Proceedings of the National Workshop on Filling in the Forage Fish Gap

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PROCEEDINGS OF THE NATIONAL WORKSHOP ON FILLING IN THE FORAGE FISH GAP

by

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ABSTRACT

Boldt, J.L., Gauthier, S., King, S. 2019. Proceedings of the National workshop on filling in the forage fish gap. Can. Tech. Rep. Fish. Aquat. Sci. 3287: v + 82 p.

Fisheries and Oceans Canada (DFO) is responsible for the management and protection of marine resources on the Pacific coast of Canada. In recent years, increased attention has focused on the importance of pelagic fishes, their role within trophic food webs and ecosystems, and the need to understand their dynamics and responses to environmental conditions. Surveys and assessments of non-commercially important species are often undeveloped and important life history attributes remain unknown. The Pelagic Integrated Ecosystem Science (PIES) team in DFO's Pacific Region identified the need to develop approaches to assess non-commercially important forage fish. To address this need, they hosted a 3-day national workshop from March 13-15, 2018 at DFO's Pacific Biological Station in Nanaimo, BC. The workshop objectives were to: i) identify data gaps for select forage fish species, ii) compare and contrast forage fish monitoring methodologies, and iii) provide practical recommendations on forage fish monitoring, including survey designs and cross-validation of methods. The workshop was attended by 31 participants from several DFO regions, other government departments in Canada and the US, and several other organizations including non-profit organizations and universities. Prior to the workshop a literature review was conducted and feedback from participants was solicited. At the workshop there were presentations from each DFO Region, as well as invited experts from Washington and Alaska, and group discussions. Discussions and information exchange resulted in several recommendations and actions items. The main recommendations included the need to 1) identify sampling methods that can be easily implemented into existing programs, 2) identify new methodologies that may have higher cost burdens but have a lot of potential, 3) bring together historical data and perform literature reviews at regional levels, and 4) develop a formal working group on forage fish. Through this workshop, within-community awareness of existing forage fish research was developed, and new connections and collaborations were established that would not have occurred otherwise. In the future, having a forage fish working group would encourage more collaborative research to 'fill the forage fish gap' and improve DFO's ability to implement its mandate of an Ecosystem Based Approach to Management.

RÉSUMÉ

Boldt, J.L., Gauthier, S., King, S. 2019. Proceedings of the National workshop on filling in the forage fish gap. Can. Tech. Rep. Fish. Aquat. Sci. 3287: v + 82 p.

Pêches et Océans Canada (MPO) est responsable de la gestion et de la protection des ressources marines sur la côte pacifique du Canada. Les dernières années ont vu émerger un intérêt accru en ce qui a trait à l'importance des poissons pélagiques, leur rôle au sein des chaînes trophiques et de l'écosystème, et le besoin de comprendre leur dynamique et leurs réponses aux conditions environnementales. Les études et évaluations qui concernent les espèces ne présentant pas d'intérêt commercial important sont souvent sous-développées; par conséquent, de nombreux aspects du cycle de vie de ces espèces demeurent inconnus. Un groupe de recherche dans la région du MPO-Pacifique a identifié le besoin de développer des méthodes d'évaluation sur les espèces de poissons fourrage qui ne présentent pas d'intérêt commercial important. Pour répondre à ce besoin, le groupe a organisé un atelier national du 13 au 15 mars 2018 à la station biologique du Pacifique à Nanaimo, C-B. Les objectifs de l'atelier étaient de i) identifier les lacunes dans les données disponibles sur les diverses espèces de poissons fourrage; ii) comparer et opposer les différentes méthodes de suivi; et iii) fournir des recommandations pratiques sur le suivi des espèces de poissons fourrage, incluant la conception des plans d'échantillonnage et la validation croisée des différentes méthodes. Trente et un participants, provenant de plusieurs régions du MPO, d'autres départements gouvernementaux du Canada et des États-Unis, et de plusieurs universités et organismes à but non-lucratif ont pris part à l'atelier. Avant la tenue de l'atelier, une revue de la littérature scientifique a été effectuée et les commentaires des participants ont été sollicités. Durant l'atelier, chaque région du MPO, de même que des experts invités de l'état de Washington et de l'Alaska, on présenté leurs travaux, et des discussions de groupe ont été tenues. Les discussions et les échanges d'information ont mené à plusieurs recommandations et mesures à prendre. Les recommandations principales incluaient le besoin de 1) identifier des méthodes d'échantillonnage qui peuvent être facilement implémentées dans les programmes existants; 2) identifier de nouvelles méthodes qui, bien que plus coûteuses, offrent un grand potentiel; 3) assembler les données historiques disponibles et effectuer des revues de littérature aux niveaux régionaux; et 4) développer un groupe de travail formel sur les espèces de poissons fourrage. À travers cet atelier, une meilleure compréhension de la recherche existante a été développée au sein de la communauté, et de nouvelles relations et collaborations ont été établies, qui n'auraient pas eu lieu sans la tenue de cet événement. Dans le futur, l'existence d'un groupe de travail sur les espèces de poissons fourrage encouragerait la recherche collaborative afin de réduire les lacunes dans nos connaissances actuelles, et améliorerait la capacité du MPO à implémenter son mandat sur la gestion des ressources halieutiques fondée sur l'écosystème.

1. BACKGROUND

Small pelagic fish are an essential part of marine trophic food webs and can also be commercially and culturally important. The abundance of small pelagic fish populations are highly variable both in space and time, attributes which complicate sampling, forecasts, and retrospective analyses related to recruitment. Population abundance of forage species can be affected by environmental conditions, system productivity, and the carrying capacity of ecosystems, as well as by a variety of factors influencing survival and recruitment to the adult population. Understanding what factors affect the abundance, recruitment, age structure, size, condition, and distribution of small pelagic fish also presents a challenge to the assessment of these species. In recent years, increased attention has been paid to the importance of pelagic fishes and the need to understand their dynamics and responses to environmental conditions, as well as their role within food webs and ecosystems.

Surveys and assessments of non-commercially important species are often undeveloped, and important life history attributes remain unknown. Many researchers have identified a lack of forage fish data as a limiting factor for our understanding of ecosystems and in tools such as ecosystem models. DFO Science requires forage fish time series in order to develop ecosystem models that can provide an indication of how changing environmental conditions will affect fish productivity. Forage fish, such as Sand Lance (*Ammodytes personatus*) and Surf Smelt (*Hypomesus pretiosus*), are recognized as critical components of marine ecosystems, contributing to the diets of a wide variety of fish, marine birds, and mammals (Ware and McFarlane 1995, DFO 2007, Ford et al. 2009). For example, piscivorous fish in BC's Hecate Strait, such as Pacific Cod (*Gadus microcephalus*) and juvenile Rock Sole (Lep*idopsetta bilineata*), consume 32% to 74% forage fish (by weight; Pearsall and Fargo 2007). DFO monitors commercially important forage species; however, there is limited monitoring of most forage species that are not commercially fished but that can play an important prey role supporting commercial fish populations or other top predators (e.g., marine mammals). Fisheries management can use forage fish abundances as indices for commercially important fish productivity. This would also benefit the Species At Risk Act (SARA) through improvement of methods for detecting rare species, and benefit Marine Conservation Planning, by improving our ability to identify critical foraging habitats and inform decisions to develop and define boundaries for Ecologically or Biologically Significant Areas (EBSAs) and Marine Protected Areas (MPAs).

The Pelagic Integrated Ecosystem Science (PIES) team in the Pacific Region identified the need to develop approaches to assess non-commercially important forage fish. To address this need, they developed a proposal to host a 3-day national workshop titled "Filling in the Forage Fish Gap" with invited experts, followed by a report on recommendations. The proposal was submitted to and successfully funded by Fisheries and Oceans Canada's (DFO's) Strategic Program for Ecosystem-Based Research and Advice (SPERA). The objectives of the workshop were to i) identify data gaps for select forage species, ii) compare and contrast forage fish monitoring methodologies, and iii) provide practical recommendations on forage fish monitoring including survey designs and cross-validation of methods.

2. INTRODUCTION

The workshop was held over three days, from March 13 to 15, 2018, in the seminar room at DFO's Pacific Biological Station in Nanaimo, BC. It was attended by 31 participants from several DFO Regions, other government departments in Canada and the US, and several other organizations including non-profit organizations and universities (Appendix A and B; Figure 1). The workshop was co-chaired by Jennifer Boldt and Stéphane Gauthier, and the rapporteur was Stephanie King.

Prior to the workshop a literature review on select non-commercially important forage fish species was assembled for the Pacific Region (Appendix C). The literature review summarized gaps in life history information for select forage fish, methods used to assess them in BC, assessment or monitoring methods used in other regions of Canada and the US, and advantages and constraints of those methods. The literature was made available to workshop participants via email and on an FTP site. To complement this review, participants were asked to identify forage fish species that are not well sampled in their region and any known life history information (Appendix D, Tables D1-D10). In addition, participants were asked to list methods used to sample forage fish species and to identify advantages and constraints of those methods, along with references (Appendix D; Tables D1-D10).

The workshop format included a series of presentations on sampling methods and data gaps in regions across Canada. Three experts on forage fish species from the US West Coast were invited to share their experience and provide broader perspectives. There were two break-out sessions and the meeting was concluded with a discussion of recommendations to address forage fish data gaps in Canada. After the workshop, presentations were uploaded to an FTP site. This report serves to communicate the outcome of constructive workshop discussions and recommendations that were identified to address forage fish knowledge gaps. Many of these recommendations could be implemented by DFO Science.

Figure 1. Participants at the March 13-15, 2018 Pacific Region workshop on filling the forage fish data gap.

The workshop was opened by the co-chairs, Drs. Jennifer Boldt and Stéphane Gauthier, who welcomed the participants, reviewed the agenda and objectives, and asked the workshop participants to introduce themselves (Appendix A). Dr. Boldt provided background information on the workshop and reviewed the workshop objectives and agenda (Appendix B) and gave an overview of the literature review. This review focused on describing general life history characteristics of forage fish in BC, methods used to monitor or assess forage fish, and the advantages and constraints of those methods (Appendix C). It was acknowledged that invertebrates (such as squid and euphausiids) are also an important forage group, but that this workshop was focused primarily on non-commercially important forage fish. It was also noted that this workshop focused on monitoring and sampling forage fish species, and not on modeling forage fish populations, another important area of research.

3. INVITED PRESENTATIONS ON PROTOCOLS

The first 1.5 days of the workshop included a series of 20 to 30 minute presentations given by forage fish experts from various regions or organizations.

3.1. Matt Baker, North Pacific Research Board

Dr. Matt Baker is the Science Director of the North Pacific Research Board (NPRB) in Alaska and was invited to share his forage fish research as well as related projects funded by the NPRB.

He described three research areas related to forage fish in Puget Sound and in Alaska. The first project is with the Pelagic Ecosystem Research Apprenticeship at the University of Washington's Friday Harbor Laboratories which has been running since 2010. Much of this work has focused on Pacific Sand Lance and their habitat, but there are still considerable knowledge gaps on the species. Recent work has examined relative abundance, condition, age structure, feeding behavior, and responses to environmental variation, over both seasonal and inter-annual timescales, at two main sites in Puget Sound. Sampling methods included 1) beach seines at dawn and dusk when Sand Lance were in the water column feeding, and 2) acoustic bottom type/habitat mapping with verification using Van Veen grabs. The second project he described was the collaborative, large-scale spring and summer surveys in the Bering, Chukchi and western Beaufort Seas which started in 2017. Lastly, Matt described a number of projects through the North Pacific Research Board (http://projects.nprb.org/) including work on age-0 Walleye Pollock (*Gadus chalcogramma*), Pacific Herring (*Clupea palasii*), Capelin (*Mallotus villosus*), and Pacific Sand Lance as well as a number of regional forage fish and forage fish prey studies around the Gulf of Alaska.

Participants discussed potential causes of observed Sand Lance abundance trends in the Salish Sea including skip spawning (where fish do not spawn every year) vs. recruitment failures due to limited burrowing habitat (a density dependent effect) vs. sampling efficiency (perhaps Sand Lance can access a wider range of habitats than can be sampled with survey gear). Matt noted that they are going to do some work with a remotely operated vehicle (ROV). Other methods discussed included upwards-looking acoustic moorings.

3.2. Todd Sandell, Washington Department of Fish and Wildlife

Dr. Todd Sandell was invited to share the forage fish work being done by the Washington Department of Fish and Wildlife (WDFW) Marine Fish Science Unit. WDFW monitoring currently covers Pacific Herring and Surf Smelt, and to a lesser extent Sand Lance and Eulachon (*Thaleichthys pacificus*). The Pacific Herring biomass time series comes from commercial catch records, sport bait catch records, acoustic trawl surveys (1990s-2009), and a spawn deposition ("rake") survey (1973-present). The historic acoustic trawl surveys were dropped in 2009 because the biomass estimates were similar to the rake surveys, which are ongoing and cheaper to conduct (although the rake surveys only go to 7 m, which may not be deep enough in a few places). Todd mentioned that they are also interested in using drones (vegetation and fishing effort surveys) and light traps (ichthyoplankton) for monitoring. One issue is that they do not handle fish during the annual rake surveys and so do not get biometrics data. For recording data they use an Ipad with a waterproof case and the Iforms app which Todd described as excellent for convenience, data quality control, and data uploads.

In 2016-2017, they also conducted midwater acoustic-trawl surveys using a Biosonics DTX® (split beam 38 and 120 kHz) and polish rope trawl every other month. They use a Marport® unit mounted on the headrope that communicates net depth in real-time with the survey vessel and greatly improved their catch. These surveys can over-represent larger species and sources of error may include target strength scaling factors and the time difference between when the acoustic boat and trawl boat were sampling (average lag time was 52 min). Other Pacific Herring work includes a variable mesh gill netting study to characterize the Cherry Point spawning population and a wide-scale genetics study to analyze differences in WA state Pacific

Herring stocks. WDFW is also working to develop a standardized beach seining protocol for Puget Sound so that data from ongoing studies by WDFW, NOAA, Tribes, and NGOs can be compared as long-term datasets.

WDFW also does beach spawn surveys to monitor shore spawners (Surf Smelt and Sand Lance), and if eggs are found the beach receives protection under existing statutes. The method used is described in the 2006 "Field Manual for Sampling Forage Fish Spawn in Intertidal Shore Regions," by Dan Penttila and Lawrence Moulton, except that they now use a vortex to separate the eggs instead of winnowing, which gives better results and takes less time (protocols are online). They tried monitoring Surf Smelt with VIE tagging but the tag recoveries were too low to estimate abundance; however, they did learn about their movements, residency and spawning frequency. Midwater trawl nets do not appear to sample Surf Smelt or anchovy sufficiently because the fish are too close to shore; in 2018 they will try lampara seine nets because they can be set in shallow areas and above vegetation beds without damaging them. Sand Lance have been sampled at night in the nearshore by digging out the top layer of sediment within a square meter area; they are exploring using a using half of a plastic 50 gallon barrel dug into the sand in areas where the sand is fluid. They also conduct Eulachon ichthyoplankton surveys on the Columbia as an index of spawner abundance, and recently used eDNA to verify Eulachon and Longfin Smelt (*Spirinchus thaleichthys*) presence in the Chehalis River.

Sampling protocols, identification guides, a forage fish mapping tool for the southern Salish Sea, and other materials are available online at: https://wdfw.wa.gov/conservation/research/projects/marine_beach_spawning/.

After the presentation, questions mainly focused on the WDFW monitoring methods. Todd clarified that the vortex method uses a water pump to create a whirlpool that helps separate eggs while the winnowing method consists of manually rocking the sample back and forth, similar to gold panning. The vortex method is more efficient than the winnowing method, and produces better egg recovery efficiency while saving time. They are also taking Pacific Herring egg samples, aging fish, and trying to back calculate the date of fertilization and emergence. Doug Hay commented that Pacific Herring size-at-age and densities appear to be correlated in BC, and wondered if WDFW has looked at either metric in Puget Sound. Todd noted that, because previous efforts focused only on spawning fish, there was not enough data to answer that question at present. In response to a question about the abundance and importance of Threespine Stickleback (*Gasterosteus aculeatus*), Todd described Stickleback as abundant and a known predator of Pacific Herring eggs in the Atlantic and Baltic Seas, but there is little information available on abundance in the southern Salish Sea.

3.3. Mayumi Arimitsu, USGS-Alaska Science Center

Dr. Mayumi Arimitsu, from the United States Geologic Survey Alaska Science Center in Juneau, Alaska, was invited to describe forage fish monitoring in Alaska. She started by describing the issues with monitoring as 1) there being limited resources for monitoring non-commercial species, 2) the large number of species with different life histories, and 3) that the abundance of small pelagics is highly variable. Sampling has been done under the Seabird and Forage Fish Ecology Program and Gulf Watch Alaska which is in its 7th year. They tried several survey methods and had quite a lot of difficulty sampling forage fish in coastal waters. For stratified systematic acoustic surveys they used two frequencies (38 and 120 kHz), however, Mayumi noted that five would be better. They also used GoPro cameras to validate acoustic targets, beach seining for collecting samples, and aerial surveys to identify Sand Lance and Pacific Herring schools. Acoustic surveys provide quantitative estimates of fish biomass in the water column, but could not be used in very nearshore areas, and may not account for vessel avoidance, and acoustic software licenses are expensive. They found that the aerial surveys were complementary to the acoustic surveys although both are expensive. Aerial surveys provide a method to acquire an index of the number and surface area of Pacific Herring and Sand Lance schools in nearshore areas where acoustic data could not be collected and aerial surveys did not have the issue of vessel avoidance. Constraints of the aerial surveys were that it was difficult to classify the difference between age-0 and age-1 Pacific Herring. There is also potential to monitor Capelin and Eulachon on the aerial surveys. The program will not likely have the resources to establish forage fish population trends but going forward, they will conduct acoustic trawl surveys in predator aggregations to improve the understanding of predator-prey interactions.

