.43	3.35	0.59	3.94	6.13	0.45	6.58	31.29	2.86	34.16	0.56	4.91	5.47	7.27	1.56	8.83
	2011-03-03	3.16	1.18	4.34	7.49	1.22	8.72	9.12	1.83	10.95	48.15	2.86	51.01	16.01	2.35	18.36	2.03	4.08	6.10	14.33	2.25	16.58
																					weekly mean	12.71
8	2011-03-07	0.38	0.57	0.96	0.67	2.32	2.99	1.44	2.23	3.68	1.32	6.25	7.57	10.92	5.51	16.44	0.57	4.21	4.78	2.55	3.52	6.07
	2011-03-11	0.53	11.03	11.55	2.84	15.23	18.07	2.58	14.85	17.43	4.98	22.84	27.82	9.13	45.43	54.56	0.45	60.13	60.58	3.42	28.25	31.67
																					weekly mean	18.87
9	2011-03-15	0.28	12.02	12.31	0.88	15.94	16.81	1.12	15.85	16.97	6.22	22.38	28.60	2.19	26.57	28.76	0.26	28.52	28.79	1.83	20.21	22.04
	2011-03-18	1.44	16.80	18.24	1.80	10.19	11.99	1.04	14.91	15.95	2.31	20.58	22.89	3.61	13.06	16.67	1.09	38.00	39.09	1.88	18.92	20.80
																					weekly mean	21.42
10	2011-03-21	0.00	9.28	9.28	0.81	12.52	13.32	0.36	6.58	6.94	2.06	21.34	23.40	3.08	7.82	10.90	0.14	6.21	6.35	1.08	10.62	11.70
	2011-03-25	0.42	5.49	5.91	0.41	7.75	8.16	0.58	8.64	9.22	2.45	10.31	12.76	3.82	11.19	15.01	0.36	10.19	10.55	1.34	8.93	10.27
																					weekly mean	10.98
11	2011-03-30	0.14	2.90	3.04	0.26	6.53	6.79	0.34	4.17	4.50	3.62	12.43	16.04	2.13	8.87	11.01	0.62	8.37	8.99	1.18	7.21	8.40
	2011-04-01	0.10	6.61	6.71	1.09	7.62	8.70	0.49	3.96	4.45	0.73	7.15	7.88	6.45	6.52	12.98	0.79	13.93	14.73	1.61	7.63	9.24
																					weekly mean	8.82
12	2011-04-04	0.12	2.45	2.57	0.67	3.91	4.59	0.42	3.08	3.50	1.84	5.24	7.09	2.39	3.20	5.59	0.63	11.04	11.67	1.01	4.82	5.84
	2011-04-08	1.00	2.21	3.20	0.37	1.29	1.66	0.44	1.65	2.09	0.73	1.78	2.51	1.20	3.34	4.54	0.51	10.14	10.65	0.71	3.40	4.11
																					weekly mean	4.97
13	2011-04-12	0.23	1.63	1.86	0.72	1.98	2.71	0.24	1.43	1.67	0.14	2.12	2.25	0.61	3.31	3.91	0.12	6.79	6.91	0.34	2.88	3.22
	2011-04-15	0.11	1.93	2.04	0.14	1.36	1.50	0.06	1.45	1.50	0.22	2.22	2.44	0.53	2.31	2.84	0.00	4.22	4.22	0.17	2.25	2.42
																					weekly mean	2.82

Table D1 (cont.). Daily and weekly Columbia River eulachon egg and larval sample densities collected from the six sites situated along the Price Island/Clifton Channel transect, January 13 through May 26, 2011.

Sample		Site 1			Site 2			Site 3			Site 4			Site 5			Site 6			Mean		
Week	Date	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.
14	2011-04-18	0.14	0.59	0.73	0.18	0.95	1.12	0.03	0.48	0.51	0.41	3.73	4.14	0.58	2.26	2.84	0.03	2.07	2.10	0.23	1.68	1.91
	2011-04-21	0.13	1.54	1.67	0.22	1.20	1.42	0.10	1.17	1.27	0.02	1.38	1.40	0.09	0.89	0.99	0.04	4.22	4.26	0.10	1.73	1.84
																				weekly mean		1.87
15	2011-04-26	0.00	0.62	0.62	0.02	1.24	1.26	0.04	0.76	0.79	0.15	1.38	1.53	0.05	0.57	0.61	0.03	1.52	1.55	0.05	1.01	1.06
16	2011-05-04	0.00	0.59	0.59	0.00	0.79	0.79	0.00	0.42	0.42	0.07	0.63	0.70	0.08	0.43	0.51	0.00	0.52	0.52	0.02	0.56	0.59
17	2011-05-11	0.04	0.74	0.78	0.00	1.03	1.03	0.00	0.43	0.43	0.00	0.67	0.67	0.04	0.33	0.37	0.00	0.65	0.65	0.01	0.64	0.65
18	2011-05-16	0.00	0.34	0.34	0.00	0.71	0.71	0.00	0.30	0.30	0.00	0.24	0.24	0.00	0.84	0.84	0.02	1.10	1.11	0.00	0.59	0.59
19	2011-05-26	0.00	0.34	0.34	0.00	0.40	0.40	0.00	0.20	0.20	0.00	0.31	0.31	0.00	0.17	0.17	0.00	0.47	0.47	0.00	0.32	0.32

Table D2. Daily and weekly Columbia River eulachon egg and larval sample densities collected from the six sites situated along the Price Island/Clifton Channel transect, December 6, 2011 through May 21, 2012.

Sample		Site 1			Site 2			Site 3			Site 4			Site 5			Site 6			Mean		
Week	Date	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.
1	2011-12-06	0.00	0.00	0.00	0.10	0.03	0.13	0.00	0.00	0.00	0.04	0.00	0.04	0.02	0.00	0.02	0.03	0.00	0.03	0.03	0.01	0.04
2	2011-12-16	0.00	0.00	0.00	0.12	0.03	0.15	0.07	0.10	0.17	0.00	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03	0.06
3	2011-12-21	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.09	0.11	0.00	0.00	0.00	0.00	0.02	0.02	0.08	0.08	0.16	0.02	0.03	0.05
4	2011-12-30	0.00	6.03	6.03	0.04	4.74	4.77	0.00	2.63	2.63	0.03	7.82	7.85	0.04	1.97	2.00	0.07	5.62	5.69	0.03	4.80	4.83
5	2012-01-05	0.00	5.75	5.75	0.03	2.66	2.69	0.00	0.51	0.51	0.00	1.43	1.43	0.00	0.54	0.54	0.00	0.97	0.97	0.01	1.98	1.98
6	2012-01-09	0.00	21.37	21.37	0.00	2.03	2.03	0.00	0.63	0.63	0.00	1.54	1.54	0.05	0.40	0.45	0.00	8.71	8.71	0.01	5.78	5.79
7	2012-01-19	0.03	0.84	0.86	0.00	1.72	1.72	0.00	0.26	0.26	0.00	0.40	0.40	0.05	0.43	0.48	0.00	2.12	2.12	0.01	0.96	0.97
8	2012-01-23	0.00	20.53	20.53	0.03	1.92	1.95	0.00	0.34	0.34	0.03	0.20	0.23	0.02	0.52	0.54	0.00	5.48	5.48	0.01	4.83	4.85
9	2012-01-31	0.09	0.54	0.63	0.22	0.18	0.41	0.04	0.04	0.08	0.03	0.31	0.34	0.23	0.19	0.41	0.00	1.01	1.01	0.10	0.38	0.48
10	2012-02-06	0.00	0.66	0.66	0.02	4.21	4.23	0.03	0.26	0.29	0.10	0.93	1.03	0.02	0.88	0.90	0.00	2.50	2.50	0.03	1.57	1.60
11	2012-02-14	0.00	3.77	3.77	0.02	1.28	1.31	0.04	0.77	0.81	0.00	2.15	2.15	0.40	1.07	1.48	0.04	0.54	0.58	0.08	1.60	1.68
	2012-02-17	0.00	0.43	0.43	0.13	2.09	2.22	0.15	0.86	1.01	0.04	0.76	0.79	0.99	1.06	2.05	0.00	2.07	2.07	0.22	1.21	1.43
																					weekly mean	1.55
12	2012-02-21	0.05	14.73	14.79	0.00	0.77	0.77	0.91	1.06	1.97	3.08	1.18	4.26	2.35	2.01	4.36	0.32	2.54	2.86	1.12	3.72	4.83
	2012-02-23	0.00	10.39	10.39	0.27	2.07	2.34	0.37	2.79	3.16	0.15	2.61	2.76	1.25	1.95	3.19	0.45	2.97	3.42	0.41	3.80	4.21
																					weekly mean	4.52
13	2012-02-28	0.57	1.02	1.59	1.60	1.09	2.69	1.13	0.62	1.76	1.30	0.42	1.72	6.04	0.86	6.90	0.00	2.50	2.50	1.77	1.08	2.86
	2012-03-02	0.00	0.53	0.53	0.38	0.72	1.09	0.63	0.84	1.47	0.19	1.20	1.39	1.25	3.32	4.57	0.00	3.13	3.13	0.41	1.62	2.03
																					weekly mean	2.45
14	2012-03-05	0.27	2.97	3.25	1.19	2.04	3.23	1.59	1.50	3.09	4.68	5.08	9.76	1.84	3.10	4.94	0.12	2.22	2.34	1.61	2.82	4.43
	2012-03-08	0.04	4.91	4.96	1.14	1.87	3.01	1.66	3.18	4.84	3.38	6.01	9.40	4.59	14.38	18.98	0.19	11.82	12.01	1.83	7.03	8.86
																					weekly mean	6.65
15	2012-03-14	1.87	25.72	27.59	0.96	20.45	21.41	1.84	18.40	20.24	7.04	35.49	42.54	4.43	15.46	19.89	0.80	15.06	15.86	2.82	21.76	24.59
	2012-03-16	0.04	11.42	11.45	0.28	17.88	18.16	0.71	15.75	16.47	7.40	28.68	36.08	3.37	10.94	14.31	0.39	13.20	13.59	2.03	16.31	18.34
																					weekly mean	21.47
16	2012-03-20	0.63	14.81	15.45	0.75	10.38	11.13	0.79	6.95	7.74	3.41	20.18	23.58	2.55	9.26	11.81	0.00	3.39	3.39	1.36	10.83	12.19
	2012-03-22	0.55	13.66	14.21	1.91	13.80	15.71	1.19	8.61	9.81	3.81	9.84	13.65	3.91	4.27	8.18	0.50	4.36	4.86	1.98	9.09	11.07
																					weekly mean	11.63

Table D2 (cont.). Daily and weekly Columbia River eulachon egg and larval sample densities collected from the six sites situated along the Price Island/Clifton Channel transect, December 6, 2011 through May 21, 2012.

Sample		Site 1			Site 2			Site 3			Site 4			Site 5			Site 6			Mean		
Week	Date	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.
17	2012-03-27	1.08	6.99	8.07	1.79	10.52	12.32	0.77	12.01	12.78	6.74	15.04	21.78	3.16	9.02	12.18	0.54	6.75	7.29	2.35	10.06	12.40
	2012-03-29	0.16	12.38	12.53	0.35	16.16	16.50	0.45	14.54	14.98	1.38	14.39	15.77	0.79	16.52	17.31	0.05	8.79	8.84	0.53	13.80	14.32
																				weekly mean		13.36
18	2012-04-04	0.55	3.01	3.55	0.86	3.66	4.52	0.12	1.40	1.53	5.83	6.15	11.97	0.49	1.97	2.46	2.68	17.68	20.35	1.75	5.64	7.40
	2012-04-05	0.28	3.70	3.98	0.40	2.56	2.95	0.89	2.58	3.48	2.08	3.21	5.29	0.78	3.98	4.75	0.06	1.77	1.84	0.75	2.97	3.72
																				weekly mean		5.56
19	2012-04-11	0.28	2.13	2.41	0.20	3.63	3.83	0.18	3.13	3.31	2.19	4.38	6.57	1.11	3.14	4.26	0.11	4.25	4.36	0.68	3.44	4.12
	2012-04-13	0.15	4.10	4.25	0.70	3.94	4.63	0.31	2.63	2.95	1.82	4.49	6.31	0.12	2.80	2.92	0.00	3.27	3.27	0.52	3.54	4.06
																				weekly mean		4.09
20	2012-04-17	0.10	1.81	1.91	0.03	1.07	1.10	0.19	0.75	0.94	0.43	2.47	2.89	0.76	1.42	2.18	0.00	1.82	1.82	0.25	1.56	1.81
21	2012-04-26	0.12	0.12	0.24	0.29	0.60	0.90	0.11	0.16	0.27	0.32	0.46	0.78	0.08	0.29	0.37	0.10	0.60	0.70	0.17	0.37	0.54
22	2012-05-02	0.06	0.17	0.22	0.03	0.07	0.10	0.04	0.13	0.17	0.04	0.24	0.29	0.06	0.03	0.09	0.00	0.20	0.20	0.04	0.14	0.18
23	2012-05-07	0.00	0.06	0.06	0.00	0.02	0.02	0.01	0.00	0.01	0.04	0.11	0.15	0.00	0.00	0.00	0.00	0.03	0.03	0.01	0.04	0.04
24	2012-05-15	0.00	0.00	0.00	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.00	0.00	0.00	0.01	0.00	0.01
25	2012-05-21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table D3. Daily and weekly Columbia River eulachon egg and larval sample densities collected from the six sites situated along the Price Island/Clifton Channel transect, November 28, 2012 through June 21, 2013.

Sample		Site 1			Site 2			Site 3			Site 4			Site 5			Site 6			Mean		
Week	Date	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.
1	2012-11-28	0.00	0.00	0.00	0.02	0.00	0.02	0.02	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.01	0.00	0.01
2	2012-12-10	0.02	0.00	0.02	0.03	0.00	0.03	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.02	0.07	0.02	0.00	0.02
3	2012-12-21	0.02	0.28	0.30	0.02	0.07	0.08	0.01	0.04	0.05	0.02	0.02	0.04	0.00	0.00	0.00	0.00	0.12	0.12	0.01	0.09	0.10
4	2012-12-27	0.00	24.11	24.11	0.00	13.27	13.27	0.00	1.47	1.47	0.00	1.20	1.20	0.00	0.75	0.75	0.00	4.04	4.04	0.00	7.47	7.48
5	2013-01-04	0.04	2.44	2.48	0.04	0.74	0.78	0.00	0.59	0.59	0.00	0.62	0.62	0.00	0.10	0.10	0.03	1.36	1.39	0.02	0.97	0.99
6	2013-01-08	0.03	6.19	6.22	0.00	0.45	0.45	0.01	0.42	0.43	0.00	0.19	0.19	0.00	0.06	0.06	0.09	3.91	4.01	0.02	1.87	1.89
7	2013-01-18	0.00	1.21	1.21	0.05	0.76	0.82	0.00	0.23	0.23	0.04	0.28	0.32	0.01	0.44	0.45	0.00	0.76	0.76	0.02	0.61	0.63
8	2013-01-22	0.02	1.00	1.02	0.02	0.63	0.65	0.02	0.12	0.14	0.00	0.27	0.27	0.03	0.26	0.30	0.03	0.83	0.87	0.02	0.52	0.54
9	2013-02-01	0.07	4.34	4.41	0.04	0.90	0.94	0.01	0.55	0.56	0.03	1.11	1.13	0.02	0.84	0.86	0.07	4.52	4.58	0.04	2.04	2.08
10	2013-02-06	0.00	0.55	0.55	0.00	1.54	1.54	0.00	0.36	0.36	0.00	0.45	0.45	0.00	0.34	0.34	0.00	1.37	1.37	0.00	0.77	0.77
11	2013-02-15	0.05	1.62	1.66	0.03	0.29	0.32	0.03	0.27	0.30	0.00	0.30	0.30	0.12	0.21	0.34	0.14	1.49	1.62	0.06	0.70	0.76
12	2013-02-19	0.00	0.12	0.12	0.03	0.26	0.29	0.00	0.05	0.05	0.00	0.19	0.19	0.03	0.11	0.14	0.00	0.48	0.48	0.01	0.20	0.21
	2013-02-22	0.00	0.52	0.52	0.00	0.07	0.07	0.00	0.07	0.07	0.07	0.10	0.17	0.00	0.04	0.04	0.00	0.91	0.91	0.01	0.28	0.30
																					weekly mean	0.25
13	2013-02-25	0.00	0.27	0.27	0.04	0.35	0.39	0.02	0.09	0.10	0.03	0.44	0.47	0.03	0.42	0.45	0.00	0.06	0.06	0.02	0.27	0.29
	2013-02-27	0.04	0.50	0.53	0.00	0.21	0.21	0.00	0.36	0.36	0.03	0.29	0.32	0.00	0.07	0.07	0.08	0.76	0.84	0.02	0.36	0.39
																					weekly mean	0.34
14	2013-03-06	0.03	0.28	0.31	0.10	0.16	0.26	0.15	0.13	0.28	0.13	0.06	0.19	0.03	0.07	0.10	0.03	0.20	0.23	0.08	0.15	0.23
	2013-03-07	0.00	0.17	0.17	0.18	0.18	0.36	0.16	0.11	0.27	0.09	0.06	0.14	0.08	0.02	0.09	0.18	0.55	0.73	0.11	0.18	0.29
																					weekly mean	0.26
15	2013-03-12	0.08	0.47	0.55	0.07	0.11	0.18	0.07	0.20	0.27	0.06	0.09	0.15	0.30	0.05	0.35	0.09	0.47	0.56	0.11	0.23	0.34
	2013-03-13	0.03	0.75	0.78	0.02	0.17	0.20	0.02	0.19	0.21	0.03	0.27	0.30	0.57	0.14	0.71	0.00	0.39	0.39	0.11	0.32	0.43
																					weekly mean	0.39
16	2013-03-19	0.00	0.04	0.04	0.00	0.09	0.09	0.06	0.06	0.12	0.00	0.16	0.16	0.98	0.00	0.98	0.08	0.15	0.23	0.19	0.08	0.27
	2013-03-21	0.00	0.00	0.00	0.09	0.11	0.20	0.07	0.00	0.07	0.11	0.03	0.14	0.07	0.10	0.17	0.11	0.14	0.25	0.07	0.06	0.14
																					weekly mean	0.20
17	2013-03-25	0.08	0.06	0.14	1.03	0.32	1.35	2.03	0.18	2.21	2.13	0.18	2.32	3.36	0.20	3.56	0.21	0.27	0.48	1.48	0.20	1.68
	2013-03-28	0.49	0.51	1.00	3.10	0.74	3.84	0.91	0.59	1.50	1.53	0.48	2.01	1.69	0.07	1.77	0.50	0.74	1.24	1.37	0.52	1.89
																					weekly mean	1.78

Table D3 (cont.). Daily and weekly Columbia River eulachon egg and larval sample densities collected from the six sites situated along the Price Island/Clifton Channel transect, November 28, 2012 through June 21, 2013.

Sample		Site 1			Site 2			Site 3			Site 4			Site 5			Site 6			Mean		
Week	Date	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.	Eggs	Larvae	Comb.
	2013-04-02	0.45	2.63	3.08	1.02	3.48	4.50	1.06	1.62	2.67	1.67	1.04	2.71	3.74	0.93	4.66	1.75	2.69	4.44	1.61	2.06	3.68
18	2013-04-05	0.25	0.71	0.96	1.28	7.04	8.32	0.88	3.45	4.33	4.73	1.92	6.65	2.39	1.85	4.25	1.27	10.34	11.60	1.80	4.22	6.02
																				weekly mean		4.85
	2013-04-09	0.39	23.36	23.76	4.30	14.60	18.90	5.11	10.13	15.24	8.31	26.45	34.76	11.29	14.10	25.39	0.93	35.52	36.45	5.06	20.69	25.75
19	2013-04-11	0.89	12.09	12.98	2.57	9.12	11.70	0.97	4.45	5.42	7.72	29.45	37.17	5.03	27.52	32.55	0.27	36.59	36.87	2.91	19.87	22.78
																				weekly mean		24.27
	2013-04-17	0.05	12.53	12.59	0.85	46.09	46.94	0.98	37.04	38.02	0.41	65.40	65.80	2.25	89.41	91.67	0.32	69.10	69.42	0.81	53.26	54.07
20	2013-04-19	0.12	87.78	87.90	0.41	52.77	53.18	0.00	10.40	10.40	0.48	55.46	55.94	0.52	97.51	98.03	0.04	45.74	45.78	0.26	58.28	58.54
																				weekly mean		56.31
	2013-04-22	0.23	51.55	51.78	0.21	21.63	21.84	0.26	19.20	19.46	0.29	152.80	153.09	0.85	60.80	61.65	0.23	88.90	89.13	0.34	65.81	66.16
21	2013-04-25	0.00	78.85	78.85	0.04	46.97	47.00	0.12	51.71	51.83	0.16	270.55	270.72	0.36	113.68	114.04	0.06	33.93	33.99	0.12	99.28	99.40
																				weekly mean		82.78
	2013-04-30	0.00	19.76	19.76	0.07	190.09	190.16	0.25	279.99	280.24	0.25	282.12	282.37	0.28	70.54	70.81	0.00	106.44	106.44	0.14	158.16	158.30
22	2013-05-02	0.00	16.81	16.81	0.00	45.39	45.39	0.00	45.41	45.41	0.00	113.42	113.42	0.00	32.39	32.39	0.00	35.90	35.90	0.00	48.22	48.22
																				weekly mean		103.26
	2013-05-06	0.00	9.59	9.59	0.00	5.28	5.28	0.07	45.21	45.28	0.70	132.59	133.29	0.00	34.10	34.10	0.00	7.92	7.92	0.13	39.12	39.24
23	2013-05-09	0.00	22.08	22.08	0.00	3.60	3.60	0.02	1.92	1.94	0.00	26.11	26.11	0.00	31.32	31.32	0.00	5.45	5.45	0.00	15.08	15.08
																				weekly mean		27.16
	2013-05-16	0.00	1.85	1.85	0.00	1.21	1.21	0.05	0.87	0.93	0.00	5.92	5.92	0.01	2.79	2.80	0.00	4.93	4.93	0.01	2.93	2.94
24	2013-05-17	0.00	1.37	1.37	0.03	1.29	1.32	0.07	0.48	0.55	0.00	3.14	3.14	0.00	2.90	2.90	0.00	3.61	3.61	0.02	2.13	2.15
																				weekly mean		2.54
	2013-05-21	0.00	0.00	0.00	0.00	0.53	0.53	0.00	0.28	0.28	0.00	0.15	0.15	0.00	0.15	0.15	0.00	0.35	0.35	0.00	0.24	0.24
25	2013-05-23	0.00	0.93	0.93	0.00	0.19	0.19	0.00	0.09	0.09	0.00	1.04	1.04	0.00	0.08	0.08	0.00	2.33	2.33	0.00	0.78	0.78
																				weekly mean		0.51
26	2013-05-30	0.00	0.37	0.37	0.00	0.68	0.68	0.00	0.50	0.50	0.00	2.77	2.77	0.00	0.58	0.58	0.00	0.75	0.75	0.00	0.94	0.94
27	2013-06-06	0.00	0.00	0.00	0.00	0.07	0.07	0.00	0.03	0.03	0.00	0.00	0.00	0.00	0.03	0.03	0.00	0.00	0.00	0.00	0.02	0.02
28	2013-06-13	0.00	0.02	0.02	0.00	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.00	0.00	0.00	0.00	0.02	0.02
29	2013-06-21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Report B

Freshwater Distribution of Eulachon in Oregon and Washington

Adam J. Storch
and
Erick S. Van Dyke

Oregon Department of Fish and Wildlife
Ocean Salmon and Columbia River Program
Columbia River Investigations
17330 SE Evelyn Street
Clackamas, Oregon 97015

Olaf P. Langness
Phillip E. Dionne
Chris W. Wagemann
and
Brad J. Cady

Washington Department of Fish and Wildlife
Region 5 Fish Program
2108 Grand Boulevard
Vancouver, Washington 98661-4624

Final Report to:

National Oceanic and Atmospheric Administration
1401 Constitution Avenue, NW
Room 5128
Washington, DC 20230

For NOAA Fisheries Protected Species Conservation and Recovery
Grant Number NA10NMF4720038

September, 2014

Acknowledgements

Work carried-out by the Oregon Department of Fish and Wildlife would not have been possible without the assistance of many individuals. Jennifer Blaine, Jeremy Cameron, Hayden Howell, Shaffron Shade and Elizabeth Torrey spent countless hours on boats and in the laboratory helping to shed light on the spawning distribution of eulachon in Oregon waters. Tom Rien was essential in the development of this project and provided technical advice and leadership throughout.

The Washington Department of Fish and Wildlife also wishes to thank numerous individuals for their tireless efforts on various aspects of this project. Ned Pittman, Ryan Nauer, Jennifer Blaine, Shaffron Schade, Mike Brown, Mike Hill, Jerry Pruiett, Mike Wall, Dennis Gilliland, Laura Lloyd, and Dean Pyzik assisted the WDFW authors with the egg and larvae surveys. Shaffron Schade, Jennifer Blaine, and Laura Lloyd helped to process samples in the laboratory. Craig Olds and staff with the Cowlitz Indian Tribe Natural Resources Department helped augment our field surveys through their grant work.

This work was supported by funding from NOAA Fisheries Protected Species Conservation and Recovery Grant Award Number NA10NMF4720038.

Table of Contents

Acknowledgements 61
List of Figures 63
List of Tables 64
Abstract 65
Introduction 66
Study Objectives and Report Structure 66
Methods 67
Study Area 67
Columbia River 67
Sandy River 67
Oregon Coastal Streams 67
Washington Water Bodies 67
Field Data Collection 67
Columbia River 67
Sandy River 68
Oregon Coastal Streams 68
Washington Water Bodies and Main Stem Columbia River 69
Laboratory Processing 70
Artificial Substrates 70
Ichthoplankton tows (ODFW) 70
Ichthoplankton tows (WDFW) 70
Results and Discussion 70
References 73
Figures 74
Tables 79

List of Figures

Figure 1. Distribution of sampling locations where artificial substrate and/or ichthyoplankton nets were deployed in the Columbia River below Bonneville Dam, 10 January–31 May 2011 and 21 November 2011–24 July 2012.. 74

Figure 2. Distribution of sampling locations in the Sandy River, 27 January–2 June 2011........ 75

Figure 3. Distribution of sampling locations (artificial substrate sets and/or oblique ichthyoplankton tows) in the Umpqua River, 20 January–8 June 2011....................... 75

Figure 4. Map of the tributaries of the lower Columbia River surveyed by WDFW for eulachon eggs and larvae during 2011-2013 76

Figure 5. Map of the Washington State rivers outside the Columbia River system where eulachon egg and larvae samples were collected by WDFW during 2011 and 2012 .. 77

Figure 6. Temporal distribution of eulachon larvae encounters in the Columbia River below Bonneville Dam. Error bars represent one standard deviation from the mean 78

List of Tables

Table 1. Summary of main stem Columbia River sites surveyed by WDFW for the presence of eulachon egg and larvae during 2011-2013 79

Table 2 Summary of lower Columbia River tributaries surveyed by WDFW for the presence of eulachon egg and larvae during 2011-2013 80

Table 3. Summary of Washington State rivers (outside the Columbia River watershed) surveyed by WDFW for the presence of eulachon egg and larvae during 2011 and 2012 82

Abstract

In 2011, the Oregon Department of Fish and Wildlife (ODFW) and the Washington Department of Fish and Wildlife (WDFW) initiated a three-year monitoring program to help track coast-wide status and trends in abundance and distribution of the ESA-listed southern eulachon distinct population segment (DPS). One objective of this work directed the two agencies to conduct egg and larvae surveys of known and potential spawning areas in the main stem Columbia River below Bonneville Dam, Columbia River tributaries, and coastal river systems of Oregon and Washington to better characterize current eulachon distribution and to inform NOAA Fisheries critical habitat decisions for the southern DPS. ODFW completed ichthyoplankton tows and artificial substrate sampling at several stations throughout the lower Columbia River during 2011 and 2012. During this sampling, encounters with egg and/or larvae were confined in space and time. WDFW conducted a survey of sites opportunistically in the vicinity of the Ports of Longview and Kalama during 2011. During 2011, ODFW sampled the Sandy River while WDFW conducted surveys in the Grays River, Skamokawa Creek, Cowlitz River, Kalama River, and Lewis River. Columbia River tributary sampling was limited to the Grays River during 2012 and 2013 due to budget constraints; the Grays River was sampled systematically to generate annual eulachon spawner stock biomass (SSB) estimates. Both agencies completed ichthyoplankton tows and/or spawning substrate sampling in coastal streams outside the Columbia Basin. During 2011, ODFW carried out a presence/absence survey in the Umpqua and Coos rivers. WDFW conducted similar surveys in the Naselle and Bear rivers (Willapa Bay system). During 2012, WDFW was able to survey the North Fork of the Willapa River. Two rivers in the Grays Harbor system were surveyed (Humptulip and Chehalis rivers). Along the North Coast of Washington, WDFW surveyed the Moclips River, Clearwater River, Hoh River, Goodman Creek, and Quillayute River. Along the Strait of Juan de Fuca, WDFW surveyed the Clallam and Elwha rivers. Three rivers in Hood Canal were also surveyed in 2012 (Big Quilcene, Little Quilcene and Tahuya rivers). Eulachon larvae and eggs were collected at all stations in the Columbia River and its tributaries. Outside the Columbia Basin, eulachon larvae and eggs were only detected in the Umpqua, Naselle, Bear, Willapa, and Chehalis rivers. Eulachon may have gone undetected in the other rivers surveyed due to the surveys consisting of only one or two sampling events.

Introduction

Current knowledge suggests the Pacific eulachon smelt (*Thaleichthys pacificus*) population consists of at least two distinct population segments—the listed Southern DPS (spawning south of the Nass River, BC), and the Northern DPS (spawning in the Nass River, BC, and northward to Bristol Bay, AK). Fish from the Southern DPS are most readily apparent during their winter-time spawning in the Columbia and Fraser rivers; however, juvenile fish are handled in the ocean shrimp trawl fisheries off the West Coast of the United States and Canada. Listing of the Southern DPS, motivated various groups (including Oregon Department of Fish and Wildlife and Washington Department of Fish and Wildlife—ODFW and WDFW respectively) to devote more resources to understand life history and abundance dynamics.

