SUMMARY OF THE NORTHWEST POWER AND CONSERVATION COUNCIL'S EULACHON STATE OF THE SCIENCE AND SCIENCE TO POLICY FORUM

Prepared for

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LIST OF ACRONYMS AND ABBREVIATIONS

BRD	bycatch-reduction device
BRT	Biological Review Team
DFO	Department of Fisheries and Oceans
DU	distinct unit
DPS	distinct population segment
eDNA	environmental DNA
ESA	Endangered Species Act
FCRPS	Federal Columbia River Power System
Forum	Science-policy Forum
JSATS	juvenile salmon acoustic telemetry system
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
NPCC	Northwest Power and Conservation Council
ODFW	Oregon Department of Fish and Wildlife
Plan	Eulachon Recovery Plan
Program	Columbia River Basin Fish and Wildlife Program
SSB	spawning stock biomass
WDFW	Washington Department of Fish and Wildlife

1 PURPOSE, BACKGROUND, AND OBJECTIVES

The Northwest Power and Conservation Council (NPCC) hosted a 1-day Science-policy Forum (Forum) in Portland, Oregon, on August 21, 2015, that focused on the current state of scientific knowledge about eulachon (*Thaleichthys pacificus*) and potential recovery actions for consideration in the development of the National Oceanic and Atmospheric Administration's (NOAA's) Eulachon Recovery Plan (Plan). The southern distinct population segment (DPS) of eulachon was listed as threatened under the Endangered Species Act (ESA; 1973) on March 18, 2010.

The 2014 Columbia River Basin Fish and Wildlife Program (Program) calls on the NPCC, the U.S. Army Corps of Engineers, Bonneville Power Administration, NOAA Fisheries, resource agencies, and tribes to "help organize and facilitate a science/policy forum in 2015 to address the biological requirements of eulachon, combined with related inquiries into the relationship between flow, current hydropower dam operations, and the biological requirements of lamprey and sturgeon" (NPCC 2014). The Forum held on August 21, 2015, addressed the action identified in the Program. Its purpose was to synthesize and transfer information from scientists to resource managers to inform the development of recovery actions for the Plan.

The goal of the workshop was to identify what is known and unknown regarding the biology and biological requirements of eulachon, especially the abundance and productivity of the species, its spatial distribution, and its genetic and life history diversity. The workshop was also designed to assess the available research on eulachon and link that information to major threats affecting the species. In particular, the major threats (Section 3) identified by the Biological Review Team (BRT) established by NOAA were factors in the eulachon listing. Identifying the key information and research gaps will help inform the development of recovery actions, including research and monitoring necessary to refine and demonstrate attainment of recovery criteria.

John Ferguson, a scientist with Anchor QEA, LLC, based in Seattle, Washington, moderated the Forum. Dr. Ferguson's background on the recovery potential of ESA-listed anadromous fish stocks and how salmonid populations respond to climate variability allowed him to facilitate and focus the discussion on what information is available and research gaps. The focus included critical uncertainties and the potential effects of Federal Columbia River Power System (FCRPS) operations on eulachon, and how this information might inform needed recovery actions.

The information and ideas summarized in this report result from the knowledge, experience, and insights of Forum presenters and participants (Appendix A). The agenda for the Forum in presented in Appendix B. Key findings and recommendations from the Forum are presented in the following sections. Critical uncertainties identified by the NPCC for eulachon are listed in Appendix C.

2 PRESENTATIONS

2.1 “Why we are Here: Eulachon and Recovery” by Robert Anderson, NOAA Fisheries

2.1.1 Summary

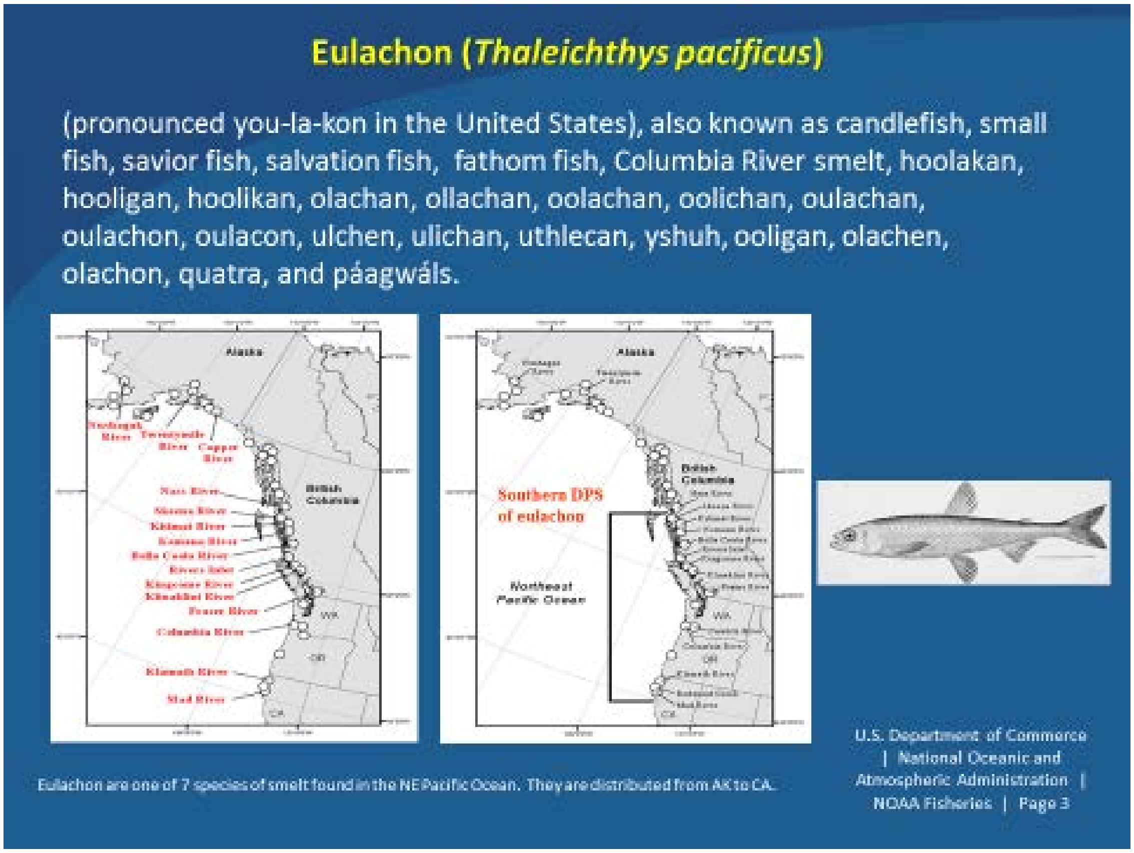
Robert Anderson provided a broad overview of eulachon biology and ecology, the cultural and historical setting, ESA listing and critical habitat, threats and limiting factors, and factors for decline that recovery actions need to address. Eulachon are distributed from Mad River in California to Nushagak River in Alaska; the southern DPS occurs from Skeena River in British Columbia to the southern end of distribution (Figure 1).

Eulachon are an anadromous forage fish that spawn typically in the lower reaches of large snowmelt-fed rivers. Eulachon adults have a high fecundity and die after spawning (termed semelparous). Eggs attach to small sediment particles, incubate for 30 to 40 days, and drift downstream with the particle and current until they hatch. Newly hatched larvae are transported downstream on spring freshets. Juveniles typically spend 2 to 5 years in saltwater before returning to freshwater to spawn from late winter through spring.

Eulachon are a culturally and historically significant species for Native American and First Nations people; they are fatty fish that act as a “gap species” between salmon runs, providing nutritional and medicinal value in a time of otherwise low harvest.

Eulachon runs are highly variable year to year based largely on ocean conditions. For example, the period from 1835 to 1858 indicates one distinct and mysterious gap in smelt runs in the Columbia River. A similar species-wide collapse (up to a 90% decline) occurred between 2005 and 2010, coinciding with their ESA listing and designated critical habitat final rule in October 2011. Many threats, limiting factors, and factors for decline were identified by the BRT, including (but not limited to) human activities and natural events; physical, biological, or chemical features resulting in viability reductions; and the destruction, modification, or curtailment of habitat or range.

The goal of NOAA’s recovery actions is to reduce the severity of threats to Eulachon to the point where special management consideration is no longer necessary. Anderson presented this talk to generate discussion of potential recovery options. Actions need to be site-specific and measureable, and costs associated with the actions need to be estimated.



Eulachon have many names and are one of seven smelt species that reside in the Northeast Pacific Ocean. The DPS listed by NOAA Fisheries in 2010 occupies the lower portion of their range.

Figure 1

Eulachon (*Thaleichthys pacificus*)

2.1.2 Questions and Comments

- *Will publishing the Plan in 2016 directly result in funding and support for research?* Anderson replied that the Plan will provide leverage to acquire funding and support.

2.2 "WDFW and ODFW Eulachon Monitoring and Research" by Olaf Langness, Washington Department of Fish and Wildlife

2.2.1 Summary

Olaf Langness summarized Washington and Oregon's efforts to estimate spawning stock biomass (SSB), the types of data collected and results, and fisheries management actions. He also discussed key biological parameters, critical habitat, and the effects of eulachon bycatch in the shrimp trawl fishery. Following the eulachon fisheries decline in the mid-1990s, Washington and Oregon developed a 2001 Eulachon Management Plan. After the 2005 run collapse, Washington and Oregon were funded to monitor eulachon spawning starting in 2010. Spawning stock biomass was estimated at 70,000 pounds in 2005 and peaked in 2014 at approximately 16.6 million pounds.

