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Research Inventory and Recommendations Regarding Marine Forage Species in Alaska

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National Oceanic and Atmospheric Administration
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NOAA FISHERIES

Research Inventory and Recommendations Regarding Marine Forage Species in Alaska

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Executive Summary

Forage species (including classic “small pelagic fishes” as well as juvenile fishes and invertebrates) serve a key intermediate trophic role in marine food webs, functioning as both predator and prey, through which energy is transferred from primary consumers to higher trophic levels. Environmentally-driven changes in the availability of forage species as prey can have profound impacts on commercial, protected, and subsistence species (Pikitch et al. 2014), but projecting future impacts will be challenging. In particular, numerical ocean models can support seasonal and end-of-century forecasting for ocean physics and lower trophic levels (primary and some secondary producers), but forage species will likely require ongoing monitoring, process research, and syntheses to predict environmental impacts. Furthermore, stakeholders are increasingly interested in forage species impacts, as shown by North Pacific Fishery Management Council (NPMFC) inquiries and legislative requests (Ormseth 2020).

Given these interests, the National Oceanic and Atmospheric Administration’s (NOAA) Alaska Fisheries Science Center (AFSC) convened a virtual “Forage Congress” with two half-day meetings on 30 March and 6 April 2022, organized by a Steering Committee representing AFSC’s major programs and divisions. This Forage Congress had four major objectives:

1. Identify major forage taxa for each Large Marine Ecosystem (LME) in Alaska.
2. Inventory major forage research including surveys, process research, fishery-dependent collections, and analytic methods.
3. Identify major scientific goals and knowledge gaps.
4. Provide recommendations to AFSC leadership regarding future research priorities.

Here, we first identify major forage taxa across LMEs and summarize results from the research inventory. In the Gulf of Alaska (GOA), forage species identified as the highest priority for data needs to support management are capelin, eulachon, Pacific herring, juvenile gadids (age-0 walleye pollock and Pacific cod), sand lance, and euphausiids. In the Bering Sea and Aleutian Islands (BSAI), priority forage species include juvenile walleye pollock and other groundfish, juvenile salmon, and key species within the NPFMC’s Fishery Management Plan forage group (capelin, sand lance, eulachon, herring, myctophids, bathylagids, euphausiids, and squids). In the Arctic (Chukchi and Beaufort Seas), Arctic cod is the key forage species, while lesser abundant species including capelin, saffron cod, and Arctic sand lance are important in coastal waters.

The following is a summary of knowledge gaps and research priorities identified for each LME:

GOA

- Abundance and distribution of key forage species to assess their availability to predators.
- Characterization of the food web in all seasons.
- Availability and importance of benthic prey to predators.

BSAI

- Current and future impacts of long-term changes in environmental variability on forage species.
- Resolving uncertainty in the role/influence of forage species in BSAI food webs.
- Improving characterization of habitat needs and ecosystem roles of understudied species that occupy off-shelf waters (e.g., myctophids, squids).

Arctic

- Limited understanding of Arctic cod population dynamics and their distribution.
- Movement of sub-Arctic species into the Arctic.
- Identifying mechanistic links between forage species and oceanographic conditions.

Our research recommendations to AFSC leadership are organized into three management needs:

1. Understand and report direct and indirect fishery impacts on forage species.
    - Monitor abundance and species composition.
    - Estimate status of the forage community relative to ecosystem requirements.
    - Identify habitat utilization for forage species.
    - Improve essential fish habitat (EFH) Component 7.
    - Treat impacts on forage species as "fishing effects" in EFH.

2. Understand the impact of changes in forage species on their managed predators.
    - Further develop synoptic versions of zooplankton indicators.
    - Understand connections between prey population dynamics and predator productivity.
    - Attribute changing productivity to forage species.

3. Measure ecosystem status to support sustainable fisheries.
    - Determine the quantity and quality of prey for species of commercial and conservation importance to achieve fitness, reproductive success and growth.
    - Define the general structure and characteristics of energy transfer through the food web.
    - Understand top-down effects through predator removals.
    - Parameterize ecosystem models to include availability of forage species.
    - Improve ROMS-NPZ.

Implementing these recommendations would benefit from fostering collaborations to combine prey data across predator groups, reporting those data by supporting partnerships within and outside NOAA, and centralizing forage species information. Increased collaboration among modelers, field teams, and experimental groups will also be important for improved process understanding of forage species in Alaska's LMEs.

Knowledge gaps for priority forage species should direct prioritization of future AFSC research in this area. To address these gaps in the next 5–7 years, we provide recommendations to improve monitoring and inform future research priorities that encompass the following:

- Minor to moderate changes to existing surveys.
- Utilizing or developing analytic approaches using existing data.
- Potential new data sources.
- Opportunities for expanding collaborations and improve information sharing within and outside AFSC.
- Using process studies to better understand the habitat characteristics required to support critical life stages, as well as identify which life history stages are most sensitive with impacts on survival and recruitment.

Introducing the Forage Congress

The Forage Species Congress (hereafter the Congress) aimed to improve the AFSC's state of knowledge regarding forage species in Alaska's LMEs (Fig. 1) by addressing the following objectives:

1. Identify species and species groups that serve important ecosystem roles as forage in Alaska LMEs.
2. Assess forage-related research efforts at the AFSC and other institutions.
3. Identify major scientific goals for forage-related research across the AFSC and associated knowledge gaps, and identify paths to improve data collection, analysis, and information-sharing.
4. Provide specific recommendations to Center leadership regarding (1) important ecological and management questions that could be addressed in the next 5–7 years and (2) organization of cross-program forage research.

This report synthesizes information from plenary discussion and breakout groups (Appendix 1), starting with topics identified in topical presentations (on Day 1) and breakout groups (Day 2). For each breakout group, topics were discussed Alaska-wide and by grouping Alaska's LMEs within each of their respective NPFMC Fishery Management Plan (FMP) areas (Table 1): GOA, BSAI, and Arctic.