In the Federal Recovery Outline for Eulachon Southern DPS of June 21, 2013, NMFS states that it has been difficult to evaluate the status of eulachon "due to the lack of reliable long term data", and that available abundance data "are confounded by intermittent reporting, fishery-dependent data, and the lack of directed sampling" (NMFS-NWR 2013). In light of these gaps in knowledge, in 2010, the Oregon Department of Fish and Wildlife (ODFW) and WDFW were awarded a National Oceanic and Atmospheric Administration (NOAA) Fisheries Protected Species Conservation and Recovery (Section 6 of the ESA) grant to fund eulachon studies during Federal Fiscal Years (FY) 2010-2013 ("Protected Species Studies of Eulachon Smelt in Oregon and Washington"; Award Number NA10NMF470038). The goal of this work was to design and implement a monitoring program to track coast-wide status and trends in abundance and distribution to better manage anthropogenic impacts and other threats to recovery of the proposed threatened southern eulachon distinct population segment.

Study Objectives and Report Structure

Specific objectives to support the primary goal of this project were: 1) to develop and implement an annual eulachon SSB estimate for the Columbia River that will allow managers to better track recovery and manage fishery impacts; 2) to better characterize current eulachon smelt distribution using egg and larvae surveys of known and potential spawning areas in the lower Columbia River, Columbia River tributaries, and coastal river systems of Washington and Oregon, to aid in determination of critical habitat for the DPS; 3) to assess and reduce the impacts of shrimp trawl operations on eulachon smelt by initiating an observer program to estimate the bycatch rates in Washington's ocean shrimp trawl fishery and by developing and testing modifications to ocean shrimp trawl; and 4) to assess the genetic makeup of spatial and temporal components of the Columbia River and Washington/Oregon coastal eulachon smelt runs.

This report presents the work and findings to meet objective 2 specified above. The objective was accomplished by: collecting and enumerating eggs and larvae at several sites within Oregon and Washington waters. As stated in the objective, this information will be used ultimately to improve understanding of the current eulachon smelt distribution and serve to inform the determination of critical habitat for the DPS. New information on timing and geographic extent of spawning will inform permit applications and federal regulations regarding potential hydraulic impacts and critical habitat. Identification of river systems that support eulachon production can be useful to managers in developing the eulachon recovery plan.

Under Methods, we describe the sample locations, protocols for collecting samples in the field and laboratory processing. Results and discussion are combined, summarizing sampling effort and detections larvae or eggs across space and time.

Methods

Study Area

Columbia River

Eulachon eggs and larvae were sampled by ODFW at fixed locations in the Columbia River below Bonneville Dam. Sites were selected near the Oregon shore between Cathlamet and North Bonneville, Washington. For logistical purposes, sampling locations were spaced approximately 6 river kilometers apart. Further, sites were grouped into four zones to allow for a rotating sampling strategy (see Field Data Collection; Figure 1). Wherever possible, sampling was conducted over sandy substrate, in areas of reduced flow (e.g., river margins), and at depths ranging from 15–30 feet.

Sandy River

Sampling to assess the current freshwater distribution of eulachon was conducted opportunistically in the Sandy River at several locations between approximately 3 and 5 river kilometers from the confluence with the Columbia River (Figure 2). As in the Colombia River, sites were selected based on water depth at the time of sampling and substrate type.

Oregon Coastal Streams

As in the Sandy River, sampling in the Coos and Umpqua (Figure 3) rivers was conducted opportunistically. In both streams, samples were collected from areas associated with sandy substrate.

Washington Water Bodies

The Washington Department of Fish and Wildlife sampled eggs and larvae at sites in Washington tributaries of the Columbia River and several coastal water bodies (Figures 4 and 5; Tables 2 and 3). To compliment ODFW efforts, WDFW also sampled opportunistically several sites near the Washington shore of the main stem Columbia River (i.e., near the Ports of Longview and Kalama; Table 1).

Field Data Collection

Columbia River

Staff from ODFW sampled the eggs and larvae of eulachon smelt in the Columbia River below Bonneville Dam during the periods 10 January–31 May 2011 and 21 November 2011–24 July 2012. During 2011, sites comprising the four zones described previously were sampled on a weekly rotating basis. For example, sites in zone 1 were sampled during the first week of a given month, sites in zone 2 the second week and so on until all sites had been sampled (Figure 1). This pattern was then repeated throughout the contracted field season. Due to funding constraints during 2012, zone 1was not sampled; thus the remaining zones were sampled according to a three-week rotation.

At each site, duplicate artificial substrates were set to collect demersal eggs. Substrates were constructed of commercial air filter material secured to a square metal frame (77 cm wide x 91.5 cm tall x 3.2 cm deep). Frames consisted of an inner and outer panel, where the panels were subdivided into six cells by thin metal strips welded to the outside edges of each panel. Metal strips (3.2cm wide) also were welded to the edges of the outer panel at 90° angles, effectively creating a "box" within which the inner panel rested when assembled. Bolts were welded at regular intervals to the perimeter of the outer panel (i.e., within the "box"; Figure 3A). Appropriate-sized holes are drilled through the perimeter of the inner panel so the position of these holes matches those of the bolts (Figure 3C). Two rings are welded to the top of the egg mat through which a length (~160cm) of cable is secured using cable clamps. A third clamp is used to create a loop at the approximate mid-point of the cable.

At each site, substrates were deployed from a boat and allowed to sample for approximately 24h. Upon retrieval, individual substrates were placed immediately into a large plastic bin. Filter material was then removed carefully from the frame and placed in a clean 5-gallon bucket. Particles adhering to the frame were rinsed into the tote with filtered water. Contents of the tote were then rinsed into the bucket containing the filter material. Particles remaining on the inside of the tote were rinsed into the sample bucket and, if necessary, additional filtered water was added to ensure filter material remained submerged completely until subsequent laboratory analysis.

After deploying artificial substrates at a given site, pelagic larvae and eggs were sampled in oblique plankton tows. To this end, we used a standard non-closing ichthyoplankton net, constructed of 60 µm nitex mesh with a 0.6 m opening and a detachable PVC cod end (243 µm mesh). To quantify the volume of water sampled, a mechanical flow meter was attached at the center of the opening. A 4.5 kilogram pyramid anchor was attached by a leader to the bottom of the net opening and a line was attached near the center of the opening to allow for deployment.

At each site, the net was lowered into the water column and allowed to descend at a constant rate until the anchor/weight reached the river bottom. The net was then retreived using a hydraulic winch. After being removed completely from the water, any material remaining in the main net was rinsed into the cod-end with a high pressure hose. Contents of the cod end were then rinsed into a sample bottle with 95% ethanol to preserve contents until laboratory analysis.

Sandy River

Eggs and larvae were sampled in the Sandy River opportunistically throughout 27 January–2 June 2011. Procedures for sampling pelagic eggs and larvae using the ichthyoplankton net and demersal eggs using artificial substrates were the same as those followed in the Columbia River with one exception; artificial substrates deployed in the Sandy River were set and retrieved on foot.

Oregon Coastal Streams

Sampling of eggs and larvae was conducted in the Umpqua and Coos rivers during 20 January–8 June 2011 and 24 January–28 February 2011, respectively. District biologists sampled these rivers opportunistically using artificial substrates and ichthyoplankton nets as outlined above for the main stem Columbia River.

Washington Water Bodies and Main Stem Columbia River

The Washington Department of Fish And Wildlife sampled 41 sites in 21 water bodies in the State of Washington, and opportunistically at several sites in the main stem Columbia River near the ports of Longview and Kalama, during 20 January 2011–7 May 2013 (Table 1–3). Field protocols were similar to those described in James et al. (2014; Report A).

Laboratory Processing

Artificial Substrates

In the laboratory, filter material used to sample demersal eggs was removed from the sample buckets and scanned under a magnifying lens. Any eggs encountered during examination were collected with jeweler's forceps and placed in a petri dish containing ethanol. Water and other material remaining in the bucket after processing of the filter material was poured through a 60-micron sieve to isolate particles. Contents of the sieve were then rinsed into a sorting tray and examined under magnification. As with the filter material, any eggs encountered were collected with forceps and placed in a petri dish containing ethanol. Specimens in the petri dish were then examined under a dissecting microscope for identification. Eggs were enumerated as either "eulachon" or "other" and then placed in a labeled 0.5ml centrifuge vial containing ethanol.

Ichthoplankton tows (ODFW)

Ichthyoplankton tow samples collected by ODFW were processed in a manner similar to that described by James et al. (2014), were one-hundred percent of each sample was examined. The contents of sample bottles were poured through a 60 μm sieve to isolate solid material. Material remaining in the sieve was then transferred into a sorting tray and examined under a magnifying lens. Any larvae or eggs encountered were collected with forceps in a petri dish containing ethanol. Separated eggs and larvae were then identified under a stereomicroscope. Larvae or eggs from each sample were counted and placed in separate micro-centrifuge vials containing ethanol and labeled according to sample code.

Ichthoplankton tows (WDFW)

Eggs and larvae collected in ichthyoplankton tows by WDFW were enumerated following the protocols outlined in James et al. (2014; Report A).

Results and Discussion

Staff from ODFW conducted 300 artificial substrate sets and 618 oblique ichthyoplankton tows in the Columbia River below Bonneville Dam. Throughout the time periods sampled, 144 eggs were collected on artificial substrates, while 652 eggs and 2,410 larvae were encountered in ichthyoplankton tows. Of the larvae captured, 1,506 (63%) were identified conclusively as eulachon. Alternatively, no eggs were identified unequivocally as the product of eulachon spawning. A majority (93%) of eulachon larvae were encountered during March of 2011 downstream of the Cowlitz River between Cathlamet and Longview, Washington (Figures 1 and 6). Several tributaries of the Columbia River (e.g., the Elochoman, Cowlitz, Kalama, and Lewis rivers), where eulachon spawning is known to occur (Smith and Saalfeld 1955) originate in Washington. In attempting to capture spawning activity on the main stem of the Columbia River, we confined our sampling to the Oregon shore. Further, the greatest numbers of eulachon larvae were found in samples collected well downstream of the Lewis, Kalama and Cowlitz rivers and upstream of the Elochoman. While the relatively distant proximity of sampling events to known spawning areas does not discount the possibility that larvae in our samples may be the product of spawning in these tributaries, our findings highlight the potential for at least limited spawning in the main stem Columbia River near the Oregon shore. Future work should seek to discriminate among site-specific sources of production, perhaps by considering spatial probability.

Due to funding constraints occurring during the second sampling in the Sandy River and select coastal streams was conducted infrequently and encompassed a relatively narrow spatial scope. In the Sandy River, 4 artificial substrate sets and 27 ichthyoplankton tows were conducted. During the period sampled, two eggs were captured on artificial substrates while six eggs and seven larvae were encountered in ichtyoplankton tows; no eggs or larvae were identified as eulachon. Umpqua River District biologists opportunistically conducted 12 artificial substrate sets and 16 ichthyoplankton tows. No eggs were observed in artificial substrate sets. One egg and 15 larvae were collected during vertical plankton tows in the Umpqua River; however, none of these specimens were identified as eulachon. In the limited sampling that took place in the Coos River (nine artificial substrate sets), no eggs from any species were encountered. Given catch of eulachon larvae and eggs can vary considerably in both space and time (see above and Report A), an opportunistic sampling approach may be insufficient to characterize freshwater distribution for the purpose of identifying critical habitat. Certainly, devoting a greater number of resources would allow for a more intensive sampling regimen, which would presumably provide for greater confidence in evaluating the presence or absence of spawning activity. Future work should focus on capturing both spatial and temporal variability and sampling designs should be developed to maximize the probability of encountering demersal eggs or ichthyoplankton should they be present.

Eggs and/or larvae were encountered at 38 of the 52 (73%) sites sampled by WDFW from 20 January 2011–7 May 2013. Where the same site was sampled in consecutive years, eggs and/or larvae were always encountered during all sampling events (Tables 1–3).

In addition to the systematic sampling of the mainstem Columbia River (James et al. 2014, Report A), WDFW conducted a limited survey at sites off the Ports of Longview and Kalama on February 10, 2012. Eulachon larvae and eggs were present both inshore and in the shipping channel near sites being proposed for port development and dredging (Table 1).

WDFW staff surveyed several lower Columbia River tributaries on multiple occasions during 2011. These tributaries included the Grays River, Skamokawa Creek, Elochoman River, Cowlitz River, Kalama River and Lewis River. The Grays River was also surveyed during 2012 and 2013 as part of work carried-out for the SSB objective (James et al. 2014, Report A). Eggs and/or larvae were detected at each site during all sampling events (Table 2).

One of the tasks proposed under the freshwater distribution objective was to complete surveys of the Sandy and Cowlitz rivers to assess the spatial extent of spawning activity. This work was to be conducted during January 1-May 31, 2011-2013; however, due to the substantial budget reductions, this element was only partially addressed. During 2011, researchers from the Cowlitz Indian Tribe evaluated the upriver extent of spawning in several rivers through the collection of eggs, larvae and adult eulachon.

WDFW sampled 15 rivers outside the Columbia River drainage (Table 3). During 2011, ichthyoplankton surveys were conducted in the Naselle and Bear rivers (Willapa Bay system). During 2012, staff from WDFW surveyed the North Fork of the Willapa River and two rivers in the Grays Harbor system (Humptulip and Chehalis rivers). Along the North Coast of Washington, researchers surveyed the Moclips River, Clearwater River, Hoh River, Goodman Creek, and Quillayute River. Sites sampled along the Strait of Juan de Fuca included the

Clallam and Elwha rivers, while in Hood Canal, the Big Quilcene, Little Quilcene and Tahuya rivers were surveyed.

Surveys outside the Columbia River drainage typically consisted of only a single plankton tow. Given this infrequency, it is not surprising that eulachon larvae and eggs were only detected in less than half of these locations: Naselle, Bear, Willapa, and Chehalis rivers. Further sampling effort is required in these and similar locations to assess with confidence the distribution of eulachon spawning within the designated range of the species.

References

NMFS-NWR (National Marine Fisheries Service Northwest Region). 2013. Federal Recovery Outline: Pacific Eulachon Southern Distinct Population Segment. 24p.

Smith, W.E. and R.W. Saalfeld. 1955. Studies on Columbia River smelt *Thaleichthys pacificus* (Richardson). WDF Fisheries Research Papers 1 (3): 3-26.

Figures

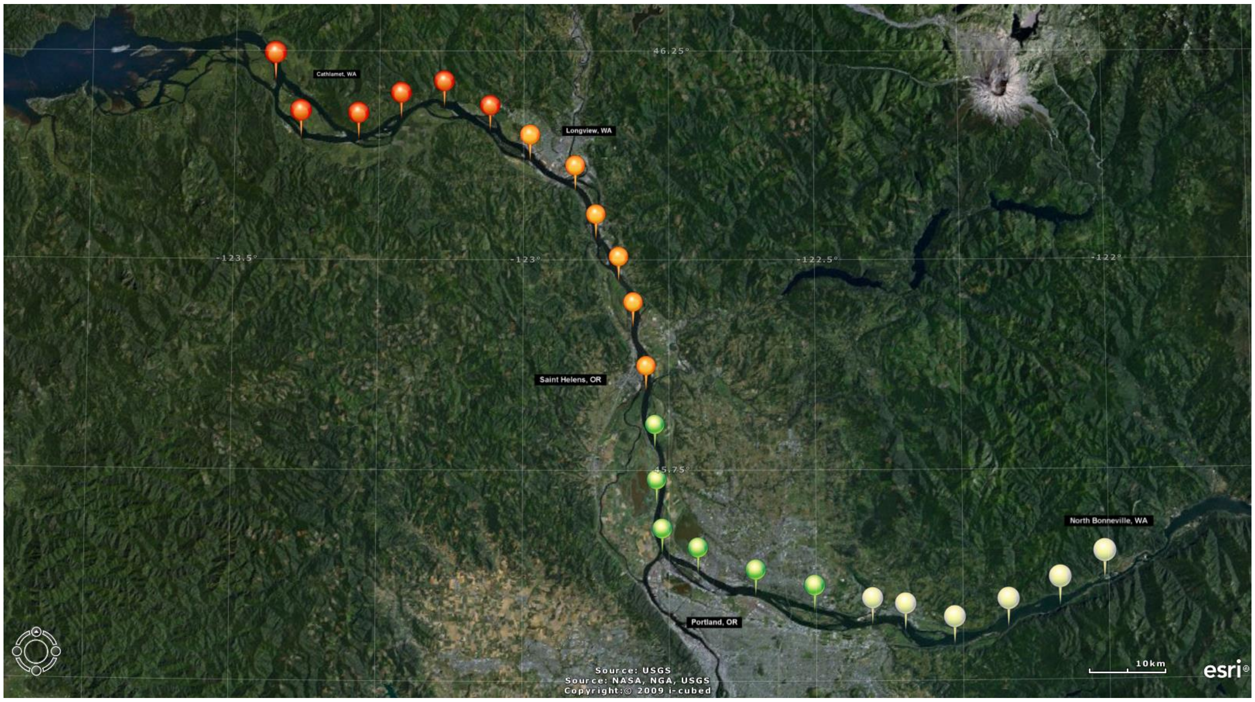

Figure 16. Distribution of sampling locations where artificial substrate and/or ichthyoplankton nets were deployed in the Columbia River below Bonneville Dam, 10 January–31 May 2011 and 21 November 2011–24 July 2012. Red symbols = zone 1, orange symbols = zone 2, green symbols = zone 3, pale green symbols = zone 4. Due to budget constraints, sites in zone 1 were not sampled in 2012.

Figure 2. Distribution of sampling locations in the Sandy River, 27 January–2 June 2011. Red symbols indicate the locations of artificial substrate sets and orange symbols identify locations where ichthyoplankton tows were conducted.

Figure 3. Distribution of sampling locations (artificial substrate sets and/or oblique ichthyoplankton tows) in the Umpqua River, 20 January–8 June 2011.

Figure 4. Map of the tributaries of the lower Columbia River surveyed by WDFW for eulachon eggs and larvae during 2011-2013.

Figure 5. Map of the Washington State rivers outside the Columbia River system where eulachon egg and larvae samples were collected by WDFW during 2011 and 2012.

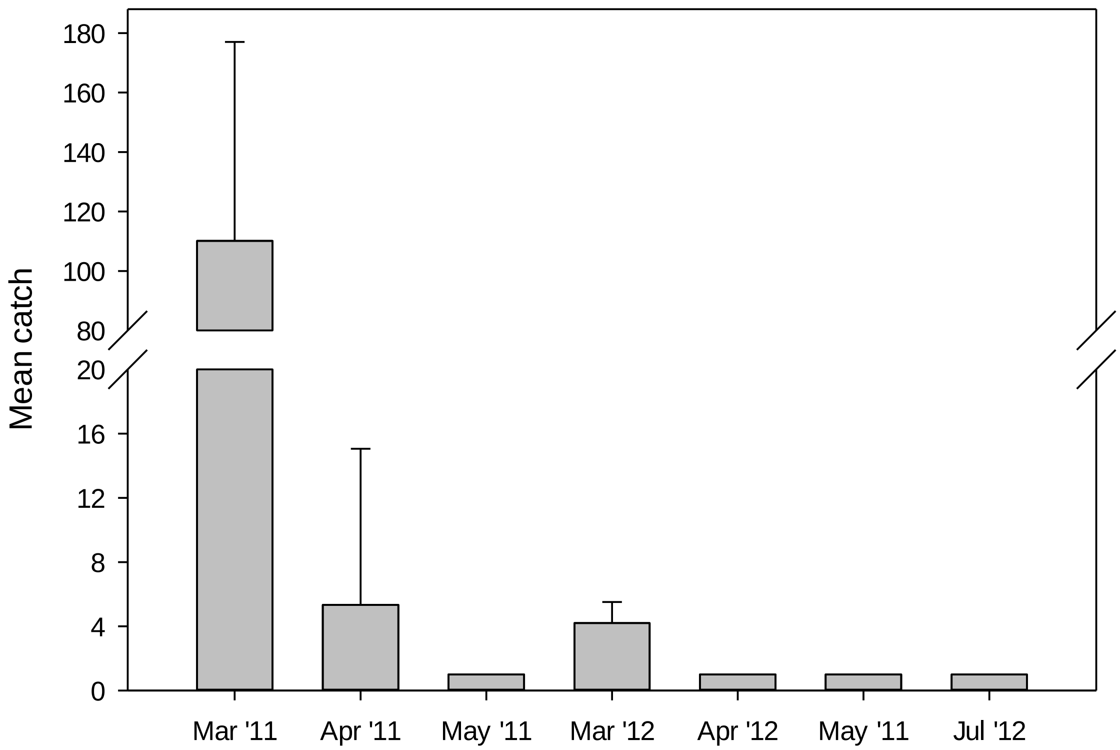

Figure 6. Temporal distribution of eulachon larvae encounters in the Columbia River below Bonneville Dam. Error bars represent one standard deviation from the mean.

Tables

Table 1. Summary of main stem Columbia River sites surveyed by WDFW for the presence of eulachon egg and larvae during 2011-2013.

Sample Sites	River Kilometer	Run Year Sampled	Sample Dates	Mean Secchi Depth (cm)	Mean Temperature (^oC)	Mean Depth (m)	Mean Tow (mm:ss)	Mean Tow (m^3)	Eggs/Larvae Observed
Port of Longview above Barlow Pt.	101	2012	2/10	140	5	9	4:49	30	Yes
Same - inshore shallower	101	2012	2/10	140	5	3	6:41	14	Yes
Just below Alum plant	102	2012	2/10	140	5	10	5:00	45	Yes
Same - inshore shallower	102	2012	2/10	140	5	4	3:38	28	Yes
Off old Alum plant	103	2012	2/10	140	5	10	4:48	40	Yes
Same - inshore shallower	103	2012	2/10	140	5	4	3:45	23	Yes
Off fiber channel below Cowlitz R. mouth	109	2012	2/10	140	5	4	4:04	3	Yes
same off futher	109	2012	2/10	140	5	8	4:05	20	Yes
Lower end Carrolls slough off old dolphin island	110	2012	2/10	140	5	3	3:45	64	Yes
Port of Kalama below steel dock, off dredge spoil	116	2012	2/10	140	5	11	7:24	32	Yes
off middle of steel dock	116	2012	2/10	140	5	14	8:01	5	Yes

Table 2 Summary of lower Columbia River tributaries surveyed by WDFW for the presence of eulachon egg and larvae during 2011-2013.

Water Body	Sample Sites	River Kilometer	Run Year Sampled	Sample Dates	Mean Secchi Depth (cm)	Mean Temperature (°C)	Mean Depth (m)	Mean Tow (mm:ss)	Mean Tow (m^3)	Eggs/Larvae Observed
Grays River	Power Lines	9	2011	1/20, 2/1, 2/10, 2/12,2/18,3/2, 3/17, 3/24, 3/29, 4/11, 4/19, 4/28, 5/2, 5/12	175	6	5	4:13	23	Yes
	Below Impie Creek (Barn/Crane/Metal Shop gone)	7	2011	1/20, 2/1, 2/10, 2/12,2/18,3/2, 3/17, 3/24, 3/29, 4/11, 4/19, 4/28, 5/2, 5/12	154	6	4	3:48	18	Yes
	Power Lines	9	2012	12/20/11, 1/4, 2/1, 2/16, 3/6, 3/21,4/3, 4/9, 4/20, 4/24, 5/3, 5/14	192	8	5	4:12	25	Yes
	Below Impie Creek (Barn/Crane/Metal Shop gone)	7	2012	12/20/11, 1/4, 2/1, 2/16, 3/6, 3/21,4/3, 4/9, 4/20, 4/24, 5/3, 5/14	192	8	4	4:17	24	Yes
	Bridge State Hwy 403 at Rosburg	8	2012	2/1, 2/16, 3/1, 3/6, 3/21,4/3, 4/9, 4/20, 4/24, 5/3	172	8	2	3:20	26	Yes
	Power Lines	9	2013	12/24/12, 1/7, 1/17, 1/23, 1/28, 2/5, 2/11, 2/20, 2/26, 3/8, 3/11, 3/22, 3/26, 4/3, 4/12, 4/18, 4/23, 5/1, 5/7	273	8	5	4:15	22	Yes
	Below Impie Creek (Barn/Crane/Metal Shop gone)	7	2013	12/24/12, 1/7, 1/17, 1/23, 1/28, 2/5, 2/11, 2/20, 2/26, 3/8, 3/11, 3/22, 3/26, 4/3, 4/12, 4/18, 4/23, 5/1, 5/7	273	8	3	4:15	25	Yes
	Bridge State Hwy 403 at Rosburg	8	2013	1/27,1/23, 2/5, 3/22, 3/26, 4/3, 4/12, 4/23	258	7	2	3:48	27	Yes

Table 2 (cont.). Summary of lower Columbia River tributaries surveyed by WDFW for the presence of eulachon egg and larvae during 2011-2013.

Water Body	Sample Sites	River Kilometer	Run Year Sampled	Sample Dates	Mean Secchi Depth (cm)	Mean Temperature (°C)	Mean Depth (m)	Mean Tow (mm:ss)	Mean Tow (m^3)	Eggs/Larvae Observed
Skamokawa Creek	Hwy 4 side of foot bridge	0.3	2011	4/19	78	10	4	9:37	32	Yes
	Vaughn Road Bridge (first County road bridge)	5	2011	4/21	ND	ND	1	6:20	56	Yes
Elochoman River	Hwy 4 Bridge	4	2011	2/1, 2/10, 3/24, 3/29	170	ND	2	3:51	11	Yes
Cowlitz River	Gearhart (~0.5 RM above Coweeman R@ RM 1.3)	3	2011	1/25, 2/16, 3/4, 3/14	24	6	6	2:48	48	Yes
	Maxwells (Carnival Market)	9	2011	1/25, 2/16, 3/4, 3/14	24	6	4	2:38	42	Yes
	Lexington (1.8 RM above Bridge@ RM 7.8)	15	2011	1/25, 2/16, 3/4, 3/14	24	6	5	2:15	50	Yes
	Castle Rock Bridge	29	2011	1/25, 2/16, 3/4, 3/14	24	6	3	2:22	56	Yes
Kalama River	Sportsman Club	0.3	2011	2/1, 3/9	159	5	6	2:20	16	Yes
	Monkey Hole	1	2011	2/1, 3/9	159	5	5	2:29	22	Yes
	Camp Kalama	2	2011	2/1, 2/23, 3/9	146	5	4	4:03	26	Yes
Lewis River	Beebees	1	2011	1/18, 2/23, 3/9, 3/31	188	5	6	3:15	39	Yes
	RR Bridge	3	2011	1/18, 2/23, 3/9, 3/31	188	5	5	3:54	27	Yes
	Forks (East Fork Lewis River confluence)	4	2011	1/18, 2/23, 3/9, 3/31	188	5	6	4:11	49	Yes
	I-5 Bridge	9	2011	1/18, 2/23, 3/9, 3/31	188	5	5	4:06	36	Yes

Table 3. Summary of Washington State rivers (outside the Columbia River watershed) surveyed by WDFW for the presence of eulachon egg and larvae during 2011 and 2012.

System	Water Body	Sample Sites	River Kilometer	Run Year Sampled	Dates	Mean Secchi Depth (cm)	Mean Temperature (°C)	Mean Depth (m)	Mean Tow (mm:ss)	Mean Tow (m^3)	Egg/Larvae Observed
Willapa Bay	Naselle R.	Hwy 401 Bridge (Swinging Bridge) Northside	13	2011	3/2	ND	ND	5	4:28	44	Yes
	Bear R.	Hwy 101 Bridge	3	2011	3/2	20	7	2	5:25	25	Yes
	N. Fork Willapa R.	WDFW launch at mouth of Wilson Creek	16	2012	1/30	ND	ND	ND	3:00	ND	No
		Off of 101 Hwy bridge	10	2012	1/30	ND	ND	ND	5:00	ND	Yes
Grays Harbor	Chehalis R.	Friends Landing boat ramp	16	2012	3/19	ND	ND	ND	5:30	ND	Yes
	Humptulips R.	Boat launch @ Hwy bridge	2	2012	3/19	ND	ND	ND	10:00	ND	No
North Coast	Moclips R.	At Hwy bridge	0.2	2012	3/20	ND	ND	ND	5:00	ND	No
	Clearwater R.	WDNR access site[1]	0.2	2012	3/19	ND	ND	ND	10:00	ND	No
	Hoh R.	Lower river, Oil City	0.2	2012	2/1	ND	ND	ND	10:00	ND	No
		Park boundry, Oil City road	2	2012	3/20	ND	ND	ND	10:00	ND	No
	Goodman Cr.	3 miles from mouth	5	2012	2/1	ND	ND	ND	10:00	ND	No
		Trail end of spur road near highway bridge	0.3	2012	3/20	ND	ND	ND	3:00	ND	No
	Quillayute R.	Near mouth (outgoing tide)	0.2	2012	2/2	ND	ND	ND	10:00	ND	Maybe
		Tribal lauch site off La Push Road	0.3	2012	3/20	ND	ND	ND	8:00	ND	No
Strait of Juan de Fuca	Clallam R.	City park footbridge (outgoing tide)	0.2	2012	2/2, 3/19	ND	ND	1	10:00	ND	No
	Elwha R.	Picnic area @ WDFW Hatchery	3	2012	3/19	ND	ND	ND	3:00	ND	No
Hood Canal	Big Quilcene R.	Bridge (PD Waypoint 4)	1	2012	4/28	ND	ND	1	9:39	ND	No
	Little Quilcene R.	Bridge (Waypoint 3)	2	2012	4/28	ND	ND	1	10:18	ND	No
	Tahuya R.	Bridge (PD Waypoint 5)	1	2012	4/28	ND	ND	2	15:29	ND	No

Report C

Marine Life Stage of Eulachon and the Impacts of Shrimp Trawl Operations

Lorna L. Wargo
Kris E. Ryding
Brad W. Speidel
and
Kristen E. Hinton

Washington Department of Fish and Wildlife
Fish Program
Marine Resources Division
600 Capitol Way N.
Olympia, Washington 98501-1091

Final Report to:

National Oceanic and Atmospheric Administration
1401 Constitution Avenue, NW
Room 5128
Washington, DC 20230

For NOAA Fisheries Protected Species Conservation and Recovery
Grant Number NA10NMF4720038

September, 2014

Acknowledgements

We would like to thank the Washington shrimp fleet for generously cooperating with our research efforts and for safely housing our observers aboard their vessels. Their willingness to collaborate and share information was appreciated.