Adopting methods used by Canadian researchers, the SSB method employed by Washington and Oregon involves collecting eulachon ichthyoplankton (dead eggs, live eggs, and larvae). Collection activities are conducted as far down a system as feasible to capture most of the production. These data are then expanded to the average egg and larval density relative to discharge and time. The number of females needed to produce the larval output for eulachon in a river system is then calculated based on mean fish size, fecundity, and sex ratios, along with the seasonal eulachon ichthyoplankton estimate. (Note: For more detail on SSB estimation methods, see Hay et al. [2002], Hay and McCarter [2003], and Therriault and McCarter [2005]). Peak larval flux occurs generally in March and typically peaks between March 31 and April 9 each year (Figure 2). However, there is also an increase in larvae counted in January due to a "pilot run" of adults that ascend the Columbia River system in December.

Grays River is a significant spawning site that is located below the mainstem Columbia River eulachon index sampling site. Grays River may provide worthwhile data for assessing distribution of spawners within and outside the Columbia Basin. Looking at rivers other than the Columbia River may inform theories on how eulachon adjust their distribution by selecting other rivers to spawn in if conditions in the Columbia River are unfavorable in a given year. Surveys for eulachon have occurred in coastal Washington and Oregon rivers. On some occasions, it appeared eulachon were choosing another river, such as the Chehalis

River, as a spawning location instead of the Columbia River. Identifying spawning criteria (flow, water temperature, substrate, etc.) would help determine if coastal streams and rivers are truly “sinks” for Columbia River eulachon.

Annual sampling of adult eulachon is critical for use in SSB calculations, including length and weight sampled throughout run and relative fecundity (number of eggs per gram of body weight). These assessments may also provide an opportunity to collect genetic samples. Sport and commercial fisheries also contribute data and generate interest by the public in the species and its protection.

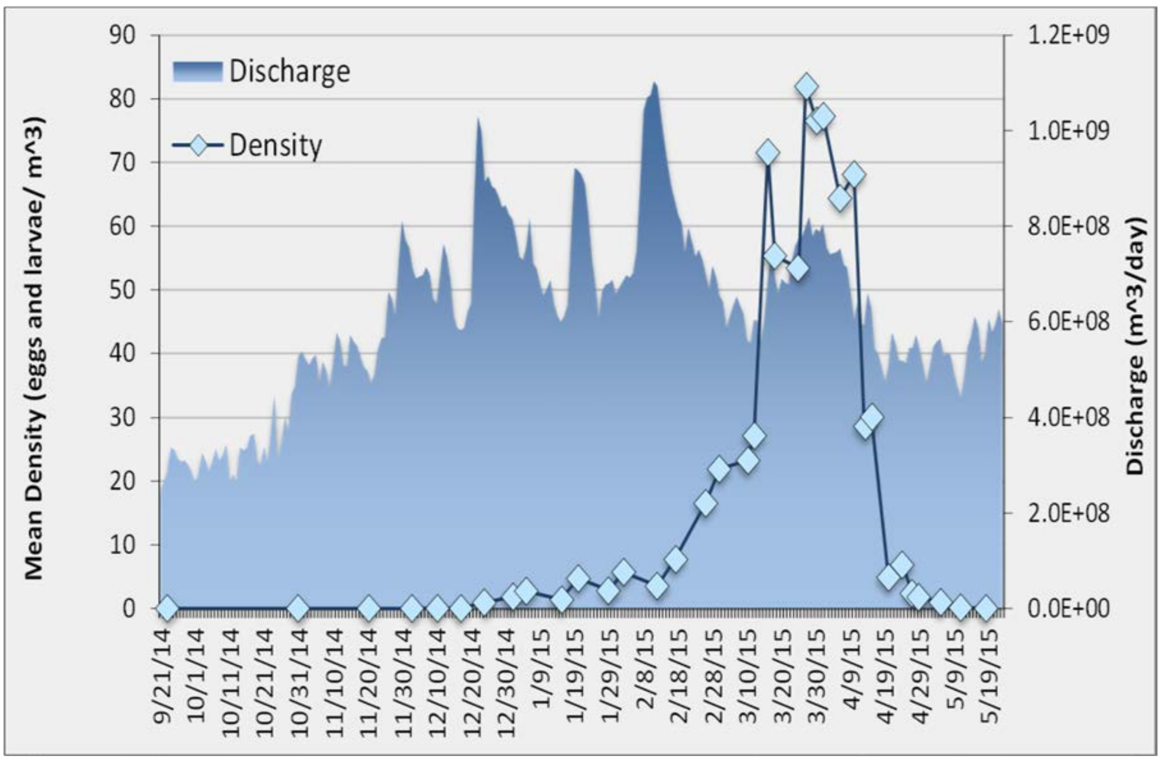


Figure 2

Columbia River Discharge Versus Peak Larvae Densities in 2015

Discharge is indicated in blue from September 21, 2014, through May 19, 2015, versus the peak larvae densities (eggs and larvae per cubic meter of water sampled by Washington Department of Fish and Wildlife [WDFW] and Oregon Department of Fish and Wildlife [ODFW] during spawning stock biomass sampling) in 2015. Peak larval and eggs biomass typically occurs in late March. Note the small number of eggs and larvae collected in January 2015. This production is associated with an early pilot run of eulachon in the Columbia River that occurs in late fall or early winter.

2.2.2 Questions and Comments

- *How plastic is the life history of eulachon in regard to returning to natal streams? Does this happen at a stock level or population level?* Langness replied that the stocks are well-mixed, and cited the Columbia River-Fraser River stocks as an example. The Columbia River and Fraser River are genetically similar. When large runs return to the Columbia River in a given year, the fish expand their distribution into available habitat (e.g., past Bonneville Dam).
- *Ocean shrimp have moved north. What is the impact on eulachon?* Langness replied there is a high likelihood that Columbia River eulachon are in the fishery off the west coast of British Columbia. They may be distributed northward by the plume when young, though this is unconfirmed.
- *How old are these fish?* Langness replied that sometimes they are all 2-year olds, and sometimes they are all 3- or 4-year olds; it varies among years. For example, in 2013 the adults were all 2- to 3-year olds. In 2015, they are mostly 3- to 4- year olds. Scientists are exploring alternatives to using otoliths to age these fish, though using otoliths is still common. However, WDFW is exploring the use of oxygen isotopes in otoliths to determine fish age instead of barium to calcium ratios. Being able to assign accurate ages to sampled eulachon is important because it will allow managers to track abundance trends by brood year and examine factors that affect survival and growth by brood year.

2.3 "Update on Eulachon from Canada" by Sean MacConnachie, Department of Fisheries and Oceans, Canada

2.3.1 Summary

Sean MacConnachie provided an overview of the status of eulachon in Canada, research initiatives led by the Department of Fisheries and Oceans (DFO), and listing and recovery activities. Three distinct units (DUs) are identified with a high degree of genetic separation from each other in Canada: Fraser River, the Central Pacific Coast, and Nass/Skeena.

Comparing these DUs could help researchers assess how various environmental and biological factors affect growth and survival. DFO has conducted egg and larval surveys in the Fraser River since 1995, which are used to derive SSB by applying river flow data and relative fecundity. Since 1995, Fraser River SSB peaked in 1996 and declined dramatically through 2004 (estimated SSB was 4 tons), stayed low through 2014, and increased in 2015 to 317 tons. The fishery was closed starting in 2005.

In the ocean, DFO conducts small mesh-size, multi-species surveys in three areas off the west coast of Vancouver Island and in Queen Charlotte Sound. These are primarily for shrimp stock assessments. Length frequency distributions developed to assess variability in population and age structure are both bimodal and unimodel (Figure 3). Genetic assessments using 14 microsatellites for population identification show that the majority of fish caught off the west coast of Vancouver Island come from the Columbia River, and the rest are generally from the Fraser River. Factors responsible for the marine distribution of eulachon are not well known; additional data may help researchers understand the factors affecting eulachon distribution, survival, and growth.

DFO has taken conservation actions to protect this species, such as shrimp trawl bycatch reductions, recreational and commercial fisheries closures, suspension of dredging during spawning in the Fraser River, initiation of research, and funding of community projects. DFO plans to continue ongoing research, continue and expand its multi-species surveys, and re-establish data collection on Chatham Sound. In addition, it will continue to support non-DFO led initiatives including egg and larval surveys in other rivers, research by independent investigators, and listing consultations under the Canadian Species at Risk Act.