Through Gulf Watch they hope to continue a monitoring program of seabird diets at Middleton Island. Predator diets are used to assess trends in Capelin and Sand Lance and are included in NOAA's Ecosystem Considerations report. The Gulf Watch data have also been used to examine prey availability in predator foraging areas, Capelin age at maturity, Sand Lance growth and length frequency. Mayumi concluded by describing the process for how they designed the surveys for forage fish monitoring. Her suggestions for designing this kind of program is to first get input from data users and decide what the purpose will be (e.g., ecosystem predator-prey interactions).

Several participants asked questions about the aerial surveys and Mayumi gave the following clarifications:

- The cost for a survey over one month covering the whole coastline was about $35K.
- Validation teams could not keep up with the plane.
- There is a lot of potential for using drones and the drone validation would be easier, plus fluid lensing is available on drones to cut out the glare off the surface of the water.
- Confidence intervals around the number of schools are large because of school patchiness; this could be refined to use surface area of schools.
- They were able to accurately distinguish between Pacific Herring and Sand Lance 84% of the time.

Gary Melvin suggested using a forward-looking sonar for a qualitative assessment. Todd Sandell noted that they used aerial surveys for crab pots in Puget Sound (WA), but they never see schooling fish.

3.4. Brian Hunt, University of British Columbia

Dr. Brian Hunt was invited to discuss monitoring forage fish using environmental DNA (eDNA). He described eDNA as extra-organismal genetic materials such as sloughed cells, feces, gametes, or any organic material found in the environment. To collect eDNA, water samples are collected from a pre-specified depth, filtered, frozen (-80ºC ideally), then sent to a laboratory for DNA extraction, amplification, sequencing, and analysis to determine taxonomic assignments. On the Canada 3 Oceans cruise they collected samples in 2 L Whirl-Pak© bags. The field of eDNA research is quickly developing and there are tools available such as an automated sampling backpack used to test for single species.

Applications include assessing biodiversity, seasonal species composition, and relative abundance / biomass. The advantages of using eDNA include: 1) it results in higher biodiversity estimates compared to other methods, 2) samples are easy and inexpensive to collect, 3) results are not affected by net sampling bias, 4) many species of fish have already been barcoded. Constraints of eDNA include: 1) contamination can be an issue, 2) eDNA degrades in the environment and degradation rates depend on the species, medium (water vs. sediment), the abiotic and biotic environment, but not UV exposure, 3) results may also depend on sloughing rates, 4) there are still many unknowns, 5) it does not provide density estimates, and 6) not all species have been barcoded.

Brian showed some results from the Trans-Canada eDNA Biodiversity Mapping Project on the Canada C3 survey, and concluded with futures steps, including streamlining field methods, calibration studies, and establishing BC baseline data. Chrys Neville noted that eDNA samples are collected on DFO's fall juvenile salmon trawl survey.

3.5. Jennifer Boldt, Pacific Biological Station, DFO

Dr. Jennifer Boldt described the age-0 Pacific Herring surveys in the Strait of Georgia which have been conducted annually in the fall since 1992 (except 1995). The survey has the following objectives:

- Estimate the relative abundance of age-0 Pacific Herring,
- Estimate mean lengths, weights, and condition of age-0 Pacific Herring,
- Provide a potential leading indicator of recruitment to the adult Pacific Herring population,
- Provide an indicator of prey availability and quality to predators in the SOG, such as Coho (*Oncorhynchus kisutch*) and Chinook (*Oncorhynchus tshawytscha*) Salmon, and
- Monitor zooplankton and environmental conditions associated with age-0 Pacific Herring.

There are ten core transects, each with 3 to 5 core stations (total 48 core stations), distributed at approximately equal intervals around the perimeter of the SOG that have been consistently sampled during the autumn. Sampling was conducted at these predetermined stations after dusk when Pacific Herring were near the surface and, generally, one transect was sampled per night over the course of a 4-7 hour period. Seines can be used nearshore, however tides can affect catches and the area sampled is relatively small. Catch weights were estimated and all fish (or a subsample of fish) were retained for sampling in the laboratory, with the exception of large predator species (e.g. adult salmon and flatfish), which were individually measured in the field. In the laboratory, fish from each station were sorted to species and up to 100 individual age-0 Pacific Herring were weighed, and measured. Pacific Herring were measured to standard length (nearest mm). The age-0 Pacific Herring index was calculated using Thompson's (1992) two-stage (transect, station) method and variance estimator to calculate the mean (and associated variance) of juvenile Pacific Herring survey catch weight per-unit-effort (CPUE) (for details see: Boldt et al. 2015). In addition, Pacific Herring condition was calculated as residuals from a double-log-transformed length-weight regression. All survey information is published annually in the Canada Manuscript Report series.

This survey is directed at age-0 Pacific Herring however, other forage fish species are caught in this survey. Other species (e.g., Northern Anchovy (*Engraulis mordax*)) are not well-sampled by the survey (abundance estimate coefficient of variations are high), so in some cases the proportion of sets with presence has been used for these other species. One workshop participant commented that using the proportion of sets with anchovy might be biased because of patchy distributions of fish. Jennifer acknowledged this and noted that the survey is directed towards estimating the relative abundance of age-0 Pacific Herring.

3.6. Chrys Neville, Pacific Biological Station, DFO

Ms. Chrys Neville presented information on the Pacific Salmon Marine Interaction purse and beach seine survey in the Strait of Georgia. The purse seine samples fish within the top 15-20 m of the water column and wide range of species are caught. The primary focus of this survey is to sample juvenile salmon, however all species caught are enumerated and biological data are collected. Advantages of purse seines include the ability to sample nearshore, samples can be released live, and they provide information on species occurrence. Disadvantages of the purse seine surveys include difficulty setting the net in strong tidal currents, the surface area sampled is relatively small, they sample to 15-20 m depth, some fish species may be able to avoid the net, and catch depends on the skill of the skipper. Another consideration that applies to all nets is size selectivity. Comparisons with midwater trawl catches show a difference in the size distribution of fish caught; for example, the midwater trawl net catches a wider range of Sand Lance size classes than the purse seines.

3.7. Jackie King, Pacific Biological Station, DFO

Dr. Jackie King described DFO's various pelagic trawl surveys. They all use a CanTrawl 250 mid-water trawl with a net opening of 28x16 m, and 1.5" knotted nylon codend fitted with a 0.25" insert. The net was set at various depths (depending on survey) and towed at about 5 knots. All surveys also collected zooplankton and environmental data as well. The four pelagic trawl surveys are:

1. Salmon Marine Interactions (SMI; Strait of Georgia) Survey (Lead investigator: Chrys Neville). This is a daytime survey that has been conducted annually in the summer and fall following a standard track aimed at catching juvenile salmon, 1998-present. A wide range of forage fish species are sampled as bycatch. Data have been used to describe trends in anchovy, the relative abundance of Walleye Pollock, and Sand Lance biology. The midwater trawl is towed at 5 knots for 30 minutes at depths of 0, 15, 30, 45, and 60 m. All catch is identified and enumerated.
2. Offshore Juvenile Salmon Survey (Lead investigator: Jackie King). This is daytime survey that has been conducted in summer, fall, and winter on a standard track aimed at catching juvenile salmon, 1998-2016. The objectives of this survey evolved over time,

and have included 1) defining the cross-shelf/off-shelf distribution and migration rates of juvenile salmon, 2) identifying seasonal stock specific migration for coho, chinook, and sockeye salmon, 3) identifying factors driving growth and survival, and 4) examining the distribution, abundance, condition, and diet of all pelagic fish species. Midwater trawl speed, depths, and tow durations were the same as the SMI survey. Catch data can be used to describe forage fish spatial distribution, proportion of catch, and relative abundance of Sand Lance.

3. Pelagic Ecosystem Night Trawl (Pacific Sardines (*Sardinops sagax*)) Survey (Lead investigator: Linnea Flostrand). This surface trawl survey was conducted in summer annually from 1997 to 2014. The original objectives of the survey were to determine Pacific Sardine ecology and abundance. In approximately 2006, the objective evolved to determine the distribution, abundance, and trophodynamic interactions of all pelagic fish species. During 1997-2005, the survey was conducted during the daytime. One issue was the 'boom' or 'bust' catches of Pacific Sardines, because fish were tightly schooled during the day. In 2006-2014, the survey switched to sampling during night time hours when fish were more dispersed in the upper water column. The survey design was altered to a random stratified survey design in 2010. In 2011 to 2014, acoustic data were collected along standardized transects during daytime hours, with occasional accompanying marine mammal observations. The net was fished at the surface or 15 m depth. Data on catch weights, species composition, catch per unit effort (CPUE), and diet were collected. These data have been used to describe tends in Pacific Sardine, Eulachon, Whitebait Smelt (*Allosmerus elongates*), Jack Mackerel (*Trachurus symmetricus*), and Northern Anchovy.
4. Integrated Pelagic Ecosystem Survey (Lead investigators: Jackie King, Jennifer Boldt, Linnea Flostrand and Strahan Tucker). This is a collaborative integrated pelagic ecosystem survey that provides empirical-based process studies linking climate forcing to lower trophic levels and forage fish through coastal oceanographic processes. It formed as a collaboration between the offshore juvenile salmon survey and the pelagic ecosystem night trawl survey starting in 2017. The main goal of the survey is to understand factors affecting the distribution, abundance, and food web linkages of pelagic fish species, such as Pacific Herring and juvenile salmon. To accomplish this goal, a random stratified survey design was used to identify blocks, and samples were collected within those blocks with a midwater trawl net towed at the surface or 15 m depth during both daytime and nighttime hours. The prey and physical environment were also sampled (i.e., zooplankton and water properties). Data on fish catch, CPUE, species composition, diet, stable isotopes, and genetics were collected.

Advantages of these surveys include the provision of long time-series data on relative abundance trends of forage fish, biological samples, and information on life stages of fish that are not sampled well elsewhere. They also cover a wide geographic area and describe spatial distributions of fish species. The disadvantages of these surveys are that they do not sample close to shore and they miss the upper 0-5 m layer of the water column. Solutions for these drawbacks are to use smaller trawl gear on smaller vessels and a headrope apron as used on the National Marine Fisheries Service (NMFS) surveys. A new midwater trawl was acquired for the 2018 survey which will be easier to maintain at-depth and at the surface.

In response to a question about how the data are used, Jackie noted that they are used to assess resident populations and hatchery-wild interactions. There was also some discussion about the inability to do an inter-vessel comparison, however, it was noted that other surveys (e.g., DFO groundfish survey and NOAA's Alaska Fisheries Science Center groundfish surveys) use multiple vessels and generally found that the inter-vessel variably was less than interannual variability.

3.8. Stéphane Gauthier, Institute of Ocean Sciences, DFO

Dr. Stéphane Gauthier gave a presentation on DFO acoustic surveys in the Pacific Region. Generally, in these surveys, acoustic data are collected along standardized parallel transects and echosigns are verified with a midwater trawl net or other sampling tools (e.g., cameras). Acoustic backscatter is converted to biomass, using information about the species and size composition of the aggregations coupled with species-specific acoustic target strength.

A large scale acoustic trawl survey is conducted on a biennial basis from California to northern BC. The target is Pacific Hake (*Merluccius productus*), but other pelagic fish species are sampled as well. Stéphane showed examples of acoustic echograms of Pacific Herring, rockfish and myctophids, and noted that large-scale acoustic surveys do not tend to detect species that have very low abundance.

The annual La Perouse survey (2013-2015; Boldt et al. 2016) focused on examining the distribution, relative abundance, and trophodynamics of pelagic fish and prey species – with a particular focus on Pacific Herring. Data collected on these surveys included catch weights, CPUE, species composition, morphometric data, diet data, as well as zooplankton and environmental data. On a smaller spatial scale, there is also the Strait of Georgia pelagic ecosystem survey which assesses the distribution of Pacific Hake, Walleye Pollock, and other pelagic fish.

These surveys provide quantitative biomass estimates for fish under the vessel to near bottom. The disadvantages are that acoustics miss the top 14 m of the water column. It was also acknowledged that for less common species (e.g., smelts), it is likely that these surveys can only provide presence data. These surveys also miss nearshore areas, but in the future smaller vessels could be used to address this gap.

Midwater trawls are typically used to verify species and size of individuals in echosigns. Other sampling tools to verify acoustic targets include the Hydrobios multinet (0.25 m^2 opening) which is useful to sample zooplankton and krill, and the MOCNESS (2.0 m^2 opening), useful to sample larger mobile nekton, larger zooplankton, and small forage species. Optical tools, such as stereo cameras (e.g., Slycam; Boldt et al. 2017) are valuable for verifying fish species while also collecting needed length data, and in-net trawl cameras help identify net selectivity (e.g., pressure waves in front of the cod end that can force fish out of the net meshes). New acoustic tools used in the Region include autonomous echosounders, acoustic moorings, and imaging sonars (DIDSON and ARIS), which can all be used to monitor forage species.

3.9. Cliff Robinson, Pacific Biological Station, DFO

Dr. Cliff Robinson gave an overview of Pacific Sand Lance research along the BC coast, Parks Canada eelgrass fish assemblage research program, and knowledge gaps. Sand Lance predators and life history were reviewed. A number of projects on Sand Lance spawning habitat have been conducted off southern Vancouver Island and in Puget Sound, including a new initiative by the World Wildlife Fund Canada and partners assessing potential forage fish spawning habitat in the intertidal zone of the Gulf Islands, using ShoreZone imagery for mapping and modeling. There are data gaps on spawning habitat on the outer west coast of Vancouver Island, the Northern Shelf Bioregion, and in subtidal areas.

Cliff noted that there is no long-term sampling program for Sand Lance larvae in BC, although, opportunistic samples have shown that larvae are widespread throughout BC. Several studies have been done in intertidal habitats, but the distribution and surface area of intertidal habitats is unknown and there are no monitoring data on young of the year abundance, settlement, or recruitment. In subtidal areas, studies show that silt content is important to determining Sand Lance burying habitat. Work is being done to model burying habitat distribution on the BC coast, and Cliff listed a number of other recent studies on diet of Sand Lance, including microplastics in Sand Lance diets and habitat. The key coastwide data gaps include knowledge about:

- Spawning habitats in subtidal locations
- Burying habitats in intertidal and subtidal locations
- Pelagic foraging habitat locations
- Larval distribution/abundance
- Adult abundance estimates

3.10. Doug Bertram, Wildlife Research Division, Environment and Climate Change Canada

Dr. Doug Bertram presented information on forage fish as drivers of historical and seasonal changes in the at-sea distribution and abundance of marine birds in the Salish Sea. Declines in bird populations can possibly be explained by declines of forage fish in their diets. For example, Western Grebes (*Aechmophorus occidentalis*) now overwinter farther south because of changes in Pacific Herring spawn distribution. One study examined isotopes in museum samples of Marbled Murrelet (*Brachyramphus marmoratus*) feathers and found that the trophic level of their diet has been declining for the last 150 years. Marbled Murrelets historically had more forage fish in their diets, and now feed more on euphausiids. Recent work includes modeling Marbled Murrelet critical habitat in terms of shoreline and Sand Lance burying habitat. Surveys have been conducted in Haro Strait to identify linkages between seabirds and forage fish habitat. Monthly sediment grab samples in the Sidney Channel important bird area (IBA) showed that Rhinoceros Auklets (*Cerorhinca monocerata*) are absent when Sand Lance are dormant during the fall-winter. Other studies have linked bird counts to Pacific Herring spawning biomass, which is a major draw for birds in the Strait of Georgia.

3.11. Mark Hipfner, Wildlife Research Division, Environment and Climate Change Canada

Dr. Mark Hipfner gave a presentation on using Rhinoceros Auklets as samplers of forage fish distribution and abundance on the BC coast. Stable isotopes studies indicate that Rhinoceros Auklets are generalist foragers, but rely on forage fish while provisioning their offspring. Since 2006 Mark has been involved in a three trophic level study involving birds, forage fish and zooplankton which focused on environmental drivers, forage fish as conduits for microplastics in food webs, and consumption of salmon smolts by seabirds. They have assessed the diet of Rhinoceros Auklet nestlings at several breeding colonies on the coast and found spatial and temporal changes in the diet. Sand Lance and Pacific Herring generally comprise the majority of the diet, except at Triangle Island where very little Pacific Herring were consumed. The breeding success of Rhinoceros Auklets has been linked to the amount of Sand Lance in their diet. Mark also showed the track of tagged Rhinoceros Auklets at Pine Island, where birds flew farther to forage in 2017 than in 2016.

3.12. Ian Perry, Pacific Biological Station, DFO

Dr. Ian Perry summarized the DFO zooplankton / larval fish surveys in BC waters. The Institute of Ocean Sciences houses a large database of zooplankton data collected by the Institute of Ocean Sciences, the Pacific Biological Station, and universities, under a number of different sampling programs. The data are grouped into 6 statistical areas, each with 10 to 30 samples from 2 to 4 surveys per year, over 12 to 30 years, depending on area. There are some variations in sampling methodology, but the database has been designed to track these variations.

Ian showed an example of time series of mean annual abundance, biomass and abundance anomalies for Actinopterygii larvae (boney fish); the time series are quite different between northern and southern Vancouver Island. He also presented the time series for Northern Anchovy eggs and larvae in the Strait of Georgia which suggest that Northern Anchovy have been spawning in the Strait since 2013.

Advantages of the surveys utility for monitoring forage fish include:

- Long time series (from 1970-2000 to current, depending on region)
- Variations in collection methods can usually be accounted for
- Strait of Georgia sampling since 2015 at intervals of two weeks (Feb-Oct)
- Identified to lowest possible taxonomic level
- Staged to egg, larval/juvenile (3 size classes)
- Useful for biodiversity analyses, may be useful for stock abundance estimates.