Mike Allen	William Dickey	Tom Jones	Michael Smith
Ed Bittner	Ben Downs	Buddy King	Cody Vandercoevering
Rich Brown	Craig Howse	Roger Marshall	Gary Vining
Jam Copenhaver	Bert Johns	Jimmy Myers	Rocky Walker
Paul Daniels	Robert Johnstone	Tung Nguyen	Jerry Wright

We would also like to thank our observers whose data collection was vital to this study.

Richard Burrows	Kristen Hinton	James Pace	Brad Speidel
Mark Flahaut	Ross Kary	Michael Sinclair	

Paul Daniels (F/V Swell Rider) and Ben Downs (F/V Pacific Dove) were instrumental in helping us with this study, providing advice, and by doing advanced voluntary work with their excluders and net configurations in the early stages of, as well as throughout, this study.

For assisting in tracking down vessels and for allowing us a portion of the annual shrimper's industry meeting agenda, the ever helpful Bill Weidman at Washington Crab Producers Inc., deserves our recognition.

To Dr. Tien-shui "Theresa" Tsou, we offer our thanks for her wise leadership and thoughtful direction throughout the project.

Last, but certainly not least, we would like to extend our thanks to Dr. Robert "Bob" Hannah (ODFW), for guiding us in the early stages of this project, and for always being our "go-to guy" while setting up and carrying out this project.

Table of Contents

ACKNOWLEDGEMENTS 84
LIST OF FIGURES 87
LIST OF TABLES 90
ABSTRACT 92
INTRODUCTION 93
  Fishery Description 93
STUDY OBJECTIVES AND REPORT STRUCTURE 95
METHODS 96
  Catch and Logbook Data 96
  Vessel Selection 96
  Observer Data Collection 97
    Trip 97
    Tow 97
    Catch Composition 97
    Biological Data 97
  Data Processing 98
    Error Checking 98
    Bycatch Ratios 98
RESULTS AND DISCUSSION 99
  Fishery Catches and Effort 99
  Observer coverage levels 100
  Eulachon Catch, Rates and Spatial Distribution 100
  Eulachon Bycatch Evaluation 101
    Analysis of factors effecting Eulachon bycatch 101
    Analytical Techniques 101
    Exploratory Analysis 102
  Results and Discussion of Eulachon Bycatch Evaluation 103
    Vessel, Gear, and Month - 2011 103
    Vessel and Month - 2012 105
    Depth, Latitude, and Tow Time 106
      Depth 106

Latitude 107
Tow Time.. 107
Eulachon biological sampling.. 108
CONCLUSIONS.. 109
REFERENCES.. 111
FIGURES.. 113
TABLES.. 138
APPENDIX A. WDFW PINK SHRIMP TRAWL LOGBOOK PAGE EXAMPLE 159

List of Figures

Figure 1. Stylized schematic of a pink shrimp trawl net with “ladder” style groundgear. This net is configured from the front and is not to scale; all measurements are approximations (Hannah 2011). 113

Figure 2. Stylized schematic of a pink shrimp trawl net without a ground line, but with a “tickle chain.” This net is configured from the front and is not to scale; all measurements are approximations (Hannah 2011) 113

Figure 3. Stylized schematic of fishing net with BRD and escape hole, showing how fish enter net and can escape prior to entering the cod end (Doyle and Hildenbrand 2013) 114

Figure 4. Stylized map showing Oregon Dept. of Fish and Wildlife pink shrimp areas versus Washington Dept. of Fish and Wildlife marine fish/shellfish areas........ 115

Figure 6. A comparison of annual landing by grouped catch area 116

Figure 7. Monthly Washington landings by ODFW management area in 2011 117

Figure 8. Monthly Washington landings by ODFW management area in 2012 117

Figure 9. Monthly Washington CPUE grouped by ODFW management area in 2011........ 118

Figure 10. Monthly Washington CPUE grouped by ODFW management area in 2012........ 118

Figure 11. Eulachon CPUE (a) and bycatch ratios (b) across 2011 and 2012........ 119

Figure 12. Density plots of bycatch ratios of eulachon for each of the vessels observed in 2011 120

Figure 13. Density plots of the natural logarithm of bycatch ratios of eulachon for each of the vessels observed in 2011 120

Figure 14. Density plots of bycatch ratios of eulachon for each of the vessels observed in 2012 121

Figure 15. Density plots of the natural logarithm of bycatch ratios of eulachon for each of the vessels observed in 2012 121

Figure 16. A dot plot of the difference from the mean overall logarithm of bycatch for each vessel observed in 2011........ 122

Figure 17. Boxplots of the natural logarithm of the bycatch ratio of eulachon for month fished in 2011 122

Figure 18. Boxplots of the natural logarithm of bycatch ratio by excluder size used in the 2011 pink shrimp fishery........ 123

Figure 19. Interaction plot of the effects of gear (excluder bar spacing) and month on the natural logarithm of eulachon bycatch. If no interactions were present, the line would be parallel 123

Figure 20. Interaction plot of gear type by month. The increased bycatch in October for the 0.875 bar spacing is most likely the reason for the significant interaction. No interaction effect is typically indicated by parallel, or nearly parallel lines........ 124

Figure 21. Differences from mean bycatch for the 13 vessels with observers that fished in 2012 and were included in this analysis ... 124

Figure 22. Boxplots of the distribution of bycatch ratios for each month fished in 2012. May had the highest ratios, April and October the lowest ... 125

Figure 23. Relationships between depth in fathoms and log (bycatch ratio) for each month in 2011. The difference among months indicates a significant interaction effect ... 125

Figure 24. Relationships between depth in fathoms and log (bycatch ratio) for each month in 2012. The difference among months indicates a significant interaction effect ... 126

Figure 25. Boxplot of the natural logarithm of bycatch ratios for tows fished north and south of the Columbia River plume ... 126

Figure 26. Relationships between fishing location as measured by latitude and log (bycatch ratio) for each month in 2012. The difference in slopes among months indicates a significant interaction effect ... 127

Figure 27. Relationships between tow time and log (bycatch ratio) for each month in 2012. The difference in slopes among months indicates a significant interaction effect ... 127

Figure 28. Eulachon total length to fork length (n = 2950), derived from study data, to be used when only total length was recorded ... 128

Figure 29. Eulachon length frequency for 2011 with lengths pooled in two millimeter increments ... 128

Figure 30. Eulachon length frequency for 2012 with lengths pulled in two millimeter increments ... 129

Figure 31. Eulachon length frequency for April, in standard length, presented for comparison with DFO findings (DFO 2014) ... 129

Figure 32. Eulachon length frequency for May, in standard length, presented for comparison with DFO findings (DFO 2014) ... 130

Figure 33. Eulachon length frequency for June, in standard length, presented for comparison with DFO findings (DFO 2014) ... 130

Figure 34. Eulachon length frequency for July, in standard length, presented for comparison with DFO findings (DFO 2014) ... 131

Figure 35. Eulachon length frequency for August, in standard length, presented for comparison with DFO findings (DFO 2014) ... 132

Figure 36. Eulachon length frequency for September, in standard length, presented for comparison with DFO findings (DFO 2014) ... 132

Figure 37. Eulachon length frequency for October, in standard length, presented for comparison with DFO findings (DFO 2014) ... 133

Figure 38. Eulachon median length frequency by month in 2011 ... 134

Figure 39. Eulachon median length frequency by month in 2012 ... 134

Figure 40. Mean length frequencies pooled by ODFW management area for 2011 ... 135

Figure 41. Mean length frequencies pooled by ODFW management area for 2012 135
Figure 42. Eulachon lengths by tow depth, in fathoms, in 2011 136
Figure 43. Eulachon lengths by tow depth, in fathoms, in 2012 136
Figure 44. Eulachon median length frequency by year 137
Figure 45. Eulachon median length by BRD bar-spacing with 0.75 inches for both 2011 and 2012 137
Figure 46. Eulachon median length by BRD spacing with 1.25 inches in 2011 and 0.75 inches in 2012 137

List of Tables

Table 1. Crosswalk table of ODFW catch areas and WDFW marine fish-shellfish fish ticket catch area codes. ... 138

Table 2. Species encountered as bycatch and recorded by observers pooled for both 2011 and 2012 ... 139

Table 3. The number of observed tows with eulachon for each vessel/month combination in the 2011 Washington pink shrimp fishery ... 144

Table 4. The number of observed tows with eulachon for each of the 5 gear types by vessel in the 2011 Washington pink shrimp fishery ... 144

Table 5. The number of observed tows with eulachon by month and gear type in the 2011 Washington pink shrimp fishery ... 145

Table 6. The number of observations that were south and north of the Columbia River plume by vessel in 2011 ... 145

Table 7. The number of observed tows with eulachon for each vessel/gear type combination in the 2012 Washington pink shrimp fishery ... 146

Table 8. The distribution of tows with eulachon by month and vessel for the 2012 pink shrimp fishery. All tows in this table were made with the 0.75 inch bar spacing ... 146

Table 9. Estimates of the contribution of Vessel to the overall variance of the logarithm of bycatch ratios for 2011 ... 147

Table 10. Results of the analysis that removed month first from the above model using observations from June, July, and August, gear types 0.75, 0.875, 1.25, and 1.5 ... 147

Table 11. Results of the analysis that removed gear type first from the model (Eq. 3) using observations from June, July, and August, gear types 0.75, 0.875, 1.25, and 1.5 ... 147

Table 12. ANOVA results table for the analysis of the August tow data (Eq. 4) ... 148

Table 13. Results of the pairwise comparison analysis for different gear types in August 2011. The 0.875 gear type was significantly lower than the 0.75, 1.25, and 1.5 inch bar spacing ... 148

Table 14. Results of the analysis that compared the effects 0.875 and 0.75 bar spacing across all months both gears were fished. Month was removed first in this analysis ... 148

Table 15. Results of the analysis that compared the effects 0.875 and 0.75 bar spacing across all months both gears were fished. Gear was removed first in this analysis ... 149

Table 16. Results of the analysis testing the effect of month for tows using the 0.875 gear type only ... 149

Table 17. Results of the pairwise comparisons of mean bycatch ratio by for the months fished with the 0.875 gear types. April is significantly higher than all months except October ... 150

Table 18. Estimates of the contribution of Vessel to the overall variance of the logarithm of bycatch ratios for 2012 ... 151

Table 19. Results of the analysis testing the effect of month for 2012 151

Table 20. Results of the pairwise comparisons from the Tukey HSD test for months fished in 2012. May was consistently higher than all months but June 152

Table 21. Results of the analysis testing the effect of depth with month for 2011. Only the 0.875 gear types and associated months were used for the analysis 153

Table 22. The effect of changes in one fathom of fishing depth on the amount of bycatch, in pounds, for each month fished in 2011 (Eq. 6) 153

Table 23. Analysis of deviance table for the analysis of the effects of month and depth on log(bycatch) for 2012 154

Table 24. The effect of changes in one fathom of fishing depth on the amount of bycatch, in pounds, for each month fished in 2012 (Eq. 6) 154

Table 25. The number of tows for north and south of the Columbia River plume in 2011....... 155

Table 26. The number of tows for each type and location with regard to the Columbia River plume in 2011 155

Table 27. Analysis of deviance table for the analysis of the effects of month and latitude on log(bycatch) in 2011 for tows fished north of the Columbia River 155

Table 28. Analysis of deviance table for the analysis of the effects of month and latitude on log(bycatch) in 2012. All fishing occurred north of the Columbia River 156

Table 29. The effect an 0.5 degree increase in latitude of fishing on the amount of bycatch, in pounds, for each month fished in 2012 (Eq. 7) 156

Table 30. Analysis of deviance table for the analysis of the effects of month and tow time on log(bycatch) in 2011 157

Table 31. Analysis of deviance table for the analysis of the effects of month and tow time on log(bycatch) in 2012 157

Table 32. The effect a 30 minute increase in time per tow on the amount of bycatch, in pounds, per 10,000 pounds of shrimp for each month fished in 2012 (Eq. 8)......................... 158

Abstract

In March 2010, the National Marine Fisheries Service (NMFS) listed the southern Distinct Population Segment (DPS) of *Thaleichthyus pacificus*, also known as "eulachon," as threatened under the Endangered Species Act (75 FR13012). The Eulachon Biological Review Team (BRT) ranked bycatch in the shrimp trawl fishery second among the severity of threats impacting recovery of eulachon stocks (Gustafson et al. 2010). At that time, bycatch data was lacking for the Washington ocean shrimp trawl fishery. In this study we evaluate various factors influencing the catch of eulachon by placing observers onboard Washington shrimp trawl vessels in 2011 and 2012 to collect catch composition data at the tow level. In 2011, 24 % of trips were observed. In 2012, following reduced funding, 16% of trips were observed. During these two comparatively strong years for pink shrimp production, eulachon bycatch was estimated at 7.8 mt (17,132 pounds) for 2011 and 171 mt (378,011 pounds) for 2012. This increase in bycatch occurred at the same time fishery regulations reduced the allowable bar spacing for fin fish excluders to 0.75 inch (19mm) in 2012. Results indicate a reduction in bycatch amounts by excluders with smaller, or 1 inch and less, bar-spacing in the panel, compared to larger, or more than 1 inch, excluders but not a significant difference among the smaller excluders.

Introduction

In March 2010, the National Marine Fisheries Service (NMFS) listed the southern Distinct Population Segment (DPS) of *Thaleichthyus pacificus*, also known as "eulachon," as threatened under the Endangered Species Act (75 FR13012). The southern DPS range includes and extends from the Mad River in California to the Skeena River in British Columbia. In the listing, the Pacific Northwest trawl fishery for ocean pink shrimp (*Pandalus jordani*) was deemed a moderate threat to eulachon recovery; the Eulachon Biological Review Team (BRT) ranked bycatch second among the severity of threats impacting recovery of eulachon stocks (Gustafson et al. 2010). At that time, bycatch rates were available for the California, Oregon, and British Columbia ocean pink shrimp trawl fisheries, but was lacking for the Washington ocean shrimp trawl fishery. To close this data gap, the Washington Department of Fish and Wildlife (WDFW) undertook two actions: 1) implemented regulations effective in 2010 to require participation of Washington licensed shrimp trawl fishers in the West Coast Groundfish Observer Program (WCGOP); and 2) under Objective 3 (Marine Life-stage) implemented a state-based observer program to assess pink shrimp trawl fishery impacts on eulachon.

The purpose of the Marine Life-stage objective was to evaluate the scale of bycatch in the fishery, determine any temporal or spatial patterns of eulachon distribution in the shrimp trawl fishery which might point to management strategies to reduce encounters, and finally, collect biological data from eulachon during the marine life history phase. In this report, we present project results for eulachon; an expanded WDFW technical report (in process) addresses results for other species or categories of species (rockfish and flatfish) encountered during the study.

Fishery Description

Dating from the late 1950's, the ocean pink shrimp trawl fishery is a vital component of Washington's coastal economy. Beginning off Grays Harbor in 1956, the inception of mechanical peelers and growing consumer demand for "cocktail" shrimp spurred fishery development and catches in 1958 exceeded 6.5 million pounds (Alverson et al. 1960). Through the 1960's landings did not exceed two million pounds. During the following two decades the fishery expanded with abundant shrimp and good markets. In 1990, nearly 100 vessels landed about 15 million pounds. However, dramatic declines in local abundance drove many fishers out of the fishery; by 1994 the active fleet totaled just over 50 vessels with fewer than 30 several years later. Since the late 1990's, landings have generally increased, and the direct value of the fishery has trended continuously upward while fleet size has continued to decline. During this same period, annual shrimp landings into Washington averaged about 20 percent of the coastwide total for California, Oregon, and Washington combined.

The US west coast ocean pink shrimp fishery is state managed, although it is also subject to federal restrictions for groundfish catch and essential fish habitat (EFH) through the Pacific Fishery Management Council Groundfish Fishery Management Plan (PFMC 2014). Along the Washington coast, the pink shrimp fishery operates in federal waters (3-200 miles); most commercial gears, including trawl, are prohibited inside Washington state waters (0-3 miles). A 1994 limited entry (LE) license program established 143 licenses. As of 2012, the number of LE licenses stood at 83. Licenses must be renewed annually, but do not need to be fished actively to remain valid; the decline is attributed to LE license owners electing not to renew.

The regulatory history of the coastal pink shrimp fishery is marked by few changes. In 1982, the states of Washington, Oregon, and California established a common season and a maximum count per pound regulation to minimize regulatory conflicts. Washington rules for minimum codend mesh size were rescinded in 1994. Following the overfished designation of canary rockfish (*Sebastes pinniger*) by the Pacific Fishery Management Council in 1999 (Wallace 2011) and a two-year implementation program, the mandatory use of biological reduction devices (BRDs), or fin fish excluders, was set in permanent rule, effective 2003. Typically, rockfish and other species had represented about 5% of the total direct value of the shrimp fishery.

For the purposes of this study and report, data attributed or references to "fleet" mean only Washington licensed vessels that landed catch at Washington ports. State pink shrimp trawl fishery licenses issued by Washington, Oregon, and California regulate where a vessel may land; licensed fishers/vessels may fish in federal waters (3-200; EEZ) offshore Washington, Oregon or California. Landing receipts (fish tickets) and logbook data document that Washington licensed vessels routinely land shrimp to Washington ports that were caught off Oregon and occasionally California. Fleet size is not static and can fluctuate within and between seasons as dual licensed vessels move between states/ports. Since 2000, the total active Washington fleet size has not exceeded 30 vessels. Washington coastal shrimp fishing activity is split between two ports: Westport and Ilwaco, with processors located at each.

The fishing season is fixed in permanent rule, opening and closing on April 1 and October 31, respectively. Fishing occurs during daylight hours reflecting the behavior of ocean pink shrimp which exhibit a vertical diurnal migration, moving to the bottom during daylight hours and ascending to feed at night. The typical commercial trip ranges from 3 to 6 days including transit to and from the fishing grounds. Shorter trips can occur when fishing is especially productive.

Fishing activity occurs over muddy bottom within the continental shelf. The fleet includes vessels that tow one or two independent nets, and that are referred to as single or double rigged, respectively. Towing duration is typically 0.5 to 2 hours at speeds of 1.5 to 2 knots. On double rigged vessels, the nets are deployed and retrieved simultaneously and the contents dumped into a container or "hopper," or an area on deck. Bycatch species are manually removed by crew as pink shrimp are run across a sorting belt and then loaded and iced in the vessel hold.

The majority of active vessels in the Washington fleet are double-rigged with semi-pelagic, fine-meshed shrimp trawl nets. These vessels tow their nets from the end of their out-riggers (a long boom guyed out perpendicular to the centerline of the vessel) which handle each net independently. Each net has its own mouth-spreading doors and is operated by its own winch to maintain an even balance while towing. Nets utilize groundgear (the portion of rigging attached to the bottom of the net) to maximize shrimp catch. Typically, one of two types of groundgear is used: a ladder style or tickler chain type (Figures 1 and 2). The ladder style ground gear is either chain, cable, or a mix of both, rigged in the shape of a ladder and attached to the bottom line of the net known as the fishing line. When a net is equipped with a "tickler chain" the fishing line is usually weighted with rigging (chain) and preceded by a length of chain attached to the door-connecting lines which span the width of the net. The tickler chain skims the seafloor ahead of the opening as the nets are towed.

From 2003 to the outset of this study in 2011, Washington regulations permitted rigid-panel fin fish excluders, also known as biological reduction devices or BRDs, with bar spacing of up to 2 inches or soft-panel excluders constructed of netting with meshes not exceeding 5.5 inches (140 mm). Yet, by 2011, within the Washington fleet, none of the rigid-panel excluders in use had bar spacing in excess of 1.5 inches (38mm) and only one vessel was outfitted with a soft-panel excluder.

Based on this and findings by Hannah (2007) that 0.75 inch (19mm) bar spacing could maintain shrimp production while reducing bycatch, Washington rules were amended in 2012 to allow only rigid-panel style excluders and to reduce legal bar spacing to a maximum of 0.75 inch. However, a limited number of special gear permits were issued that allowed an excluder in only one net to exceed 0.75 inch for a specified duration of time. Fishers requested this accommodation to allow testing of net configurations with the 0.75 inch excluder against a control – a previously used excluder – to compare catch rates.

The use of excluders with 2 inch (51mm) bar spacing became a permanent requirement in 2003 as a means to reduce the bycatch of rockfish species, mainly canary rockfish. As a result, most adult finfish and other bycatch avoided capture, greatly reducing the time and effort associated with sorting (Hannah et al. 2011). Spurred by the convenience of sorting less bycatch, many fishers began installing excluders with narrower bar spacing, effectively staying ahead of regulatory requirements.

Figure 3 depicts a trawl net- excluder configuration typical to the Washington fleet. The excluder panel is set at an angle, with the degree varying by vessel. As catch moves down the net, the excluder allows or deflects larger fish out through an escape hole positioned in front of and generally atop the excluder; shrimp and smaller fish unable to escape, pass through the bars and into the codend of the net. Washington regulations stipulate a minimum escape hole of 100 square inches (0. 64 m^2); however, a number of vessels have enlarged the opening, the largest opening is almost 20 square feet (1.9 m^2).

Study Objectives and Report Structure

When originally proposed, the Marine Life-stage objective was comprised of two separate subobjectives. The first, led by Dr. Robert Hannah, Oregon Department of Fish and Wildlife (ODFW), was to evaluate trawl gear and bycatch interactions. This objective was removed from the project due to reductions in funding and accomplished through other fund sources. This report presents the work and findings to meet the second Marine Life-stage subobjective: observation and evaluation of eulachon bycatch in the Washington pink shrimp trawl fishery.

More specifically, the goal for the study was to evaluate various factors influencing the catch of eulachon. This was accomplished, in part, by placing observers onboard shrimp trawl vessels to collect catch composition data at the tow level. Ultimately this information will be used to inform management strategies to reduce eulachon bycatch in the pink shrimp trawl fishery.

Under Methods, we describe fishery catch data sources and compilation; skipper logbook data; the observer program including vessel selection, observer deployment and observer sampling protocols; and bycatch ratio calculation. Results and discussion are combined, and cover fishery and observer performance, eulachon bycatch estimates, bycatch evaluation modeling and eulachon biological data. Key findings are summarized at the end.

Methods

Catch and Logbook Data

Fishery catch data were retrieved from the WDFW LiFT database. To facilitate comparison of fishery catch statistics between Washington and Oregon, catch areas described by the Oregon Department of Fish and Wildlife were utilized for this report. Table 1 and Figure 4 provide a crosswalk between these and WDFW marine fish-shellfish fish ticket catch area codes.

Estimates of catch, hours fished, and location were documented for each trip at the tow level and obtained from skipper logbooks. For all analyses, skipper catch estimates were adjusted to the weight documented on fish tickets since the former are approximations and the latter measured values. Catch was assigned to areas using skipper tow location data. Hours fished were computed as single-rig equivalents (SRE): a single rig hour equals 1.6 times a double-rig hour.

In instances when a logbook was not received, the catch, documented on the WDFW fish ticket from that trip, was assigned by month, proportionally to the corresponding Oregon Department of Fish and Wildlife (ODFW) catch area. Estimates of total bycatch and hours fished were expanded to the fleet level from logbook data.

Vessel Selection

Random vessel selection was intended by design. In practice, selection was more opportunistic. Vessels were selected across ports for observation on a trip by trip basis depending on observer availability. Selection was not stratified by port because data confidentiality standards requiring reported data to represent at least three vessels would have precluded the use of a substantial amount of information. The observation period was the length of one trip. Because this study ran concurrently with the WCGOP, vessels were not included in the trip by trip selection process for state coverage while carrying a federal observer. Observer assignment in the WCGOP is on a monthly basis. Vessels were included when federal coverage concluded.

Vessels were also not included under certain other circumstances. Waivers were given to vessels that would have normally been part of the selection process if a vessel was deemed by the observer coordinator to be unsafe for WDFW personnel. In a few instances vessels were carrying extra crew and sufficient living quarters were not available for observers; these vessels were also not included in the selection process during those times. If a normally selected vessel was found not available for observation, e.g. due to a mechanical breakdown, the observer was transferred to the next available vessel. On rare occasions, observers were deployed onboard a vessel departing from Warrenton, Oregon when the skipper indicated the vessel intended to land in Washington.

To ensure new vessels entering the fishery were identified and considered in the selection process, ports and incoming fish tickets were monitored by observers and the observer coordinator. During the study, fishers intending to fish for and land pink shrimp at Washington ports were required to give advance (usually 24 hours) notice of departure to the observer coordinator as a condition of the fishing permit. Close contact was maintained between the observer coordinator and fishers participating in the pink shrimp fishery to maximize observer coverage.

Observer Data Collection

Data collection methods followed protocols outlined in the NMFS WCGOP sampling manual (NWFSC 2006). Where necessary, methods were adapted or simplified for this study. Compared to groundfish trawl fisheries, sampling the pink shrimp fishery is less complicated because subsampling large catches falling over multiple species categories is not necessary. The targeted retained species – pink shrimp – is homogenous and all other catch is discarded at sea. In this fishery, the quantity of bycatch can be small enough that it is practical to sample an entire haul.

Data collection was broken into a hierarchal organization: trip level, tow level, catch composition, and biological data. At the trip level, observers collected general information about the vessel, fishing gear, logistics, and sampling issues. At the tow level, location, time, depth, and total catch estimate were recorded. For each tow, observers sorted and weighed the catch as close to the species level as their ability and time would allow. When time allowed on any given tow, length frequency data was collected for most species. Priority was given to eulachon and tissue samples were gathered from eulachon for genetic analysis.

Trip

Observers kept logbooks detailing their trip, as well as recording pre trip and general information about the vessels. Before each trip, scale calibration and vessel safety were checked. The vessel's fishing gear was documented with an emphasis on the ground gear used. Each vessel uses a hopper bin on deck to dump the contents of the codend into on each tow. The hopper bin capacity was measured for each vessel to be used during the trip on some tows to calculate volumetric estimates of catch.

Tow

A daily log of tows was kept to collect information regarding the fishing location specifics. New permit requirements included a mandatory skipper logbook to be kept for all coastal pink shrimp fishing activity. These logbooks were referenced by observers throughout each trip to gather information related to their onboard data collection. Skippers would record GPS location, time at beginning and end of the tow, the depth fished, a visual total catch estimate (TCE), and an estimate of bycatch for each tow. This information was transferred daily to observer data and was included with the observer's data packet for each trip.

Catch Composition

It was the observer's goal for each tow to sort and weigh, by species, the entire amount of bycatch. If time did not allow, or the amount of bycatch was too large, a random subsample was collected for composition and the total weight of all bycatch was collected. At times, some bycatch species were sorted into groups above species level when time did not allow a full sort or species identification was problematic. Unknown species were documented and saved for later identification. Table 2 depicts all bycatch species, common and scientific name, encountered over the two year observation period.

Biological Data

After catch compositions were complete, observers randomly collected lengths from encountered species until 50 fish of that species were measured for a trip. In addition, weight data were collected from batches of 50 individuals. Eulachon were prioritized for biological sampling. A caudal fin clip was collected from eulachon and preserved in ethanol. Samples are archived with the WDFW Genetics Unit for later analysis.

Data Processing

Error Checking

All observer data underwent a rigorous quality assurance procedure producing the final data set archived in a Microsoft Access 2010 database. Observers were debriefed weekly, or by trip, to collect and check data, and to address and resolve any sampling issues or data errors. All data were checked prior to keypunching and after against the field sheets. Finally, queries were designed to highlight outliers, GIS software (ArcMap 10.1) was used to identify incorrect location information, and data were matched to fish tickets. Incomplete data or data not meeting sampling protocol standards were eliminated if the omission or error could not be resolved. All remaining data were expanded to the tow level.

Skipper logbooks were checked for errors, omissions, and discrepancies; however, changes were made only when the correct information could be determined without subjectivity.

Bycatch Ratios

Bycatch ratios were the final yielded data product after data processing was complete. Data were expanded to the tow level and then included in a ratio of bycatch to catch.

Observed Weight = the measured weight of a species/species group for the tow

Adjusted Retained Shrimp = the adjusted amount of shrimp retained for the tow

Bycatch Ratio = Observed Weight / Adjusted Retained Shrimp

Retained shrimp estimates for each tow were adjusted so that the sum of these estimates equaled the amount landed on the fish ticket.

TCE = total catch estimate = a visual or measured estimate of the total catch for the tow

Observed Weight = the measured weight of all bycatch for the tow

Adjusted Retained Shrimp = TCE – Observed Weight

When the volume of bycatch precluded complete sampling, tows were subsampled and expanded to the tow level. All observed vessels sorted bycatch species from pink shrimp catch with deck sorting equipment. Generally, a single conveyor-like sorting belt was used to move shrimp into the hold, allowing deckhands to pick fish out along the way. Additional sorting capability was sometimes necessary for tows with large amounts of bycatch. Extra belts, or “smelt belts,” with sandpaper-like surfaces set on an incline select for certain body forms. Shrimp tumble down these belts onto the main belt, whereas small fish stick to the rough surface and drop into a separate chute to be diverted overboard. These two belts (the smelt belt and the main belt) were subsampled simultaneously but separately due to their different compositions.

Tows that were subsampled with only one belt in operation were simply expanded to the tow level. For tows where the smelt belt was utilized and separate catch compositions were recorded, expansions to the tow level were completed separately for each belt and then totaled for the tow.