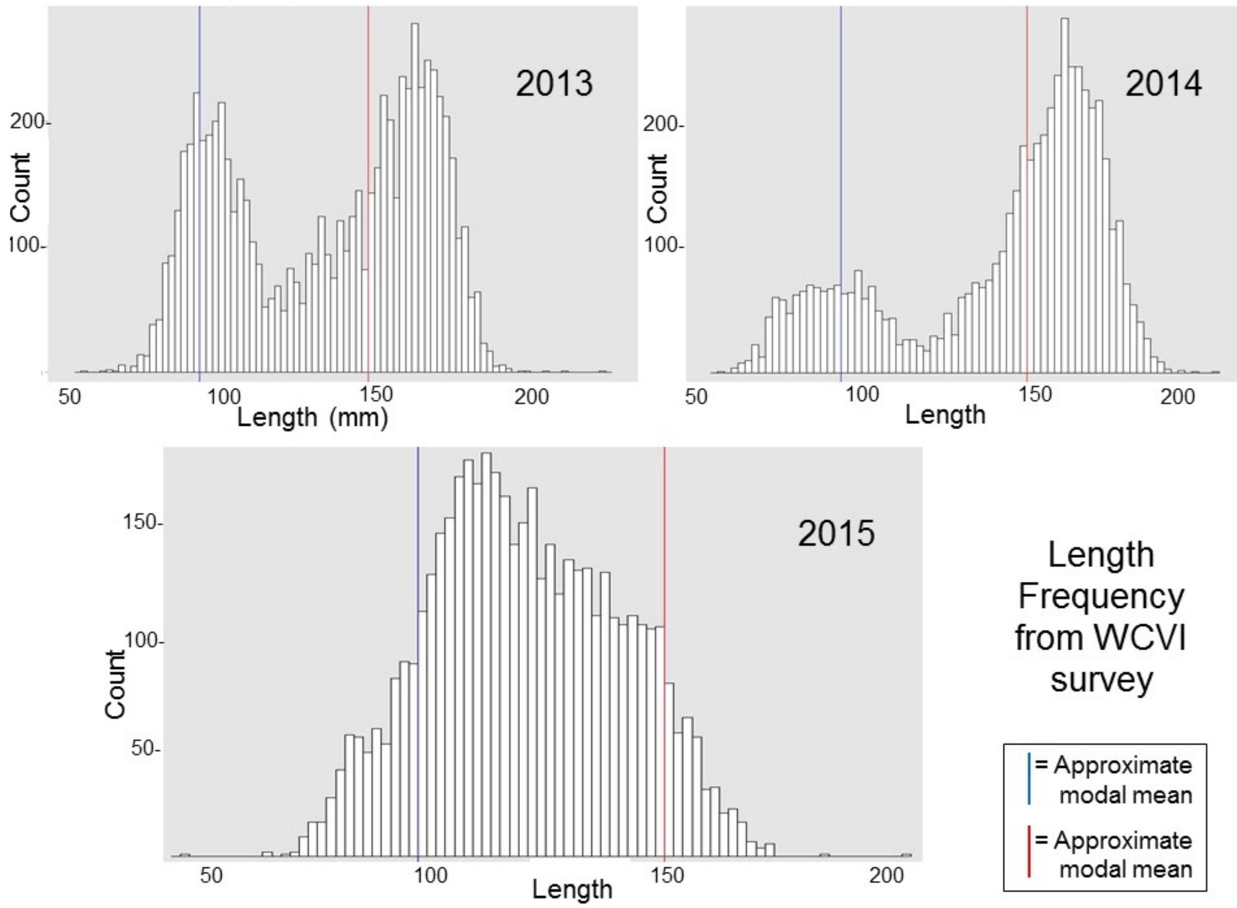


Figure 3
Eulachon Age Class Structure Variation Among Years in West Coast Vancouver Island (WCVI) Ocean Survey Trawls (Source: DFO, Canada)

In 2013 and 2014, length frequency distributions for fish sampled off the west coast of Vancouver Island were bimodal, whereas in 2015, the distribution was unimodal.

2.3.2 Questions and Comments

- *Even off central Vancouver Island, approximately 20% of the eulachon caught are from the Columbia River.* MacConnachie replied that single-nucleotide polymorphism work suggests these data are very blurry, but adult fish coming from the Columbia River are likely transported by currents.
- *Has DFO worked with Washington and Oregon agencies and data to use the Canadian SSB sampling as an indicator for Columbia River populations? Has that*

quantitative linkage been made? MacConnachie replied that abundance estimates from Canada have been used in Columbia River stock assessment. Olaf Langness pointed out that age composition and bycatch data and run estimates have been used by Washington and Oregon agencies.

2.4 "Eulachon Spawning Stock Biomass for the Cowlitz River, 2014-2015" by Nathan Reynolds, Cowlitz Tribe

2.4.1 Summary

Nathan Reynolds described background information on eulachon, including historical use by the Cowlitz Indian Tribe, and SSB estimate methods and results in the Cowlitz River. SSB is estimated based on the total productivity (larvae and egg flux) of the population, mean fecundity, and proportion of mature females (based on the estimated sex ratio). Cowlitz Indian Tribe performed sampling for these metrics from November 2014 through May 2015 just upstream (river mile 1) of the confluence with the Columbia River, and also acquired some data from other sources, such as recreational catch data and U.S. Geological Survey Cowlitz River gage data at Castle Rock, Washington.

The eulachon run into the Cowlitz River was estimated to have comprised 34% of the total Columbia River escapement that year. Interestingly, the male-to-female sex ratio for Cowlitz River adults was calculated at 4.51 to 1. This compares to a 1:1 ratio observed in the Columbia River estuary (see Section 2.6) and suggests a loss of females between the Columbia River estuary and Cowlitz River sampling sites. Historically, runs returning to the Cowlitz River have not shifted their spawning distribution into other watersheds among years, as has been reported elsewhere. However, in some recent years, eulachon that were expected to spawn in the Cowlitz River were observed spawning in a different tributary. The cues driving eventual spawning site preferences remain unknown.

2.4.2 Questions and Comments

- *In comparison to other systems, and considering spawning substrate, the Cowlitz River is very turbid. Have you performed a before-and-after comparison for the Mount St. Helens eruption?* Reynolds replied many species of fish have been present in the Cowlitz River before and after the eruption and have responded or adapted.

The river clears out volcanic debris relatively quickly. Changes in land use after the 1980 eruption likely affected the distribution of sediment; it has not been entirely flushed out of the system, possibly having a negative effect on eulachon.

- *Are longfin smelt ascending the Cowlitz River system?* Reynolds replied yes, but they have only caught four longfin smelt from 2014 to 2015. This represents a range extension, but not a significant expansion in abundance.

2.5 "Eulachon Research on the Klamath River" by Robert Anderson, NOAA Fisheries

2.5.1 Summary

Based on reports by Yurok Tribal fishers, Robert Anderson described the timing, duration, and catch of historical eulachon runs in the Klamath River before their decline. Eulachon experienced a massive decline in the Klamath River, reported as starting in the 1950s to 1980s, before which the maximum catch number was reported as "unlimited."

The Yurok Tribe began sampling for adult and juvenile eulachon through a Protected Species Conservation and Recovery Grant Program to Tribes and observed seven adult eulachon in 2011. Adult eulachon numbers have increased since, with a collection of 40 adults in 2012, 112 in 2013, and approximately 1,000 in 2014. The Yurok Tribe is developing the first SSB estimate for the Klamath River.

2.5.2 Questions and Comments

- *Were the smelt collected from 2011 to 2014 for subsistence or for data?* Anderson replied that the eulachon were collected for data.
- *Have there been any other northern California eulachon surveys, like in the Mad River, for example?* Anderson replied there have been proposals to study eulachon in the Mad River, but they have not been funded because National Marine Fisheries Service (NMFS) funding under Section 6 of the ESA is limited. Surveying northern California streams for the presence or absence of eulachon would inform their distribution.
- *Is the Klamath River designated critical habitat?* Anderson replied yes, from the mouth of the river to Blue Creek is designated as critical habitat (river mile 15.8).

2.6 "Eulachon in the Columbia River Estuary and Plume" by Jeannette Zamon, NOAA Fisheries

2.6.1 Summary

Jeannette Zamon described research trawls and hydroacoustics in the Columbia River estuary and tidal freshwater, run timing, size distribution, and the potential for hydroacoustic estimates of SSB. The work was conducted in 2013 as part of a joint proof-of-concept effort with WDFW to combine trawl with hydroacoustics data and compare the results to historical data from the estuary.

Eulachon are present in the estuary weeks before spawning in distinct bottom-oriented schools with a sex ratio of 1:1 (male to female). Comparing 1980-to-1981 data to trawl data collected in 2013 indicated that eulachon size distribution shifted toward larger (or older) eulachon between the two periods sampled. In 2013, American shad were the most abundant species in estuary trawls, which may compete with eulachon for plankton. Zamon pointed out that further studies of eulachon diet and distribution would help inform predator-prey interactions.

Hydroacoustic surveys in the estuary provide a direct observation of run timing, biomass, and population abundance. Shoals of eulachon were visible in hydroacoustic images near the bottom of tidal freshwater in the estuary.

At-sea surveys provide size distribution data, and data from 2000 displayed a bimodal distribution (similar to that observed off the West Coast of Vancouver Island in 2013 and 2014; Figure 3). Zamon noted that sampling in the estuary, plume, and ocean could provide information on the food habits of eulachon as they enter the ocean.

Zamon summarized the information on eulachon in the Columbia River estuary as follows:

- Known
  - Spawners can hold up in the in estuary habitat for weeks before peak spawning, depending on water temperatures.
  - Size distribution of spawners is variable.
  - Eulachon are bottom-oriented during the day.