The disadvantages were listed as:

- Small size of sampling gear (Bongo, SCOR nets) and low volumes filtered
- Currently, major surveys on outer BC coast occur only in May and September (usually too late for most fish spawning periods).

3.13. Linnea Flostrand, Pacific Biological Station, DFO

Ms. Linnea Flostrand gave an overview of Eulachon egg and larval surveys in BC. She referred to several documents describing the data available on http://www.pac.dfo-mpo.gc.ca/science/species-especes/pelagic-pelagique/eulachon-eulakane-eng.html, and also to a sampling manual (McCarter and Hay 2003). The Eulachon egg and larval surveys are conducted with plankton nets providing information on distribution, presence/absence, relative abundance, and seasonal and inter-annual variability. There are sampling programs in rivers throughout the BC coast. The Fraser River time series started in 1997 and is sampled twice a week from April to June by DFO. Uncertainties in this survey include the start and end dates of seasonal down river drift of eggs and larvae, river conditions (e.g., tides, discharge) limiting sampling frequency, missing some eggs (e.g., lost eggs, spawning below the lowest station), and links to marine populations. Linnea noted that the survey does not provide information on river spawning sites, trophic interactions, or in-season forecasting of spawning stock biomass.

3.14. Ian Perry, Pacific Biological Station, DFO

Dr. Ian Perry summarized the west coast of Vancouver Island small-mesh multispecies bottom trawl survey. The surveys target pink shrimp and have been conducted annually in May since 1973. A number species are sampled, 16 of which are considered to be well-sampled. Ian showed several examples of time series, including biomass anomalies for Pink Shrimp, Arrowtooth Flounder (*Atheresthes stomas*) and Walleye Pollock, as well as Eulachon CPUE, and a composite index for well-sampled taxa. The advantages of this survey are that there is a long time series using consistent methods with good taxonomic resolution. The constraints are that a relatively small area is surveyed, the survey area is mostly over sandy bottom, a bottom trawl net is used, which may not sample pelagic fish well, and the survey is conducted only once per year.

3.15. Ramona C. de Graaf - Sea Watch Society

Project: BC Shore Spawners Alliance

Ms. Ramona de Graaf, MSc., gave an overview of the citizen science monitoring and mapping of Surf Smelt and Pacific Sand Lance habitat in the Strait of Georgia. Prior to 2000 there were no data on Sand Lance spawning sites, but through the support of Dan Penttila and a number of organizations, and using the protocols of the Washington Department of Fish and Wildlife, over 150 positive spawning beach sites have been identified through embryo surveys. Surf Smelt spawning structure and locations were also identified. Numerous regional districts and the Island Trust use the data for land-use planning. Advantages of the embryo surveys include the use of consistent methodology with high spatial/temporal coverage that can be used to provide information on species ecology and habitat. The methods can also be adapted for other species, such as Capelin. Constraints of the surveys are that they cannot disprove absence of spawning, they can only show spawning occurred and provide only a relative measure of abundance, sites are affected by storms or human disturbance, and long-term funding is difficult to maintain.

Ramona also described the forage fish spawning habitat suitability model which is based on sediment grain-size. The output of these models has been used for land-use planning and provides output for modeling impacts of multiple stressors. The advantages of habitat suitability models are that they incorporate many habitat metrics, data sets for spawning and adult presence, and fish behaviour. The constraints noted were the limited weather window for optimal sediment conditions, the model assesses suitability and does not provide data on presence of embryos, and the high cost of Trimble navigation.

Next steps are to focus on Burrard Inlet Surf Smelt conservation and important bird areas. A beach condition index will be used to classify the coastline based on spawning, marine riparian, salmonid rearing, and also sea level rise vulnerability work done by BC Parks. Several other projects described included Fraser River Eulachon habitat restoration and monitoring in the Skeena River estuary. Together with Dan Penttila, Ramona is expecting to publish the results of the 12-year survey in 2018.

Ramona also conducts research on the thermal characteristics of spawning beaches as they affect the variability in embryo hatching and survivability rates with varying emersion periods.

3.16. Hannah Murphy, Northwest Atlantic Fisheries Center, DFO

Dr. Hannah Murphy was asked to describe forage fish monitoring and data needs in the Newfoundland Region, as well and provide information on species biology and monitoring methods. She reviewed the assessment methods for Capelin and Atlantic Herring (*Clupea harengus*), both commercially fished species. The Capelin assessment is based on an acoustic survey of the immature stock in the spring which provides an abundance index, and data on diet, ages, maturity, lengths, and weights. There are also two larval indices based on surface tows in July-August to sample emergent larvae and bongo tows in Aug-Sept to sample late-stage larvae. There is a significant relationship between the age-2 recruitment index from the acoustic survey and the Capelin larval abundance index. This relationship is the foundation of a forecast model for Capelin that is currently in development. Capelin information is also collected from spawning diaries (diarists are paid to look at the beaches near them for evidence of spawn), citizen science (working with WWF-Canada to have citizens upload photos of spawn), as well as from Capelin in the diets of predators, which are sampled in an offshore multi-species survey, and from commercial fishery samples (although the fishery does not provide very much information any more due to the short season). Challenges listed include estimating the spawning stock biomass and reference points, only one age-class (age-2) is primarily surveyed in the acoustic survey as other age classes are not fully recruited to the survey, either due to their poor recruitment to the trawling gear and their weak acoustic signal (age-1 or younger) or due to their behaviour (ages-3+) (e.g., more northerly distribution of older fish and highly aggregated shoals for a spawning migration), and the level of consumption of Capelin in the ecosystem is currently unknown. One participant asked about the crash in Capelin, which was explained by cold conditions, persistent changes in their biology, spawning later leading to a mismatch in early life with prey, and loss of productivity in the offshore.

The region monitors Atlantic Herring using a gill net survey, acoustic surveys (1982-2000, 2016), a telephone and log-book surveys, and commercial samples. Also, Atlantic Herring larvae are sampled in the Capelin ichthyoplankton surveys. Challenges and gaps for Atlantic Herring include estimating the spawning stock biomass to develop an assessment model, knowledge of their early life history, and monitoring bait removals.

Sand Lance are another important forage fish and are sampled in spring and fall bottom-trawl surveys. Biological data and some opportunistic acoustic data are collected. There is no dedicated survey for this species and interactions with Capelin are not known. There is an unused otolith collection that could be accessed.

Arctic Cod (*Boreogadus saida*), a non-commercial species, are monitored on the fall bottom trawl multispecies survey which provides some information on distribution and morphometric data. Acoustic data is collected but has not been analyzed to date. There is limited biological sampling on this species. There is no dedicated survey for Arctic Cod, and the bottom trawl sampling gear used may not be effective for this species.

3.17. Maxime Geoffroy, Memorial University of Newfoundland, St. John's

Dr. Maxime Geoffroy gave a presentation on acoustic surveys being used to monitor forage fish at the Atlantic-Arctic gateway. He started by providing several examples of the northward expansion of boreal species observed in Europe (e.g., Mackerel, Capelin), Greenland (Bluefin Tuna, *Thunnus thynnus*) and Canada (Capelin and Sand Lance). There is interest in developing new fishing grounds but more scientific knowledge is needed first, and a moratorium has been established on fishing in the central Arctic and Beaufort Sea. It is also unclear how competition with boreal species will affect the native Arctic species.

There are no systematic forage fish surveys off most of Labrador or in the eastern Arctic. The DFO AZMP survey collects acoustic data which offers some potential for monitoring, and there have been efforts to try to use opportunistic sampling to help design more directed surveys. There are also plans to deploy upward and downward looking acoustic moorings.

Maxime also described other work in the area including surveys being conducted during the construction of a large hydroelectric dam in Lake Melville. A survey near Makkovik is also planned to cover spawning of Capelin in summer 2018. New broadband echosounders are being explored which will likely increase capacity for species identification, and there is a lot of potential for ground-truthing by eDNA. He concluded by emphasizing the need for more baseline data on forage fish in the northwestern Atlantic.

Several participants had suggestions about monitoring including:

- Using moored stereo-cameras such as those being developed in Alaska that are triggered by movement
- Choosing locations of moorings so specific habitats are sampled

Maxime noted that ArcticNet has an EK60 and the data is accessible, noting that Capelin and Arctic Cod are the main targets.

3.18. Andrew Majewski, Freshwater Institute, DFO

Mr. Andrew Majewski presented information on forage fish studies in the western Canadian Arctic. He noted that forage fish data are sparse in the Canadian Arctic, but over the last 10 years research has improved, partly driven by interest in oil/gas expansion. Andrew described the importance of forage fish in the western Arctic, with, for example, dietary linkages to beluga whales. The water column in the Western Arctic is strongly stratified and each layer has a different fish assemblage. Arctic Cod are found throughout the water column and are the dominant forage fish species; however, they show ontogenetic changes in their vertical distribution. Also, Age-1+ Arctic Cod distribution varies spatially and temporally. Factors potentially affecting the biomass of age-0 Arctic Cod include the timing of ice-breakup and sea surface temperatures. Andrew noted possible ecosystem responses to a variable food supply demonstrated by changes in Beluga Whale (*Delphinapterus leucas*) diets. Capelin distribution was also described as a knowledge gap. Recent work has shown a high level of dietary overlap with Arctic Cod. Current marine ecosystem assessment surveys are collecting acoustic data as well as otolith microchemistry to examine life histories, thermal environments, and spawning habitats; genomics to identify populations; and tagging Beluga Whales to look into food-web linkages.

A question was raised as to whether Herring are becoming more abundant in less saline areas of the Arctic. Andrew noted that there are more Capelin than Herring, but that there used to be more Cod.

3.19. Gary Melvin, St. Andrews Biological Station, DFO

Dr. Gary Melvin was invited to describe forage fish monitoring in the Atlantic Region. Like other areas, he described a history of limited pelagic sampling. Monitoring has been focused on groundfish and bottom habitat, and has been linked to the industry. However, over the past 30 years, pelagic landings have increased relative to groundfish landings. Through the 2000s, it became understood that improvements in monitoring forage fish were needed, and in 2008 the Atlantic Zone Forage Working Group was formed. The working group's objectives were to establish an expert group, encourage interaction among public and private experts in the synthesis of information, promote the development of relevant performance indicators and reference points for trophic level productivity under an ecosystem based management approach, explore methodologies to estimate forage species requirement budgets for the ecosystem, and coordinate research. They identified four categories of forage species: 1) commercially exploited species, 2) non-commercially exploited species, 3) transient and migratory species, and 4) plankton (which they did not consider). In 2010 they developed a national working group to bring experts together and define key Canadian forage species, identify data gaps, and to promote monitoring and research using standardized methods. The conclusions and recommendations of the national working group were listed as:

- The forage theme is complex and extends far beyond a single species fisheries into the multi-species, inter-disciplinary world of seabirds, marine mammals, fishes, oceanography, and plankton.
- The working group recommended that effort initially focus on the key species in first two categories. These include Atlantic Herring, Mackerel, Capelin, shrimp, Sand Lance, Arctic Cod, and krill.
- The working group acknowledged the importance of many other forage species and will encourage efforts to address issues related to species in all categories and for developing fisheries.
- To initiate a Regional/National/International workshop on forage related issues from a science perspective. The workshop would operate under the general theme of "Forage and Fisheries in the Marine Ecosystem" with several theme sessions.

Unfortunately, due to funding restrictions, the working group was dissolved and the proposal never implemented. Now most initiatives are regionally dominated. He concluded that improved data collections for key forage fish are required if an ecosystem based approach to management is to be effective.

A question was asked about anadromous clupeids to which Gary responded that there is little to no information about them. There are still some small scale fisheries, but it is unknown how much they contribute to the ecosystem. There also used to be a substantial shad run but it is unknown what is happening with that species now. Gary also noted that there was no national effort to tie together forage fish issues.

3.20. Allan Debertin, St. Andrews Biological Station, DFO

Mr. Allan Debertin described the acoustic-based indices of forage fish from a bottom trawl survey in the Maritime Region. There is a long-term annual bottom trawl survey in the Maritimes region in the winter (1979-2017) and summer (1970-2018). Forage fish caught on these surveys can be described in terms of CPUE, but it is probably not a very reliable index because they are not well sampled. Examples of CPUE and distributions were shown for Atlantic Herring, Mackerel, Alewife (*Alosa pseudoharengus*) and Sand Lance.

Acoustic-based indices were developed in response to industry concerns that the bottom trawl surveys were not sufficiently sampling the water column for pollock. Acoustic and biological data were collected from commercial boats. There was a strong relationship between fish length and target strength which varies by species, enabling assignment of species composition to acoustic backscatter, and the calculation of a biomass index. There was lower estimate of variability for the acoustic-based index compared to trawl-based index of biomass. Next steps for this work will be more surveys, comparing indices from different vessels, species identification using acoustics, and linking distributions to oceanography.

Allan also reported on research in the Gulf Region where an annual summer trawl survey has been conducted since 2000. The sampling consists of oceanographic measurements, zooplankton sampling, and fish sampling.

A comment was made that catchability of forage fish in the bottom trawls might be more important than oceanography in contributing to variability around abundance estimates. Allan responded that it would be good to use the Gulf Region data to help address those issues.

3.21. Ian McQuinn, Institut Maurice-Lamontagne, DFO

Mr. Ian McQuinn presented information on multi-frequency acoustics for monitoring pelagic species in the Quebec Region. He began by emphasizing the ability of acoustics to sample the water column at multiple spatial scales simultaneously. The use of acoustics in the St. Lawrence Estuary resulted in improved euphausiid detection and classification which was then related to Blue Whale (*Balaenoptera musculus*) habitat. Multi-frequency classification was applied to fish with and without swim bladders, resulting in the ability to detect the redfish explosion two years before the groundfish surveys.

There are 7 large scale ecosystem surveys in the Gulf of St. Lawrence and they all collect acoustic data. Data collection and analysis includes calibration of the acoustic systems, installation of the equipment, and data processing and analysis. Ian listed the advantages of acoustics as non-intrusively sampling at several spatial scales simultaneously and effectively assessing the pelagic fish groups. Constraints include not being able to sample low density species, inter-mixed species, or the surface layer (upper 5-10 m).

A workshop participant asked if Sand Lance were always close to the bottom and Ian replied that they were. Another participant asked about the range in bottom depths where Sand Lance were found, to which Ian replied that they are found up to about 150 m depth, but they are trying to build maps with bottom type; he has been finding that silt content limits the distribution of Sand Lance. Most Sand Lance were found in the upper estuary where bottom depths are 60 to 80 m.

3.22. Nadia Ménard, Saguenay-St. Lawrence Marine Park, Parks Canada

Ms. Nadia Ménard summarized Parks Canada's monitoring of pelagic prey species in the Saguenay – St. Lawrence Marine Park in the St. Lawrence Estuary. This area is important habitat for spawning forage fish and is a whale feeding area. There has been significant research on euphausiids in the area, but there are large data gaps on pelagic forage fish in the estuary. They have been conducting weekly acoustic surveys to help answer questions about forage fish population trends, linkages to declines in Belugas Whales, and to help understand the role of Sand Lance in the food web.

Acoustic data were collected with a Simrad EK60 multi-frequency acoustic system on transects where predators were also recorded. Data were classified using Echoview and groundtruthed with line fishing, towed nets, and trawling. Underwater cameras were also tested, but found to not work well because of water turbidity and current. Sand Lance have been difficult to catch so eDNA was tested as an alternative. Markers were developed and the quantitative PCR method was used, yet little evidence of Sand Lance was found. Reasons for this may be related to interspecies differences in DNA release or mixing in the water column.

Participants discussed the reasons for the low levels of Sand Lance in the eDNA data. Sand Lance may be sloughing in the sand and not releasing much DNA into the water column. More work is needed on DNA release rates. Another option would be to use presence/absence rather than trying to quantify Sand Lance. One participant suggested that there may not be Sand Lance in the areas sampled, but Nadia and Ian McQuinn both agreed this is not the case. Monitoring with an ROV is another option, but they are difficult to use in high current areas and not very useful for fish present in the water column.

Nadia provided tables on the species biology for her region (Appendix D, **Error! Reference source not found.**).

4. DISCUSSION OF SURVEY METHODS

After lunch on day two, a group discussion was held on the various methods for surveying forage fish. Jennifer Boldt facilitated the discussion while adding discussion points to a table on the advantages and constraints of each method (Table 1). Many of the methods share similar advantages, constraints, and solutions (and are not repeated for all rows in Table 1, rather they are marked with an asterisk). For example, many methods can be used to sample multiple forage species, but each method does not sample all forage fish species. A solution to this constraint is to use a combination of methods and tools.

All sampling methods have advantages and constraints that vary with the location, spatial scale, species, and objectives of the study. Generally, net sampling can provide information on the biomass and distribution of multiple fish species and size classes as well as biological samples (Table 1). Many of the net sampling methods have similar constraints, such as fish avoidance of the net, herding or scattering of fish by the net affecting catchability, nets may be selective (e.g., size selectivity), and fish behaviour or response to nets may vary by species or by the presence of other species (Table 1). All net sampling (including commercial fisheries) are limited by depth; for example, large vessels cannot deploy bottom trawls and midwater trawls in shallow, nearshore areas, bottom trawls do not sample the water column well, midwater trawls miss the top ~4 or 5 m, purse seines and gill nets only sample a portion of the water column (to the depth of the net), and beach seines are limited to unobstructed beach sites and do not sample deep water (Table 1). Acoustics are a valuable tool for multiple pelagic species, however it can miss portions of the water column (surface and near-bottom), it needs verification of fish species and size, and fish may avoid the vessel. Snorkel and SCUBA surveys have the advantage of being non-destructive, but have the issue of fish avoidance and difficult fish identification. Egg and larval surveys can provide quantitative estimates of abundance for multiple fish species that have pelagic eggs. Although identification of egg and larval fish can be difficult, sampling can cover a broad geographic range, samples are relatively easy and inexpensive to collect, and sampling can be added to existing surveys. Sampling could also be conducted at multiple times each year to track seasonal trends and/or species that spawn over extended periods or at different times of the year. Beach sediment sampling also targets the egg phase and provides a presence-index for shore spawners, but does not provide an abundance estimate, nor disprove spawning. Beach sediment mapping provides an indicator of habitat suitability, but not forage fish presence, while eDNA provides an indicator of presence, but no biological sample or abundance estimate (at the date of writing this document). Other survey techniques discussed include aerial surveys, optical surveys, bottom grab surveys (e.g., Van Veen grab), tagging, moored acoustics, and more.