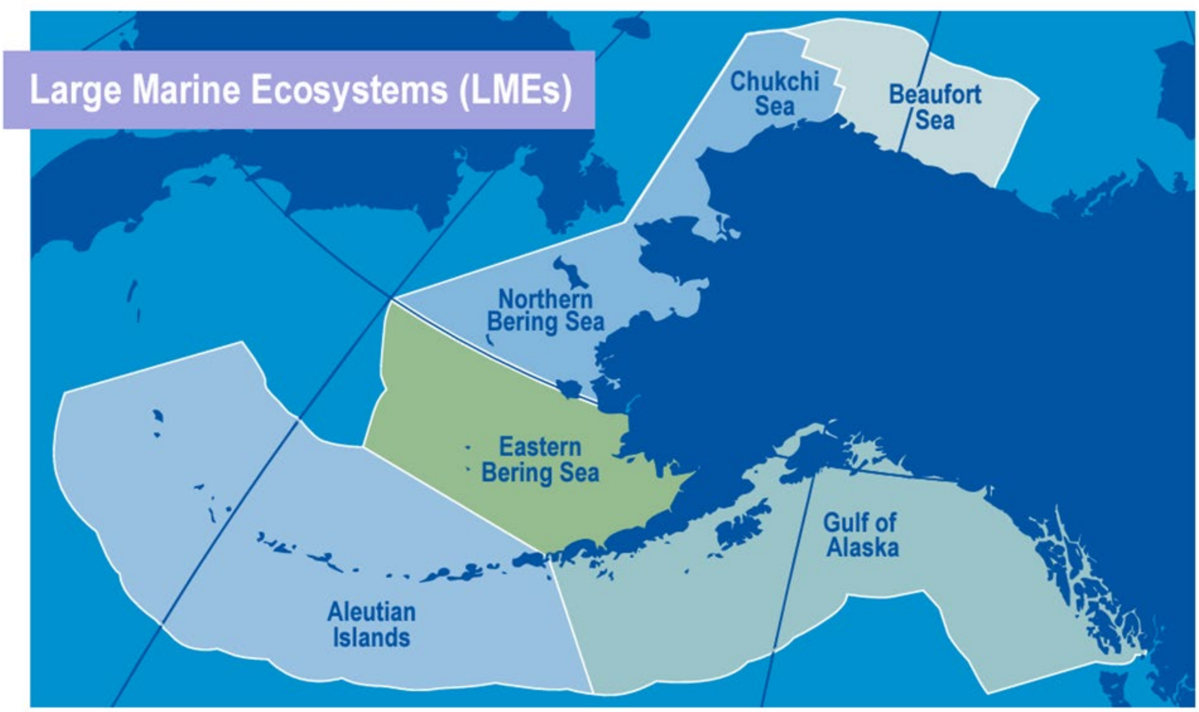

Figure 1. -- Large marine ecosystems in Alaska.

Objective 1: Identifying Major Forage Taxa

1.1. Overview of forage species in Alaska LMEs and fishery management

Forage species are not easily identified taxonomically; we instead adopt a definition based on their functional role; that is, as species that contribute substantially to the volume or energetic quality of forage for species of importance for commercial or subsistence fisheries, or protected species (Table 1). This definition does not include species with limited active mobility like copepods, infauna, or immobile epifauna.

Forage species are managed in Alaska via diverse methods and by a patchwork of authorities under federal FMPs managed by the NPFMC and by the State of Alaska (Table 1):

- "FMP" forage fish group: a large and diverse group, comprised of over 50 species of fish (i.e., smelts, sand lance, pricklebacks, gunnels, myctophids, blacksmelts, bristlemouths) and krill; targeting is prohibited under FMP amendment 36 (1998), which states that 1) there is no directed fishing, 2) there is a 2% maximum retention allowance, and 3) processing is limited to fishmeal. Alaska passed similar regulation in 1999 but with no limits on processing.
- Herring: Commercial fisheries in Alaska state waters are managed by the State of Alaska, primarily for herring roe and bait in Southeast Alaska (SEAK), Kodiak, Bristol Bay (Togiak), and Norton Sound. Herring are managed as a Prohibited Species in federal groundfish fisheries, which means directed fishing is banned and all bycatch must be returned to the sea immediately.
- Shrimp: Commercial fisheries for pandalids in state waters managed by the State of Alaska, currently closed in the BSAI area and mostly limited to SEAK in the GOA.
- Juvenile groundfishes: Adult walleye pollock (*Gadus chalcogrammus*, hereafter pollock) and Pacific cod (*Gadus macrocephalus*, hereafter P. cod) are targeted by large commercial fisheries that are federally managed. In the federal Arctic FMP, Arctic cod (*Boreogadus saida*) are considered a target species but directed fishing is currently prohibited due to data limitations and ecosystem concerns.
- Juvenile hexagrammids: Adult Atka mackerel (*Pleurogrammus monopterygius*) are federally managed in targeted fisheries in the Aleutian Islands and as bycatch in the GOA. Lingcod (*Ophiodon elongatus*) are managed by the State of Alaska in state and federal waters. Other greenlings (*Hexagrammos* spp.) are caught incidentally and not managed as commercial, sport, or subsistence fisheries (J. Sullivan, AFSC, pers. comm.).
- Juvenile salmon: The commercial harvest of adults is managed by the State of Alaska in all areas except federal waters within Cook Inlet where all salmon fishing is managed under a recently amended federal FMP (NPFMC et al. 2024). Outside the Cook Inlet area, juvenile and adult salmon are considered Prohibited Species in federal waters and bycatch must be returned to the sea.
- Crab: Adults are managed jointly by the state and federal governments. In federal groundfish FMPs, king and Tanner crabs are considered Prohibited Species.
- Squid: Squid are federally managed as Ecosystem Components. Directed fishing is prohibited and retention is limited to 20% of individual commercial catches.