- Research trawl captures fish with greater size range, lower mortality (<0.1%), and in better condition than commercial gear.
- Hydroacoustic surveys can map, target, and enumerate spawners.
- Spawning runs attract large numbers of predators (e.g. seabirds, pinnipeds, sturgeon)

- Unknown (or continued research needed)
  - Size-at-age structure of spawners
  - Sex ratio of spawners
  - Variation in run magnitude and timing
  - Direct estimate of spawner biomass
  - Mechanisms triggering upriver movement of spawners (temperature, flow, etc.)
  - Larval density, size, condition, and timing at ocean entry with respect to flow, tides, and other estuary conditions (present larval sampling in tidal freshwater, river kilometer 55 to 65)

Zamon summarized the information on eulachon in the Columbia River plume as follows:

- Known
  - Juveniles, sub-adults, and adults definitely present during April to July
  - Length-frequencies suggest:
    - Critical marine growth from April to June
    - Recruitment to spawner size classes
  - Not caught in daytime surface trawls or estuary seines
- Unknown (or continued research needed)
  - Variation in size-at-age composition
  - Larval, juvenile marine distribution - hydrography
  - Marine growth and survival – hydrography, food, and predators
  - Whether eulachon function as alternative prey for salmon predators

Zamon suggested the following critical uncertainties could be resolved with a high probability of success:

- Tidal freshwater and estuary
  - Adult spawning stock biomass and run timing (using direct and indirect methods)
  - Age, size, and genetic structure of estuary spawners and larvae
  - Spawning migration timing versus flow, temperature, and other estuary and ocean conditions
  - Ocean entry timing, size, and condition for larvae with respect to temperature and flow
- Plume
  - Synthesize and analyze existing ocean eulachon data with physical and biological ocean ecology data
  - Marine distribution, age, and size structure of larvae
  - Juvenile and adult age and size structure

2.6.2 Questions and Comments

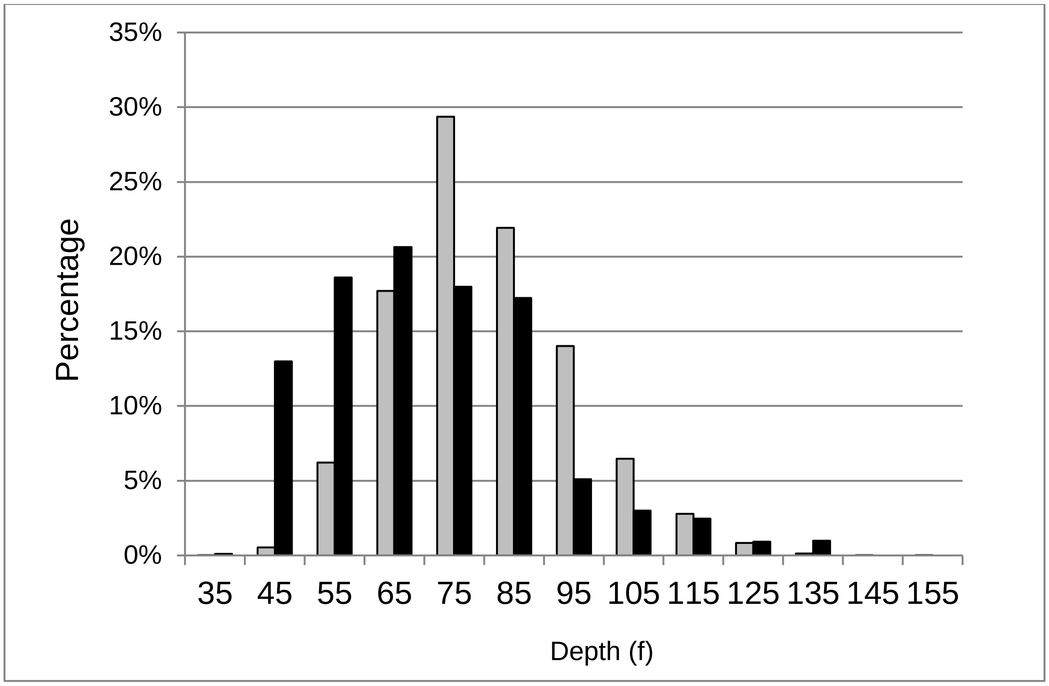
- *How do you explain the July results in the length-weight distribution?* Zamon replied they may move out of the areas because the temperatures get too high.
- *Do predators target females?* Zamon replied that the difference between observed sex ratios in the estuary and on the spawning grounds could be due to males and females behaving differently on spawning grounds. There was also a discussion of predators (pinnipeds) perhaps targeting females due to pheromones.
- *What is the diet of eulachon in the plume? Do they compete with shad?* Zamon replied data are not available for juvenile eulachon diets. In addition, Zamon said predators have been observed targeting eulachon during the hydroacoustic survey.

2.7 "Progress in Reducing Eulachon Bycatch in the Ocean Shrimp Fishery" by Robert Hannah, Oregon Department of Fish and Wildlife

2.7.1 Summary

Robert Hannah provided information on eulachon and shrimp spatial overlap in the ocean, the ocean shrimp fishery, and bycatch-reduction device (BRD) studies, and the use of artificial lights to reduce bycatch. Ocean shrimp catch and the size and location of shrimp geographic stock area varies widely from year to year between northern California and southern British Columbia. Eulachon are present at the same depths and in similar habitats as ocean shrimp (Figure 4), and historically have been a large portion of ocean shrimp bycatch. Many boats even had “smelt belts” to help sort out smelt from ocean shrimp when trawls were brought on board. In 2003, BRDs became mandatory for ocean shrimp fishing, greatly reducing bycatch by 66 to 88% by weight of catch. In 2005, fish bycatch was 7.5% of total catch. In 2001, NMFS fishery observer data indicated fish bycatch in the shrimp fishery was less than 2% of total catch.

To reduce bycatch further, ODFW studied the effects of artificial lights on bycatch. The presence of artificial light on the BRD itself interfered with behavioral escapement and increased bycatch, but the presence of artificial light on the fishing line greatly reduced bycatch of eulachon (with a reduction of 90.5%) and other species (56 to 82%). Researchers hypothesized that the presence of light facilitated the escapement of fish under the fishing line. Today, Lindgren-Pitman artificial lights are currently being used widely by the ocean shrimp fishing industry with reports of excellent results. Additional bycatch reductions using light technology continue to be developed. The ocean shrimp fishery in British Columbia is not yet utilizing artificial lights due to regulations preventing their use.



Oregon shrimp hauls are indicated with gray bars, and eulachon catches are indicated with black bars.

Figure 4

Depth Distribution of Oregon Shrimp Hauls from 2007 to 2011 and Eulachon Caught in NMFS Triennial Ocean Surveys

2.7.2 Questions and Comments

- *Do the artificial lights negatively affect shrimp catch?* Hannah replied no, their use even improves efficiency because sorting out less bycatch saves time.
- *Have these methods been tested in a big year of eulachon production?* Hannah replied yes, the study was performed in 2014, a year of big eulachon returns.

2.8 "Environmental DNA for Detecting and Quantifying Anadromous Eulachon" by Taal Levi, Oregon State University

2.8.1 Summary

Taal Levi presented information from pilot studies conducted in 2014 and 2015 using environmental DNA (eDNA) to quantify eulachon in Auke Creek and the Chilkoot River, Alaska. DNA shed by an organism can be collected in water and amplified to identify the species of the organism. At the Auke Creek research weir, eDNA concentrations in water reflected count data of salmon in the channel, and even identified otherwise-unrecorded Chinook jacks entering the system. A eulachon mark-recapture study on the Chilkoot River provided a run estimate for comparison with eDNA results. Accounting for water flow also improves abundance estimates based on eDNA. In the Chilkoot River, estimated eulachon abundance using eDNA techniques was 3.4 million in 2014 compared to 320,000 in 2015, indicating large variations in abundance between years and a near run failure in 2015. Levi suggested the results of the pilot studies suggest that eDNA may provide an inexpensive means to conduct large-scale indexing eulachon abundance throughout its range.

2.8.2 Questions and Comments

- *What is the source of the eDNA and does it vary?* Levi replied eDNA is detected with the presence of an organism, not necessarily a certain life-stage or event like spawning. Residual eggs even produce eDNA in lower concentrations.
- *Has eDNA been studied in a tidal system with backwater?* Levi replied their study only sampled at low tide to avoid contamination, but it would be useful to sample transects in an estuary because eDNA amounts likely vary in any system.

2.9 "Evaluation of Transmitter Application Techniques for use in Research of Adult Eulachon" by Kyle Hanson, U.S. Fish and Wildlife Service

2.9.1 Summary

Kyle Hanson presented information on assessment of methods for deploying ultrasonic transmitters in eulachon. Hanson pointed out that since eulachon have a high fidelity to their natal river, translocation techniques to rebuild populations might be a viable recovery tool. Eulachon had not previously been implanted with JSATS (juvenile salmon acoustic telemetry system) tags, so surgical techniques used for salmon were used as a starting point for this study.

Adult eulachon collected by the Cowlitz Indian Tribe in February 2012 were provided to the U.S. Fish and Wildlife Service researchers, who separated test fish into five treatment groups at the Abernathy Fish Technology Center in Longview, Washington: control, handling control, external attachment, sham implantation, and internal implantation.

Researchers found that eulachon were a hardy species and survived the anesthetic and handling during tagging experiments well. Both internal implantation and external attachment techniques are valid application methods, but sub-lethal stress and its potential effect on recovery and survival in the wild should be taken into account when tagging eulachon. Additionally, there may be sex-based differences in survival of tagged eulachon due to egg loss through incision and the implantation of tags in females.

2.9.2 Questions and Comments

- *Have injectable JSATS tags been used?* Hanson replied no, but he thinks they may solve issues related to incision and surgery stress.
- *Oral insertion of tags works well on juvenile salmon. Has that been attempted for eulachon?* Hanson replied no, because small tags are often spit up by the fish, but it might be worth studying.
- *Have tagged eulachon been released in any systems?* Hanson replied no, but this presents a big opportunity for research.