To resolve constraints of sampling, the group recommended utilizing a combination of tools. For example, acoustic data can be verified using multiple tools, such as midwater trawls, in-net cameras, stereo drop cameras, and multiple opening and closing nets (e.g., multinet) to improve our ability to determine the distribution and abundance of forage species, while occasionally collecting biological samples for information on length, weight, diet, stable isotopes, etc. In addition, autonomous platforms could address the blind zones not well sampled with down-looking echosounders. Midwater trawl nets can be equipped with an apron to capture the top 5 m of the water column and the use of in-net cameras can help resolve net catchability issues. Some surveys (e.g., in Norway) conduct midwater trawls in a circular path, so the net is towed outside of the ship's wake, thereby minimizing fish vessel avoidance. Although bottom trawl nets are not the best tool to sample many forage fish species (particularly those in the water column), quantifying groundfish diets could provide an indicator of the abundance of their forage fish prey. Also, concurrent collection of acoustic data could help verify if bottom-oriented fish are being missed by the net or if certain species are not well-sampled by the net. Another recommendation was the development of dedicated ichthyoplankton surveys to assess large-scale trends in abundance and recruitment for those species that are sampled, and to understand linkages between climate, oceanographic conditions, eggs, larvae, and their predators and prey. Finally, for all fish surveys, it is recommended that zooplankton and environmental data be collected along with fish data to better understand fish distribution, trends in abundance, and trophodynamics.

General survey considerations were also discussed among workshop participants. Suggestions included standardizing sampling protocols and survey designs, conducting simulations to help identify sampling designs and to understand how the survey scales up to a larger area, creating metadata archives for the surveys, and trying to standardize gear across areas where possible. It was stressed that changes to survey design and technology should be noted in databases and cruise reports. Another consideration is that biases may be introduced when using survey data for a species or life history stage other than the intended target(s). Analysts need to take this into account.

Table 1. Advantages, constraints, and solutions of methods for monitoring forage fish populations. Those marked with an asterisk apply to multiple methods and solutions. Acronyms defined below table.

Monitoring method	Advantages	Constraints	Solutions/Considerations/ Recommendations
Bottom trawl surveys (groundfish, small mesh)	- Multiple species (aimed at groundfish but catches other fish such as Eulachon) - Might be good sampler of benthic-oriented forage fish - Information on fish distribution and biomass - *Provides biological samples - Groundfish diets as samplers of prey forage fish	- *Depending on vessel size may be limited in shallow/coastal waters - Limited by bottom types (e.g., no rocks) - Likely underestimates pelagic forage fish - *May not account for vertical shifts in species distribution - *May not account for spatial shifts if fish move outside of fixed survey area - *Caution: applying to non-target species; index bias; presence/absence can also be biased - *Net catchability (size selection, herding, net avoidance); can be species-specific	- *Use combination of methods and tools (e.g., acoustic trawls surveys, sensors to assist, use in-net cameras) - Examine diet of groundfish as an index of prey forage fish abundance - Deployment of smaller gear and doors off of smaller vessels to get nearshore - Collaborate with industry to develop new tools, surveys (although, may only be of interest for commercially important species)
Midwater trawl nets (midwater and surface)	- Multiple pelagic fish species - A valuable tool to verify acoustic echosign - *Provides biological samples - Information on fish distribution and biomass - Predators diets as samplers of prey forage fish	- Misses 0-5 m of water column - *Affected by currents, tides - *Depending on vessel size may be limited in shallow/coastal waters - *May not account for spatial shifts if fish move outside of fixed survey area - Not good samplers of benthic forage fish - *Net catchability (size selection, herding, net avoidance); can be species-specific	- *Use combination of methods and tools (e.g., acoustic-trawl surveys, sensors to assist, use in-net cameras) - Apron on trawl to capture top of water column - Consider that fish avoidance may not be an issue at different life history stages (i.e., some fish may not avoid the net when they are spawning or near spawning)

Monitoring method	Advantages	Constraints	Solutions/Considerations/ Recommendations
		- *Patchy, non-randomly distributed fish difficult to sample (e.g., sardine)	
Experimental gillnets	- Sample a wide range of sizes - Easy replications over time	- Size selective - Rely on fish behavior (swimming activity) - Target limited area	- Use in well-designed experiments that are suitably targeted at specific areas/species.
Beach Seining	- Information on beach spawners (e.g. Sand Lance and Surf Smelt) and nearshore species - *Live samples	- Limited by adverse weather - Difficult on rugged coastlines - Depth and habitat limited - Fish avoidance - Boom or bust catches (e.g. only at certain times of day for some species) - Small area sampled in one sampling event	- See AFS for standards
Purse seines	- Sample nearshore - *Live samples	- Depth limited - Small surface area sampled	- *Use in combination with other sampling methods and tools
Egg and larval surveys (Bongos (vertical, oblique), MOCNESS)	- Useful for tracking population trends for multiple species - Flexible to inconsistent sampling methods - Can be more accurate or less costly for some species - Can use multiple small boats to get broad spatial coverage - For multi-seasonal surveys, can get status and trends of multiple species - Data are useful even if not correlated with adult abundance (ecosystem)	- Can be difficult to identify species in their early life stages - Often not correlated with adult abundance, so seen as not useful by some managers - Net avoidance by larval fish - Can be affected by freshwater discharge	- Use multiple small boats to get broad spatial coverage - Net and mesh size selection may help minimize avoidance (MOCNESS vs Bongo vs neuston nets vs CUFES) - Consider oblique vs. vertical net hauls (vertical may have more net avoidance) - Bongos from bow of vessel without wire disturbance - Complement with dedicated ichthyoplankton surveys

Monitoring method	Advantages	Constraints	Solutions/Considerations/ Recommendations
			- Integrate ichthyoplankton surveys beyond forage fish (e.g., sablefish recruitment prediction)
Acoustic surveys	- Can be used nearshore (small vessels) and offshore (large vessels) - Multispecies including smelts - Produces biomass estimates - Broad, continual spatial coverage	- Down-looking acoustics do not sample the upper part of the water column (blind zones), or close to the bottom. - Should be validated with trawl data - Does not sample low density species or intermixed species as well - Weather-dependent - Potential avoidance in surface waters that vessel disturbs - Detectability may vary by species - Expert required to interpret data	- Use sonar to assess what is missed in surface dead zone - Use a variety of complementary tools to help interpret acoustic data (in-net cameras, stereo-drop-cameras, MOCNESS, trawls, etc.) - Autonomous platforms to address blind-zones (surface, bottom); upward-looking sounders - Quality assurance for consistency across platforms - Use smaller platform and systems to get nearshore
Snorkel surveys	- Used for species like Pacific Sand Lance - Non-invasive	- Depth limited - Can be difficult to accurately identify species - Fish avoidance - Weather-dependent	- *Use in combination with other sampling tools and methods.
Beach sediment mapping (visual)	- Habitat suitability for beach spawners (Sand Lance and Surf Smelt)	- Not a record of actual presence - Labour intensive; lack of funds	- Community engagement
Beach sediment sampling,	- Suitable for beach spawners (e.g. Sand Lance and Surf Smelt) - Detects eggs	- Does not provide estimates of abundance - Does not disprove spawning - Storms affect sampling	- Improved acoustic bottom sampling (multibeam surveys) can help focus effort and target areas of interest - UAV (drone) aerial imagery and TEK GPS/GNSS ground surveys can

Monitoring method	Advantages	Constraints	Solutions/Considerations/ Recommendations
mapping, modeling	- Identifies the range of sediments associated with specific species - Science-based mapping for land-use planning	- Grab samples achieve a 30% capture rate - Model limited by data inputs (e.g. high res acoustic data vs. charts) - Limited BC expertise in egg verification	provide improved resolution and precision; validated data can be used to identify potential beach spawning habitats and produce tools like Digital Elevation Models that can monitor sea level rise and other impacts
eDNA	- Cost-effective, sensitive, non-invasive, rapid - All species presence - No net avoidance	- Biomass estimates not yet standardized - eDNA quickly disperses in marine environment ; unknown degradation rates - Currents may move eDNA to areas where the species does not occur - No biological sample obtained	- This is a quickly developing field that holds promise for resolving some of the constraints identified.
Fisheries data	- Multiple species - Can be sampled onboard or dockside - Can represent large spatial and temporal coverage - Can be used to describe the size, age, spawning component, predator condition, etc - Can be useful for management	- May be subject to biases (i.e., non-randomized sampling) - May not be proportional to abundance because of changes in catchability - Affected by regulations and fishing gear restrictions (e.g, mesh size)	- Use with caution
Aerial surveys	- Used to estimate school biomass	- Limited by sea condition, the presence of cloud or fog cover - Needs ground truth data - Expensive	- Use and test against other methods under experimental designs (e.g. acoustic vs aerial surveys in same area and time) - Use of drone surveys

Monitoring method	Advantages	Constraints	Solutions/Considerations/ Recommendations
- Other methods mentioned include: optical surveys (cameras, stereo cameras, in-net cameras, drones, ROV), DIDSON sonar and other imaging sonars, tank studies, tagging, van Veen grabs of sediment with fish (e.g., Sand Lance), stable isotopes (in prey, forage fish, predators), light traps, predators as samplers, Lampera net, moored echosounders.			

AFS = American Fisheries Society
CUFES = Continuous, Underway Fish Egg Sampler
GPS = Global Positioning System
GNNS = Global Navigation Satellite System
MOCNESS = Multiple Opening/Closing Net and Environmental Sensing System
ROV = Remotely Operated Vehicle
UAV = unmanned aerial vehicle

5. SUBGROUP DISCUSSION -DAY 2

In the afternoon of Day 2, participants were split into two sub-groups and asked to:

1. List data types with specific source examples that can inform forage fish assessment, and
2. Identify strategies for data: compiling, assembling, centralizing, and distribution.

After a 45 minute session, the two subgroups reported on the outcomes of their discussions.

Figure 2. Sub group discussions at the Forage Fish workshop.

5.1.Sub-group 1 report

Todd Sandell took notes and reported on Sub-group 1 discussions:

Existing data sources:

- Seabird Data – including colony surveys (Hudson Bay, Arctic, data back to 1970s), bird diet, counts, eBird, North Pacific pelagic seabird dataset, proportion by biomass. Data tend to be fragmented by month of rearing which might make using the data more challenging, but there is also information on the growth of forage fish.
- Stomach content data from DFO pelagic ecosystem and salmon surveys. So far diet data is not collected on DFO and WDFW groundfish surveys (except for 2014-2016).
- Seal/sea lion/whales scat analysis, including eDNA: there are historical samples in freezers, ice cores, and other archived samples that have potential to provide information on forage species.
- Egg and larvae surveys. CALCOFI (west coast), east coast-NOAA ("MARMAP", has changed names), but these data are difficult to access.
- Aerial surveys of Pacific Herring spawn in Alaska.

- Fishery data (confidentiality is a consideration).
- Columbia River Plume surface trawl study, 1998-ongoing.
- Oceanographic time series data including physical data (e.g., from CTDs), Oceans Network Canada data, upwelling indices (DFO, Universities, NOAA), satellite data (CSA and NASA), gliders, autonomous data collection.
- Fisheries acoustic data – at DFO, there is a need for back up and modernization of the data storage, quality control, and dissemination. A Bluefin Tuna data paper was published by re-analyzing Herring acoustic data, proving the usefulness in properly archiving data.
- eCapelin, The Capelin Observer Network and the St. Lawrence Global Observatory
- LEO network, a large citizen science platform (local environmental observer network).
- Citizen science data.

Strategies for data and accessibility:

- All US data collected by the government is to be available to the public within three years of collection. Data generally has to be requested. The National Science Foundation is doing something similar. The USGS provides data accessibility by requiring data to be published along with published manuscripts. DFO scientific data are subject to full and open access within two years of being acquired or generated.
- Metadata is important for the interpretation of the data.
- Universities have data too.
- Cruise reports.
- Cloud storage as a potential solution.
- Other examples of programs making data accessible include :
  - Gulf watch (Alaska program)- broad platform (AOOS – Alaska Ocean Observing System) is the data repository for public and private input and output. There are research workspaces for collaboration between Principal Investigators.
  - NANOOS (Northwest Association of Networked Ocean Observing Systems) and AOOS are coordinated at a national level but there is also the global equivalent GOOS (Global Ocean Observing System); Some of the DFO Institute of Ocean Sciences data are part of GOOS.
  - CTD data for DFO west coast is available online.
  - DFO State of the Pacific Ocean reports.
  - The Pacific Salmon Foundation has data available online on their Strait of Georgia Data Center.

Some issues were noted; for example:

- Commercial fisheries data have privacy and/or confidentiality issues.
- Danger of misinterpretation and misuse of data when made available to the public.
- Issues with “releasing” processed acoustic data; there is a need to standardize data quality assurance and control.

5.2.Sub-group 2 report

Maxime Geoffroy reported on Sub-group 2 discussions:

Existing data sources:

- Stomach content data from seabirds, mammals, and predatory fish. Universities and government agencies have this type of data (e.g., UBC and DFO). Data on occurrence of forage fish in predators along with predator behavior information would be helpful.
- The National Acoustic Data Archive (NADA) should be a repository for all DFO-collected acoustic data.
- Opportunistic data collected on ferries and other boats.
- Need to digitize all graphs and tables from the pre-internet era.
- Underwater imaging datasets.
- Coastal geological data and bottom type mapping – e.g., for Sand Lance habitat.

Strategies for data and accessibility:

- The ideal scenario is to centralize data in one database and make it available on the Cloud
- Metadata are important and need to be made available, as they provide links to researchers and data sets.
- Use existing database repositories including AXIOM (Axiom Data Science is an informatics and software development firm focused on developing scalable solutions for databases), Oceans Networks Canada, Google. Google has allocated funds and staff to work with scientists to make data available, especially remote sensing data.
- There could be one central repository with links to other repositories (even if data is not available, it identifies what data exist).
- Researchers could rate the confidence they have in their datasets so that people have an idea of how to utilize them.

Some issues were noted; for example:

- There are issues when providing processed data vs. raw data.
- There are risks associated with having data completely open-source (e.g., misinterpretation)

5.3.Combined discussion

Following the reporting by sub-groups, the group discussed additional issues and common themes. Participants agreed that having one data repository (or metadata repository) would be really helpful. There are a lot of websites and online data, and a repository would help people find what is already available. One challenge will be to identify the data that is not already available. Another challenge will be standardization of data formats, because different groups use different platforms and/or protocols.

Having a geoportal to show where data exists and where it can be accessed would be particularly useful. The National Acoustic Data Archive (NADA) has been developing a geoportal for acoustic data. One issue however, was that DFO was not prepared to deal with a large amount of data. Optical data (e.g., camera images, video) are also voluminous, creating storage issues. Old data need to be saved and archived regardless of these issues; for example, Jennifer Boldt is archiving data from historical Pacific Herring surveys. DFO's marine spatial planning group has a geo-referenced database (contact is Joanne Lessard). The plan is that the database would connect to other marine databases and would be used for responding to emergencies such as oil spills. It might be an option to include forage fish data here as well. The Ocean Protections Plan (OPP) is working on geo-referenced data management as well (contact is Steven Schut). One option might be to include metadata and a contact, so that detailed data can be provided upon request.

The group discussed the benefits of having a list of data already available from workshop participants and that we should establish a network of people working on forage fish. One participant suggested Basecamp (https://basecamp.com/) as a good platform for such a network.

The group then discussed who in DFO will be interested in the results of this workshop, and whether there would be funding allocated for forage fish research. Workshop recommendations, with linkages to government priorities, could be put forward to the Science Executive Committee. Also, the Pelagic Integrated Ecosystem Science (PIES) team could follow up with some of the recommendations from the group.

6. SUBGROUP DISCUSSION - DAY 3

The third day of the workshop began with a review and refinement of topics for subgroup discussions. The following subgroup discussion topics were put forward:

1. Implementation of complementary approaches.
    - List of complementary sampling that can be integrated into existing programs (e.g., DFO, BC, ECCC, Parks Canada, Indigenous, Citizen Science).
    - How can we implement these? Requirements / Standardization?
    - Qualitatively: How difficult is it to implement them? What level of resources is needed to implement them?
2. New efforts or sampling programs to monitor forage fish.
    - List of new time-series that would best address identified gaps, along with their advantages and constraints.
    - Identify the priorities, as well as hypothesis-driven objectives.

Participants agreed that a good first step for addressing the forage fish gap was to incorporate new tools into existing surveys (e.g., turn on acoustic sounders on all surveys). Issues with this include the large amount of extra data collected and calibration of systems; however, even organizations like Ocean Networks Canada have issues with handling large amounts of data, but it is something to plan for and should not be a barrier to collecting data. Another step to addressing gaps in forage fish data is to collect additional complementary data (e.g., zooplankton) during existing surveys. Engaging Indigenous communities in sampling programs could include the provision of new tools and/or training (e.g., eDNA sampling).