Table 1. -- Types of forage species in Alaska marine ecosystems, including key taxa and their respective names referred to in this report.

Forage species type	Key species	Report name
FMP forage group [1]		
Osmeridae (smelt)	Eulachon (*Thaleichthys pacificus*)	eulachon
	Capelin (*Mallotus* spp.)	capelin
Ammodytidae	Pacific sand lance (*Ammodytes personatus*)	sand lance
Trichodontidae	Pacific sandfish (*Trichodon trichodon*)	sandfish
Stichaeidae		pricklebacks
Pholidae		gunnels
Myctophidae (lanternfish)		myctophids
Bathylagidae	Northern smoothtongue (*Leuroglossus schmidti*)	blacksmelts
Gonostomatidae		bristlemouths
Euphausiacea (krill)	*Thysanoessa* spp. and *Euphausia pacifica*	euphausiids
Herring [2]	Pacific herring (*Clupea pallasii*)	herring
Shrimp [3]	Pandalids (*Pandalus* spp., *Pandalopsis dispar*)	shrimp
	Crangonids (*Crangon* spp.)	
Juvenile groundfish [4]	Walleye pollock (*Gadus chalcogrammus*)	pollock
	Pacific cod (*Gadus macrocephalus*)	P. cod
	Arctic cod (*Boreogadus saida*)	Arctic cod
Juvenile Pacific salmon [5]	*Oncorhynchus* spp.	salmon
Juvenile Hexagrammidae (greenlings)	Atka mackerel (*Pleurogrammus monopterygius*) [4]	Atka mackerel
	Lingcod (*Ophiodon elongatus*) [6]	lingcod
	Hexagrammos spp. [7]	greenlings
Juvenile invertebrates [6]	Snow crab (*Chionoecetes* spp.)	crab
Squid [8]	Magistrate armhook squid (*Berryteuthis magister*)	squid
	Unidentified squid	

[1] Comprises those forage species included as Ecosystem Components in the federal FMPs for the Gulf of Alaska and Bering Sea/ Aleutian Islands regions.
[2] State management in AK waters, federal Protected Species.
[3] State management in AK waters.
[4] Federal management of adults.
[5] State management of adult harvest outside Cook Inlet, and federal management of juvenile and adult bycatch and all salmon fishing in federal waters within Cook Inlet.
[6] State management of adults.
[7] No federal or state management.
[8] Federal management of bycatch.

Federal management involves a biennial forage report included in the Stock Assessment and Fishery Evaluation (SAFE; e.g., Szuwalski 2022, Szuwalski et al. 2023, Vollenweider et al. 2024) reports to the NPFMC. The report includes abundance trends, catch data, and various special topics. Forage species information is also included in the annual Ecosystem Status Report (ESR; e.g., Ferriss 2023, Ortiz and Zador 2023, Siddon 2023) where, for example, time series of euphausiid and Pacific capelin (*Mallotus catervarius*, hereafter capelin) abundance are emphasized as one of the 10 important indicators for the eastern Bering Sea (EBS) and western GOA, respectively.

Management of forage species in Alaska is challenging due to the difficulty of adequately surveying species that are typified by pelagic, patchy and/or nearshore distributions. The major surveys used to monitor Alaska fish populations are designed to sample adult fishes and most do not access areas where a large fraction of forage abundance occurs. As a result, biomass estimates for forage species are highly uncertain and likely underestimate population size. For example, biomass estimates for capelin in the GOA from bottom trawl surveys, acoustic-trawl surveys and ecosystem-model estimates differ by orders of magnitude (Table 2).

Table 2. -- Comparison of survey-based biomass estimates (metric tons) for capelin, eulachon and sand lance in the Gulf of Alaska (GOA) with a food web model (Ecopath) consumption-based biomass estimate for 1990 to 1993 (Aydin et al. 2007). Biomass estimates from summer GOA bottom trawl and summer GOA acoustic-trawl surveys (capelin only) are reported as the mean (range) for biennial surveys conducted from 2013 to 2023.

Species	Bottom trawl survey	Acoustic-trawl survey	Ecopath model
Capelin	2,432 (142 – 5625)	36,192 (3,284 – 147,107)	2,050,112
Eulachon	47,011 (16,858 – 108,649)	–	335,636
Sand lance	11 (3 – 25)	–	712,880

1.2. Forage species in ecosystem-based fisheries management

In addition to the single-species stock assessments for particular forage species in SAFE chapters for the BSAI and GOA FMP areas, this Congress summarized the importance of forage species for ecosystem-based fisheries management (EBFM), which is understood to account for:

- Trophic interactions; for example, how forage species contribute to a system-level maximum sustainable yield (MSY).
- Spatial overlap between multiple human uses and economic sectors; for example, how localized commercial harvest or bycatch might affect subsistence access and protected species productivity.

- Single-species population dynamics and assessment; for example, time series of forage species abundance might be suitable as indices for predicting spatial or temporal variation in demographic rates for focal and assessed species.
- Environmental attribution and projections; for example, how much of previous changes in distribution, abundance, and composition of forage can be attributed to previous environmental impacts (temperature and acidity changes) and how are these likely to change under future environmental variability.

This expansive definition of EBFM is currently implemented by multiple agencies and is not under the sole jurisdiction of NOAA's National Marine Fisheries Service (NMFS) or the NPFMC.

Forage fish are discussed in some Alaska strategic plans, but not yet directly informing EBFM. The Alaska region has Climate Regional Action Plans (Shotwell et al. 2023, Dorn et al. 2023) that highlight the importance of forage fish monitoring and research to inform trophic dynamics throughout the ecosystem, including groundfish recruitment. The most encompassing planning document available for Alaska regions is the Bering Sea Fisheries Ecosystem Plan (BSFEP; (NPFMC 2019), which was developed by the NPFMC with input from partners including the AFSC. The BSFEP includes two action "modules," which could incorporate information regarding forage species:

- Environmental analysis; for example, where access to forage will determine whether focal species can compensate for temperature increases by increasing consumption or not.
- Incorporating local and traditional knowledge into fisheries management; for example, where northern Bering Sea communities are often interested in subsistence harvest of species that are not targeted commercially.