2.10 Comments from Haisla First Nation Representatives

2.10.1 Summary

Haisla First Nation members spoke briefly regarding their experience with eulachon in the Kemano River. Haisla First Nation has been studying eulachon in the Kemano River since 1988 and recently completed a literature review summarizing 20 years of its work. It is currently looking at options for a eulachon hatchery on the Kemano River. Developers in the territory are willing to help with the construction and operation of a hatchery. Eulachon rearing in a hatchery setting was attempted in the Bella Coola River, British Columbia, but the fish did not survive past the larval stage.

2.11 "Water Management Actions called for in NOAA Fisheries 2014 BiOp on the FCRPS" by Paul Wagner, NOAA Fisheries

2.11.1 Summary

Paul Wagner presented information on the operation of dams in the FCRPS relative to ESA consultations, altered Columbia River hydrograph, and effects on salmonid migration through the FCRPS. Dams restrict habitat access for fish, alter habitat, alter hydrology, and create a passage hazard for fish. Reservoirs can store 25% of the average annual runoff, which is sufficient to significantly change the natural hydrograph in the Columbia River and reduce turbidity. Peak flows during spring and summer are reduced, and flows during fall and winter are increased under contemporary conditions. Juvenile salmonid travel times through the FCRPS are substantially longer since mainstem FCRPS dams were constructed.

FCRPS flow is managed based on evolutionary considerations (e.g. the fish evolved to outmigrate on the spring freshet), recognition that there is a flow-travel time relationship for juvenile salmon, data suggesting adult returns are higher under higher flows, and the beneficial effects of a larger plume size associated with higher discharge.

Spring and summer flow targets have been established for both the Columbia and Snake Rivers to re-establish a freshet as much as possible to aid juvenile outmigrations, increase the size of the freshwater plume in the ocean, increase turbidity and nutrient supply to the coastal environment, and increase salmon survival. Flow targets have been largely met by adjusting storage reservoir flood control operations.

2.11.2 Questions and Comments

- *Will the onset of wind power in the upper basin provide flexibility in operation of the FCRPS?* Wagner replied that wind power is unpredictable and produces the most energy at a time of year when the hydroelectric projects are already producing a lot of energy.
- *How much room for change in the operation of FCRPS is there for eulachon?* Wagner replied there is not much room for change in FCRPS operations due to flood control restrictions. Unless other options for flood control are pursued, which are very expensive, it is unlikely that there would be much room for change in FCRPS operation for eulachon.

2.12 "Estuary/Plume and Ocean Conditions" by Antonio Baptista, Oregon Health Sciences University

2.12.1 Summary

Antonio Baptista presented information on the physical, biological, and geochemical context for eulachon in the Columbia River estuary/plume environment and ocean conditions. He discussed three main points: 1) the plume is highly variable environment, 2) the plume is susceptible to the effects of climate change, and 3) the SATURN observations and simulations offer unique eyes into the physics and biogeochemistry of the estuary and plume and might conceivably help contextualize eulachon life cycle.

The Columbia River plume varies in its size and direction (both north and south) and has many intermediate shapes. The volume of water in the plume changes seasonally and varies greatly between months and years. It is susceptible to change from climate, FCRPS operations, and other sources. Studies conducted by Baptista and the National Science Foundation Science and Technology Center for Coastal Margin Observation and Prediction also indicate the passive estuarine and plume transport mechanisms are very complex, and the physics of the system strongly influences the biogeochemistry (e.g., salinity, phytoplankton, detritus, and zooplankton) of these environments. Changes in eulachon outmigration depend on plume characteristics such as salinity-intrusion length because salinity in the estuary affects primary productivity.

The year 2015 has been an abnormal year in the Pacific Ocean and Pacific Northwest Coast. Baptista referred to the "blob" or mass of warm water of the western coast of the United States. High temperatures and weakened discharges caused an increase in salt-intrusion length. A late-developing El Niño could lead to further ecosystem disruptions if strong upwelling seen in 2015 is weakened. An observation and modeling network called SATURN collects and analyzes physical and biological data changing throughout the estuary, including salinity, temperature, turbidity, dissolved oxygen, pH, and velocity. Baptista believes the data being collected provides strong evidence of the potential for extreme physical changes associated with climate change and very significant changes in biogeochemistry and salmon habitat in the estuary and plume. He provided data indicating that effects of the "blob" have been observed in the estuary on SATURN network monitors and estimates of how far inland salt water intrusion would occur in the Columbia River estuary associated with projected sea level related to climate change. This information could be integrated with information on eulachon biological requirements to assess potential effects of climate change on eulachon,

2.12.2 Questions and Comments

- *Some scientists say the unusually warm patch of water in the Pacific Ocean called the "blob" may not dissipate soon. For how long do you think it will stay around?* Baptista replied he thinks the "blob" will be present in 2016, but that it may be kept in check by upwelling.
- *One challenge will be collecting biological samples of eulachon in the estuary at a high enough frequency to capture changes to the events Baptista measures. Fish should be sampled in the same locations as the physical data collection in order to make use of available resources.* Baptista replied that SATURN designed one or two stations as laboratories, where a sampler for DNA and RNA analysis has been deployed. There could be synergies for these samples; they could support secondary datasets. However, SATURN sites are selective about collecting DNA and RNA because of cost.

2.13 "FCRPS, Dams, and Water Management in the Columbia Basin and Effects on Eulachon" by Robert Anderson, NOAA Fisheries

2.13.1 Summary

Robert Anderson presented information concerning how the operation of the FCRPS and dams in the Columbia Basin affect eulachon, especially at the larval and juvenile outmigrant life stages. Flow regulation on the Columbia River has shifted the peak freshet earlier in the year, and significantly decreased the magnitude of the freshet (by approximately 41%). Egg and larval survival of eulachon are dependent on synchronization with river conditions. Shifts in flow intensity and duration could result in reduced survival. Water management operations continue to alter the hydrograph, affecting spawning production, egg incubation, and larval and juvenile growth, development, and survival in the estuary-plume environment. From April through July, water management operations likely affect the physical and chemical processes in the estuary-plume environment, potentially having negative impacts on survival of eulachon larvae and juveniles during outmigration. Overall, changes in Columbia River flow attributable to the FCRPS is substantial, particularly as these effects are long term (i.e., decades long).

2.13.2 Questions and Comments

- *What are specific changes in operations FCRPS could implement?* Anderson stated eulachon are a stochastic expressive species, and changes in their population structure occur on a multi-decadal scale. Improve flow conditions to target larvae leaving the estuary and entering the plume, such as synchronizing the river flows (spring freshet) with the upwelling of the California current. This is a critical step in their transition from river to the ocean environment that will greatly increase the likelihood of survival. Eulachon are a plastic species that can respond to changes in FCRPS operation, but the FCRPS should be careful not to push them beyond their stochastic limits, and instead attempt to offset negative impacts with small changes in operations.

3 MAJOR THREATS TO COLUMBIA RIVER EULACHON

The major threats addressed in this section represent common themes encountered in the Biological Review Team's report, scientific literature, NOAA's Recovery Plan Outline, NOAA's 2014 Supplemental Biological Opinion consultation on FCRPS Operation, and Forum presentations and discussions. These do not represent every threat to the southern DPS of eulachon, but rather the key threats that stood out based on a review and synthesis of the scientific literature and Forum discussions and presentations.

3.1 Climate Change Impacts on Ocean Conditions

The BRT identified climate change impacts on ocean conditions as a major threat to the Columbia River population of eulachon, with a qualitative mean score of 4.3 (Gustafson et al. 2010). Climate change impacts could include warmer upper ocean temperatures, decreased productivity along the coast, and changes in upwelling patterns (NMFS 2013). Increasing ocean temperatures are likely to induce size and species shifts in zooplankton, causing a potential decline in forage fishes and a mismatch between eulachon distribution and preferred prey species (ISAB 2007). Early juvenile survival is likely linked to timing and intensity of upwelling in the northern California Current; a shift in the peak of this upwelling could result in a reduction in the temporal overlap of eulachon and their primary prey species (NMFS 2013). Eulachon had poor returns to spawning grounds from 2004 to 2008, coinciding with unfavorable ocean conditions reflecting warm temperatures similar to climate change predictions (JCRMS 2008).

3.2 Eulachon Bycatch in Ocean Shrimp Fishery

The BRT identified eulachon bycatch in fisheries as a major threat to the Columbia River population of eulachon, with a qualitative mean score of 3.8 (Gustafson et al. 2010). Ocean shrimp (*Pandalus jordani*) trawl fisheries off the coasts of California, Oregon, and Washington take eulachon as bycatch (NWFSC 2008). BRDs became mandatory in all U.S. West Coast shrimp trawl fisheries in 2003 (NMFS 2013). By 2005, bycatch was reduced by 66 to 88% by weight, leaving fish bycatch at 7.5% of total catch (NMFS 2013). BRD research using artificial lights was performed in 2014, resulting in a 90.5% decrease in eulachon bycatch.