The importance and specificity of objectives were discussed. Key issues and objectives at the National and Regional levels need to be identified. It was noted that in Alaska, the initially identified Gulf Watch objectives evolved over time as scientists gained knowledge about forage fish. One participant referred to a risk analysis project done for Capelin in the St. Lawrence (Giguère et al. 2011); vulnerability assessments are a National priority and should address forage fish.

Following this discussion, participants split into two groups for about 45 minutes.

6.1.Sub-group 1 report

Todd Sandell took notes again and reported on Sub-group 1 discussions:

Complementary sampling that can be added to existing programs include:

- Seabird programs interested in forage fish as prey. Data on condition, disease, etc. can be used to inform seabird and forage fish researchers; however, predators can be selective and this may affect the data produced.
- Gulf of Alaska groundfish - examine the pelagic phase of groundfish species (larval fish sampled with Bongo nets); how do groundfish and forage fish compete; what are the predator/prey interactions and how does that impact groundfish recruitment? Examine salmon diets, for prey larval groundfish species.
- Diet studies are a good way to link the entire ecosystem through trophic interactions (an integration approach). Suggestions for data collection include collecting diet data at sea; if not at sea, samples could be preserved for later laboratory analyses (e.g., freeze stomachs, or preserve them in ethanol, which enables genetic analyses as well). Dr. Jason Link (NOAA Fisheries) conducted a study examining the value added of conducting stomach analysis at sea.
- Genetics are an easy addition to most sampling programs; samples can now be dried on filter paper. This can also include DNA barcoding of stomach contents.
- Add oceanographic sampling to examine environmental drivers of forage fish recruitment and responses to climate change.
- Collaborate with industry to collect data (e.g., ferries, power plants, oil rigs, fishing boats).
- Examine physical and zooplankton data to explore the top down vs. bottom-up drivers of fish productivity.
- An alternate approach could be to focus on geographic areas (all ecosystem components) rather than species or guilds to encourage cross-pollination between specialists (birds/fish/zooplankton, etc.). For example, WCVI scientists of all disciplines could attend a region-focused meeting rather than attending only discipline-specific meetings. DFO’s State of the Pacific Ocean meeting is an example of this type of integration.
- Develop a forage fish index as a way to disseminate this information to other programs. Ecosystem indicators may help resolve this separation of programs (and help integrate ecosystem considerations into single-species stocks assessment programs). Forage fish are often described as too “patchy” to worry about; a solution to this is to record acoustic data during all surveys. Opportunistic surveys will however not replace dedicated surveys, and there may be specifically a need for more dedicated acoustic surveys in known forage fish areas. Timing is another issue- many forage fish species are not present year-round.

- Habitat description may be informed by research on other species; for example research on "whale feeding areas" may yield data on forage fish habitat.
- Cameras are increasingly cheap to deploy and can provide valuable information.

Standardization issues:

- Diet analyses – there is a technical report on recommended diet sampling protocols for DFO's Pacific region (King et al. 2018).
- Dietary genetics – there may be a need to neutralize digestive enzymes before drying samples.
- Ichthyoplankton time series would be useful; however, some regions do not collect these data and of those that do, different nets (mesh, length) and deployment methods are used. There is a need to compare differences and standardize protocols; other programs may have solutions (e.g., CALCOFI).

Time series:

- Seabirds time series exist from all around the Pacific. Seabirds are selective, so their diet may not by indicative of the fish community composition, but can provide information on species presence and fish biometrics.
- Pinnipeds scat time series (Pacific) and stomachs content analyses (East coast) are up to 50 years long.
- Ichthyoplankton:
    - West coast – a high spatial resolution survey is an important priority; currently, there are no programs in place, outside of what is collected in the zooplankton samples (mostly from BONGO nets).
    - Newport line (OR, USA) – the ichthyoplankton survey time series is 25+ years long and now in peril due to funding cuts.
    - East coast – there have been previous sporadic time series on ichthyoplankton.

6.2. Sub-group 2 report

Linnea Flostrand reported on Sub-group #2 discussions. In terms of implementing complementary approaches the group discussed the need of a plan and to establish the context and format of the data before it is collected.

Complementary sampling that can be added to existing programs and some issues include:

- Diet
    - Fish diet analyses.
    - Fatty acids and isotopes have potential because they are inexpensive and just require a tissue sample.
    - Other possibilities include sampling fish from recreational fishers, subsistence catches, port sampling, and seabird diets.
- eDNA
    - Efforts are underway to ground truth and validate eDNA from water collections.
    - The role of ethanol in preservation was discussed.
    - There is a need to extend barcodes to forage fish species.
    - Inter-calibration among other surveys would be beneficial.

- Traditional knowledge
    - Effective engagement with Indigenous communities: youth involvement, information from elders.
    - Information from middens, which have been useful for understanding historic presence of anchovy.
    - Ocean Drilling Program; Verena Tunnicliffe (University of Victoria) conducts paleoecology research and may be a good contact.
- Distribution maps
    - Build species distribution maps from Alaska to California, integrating government, traditional knowledge, and university data.
    - Distribution maps could be updated with changes to climate, and may be of interest to DFO's Ocean Protection Plan (OPP).
- Egg and larval fish sampling
    - There is a need to identify gaps in egg and larvae sampling areas and seasons.
    - Other programs, such as the juvenile salmon surveys, could potentially incorporate this into their sampling protocols.
    - The multinet and/or MOCNESS could be used, when it is feasible.
    - Other nets, such as BONGO nets, could potentially be towed obliquely to sample ichthyoplankton more efficiently.
    - There is a need to standardize gear and sampling methods used (e.g., mesh sizes), with expert review on methods for fish and larvae collection. Larval surveys have been used on the east coast by DFO for predicting Capelin spawner biomass. The abundances of larvae emerging from beaches are used to predict recruitment. This could be explored for Sand Lance and Surf Smelt in BC.

6.3.Combined discussion

Most of the subgroup discussions were based on complementary approaches that could be added to existing programs. The workshop co-chairs then asked the group for ideas about new sampling programs. This prompted discussion on existing knowledge gaps – the main gap being fish eggs and larvae surveys; funding for this type of monitoring seems to be one of the main constraints.

One approach would be to collect samples (e.g., ichthyoplankton, zooplankton, eDNA), even if there are no funds to process them immediately. It was noted, however, that this does not resolve the need for capacity-building of taxonomic identification skills and eDNA analyses, to enable continuity in laboratory analyses. In addition, data analyses and interpretation require additional time. Lab analyses for eDNA are expensive ($70-$100/sample), however if stored at -80°C, samples can last for long periods of time (>10 years).

There is a need to identify large-scale science objectives and illustrate what DFO gaps they fill. For example, understanding the climate forcing on forage fish dynamics could be partly met by larval fish sampling programs. This would improve our understanding of salmon populations and help with early forecasting for groundfish. Another example is to identify forage fish spawning habitat, which could be done by examining species distribution changes through vulnerability assessments. This links to OPP, baseline monitoring, marine spatial planning and Marine Protected Areas (MPAs), and could incorporate Indigenous communities along the coast. It was also acknowledged that forage fish species link directly to the Species at Risk Act (SARA), for example via the connection of Sand Lance to Chinook Salmon to Killer Whales, or Surf Smelt to Cutthroat Trout. Forage fish are central to marine ecosystems and will be undoubtedly affected by climate variability (as exemplified by Arctic Cod), stressing the need for more dedicated research and monitoring.

7. CONCLUSIONS AND RECOMMENDATIONS

Scientists from DFO, the US, Universities, and non-government organizations have identified a lack of information about forage fish that is needed for understanding marine ecosystems. This knowledge gap exists in all DFO Regions, especially in the Arctic, subarctic, and in coastal areas, which are undergoing significant changes with global warming. DFO's mandates, priorities, and policies require the assessment of bycatch species and ecosystem adaptations to climate change. Incorporating ecosystem needs for forage fish into stock assessments and addressing trophic linkages will reduce the uncertainty in ecosystem modeling and in forecasting effects of climate change.

The Lenfest (http://www.lenfestocean.org/) Forage Fish Task Force, a group of thirteen preeminent scientists with expertise in a wide range of disciplines, conducted a comprehensive examination of the science and management of forage fish populations (Pikitch et al. 2012). They found that conventional management can be risky for forage fish because it does not adequately account for their wide population swings and high catchability. It also fails to capture the critical role of forage fish as food for marine mammals, seabirds, and commercially important fish such as tuna, salmon, and cod. The Lenfest report recommends stringent measures in catch rate reduction and a precautionary approach to the management of forage species and ecosystems. DFO's Ecosystem Research Initiative also highlighted key uncertainties in applying an ecosystem based approach to management, including uncertainties about forage fish distribution and use of nearshore habitat (DFO 2013). By addressing knowledge gaps and increasing science programs and monitoring on forage fish species, DFO has the opportunity to become a world leader in this field.

Workshop participants identified knowledge gaps, objectives, research priorities and opportunities (Table 2), as well as linkages to DFO's mandates. Complementary sampling or additions to existing surveys would improve information about forage fish; however, it will not fill all knowledge gaps. Surveys that are designed for one or more commercially important species may not sample forage fish sufficiently; therefore, new and focused research is required.

Table 2. Knowledge gaps, objectives, and research priorities and opportunities that link to DFO's mandates and priorities.

Knowledge gap	Objectives	Research priority or opportunity
Effects of climate and oceanographic forcing effects on fish	Identify factors affecting forage fish abundance and distribution (spatially and by depth); enable the forecast of adult biomass of commercially important fish species as well as forage fish species	Region-wide ichthyoplankton surveys (e.g., standardized; multinet) and adult forage fish abundance surveys
Spawning habitats of forage fish	Identify spawning habitat of forage fish; link to species distribution changes and vulnerability assessments to provide baseline coastal monitoring in collaboration with Indigenous communities; provides advice to the Fisheries Protection Program (FPP) and OPP that cannot currently be provided.	Beach spawning surveys; habitat suitability modelling
How does the forage fish community support resiliency and biodiversity of MPA networks?	Identify forage fish communities, diversity, and trophic interactions for use in marine spatial planning.	Dedicated acoustic surveys for forage fish (with sample verification); also surveys of nearshore and spawning habitats, for coastal MPAs.
Benthic forage fish habitats	Identify spawning habitats of other forage fish that have a benthic life history (e.g., Eulachon, Sand Lance).	Conduct surveys of benthic habitat (use new tools, such as bottom-type mapping or ROVs); conduct habitat distribution modelling
Bycatch mortality of unassessed species	Determine mortality associated with unassessed species; apply stock assessment tools to assess stock status of non-commercially important species	Modelling, MSE (Management Strategy Evaluation).

DFO Mandates, priorities, and programs that would be addressed by these research activities include:

1. Engagement with Indigenous people
2. Aquatic Climate Change Adaptation Services Program (ACCASP)
3. Ocean Protection Plan (OPP)
4. Fisheries Protection Program (FPP)
5. Marine spatial planning; marine protected areas (MPA)
6. Ecologically or Biologically Significant Areas (EBSAs)
7. Species at risk (SARA)

8. Data poor species
9. Vulnerability assessments
10. Ecosystem based management
11. Oil spill readiness
12. Climate change impacts
13. Forage fish policy
14. Ecologically significant species (ESS)

Adding complementary sampling to existing surveys was identified as an opportunity to collect more information on forage fish species. Detailed suggestions for complementary sampling are listed in Section 6.1 and 6.2. There are likely other opportunities, such as integrating the pelagic ecosystem into MPA planning, baseline monitoring of diseases and parasites, and transferring knowledge of shoreline spawning habitat assessments to link with OPP, and baseline monitoring in collaboration with Indigenous communities. There are issues with adding on complementary sampling to existing programs or using data from existing programs for species other than those targeted. Survey designs should be reviewed for efficiencies/deficiencies in sampling forage fish species. Finally, participants assembled a list of recommendations (below) and action items resulting from this workshop (Appendix E).

Recommendations:

1. Develop a formal working group on Forage Fish, with support from the Science Executive Committee. This would require a strategic plan, Terms of Reference (TOR), and reporting requirements. It would involve DFO and partners (ECCC, ENGOs, Academia, Indigenous communities, NOAA, Parks Canada, etc.). Initial action items and terms of reference for this working group should be to:
    a. Develop concrete TORs.
    b. Share information and data on forage fish species; prioritize data gaps to be addressed.
    c. Evaluate and compare approaches, and identify best practices for assessing forage fish species.
    d. Develop hypothesis-driven studies and develop research proposals.
    e. Identify complementary tools, new technologies, and methods that could be incorporated into existing programs.
    f. Meet regularly (potentially develop a regular forage fish summit; or Canada-US technical meeting, as done for the groundfish technical group) and provide an annual (or regular) report.
    g. Compile list of publications and output products from the working group.
2. Identify and conduct sampling methods that can be easily implemented in existing programs, providing added value information for the target species being surveyed but also for forage fish. For example, conduct diet analyses on survey-caught fish to add value to current research surveys and provide an index of forage fish abundance.

Acoustic data from scientific echosounders should be collected whenever and wherever possible.

3. Identify new methodologies that may have higher cost burdens but have a lot of potential; organizations such as Ocean Networks Canada may be able to help with data processing and management.
4. Collate historical data and perform literature reviews at regional levels, including historical baseline data and in-depth data mining (e.g., digitizing old reports). Regional literature reviews may have to be done on a species-by-species basis. It is also important to highlight the species that have no or little data.

8. CLOSING REMARKS

The co-chairs thanked participants and appreciated the interest from different DFO Regions and neighboring states. New connections and collaborations were established that would not have occurred without this workshop. In the future, a forage fish working group would encourage more collaborative research to 'fill the forage fish gap' and improve DFO's ability to implement its mandate of an Ecosystem Based Approach to Management.

Figure 3. Co-chairs Jennifer Boldt and Stéphane Gauthier

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APPENDIX A. LIST OF PARTICIPANTS

Table A1. Workshop participants and their affiliation.

Name	Affiliation
Allan Debertin	DFO, Maritimes Region
Andrew Majewski	DFO, Central and Arctic Region
Brian Hunt	University of British Columbia
Caihong Fu	DFO, Pacific Region
Chrys Neville	DFO, Pacific Region
Cliff Robinson	DFO, Pacific Region
Doug Bertram	Environment Canada
Doug Hay	DFO, Pacific Region
Gary Melvin	DFO, Maritimes Region
Hannah Murphy	DFO, Newfoundland and Labrador Region
Hilari Dennis-Bohm	DFO, Pacific Region
Ian McQuinn	DFO, Quebec Region
Ian Perry	DFO, Pacific Region
Jackie King	DFO, Pacific Region
Jennifer Boldt	DFO, Pacific Region
Linnea Flostrand	DFO, Pacific Region
Mark Hipfner	Environment Canada
Martin Godefroid	DFO, Pacific Region
Matt Baker	North Pacific Research Board, USA
Maxime Geoffroy	Memorial University of Newfoundland
Mayumi Arimitsu	United States Geological Survey, USA
Nadia Ménard	Parks Canada
Rachel Wang	World Wildlife Fund Canada
Ramona de Graaf	BC Shore Spawners Alliance
Shani Rousseau	DFO, Pacific Region
Stéphane Gauthier	DFO, Pacific Region
Stephanie King	Sea This Consulting
Strahan Tucker	DFO, Pacific Region
Todd Sandell	Washington Department of Fish and Wildlife, USA
Tyler Zubkowski	DFO, Pacific Region

APPENDIX B. MEETING AGENDA

Filling in the Forage Fish Gap
Pacific Biological Station (PBS), Nanaimo, 13-15 March 2018
Internet access is NOT available at PBS

13 March 2018		
09:00 - 09:30	Arrivals, Introductions, Scope and structure of the workshop	Jennifer Boldt and Stéphane Gauthier
09:30 – 10:15	Overview of Forage species in BC; knowledge gaps, methodologies	
Coffee break		
Panel of invited experts		
10:30 – 11:00	Forage fish sampling in Alaska and studies of Pacific Sand Lance in the San Juan Islands, WA	Matt Baker
11:00 – 11:30	Pacific Herring, Surf Smelt, and the Rest-Assessment and Data Gaps of Forage Fish in the Southern Salish Sea	Todd Sandell
11:30 – 12:00	Alaska: lessons learned and recommendations for detecting change in non-commercial prey populations	Mayumi Arimitsu
Pacific Region status on forage fish research/monitoring		
12:00 – 12:20	eDNA and other initiatives	Brian Hunt
Lunch break (not provided)—the cafeteria has sandwiches, soup, salads and a hot lunch special (<$12), cash only (Canadian)		
13:20 – 13:40	Pelagic fish purse seine surveys in BC	Chrys Neville/ Jennifer Boldt
13:40 – 14:00	Pelagic ecosystem surveys in BC	Linnea Flostrand, Jackie King, Chrys Neville
14:00 – 14:20	Fisheries acoustics surveys and monitoring in DFO's Pacific region - recent history and future developments.	Stéphane Gauthier, Jennifer Boldt
Coffee break		
14:40 – 15:00	Overview of Pacific Sand Lance and eelgrass fish assemblage research in BC	Cliff Robinson
15:00 – 15:20	Forage fish drivers of seasonal changes in the at-sea distribution and abundance of marine birds in the Salish Sea	Doug Bertram

15:20 – 15:40	Rhinoceros Auklets as samplers of forage fish distribution and abundance in distinct regions along the BC/WA coast	Mark Hipfner
15:40 – 16:00	Egg and larvae surveys	Linnea Flostrand, Ian Perry
16:00 – 16:20	Small mesh multispecies bottom trawl surveys	Ian Perry
16:20 – 16:30	Wrap up and Group Photo	All
18:00	Group supper (not provided)	