The Congress noted that some stock assessments have sought to incorporate environmental variables as covariates for demographic processes. Ocean physics, phytoplankton, and zooplankton dynamics are increasingly feasible to predict using Regional Ocean Modelling Systems (ROMS) (Sullaway et al. 2025), but mobile forage species are likely to be difficult to forecast using ROMS. Forage species may be critical for interpreting environmental impacts on stock assessments and therefore monitoring and process research for forage species will continue to be necessary in coming years.

1.3. Key predator-prey relationships (fishes, birds, marine mammals)

Key ecological predator-prey relationships can be described by three perspectives: the predator, the prey, and the food web. Key relationships from the predator perspective reflect the availability, abundance, and nutritional quality of its primary prey. From the prey perspective, key predators are those with higher contributions to its predation mortality. The food web perspective reflects the portfolio of predators and prey species, and how they contribute to the stability, resilience, and general transfer of energy through the system.

A predator's prey base can be influenced by the prey's spatial variation (e.g., tufted puffins *Fratercula cirrhata*: Sydeman et al. 2017), distribution or predator-prey overlap (e.g., P. cod and capelin: Ciannelli and Bailey 2005), environmental variation (e.g., zooplankton: Kimmel and Duffy-Anderson 2020); sea ice extent: Siddon et al. 2020), nutritional quality (e.g., sand lance:

von Biela et al. 2019); sablefish *Anoplopoma fimbria*: Coutré et al. 2015), and phenology (e.g., larval P. cod: Laurel et al. 2021). Variability in these prey characteristics may impact predator growth, fitness and/or reproductive success (e.g., Gjøsæter et al. 2009, Cury et al. 2011, Robinson et al. 2015), as demonstrated by the dramatic die-off of the common murre (*Uria aalge*) during the GOA 2014–2016 marine heatwave (Piatt et al. 2020). Understanding basic diet information for species that are commercially fished, are ecologically significant, and/or of conservation concern is important. The next step is to understand, and ideally predict, how these diet compositions (and prey nutritional quality) can vary across spatial, environmental, and temporal gradients.

The prey perspective focuses on the predator landscape for a given prey population. Often a few predators account for most predation on a given species. In addition, some species are more influenced by predation mortality than fishing mortality or food availability. As an example, GOA pollock is more influenced by predation mortality (primarily by arrowtooth flounder *Atheresthes stomias*) than other sources of mortality (Gaichas et al. 2010, Holsman et al. 2016, Barnes et al. 2020). Identifying key populations that are influenced by predation mortality (Oken et al. 2018, Barnes et al. 2020), and understanding the foraging behavior, spatial dynamics (e.g., mobility), and energetic requirements of those predators (e.g., Holsman and Aydin 2015) can advance our ability to characterize and predict changes in predation mortality under varying environmental conditions.

Key predator-prey relationships can also influence ecosystem stability and resilience. The species contributing to prey and predator landscapes can vary due to environmentally-induced distribution shifts (e.g., market squid: Burford et al. 2022). The level of covariance between various species in the prey and predator functional groups can influence food web stability (Thorson et al. 2018). Ecosystem stability could be better understood and predicted through the development of early warnings of change due to shifts in energy transfer through forage species (e.g., Arimitsu et al. 2021), understanding of simultaneous effects of ocean temperature on key predators and prey (P. cod: Barbeaux et al. 2020), thermal ranges (Laurel et al. 2016, Laurel and Rogers 2020), and developing our mechanistic understanding of how changes in the system affect other species.

Objective 2: Inventory Major Research

2.1. Forage species surveys

Active and historical AFSC surveys

Forage species have been sampled by dozens of active and historical monitoring programs conducted in all of Alaska's LMEs by federal agencies including the AFSC, Alaska state agencies, and other institutions (Appendix Table A-2). However, few of the surveys conducted by the AFSC were designed to directly sample forage species and they do not have the spatial and temporal coverage needed for long-term monitoring in federal waters. The primary surveys and monitoring programs that are currently active, as well as the historical surveys that sampled forage species, have been conducted by the AFSC's Resource Assessment and Conservation Engineering (RACE) Division and Auke Bay Laboratories (ABL) and are summarized below by each of Alaska's LMEs.

In the GOA, small pelagic fishes (e.g., capelin, eulachon, herring) and juvenile gadids (age-1+ pollock and P. cod) are routinely sampled during the primary fisheries-independent surveys conducted biennially during odd years by RACE to monitor groundfish abundance: the GOA bottom trawl survey conducted in summer by the Groundfish Assessment Program (GAP), the summer GOA pollock acoustic-trawl survey conducted by the Midwater Assessment and Conservation Engineering (MACE) Program, and the annual winter Shelikof Strait and Shumagin Islands pollock acoustic-trawl surveys conducted by MACE. The summer GOA pollock acoustic-trawl survey (McGowan et al. 2025) also provides a time series of euphausiid abundance that begins in 2003 (Simonsen et al. 2016, Ressler 2019). The Recruitment Processes Program (RPP) within RACE conducts some of the few surveys targeting forage species by the AFSC in partnership with the NOAA Pacific Marine Environmental Laboratory (PMEL) as part of the Ecosystems and Fisheries Oceanography Coordinated Investigations (EcoFOCI) Program. The EcoFOCI-led surveys include the biennial spring larval fish survey and the biennial late-summer, small-mesh trawl survey that was designed for age-0 pollock but also regularly samples small pelagic fishes. A current ABL study ground-truthing the juvenile P. cod individual-based model predicting nearshore settlement areas across the entire GOA is assessing juvenile gadids and other forage species (K. Miller, NMFS, pers. comm.). At smaller spatial scales, the Kodiak and expanded juvenile cod surveys conducted annually by the Fisheries Behavioral Ecology Program (FBEP), in partnership with Alaska Coastal Observations and Research (ACOR), targets age-0 and age-1+ P. cod in shallow nearshore waters of the Kodiak Archipelago and Alaska Peninsula. The Southeast Coastal Monitoring survey (SECM) is conducted annually by ABL to sample juvenile salmon in the inner waters of SEAK using a surface trawl. In the Aleutian Islands, GAP conducts a biennial summer bottom trawl survey during even years, alternating with the odd-year GOA summer bottom trawl survey.