3.3 Climate Change Impacts on Freshwater Habitat

The BRT identified climate change impacts on freshwater habitat as a major threat to the Columbia River population of eulachon, with a qualitative mean score of 3.4 (Gustafson et al. 2010). The majority of eulachon spawning rivers are fed by glacial runoff, therefore changes in snow pack, higher temperatures, and changes in the intensity of stream flows due to climate change will likely impact eulachon (Gustafson et al. 2010). Eulachon may spawn earlier or be flushed out of spawning areas earlier from climate change, potentially causing a "mismatch" in timing between ocean entry and coastal upwelling, which is key to marine survival (Gustafson et al. 2010, 2012). There is already evidence of eulachon returning earlier to rivers than has occurred historically in the southern DPS (Moody and Pitcher 2010).

3.4 Dams and Water Diversions

The BRT identified Columbia River basin dams and water diversions as a major threat to the Columbia River population of eulachon, with a qualitative mean score of 3.3 (Gustafson et al. 2010). Extensive water resource development of the basin on the mainstem and in tributaries has changed seasonal flow patterns, turbidity and sediment transport, and the level and timing of freshwater inputs into the near-shore ocean environment (ISAB 2000). Eulachon rely on spring-freshet flows for larval outmigration, which have been reduced by more than 40% due to hydropower development and irrigation (Bottom et al. 2005; NMFS 2013). The development of water storage capacity in the basin, including the FCRPS, changed the flow and sediment discharge levels under which eulachon evolved.

Spring-freshet flows required for juvenile outmigration and substrate conditions for spawning are altered by dam operations, and dams and their operations impact habitat, restrict access to habitat, and change flow rates over spawning grounds. Water storage and operations affect larval transport and timing patterns leaving the freshwater ecosystem and through the estuary. Further downstream, the Columbia River plume environment is also affected by water storage and operations, including FCRPS operations. The plume provides important habitat for larval out-migrants and adults returning to spawn, yet the effects of FCRPS operation on larval or adult eulachon in the plume environment are unclear (Gustafson et al. 2012; NMFS 2013).

4 MINOR THREATS TO COLUMBIA RIVER EULACHON

The BRT identified the following minor threats to Columbia River eulachon.

4.1 Water Quality

The BRT identified water quality as a minor threat to the Columbia River population of eulachon, with a qualitative mean score of 3.0 (Gustafson et al. 2010). Water quality is a physical and biological feature of eulachon critical habitat (NMFS 2013). Water quality factors include general contaminants (eulachon high lipid content makes them susceptible to absorption of lipophilic organic contaminants), temperature (which controls spawn timing and egg development), and catastrophic events such as the eruption of Mount St. Helens and the associated high turbidity levels. Adequate water quality is necessary for spawning, rearing, and migration of eulachon.

4.2 Dredging

The BRT identified dredging as a minor threat to the Columbia River population of eulachon, with a qualitative mean score of 2.9 (Gustafson et al. 2010). Dredging can be a concern in riverine and estuarine habitats and is one habitat alteration that can be, and is, managed to protect eulachon. DFO suspended dredging in the Fraser River during the eulachon spawning season beginning in 1995. In 2012, NMFS issued a Biological Opinion on maintenance dredging in the Columbia River that includes measures to reduce impacts. Pickard and Marmorek (2007) summarized the topic in their DFO workshop to determine research priorities for eulachon in Canada by stating that "there is consensus that dredging is not the cause of the coast-wide decline in eulachon, but there is disagreement about the importance of dredging impacts on eulachon resilience in rivers where it occurs."

4.3 Predation

The BRT identified predation as a minor threat to the Columbia River population of eulachon, with a qualitative mean score of 2.9 (Gustafson et al. 2010). Predators on eulachon include other fishes, marine mammals, seabirds, and terrestrial mammals (NMFS 2013). Harbor seals in the Columbia River rely on eulachon for a huge portion of their diet (98% of prey in winter; NMFS 2013). Hake may also be significant predators in the ocean.

4.4 Additional Threats

The BRT also identified the following threats, which received qualitative mean scores ranging from 2.8 (catastrophic events) to 1.2 (scientific monitoring; Gustafson et al. 2010):

- Catastrophic events
- Commercial harvest
- Shoreline construction
- Disease
- Competition
- Recreational harvest
- Tribal harvest
- Non-indigenous species
- Scientific monitoring

5 MAJOR GAPS AND UNCERTAINTIES FROM FORUM DISCUSSIONS

The major gaps and uncertainties addressed in this section represent common themes encountered during the Forum presentations and discussions. These do not represent every gap or uncertainty about eulachon biology and ecology, but rather include key topics raised during the discussions and presentations or topics where information is available but was not identified during the Forum discussions.

5.1 Biology and Ecology

The following six areas and aspects of eulachon biology and ecology were discussed during the Forum.

5.1.1 Genetics of Stocks and Populations

- Are there genetic differences between the March spawning run and the December/January (pilot) run? Is this an important life history trait in the face of climate change, or is the pilot run comprised of older and larger fish that are simply returning early? In other words, the pilot run may represent the fastest growing component of a broodyear, or conversely, the slowest growing component that took a year longer to mature than most of their cohort. Age, size, and genetic data are needed to resolve these questions and understand the role of the pilot spawning run to the overall population.
- What is the genetic relationship between stocks in the Columbia River and Fraser River? Do they act as sinks for each other?
- Why is there a bimodal age class distribution in adults caught off British Columbia in some years?

5.1.2 Juvenile Life Stage

- What are their food sources?
- What habitats do juveniles utilize in the lower Columbia River? Do they occupy habitat, or just drift and go where the currents take them?

5.1.3 Life History Cycles

- What factors drive the population dynamics of eulachon, which tend to be a boom or bust species?
- What happened in the Columbia River between 1835 and 1858?

5.1.4 Spawning

- Do eulachon have a preferred spawning substrate?
- Is there a thermal threshold for spawning?
- How much do flow and water quality drive the spawning run?
- What is the sex ratio at spawning? Do eulachon undergo differential predation in the estuary? Sampling of adults in the estuary indicated a 1:1 sex ratio, whereas sampling in the Cowlitz River indicated a male-to-female ratio of 4:1.
- What is the survival of eggs entrained in sediment?

5.1.5 Trophic Interactions

- What are the relationships between hake and eulachon?
- What are the relationships between pinnipeds and eulachon?
- Do predators target gravid females?

5.1.6 Climate

- What climatic drivers affect eulachon?
- What are the right metrics for assessing eulachon?

5.2 Research Methods

The following categories of eulachon research were discussed.

5.2.1 Determining Age

- What are the best methods for aging eulachon using otoliths? Isotopes or annuli?
- What are the best methods for using length frequencies to age eulachon?

5.2.2 Fecundity

- What factors affect measurements of fecundity?
- Why do measurements vary so widely?
- What are the effects of size and age on fecundity?

5.2.3 Hydroacoustics

- How can hydroacoustic techniques be used to understand eulachon spawning biomass abundance in the Columbia River estuary and eulachon-plume dynamics?

5.2.4 Tagging

- Preliminary evaluations indicated that eulachon are a hardy species, accepted anesthesia well, and could be tagged with JSATS acoustic tags. What are the next steps in using tags to study eulachon in the Columbia River?

5.2.5 eDNA

- Can eDNA be used to widely study eulachon distribution and plasticity? What are the next steps?

6 RECOMMENDATIONS FROM FORUM DISCUSSIONS

Forum participants were asked to share their highest priority recommendations, with consideration for the presentations and open discussions throughout the day and at the close of the Forum. Based on the input received during the closing discussion and follow-up emails, the following themes and topics emerged as key recommendations.

Create and maintain long-term time series of abundance in SSB estimates in major rivers and tributaries; overlay physical and biogeochemical data

- *Maintain SSB estimates in all major spawning rivers of the southern DPS, especially the Fraser River, mainstem Columbia River, and Cowlitz River. Obtain physical and biogeochemical data for the Cowlitz River to accompany SSB estimates.* Long-term time series monitoring could help inform eulachon homing fidelity and determine which biogeochemical triggers affect eulachon spawning distribution in a given year. The BRT lacks strong eulachon population models; consistent SSB estimates would improve population models and provide important data for understanding potential changes due to climate, FCRPS operations, and recovery actions.
- *Synthesize existing high-quality data from other fish and environmental data sets that could aid in the understanding of physical, biological, and chemical factors affecting eulachon distribution, size, run timing, and run magnitude. For example, data collected by NOAA's Northwest Fisheries Science Center to inform salmon recovery in the Columbia River could provide insight into which types of river flow and plume characteristics are associated with eulachon catches*. Relating high-quality environmental datasets to abundance estimates could improve the understanding of historical and current distribution and abundance of eulachon, helping to inform population models and understand factors driving decline and productivity, and requiring no new data collection.

Improve and expand SSB methods and coordinate with new methods

- *Coordinate eDNA surveys with SSB estimates.* eDNA has the potential to broadly assess eulachon distribution and site biodiversity at a relatively low cost and could be used to study range expansion and contraction related to different SSB estimates. Understanding range expansion and contraction would help inform how eulachon act as "generalists," and could provide a large, valuable dataset on habitat suitability. Calibrating eDNA surveys with SSB estimates could inform range-wide biomass estimates.

- *Develop a method for the direct hydroacoustic measurement of adult SSB and compare it to existing SSB estimates (using the indirect, egg-larval method).* A comparison of acoustic biomass SSB and egg-larval SSB estimates would improve validation and accuracy in SSB estimates. Acoustic SSB estimates would also provide information on run timing and fish distribution relative to estuary conditions such as flow, temperature, and turbidity. A more accurate SSB estimate would inform population modeling for exploration of management actions.
- *Convene a eulachon aging technical group to compare and standardize methods.* Standardizing methods could help develop a better understanding of eulachon age structure, which would aid in the development of population modeling.
- *Determine size-at-age structure and true sex ratios of the Columbia River eulachon population. This would require collecting specimens from the spawning run and different size classes encountered at sea.* These data could inform population models which are required to make accurate predictions of recovery and decline. Different management action scenarios could then be explored using more effective population models.