Subsampled tow expansions:

Weight (species) = the measured weight of a species/species group in the subsample

Expanded weight = weight (species) / weight (subsample) * weight (bycatch)

Dividing TCE for tows with two catch compositions:

Weight (bycatch) = measured total weight of bycatch from the main belt or smelt belt

Weight = measured weight of the total bycatch from the tow

New TCE = the proportion of the total catch estimate now assigned to main belt composition or the smelt belt composition

New TCE = (Weight (bycatch) / Weight * TCE

Results and Discussion

In this section, fishery performance, observer coverage rates and levels of skipper logbook reporting are summarized. Next, we provide estimates of eulachon catch, catch per unit effort (CPUE), and spatial distribution at the fishery level. The subsection entitled, *Eulachon Bycatch Evaluation*, details the modeling approach and results used to evaluate the influence of various factors affecting bycatch at the tow level. Finally, biological data collected during the study from eulachon are presented.

Fishery Catches and Effort

The 2011 and 2012 fishery seasons were comparatively strong for the Washington shrimp trawl fishery (Figure 5). Landings these two years were increased approximately 40% over the average from 2000 through 2010. However, the fleet size was similar to recent years with 15 and 16 vessels in 2011 and 2012, respectively. The direct value of landed catch was about $4.6 million in 2011 and about $4.4 million in 2012; both double the long-term average of $2.2 million from 2000 through 2010.

Discontinued in the early 1990's due to funding reductions, the Washington shrimp trawl logbook program was fully reinstated in 2011. Logbooks were returned for 75 percent of trips in 2011 and 88 percent of trips for 2012 (Appendix 1).

Absent a logbook program prior to 2011, fishery location information could only be derived from catch area reported on fish tickets. Typically, the most productive fishing occurs along the mid-coast of Washington and south to Oregon (Figure 6). Since 2000 catches originating off Oregon have ranged from eight to fifty percent of the annual total landed in Washington. In 2011 and 2012 only, Washington landings include catch taken offshore California. With the inception of the logbook program, catch by area can be derived from skipper data. Figures 7 and 8 depict monthly landings by ODFW management area for 2011 and 2012. Overall, 2011 catches from Oregon and California represented a smaller percentage of the annual total than in 2012, but with a more southerly distribution, coming from the Mud Hole and areas to the south. In comparison, the majority of catches originating offshore Oregon and/or California in 2012 were from the Mud Hole and areas to the north.

Logbook data were used to estimate hours fished and CPUE for the fishery in 2011 and 2012. Data are not available for comparison across years within the fishery, but similar to Oregon, catch rates were higher in 2011 than 2012 (Hannah 2013). Overall CPUE was 1,018 pounds/SRE hour in 2011 and 898 pounds/SRE hour in 2012. Monthly CPUE was higher towards the latter part of the season in 2011, while fairly consistent across months in 2012; and by area, CPUE was higher generally for beds off Oregon and Destruction Island (Figures 9 and 10).

Observer coverage levels

The project objective was to observe no less than 20% of the trips in a season. In 2011, the total number of trips was 207 and coverage was 24% at this level, or 26% relative to landed pink shrimp catch. Coverage rates at the trip level and relative to pink shrimp landed in 2012 were 16% and 14%, respectively. The decreases are due to an increase in total trips, 252 in 2012, and a reduction in the number of observers following federal funding cuts for the project.

Observed trips ranged from Cape Blanco, Oregon to La Push, Washington; most were primarily off the mid-coast of Washington.

Eulachon Catch, Rates and Spatial Distribution

Applying the ratio of total observed eulachon bycatch to total adjusted shrimp landed weight produces total fishery estimates of eulachon bycatch of 7.8 mt (17, 132 pounds) for 2011 and 171 mt (378,011 pounds) for 2012. This increase in bycatch occurred at the same time fishery regulations reduced the allowable bar spacing for BRDs to 0.75 inch (19mm) in 2012. With no estimate of eulachon population size it is not possible to evaluate whether the magnitude of bycatch would have been higher yet in 2012 without the mandated gear changes or voluntary improvements to reduce bycatch. As the West Coast Vancouver Island shrimp trawl fishery encounters eulachon of both Columbia River and Fraser River origin, data from that fishery may provide some context for the increase in eulachon bycatch (Gustafson et al. 2010). The Canada Department of Fisheries and Oceans (DFO) age composition of eulachon sampled in the West Coast Vancouver Island shrimp fishery points to an increase eulachon abundance and supports anecdotal reports by shrimpers of noticeably greater abundance of eulachon in 2012 than in 2011 (JCRMS 2014). Although not officially published, estimates of age 1+ and 2+ eulachon in terms of number of individuals are produced, and the combined value was 88.5 million in 2011 and 448.7 million in 2012.

Eulachon were encountered across the full extent of shrimp fishing grounds with some exceptions. Eulachon CPUE and bycatch ratios from observed tows in 2011 and 2012 are plotted in Figure 11a and 11b. Depicting both years together was done to more fully represent fishing grounds and meet confidentiality standards. The furthest northern and southern beds where characterized by the lowest eulachon CPUE and bycatch ratios. The highest CPUE and bycatch ratios were found along the mid-coast of Washington and the northern portion of Oregon. High CPUEs for eulachon generally corresponded to high bycatch ratios indicative of a high degree of co-occurrence. Some extraordinarily high bycatch ratios are apparent (Figure 11b). These tows may represent the first tow of the day when skippers are prospecting for shrimp and the presence of other fish is unknown. If bycatch is unacceptably high, skippers will move to relocate fishing to grounds where the prevalence of fish is lower. It is also common practice for skippers to warn each other incidences of high bycatch. Otherwise, the high bycatch ratio tows may reflect random occurrence.

Eulachon Bycatch Evaluation

Analysis of factors effecting Eulachon bycatch

Along with the weight for each species of bycatch encountered in a tow, observers recorded the month, depth, location as measured by latitude and longitude, duration of the tow in minutes, and time of day as measured by the number of minutes before sunrise and before sunset. These data were recorded in 2011 and 2012. The analysis focused on testing which factors had the largest effect on the ratio of eulachon to pink shrimp weight in each tow. We are particularly interested in the effect of gear type, or excluder bar spacing on bycatch. However, fishing month, location, depth and duration of tow could also affect bycatch ratios, and work synergistically with bar spacing. Owing to differences in gear types used, pink shrimp abundance, and other factors discussed elsewhere in the report between the 2011 and 2012 fishing seasons, the two years were analyzed separately. This section begins with a brief description of analytical techniques followed by the results.

Analytical Techniques

Ratios of eulachon bycatch originate from observations made for each tow on a random selection of boats from the fleet involved in the pink shrimp fishery. We used linear mixed effects modelling to account for the correlation between ratios from tows of the same boat under the assumption that these observations might be more similar due to use of the same gear and fishing methods than observations made from different vessels (Diggle et al. 1996). If the correlation between observations within a vessel is not taken into account, variances of estimated regression coefficients will be overestimated.

In the linear mixed model of this project, the random effect is vessel and the model is:

$$Ratio_{ij} = \boldsymbol{X\beta} + \boldsymbol{Zu} + \boldsymbol{\varepsilon}$$

where,

$Ratio_{ij}$ = the bycatch ratio from tow *i*, in the vessel j;

$\boldsymbol{X}$ = the matrix of fixed effects in the linear model, where each row is an observation (tows) and each columns is a predictors, e.g., excluder size and;

$\boldsymbol{\beta}$ = a vector of coefficients for the predictors (fixed effects) of length equal to the number of columns in matrix $\boldsymbol{X}$;

$\boldsymbol{Z}$ = the matrix of random effects in the linear model, where each row is an observation (tows) and the number of columns is equal to the number of vessels by the number of observations per vessel;

$\boldsymbol{u}$ = a random vector with length equal to the number of column in $\boldsymbol{Z}$, distributed $N(0, \sigma_j^2 \boldsymbol{I})$;

$\boldsymbol{\varepsilon}$ = the error term, distributed $N(0, \sigma_\epsilon^2)$ independent of $\boldsymbol{u}$.

The fixed effects (predictors) of the model were excluder size, month, depth, location, and tow time. The purpose of the analysis is to determine if any of the above predictors has an effect on bycatch ratios across the entire fleet, not just the vessels above. We tested the significance of fixed effect using the change in residual deviance between nested models (). All tests were conducted at the $\alpha = 0.05$ level. Analyses were conducted using the R statistical software package (version 3.1.0), lme4 library (R Core Team 2012; Bates 2010).

Assumptions used in the analysis are:

(1) Vessels sampled in the study were chosen randomly and are representative of the pink shrimp fishery fleet.

(2) Observations from one vessel are independent of observations between all other vessels.

(3) The error term, $\varepsilon \sim N(0, \sigma_\epsilon^2)$, and is independent of the random errors, $\boldsymbol{u}$.

(4) The random error term $\boldsymbol{u} \sim N(0, \sigma_j^2 \boldsymbol{I})$.

Although the original study design had observers randomly assigned to vessel, logistically this was not always possible and in these cases observers were assigned to boats that were available. We make the assumption that boat availability is a random process and that observations were still representative of the fleet.

Exploratory Analysis

Before fitting models to the data directly, we conducted exploratory analyses to determine if assumptions of normality were reasonably met, and if observations, the bycatch ratio in a tow, were distributed evenly across months, gear types, locations, and vessels in 2011 and 2012. There were major differences between 2011 and 2012 in which vessels fished, and the gear types used. This determined what factors could be analyzed as having an effect on bycatch ratios in 2011 and 2012.

In 2011, only 9 vessels fished for pink shrimp from April to October, inclusive (Table 3), but not all vessels fished in all months. Most of the vessels fished with one gear type (Table 4), with the exception of vessel 7 which fished with the two smallest gear types. In 2011 all vessels fished only one gear type at a time. Further, the larger gear sizes, 1, 1.25, and 1.5 inch excluders, were only fished by one vessel each. Five and three vessels fished with the 0.75 and 0.875 inch excluders, respectively. Because not all vessels fished in all months, gear types were not fished in all months (Table 5). All of these factors complicated the analysis of determining the effect of fishing month and gear type on bycatch ratios in 2011. Most of the fishing in 2011 occurred north of the Columbia River plume (Table 6). Only two vessels fished south of the Columbia River plume, with one fishing exclusively in that area.

In the 2012 Washington pink shrimp fishery only excluders with 0.75 inch bar spacing were allowed, with some exceptions made. Vessel 3 fished two different excluder types simultaneously, and vessel 8 had 26 tows with the 1.25 excluder bar spacing (Table 7). These observations were not included in the analysis, leaving only tows made with the 0.75 inch excluders in the analysis. Subsequently, we did not examine gear effect in 2012. The months in which each of the remaining 13 vessels fished varied across the 2012 season (Table 8). All vessels fished north of the Columbia River plume in 2012.

The assumption of normally distributed errors can be checked by plotted the density of bycatch ratios for each vessel. On the original scale, bycatch ratios are clustered at the lower end (Figure 12). If the errors in the model were normally distributed, the bycatch ratios should be more evenly distributed horizontally, and take on the shape of a bell curve. Taking the natural logarithm of 2011 bycatch ratios produced plots of the data that would be expected if errors were normally distributed (Figure 13). Plots of the bycatch ratios from 2012 had the same results. On the original scale, observations are clustered at the lower end (Figure 14). Taking the natural logarithm of bycatch ratios resulted in density plots more typical of normally distributed data, and hence errors (Figure 15).

Results and Discussion of Eulachon Bycatch Evaluation

One of the more important questions in the study is the effect of gear size, specifically bar-spacing on excluders, on bycatch of eulachon. Testing the effect of gear size on bycatch can only be done using the 2011 data because it was the only year in the study in which multiple bar spacing were used. The analysis is complicated by not all vessels fishing the same gear; only one vessel fished each of the 1, 1.25, and 1.75 bar-spacings. Further, they were not fished evenly across the fishing season. Hence, the effects of vessel, gear, and month are not easily analyzed for the 2011 data. Only the effects of month and vessel can be analyzed for the 2012 data. Analysis of the other predictors such as latitude, depth, and tow time will be dependent on the results of vessel, gear, and month effects.

Vessel, Gear, and Month - 2011

The first step in the analysis was to determine whether the predictor *Vessel* contributed enough to the variance to include it as a random effect. We used the *lmer* function in R (R Core Team, 2012; Bates 2010) to obtain estimates of the variance contribution of *Vessel* to the overall error variance. Correlation between tows of the same vessel contributed approximately 13.4% to the overall error variance (Table 9), too small to be ignored. If there were no correlation within tows from the same vessel the estimate of the vessel variance would be zero.

Ordering each vessel by the amount of average bycatch for a vessel differed from the average across all vessels; Figure 16 showed that vessel number 10 had the highest bycatch ratio. This was also the vessel having the fewest number of tows (18; Table 3), fishing in June and July with the 0.75 excluder. The next two highest, vessels 3 and 15, fished with the 1.5 and 1.25 excluders, respectively, and were the only boats with this gear type. These vessels fished in June, July, and August. The only boat to fish the 1 inch excluder, vessel 6 had the smallest bycatch ratios. Vessel 6 only fished in August, the month with the lowest observed bycatch (Figure 17), and this might be why the 1 inch excluder size had the smallest bycatch ratio. No boat fished in all months, although boat 11, with the second lowest ratio, and boat 14, which was slightly above the mean, fished in every month except September with the 0.875 excluder size. There is a marked difference between the amount of bycatch caught by the small and larger excluder sizes (Figure 18).

The above description, Tables 3 through 6, and Figure 16 through 18 underscore the complications in teasing apart the effects of vessel, gear, and month in the analysis. To look at the effects of gear and month, we confined the analysis to the months of June, July, and August, gear types (excluder sizes) 0.75, 0.875, 1.25, and 1.5 because these were the combinations available (Table 10). We fit the following series of nested models to test if any of the fixed effects of month, gear type, and the interaction between the two was significant,

Model 1 $\boldsymbol{Bycatch_{ijk} = \mu + Month_j + Gear_i + Gear_i{:}\,Month_j + Vessel_k}$ **Eq. 1**

Model 2 $Bycatch_{ijk} = \mu + Month_j + Gear_i + Vessel_k$

Model 3 $Bycatch_{i.k} = \mu + Gear_i + Vessel_k$

Model 4 $Bycatch_{..k} = \mu + Vessel_k$

where, μ = the overall mean of bycatch.

Significance of each of the factor effects, Month, Gear, and interaction, is determined by the difference in the residual deviance, $\Delta Deviance$, between the model having that factor in and the model with the factor removed, calculated as:

$$\boldsymbol{\Delta Deviance = Deviance(Model\ (i-1)) - Devaince\ Model\ (i)}, \qquad \textbf{Eq. 2}$$

where, $\Delta Deviance$ is distributed χ^2_{df}.

Results of the analysis indicate a significant interaction between gear type and month (Table 11), and a significant month effect.

Model 1 $\boldsymbol{Bycatch_{ijk} = Month_j + Gear_i + Gear_i{:}\,Month_j + Vessel_k}$ **Eq. 3**

Model 2 $Bycatch_{ijk} = Month_j + Gear_i + Vessel_k$

Model 3 $Bycatch_{.jk} = Month_j + Vessel_k$

Model 4 $Bycatch_{..k} = Vessel_k$.

A significant interaction between month and gear indicates that for each level of month, each level of gear will change with regard to how it increases or decreases bycatch. Further, regardless of the test outcome for each main effect, both must be kept in the model in the presence of significant interaction. Parameters estimates, standard errors, and their interpretation are included in the appendix.

An interaction plot of the effects of month and gear type supports the results of the analysis (Figure 19). The effects of gear type are not consistent across months. For example, bycatch of eulachon increased in July for the 1.5 inch spacing while all other gear types decreased. Also, while the 0.75, 0.875, and 1.5 inch gear types decreased in the amount of bycatch caught in August, the 1.25 spacing increased. In a non-significant interaction, the lines would be nearly parallel.

To look at the effects of gear type more closely, we analyzed the data for tows conducted in August, the only month that all bar spacings were fished. There was no need to model vessel as a random effect for August as the within vessel variance was estimated as zero. The model for bycatch in the August tows was

$$\boldsymbol{Bycatch_{ij} = Gear_i + Vessel_j + \varepsilon}. \qquad \textbf{Eq. 4}$$

The results of an analysis of variance (ANOVA), used to analyze categorical data, showed a significant gear effect on the amount of bycatch of eulachon (Table 12). An ANOVA only tests for an inequality somewhere among gear types. Subsequently we conducted pairwise comparisons for the 5 gear types using Tukey's honestly significant difference (TukeyHSD). The 0.875 inch bar spacing was consistently lower than all other types except for the 1 inch spacing (Table 13). The one inch spacing was fished only in August by one boat and had a total of 27 tows. Eulachon catch for the 0.75 bar spacing was not significantly different from the larger gear types.

Results of the ANOVA should be approached with caution when the number of observations is not equal across categories, particularly when p-values are close to the significance level of the test. However, there are enough observations in each category, and p-values are much lower than the 0.05 significance level that this should not be a concern.

To examine the effects of gear more broadly across the fishing season, we restricted the analysis to the 0.75 and 0.875 bar spacing so that we could test for month effect across the entire season. We first restricted the analysis to the months of May, June, July, August, and October, when both gear types were fished. Results of the analysis for the model in which month is removed first (Table 14) differed from previous results regardless of whether gear was removed first (Table 15 and Table 16; Eq 1. and Eq. 3, respectively) in that gear type was not significantly different in the amount of bycatch. The 0.875 bar spacing was constantly lower than the 0.75 spacing except in October (Figure 9). The change in the relative difference between the two gear types in October could be cause of the significant interaction, particularly in larger sample sizes. The number of tows for the 0.75 and 0.875 were 15 and 29, respectively (Table 5).

Because gear type must be considered when looking at differences in bycatch across months in 2011, we conducted one last analysis for the effect of month on bycatch of eulachon using tows made with the 0.875 gear type only. This bar spacing was fished in every month except September, thus covering the temporal span of the 2011 season. Controlling for the extra variation due to vessel in the model by considering it a random effect, results showed significant differences by month in eulachon bycatch (Table 17). Pairwise comparisons conducted using Tukey's HSD showed that eulachon bycatch was greatest in April, followed by October.

Vessel and Month - 2012

Analysis of the effect of fishing month was simpler in 2012 than in 2011. By regulation, only one gear type was fished in 2012. One boat made tows from two gear types simultaneously.

Because bycatch ratios were calculated by the tows from the two gear types, observations from this boat were excluded from the analysis. Another boat used the 0.75 and 1.25 bar spacing, although not simultaneously. The 26 tows made with the 1.25 bar spacing were also removed from the analysis, however there were still 59 observed tows from this vessel. Across all 13 remaining vessels in the analysis, there were 508 observed tows with eulachon bycatch. Vessels 6, 3, and 2 were not included in the 2012 analysis.

The first step in the analysis was to determine if vessel needed to be included in analytical models as a random effect. The results were the same as with the 2011 analysis. Correlation of observations within vessel contributed 24.3% to the overall variance (Table 18). By modelling vessel as a random effect, the variance structure of the data will be adequately captured, and the estimate variance of other model parameters will be more accurate than if the within vessel variation was not taken into account. Differences among vessels with regard to the overall mean log bycatch ratio are displayed graphically in Figure 21. In both 2011 and 2012 vessel number 10 had the highest bycatch ratios and vessel 11 was among the lowest.

A plot of the natural logarithm of ratios for each month show that the highest eulachon bycatch occurred in May, the lowest in October (Figure 22). April had the highest variability in bycatch. Results of the analysis showed that were significant differences among month in eulachon bycatch (Table 19). Pairwise comparison conducted using Tukey's HSD supported the plot in Figure 22. May was significantly higher than all other months, and October significantly lower than all months except April (Table 20). April had the highest variability, and hence was not statistically different from any of the other months.

<u>Depth, Latitude, and Tow Time</u>

Three continuous predictor variables were analyzed for their effect on bycatch of eulachon, depth of tow measured in fathoms, time of tow measured in minutes, and the latitude of the tow as a measure of location. The model used in to analyze the effect of the continuous predictor, *X*, was,

$$\mathbf{log}(\boldsymbol{Bycatch_{ijk}}) = \boldsymbol{\alpha} + \boldsymbol{Month_j} + \boldsymbol{\beta} \cdot \boldsymbol{X_i} + \boldsymbol{X_i}{:}\,\boldsymbol{Month_j} + \boldsymbol{Vessel_k}. \qquad \textbf{Eq. 5}$$

Month was included in the analysis because it was shown to have a significant effect on bycatch. The term $X_i{:}\,\boldsymbol{Month_j}$ is the interaction. Significance of this term indicates that the linear relationship between the continuous predictor and bycatch is different among months.

Depth

The relationship between depth and bycatch ratio differed among months in 2011 as indicated by the significant interaction (Table 21). The difference in the direction and degree of the regression lines for each month support the results of the analysis, and indicate the difficulty of assessing the effect of any one predictor in the presence of an interaction (Figure 23). Three of the six months had a significantly positive depth-bycatch relationship (Table 22).

The interpretation of the regression parameter b is that it is the change in the log of bycatch ratio for each unit increase in the predictor X. Analytical results indicate a significant relationship between depth and bycatch. However, this may not be biologically significant. The effects of depth on bycatch for each month were calculated as follows

$$\Delta \boldsymbol{Ratio} = \boldsymbol{e}^{\widehat{\alpha}}\left(\boldsymbol{e}^{(1+AvgDepth)\widehat{\beta}} - \boldsymbol{e}^{(AvgDepth)\widehat{\beta}}\right) \qquad \textbf{Eq. 6}$$

The change in bycatch for an increase in one fathom of fishing was estimated to be 6.594 lbs of eulachon per 10,000 pounds of shrimp caught. Hence, although the bycatch relationship with depth is statistically significant, it may not be biologically meaningful.

Consistent with 2011, the depth-bycatch relationship was statistically different in each month and overall (Table 23). The relationship was significantly positive in only two out of the seven months in 2012, and estimated as positive in two other months (Table 24, Figure24). The largest change in pounds eulachon per 10,000 pounds shrimp for a one fathom increase in depth is an increase in June of 22.98 pounds. The next largest change is an increase of about 9 pounds.

Latitude

Latitude was used as a measure of fishing location off the coast. In 2011 most of the fishing occurred north of the Columbia River plume, but there were 32 observations south of the plume in October (Table 25) using excluder devices with the 0.75 and 0.875 inch bar spacing (Table 26). There was no apparent difference in the bycatch between locations fished north and south of the plume (Figure 25). Although the interaction between month and latitude was significant for tows north of the plume in 2011, this may be an artifact of the strong month effect observed in 2011 as the effect of latitude alone was not significant (Table 27).

All tows included in the analysis in 2012 were conducted north of the Columbia River plume, and bycatch was significantly different among months as indicated by a significant interaction effect (Table 28). Relationships between latitude and depth were significant in five out of the seven months but the direction was not consistent (Table 28). Changes in the bycatch of eulachon for a half a degree increase was estimated for each month (Table 29) by,

$$\Delta \boldsymbol{Ratio} = \boldsymbol{e}^{\widehat{\alpha}}\left(\boldsymbol{e}^{(0.5+Avg.Latitude)\widehat{\beta}} - \boldsymbol{e}^{(Avg.Latitude)\widehat{\beta}}\right). \qquad \textbf{Eq. 7}$$

The large change in October is an artifact of a very steep slope over a narrow range of values (Figure 26). Under these conditions, small perturbations in the value of latitude will produce vastly different estimates. Further, a 0.5 degree increase in the relationship for October is predicting beyond the range of the data. Other estimates are below an increase in 100 pounds but the direction of change is not consistent.

Tow Time

The average time per tow was approximately 100 minutes. There was no significant interaction between tow time and month (Table 30) and the overall time-bycatch relationship was significant and the same across all months, but at -0.007 not very strong. For example, a 30 minute increase in tow time in April would be associated with a decrease of 8 pounds of eulachon per 10,000 pounds of shrimp.

Tow time-bycatch relationships were not constant across months fished in 2012 (Table 31; Figure 27). The strongly increasing slope estimated for April is most likely driving the significant interaction. All other months were either not significantly different from zero or negative. Changes in eulachon bycatch on the original scale for a 30 minute increase in tow time were calculated as

$$\Delta \boldsymbol{Ratio} = \boldsymbol{e}^{\alpha}\left(\boldsymbol{e}^{(30+AvgTowTime)\hat{\beta}} - \boldsymbol{e}^{(AvgTowTime)\hat{\beta}}\right). \qquad \textbf{Eq. 8}$$

Even with the strong positive relationship in April, the increase in eulachon bycatch is 21 pounds per 10,000 pounds shrimp (Table 32). All other changes are ±5 pounds.

Eulachon biological sampling

In total, 3,311 eulachon were sampled for length; due to reduced observer coverage fewer were collected in 2012 (n = 956) than 2011 (n = 2355). Sample sizes by month varied due to fewer numbers of active vessels in the early and latter parts of the season. Both total and fork lengths were measured but fork length data were used for analysis. Fork length was calculated from total length when the former data were missing. The total to fork length conversion factor was derived from study data (Figure 28). For frequency plots, length data are pooled in two millimeter increments.

Overall, eulachon length ranged from 74 to 231 mm during the two years of observation. The ranges for 2011 and 2012 were essentially identical yet the modes for each were distinctly different (Figures 29 and 30). The median length in 2011 was 181 mm compared to a median of 127 mm in 2012. Within year variation was low with mean lengths of 178 mm and 128 mm or nearly equal to the medians for 2011 and 2012, respectively.

Monthly length frequency plots for each year are consistent with annual distribution: figures 31 through 37 show eulachon length frequency data collected on approximately the same date(s) each month for each year. The bimodal distribution of LF data in 2011, although weak, suggests the presence of two age classes, where only one is evident in 2012. Despite sample size variations between years and across months, in both years median length generally trended up from April to October pointing to intra-annual growth, Figure 38 and 39.

The DFO evaluates eulachon length frequency data from shrimp trawling offshore the west coast of Vancouver Island (WCVI) from approximately one date from late April and early May across years. To facilitate comparison, study eulachon length frequency data from April and May were computed as standard lengths and presented in a similar manner (Figure 31 and 32). The 2011 WCVI distribution peaked at about 110mm and 168mm, corresponding to modes at 110mm and 114mm in our study. The WCVI data from 2012 was bimodal with peaks at about 104mm and 176mm. This contrasts with the single mode from 2012 in the Washington fishery at 102mm.

Spatially, no length trends are apparent. Mean length frequencies pooled by ODFW management area for each year reflect only the annual difference in size distribution (Figures 40 and 41). Eulachon (n = 3290) were sampled from tows ranging from 104 m to 182 m. For each tow, set and up depth were recorded. As fewer than 10 percent of the tows had set and haul depths that differed by more than 9 m, mean tow depth was calculated and used to evaluate length distribution and tow depth. No significant difference in eulachon size by tow depth is evident in either year (Figures 42 and 43).

Likewise, no apparent size distribution differences were evident in comparisons by BRD bar spacing. Although not required by rule until 2012, several vessels had already installed BRDs with bars spaced at 19.1 mm (0.75 inches) in 2011. Median length frequency for these vessels was 180 mm in 2011 and 126 mm in 2012; or essentially the same as the fleet median in each year (Figure 44 and 45). Similar results are produced comparing bar spacing of 31.8 mm (1.25

inches) and 19.1mm (0.75 inches; Figure 46). Hannah et al. 2011 found no difference in eulachon mean total length between grates with 19.1 and 25.4 mm bar spacing. In that study observed reductions in eulachon bycatch with the 19.1mm bar spacing were attributed to greater efficiency to exclude eulachon overall and not to selective exclusion of larger eulachon. Our results, spanning varying differences in bar spacing found in the fleet, also suggest that eulachon are not excluded only on the basis of length.

Determination of eulachon ages poses challenges due to overlapping age at size and otolith versus scale aging method discrepancies (Hay and McCarter 2000); and no method has been validated (Scweigert et al. 2012). Ageing conventions based on standard length have been developed and are used by DFO; under this scheme age 1+ range from 60-130mm, age 2+ range from 100-180mm and age 3+ range from 140-200mm. Applying this scheme, age 1+ and age 2+ plus fish were present in the Washington fishery in 2011, whereas only age 1+ were predominant in 2012.

Conclusions

The primary purpose of this study was to improve our understanding of the factors influencing eulachon bycatch in the Washington shrimp trawl fishery. Access to eulachon for biological and genetic sampling was also made possible.

In the evaluation of bycatch, results from the study indicate a marked difference between the amounts of bycatch caught by excluders with smaller, or 1 inch and less, bar-spacing in the panel, compared to larger, or more than 1 inch, excluders. However, there is not a significant difference among the excluders with smaller bar-spacing. Among the smaller group, the middle sized excluder bar spacing, 0.875 inch, was associated with the lowest bycatch ratios. Gear effects other than bar-spacing may account for this result. The type of ground gear used may influence bycatch rates, as well as, the height of the net off the bottom. Also, it should be noted that concurrent with the study, some skippers were actively evaluating gear performance. At least two vessels took advantage of the Pacific States Marine Fisheries underwater camera system loan program. In 2012, WDFW deployed a similar camera system on observed vessels. The video footage collected provided a first-time opportunity for fishers and managers to see the interaction between gear, shrimp, and fish. Dozens of hours of footage were taped and viewed. Based on these observations, skippers began testing and adopting different gear, e.g. rectangular excluder panel, and gear configurations, e.g. angle of excluder, orientation of escape hole, and size of escape hole. These efforts were not discouraged although study results are likely confounded by some of the changes. Documenting these changes was also difficult given the rapidity of change. Of the changes, the most effective appears, at least anecdotally, to be increases in escape-hole size. A larger escape-hole could result in the excluder with slightly larger bar-spacing to out-perform the very similar excluder with smaller bar-spacing. This along with other gear configurations specific to each vessel requires consideration when interpreting results. Absolute and relative abundance of eulachon and pink shrimp may also influence results. Finally, the among vessel difference suggests increased fleet performance, overall, in reducing bycatch is possible.

Other factors affecting bycatch ratios were variously significant across month, depth, and latitude. By month, April and October were associated with significantly different and higher bycatch ratios in 2011. In 2012, the bycatch ratios were significant and highest for May, and the lowest in October. This is consistent with observer impressions that bycatch overall is highest in the spring. Whereas, the bycatch relationship with depth is statistically significant; it may not be biologically meaningful. Likewise, latitude and depth relationships were significant but inconsistent. Generally, spatial distribution results point to the co-occurrence of eulachon and pink shrimp.