Several historical surveys are important data sources for forage species in the GOA. ABL conducted the GOA assessment survey from 2011 to 2017 in the eastern GOA, sampling larval fish with bongo nets and targeting age-0 groundfish and juvenile salmon in the upper 20 m water column using a surface trawl while also catching some small pelagic fishes (Moss et al. 2016). As part of the North Pacific Research Board (NPRB)-funded GOA Integrated Ecosystem Research Program (IERP) in 2011 and 2013, the GOA assessment survey also covered the central GOA and included summer and fall surveys along with acoustic and midwater trawl sampling (McGowan et al. 2019a). Another project component conducted seasonal nearshore surveys inventorying fish and invertebrates using acoustics, beach seines and small midwater and bottom trawls (Ormseth et al. 2017). During the early 2000s, the Fisheries Interaction Team and EcoFOCI Program conducted acoustic-trawl surveys of Barnabas and Chiniak Troughs in the central GOA to sample juvenile pollock and capelin over a 5-year period (Hollowed et al. 2007, Logerwell et al. 2007, 2010a). In the inside waters of SEAK, ABL assessed Steller sea lion prey availability quarterly from 2001 to 2004 using acoustic-trawl surveys and long-line sampling (Sigler et al. 2009, Csepp et al. 2011). Subsequent spinoff studies focused on herring (Boswell et al. 2016) and eulachon (Csepp et al. 2017) in the same area. Additionally, a variety of small, focused ABL studies have quantified nearshore fish species that are archived in the Nearshore Fish Atlas of Alaska[1] (Grüss et al. 2021).

In the EBS, forage species are primarily sampled during the following surveys: annual summer bottom trawl surveys of the continental shelf in the EBS and northern Bering Sea (NBS)

[1] https://www.fisheries.noaa.gov/alaska/habitat-conservation/nearshore-fish-atlas-alaska

conducted jointly by GAP and the Shellfish Assessment Program (SAP); the annual Bering Arctic Subarctic Integrated Survey (BASIS) conducted by ABL and RPP that targets age-0 groundfish, small pelagic fishes, and juvenile salmon primarily using a surface trawl; the biennial spring larval survey conducted by EcoFOCI; and the biennial summer EBS pollock acoustic-trawl survey (Stienessen et al. 2025) conducted by MACE that targets age-1+ pollock and also provides an index of euphausiid abundance (Ressler et al. 2012, Levine and Ressler 2024). Biennial surveys in the Bering Sea are conducted during even years, and all of the above Bering Sea surveys, except for the pollock acoustic-trawl survey, were canceled during 2020 due to the COVID-19 pandemic. Historically, GAP also conducted the EBS bottom trawl survey of the continental slope from 2002 to 2016. EBS forage species were also the focus of acoustic-trawl surveys conducted by ABL, RACE, and the University of Washington in 2004 and 2006-2010 as part of the Bering Sea IERP (Benoit-Bird et al. 2011, Sigler et al. 2012, Parker-Stetter et al. 2013).

Across the GOA, Aleutian Islands, and Bering Sea LMEs, forage species information is collected by the AFSC's Coordinated Seabird Studies group (CSS) while conducting the NOAA Pacific Seabird Necropsy Project. In all three LMEs, information on herring is collected by the North Pacific Observer Program in federal waters where it is managed as a prohibited species. Forage species information is also collected by the Marine Mammal Laboratory (MML) while conducting opportunistic food habitats studies of Steller sea lions (*Eumetopias jubatus*) in the GOA and Aleutian Islands and northern fur seals (*Callorhinus ursinus*) in the EBS (Pribilof and Bogoslof Islands).

In the Arctic, where commercial fisheries are prohibited, large-scale assessment surveys have not been conducted for extended periods. AFSC staff have participated in single- or brief multiple-year studies involving other agencies and institutions that have contributed to our knowledge of forage species in this region. In 2007, the BASIS survey was extended from the NBS into the Chukchi Sea (Eisner et al. 2013). The North Slope Borough (NSB) led the Shelf Habitat and Ecology of Fish and Zooplankton (SHELFZ[2]) project in partnership with the AFSC and other institutions that supported acoustic and trawl surveys of the Chukchi Sea in 2012 and 2013 (De Robertis et al. 2017b) that characterized distributions of age-0 Arctic cod and pollock along with other forage fishes. Additional acoustic and trawl surveys in the Chukchi were conducted in 2017 and 2019 as part of the NPRB-supported Arctic IERP in partnership with the AFSC (Levine et al. 2023). In the Beaufort Sea, ABL staff conducted the Cooper Island beach and nearshore survey from 2004 to 2007 and 2009 (Johnson et al. 2010). In partnership with the AFSC, an ichthyoplankton and acoustic-trawl survey of the Beaufort shelf and slope was conducted in 2008 in an area being considered for future oil and gas exploration (Logerwell et al. 2010b, Parker-Stetter et al. 2011), while the NSB supported the Shell Baseline Studies Program from 2012 to 2015 that provided more comprehensive information on forage species in brackish lagoons and along the Chukchi and Beaufort shelf near Pt. Barrow (Vollenweider et al. 2018).