Understand habitat needs and life history strategies

- *Identify spawning locations in tributaries and in the mainstem Columbia River and describe habitat characteristics for those spawning locations. Do eulachon have preferred spawning substrate or habitat? How does sediment management affect spawning and larval development? Do eggs survive entrainment in sediment? Establish how long it takes for larvae to consume the yolk reserves at different temperatures in degree-days.* Identifying preferred spawning habitat and understanding the interactions between spawning substrate selection, egg viability, and larval development mediated through temperature could be used to predict future population response to range expansion and contraction, climate change, FCRPS operational changes, and recovery actions. Existing literature reviews should be reviewed to assess information needs and identify remaining gaps. Understanding the role of sediment in spawning and larval survival also would inform regulators on how to potentially mitigate for habitat alterations, dredging, and disruptions such as landslides.

- *Identify key rearing and migration habitat in the estuary and describe the habitat characteristics for these locations.* Identifying preferred habitat for rearing and migration through the estuary would help inform recovery actions in regard to habitat restoration and protection.
- *Study timing and characteristics of larval entry into the estuary and ocean, and relate to flow and temperature measurements. Understand the mechanisms controlling larval survival. Is larval outmigration synchronized with a period of favorable estuary and ocean conditions? What happens if they get to the salt wedge too early or late? What is the duration of outmigration, and does speed of migration matter? How do changes in flow affect this relationship?* Identifying preferred habitat for spawning, rearing, or migration would help inform recovery actions in regard to habitat restoration and protection. Understanding the interactions and effects of flow, temperature, and salt intrusion in the estuary on eulachon would help predict population response to climate change and FCRPS operational changes.
- *Study the early marine distribution of larvae in the plume and nearshore ocean.* This would provide new information about the temporal and spatial distribution of larvae in the ocean and help illustrate which plume, flow, or ocean conditions are favorable for eulachon larval growth and survival. Understanding plume and flow-favorable characteristics would aid FCRPS operational decisions.
- *What is the role of the early "pilot run" as a unique life history strategy? Why is this observed, and what role does it serve in terms of population productivity, stability, and persistence?*

Coordinate protection and restoration

- *Review management plans for the Cowlitz River with Tacoma Power and state and federal agencies in order to decrease habitat degradation. Understand the importance of the Cowlitz River to the Columbia River production overall. How important is it over time? How much focus should be put on protecting this run?* The Cowlitz River is an important eulachon-producing tributary to the Columbia River system.
- *Perform lab studies on larval viability and tolerance to temperature change. Historically, larvae were transported into off channel freshwater habitats upon*

incoming tide, but those same habitats may not be suitable, considering climate change. If improving access to floodplain habitat is identified as a recovery action, performing temperature studies on larval viability could aid in prioritization of habitat. This would reduce time and effort spent on providing access to habitat in which eulachon would not be viable.

- *Identify site-level impacts of construction projects. Pile driving may have an impact on eggs and larvae during outmigration and adults during the spawning run.* Enforcing seasonal construction restrictions would be easier with additional science-based research to support assertions that certain activities have a measureable effect on smelt. Identifying impacts could also aid the development of mitigation actions to ensure no net loss.

7 SYNTHESIS: RELATING FORUM DISCUSSIONS TO THREATS TO EULACHON VIABILITY AND POTENTIAL ACTIONS

The Forum was organized to present the latest scientific information to address eulachon management in the United States and Canada and apply it specifically to the Columbia River. The information presented and recommendations developed during the Forum are designed to increase our understanding of basic eulachon biology, address threats, understand population productivity parameters, and assess population viability. The Forum successfully allowed for the exchange of a large amount of information and stimulated good discussions.

However, an equally important element of any workshop such as this is to synthesize the information for managers and identify potential actions that arose during the workshop that should be considered when developing eulachon habitat management plans and recovery actions. While the Forum was an excellent opportunity to brainstorm potential key management questions that need to be answered, there simply was not enough time to translate all of the eulachon topics discussed into a management context during the workshop.

Therefore, this section goes beyond the discussions held in the Forum. It synthesizes the information presented, links it to the four major threats to eulachon in the Columbia River identified in Section 3, and identifies potential actions that could be implemented. The potential actions presented are intended to help guide future discussions on how to manage FCRPS and tributary dams and develop eulachon recovery actions in the Columbia River.

A workshop was held in 2007 to determine research priorities for eulachon based on key hypotheses for decline (Pickard and Marmoreck 2007). Similar to the DFO workshop in 2007, the most often suggested priority at the NPCC's Eulachon Science-policy Forum was to implement an in-river monitoring program for eulachon abundance over a number of locations. Both workshops identify the importance of understanding the role of climate in eulachon populations and survival in the plume environment. Understanding the stock composition and age structure of eulachon populations was identified as a key priority in both workshops. To summarize, there were many similarities in the conclusions from both workshops, lending support to the need to discuss further the potential actions listed in Section 7.

7.1 Climate Change Impacts on Ocean Conditions

7.1.1 Discussion

It was clear from the Forum presentations that eulachon abundance fluctuates greatly between years and over longer time periods. However, the processes affecting recruitment into the fishery and adult age class structure are largely unknown. For example, it is unclear why age class structure is unimodel in some years and bimodal in others and to what extent this diversity influences overall productivity and population resiliency to environmental variability.

Since eulachon are anadromous and spend the vast majority of their lives in marine environments, further studies of eulachon ecology in the ocean are warranted. Studies of the ocean ecology of salmon and steelhead have been conducted off the west coasts of the United States and Canada, and multi-year data sets have been developed on juvenile salmonid abundance is survey transects. In additional, the California Current Integrated Ecosystem Assessment conducted by NOAA collects data to understand the web of interactions in the California Current ecosystem and forecast how changing conditions and management actions affect this web. Also, NOAA Fisheries scientists have collected data on forage fish in the Columbia River plume since the early 2000s.

Assessing potential effects of climate change impacts on ocean conditions and eulachon productivity could start with multivariate analyses of existing salmon and Interagency Ecological Program-California Current datasets and climate indicators to identify ecological drivers acting on eulachon recruitment and population productivity. Existing diet data collected in the United States and Canada could be reviewed, along with existing literature reviews, to develop a conceptual model of trophic relationships between eulachon, their prey, and competitors. The information and hypothesis generated by the analyses could then be related to future climate change predictions to inform managers of the potential effects of climate change on population productivity. This would allow actions taken to address the freshwater phase of the eulachon life cycle to be developed with future estimates of ocean productivity and variability in mind.

7.1.2 Potential Actions

- Conduct multivariate analyses of existing ocean productivity data and relate results to ocean climate change indicators to identify how climate forcing influence stock productivity and age class structure.
- Conduct multivariate analyses of existing ocean productivity data to develop working conceptual models of eulachon trophic relationships.
- Relate SSB estimates to ocean productivity and climate change indicators to assess the strengths of the relationships between covariates and SSB.
- Develop the appropriate metrics for assessing factors that influence eulachon productivity.
- Conduct research to determine the best methods for aging eulachon.

7.2 Eulachon Bycatch in Ocean Shrimp Fishery

7.2.1 Discussion

The effects of eulachon bycatch in ocean shrimp fisheries on eulachon mortality have been addressed to the greatest extent of the four major threats to eulachon identified in Section 3. As discussed in Section 2.7, researchers have made a great deal of progress toward reducing bycatch of eulachon and other species, and the fishing industry rapidly adopted the excluder and trawl rope light devices designed to reduce bycatch.

7.2.2 Potential Actions

- Efforts to develop additional bycatch reduction methods are underway and should continue.
- Adoption of bycatch reduction measures by Canadian fishermen should be reviewed and implemented if needed, because of the reportedly large component of Columbia River eulachon caught in the ocean shrimp fishery off the west coast of Vancouver Island.

7.3 Climate Change Impacts on Freshwater Habitat

7.3.1 Discussion

Addressing this threat will involve many of the gaps and uncertainties in our basic understanding of eulachon biology and ecology that were identified during the Forum. Climate change has the potential to affect many freshwater habitat attributes and processes that influence eulachon spawning success, egg incubation, larval transport, and overall population productivity. These include changes in flow timing, volume, duration, and magnitude, and changes in water temperature. Managers will need to understand how eulachon utilize freshwater habitats and how climate change may alter these habitats and habitat-forming processes.

7.3.2 Potential Actions

- SSB
  - Continue Columbia River and Cowlitz River SSB biomass estimates; expand these assessments to additional locations to understand trends over time among Columbia River tributary locations.
  - Relate the relatively high proportion of Columbia River SSB observed in the Cowlitz River in 2014 (34%) to the longer time series to assess the role of the Cowlitz River spawning stock to the overall population.
  - Conduct side-by-side assessment of SSB using traditional and hydroacoustic methods in the Columbia River estuary and assess whether an integrated approach improves estimates of biomass and provides additional information useful to managing the stock (e.g., locations in the estuary where adults stage before moving into tributaries to spawn and effects of pinniped predation on adult schools).
  - Conduct multi-variate analyses of eulachon spawning distribution in the Columbia River and coast-wide to evaluate how, and why, ranges expand and contract relative to various environmental parameters (e.g., flow, temperature, and turbidity). Can it be determined why eulachon enter specific rivers in specific years?