Eulachon biological data were consistent with data from the Canadian West Coast Vancouver Island trawl fishery and the understanding that for eulachon the effectiveness of excluders is not solely related to fish size. Genetic samples were collected and, pending funding for analysis, could contribute further to our understanding of eulachon in the marine environment.

References

Alverson, D.L., R.L. McNeely, and H.C. Johnson. Results of Exploratory Shrimp Fishing off Washington and Oregon. Commercial Fisheries Review 22.1 (1960): 1-11.

Bates, D. M. 2010. Lme4: Mixed-effects model with R.

Clarke, A. D., A. Lewis, K. H, Telmer, and J. M. Shrimpton. Life history and age at maturity of an anadromous smelt, the eulachon *Thaleichthys pacificus* (Rishardson). Journal of Fish Biology 71 (2007): 1479-1493.

DFO (Fisheries and Oceans Canada). *Offshore Juvenile Eulachon Growth and Abundance*. Government of Canada. 09 May 2014. Web. 10 June 2014.

Doyle, J., and K. Hildenbrand. You're Excluded! An Activity Exploring Changes in Trawl Industry Technology. Oregon Sea Grant, Summer 2013.

Federal Register, Volume 75, No.13012. March 18, 2010. Final Rule: Endangered and Threatened Wildlife and Plants: Threatened Status for Southern Distinct Population Segment of Eulachon.

Gustafson, R.G, M.J. Ford, D. Teel, and J.S. Drake. 2010. Status review of eulachon (*Thaleichthys pacificus*) in Washington, Oregon, and California. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-105, 360 p.

Hannah, R. W., S. A. Jones., 2007. Effectiveness of bycatch reduction devices (BRDs) in the ocean shrimp (*Pandalus jordani*) trawl fishery. Fisheries Research 85 (2007): 217-225.3.

Hannah, R., and S. Jones. 2013. 24th Annual Pink Shrimp Review. Oregon Dept. Fish Wildlife, Marine Resources Program, Newport.

Hannah, R. W., S. A. Jones, M. J. M. Lomelli, and W. W. Wakefield. 2011. Trawl net modifications to reduce the bycatch of eulachon (*Thaleichthys pacificus*) in the ocean shrimp (*Pandalus jordani*) fishery. Fisheries Research 110:277-282.

JCRMS (Joint Columbia River Management Staff). 2014. 2014 Joint Staff Report Concerning Stock Status and Fisheries for Sturgeon and Smelt. Oregon Dept. Fish and Wildlife and Washington Dept. Fish and Wildlife.

NWFSC (Northwest Fisheries Science Center). 2006. West Coast Groundfish Observer Manual. West West Coast Groundfish Observer Program. NWFSC, 2725 Montlake Blvd. East, Seattle, Washington, 98112.

PFMC (Pacific Fishery Management Council). 2014. Pacific Coast Groundfish Fishery Management Plan for the California, Oregon and Washington Groundfish Fishery. PFMC, Portland, Oregon. 146 p.

R Core Team (2012). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/

Schweigert, J., Wood, C., Hay, D., M. McAllister, Boldt, J., McCarter, B., Therriault, T. W., and H. Brekke. 2012. Recovery Potential Assessment of Eulachon (*Thaleichthys pacificus*) in Canada. DFO Can. Sci. Advis. Sec. Res. Doc. 2012/098. vii+ 121p.

Wallace, J. R., J. M. Cope. 2011. Status Update of the US canary rockfish resource in 2011. Pacific Fishery Management Council, Portland, Oregon.

Figures

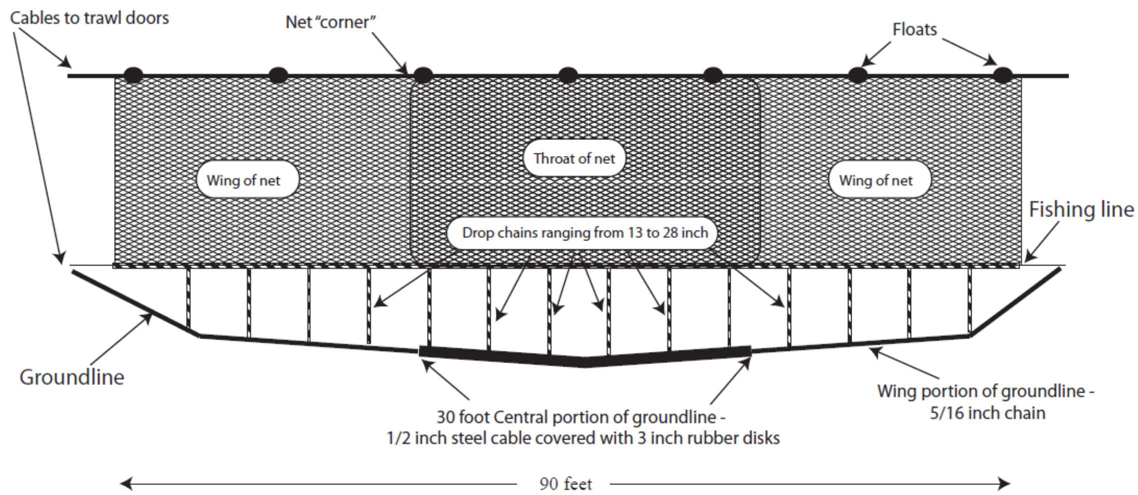

Figure 1. Stylized schematic of a pink shrimp trawl net with "ladder" style groundgear. This net is configured from the front and is not to scale; all measurements are approximations (Hannah 2011).

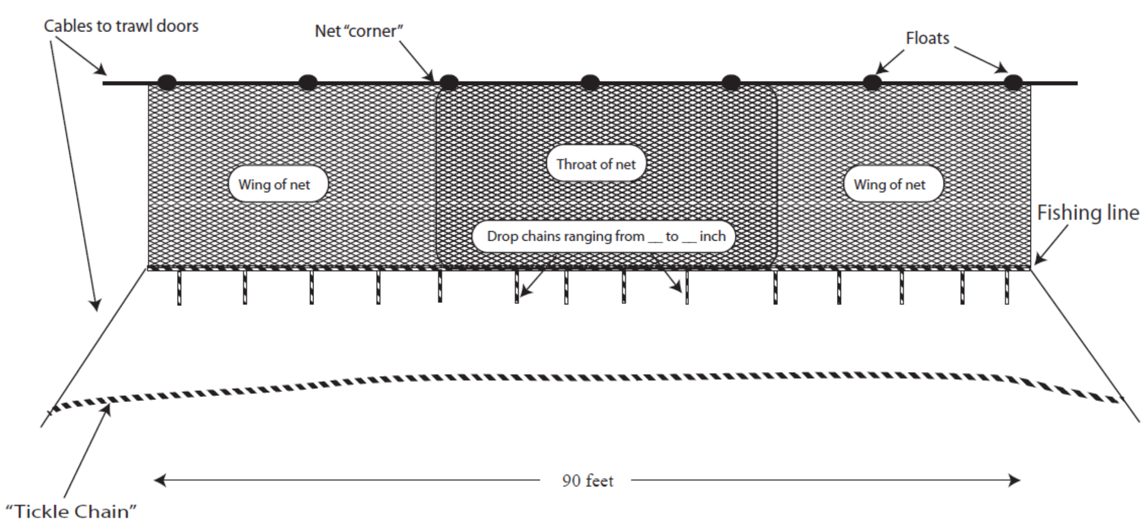

Figure 2. Stylized schematic of a pink shrimp trawl net without a ground line, but with a "tickle chain." This net is configured from the front and is not to scale; all measurements are approximations (Hannah 2011).

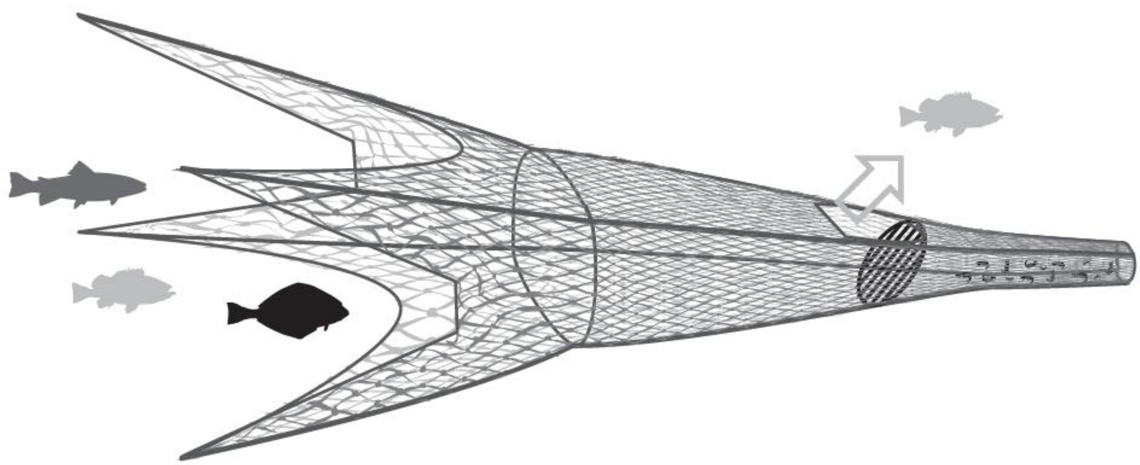

Figure 3. Stylized schematic of fishing net with BRD and escape hole, showing how fish enter net and can escape prior to entering the cod end (Doyle and Hildenbrand 2013).

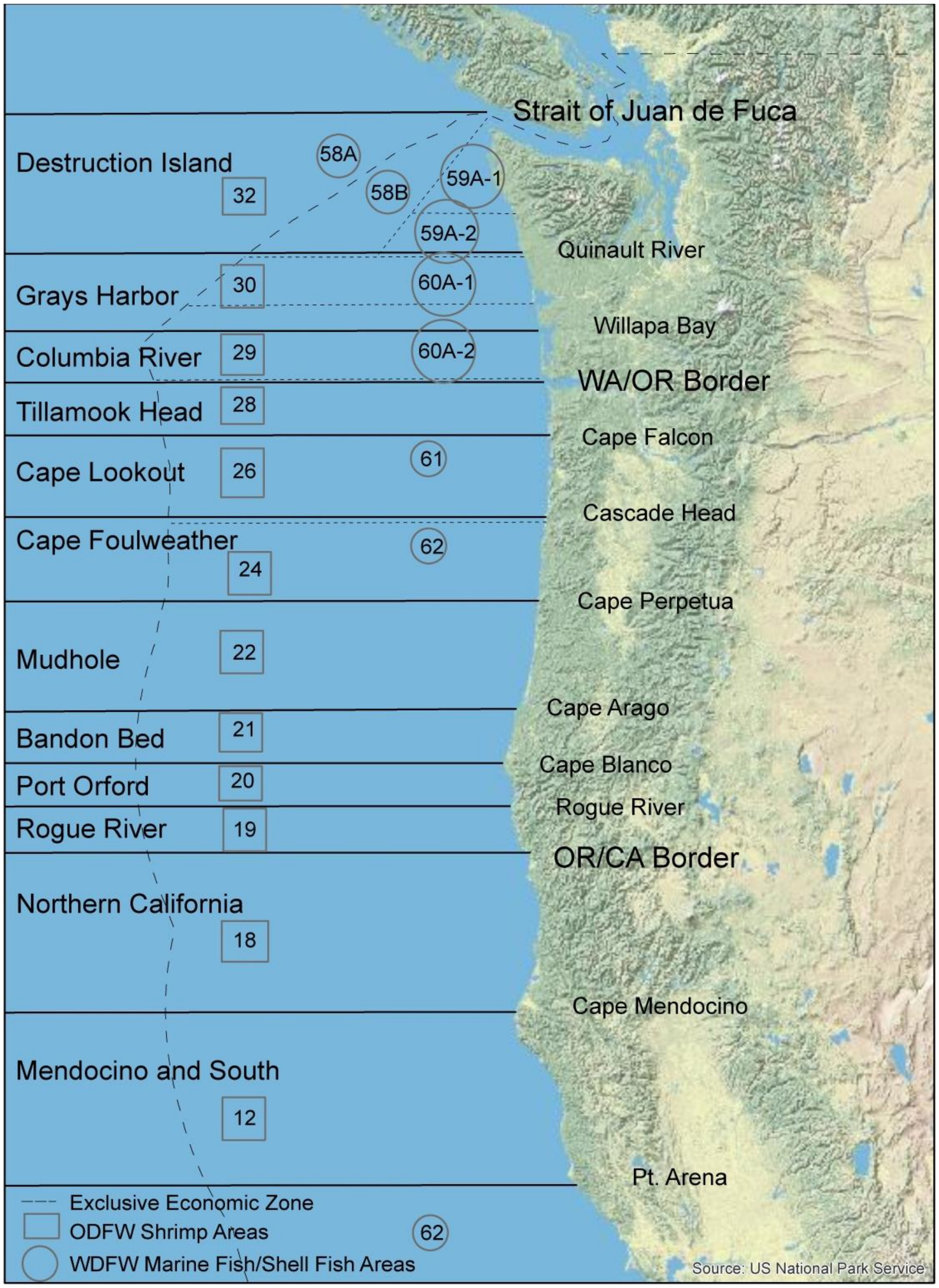

Figure 4. Stylized map showing Oregon Dept. of Fish and Wildlife pink shrimp areas versus Washington Dept. of Fish and Wildlife marine fish/shellfish areas.

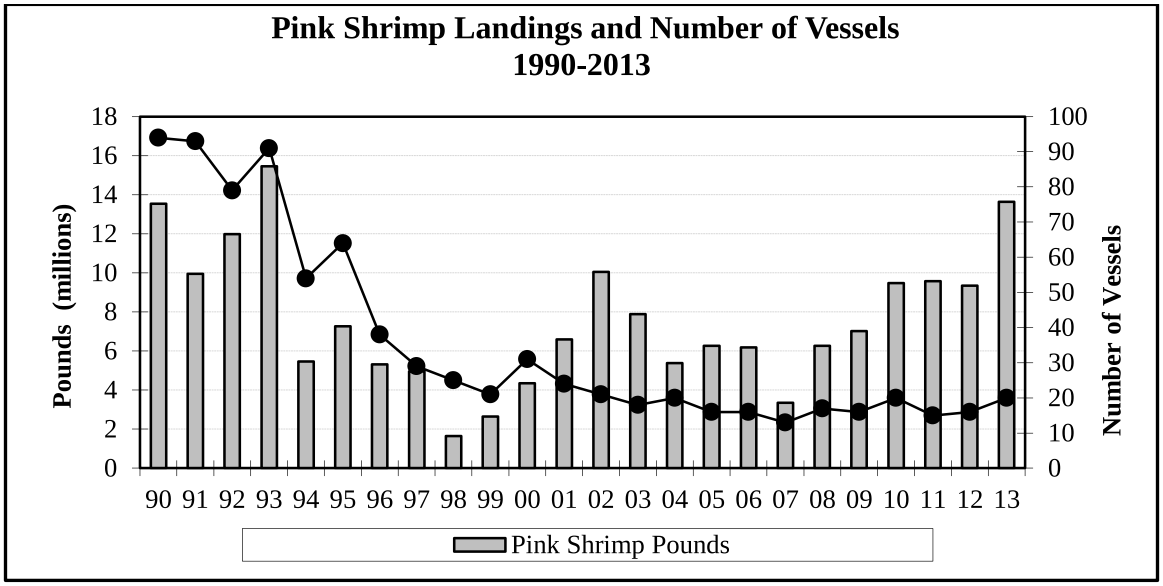

Figure 5. A comparison of pounds landed versus the number of vessels fishing.

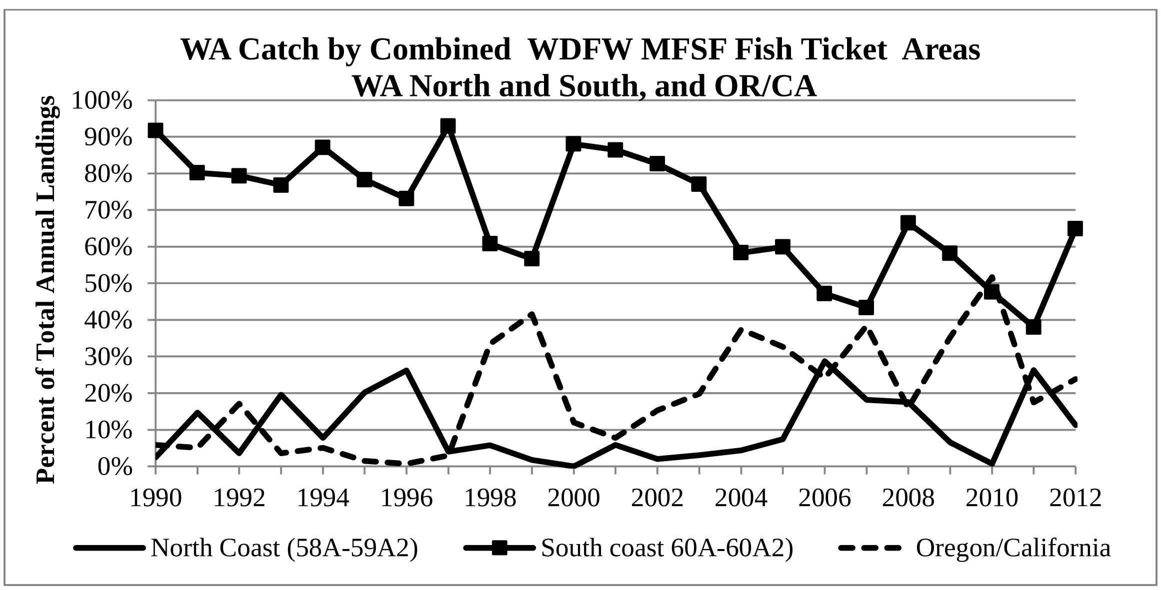

Figure 6. A comparison of annual landing by grouped catch area.

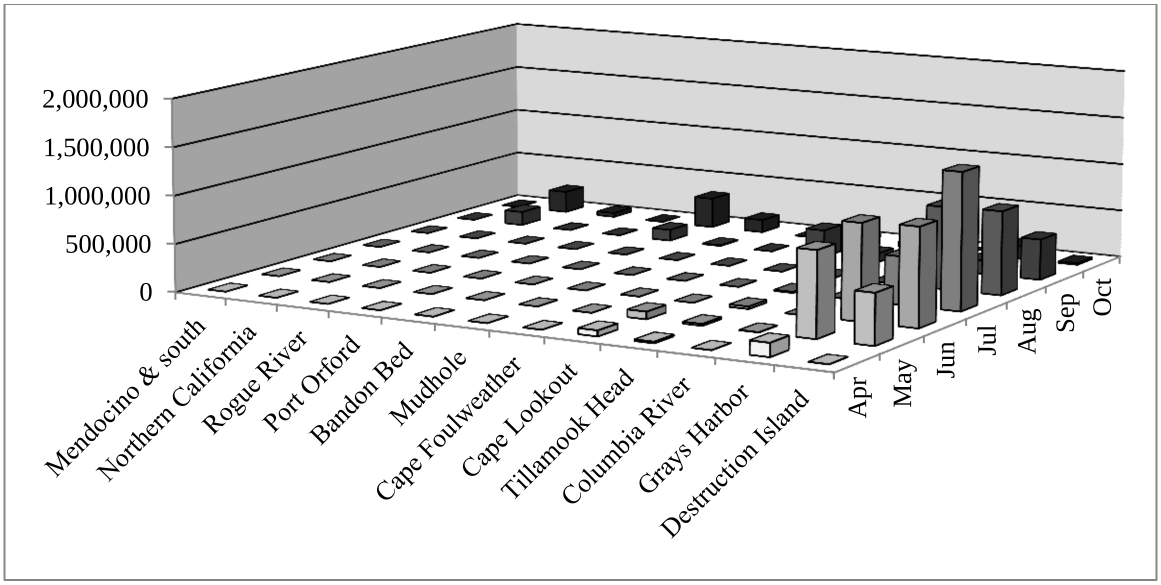

Figure 7. Monthly Washington landings by ODFW management area in 2011.

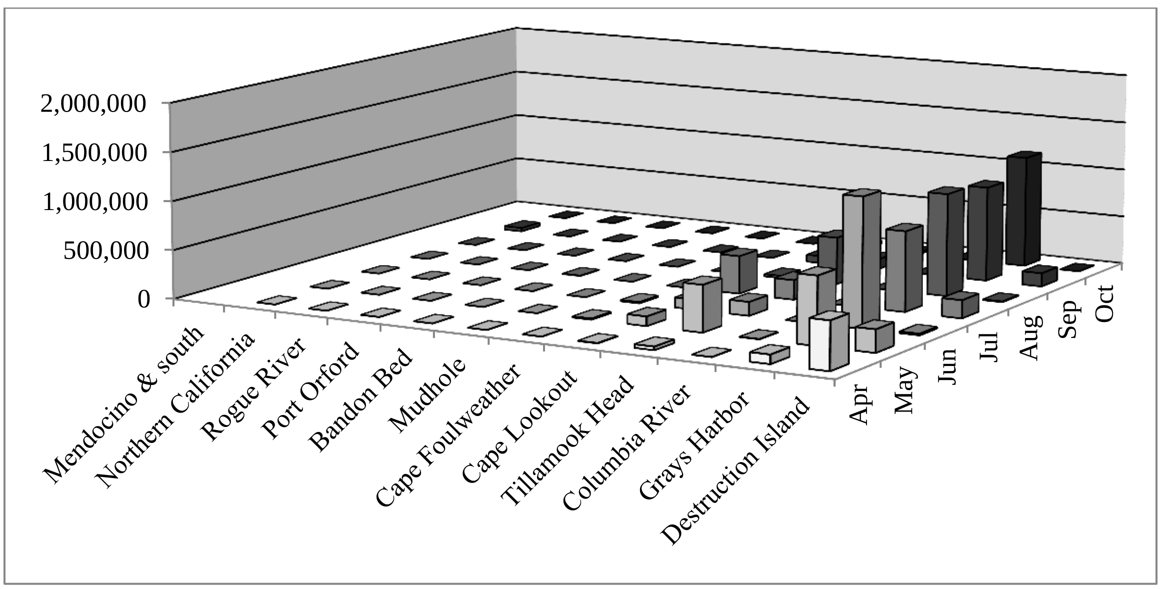

Figure 8. Monthly Washington landings by ODFW management area in 2012.

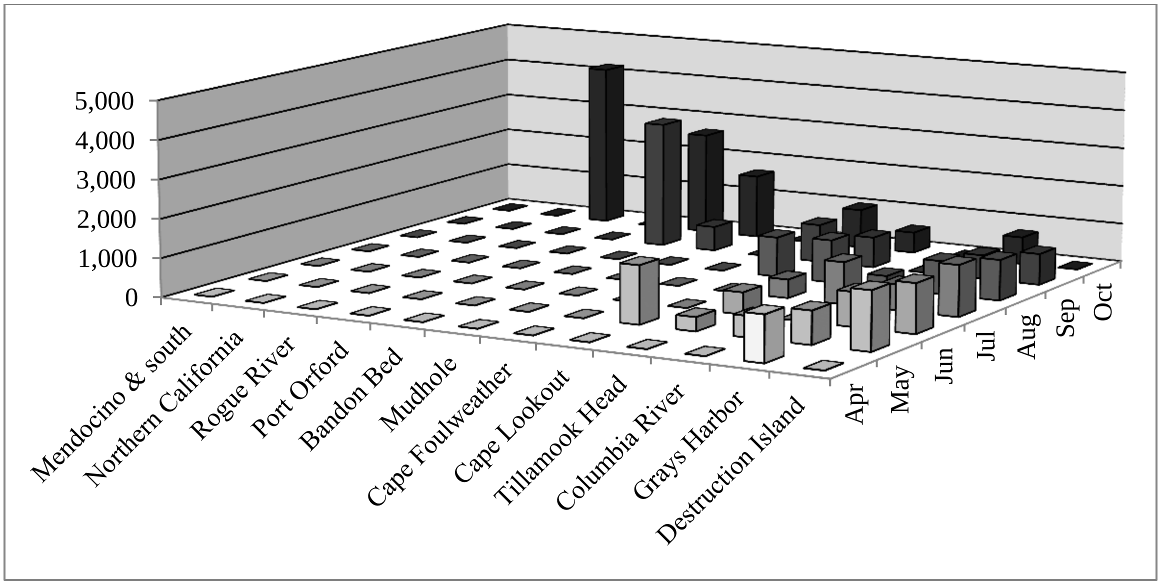

Figure 9. Monthly Washington CPUE grouped by ODFW management area in 2011.

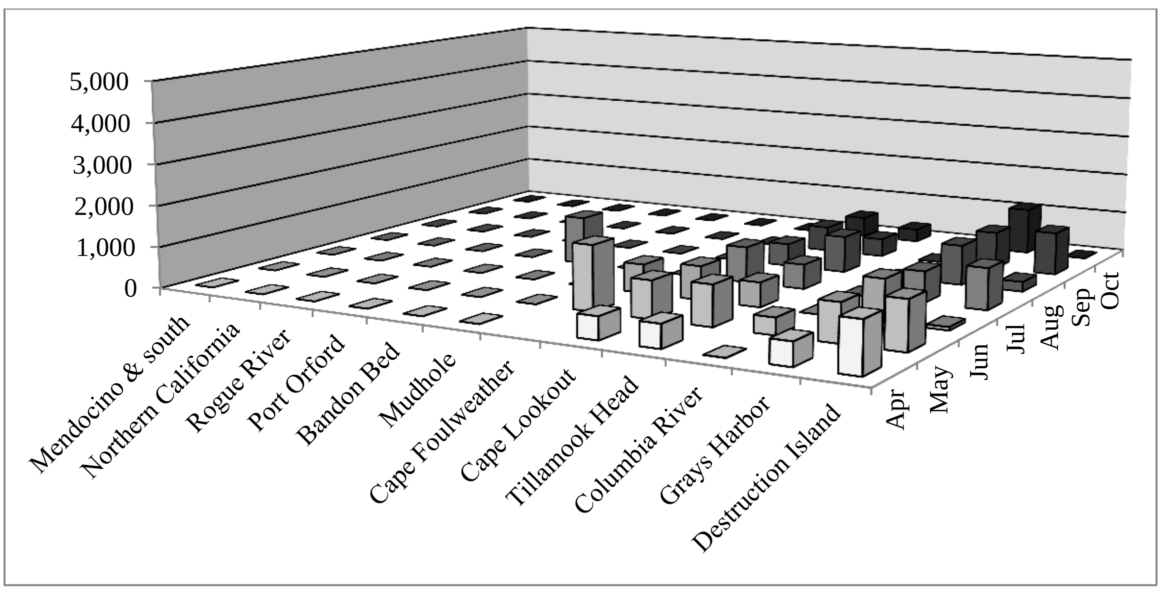

Figure 10. Monthly Washington CPUE grouped by ODFW management area in 2012.

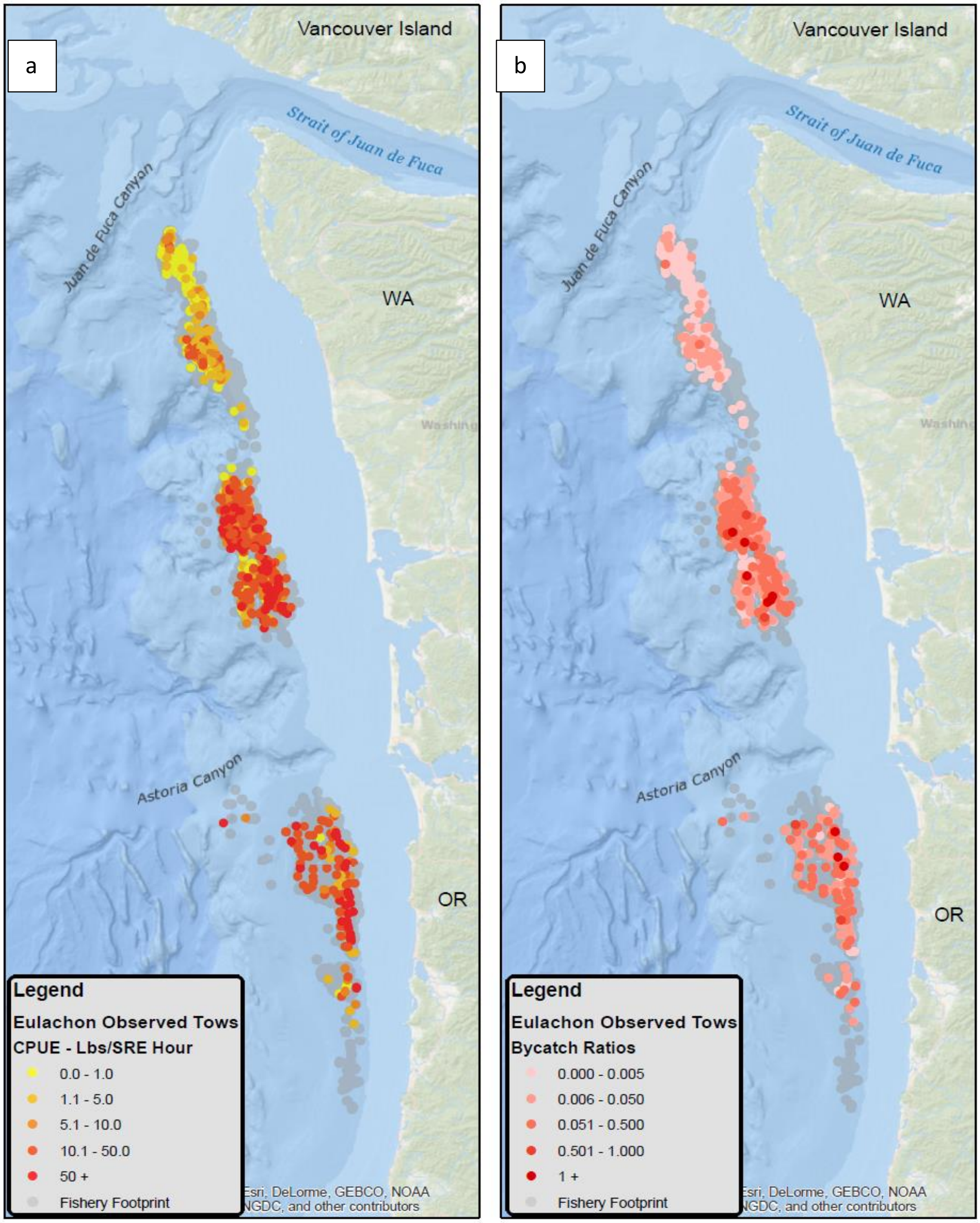

Figure 11. Eulachon CPUE (a) and bycatch ratios (b) across 2011 and 2012.