[2] https://www.north-slope.org/departments/wildlife-management/studies-research-projects/oceanography-sea-ice/oceanography-sea-ice-research/shelfz/

Surveys conducted by AFSC partners

Externally supported programs and grant-funded surveys that have facilitated collaborations between the AFSC and other institutions such as those in the Arctic have also been essential for supporting time series of forage species in the other LMEs. The U.S. Geological Service (USGS), U.S. Fish and Wildlife Service (USFWS), Alaska Department of Fish and Game (ADF&G), and other non-governmental organizations conduct a wide variety of monitoring programs that target or indirectly sample forage species on their own or in partnership with the AFSC or other partners (Appendix Table A-2). Most of these monitoring programs rely upon external funding, primarily from the Bureau of Ocean and Energy Management (BOEM), NSB, NPRB, the *Exxon Valdez* Oil Spill Trustee Council, the USFWS's Coastal Impact Assistance Program, or National Science Foundation (NSF).

Most of these surveys are typically conducted at small spatial scales (10s to 100s km) in nearshore waters as compared to AFSC stock assessment and ecosystem surveys (100s to 1,000s km) conducted over the shelf and slope, but some provide the longest time series for forage species in the Northeast Pacific. The ADF&G and AFSC small-mesh bottom trawl survey for shrimp along the Alaska Peninsula and Kodiak Island was first conducted in 1953 and has been used to characterize the abrupt decline of capelin and shrimp following the late-1970s regime shift (Anderson and Piatt 1999). A variety of surveys designed to monitor herring from the Togiak, Kodiak, Kamishak, Prince William Sound, Sitka, and other SEAK populations have been conducted in spring by ADF&G since the 1970s to support commercial herring fisheries in state waters, employing different gears and sampling approaches best-suited for the local area. Other small-scale surveys designed to monitor herring and other forage species (e.g., capelin, sand lance) in Cook Inlet (Abookire and Piatt 2005, Arimitsu et al. 2021b), Prince William Sound (Pegau 2013, Neher et al. 2015, Arimitsu et al. 2018, 2021a), SEAK (Renner et al. 2012, Arimitsu et al. 2016), and in nearshore waters along the GOA coast (Arimitsu et al. 2012, 2016) have been conducted by USGS and the Herring Research and Monitoring Program since the 1990s. The USGS surveys initially focused on one or two areas for a period of 1–5 years, but in the past decade have shifted towards long-term monitoring in Prince William Sound and lower Cook Inlet as part of the Gulf Watch Alaska forage fish project to extend these time series. More recently, long-term monitoring of euphausiids and other zooplankton species, which has occurred along the Seward Line since the late-1990s, was expanded in 2018 by the NSF-supported northern GOA Long-Term Ecological Research (LTER) project to sample euphausiids and larval forage species during tri-annual surveys in the northern GOA to maintain seasonal and annual time series while supporting process studies[3]. In the Arctic, the NSB has conducted surveys of Elson Lagoon and North Salt Lagoon near Utqiaġvik since 2009, representing one of the longest time series in U.S. Arctic waters (Sformo et al. 2019). A long running study in the autumn of 2005 to 2015, conducted by Woods Hole Oceanographic Institute, documented euphausiid hotspots as a major foraging base by Utqiaġvik (Ashjian et al. 2021). Another study by USGS evaluated nearshore fish assemblages during three, 3-year periods of variable ice cover in the eastern Alaska Beaufort from 1988 to 2019 (von Biela et al. 2023).

[3] https://nga.lternet.edu/research/

Survey biases and limitations

The sampling design and gear used in many of these surveys are poorly suited for accurately detecting changes in forage species abundance and distribution. Survey designs that sample at fixed stations or use fixed-depth gear are not as effective for monitoring forage fish that are highly aggregative and vary their vertical position (e.g., O'Driscoll et al. 2002, McQuinn 2009, Parker-Stetter et al. 2013). In the GOA, shifts in vertical position of capelin relative to bottom depth have been shown to affect their availability to different sampling gear used in the primary monitoring surveys, where differences in capelin encounter rates in bottom depths shallower or deeper than 100 m were evident between the bottom trawl, small-mesh pelagic trawl, and multiple acoustic-trawl surveys with overlapping horizontal spatial coverage (McGowan et al. 2020). Survey data for forage species are also potentially limited by sampling biases associated with gear selectivity (Williams et al. 2011, De Robertis et al. 2017a, 2021) temporal sampling (e.g., differences in diel catch rates; McGowan et al. 2019b), vessel avoidance (De Robertis and Handegard 2013), and/or uncertainties in acoustic identification of non-focal species. These selectivity differences may result in order of magnitude differences in catch-per-unit-effort (CPUE) measurements among AFSC surveys (McGowan et al. 2020) that can lead to conflicting trends in abundance indices (Ferriss and Zador 2021). Reliance on data from surveys with spatial and temporal coverage designed for other species is further complicated by variable ontogenetic habitat use of forage fish that may span large spatial domains and/or migratory behavior that affects their availability to the survey (e.g., spawning migrations from offshore shelf habitat to nearshore waters outside the survey area).