14 March 2018		
09:00-09:20	BC forage fish embryo surveys	Ramona de Graaf
Other Regions status on forage fish research/monitoring		
09:20 – 09:40	Forage fish monitoring and data needs in the NL region	Hannah Murphy
09:40 – 10:00	Forage fish at the Atlantic-Arctic gateway: new acoustic surveys	Maxime Geoffroy
10:00 – 10:20	Forage fish studies in the western Canadian Arctic – a central focus for ecosystem research	Andrew Majewski
10:20 – 10:40	Maritime perspective	Gary Melvin
Coffee break		
11:00 – 11:20	Towards Ecosystem Monitoring: Acoustic-based Indices from a Bottom Trawl Survey	Allan Debertin
11:20 – 11:40	Multifrequency Acoustics for Monitoring of Pelagic Species: The Quebec Perspective	Ian McQuinn
11:40 – 12:00	Monitoring of pelagic prey species in a whale feeding area in the St.Lawrence Estuary (Quebec) using hydroacoustics and pilot study to groundtruth forage fish species using eDNA	Nadia Ménard,
12:00 – 12:30	Panel discussion on common themes and issues	All
Lunch break (not provided)—the cafeteria has sandwiches, soup, salads and a hot lunch special (<$12), cash only (Canadian)		
13:30 – 14:30	Group discussion on identifying two or three topics (focused on methodology and logistics) to divide into subgroups	All
Coffee break		
14:50 – 16:00	Subgroup focus on key topics	Subgroups
16:00 – 16:30	Dissemination of key points from subgroups	All

15 March 2018		
09:00 – 09:20	Review of days 1-2 and modification to agenda as needed	All
09:20 – 10:30	Subgroups reconvene, with focus on identifying constraints and limitations to implementation of methodologies / new monitoring approaches, and potential ways forward	Subgroups
Coffee break		
10:45 – 12:30	Subgroup summaries and group discussion	All
Lunch break (not provided)—the cafeteria has sandwiches, soup, salads and a hot lunch special (<$12), cash only (Canadian)		
13:30 – 14:30	Group discussion, with focus on action items and deliverables	All
Coffee break		
14:45 – 16:00	Group discussion, recommendations for strategies to monitor multiple forage fish species, key points for the report	All
16:00 – 16:30	Wrap-up, self-examination, adjournment	Jennifer Boldt and Stéphane Gauthier

APPENDIX C. LITERATURE REVIEW FORAGE FISH SPECIES IN BC

1. INTRODUCTION

Forage fish are the main link between the lower and upper trophic levels and therefore a critical food source for a wide range of species including other fish, birds and marine mammals. They are difficult to assess because they are highly variable in space and time, with high rates of reproduction and widely distributed through marine, nearshore and estuarine habitats. There tends to be more data collected for commercially fished species and much less in known about non-commercially fished species (Therriault et al. 2009, Guénette et al. 2014). Surveys and assessments for some species are often undeveloped and important life history attributes remain unknown. Improved information on small pelagic fish is required to characterize their role in the ecosystem and advance both species-specific assessments as well as ecosystem models.

The first part of this literature review lays the foundation for identifying some of the knowledge gaps and data needs for select, non-commercially fished forage fish species, rather than providing an exhaustive review of all forage fish species in BC. This is done by first summarizing the available data for 8 species in BC (Table C1) to highlight some knowledge gaps, as well as describing the monitoring methods used to study and assess forage fish populations. In the second part of this literature review, methods to detect and monitor forage fish used by other organizations are discussed. Advantages and constraints of various monitoring methods were also summarized (main report, Table 1) and included input from workshop participants (Tables D1-D10). This review does not cover all forage fish species, and does not cover invertebrates or species stages that are considered as forage (e.g., juveniles of fish species, euphausiids, squids, etc.); however, the advantages and constraints identified for monitoring methods are general enough to be applicable to multiple species.

Table C1. General distribution of select forage fish species in British Columbia and the Northeast Pacific Ocean.

Species	Scientific name	Geographic range	General depth distribution (m; fishBase; Froese and Pauly 2018)	Spawning time	Spawning location
Pacific Sand Lance	*Ammodytes personatus*	Coastal areas of the North Pacific including California to the Beaufort Sea	0-275 (Coad and Reist 2004)	Aug. to Oct. (Alaska); Nov-Jan in the Strait of Georgia	Intertidal or subtidal zones in sand/gravel
Whitebait Smelt	*Allosmerus elongatus*	WCVI to San Francisco Bay	1-103 (Love et al. 2005)		
Northern Smooth Tongue	*Leuroglossus schmidti*	Vancouver Island to Japan	394-1800 (Allen and Smith 1988)		
Surf Smelt	*Hypomesus pretiosus*	Southern Alaska to southern California		Summer, winter, some year-round, (i.e., three stocks)	Intertidal or subtidal zones in sand/gravel
Longfin Smelt	*Spirinchus thaleichthys*	Alaska to San Francisco Bay	?-137 (Hart 1973)	Nov-Dec	Freshwater streams
Eulachon	*Thaleichthys pacificus*	Eastern Bering Sea to Northern California	0-300 (Allen and Smith 1988)	March (most) Apr. to May (Fraser stock)	Rivers
Northern Anchovy	*Engraulis mordax*	Baja California, Mexico to central BC	0-310 (Love et al. 2005)	Summer months	Within 100 km of the shore
Capelin	*Mallotus villosus*	Juan de Fuca Strait north along Alaska to Russia.	0-725 (Coad and Reist 2004)	Spring	Intertidal sand, gravel beaches

2. DATA GAPS

2.1. Pacific Sand Lance (*Ammodytes personatus*)

Information regarding Pacific Sand Lance populations in coastal BC is limited because there is no commercial fishery, they lack an acoustically-reflective swim bladder (Penttila 2007), and spawning and burying habitats are difficult to locate (Robinson et al. 2013). As a result there are not enough data on Pacific Sand Lance to identify stock abundance or trends in BC (Schweigert et al. 2007) or in Puget Sound (Penttila 2007). In an overview of the species, Gotthardt et al. (2005) identify research gaps around reproductive ecology, productivity, habitat requirements, population structure and sources of mortality in Alaska as well as globally. They are geographically distributed throughout coastal areas of the eastern Pacific Ocean, including coastal BC, and there are records of them throughout the Salish Sea (Robinson et al. 2013, Pietsch and Orr 2015). A thorough summary of the species biology is given in Robards and Piatt (1999).

There are several organizations interested and involved in monitoring Pacific Sand Lance and other shore spawners in BC (Table C2). The University of Victoria and Parks Canada have led a number of research projects focused on nearshore habitat use by Pacific Sand Lance on the southwest coast of Vancouver Island (Haynes et al. 2007, 2008, Haynes and Robinson 2011). One study used the by-catch data from the Strait of Georgia juvenile Pacific salmon and Pacific Herring surveys to identify potential pelagic foraging areas (Robinson et al. 2013). The authors have also attempted to map shallow subtidal benthic burying habitats of Pacific Sand Lance in the Strait of Georgia.

There has also been considerable effort to identify possible Pacific Sand Lance and Surf Smelt spawning habitat by citizen science initiatives, community groups and non-profit organizations in BC, with much of the work coordinated by the BC Shore Spawners Alliance. Records of spawning locations are housed in the Forage Fish Atlas hosted by the Community Mapping Network (http://www.cmnbc.ca). Access to the Forage Fish Atlas requires a username and login, but in 2014 the survey effort was summarized as having monitored over 100 beaches for Pacific Sand Lance and Surf Smelt (de Graaf and Penttila 2014). In addition to the Forage Fish Atlas, there are project reports on spawning habitat suitability for many of the sites such as Lasqueti Island (de Graaf 2017) and Bowen Island (de Graaf 2014). Other datasets on Pacific Sand Lance habitat mapping have been collected and reported for the purpose of assessing the shoreline for industry development (Thuringer 2003).

The Washington Department of Fish and Wildlife (WDFW) does not attempt to assess Pacific Sand Lance in Washington (Penttila 2007). However, the shoreline around Puget Sound and the US Gulf Islands have been extensively mapped for spawning habitat over the last 40 years (Moulton and Pentilla 2001) and about 10% of the shoreline is considered Pacific Sand Lance spawning habitat (Penttila 2007). Much less is known about the species away from their spawning beaches. In 2012 and 2013 the Washington outer coast was also mapped (Langness et al. 2013).

In Alaska, the majority of data on Pacific Sand Lance are available from the northern Gulf of Alaska, including abundance, size, age and diet around Kodiak Island, Cook inlet and Prince William Sound (McGurk and Warburton 1992, Robards et al. 1999b, 1999a, Johnson et al. 2008). One study found that observations of guillemot colonies reflected the relative abundance of Arctic Sand Lance on a seasonal and annual scale (Litzow et al. 2000). In southeast Alaska, 8 years of beach seine data were compiled to describe the distribution and habitat use of Pacific Sand Lance (Johnson et al. 2008). The NOAA Alaska Fisheries Science Center (AFSC) reported on Pacific Sand Lance caught in various surveys designed to sample groundfish and described the relative abundance and distribution in Stock Assessment and Fishery Evaluations. However, they note that Pacific Sand Lance are infrequently caught in these surveys with incidental catch in the Gulf of Alaska reported as zero tonnes from 2003-2016 except for in 2009 (Ormseth et al. 2016).

Table C2. Available data and monitoring methods for Pacific Sand Lance. WDFW is the Washington Department of Fish and Wildlife.

Geographic area	Time period	Data	Method	Life history stage	Depth / region	Reference
Southwest Vancouver Island	2002-2006	Abundance, behavior, size, habitat use	Subtidal snorkel and beach seine surveys, modeling study	Juvenile and adult	Intertidal and shallow subtidal	Haynes et al. 2007, Haynes et al. 2008, Haynes and Robinson 2011
Salish Sea	2002 – 2016	Maps of habitat suitability	Boat/beach surveys based on WDFW method	Eggs and spawning adults	Intertidal	de Graaf 2014, 2015, 2017, Archipelago Marine Research Ltd. 2014, Thuringer 2003
Strait of Georgia	1998-2011	Maps of burying and foraging habitats	Model validated with grab samples; Foraging identified by-catch from purse seines and mid-water trawls	Adult	<80 m depth / coastal	Robinson et al. 2013
Bering Sea (Port Moller estuary)	1990	Life history	Bongo nets for larvae	Early life history stages	<100 m / Estuary	McGurk and Warburton 1992
Cook Inlet / Prince William Sound	1996-1997	Habitat, abundance, size, age, and diet Energy content	Beach seines and digging in intertidal substrates	Juvenile to adults	Intertidal	Robards et al. 1999b, 1999a
Southeast Alaska	1998 - 2006	Distribution and habitat use	Beach seines	Early life history stages	Shallow subtidal / nearshore	Johnson et al. 2008
Washington		Maps of habitat suitability and spawning locations	Beach surveys using the WDFW method	Eggs and spawning adults	Intertidal	Moulton and Penttila 2000, 2001, Langness et al. 2013

2.2. Whitebait Smelt (*Allosmerus elongatus*)

There is very little information on Whitebait Smelt in the literature. In the Salish Sea, there are records of Whitebait Smelt in Juan de Fuca Strait and the San Juan Islands (Pietsch and Orr 2015). Several reports note their presence in trawl data off the Washington and Oregon coasts (Brodeur et al. 2005, Bailey and Ferdaña 2007). In the Columbia River plume, bottom mounted acoustic mooring data validated with trawl data were used to describe the timing and patterns of abundance of schooling forage fish, including Whitebait Smelt (Kaltenberg et al. 2010; Table C3). In National Marine Fisheries Service (NMFS) trawl surveys on the west coast of Washington, Whitebait Smelt occurred in 2.1% of hauls from 1977 to 2004 (Bailey and Ferdaña 2007).

Table C3. Available data and monitoring methods for Whitebait Smelt.

Geographic area	Time period	Data	Method	Life history stage	Depth / region	Reference
Juan de Fuca	1969	Occurrence	Otter trawl (by-catch)	Adult	70 m / 3 km offshore	Barraclough and Wilson 1971
Columbia River plume	2008-2009	Phenology and patterns of variability	Bio-acoustic moorings with trawl surveys	Adult	40 and 95 m depth / 11 and 24 km offshore	Kaltenberg et al. 2010

2.3. Northern Smoothtongue (*Leuroglossus schmidti*)

Deep-sea smelt of the North Pacific Ocean includes the Northern Smoothtongue, which have maximum lengths of 12–25 cm, and are considered important forage fish for marine birds and mammals (Conners and Guttormsen 2005). Schweigert et al. (2007) describe their widespread distribution around the North Pacific, but note that adults are observed infrequently and at night in mid-water trawls. Adults have been observed during the day-time in mid-water trawl data collected in a glacial fjord (Abookire et al. 2002; Table C4). In the Salish Sea, there are records of Northern Smoothtongue in the Strait of Georgia where their biology was described from a series of fine-mesh plankton tows and mid-water trawls (Mason and Phillips 1985). There are no records of Northern Smoothtongue in Puget Sound or Juan de Fuca (Pietsch and Orr 2015). In the Okhotsk Sea Northern Smoothtongue contribute 42-66% of the total mesopelagic fish biomass (Dulepova and Radchenko 2004).

Table C4. Available data and monitoring methods for Northern Smoothtongue.

Geographic area	Time period	Data	Method	Life history stage	Depth / region	Reference
Strait of Georgia and West Coast of Vancouver Island	2003-2017	Occurrence	Small mesh bottom trawl surveys	Adult	70-200 m	L. Flostrand, DFO, pers. comm.
Southeast Alaska	1999	Occurrence	Mid-water trawls	Juvenile to adult	<100 m/ protected coastal within 10km of shore	Abookire et al. 2002

Strait of Georgia	1981	Life history information	Fine-mesh plankton tows and mid-water trawls	All life history stages	Throughout water column / protected coastal within 20 km of shore	Mason and Phillips 1985

2.4. Surf Smelt (*Hypomesus pretiosus*)

Data on the distribution, and spawn timing and location of Surf Smelt in BC and Washington are sparse (Bargmann 1998, Therriault et al. 2002b, Schweigert et al. 2007), and there is no formal stock assessment for this species (DFO 2002a). In the Salish Sea, there are records of Surf Smelt in the southern Strait of Georgia (Pietsch and Orr 2015) and the species occurs throughout the marine waters of Washington, with about 10% of the shoreline documented as Surf Smelt spawning habitat (Penttila 2007). There may be multiple stocks in BC, and anecdotal evidence suggests that some populations are declining, but more work is needed to determine the number of stocks, let alone their status in BC (DFO 2010). There are commercial, recreational and Indigenous fisheries which are managed under the Surf Smelt integrated fisheries management plan (DFO 2012).

In BC, Surf Smelt habitat has been mapped in the Strait of Georgia and other areas by the BC Shore Spawners Alliance described in the Pacific Sand Lance section above (de Graaf 2014, 2015, 2017, etc.; Table C5). A number of recent studies on Surf Smelt were presented at the Salish Sea Ecosystem Conference including work on acoustic tagging in Puget Sound (Dionne et al. 2016, Liedtke et al. 2016), diet and feeding ecology (Fladmark et al. 2016), and spawning distribution and habitat use (de Graaf and Penttila 2014, Smith et al. 2016). In Burrard Inlet, DFO conducted a catch monitoring survey in 2003 which included data on Surf Smelt biological attributes (DFO 2010), but it's unclear whether or not these data were published.

Monitoring in Puget Sound has not been sufficient to estimate annual abundances (Penttila 2007), however much of the WDFW habitat mapping for Pacific Sand Lance also applies to Surf Smelt (Moulton and Pentilla 2001). One WDFW study aimed at characterizing Surf Smelt habitat in Puget Sound took sediments samples at 51 sites every two weeks for a year (Quinn et al. 2012). Other studies on Surf Smelt in Washington included studies on embryo ecology (Middaugh et al. 1987), effects of shoreline modification on embryos (Rice 2006) and the effects of contaminated sediments on larvae (Misitano et al. 1994). In NMFS groundfish surveys off the US west coast, Surf Smelt occurred in 0.4% of hauls from 1977 to 2004 (Bailey and Ferdaña 2007), but the surveys were not directed at forage fish.

In the Gulf of Alaska, the Recruitment Process Alliance Fisheries' oceanographic surveys document Surf Smelt bycatch in their mid-water trawl surveys. Incidental catches of Surf Smelts are reported on in NOAA's annual SAFE Reports (Ormseth et al. 2016).

Table C5. Available data and monitoring methods for Surf Smelt. WDFW is the Washington Department of Fish and Wildlife.

Geographic area	Time period	Data	Method	Life history stage	Depth / region	Reference
Salish Sea	2002 – 2016	Maps of habitat suitability	Boat/beach surveys based on WDFW method	Eggs and spawning adults	Intertidal	de Graaf 2014, 2015, 2017, Archipelago Marine Research Ltd. 2014, Thuringer 2003
Juan de Fuca		Maps of habitat suitability and spawning locations	Beach surveys using the WDFW method	Eggs and spawning adults	Intertidal	Shaffer et al. 2003 and references therein
Washington		Maps of habitat suitability and spawning locations	Beach surveys using the WDFW method	Eggs and spawning adults	Intertidal	Moulton and Penttila 2000, 2001, Shaffer et al. 2003, Quinn et al. 2012, Langness et al. 2013
Puget Sound		Distribution	Acoustic tagging	Adults	Nearshore	Dionne et al. 2016, Liedtke et al. 2016
Gulf of Alaska and Bering Sea	2003-ongoing	Biomass in by-catch	Mid-water trawls / acoustic surveys	Adults	0-35 m / offshore	Ormseth et al. 2016

2.5. Longfin Smelt (*Spirinchus thaleichthys*)

Biological data and spawning habitat information for Longfin Smelt are also sparse (Bargmann 1998). There are no stock assessment data for any marine populations and they may have the most vulnerable habitat of any marine forage fish (Penttila 2007). There are records of Longfin Smelt throughout the Salish Sea (Pietsch and Orr 2015), including a known spawning population in northern Puget Sound in the Nooksack River (Therriault et al. 2009). There are also two landlocked populations in Lake Washington and Harrison Lake (Chigbu et al. 1998). Longfin Smelt were observed in the Skeena River estuary in 2011 (Kelson 2011).