- Spawning
  - Identify key spawning habitats (i.e., map critical habitats) and preferred flow levels during spawning.
  - Analyze how shifts in water temperature and flow from climate change will potentially affect spawn timing, location, and success.
  - Assess the role and contribution of the pilot run of eulachon to overall population productivity, and determine how shifts in water temperatures and flow from climate change may affect the pilot run.
  - Conduct a pilot study to tag adult eulachon captured in the estuary with acoustic tags, monitor migration behavior relative to environmental parameters and predation pressures, estimate proportional distribution among tributaries, and identify spawning locations.
  - Conduct research to resolve whether a 1:1 sex ratio in the Columbia River estuary and a 4:1 ratio in the Cowlitz River reflects sampling error or represents real shifts in the ratio as adults move upriver. In other words, are females are being lost from the spawning population, which influences production and population productivity?
- Egg incubation
  - Conduct laboratory experiments to evaluate the effects of increased water temperature on egg incubation time and larval development.
  - Conduct laboratory studies to determine which particle size eggs attach to, and whether changes in climate will affect turbidity levels and the availability of appropriately-sized particles for attachment.
- Larval transport and habitat use
  - Calculate transport rates through the lower Columbia River based on passive transport and relate rate-to-river flow. Asses how climate change might affect river flow and larval transport rates.
  - Link changes in ocean entry timing caused by changes in flow to ocean productivity metrics, and assess whether temporal shifts in entry timing results in trophic mismatches and potential changes in population productivity.

- Conduct extensive sampling of Columbia River estuary habitat to assess whether larvae are selecting habitat types and features such as depth, substrate, velocity, proximity to shore, and shoreline vegetation.
- Assess larval diets and effects of climate change on prey production.

7.4 Dams and Water Diversions

Dams and water diversions can be divided into tributary dams and mainstem (FCRPS) dams. While there is overlap between the two categories in terms of their potential effects on eulachon, they are treated separately because the management forums that govern their operation differ. For discussion purposes, and because the Cowlitz River comprised a large proportion of the overall Columbia River abundance in 2014, the tributary discussion and action items that follow focus on the Cowlitz River.

While dams have been identified as a major threat, it was noted during the Forum that the Fraser River does not have dams and the Columbia River does, yet eulachon populations in both rivers have the same temporal variation. Similarities and differences between Columbia and Fraser river trends should be evaluated further to inform overall dam effects.

7.4.1 Discussion – Cowlitz River

Similar to climate change, water storage and re-regulation can affect many freshwater habitat attributes and processes that influence eulachon spawning success, egg incubation, larval transport, and overall population productivity. These include changes in flow timing, volume, duration, and magnitude, and changes in water temperature. Managers will need to understand how eulachon utilize freshwater habitats and dams may alter these habitats and habitat-forming processes. This will require assessment of habitats below Mayfield Dam and effects of the dam and flow regulation on water temperatures and flow levels. The potential actions subsequently identified are in addition to those in Section 7.3.

7.4.2 Potential Actions – Cowlitz River

- Establish the habitat requirements for eulachon spawning and egg incubation in the Cowlitz River.

- Evaluate existing flow and temperature regimes at spawning locations, and relate the regimes to habitat preferences based on the literature and non-regulated river systems. Identify any key differences and potential effects on spawning and rearing habitats associated with flow regulation form Mayfield Dam.
- Continue to develop Cowlitz River SSB biomass estimates to evaluate inter-annual variability.

7.4.3 Discussion – FCRPS

Similar to tributary dams, mainstem and basin-wide water storage and re-regulation can affect many freshwater habitat attributes and processes that influence eulachon spawning success, egg incubation, larval transport, and overall population productivity. These include changes in flow timing, volume, duration, and magnitude; water temperature; estuarine habitat characteristics; extent of salt water intrusion into the estuary; plume size; nutrient and turbidity levels supplied to the plume; and the timing of fish leaving the estuary and entering the plume and near-shore environment. The potential actions subsequently identified are in addition to those in Section 7.3

7.4.4 Potential Actions – FCRPS

- Establish eulachon biological requirements for the lower Columbia River and determine environmental (e.g. temperature, spawning timing, flow, and larval transport) result in cohort success and productivity.
- Develop methods to assess larval transport rates. Determine whether larvae are passively transported downstream in direct relationship to flow, or if they are selecting rearing sites as they migrate.
- Conduct multi-variate analysis of existing data to assess relationships between FCRPS flow volume, timing, and water temperature on cohort success. Ascertain whether there are any trends or relationships between FCRPS operations and SSB.
- Incorporate eulachon into real-time FCRPS water management discussions; as information on eulachon behavior, habitat requirements, larval transport, and cohort success relative to FCRPS operations are better understood, incorporate eulachon requirements into water management planning and real-time decisions.

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APPENDIX A
PARTICIPANTS AND ATTENDEES

Eulachon State of the Science and Science to Policy Forum
List of Attendees

Name	Organization	Email
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APPENDIX B
FORUM AGENDA

EULACHON:
STATE OF THE SCIENCE AND SCIENCE TO POLICY FORUM AGENDA

Thaleichthys pacificus

August 21, 2015, 9:00 a.m. to 4:30 p.m.

Northwest Power and Conservation Council (large conference room)

851 SW 6th Avenue, Suite 1100 Portland, OR 97204

Call in to the meeting: 1-800-356-8278, code 186685

To view live presentations, click "GoTo Mtg" link:

https://global.gotomeeting.com/join/855223757

Time	Presentation	Presenter and Organization
9:00 a.m.	Purpose and Introductions Relationship to Eulachon Recovery Plan and Columbia River Fish and Wildlife Program	John Ferguson, Anchor QEA
9:20 a.m.	Why we are Here: Eulachon and Recovery	Robert Anderson, NOAA Fisheries
9:40 a.m.	Eulachon Spawning Stock Biomass Estimations, Genetics, and Fishery Management in Washington and Oregon	Olaf Langness, Washington Department of Fish and Wildlife
10:00 a.m.	Eulachon Spawning Stock Biomass Estimations, Genetics, and Fishery Management in Canada	Sean MacConnachie, Dept. Fisheries and Oceans, Canada
10:20 a.m.	Eulachon Distribution, Timing, and Spawning Stock Biomass Estimations	Nathan Reynolds, Cowlitz Indian Tribe
10:40 a.m.	Break	
10:50 a.m.	Eulachon in the Klamath River	Robert Anderson, NOAA Fisheries

Time	Presentation	Presenter and Organization
11:00 a.m.	Eulachon in the Columbia River Estuary and Plume	Jen Zamon, NW Fisheries Science Center
11:20 a.m.	Progress in Reducing Eulachon Bycatch in the Ocean Shrimp Fishery	Bob Hannah, Oregon Dept. of Fish and Wildlife
11:40 a.m.	Eulachon and eDNA	Taal Levi, Oregon State University
12:00 p.m.	Lunch	
1:00 p.m.	Evaluation of Transmitter Application Techniques for use in Research of adult Eulachon	Kyle Hanson, U.S. Fish and Wildlife Service
1:20 p.m.	Summary of the morning sessions and transition to FCRPS and Ocean influences	John Ferguson, Anchor QEA
1:40 p.m.	Federal Columbia River Power System Operations (FCRPS)	Paul Wagner, NOAA Fisheries
2:00 p.m.	Estuary/Plume and Ocean Conditions	Antonio Baptista, Oregon Health Sciences University
2:30 p.m.	Break	
2:50 p.m.	FCRPS, Dams, and Water Management in the Columbia Basin and Effects on Eulachon	Robert Anderson, NOAA Fisheries
3:10 p.m.	Identify Knowns and Key Unknowns and Next Steps: Group Discussion	John Ferguson, Anchor QEA
4:10 p.m.	Closing Remarks	Lynn Palensky, NW Council/ Robert Anderson, NOAA Fisheries

APPENDIX C
LIST OF CRITICAL UNCERTAINTIES

List of Critical Uncertainties for Eulachon

From the Council's Fish and Wildlife Program's Draft Research Plan

	Research Question or Critical Uncertainty
1	What are the life history characteristics of eulachon, and what actions could be aimed at rebuilding eulachon populations? Monitor eulachon returns through a combination of scientific test sampling of adults and early life history (larval and egg) investigations and support actions aimed at rebuilding those populations towards desired and historic levels.
2	Monitor and evaluate the causal mechanisms and migration/behavior characteristics affecting survival of larval eulachon during their first weeks in the Columbia River estuary, plume, and ocean environments.
3	What is the ecological importance of the tidal freshwater, estuary, plume, and nearshore ocean environments to the viability and recovery of the Columbia River subpopulation of eulachon?
4	Develop an oceanographic indicators ecosystem conditions model to determine the significance of plume and nearshore ocean conditions that affect eulachon survival.
5	How are climate change, ocean acidification, salinity, estuary turbidity maximum (ETM), and localized hypoxia likely to affect forage fish in the coming decades?
6	How do changes in the Columbia River hydrograph affect survival, productivity, and recovery potential of eulachon?
7	How do restoration projects in the estuary contribute to reproductive success and rearing of forage fish?
8	What role do forage fish have in survival of juvenile Chinook salmon, coho, and steelhead, such as by providing alternative prey to avian predators and sea lions?