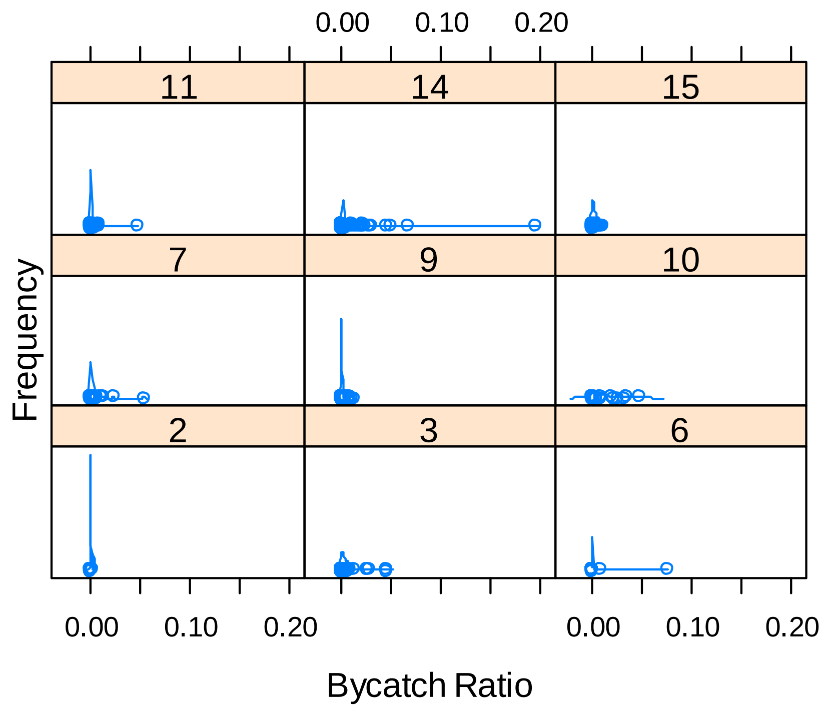

Figure 12. Density plots of bycatch ratios of eulachon for each of the vessels observed in 2011.

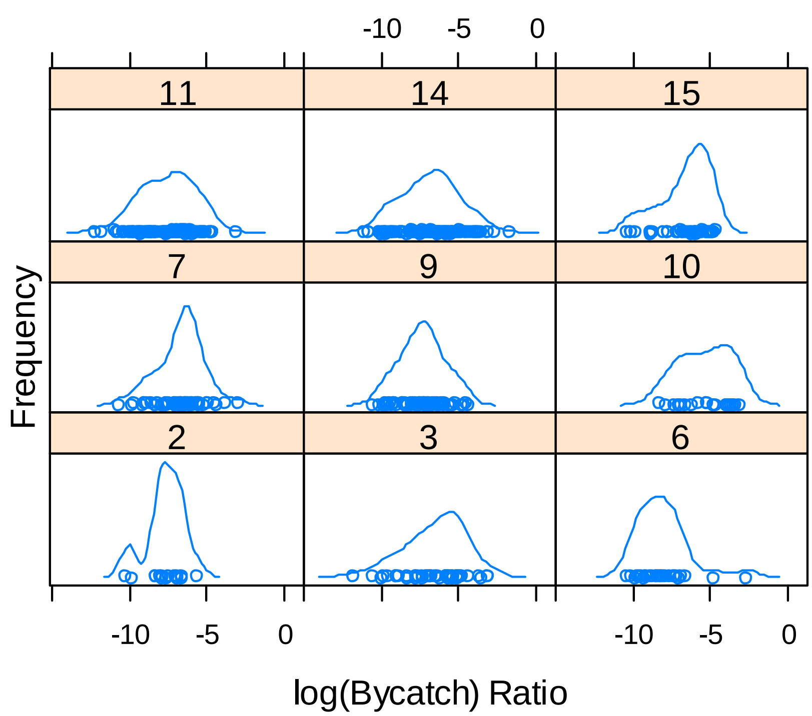

Figure 13. Density plots of the natural logarithm of bycatch ratios of eulachon for each of the vessels observed in 2011.

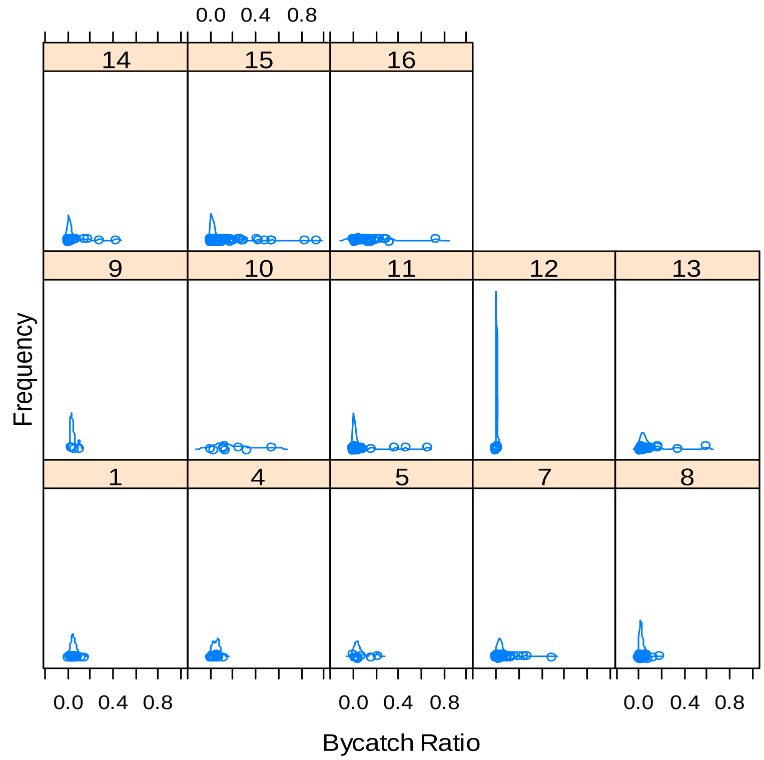

Figure 14. Density plots of bycatch ratios of eulachon for each of the vessels observed in 2012.

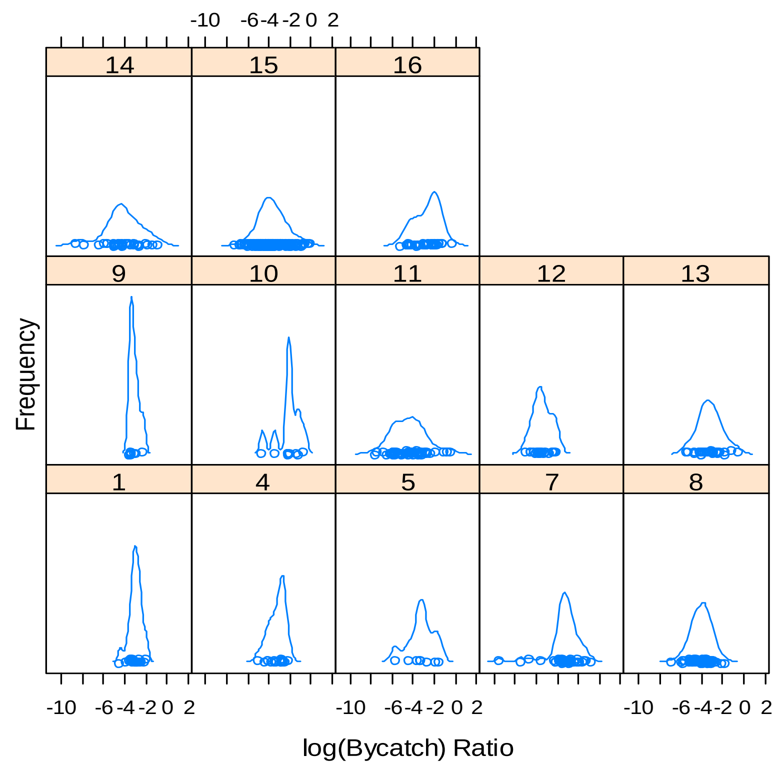

Figure 15. Density plots of the natural logarithm of bycatch ratios of eulachon for each of the vessels observed in 2012.

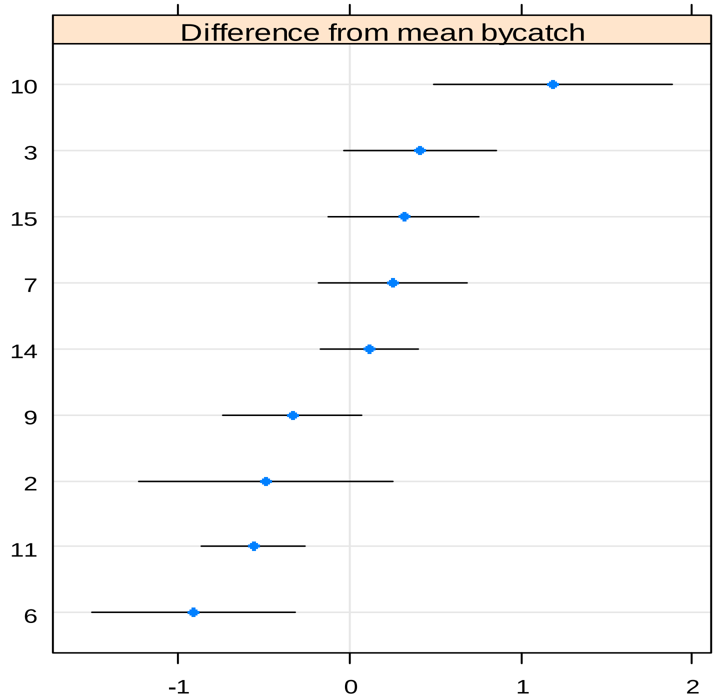

Figure 16. A dot plot of the difference from the mean overall logarithm of bycatch for each vessel observed in 2011.

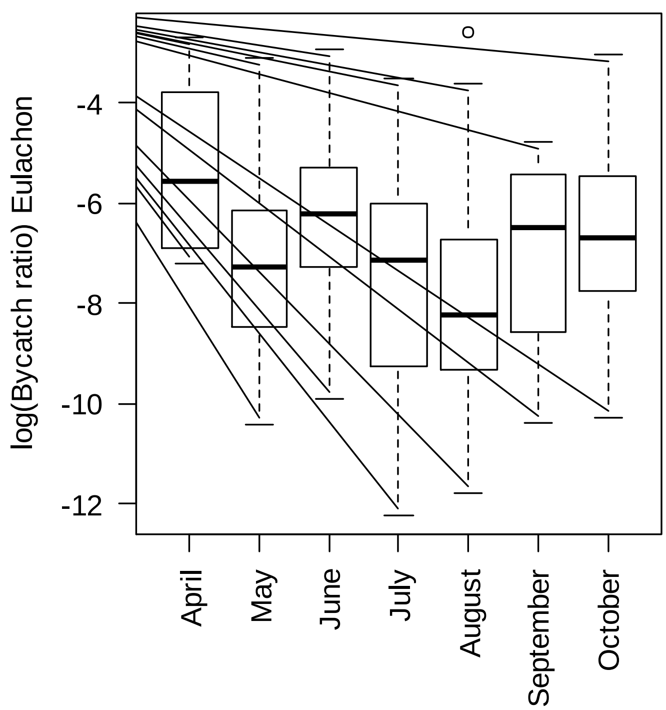

Figure 17. Boxplots of the natural logarithm of the bycatch ratio of eulachon for month fished in 2011.

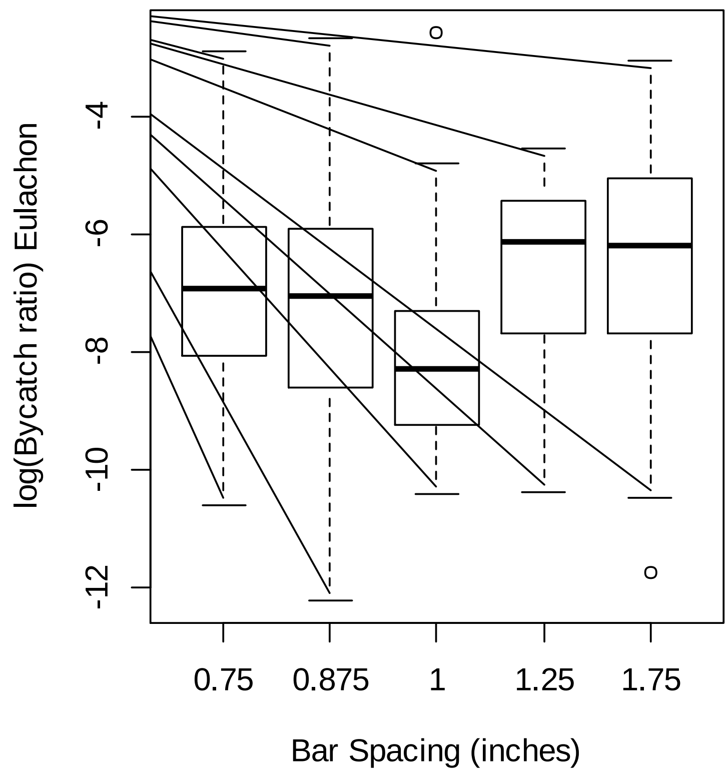

Figure 18. Boxplots of the natural logarithm of bycatch ratio by excluder size used in the 2011 pink shrimp fishery.

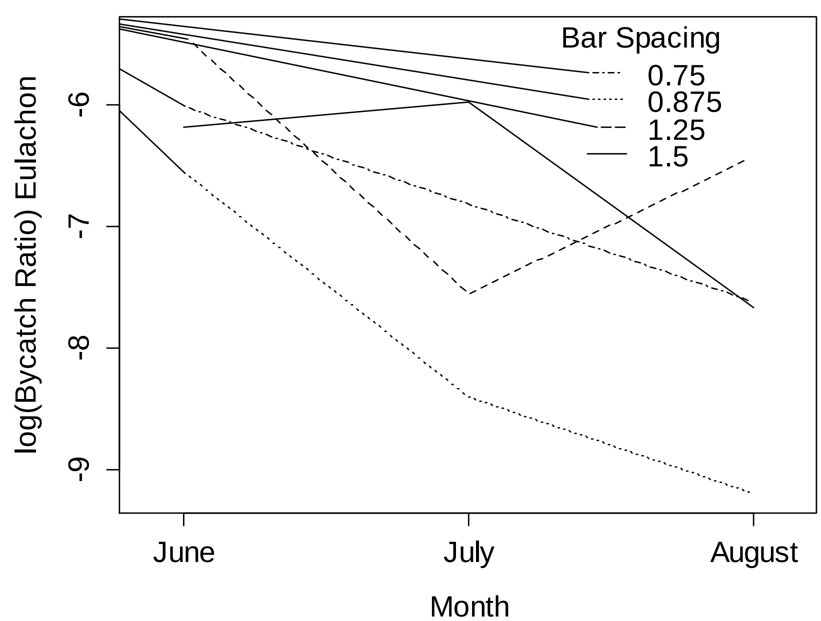

Figure 19. Interaction plot of the effects of gear (excluder bar spacing) and month on the natural logarithm of eulachon bycatch. If no interactions were present, the line would be parallel.

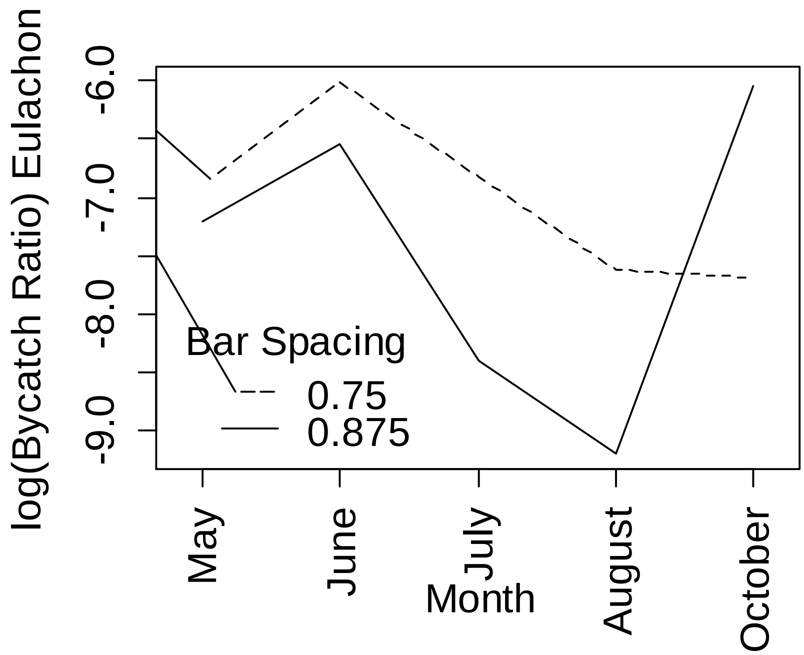

Figure 20. Interaction plot of gear type by month. The increased bycatch in October for the 0.875 bar spacing is most likely the reason for the significant interaction. No interaction effect is typically indicated by parallel, or nearly parallel lines.

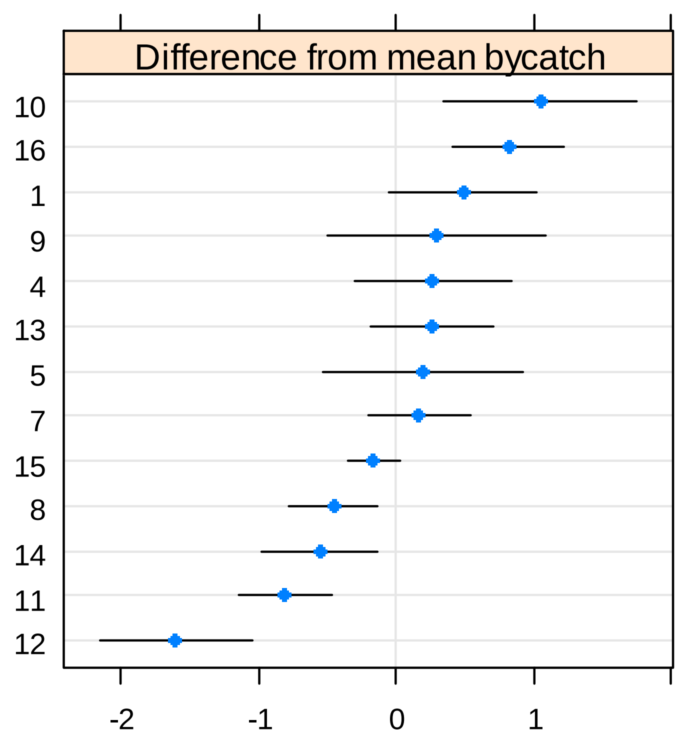

Figure 21. Differences from mean bycatch for the 13 vessels with observers that fished in 2012 and were included in this analysis.

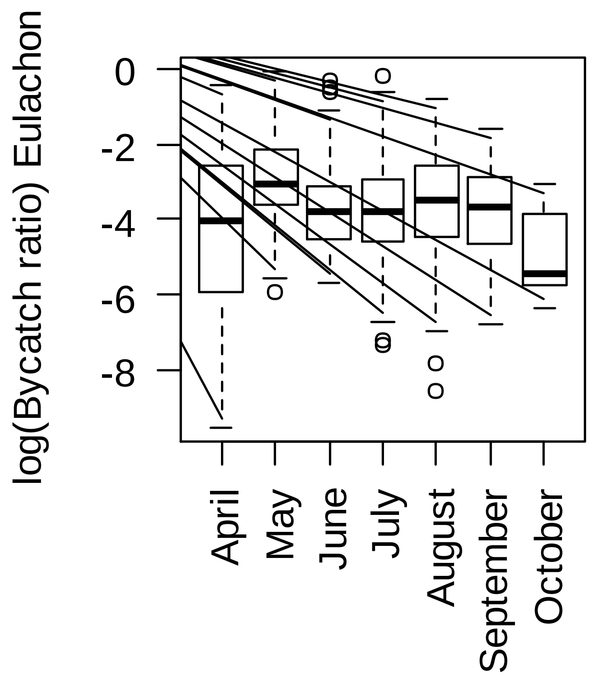

Figure 22. Boxplots of the distribution of bycatch ratios for each month fished in 2012. May had the highest ratios, April and October the lowest.

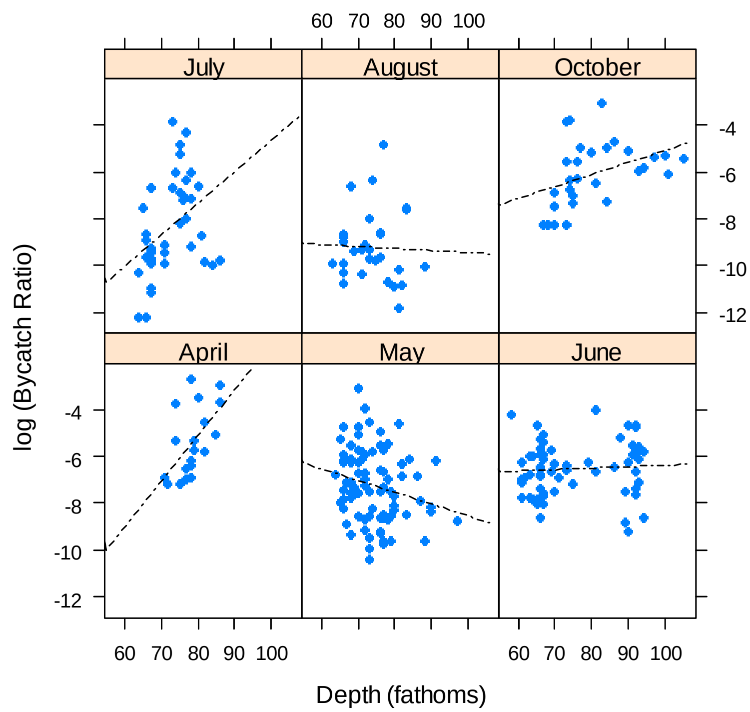

Figure 23. Relationships between depth in fathoms and log (bycatch ratio) for each month in 2011. The difference among months indicates a significant interaction effect.

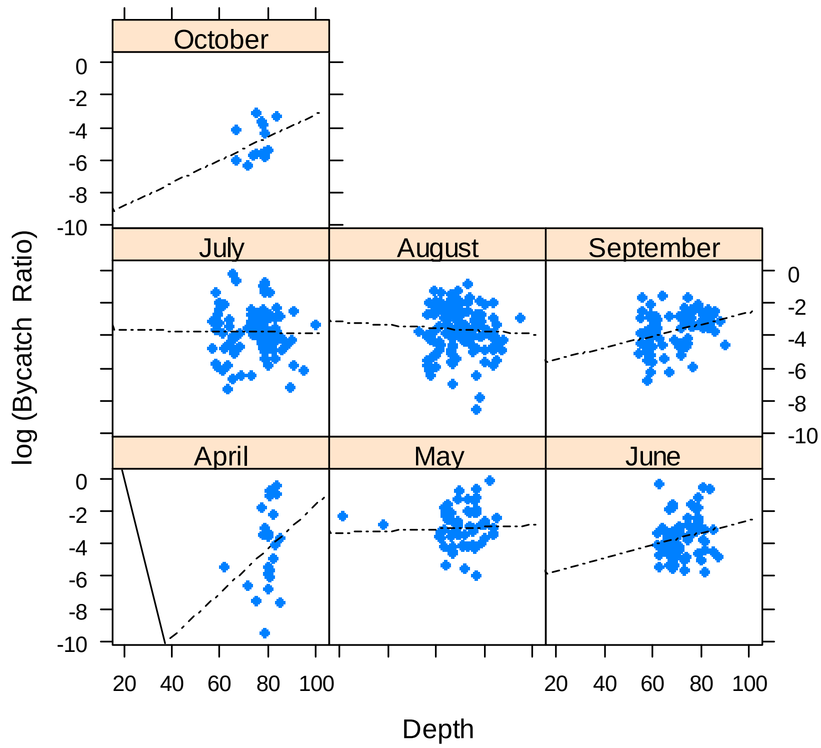

Figure 24. Relationships between depth in fathoms and log (bycatch ratio) for each month in 2012. The difference among months indicates a significant interaction effect.

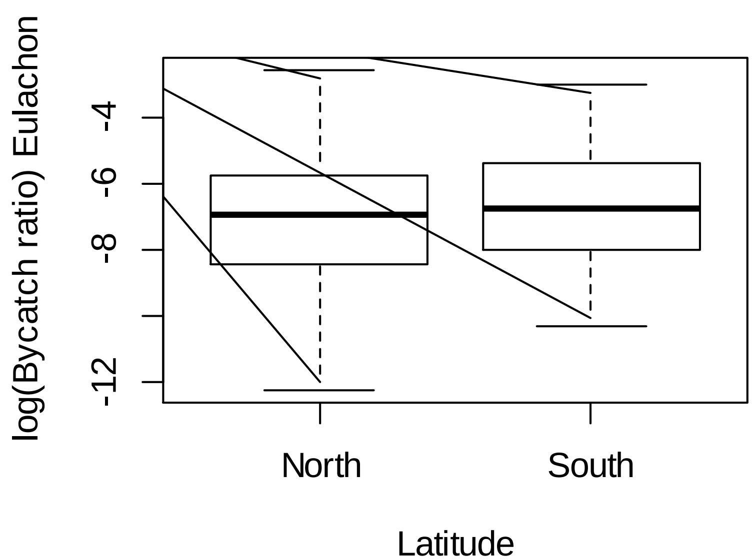

Figure 25. Boxplot of the natural logarithm of bycatch ratios for tows fished north and south of the Columbia River plume.

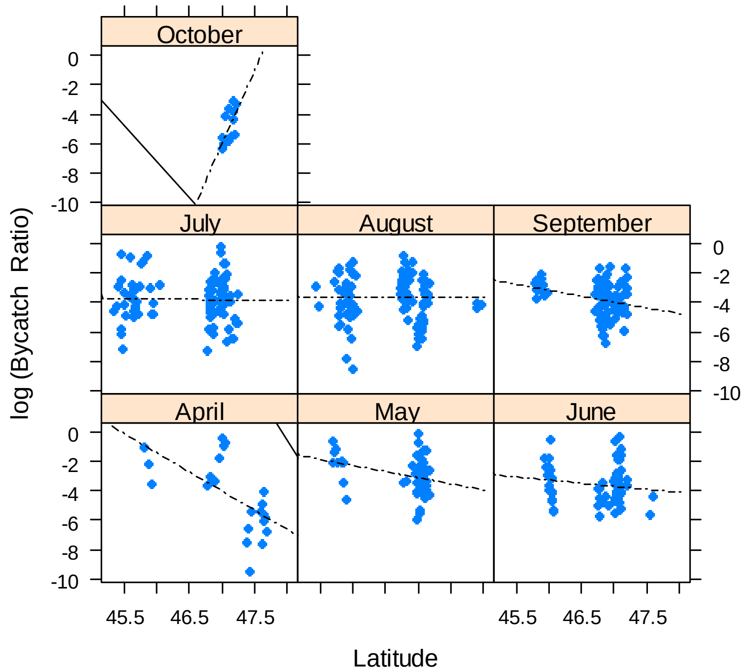

Figure 26. Relationships between fishing location as measured by latitude and log (bycatch ratio) for each month in 2012. The difference in slopes among months indicates a significant interaction effect.

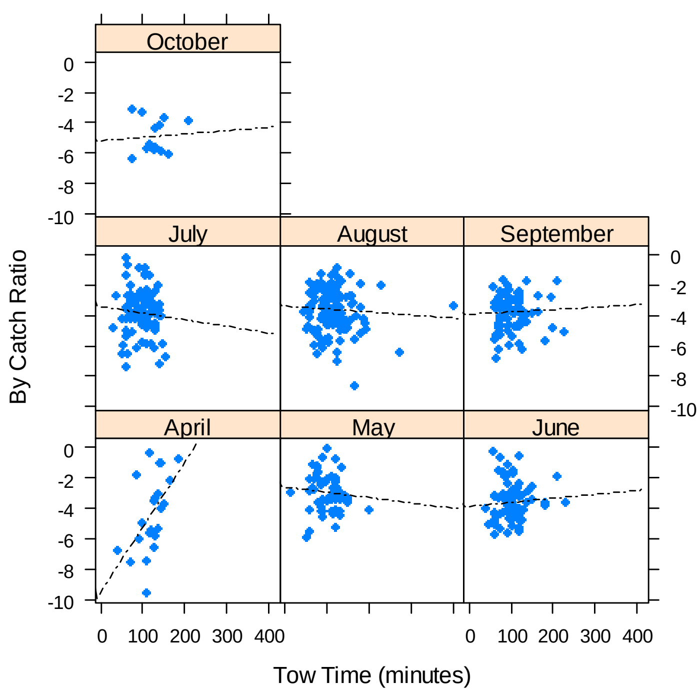

Figure 27. Relationships between tow time and log (bycatch ratio) for each month in 2012. The difference in slopes among months indicates a significant interaction effect.