Indices and survey products from AFSC surveys

Despite the limitations of available data sources, many survey products are used in ESRs, stock assessments, ecosystem and socioeconomic profiles (ESP), and the forage species chapter in the BSAI and GOA SAFE reports. AFSC and non-AFSC surveys contribute multiple indices that are used as key report card indicators in ESRs for the EBS, GOA, and Aleutian Islands regions. These include indices for euphausiids and pelagic forage fish biomass in the EBS ESR from the summer EBS pollock acoustic-trawl survey and BASIS survey, respectively, and for Sitka herring mature biomass from the ADF&G stock assessment as an indicator of forage fish trends in the eastern GOA. Numerous other relative abundance indices for forage species -- including but not limited to larval fish, age-0 pollock and P. cod, age-1 groundfish, capelin, eulachon, herring, sand lance, shrimp and squid -- are generated from AFSC and non-AFSC surveys for the annual ESRs (Ferriss and Zador 2022, Siddon 2022), species-specific stock assessments and ESPs, and/or the biennial forage species chapter in SAFE reports (Szuwalski 2022, Szuwalski et al. 2023). Survey-based indices of forage species are also used as inputs in food web and ecosystem models (e.g., Holsman and Aydin 2015, Adams et al. 2022), with model outputs such as estimates of natural mortality of age-1 pollock and other groundfish species from the CEATTLE model, a multi-species statistical catch-at-age assessment model (Holsman et al. 2016), included in ESRs (Ferriss and Zador 2022, Siddon 2022) and stock assessments (e.g., Ianelli et al. 2022). Survey products are also used to generate distribution maps for Essential Fish Habitat (EFH) reports (Harris et al. 2022, Laman et al. 2022, Pirtle et al. 2023).

2.2. Process studies

Process studies are an important component of the AFSC forage species research portfolio, used to develop a mechanistic understanding of factors controlling forage species community composition, condition, survival, abundance, distribution, and nutritional value. Collectively these aspects of forage species ecology determine the energy available to predators throughout the ecosystem, which includes harvested species and protected resources (e.g., Logerwell and Schaufler 2005). Once mechanisms are determined, easily-measured proxy indicators can be identified that are informative for fish survival and recruitment. Process studies can also be used to determine the time frames over which changes in environmental conditions are reflected in fish condition, and consequently the temporal scale over which indicators should be measured. In this capacity, process studies are crucial for directing monitoring efforts. Additionally, process studies provide a response range with which to validate and contextualize field-measured values. Process studies can also be focused to make existing datasets more informative, for example, in evaluating the impact of differential digestion rates used in stomach contents time series.

Process studies at the AFSC take many forms, often integrating across field studies, biological and analytical laboratory analyses, and laboratory experiments (e.g., Wilson et al. 2006, Logerwell et al. 2010a, Laurel et al. 2016, Copeman et al. 2020). Broad-scale programs such as regional ecosystem-focused studies (e.g., NPRB IERPs) facilitate field work to measure abundance and distribution of forage species and associated environmental parameters. Laboratory analyses are used to characterize diet (stomach contents analysis, stable isotope content), condition, and nutritional quality (energy and lipid content) of forage species from those collections (e.g. Wilson et al. 2009, Copeman et al. 2020). Experimental studies with manipulated laboratory conditions (e.g., diet type, ration, water temperature) are used to test correlations observed in field studies for mechanistic linkages (e.g., Laurel and Rogers 2020). AFSC's husbandry facilities enable the measurement of vital rates and determination of physiological responses and thresholds of forage species to perturbations such as thermal and nutritional stress (Laurel et al. 2016).

2.3. Fish predator food-habits research

The AFSC's Resource Ecology and Ecosystem Monitoring (REEM) Program's North Pacific groundfish diet database contains stomach content and prey length data collected in groundfish surveys between 1981 and the present (Livingston et al. 2017). Containing over 400,000 predator diets from more than 200 species, the database provides access to information on forage species as prey and in areas not well sampled by surveys[4].

When predators are considered as samplers, predation rates on forage species can be inferred and used to derive relative abundance indices for prey biomass. The predation rate on a forage species of interest can be derived from the product of predator biomass (estimated from a survey or stock assessment), the proportion of the prey species in the predator diet, and the predator's bioenergetics-based consumption rate (Barnes et al. 2020). An alternative approach for using diet data to infer abundance of forage species is to use spatio-temporal models to estimate the biomass of a forage species based on the product of its mass as prey in a predator stomach by the predator's total biomass (Grüss et al. 2020, Ng et al. 2021, Reum et al. 2025). Spatially-explicit

[4] https://www.fisheries.noaa.gov/alaska/ecosystems/groundfish-diet-data-description

indices of predation rates and prey biomass may be useful to management as an indirect approach for inferring abundance of forage species that are poorly sampled by surveys.

Additional work is needed to quantify sources of bias in predator diet information. For example, temperature and prey traits (e.g., energy density, exoskeleton strength) will influence stomach contents, yet digestion rates are often assumed to be constant when calculating diet proportions. Efforts should be directed towards identifying which parameters and experiments are needed to extract more/better information from the available diet data and to improve our understanding of mechanistic relationships that affect digestion processes and foraging behavior. Laboratory gut evacuation studies were identified as a high priority, as well as identifying opportunities to increase stomach collections in fall/winter/spring (J. Reum, AFSC, pers. comm.).

2.4. Seabirds as samplers

Seabird diets have long been used to monitor the relative abundance of forage species in Alaska's LMEs. Seabirds have evolved to catch forage species, making them good samplers, and may be logistically easier and cheaper to monitor relative to directly sampling some forage species. As central place foragers, seabirds nest on land during the breeding season and provision their chicks by capturing prey at sea and returning to their nest. There are different approaches for collecting seabird-based forage species samples, including burrow screening, capture and regurgitation of stomach contents, visual identification of prey, and direct stomach collections. But foraging behavior and prey preference are analogous to survey gear selectivity, potentially biasing abundance trends, and need to be accounted for when generating time series and interpreting trends.