Some work has been done on landlocked Longfin Smelt in Lake Washington (e.g. Chigbu et al. 1998 and references therein). Penttila (2007) suggested that Longfin Smelt could be monitored via acoustics and mid-water trawls at river mouths in Puget Sound, or by sampling river-bottom sediments and the water column of the lower rivers in the winter to identify spawning streams.

In the Gulf of Alaska, the Recruitment Process Alliance Fisheries' oceanographic surveys document 'smelts', including Longfin Smelt, caught in their mid-water trawls. The relative abundance and distribution of smelts is reported in NOAA's SAFE Reports, but they do not distinguish between species except for Eulachon (Ormseth et al. 2016).

Considerable work has been done on Longfin Smelt in the San Francisco Bay estuary (Rosenfield and Baxter 2007, Merz et al. 2013, Grimaldo et al. 2017; Table C6), and there are several surveys that collect Longfin Smelt data including the California Department of Fish and Wildlife (methods described in section 3.2). Abundance indices calculated from the mid-water trawl data from 1967 to 2017 are posted online and suggest major declines in the population (http://www.dfg.ca.gov/delta/data/fmwt/indices.asp). Abundance estimated from other survey data show similar declines (Hobbs et al. 2017).

Table C6. Available data and monitoring methods for Longfin Smelt. CDFG is the California Department of Fish and Game, UofC is the University of California.

Geographic area	Time period	Data	Method	Life history stage	Depth / region	Reference
Skeena Estuary	2010	Observations	Plankton and larger nets	All life history stages	Shallow / coastal estuary	Kelson 2011; R. de Graaf, pers. comm.
Lake Washington	1960s-1992s	Abundance, fecundity, age	Mid-water trawls	Adult	Shallow / lake	Chigbu et al. 1998
San Francisco Bay	1967 - present	Abundance and distribution	CDFG and UofC mid-water and CDFG otter trawls	Juvenile and adult	Shallow coastal estuary	Rosenfield and Baxter 2007

2.6. Eulachon (*Thaleichthys pacificus*)

Relative to other non-commercially fished forage fish species in BC, there is more information available on Eulachon, which is an anadromous species endemic to the Northeastern Pacific. The three 'Designatable Units' in BC are the Nass/Skeena, Central Coast and Fraser River. There are records of Eulachon throughout the Salish Sea except in parts of Puget Sound (Pietsch and Orr 2015).

In 2011, a COSEWIC status and assessment report on Eulachon was produced which included information on data gaps, assessment methods and data sources for Eulachon (COSEWIC 2011). DFO has also produced a number reports including status assessments (Hay and McCarter 2000), recovery potential assessments (Schweigert et al. 2012, DFO 2015a, 2017a) and fisheries management plans (DFO 2013). From these reports some of the main data gaps for Eulachon are as follows:

- Marine distribution and biomass - It is not well understood what controls their marine distribution. Offshore indices are not necessarily reliable indicators of spawning abundance in rivers. Information on extent of occurrence is largely unknown for the Skeena/Nass population and somewhat unknown for the Central Coast and Fraser River populations (COSEWIC 2011).
- No validated ageing technique (Schweigert et al. 2012)
- Mortality - Natural mortality difficult to estimate. It is unclear if noise and aquaculture influence survival (Schweigert et al. 2012).
- Uncertainty around genetic baselines (DFO 2017a)

There are several indices that have been used to assess Eulachon in BC (Hay and McCarter 2000, COSEWIC 2011). These include:

- Spawning stock biomass from larval/egg surveys from rivers and estuaries (McCarter and Hay 1999, Hay and McCarter 2000, MacConnachie et al. 2017)
- Catches in the DFO multispecies small mesh survey (Hay et al. 1997, Schweigert et al. 2012, MacConnachie et al 2017)
- Commercial catches in the Fraser and Columbia Rivers (MacConnachie et al. 2017)

Other work on Eulachon in the Northeast Pacific includes studies on population genetics (Beacham et al. 2005), age at maturity and repeat spawning potential (Clarke et al. 2007). Acoustic detection has also been explored in combination with modelling (Gauthier and Horne 2004), and trawl data (Csepp et al. 2017). A number of studies have collected data on Eulachon in the Skeena River (Lewis et al. 2009, Kelson 2011, Rolston 2011). Out of the University of Victoria, one study incorporated fisheries data with traditional and local ecological knowledge and used fuzzy logic to estimate the relative of abundance of Eulachon in several systems (Moody 2008).

NOAA provides crude indications of Eulachon abundance from the NOAA Gulf of Alaska acoustic surveys, mid-water trawl data (e.g. Ormseth 2014; surveys are described in more detail in section 3.1; Table C7), catch-per-unit-effort data from small-mesh trawl surveys, and biomass estimates from groundfish bottom trawl surveys. These datasets allow the identification of common trends such as the increase in Eulachon biomass during the late-2000s. Eulachon are the most abundant forage fish in the trawls and are reported on individually, but are also sometimes grouped into 'osmerid' (Ormseth et al. 2016).

In Washington, commercial landings are recorded but there is no quantitative stock assessment (Bargmann 1998), and in Puget Sound there is virtually no life-history information available (Penttila 2007). However, (Penttila 2007) suggests that information on Eulachon distribution could be obtained at the same time as data collection on Longfin Smelt, i.e. by sampling river-bottom sediments and the water column of the lower rivers. In NMFS trawl surveys on the west coast of Washington, Eulachon occurred in 16.8% of hauls from 1977 to 2004 (Bailey and Ferdaña 2007).

Table C7. Available data and monitoring methods for Eulachon.

Geographic area	Time period	Data	Method	Life history stage	Depth / region	Reference
Skeena River	2001, Spring 2010, 2011	Run timing and reproductive effort, critical spawning habitat	Gill-net, tethered cameras, ponar dredge, plankton net	All life history stages	Shallow / coastal estuary	Lewis et al. 2009, Kelson 2011, Rolston 2011
Central Coast	1994, 1996, 1997	Distribution and relative abundance of larvae	Plankton net hauls	Larva	<20 m / coastal inlets	McCarter and Hay 1999
Fraser River	1995-2016	Egg and larva survey	Plankton net hauls	Egg and larva	0-10m subsurface, In river (affected by tides)	Hay et al. 2002, MacConnachie et al. 2017
BC coast	1973-ongoing	Distribution and trends in biomass, length/size	Multispecies small mesh otter trawl; Groundfish and shrimp trawl surveys and fisheries	sub-adult, and juvenile eulachon	Bottom 50-200m; Coastal to offshore	Schweigert et al. 2012, MacConnachie et al. 2017
NE Pacific	1878-2006	Synthesis of fisheries catch data	Compiled data from commercial and Indigenous catch	n/a	n/a	Moody 2008
Gulf of Alaska and Bering Sea	2003-ongoing	Biomass in by-catch	Mid-water trawls / acoustic surveys	Adults	0-35 m / offshore	Ormseth et al. 2016
Southeast Alaska	Spring 2006	Population structure, biomass, distribution	Echo integrated-trawls	pre-spawning adults, sub-adult, and juvenile	Coastal estuary	Csepp et al. 2017
SE Alaska-Berners Bay	1994-1997	Relative abundance	Dip nets	Spawning adults	< 5m / coastal estuary	Marston et al. 2002

2.7. Northern Anchovy (*Engraulis mordax*)

Northern Anchovy are a schooling, migratory species that are widely distributed on the west coast of North America and are divided into three sub-populations: southern, central and northern. There is considerable information about the central Northern Anchovy population (https://swfsc.noaa.gov), but less is known about the northern stock which is found off the coast of BC. There is no stock assessment of Northern Anchovy in BC (Therriault et al. 2002a). There are records through-out the Salish Sea (Pietsch and Orr 2015), and Puget Sound may have a resident population (Penttila 2007). DFO reports on Northern Anchovy include a review of their biology and fisheries (Therriault et al. 2002a) and a fisheries management plan (DFO 2002b). Therriault et al. (2002a) describe the data gaps for the species as follows:

- The northern extent of their range
- Spawning locations and whether or not the species spawns locally or migrates south
- Spawning frequency and fecundity estimation are unconfirmed
- Biomass estimates
- Genetic structure of the stock
- Information on recreational users

Large fluctuations in biomass are not uncommon for Northern Anchovy populations globally, however the reason for these fluctuations are not well understood (Checkley et al. 2017). Off the coast of Oregon, temporal and spatial patterns in their distribution and abundance have been examined in terms of meso- and macroscale oceanographic variability (Litz et al. 2008; Table C8).

Northern Anchovy do not have a specific assessment by WDFW but they do occur in their mid-water trawl surveys targeting Pacific Herring (Penttila 2007). However monitoring in Puget Sound has not been sufficient to estimate the annual abundance, and more work could be done to document the distribution, densities and timing of the spawn and early life stages (Penttila 2007). In NMFS trawl surveys on the west coast of Washington, Northern Anchovy occurred in 2.0% of hauls from 1977 to 2004 (Bailey and Ferdaña 2007).

The Pacific Fishery Management Council (PFMC) includes Northern Anchovy in their SAFE reports (PFMC 2017), but notes that the species is not targeted in a fishery and is not a priority for assessment. The last full assessment for the central sub-population US west coast was completed in 1995. The SAFE reports also suggest that the Southwest Fisheries Science Center (SWFSC) acoustic trawl survey could be used for their assessment. They are also monitored on the SWFSC spring coastal pelagic species surveys (https://swfsc.noaa.gov/textblock.aspx?Division=FRD&id=1340).

Table C8. Available data and monitoring methods for Northern Anchovy. AFSC is the Alaska Fisheries Science Center, NWFSC is the Northwest Fisheries Science Center, and SOG is the Strait of Georgia, WDFW is the Washington Department of Fish and Wildlife.

Geographic area	Time period	Data	Method	Life history stage	Depth / region	Reference
Washington and Oregon Coast	1977 to 2006	Abundance, age	AFSC West Coast Triennial bottom trawl surveys; NWFSC pelagic fish surveys by rope trawl	Adult	Various depths / 0-100 km from shore	Litz et al. 2008
Oregon Coast	1975,1976, 1994, 1995	Spawning biomass	Vertical tows for larvae	Eggs and larvae	0-70 m / 9 to 190 km from shore	Emmett et al. 1997
SOG	1992-2017	Presence /absence	Small purse seine used for age-0 herring survey			e.g., Thompson et al. 2017
SOG	1968 to 1969, 1973	Abundance	Paired surface trawls			McKinnell and Perry 2016
SOG	2015-2016	Abundance, morphometric data	Midwater trawl juvenile salmon surveys			Chrys Neville (DFO, pers. comm.)
Skagit Bay	2001-2016	Abundance	NOAA survey using a two-vessel surface tow net			Rice et al. 2011
Puget Sound	1972-1985, 2003, 2011	Abundance	Two-vessel surface tow net	Adult	Surface / inshore	Greene et al. 2015
Puget Sound	2016	Abundance	Midwater trawl			WDFW
BC	1939-2001	Catch data	Commercial catch data			Therriault et al. 2002a
California		Biomass	Egg and larvae surveys			MacCall et al. 2016, Thayer et al. 2017

2.8 Capelin (*Mallotus villosus*)

In the Pacific, Capelin are distributed from Juan de Fuca Strait (southern BC) to Alaska and the Bering Sea and beyond. Hay (1998) reported that, in the 1930s, "capelin spawned regularly at night in intertidal areas on certain sandy beaches in the Strait of Georgia. Spawning usually occurred in the fall (late September and October) ... It seems that these fall-spawning capelin disappeared, in approximately the mid-1970s." Hay (1998) also noted that in 1995 and 1996, "capelin have 'reappeared' at the heads of Bute and Knight Inlets, which open into the north end of the Strait of Georgia. These 'new' capelin were captured in March … during spawning. Observations suggest that capelin have now returned to the Strait of Georgia, although these new 'Spring spawning' capelin may not be the same as the previous 'Fall spawning' capelin". There used to be small recreational fisheries for Capelin, but no commercial fisheries (Hay 1998). Other than opportunistic sampling and the potential of embryo surveys and forage fish spawning habitat suitability modeling, there are no sampling programs for Capelin and little is known about this species in BC.

2.9 Other forage fish species

There are several forage fish species in BC that are not covered in this review; however, given the range of information available for the above-described species (i.e., ranging from almost no information for Capelin to more detailed information for Eulachon), monitoring advantages and constraints identified here will likely apply to other species. Examples of other forage fish species include: Three-Spine Sticklebacks, Shiner Perch, myctophids and other mesopelagic fish species, and Blue Throat Argentine. In addition, juveniles of larger piscivorous fish, such as gadids and rockfish, also provide a forage base for upper trophic level predators. Other important forage species include invertebrates, such as squid and euphausiids, which were not covered during this workshop, given time constraints.

3. METHODS USED TO ASSESS NON-COMMERCIALLY FISHED FORAGE FISH IN OTHER REGIONS

3.1. Alaska

NOAA's Alaska Fisheries Science Center (AFSC) produces annual Stock Assessment and Fishery Evaluation (SAFE) Reports (https://www.afsc.noaa.gov/refm/stocks/assessments.htm) for forage fish. The report formats vary with year, research developments and data availability. For example, the 2014 report focused on species distribution in the Gulf of Alaska (GOA) (Ormseth 2014), whereas the 2016 report covered the eastern GOA, incidental forage fish catch and research from the Gulf of Alaska Integrated Ecosystem Research Program (Ormseth et al. 2016). Reports in odd numbered years cover forage fish in Bering Sea and Aleutian Islands.

NOAA's assessment of the distribution and abundance of forage fish in the GOA is based on bottom trawl surveys, acoustic surveys and small-mesh surveys conducted by the AFSC as well as proxies such as predator diets. The bottom trawl surveys are aimed at groundfish and do not likely sample some forage fish very well because of the large mesh size and sampling location (close to the bottom on the slope and shelf). Despite this, the bottom trawl surveys are used to investigate the cross-shelf and geographic distribution of forage fish. On these surveys, a mid-water trawl is conducted to provide species composition and biological information. These trawls are also used to provide a crude indication of abundance using the rate of incidental catches. The acoustic surveys are aimed at Walleye Pollock but can also give a crude estimate of relative Eulachon abundance. The small-mesh surveys are conducted in a range of nearshore locations and sample forage fish such smelt in demersal habitats. The catch-per-unit-effort in the small-mesh trawl and biomass estimates from the bottom trawl data are used to generate indicators of forage fish abundance. There are differences between the time series but there are also common trends such as an increase in Eulachon biomass during the late 2000s (Ormseth 2014)

The abundance estimates based on these surveys are highly uncertain and are likely much lower than reality (Ormseth 2014). NOAA also makes biomass estimates using a mass-balanced ecosystem model which are higher than those made from the trawl surveys but they are still not considered reliable estimates of absolute abundance. The reports note that because of the uncertainty in the time series their use should be limited to interpretation of broad trends.

The GOA assessment survey described in (Ormseth et al. 2016) used a smaller mesh size and sampled in the epipelagic zone. The report notes that these catch values adequately represent relative abundance and distribution.

The fisheries catch and landings reports include a summary of the kilograms caught of forage fish and grenadier, including numbers of Eulachon, Pacific Sand Lance and ‘other osmerids’. (https://alaskafisheries.noaa.gov/fisheries-catch-landings).

3.2. Washington / Oregon / California

The Washington Department of Fish and Wildlife (WDFW) recognizes the importance of forage fish, but does not attempt to assess species with no commercial fishery (Penttila 2007). They have made considerable efforts to map forage fish spawning habitat in Washington, and have developed a manual for sampling forage fish spawn on beaches (Moulton and Pentilla 2001). Initially surveys were conducted by visual inspection of beaches, but the method was considered inadequate and in 1993 they switched to collecting bulk sediments which were analyzed in a laboratory (Moulton and Penttila 2000). The WDFW conducted a series of beach spawning surveys at 35 sites on the outer Washington Coast in 2012 and 2013 (Langness et al. 2013). They generally followed the substrate sampling methods described by Moulton and Pentilla (2001), and analyzed samples for the presence and condition of forage fish eggs.

Other monitoring efforts in Puget Sound include summer surface trawl surveys conducted by several sampling programs starting in 1971. These surveys were described and the data synthesized in order to assess changes in forage fish abundance and composition by Greene et al. (2015). In the Columbia River plume bottom mounted acoustic moorings, validated with trawl data, were used to describe the timing and patterns of abundance of schooling forage fish, including Pacific Sardine, Northern Anchovy and Whitebait Smelt (Kaltenberg et al. 2010).

Monitoring efforts used to describe the distribution and abundance of Northern Anchovy on the US west coast include the US Global Ocean Ecosystem Dynamics (GLOBEC) Northeast Pacific Study, the Plume Study, and the Predator Study (Litz et al. 2008).

The Southwest Fisheries Science Center (SWFSC) conducts a spring coastal pelagic species surveys with multi-frequency echosounders, surface trawls, vertical net tows and a continuous underway fish-egg sampler (Stierhoff et al. 2017). The survey objectives include collecting data on the distribution, abundance and life history parameters of Pacific Sardine, Northern Anchovy, Pacific Herring, Jack Mackerel and Chub Mackerel (*Scomber japonicus*).