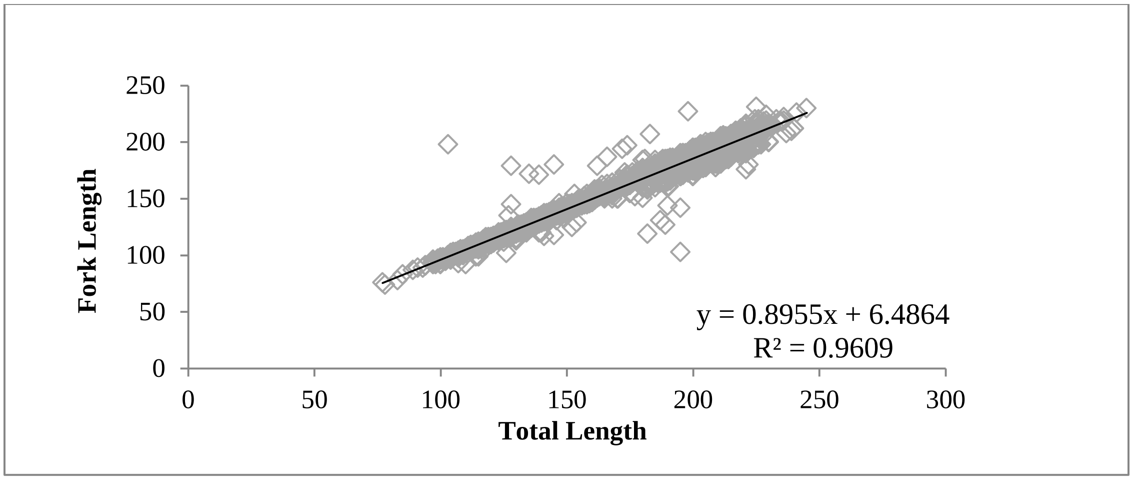

Figure 28. Eulachon total length to fork length (n = 2950), derived from study data, to be used when only total length was recorded.

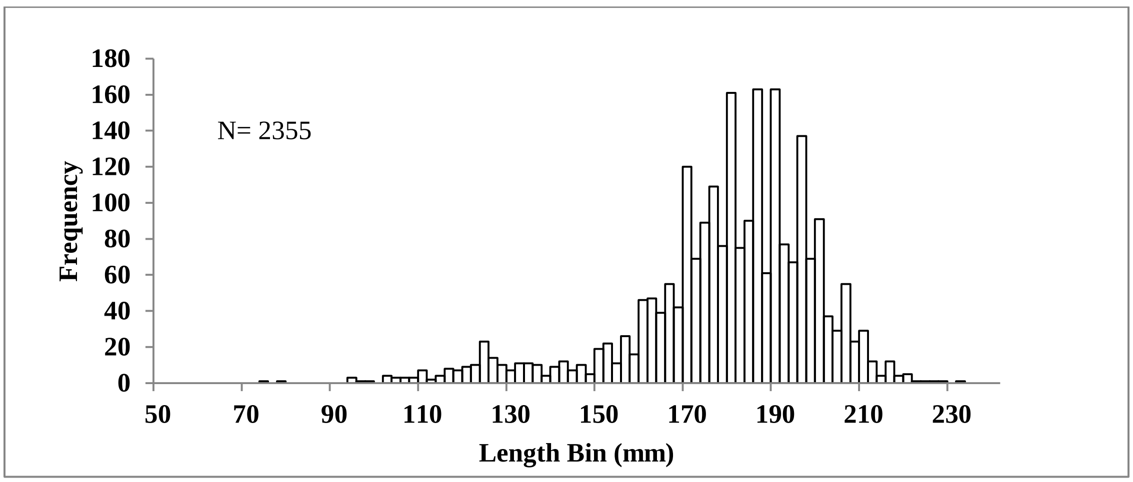

Figure 29. Eulachon length frequency for 2011 with lengths pooled in two millimeter increments.

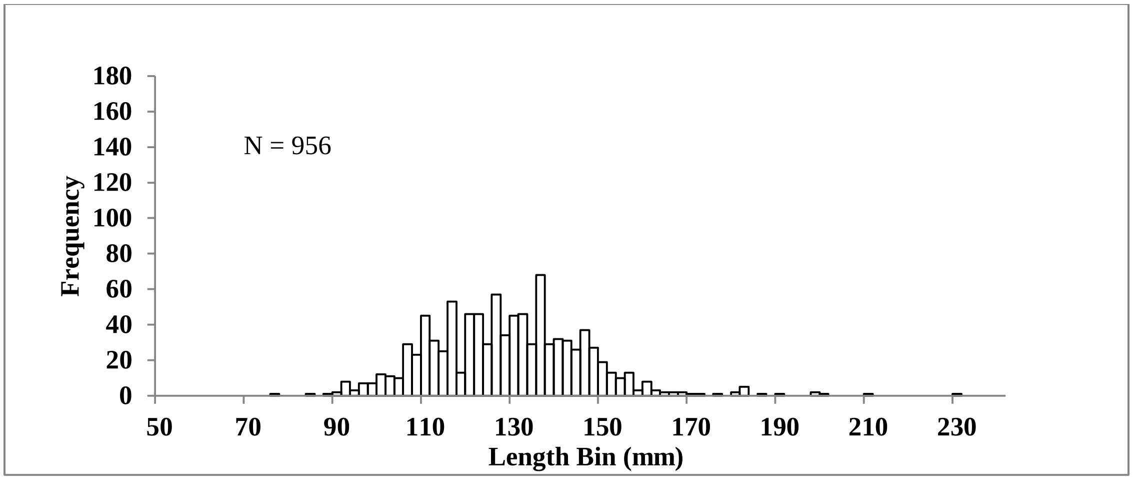

Figure 30. Eulachon length frequency for 2012 with lengths pulled in two millimeter increments.

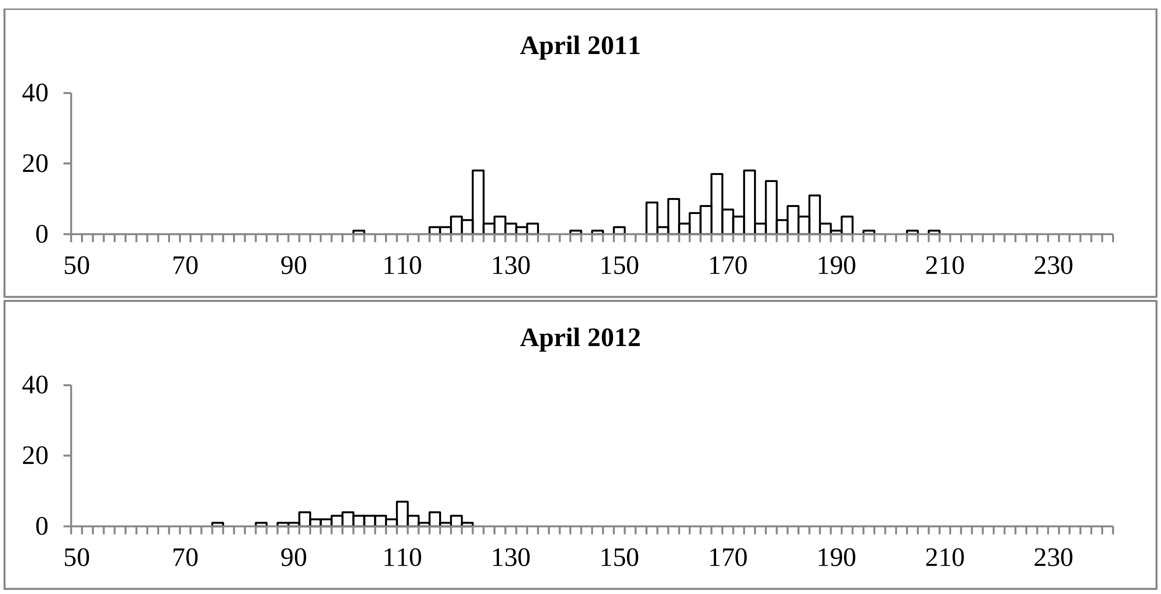

Figure 31. Eulachon length frequency for April, in standard length, presented for comparison with DFO findings (DFO 2014).

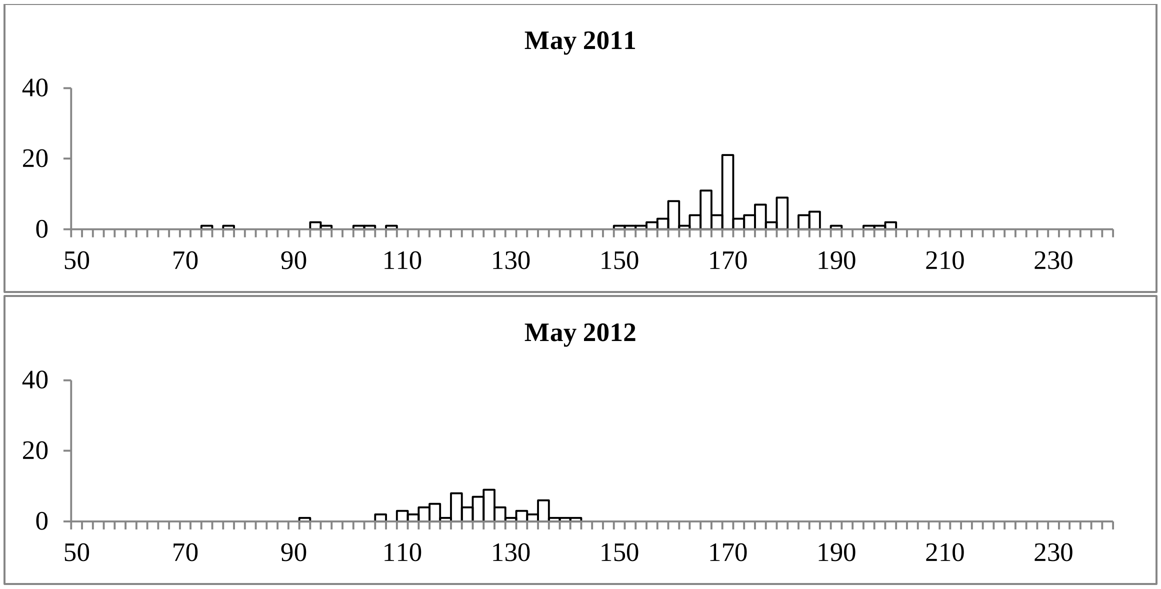

Figure 32. Eulachon length frequency for May, in standard length, presented for comparison with DFO findings (DFO 2014).

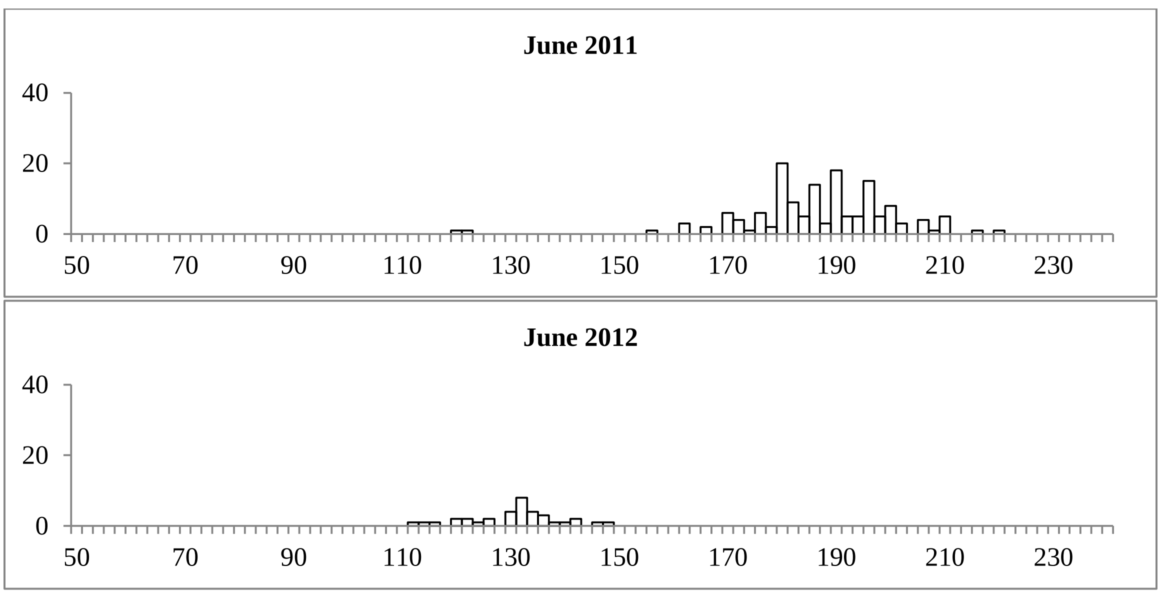

Figure 33. Eulachon length frequency for June, in standard length, presented for comparison with DFO findings (DFO 2014).

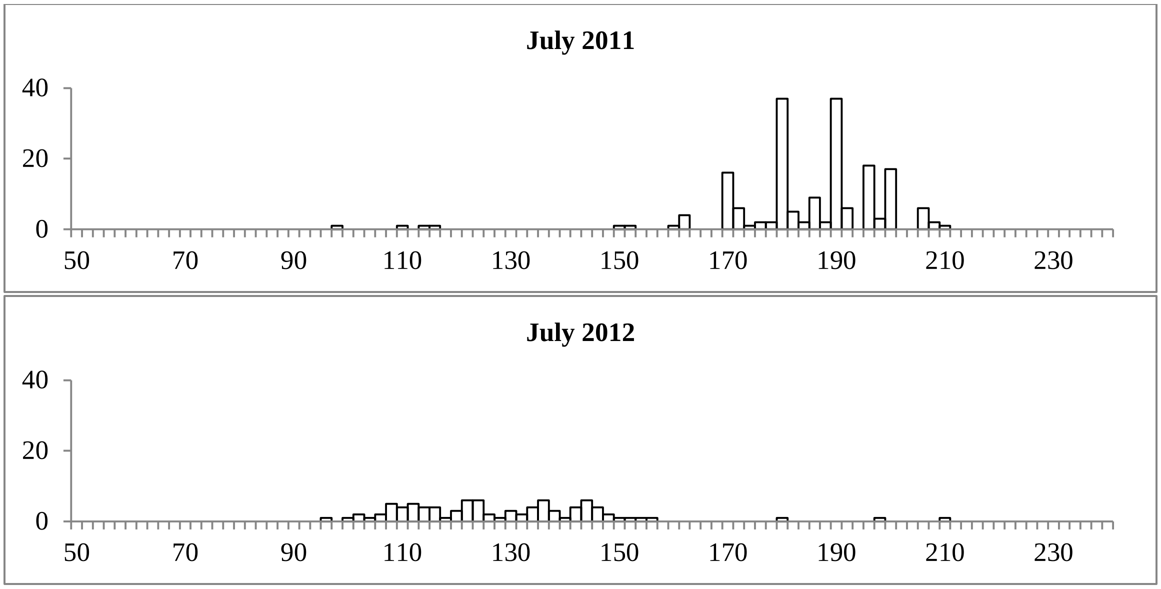

Figure 34. Eulachon length frequency for July, in standard length, presented for comparison with DFO findings (DFO 2014).

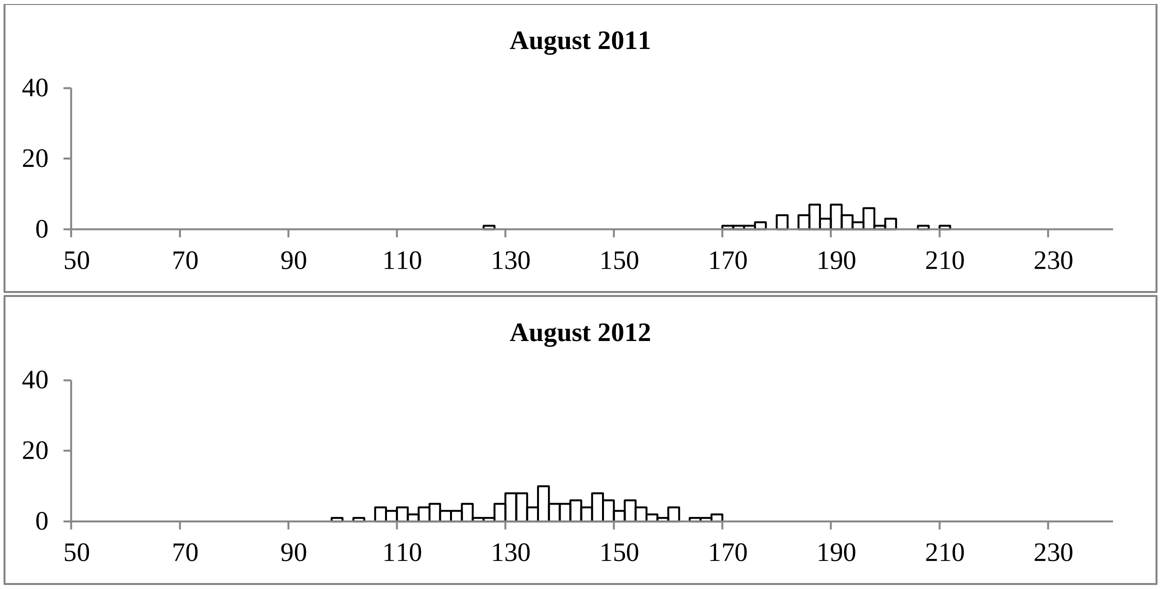

Figure 35. Eulachon length frequency for August, in standard length, presented for comparison with DFO findings (DFO 2014).

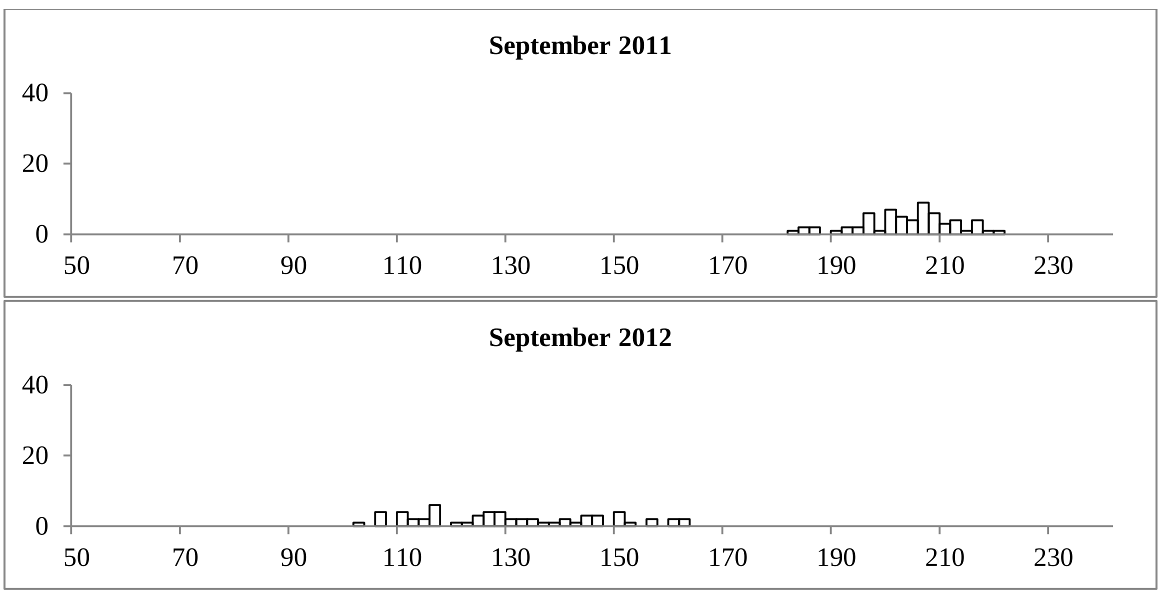

Figure 36. Eulachon length frequency for September, in standard length, presented for comparison with DFO findings (DFO 2014).

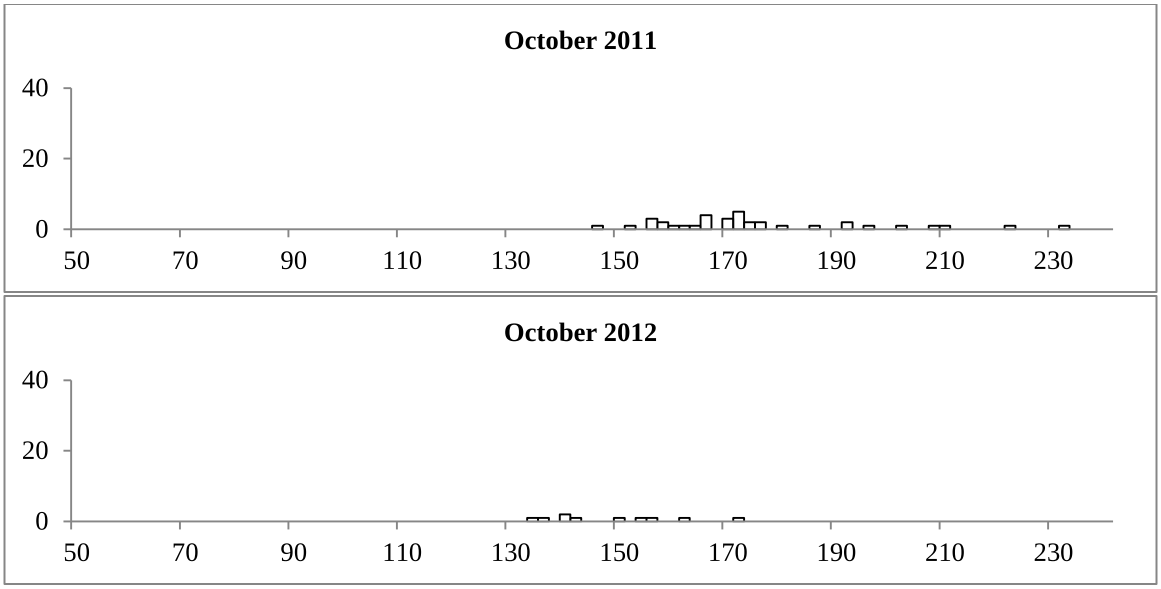

Figure 37. Eulachon length frequency for October, in standard length, presented for comparison with DFO findings (DFO 2014).

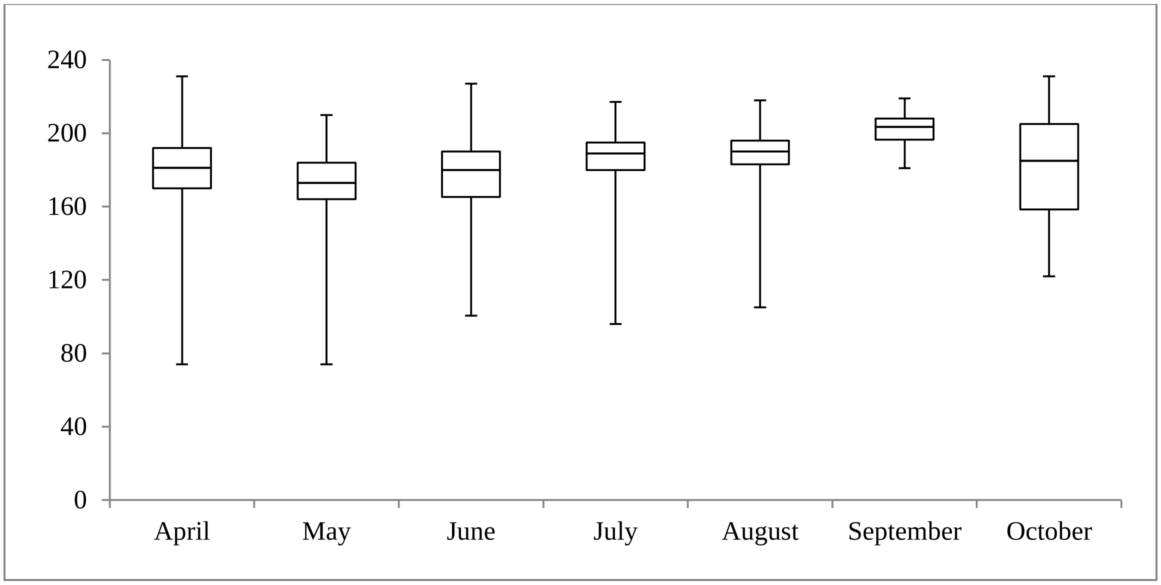

Figure 38. Eulachon median length frequency by month in 2011.

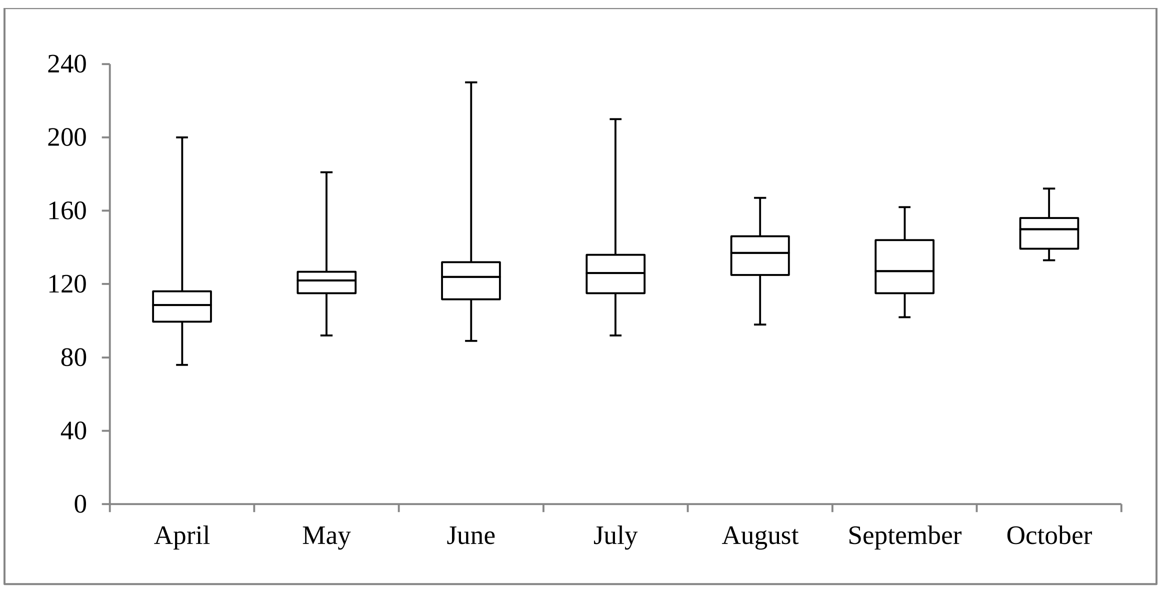

Figure 39. Eulachon median length frequency by month in 2012.

Figure 40. Mean length frequencies pooled by ODFW management area for 2011.

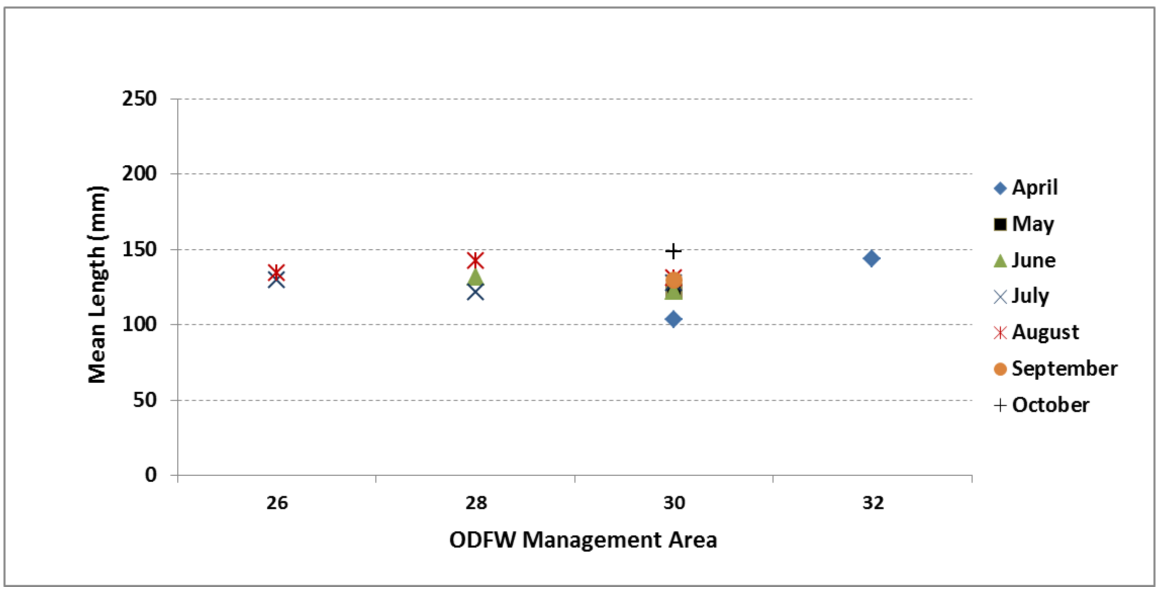

Figure 41. Mean length frequencies pooled by ODFW management area for 2012.

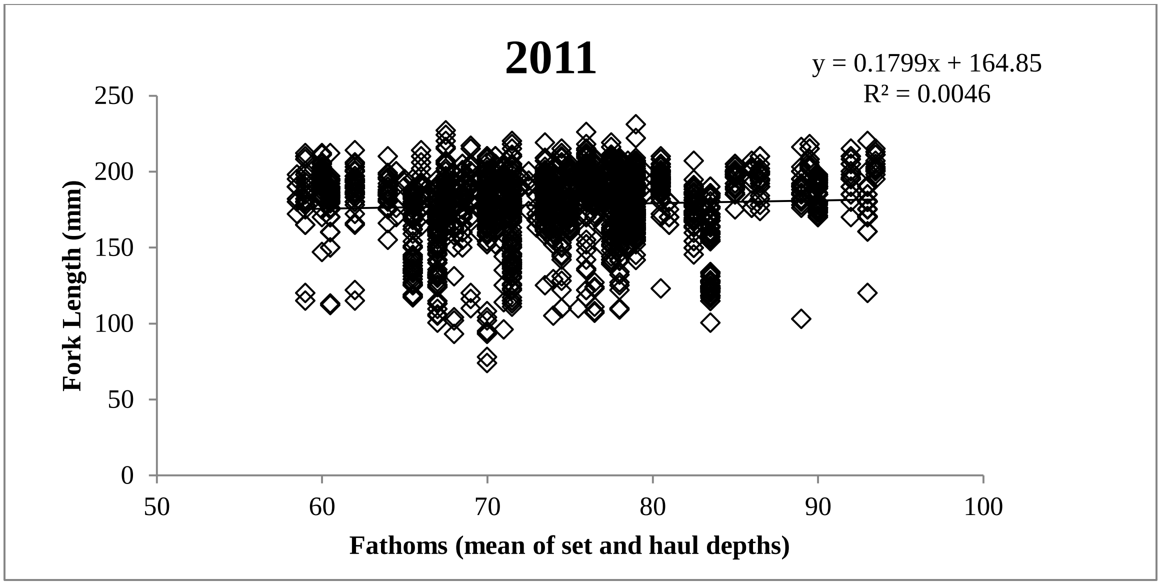

Figure 42. Eulachon lengths by tow depth, in fathoms, in 2011.