The California Department of Fish and Game (CDFG) conducts several surveys in the San Francisco Bay area which have data on forage fish:

i. Fall Midwater Trawl Survey has been conducted since 1967 for the purpose of monitoring the relatively abundance of several species including Striped Bass (*Roccus saxatilis*), smelt, Shad (*Alosa sapidissima*), and Splittail (*Pogonichthys macrolepidotus*) (http://www.dfg.ca.gov/delta/projects.asp?ProjectID=FMWT). Fish ID, counts as well as water properties are collected at 122 stations each month from September to December.
ii. The Summer Townet Survey has been conducted since 1959 and provides information on the distribution and relative abundance of Striped Bass and Delta Smelt (*Hypomesus transpacificus*) (http://www.dfg.ca.gov/delta/projects.asp?ProjectID=TOWNET). Species ID, counts and fork length are measured from species caught at 31 stations every two weeks from June to August.
iii. The San Francisco Bay Study conducts an otter trawl and midwater trawl monthly at 52 stations (https://www.wildlife.ca.gov/Conservation/Delta/Bay-Study). The surveys record data on demersal and pelagic species as well as water properties.
iv. The Smelt Larva Survey has been conducted biweekly from January to March since 2009. There are 35 stations at which larval species and juvenile fish are identified and measured.

3.3. East coast

In Eastern Canada, there is substantial information on monitoring efforts for commercially fished forage species such as Atlantic Herring and Atlantic mackerel (DFO 2011, 2017b). The Atlantic Herring assessment is based on fishery catch data such as catch-at-age and numbers-at-age data, biomass estimates from industry based acoustic surveys and fishing excursions of spawning fish (DFO 2007). Experimental gillnets are also used to estimate age-disaggregated indices of Atlantic Herring abundance (McDermid et al. 2016, Surette et al. 2016). There was a full assessment of Atlantic Mackerel in 2014 based on fishery data and an abundance index from egg surveys. A multispecies bottom-trawl survey has been conducted every fall in the southern Gulf of St. Lawrence since 1971 (Savoie 2014). An evaluation of a new fishery for Atlantic Saury (*Scomberesox saurus*) suggested that the annual bottom trawl and acoustic Atlantic Herring surveys might be useful for monitoring some other species (Chaput and Hurlbut 2010).

On the US east coast the NMFS Northeast Fisheries Science Center conducts annual fall and spring bottom trawl surveys on the east coast and into the western Scotian Shelf in Canada (Smith 2002, Richardson et al. 2014).

3.4. Arctic

Very little information was found on monitoring of forage fish in Arctic waters, especially for non-commercially fished species. DFO conducts fishery independent shrimp trawls survey every two years in the waters around Nunavut (DFO 2015b), although it is not clear if the bycatch data are used for monitoring other species. DFO also assess Arctic Char (*Salvelinus alpinus*) using mainly fisheries data (DFO 2016), but fishery-independent data are also collected using gillnets in some areas (Martin and Tallman 2013). During 2005-2015, the University of Laval and DFO conducted acoustic trawl surveys in Canadian Arctic seas between early August and late October, primarily focussed on Arctic Cod (Geoffroy et al. 2016, Bouchard et al. 2017). Sampling of ichthyoplankton on these surveys was done using a variety of nets (e.g., double square net, small midwater trawl, bongo net, Hume midwater trawl, beam trawl). These surveys provided abundance, distribution, and biological data time series on Arctic Cod. Survey efforts in the area are ongoing as part of DFO's Canadian Beaufort Sea Marine Ecosystem Assessment (CBS-MEA).

Similar to the GOA reports described above, NOAA puts out SAFE reports for the Bering Sea and Aleutian Islands (BSAI) in odd numbered years. There are no dedicated surveys for monitoring forage fish but estimates of abundance are made by aggregating data across multiple data sources or multiple survey years (Ormseth 2015). The primary sources of data are from the AFSC bottom and surface trawl surveys, and the Walleye Pollock acoustic survey. These survey data have been used to describe the density and distribution of Capelin, Walleye Pollock, and Pacific Cod (Hollowed et al. 2012, Parker-Stetter et al. 2013).

3.5. Emerging technologies

3.5.1. EDNA

Environmental DNA is a promising new technique for biological monitoring and assessing marine ecosystems. Water is filtered for biological waste (i.e. cells, metabolic waste, etc.), and analyzed using polymerase chain reaction or sequencing (Yamamoto et al. 2017). The data can be used to demonstrate presence and absence but there is evidence that it can also be used to assess species abundance (Lacoursière-Roussel et al. 2016). The majority of work has focused on freshwater systems (Takahara et al. 2012, Lacoursière-Roussel et al. 2016, Yamamoto et al. 2017), but techniques are also starting to be applied in the marine environment (Thomsen et al. 2012, Kelly et al. 2014, Stoeckle et al. 2017). Canadian researchers collected eDNA data for a coastal marine biodiversity database within the Trans-Canada eDNA Biodiversity Mapping Project on the 2017 Canada C3 survey (https://canadac3.ca/en/expedition/the-research/trans-canada-edna-biodiversity-mapping-project/).

The concentration of eDNA can be correlated with species biomass (Takahara et al. 2012). However, in a study conducted at the Monterey Bay Aquarium individual species were detected but there was no relationship developed between biomass and eDNA abundance (Kelly et al.

2014). The authors concluded that more work needs to be done on multiple marker genes and eDNA shedding rates to accurately describe the community composition. Despite these challenges, initiatives such as the Marine Biodiversity Observation Network plan to use the technique to describe ocean biodiversity (Muller-Karger et al. 2014).

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APPENDIX D. INFORMATION PROVIDED BY PARTICIPANTS PRIOR TO THE WORKSHOP

Prior to the workshop participants were asked to provide information about forage fish species biology and distribution as well as advantages and constraints of forage fish monitoring methods in their study area. Template tables (Tables D1 and D2) were sent to workshop participants to be filled out. The information provided by participants (Tables D3-D10) was integrated with discussions that took place during the workshop and finalized in the main body of the report and Table 1.

Table D1. Template table for species biology and distribution. Participants were asked to provide this information for their study area.

Species	Geographic range	Adult depth distribution (m)	Habitat (adult; feeding)	Phenology	Spawning time	Spawning location

Table D2. Template table for the advantages and constraints of forage fish monitoring methods. Participants were asked to provide this information for their study area.

Monitoring method	Examples of use	Advantages	Disadvantages	References

Table D3. Species biology and distribution for species in the Newfoundland region.

Species	Geographic range	Adult depth distribution (m)	Habitat (adult; feeding)	Phenology	Spawning time	Spawning location
Capelin	NAFO Div. 2J3KLPsNO4 RSTW	Offshore 200m, shelf break	Northern feeding, southern immature	Live to age-6, recruit into fishery age-2, high spawning mortality	July-August	Beaches and demersal sites in NL

Atlantic Herring	NAFO Div. 3KLPs	Inshore coastal	Inshore coastal; no data on diet	Live to age-11+, episodic recruitment, spring and fall spawners	Spring and fall (exact timing uncertain)	Unknown (inshore coastal)
Sand Lance	NAFO Div. 3KLPs	Inshore and offshore	Offshore diet and distribution data	Live to age 10+ Juveniles inshore, adults offshore except during spawning	Late autumn-early winter	Bays of NL based on ichthyoplankton surveys
Artic Cod	NAFO Div. 2J3KL	offshore	Offshore diet and distribution data	Arctic forage fish, associated with sea ice	Jan-Feb	unknown

Table D4. Feedback provided by participant(s) on the advantages and disadvantages for forage fish monitoring methods used in the Newfoundland region.

Monitoring method	**Examples of use**	**Advantages**	**Disadvantages**	**References**
Hydroacoustics	Spring acoustic survey in NL	- Best practice for pelagic fishes - Long time series - Advances in technology	- Deadzone - Restricted survey area - Species ID can be difficult for opportunistic surveys	Mowbray 2002
Research Gill net survey	NL region	- Control for effort - Fishery independent catch data - Long time series	- Spatio-temporal limitations	Bourne et al. 2015
Bottom trawl survey	NL region	- Distribution of forage fish - Data on non-commercial species	- No abundance data - Cannot survey pelagic spp effectively	
Citizen science and paid spawning diary program	NL region	- Pay to check local spawning beach every day for 2 months - Post photos of capelin spawning on ecapelin.ca	- Participation is voluntary - Populated areas better surveyed - Only peak spawning recorded, may miss other details	
Larval survey	1 bay	- Index to investigate drivers of recruitment - Cost is lower than acoustic survey - Forecast	- 1 Bay - Late-larval survey is fixed in time	Nakashima and Mowbray 2014 Murphy et al. 2018

Table D5. Feedback provided by participant(s) on species biology and distribution for species in the St Lawrence Estuary (SLE).

Species	**Geographic range**	**Adult depth distribution (m)**	**Habitat (adult; feeding)**	**Phenology**	**Spawning time**	**Spawning location**
Sand Lance (*A. americanus; A. dubius*)		From shore to 200 m?	Sandy bottom, pelagic	Not studies in SLE	Winter?	SLE
Capelin (*Mallotus villosus*)		From shore to 200 m?	Upwelling areas; coastal, pelagic	Spawning times vary as well as larval retention in SLE,	April-July	SLE-GSL
Atlantic Herring (*Clupea harengus*)		Coast to spawn (algae etc) up to 200 m?	Pelagic	Spawning times vary	Spring and fall	SLE. Same population as GSL?

Table D6. Feedback provided by participant(s) on the advantages and disadvantages for forage fish monitoring methods used in the St Lawrence Estuary (SLE).

Monitoring method	**Examples of use**	**Advantages**	**Disadvantages**	**References**
Acoustics		Geographic coverage	Groundtruthing challenge	

Table D7. Feedback provided by participants on species biology and distribution for species in Eastern Canada.

Species	**Geographic range**	**Adult depth distribution (m)**	**Habitat (adult; feeding)**	**Phenology**	**Spawning time**	**Spawning location**
Capelin	Labrador to the eastern portion of the Scotian Shelf	0-200 m		Pre-spawning	May - July	Intertidal – banks; between 6-10°C
Northern & American	Labrador to North Carolina	0-250 m	Intertidal or subtidal zones	Burrows nocturnally	?	General habitat

Sand Lance			in porous sandy bottoms	(?) spawns day/night		
Mackerel	Newfoundland to North Carolina	0-60 m		Post-spawning	June	sGSL - Coastal pelagic

Table D8. Feedback provided by participants on the advantages and disadvantages for forage fish monitoring methods in Eastern Canada.

Monitoring method	**Examples of use**	**Advantages**	**Disadvantages**	**References**
Acoustics	Krill Atlantic Herring	Systematic geographic coverage Continuous sampling Non-intrusive Samples wide size range of animals	Groundtruthing challenges Doesn't work well for low-density species or intermixed species Miss top 5-10 m	McQuinn et al. (2013) McQuinn & Lefebvre (1999)
Egg survey	Mackerel	Independent Systematic	Not whole population	

Table D9. Feedback provided by participants on species biology and distribution for species in British Columbia, Canada.

Species	Geographic range	Adult depth distribution (m)	Habitat (adult; feeding)	Phenology	Spawning time	Spawning location
Pacific Herring	California to Alaska	0-200 m	Offshore areas (up to 200 m depth); at depth in the day and at surface at night	Eggs hatch ~April-May; Many adults migrate to offshore, summer feeding areas	Feb-Apr	Nearshore on vegetation in intertidal-subtidal habitats
Surf Smelt	AK-Mexico	Surface (to about 100 feet)	spawning/; rearing; adult	Embryos/larvae/juveniles/adults	Year round stocks/summer/winter stocks Prince Rupert	Salish Sea (Canada and the US) Unclear; summer is known

Pacific Sand Lance	Arctic-Mexico	0-150 m	Estuary-shelf migration; adult estuarine use	As above	Late Oct-Jan Variable Oct-April	Salish Sea (SOG and Puget Sound AK; sandy habitat
Capelin	AK-BC; Mainland fjords? Rivers Inlet	Larvae upper 30m	Spawning/rearing/adult; Midwater – demersal partitioning	As above	Spring; March-April	Victoria, Lantzville, Nanaimo (see Hart) Northern SOG (recent report from local residents
Longfin Smelt			Spawning/rearing	As above	?	Skeena
Eulachon		0-120 m	Midwater-demersal partitioning		February – March	Anadromous; glacier rivers
Northern Anchovy			All stages		Summer	Salish Sea (Puget Sound [Penttila], SOG abundant larvae found
Night Smelt	BC and ?		All stages	?	?	Port of San Juan (see Hart)

Table D10. Feedback provided by participants on the advantages and disadvantages for forage fish monitoring methods for British Columbia.

Monitoring method	Examples of use	Advantages	Disadvantages	References
Plankton surveys	BC long time series in SOG and WCVI	Variations in collection methods can usually be accounted for. Identified to lowest possible taxonomic level Staged to egg, larval/juvenile (3 size classes) Useful for biodiversity analyses, possibly for stock abundance estimates	Small size of, and low volumes filtered by, sampling gear (Bongo, SCOR nets) Major surveys on outer BC coast occur only in May and Sept (late for most spawning periods)	
Embryo Surveys	Surf Smelt/Pacific Sand Lance	Accurate; straight forward	Large effect of storms Can only confirm spawning; cannot disprove spawning	Moulton & Penttila; de Graaf
Larval Tows/Trawl Surveys	Eulachon in-river egg and larval surveys	Can estimate spawner abundance	In-river survey estimates vary with tides, river discharge, and time	
Forage Fish Habitat Suitability Assessments	Surf Smelt/Pacific Sand Lance spawning habitat	Provides science-based methodology for land-use planner	Labour intensive; lack of funding	de Graaf
Beach seining	Pacific Sand Lance; juvenile Pacific Herring sampling	Samples nearshore habitat; collect live samples for experimental purposes	Depth limited; not all life stages collected; not all habitats sampled	
Purse seine	Pacific Herring; Hakai (Discovery Islands & Johsntone Strait); DFO SOG	Depending on net size can be deployed from small to medium vessels; fish can be collected or released alive. Can sample nearshore	Depth limited Small surface area sampled Affected by tides/currents	

Plankton nets	Pacific Herring larval surveys (Hakai)	Sample larval stages	Net avoidance > 25mm.	
eDNA	Bottle collections – entire water column (Hakai / UBC)	Ease of collection; not limited by boat size; not affected by net avoidance	Biomass estimates are not standardized yet; no actual specimen provided for biological analysis.	
Midwater trawl surveys	DFO's integrated pelagic ecosystem survey	Provides index of abundance and distribution Biological sample collection (morphometric and trophodynamic) Cover wide geographic area	Not always capable of sampling nearshore with large nets Miss the upper 0.5 m Often only conducted once annually or less	
Acoustics	Pacific Hake survey; downlooking acoustics	Can quantify fish biomass (14 m to near bottom)	Misses top 14 m of water column Best for fish with swim bladders; Smelt species presence only Difficult to find sardine schools	
Hydrobios multinet		Samples zooplankton and euphausiids	Fails to catch larger organisms (e.g., myctophids)	
MOCNESS		Samples larger mobile nekton including larger zooplankton	An efficient tow is speed and mesh dependent	

APPENDIX E. ACTION ITEMS

1. Jennifer to circulate this Action item list
2. Stephane and Jennifer to write draft report
3. Send a framework for survey metadata to workshop participants – Jennifer and Stéphane
4. Provide metadata from surveys/data presented at this workshop – all participants
5. In the draft report, provide information on advantages and constraints of sampling methodology – all participants
6. After report has been circulated and edited: Recommendations/presentation to Regional and then discuss with Carmel if she wants to report to National Science Executive Committee; discuss with Eddy Kennedy and Kim Hyatt, Carmel (Regional Director of Science). Jennifer and Stéphane after participants have provided input on draft report.
7. Mark Hipfner to forward information about a seabird group TORs
8. Cliff Robinson to ask about process for getting NMFS-DFO working group; how did the Aquatic Invasive Species as a national priority come about? How did Ocean Acidification working group come about? Could propose a working group in other organizations (e.g., PICES). How does forage fish become priority for DFO?
9. Brian Hunt to send information about Ocean Research and Canada Alliance (ORCA) meeting information – do they have a forage fish focus?
10. Jackie King to find out how the DFO-US Groundfish technical group got started.
11. Stephanie King to write meeting notes.
12. Gary Melvin to send DFO's past Forage Fish Working Group report to Jennifer Boldt and Stéphane Gauthier.
13. Todd Sandell to send Forage Fish management plan; Seadoc references and herring in the Salish Sea report to Jennifer Boldt and Stephane Gauthier.
14. Each Region, Institute, Organization– identify where/how regional priorities tie into forage fish
    a. Arctic: Andy (DFO), Max (Memorial University)
    b. NL: Hannah (DFO)
    c. MAR with ties to GULF: Gary and Allan (DFO)
    d. QUE: Ian McQuinn (Stéphane Plourde) (DFO), Nadia Menard (Parks Canada)
    e. PAC: Stéphane, Jackie, Strahan, Linnea
    f. UBC/PAC: Brian Hunt
    g. WWF Canada: Rachel Wang
    h. Sea watch society: Ramona de Graaf
    i. ECCC: Mark Hipfner, Doug Bertram
    j. WA: Todd Sandell
    k. AK: Matt Baker and Yumi Arimitsu
15. Literature – important sources – all to send to Jennifer and Stéphane (will put on google drive and/or incorporate into report).

16. Request presentation on value added stomach analysis at sea by volume-subsample from Jason Link (Jennifer to ask).
17. Mayumi Arimitsu to send Gulf of Alaska Forage Fish report.
18. Todd Sandell to provide Puget Sound reports on beach spawners/herring when they are available.
19. Jennifer Boldt to check in with Steve Schut regarding fish distribution maps.