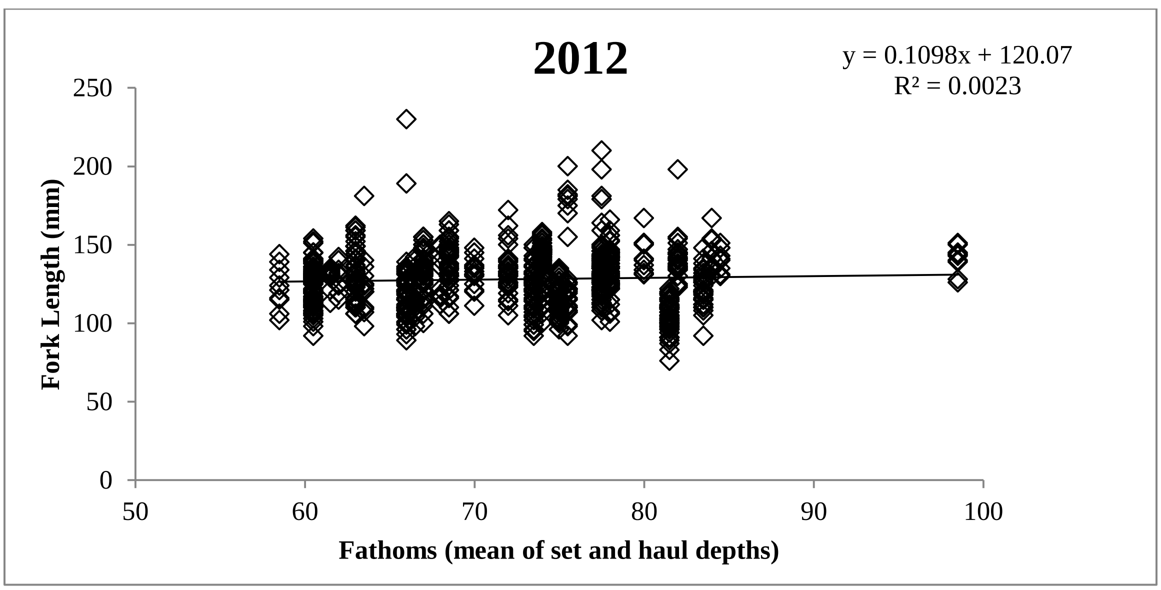

Figure 43. Eulachon lengths by tow depth, in fathoms, in 2012.

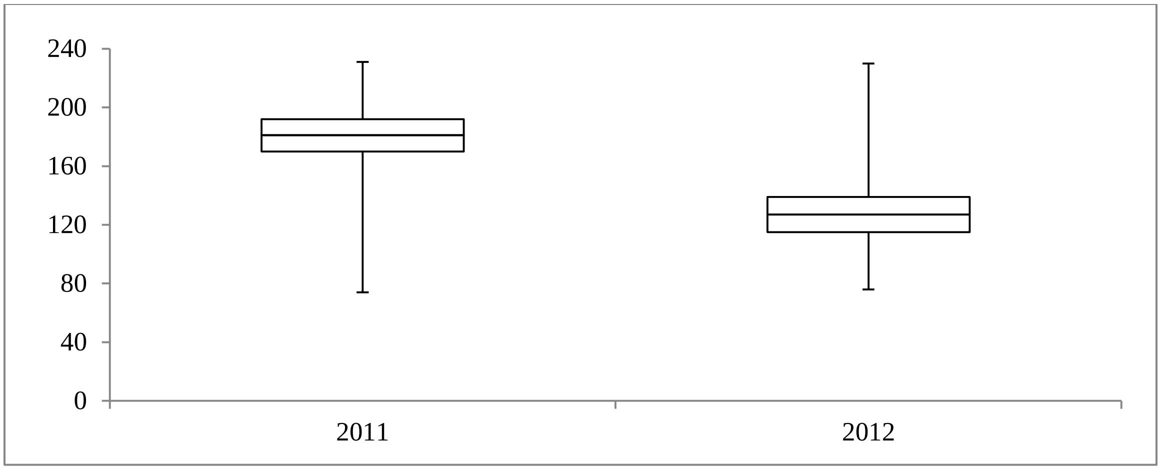

Figure 44. Eulachon median length frequency by year.

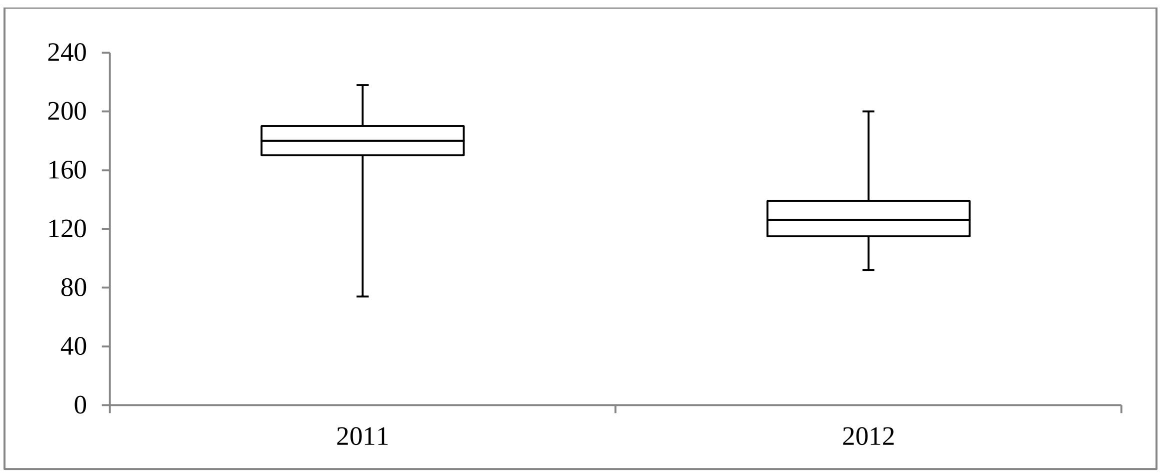

Figure 45. Eulachon median length by BRD bar-spacing with 0.75 inches for both 2011 and 2012.

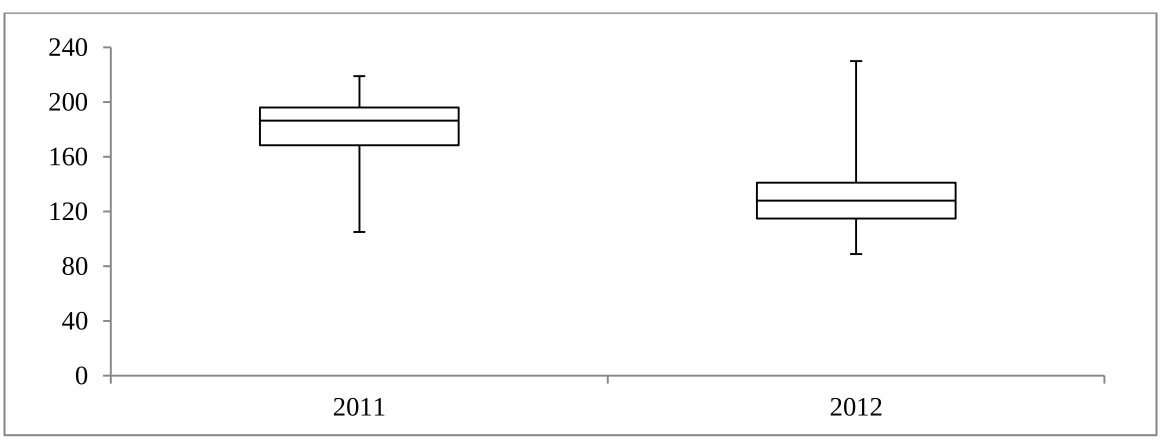

Figure 46. Eulachon median length by BRD spacing with 1.25 inches in 2011 and 0.75 inches in 2012.

Tables

Table 1. Crosswalk table of ODFW catch areas and WDFW marine fish-shellfish fish ticket catch area codes.

State area	Newsletter name	South bound (latitude)	North Bound (latitude)	WDFW MFSF Catch Area
12	Mendocino and south	38.83	40.5	62
18	Northern California	40.5	42	62
19	Rogue River	42	42.4334	61
20	Port Orford	42.4334	42.833	61
21	Bandon Bed	42.833	43.3	61
22	Mudhole	43.3	44.3	61
24	Cape Foulweather	44.3	45.05	61
26	Cape Lookout	45.05	45.76667	61
28	Tillamook Head	45.76667	46.225	61
29	Columbia River	46.225	46.6667	60A-2
30	Grays Harbor	46.6667	47.333	60A-2
32	Destruction Island	47.333	48.5	59A-2
33	North of DI	48.5	49	59A-1

Table 2. Species encountered as bycatch and recorded by observers pooled for both 2011 and 2012.

Species Encountered	Scientific Name
Arrowtooth Flounder	*Atheresthes stomias*
Barracudinia	*Paralepididae (family)*
Basket Star	*Gorgonocephalus eucnemis*
Bluebarred prickleback	*Plectobranchus evides*
Box crab	*Lopholithodes spp.*
Cephalopod (unspecified)	*Cephalopoda (class)*
Clam (unidentified)	*Bivalvia (class)*
Cod (unidentified)	*Gadidae (family)*
Crab (unidentified)	*Crustacean (subphylum)*
Ctenophore (unidentified)	*Ctenophora (phylum)*
Darkblotched rockfish	*Sebastes crameri*
Decorator crab	*Loxorhynchus crispatus*
Dover sole	*Microstomus pacificus*
Dungeness crab	*Cancer magister*
Dwarf Wrymouth	*Cryptacanthodes aleutensis*
Echinoid (unidentified)	*Echinacea (superorder)*
Eel (unidentified)	
Eelpout (unspecified)	*Zoarcidae (family)*
English sole	*Pleuronectes vetulus*
Eulachon	*Thaleichthys pacificua*

Species Encountered	Scientific Name
Flatfish (unspecified)	*Pleuronectiformes (order)*
Flathead sole	*Hippoglossoides elassodon*
Greenstriped rockfish	*Sebastes elongates*
Hagfish	*Myxinidae (family)*
Invertebrate (unspecified)	
Isopod (unidentified)	*Isopoda (order)*
Jellyfish (unidentified)	*Cnidaria (phylum)*
Lanternfish (unidentified)	*Myctophidae (family)*
Lingcod	*Ophiodon elongates*
Longnose skate	*Raja rhina*
Mackerel (unidentified)	*Scombridae (family)*
Moon Snail	*Naticidae (family)*
Northern anchovy	*Engraulis mordax*
Nudibranch (unidentified)	*Nudibranchia (order)*
Octopus (unidentified)	*Octopoda (order)*
Pacific argentine	*Argentina sialis*
Pacific hake	*Merluccius productus*
Pacific halibut	*Hippoglossus stenolepis*
Pacific Herring	*Clupea pallasi*
Pacific lamprey	*Entosphenus tridentatus*
Pacific sanddab	*Citharichthys sordidus*

Species Encountered	Scientific Name
Pacific sardine	*Sardinops sagax*
Perch (unidentified)	*Embiotocidae (family)*
Petrale sole	*Eopsetta jordani*
Plainfin midshipman	*Porichthys notatus*
Poacher (unspecified)	*Agonidae (family)*
Polychaete (unidentified)	*Polychaeta (class)*
Prickleback (unspecified)	*Stichaeidae (family)*
Rex sole	*Errex zachirus*
Rockfish (unspecified)	*Sebastidae (family)*
Sablefish	*Anoplopoma fimbria*
Sailfin sculpin	*Nautichthys oculofasciatus*
Sand Shrimp	*Neotrypaea californiensis*
Sandpaper skate	*Bathyraja interrupta*
Scallop (unidentified)	*Pectinidae (family)*
Sculpin (unidentified)	*Cottidae (family)*
Sea anemone (unidentified)	*Actiniaria (order)*
Sea cucumber (unidentified)	*Holothuroidea (class)*
Sea star (unidentified)	*Asteroidea (class)*
Sea whip (unidentified)	*Gorgonacea (family)*
Seaweed (unidentified)	
Shad	*Alosa sapidissima*

Species Encountered	Scientific Name
Sharpchin rockfish	*Sebastes zacentrus*
Shiner perch	*Cymatogaster aggregata*
Skate (unidentified)	*Rajidae (family)*
Slender sole	*Eopsetta exilis*
Smelt (unidentified)	*Osmeridae (family)*
Snail (unidentified)	*Gastropoda (class)*
Snailfish (unidentified)	*Cyclopteridae (family)*
Spiny dogfish	*Squalus acanthias*
Sponge (unidentified)	*Porifera (phylum)*
Spot shrimp	*Pandalus platycerous*
Spotted cusk-eel	*Chilara taylori*
Spotted ratfish	*Hydrolagus colliei*
Spotted ratfish egg case	
Squat lobster	*Munida quadrispina*
Squid (unspecified)	*Ancistrocheiridae (family)*
Stickleback (unidentified)	*Gasterosteidae (family)*
Striped nudibranch	*Armina californica*
Surf perch	*Embiotocidae (family)*
Thornyhead (unidentified)	*Sebastolobus spp.*
Threadfin sculpin	*Icelinus filamentosus*
Tidepool snailfish	*Liparis florae*

Species Encountered	Scientific Name
Walleye pollock	*Theragra chalcogramma*
Whitebait smelt	*Allosmerus elongatus*
Whitebarred prickleback	*Poroclinus rothtocki*
Wrymouth (unidentified)	*Cryptacanthodidae (family)*
Yelloweye rockfish	*Sebastes ruberrimus*
Yellowtail rockfish	*Sebastes flavidus*

Table 3. The number of observed tows with eulachon for each vessel/month combination in the 2011 Washington pink shrimp fishery.

	2011							
Vessel	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**Total**
2							15	15
3			22	16	14			52
6					27			27
7		8	25	3	19			55
9			26	8	22	9		65
10			6	12				18
11	4	49	24	11	18		17	123
14	18	38	30	30	11		12	139
15			12	23	10	9		54
Total	22	95	145	103	121	18	44	548

Table 4. The number of observed tows with eulachon for each of the 5 gear types by vessel in the 2011 Washington pink shrimp fishery.

Vessel	**2011 Excluder Size**				
Number	**0.75**	**0.875**	**1**	**1.25**	**1.5**
2	15				
3					52
6			27		
7	48	7			
9	65				
10	18				
11		123			
14		139			
15				54	

Table 5. The number of observed tows with eulachon by month and gear type in the 2011 Washington pink shrimp fishery.

	Excluder Size				
Vessel	**0.75**	**0.875**	**1**	**1.25**	**1.5**
April		22			
May	8	87			
June	50	61		12	22
July	23	41		23	16
August	41	29	27	10	14
September	9			9	
October	15	29			

Table 6. The number of observations that were south and north of the Columbia River plume by vessel in 2011.

Vessel	South	North
2	15	0
3	0	52
6	0	27
7	0	55
9	0	65
10	0	18
11	17	106
14	0	139
15	0	54

Table 7. The number of observed tows with eulachon for each vessel/gear type combination in the 2012 Washington pink shrimp fishery.

Vessel	Excluder 1 - Bar spacing		Excluder 2 - Bar spacing		
	0.75	1.25	0.75	1.25	1.5
1	19	0	19	0	0
3	62	0	0	0	62
4	17	0	17	0	0
5	9	0	9	0	0
7	43	0	43	0	0
8	59	26	59	26	0
9	7	0	7	0	0
10	10	0	10	0	0
11	55	0	55	0	0
12	18	0	18	0	0
13	29	0	29	0	0
14	32	0	32	0	0
15	174	0	174	0	0
16	36	0	36	0	0

Table 8. The distribution of tows with eulachon by month and vessel for the 2012 pink shrimp fishery. All tows in this table were made with the 0.75 inch bar spacing.

Vessel	April	May	June	July	August	September	October
1	0	0	0	0	5	14	0
4	0	0	0	0	17	0	0
5	0	0	9	0	0	0	0
7	4	19	1	19	0	0	0
8	0	0	15	0	14	30	0
9	0	7	0	0	0	0	0
10	0	10	0	0	0	0	0
11	16	0	0	25	0	0	14
12	0	0	0	0	18	0	0
13	3	0	19	7	0	0	0
14	0	0	0	0	32	0	0
15	0	25	25	52	28	44	0
16	0	0	11	0	25	0	0
Total	23	61	80	103	139	88	14

Table 9. Estimates of the contribution of Vessel to the overall variance of the logarithm of bycatch ratios for 2011.

	Estimate
Vessel Variance	0.4716
Residual Variance	3.0495
Total Variance	3.5211
Percent of Variability from *Vessel*	13.4%

Table 10. Results of the analysis that removed month first from the above model using observations from June, July, and August, gear types 0.75, 0.875, 1.25, and 1.5.

Source	**Deviance**	**□ deviance (χ^2_{df})**	**Chi-square df**	**p-value**
Vessel	1370.784			
Gear	1366.513	4.271	3	0.234
Month	1285.446	81.068	2	< 0.001
Interaction	1260.945	24.500	6	< 0.001

Table 11. Results of the analysis that removed gear type first from the model (Eq. 3) using observations from June, July, and August, gear types 0.75, 0.875, 1.25, and 1.5.

Source	**Deviance**	**Change in deviance (Chi-square)**	**Chi-square df**	**p-value**
Vessel	1370.784			
Month	1294.112	76.672	2	<0.001
Gear	1285.446	8.666	3	0.034
Interaction	1260.945	24.500	6	<0.001

Table 12. ANOVA results table for the analysis of the August tow data (Eq. 4).

Source	**df**	**SS**	**MSE**	**F-value**	**p-value**
Gear	4	73.846	18.462	7.30	< 0.001
Vessel	2	7.027	3.513	1.39	0.253
Residual	114	288.172	2.538		
Total	120	369.045			

Table 13. Results of the pairwise comparison analysis for different gear types in August 2011. The 0.875 gear type was significantly lower than the 0.75, 1.25, and 1.5 inch bar spacing.

Gear Contrasts	**Difference in mean log ratio**	**p-value (adj)**
0.875 - 0.75	***-1.572***	***0.001***
1 - 0.75	-0.484	0.736
1.25 - 0.75	1.197	0.213
1.5 - 0.75	-0.041	1.000
1 - 0.875	1.088	0.085
1.25 - 0.875	***2.768***	< ***0.001***
1.5 - 0.875	***1.531***	***0.030***
1.25 - 1	***1.680***	***0.040***
1.5 - 1	0.443	0.916
1.5 - 1.25	-1.238	0.334

Table 14. Results of the analysis that compared the effects 0.875 and 0.75 bar spacing across all months both gears were fished. Month was removed first in this analysis.

Source	**Deviance**	**□□deviance (χ^2_{df})**	**Chi-square df**	**p-value**
Vessel	1516.913			
Gear	1516.207	0.706	1	0.401
Month	1416.073	100.134	3	< 0.001
Interaction	1396.926	19.147	5	0.002

Table 15. Results of the analysis that compared the effects 0.875 and 0.75 bar spacing across all months both gears were fished. Gear was removed first in this analysis.

Source	**Deviance**	**□□deviance (χ^2_{df})**	**Chi-square df**	**p-value**
Vessel	1516.913			
Month	1416.073	100.840	4	< 0.001
Gear	1413.28	2.793	1	0.095
Interaction	1396.926	16.354	4	0.003

Table 16. Results of the analysis testing the effect of month for tows using the 0.875 gear type only.

Source	**Deviance**	**□□deviance (χ^2_{df})**	**Chi-square df**	**p-value**
Vessel	12904			
Month	12528	376.49	5	<0.001

Table 17. Results of the pairwise comparisons of mean bycatch ratio by for the months fished with the 0.875 gear types. April is significantly higher than all months except October.

Month Contrast	Difference	p-value (adj)	Direction
April - May	***-1.797***	< ***0.001***	**April Higher**
April - June	***-1.145***	***0.039***	**April Higher**
April - July	***-2.997***	< ***0.001***	**April Higher**
April - August	***-3.791***	< ***0.001***	**April Higher**
April - October	-0.646	0.686	Same
May - June	0.652	0.126	Same
May - July	***-1.200***	***0.001***	**May Higher**
May - August	***-1.994***	< ***0.001***	**May Higher**
May - October	***1.152***	***0.009***	**October Higher**
June - July	***-1.852***	< ***0.001***	**June Higher**
June - August	***-2.646***	< ***0.001***	**June Higher**
June - October	0.499	0.714	Same
July - August	-0.793	0.291	Same
July - October	2.352	< ***0.001***	**October Higher**
August - October	3.145	< ***0.001***	**October Higher**

Table 18. Estimates of the contribution of Vessel to the overall variance of the logarithm of bycatch ratios for 2012.

	Estimate
Vessel Variance	0.536
Residual Variance	1.669
Total Variance	2.205
Percent of Variability from *Vessel*	24.3%

Table 19. Results of the analysis testing the effect of month for 2012.

Source	**Deviance**	**deviance (χ^2_{df})**	**Chi-square df**	**p-value**
Vessel	1731.4			
Month	1712.8	18.62	6	0.005

Table 20. Results of the pairwise comparisons from the Tukey HSD test for months fished in 2012. May was consistently higher than all months but June.

Pairwise Contrast	**Difference in mean log(Bycatch Ratio)**	**p-value (adjusted)**	**Direction**
May - April	1.340	***0.002***	***May higher***
June - April	0.701	0.322	Same
July - April	0.539	0.616	Same
August - April	0.690	0.282	Same
September - April	0.547	0.617	Same
October - April	-0.569	0.886	Same
June - May	-0.639	0.093	Same
July - May	-0.800	***0.006***	***May higher***
August - May	-0.650	***0.036***	***May higher***
September - May	-0.793	***0.010***	***May higher***
October - May	-1.908	***0.000***	***May higher***
July - June	-0.162	0.986	Same
August - June	-0.011	1.000	Same
September - June	-0.154	0.991	Same
October - June	-1.270	***0.025***	***June Higher***
August - July	0.151	0.980	Same
September - July	0.008	1.000	Same
October - July	-1.108	***0.072***	***July Higher***
September - August	-0.143	0.988	Same
October - August	-1.259	***0.020***	***August Higher***
October - September	-1.116	0.074	Same

Table 21. Results of the analysis testing the effect of depth with month for 2011. Only the 0.875 gear types and associated months were used for the analysis.

Source	**Deviance**	**□□deviance (χ^2_{df})**	**Chi-square df**	**p-value**
Vessel	1097.81			
Month	990.36	107.45	5	< 0.001
Depth	983.26	7.10	1	0.008
Depth:Month Interaction	959.94	23.33	5	< 0.001

Table 22. The effect of changes in one fathom of fishing depth on the amount of bycatch, in pounds, for each month fished in 2011 (Eq. 6).

Month	Tows	Intercept ($\hat{\alpha}$)	Estimate ($\hat{\beta}$)	$SE(\hat{\beta})$	p-value ($\hat{\beta}$) for slope	Average depth in fathoms	Change in lbs. Eulachon/10000 lbs. shrimp for a one fathom increase in fishing depth
April	21	-20.280	0.186	0.059	0.003	78.19	6.594
May	87	-4.774	-0.032	0.026	0.107	74.14	-0.248
June	61	-7.063	0.007	0.012	0.290	74.98	0.102
July	41	-17.657	0.127	0.049	0.007	72.07	0.274
August	29	-2.444	-0.089	0.052	0.050	73.76	-0.104
October	29	-10.222	0.052	0.023	0.016	80.79	1.296

Table 23. Analysis of deviance table for the analysis of the effects of month and depth on log(bycatch) for 2012.

Source	**Deviance**	**□□deviance (χ^2_{df})**	**Chi-square df**	**p-value**
Vessel	3			
Month	9	18.616	6	0.005
Depth	10	5.749	1	0.017
Depth:Month Interaction	16	17.604	6	0.007

Table 24. The effect of changes in one fathom of fishing depth on the amount of bycatch, in pounds, for each month fished in 2012 (Eq. 6).

Month	Tows	Intercept ($\hat{\alpha}$)	Estimate ($\hat{\beta}$)	$SE(\hat{\beta})$	p-value ($\hat{\beta}$)	Average depth in fathoms	Change in lbs. Eulachon/10000 lbs. shrimp for a one fathom increase in fishing depth
April	23	2.097	-0.085	0.124	0.253	79.61	-7.638
May	61	-3.333	0.006	0.015	0.347	70.23	3.273
June	*80*	*-9.169*	*0.078*	*0.022*	*0.000*	*71.86*	*22.980*
July	103	-3.623	-0.001	0.015	0.466	74.34	-0.248
August	139	-1.951	-0.024	0.015	0.054	70.05	-6.274
September	*87*	*-6.160*	*0.036*	*0.013*	*0.003*	*68.36*	*9.071*
October	13	-10.260	0.071	0.065	0.30	75.93	5.652

Table 25. The number of tows for north and south of the Columbia River plume in 2011.

Month	North	South
April	22	0
May	95	0
June	145	0
July	103	0
August	121	0
September	18	0
October	12	32

Table 26. The number of tows for each type and location with regard to the Columbia River plume in 2011.

Gear	North	South
0.75	131	15
0.875	252	17
1	27	0
1.25	54	0
1.5	52	0

Table 27. Analysis of deviance table for the analysis of the effects of month and latitude on log(bycatch) in 2011 for tows fished north of the Columbia River.

Source	Deviance	□□deviance (χ^2_{df})	Chi-square df	p-value
Month	928.2207	93.391	5	< 0.001
Latitude	927.554	0.667	1	0.414
Interaction	870.7384	56.816	5	< 0.001

Table 28. Analysis of deviance table for the analysis of the effects of month and latitude on log(bycatch) in 2012. All fishing occurred north of the Columbia River.

Source	**Deviance**	**□□deviance (χ^2_{df})**	**Chi-square df**	**p-value**
Vessel	1731.431			
Month	1712.815	18.616	6	0.005
Latitude	1673.894	38.921	1	< 0.001
Latitude:Month	1631.866	42.028	6	< 0.001

Table 29. The effect an 0.5 degree increase in latitude of fishing on the amount of bycatch, in pounds, for each month fished in 2012 (Eq. 7).

Month	Tows	Intercept $(\hat{\alpha})$	Estimate $(\hat{\beta})$	$SE(\hat{\beta})$	p-value $(\hat{\beta})$	Average latitude	Change in lbs. eulachon/10000 lbs. shrimp for increase in 0.5 degrees latitude
April	*23*	*176.953*	*-3.870*	*0.879*	*0.000*	*47.12*	*-38.59*
May	*61*	*34.991*	*-0.811*	*0.324*	*0.008*	*48.84*	*-32.90*
June	79	21.760	-0.540	0.574	0.175	46.81	-70.22
July	103	-0.102	-0.077	0.240	0.375	46.52	-9.49
August	*125*	*-32.890*	*0.628*	*0.255*	*0.008*	*46.54*	*94.65*
September	*88*	*32.226*	*-0.770*	*0.305*	*0.007*	*46.78*	*-71.87*
October	*13*	*-472.116*	*9.917*	*3.609*	*0.018*	*47.11*	*10,256.45*

Table 30. Analysis of deviance table for the analysis of the effects of month and tow time on log(bycatch) in 2011.

Source	Deviance	□□deviance (χ^2_{df})	Chi-square df	p-value
Vessel	1097.81			
Month	990.36	107.447	5	< 0.001
Time	980.12	10.249	1	0.001
Interaction	975.49	4.623	5	0.464
$\hat{\beta}\ Time$ = -0. 007(SE = 0.003)				

Table 31. Analysis of deviance table for the analysis of the effects of month and tow time on log(bycatch) in 2012.

Source	Deviance	□□deviance (χ^2_{df})	Chi-square df	p-value
Vessel	1731.431			
Month	1712.815	18.616	6	0.005
Time	1684.51	28.305	1	< 0.001
Time:Month	1658.087	26.423	6	< 0.001

Table 32. The effect a 30 minute increase in time per tow on the amount of bycatch, in pounds, per 10,000 pounds of shrimp for each month fished in 2012 (Eq. 8).

Month	Tows	Intercept ($\hat{\alpha}$)	Estimate ($\hat{\beta}$)	$SE(\hat{\beta})$	p-value ($\hat{\beta}$)	Average tow time	Change in Eulachon/10000 lbs. shrimp for increase in 30 minute increase tow fishing
April	23	-9.38	0.039	0.013	0.001	121	21.01339
May	60	-2.62	-0.003	0.005	0.288	102	-4.61424
June	80	-3.456	-0.001	0.004	0.426	101	-0.84302
July	101	-3.312	-0.004	0.005	0.190	97	-2.79573
August	138	-3.164	-0.004	0.002	0.036	113	-3.04071
September	87	-3.896	0.002	0.004	0.269	102	1.541097
October	14	-5.17	0.002	0.009	0.822	127	0.453162

Appendix A. WDFW Pink Shrimp Trawl Logbook Page Example

WDFW Shrimp Trawl Log

Vessel: ______________________ Landing Date: ______________________ Excluder Type: Bar / Mesh

USCG #: ______________________ Landing Port: ______________________ Bar Spacing/Mesh Size: _____

Skipper: ______________________ Fish Ticket #: ______________________ Rig Type: Single Double

DATE	TOW #		DEPTH (ftm)	TIME (24 HR)	LATITUDE		LONGITUDE		Total Catch (lbs including bycatch)	HAUL DUMPED (Y/N)	Est. lbs bycatch discarded	COMMENTS	Optional Skipper Use	
					Degrees	Minutes	Degrees	Minutes					Daily Total	Trip Total
		SET												
		UP												
		SET												
		UP												
		SET												
		UP												
		SET												
		UP												
		SET												
		UP												
		SET												
		UP												
		SET												
		UP												
		SET												
		UP												
		SET												
		UP												
		SET												
		UP												