To use seabirds as samplers, the natural history and prey preferences of monitored seabird species need to be considered to understand what forage species and area a seabird-based index represents, and to account for potential biases. First, it is necessary to determine whether samples are from adults feeding themselves or provisioning chicks. For example, murres may consume low-quality fish and crustaceans at sea while foraging, but they will bring back (single) more energy-rich prey for chicks (Ainley et al. 2002, Drummond 2016). It is then necessary to treat natural history constraints and prey preferences similar to fisheries survey gear selectivity: is the seabird a surface feeder or does it dive for its prey; a zooplanktivore or piscivore; a prey specialist (i.e., prefers certain species) or a generalist (i.e., feeds more broadly on whatever is available and easiest to catch)? An index based on surface feeder diets should be similar to a surface trawl index, representing only the upper part of the water column (unless feeding is known to occur at night), whereas diets from a diving bird would represent a greater portion of the water column similar to an acoustic- or pelagic trawl-based index (sensu (Piatt et al. 2018). Likewise, a specialist feeder may be better suited for monitoring the relative abundance of certain forage species, while a generalist feeder may be better suited for monitoring a multispecies forage complex or detecting changes in the community composition of forage species in a specific area. The area represented by a seabird-based index also depends on the time of year samples are collected as the foraging range of seabirds decreases during the breeding season.

Seabird-derived forage species data have been used in a variety of applications to advance our knowledge of forage species in Alaska's LMEs. (Piatt et al. 2018) described the biogeography of multiple forage fish species in the GOA and Aleutian Islands using tufted puffin samples from

35 colonies, identifying core areas where forage species such as capelin concentrate that correspond with spatial patterns based on traditional surveys (McGowan et al. 2020). (Sydeman et al. 2022) also used diet samples from two puffin species (*Fratercula* sp.) and rhinoceros auklets (*Cerorhinca monocerata*) to estimate indices of age-0 pollock abundance that correspond with interannual variations in pollock spawning stock biomass (SSB) in the western GOA (lags SSB) and EBS (leads SSB). Seabird-based indices are currently used as report card indicators for forage fish abundance in the GOA and Aleutian Islands ESRs. The GOA ESR historically used the common trend identified by dynamic factor analysis in prey composition time series from multiple seabird and groundfish species as an indicator of capelin abundance, when groundfish diets are available from the biennial GOA bottom trawl survey (Zador and Yasumishii 2016); details in Section 2.7 of this report). Currently the report card indicator is based on the percent biomass of capelin from rhinoceros auklet chick diets at Middleton Island (Ferriss 2023). Similarly, tufted puffin chick diets are used as report card indicators for forage fish (sand lance, age-0 pollock, Atka mackerel) in the western and eastern Aleutian Islands (Ortiz and Zador 2023).

2.5. Marine mammals as samplers

Marine mammal predators offer a unique perspective into our understanding of the distribution and abundance of forage species because they are highly mobile, often utilize habitats that are unreachable by traditional surveys, and consume many forage species that are not actively monitored by state or federal agencies.

At the AFSC, marine mammal diet is measured using a variety of methods including identification of hard parts recovered from stomach or fecal samples, DNA metabarcoding, and stable isotope and fatty acid analysis of tissues (Iverson et al. 1997, Schell and Hirons 1999). Biologging technology including satellite location tags, dive recorders, and animal-borne video cameras are also used to infer diet and foraging behavior of marine mammals (Yoshino et al. 2020, Kuhn et al. 2022). A number of collaborative projects between MML and other AFSC Divisions have focused on joining marine mammal, fish and environmental data for a more holistic approach to species monitoring and management. Collaborative work between MML and MACE at AFSC included the integration of satellite location, dive, and video camera data from marine mammals with acoustic data on fish distribution and abundance collected using Saildrones (Saildrone, Inc.) and eventually from MACE pollock acoustic-trawl surveys (Kuhn et al. 2020). MML and ABL are collaborating to characterize the links between prey availability, environment, and foraging behavior of northern fur seals using DNA metabarcoding, stable isotope analysis, hard part analysis, satellite telemetry and eDNA. Similarly, a joint effort between AFSC, ADF&G, University of California Santa Cruz, University of San Francisco, and University of British Columbia is combining information from seal counts and distribution, stomach content and scat diet analysis, laboratory-based seal energetics, and prey energetics to estimate forage fish consumption by spotted seals (*Phoca largha*) in the Bering and Chukchi Seas (Boveng et al. In prep). Marine mammal diet data from MML were used to develop a bioenergetics model which provides consumption estimates of pollock by northern fur seals (McHuron et al. 2020); MML is collaborating with researchers from the AFSC's Resource Ecology and Fisheries Management (REFM) Division to incorporate these estimates into the CEATTLE model.

To best utilize marine mammals as samplers of forage species, additional research is needed to improve estimates of diet composition, prey numbers, and size. The primary approach to describe predator diet at MML is through the identification of prey hard parts recovered from scats. It is the only method that can provide prey numbers and size but requires a large time investment and individuals with highly specialized skills, making it extremely difficult to provide timely estimates. Furthermore, scats only represent a snapshot in time and are collected infrequently due to logistical constraints, so temporal resolution is very limited. Application of complementary and novel techniques will improve our ability to analyze data more efficiently, reduce biases and increase temporal coverage. For example, DNA metabarcoding of scat samples enables identification of species whose hard parts do not pass through in scats and can improve species resolution (Tollit et al. 2017, Trzcinski et al. 2024). Stable isotope analysis (e.g., of blood and whiskers) provides insights into foraging habitat and prey species over multiple time scales (Schell and Hirons 1999, Szpak and Buckley 2020).

2.6. Ecosystem modeling

Marine ecosystems are complex, and it is not always clear how limited resources should be allocated to monitor critical components that indicate impacts to managed species. Ecosystem models are useful tools for identifying key energy pathways and determining critical sensitivities. These models enable examination of structural sensitivities within an ecosystem, indicating what species interactions are most important and which species introduce the highest uncertainty, as well as assess what level of fishing fundamentally changes the system. Ecosystem models facilitate comparisons between adjacent systems (EBS vs. GOA), such as determining if priority forage species differ among ecosystems, which can inform research and monitoring priorities.

The primary food web models used for Alaska LMEs (Ecopath with Ecosim) are based on summer diet data for groundfish (Aydin et al. 2007, Gaichas et al. 2009, 2011, Whitehouse and Aydin 2020). While there is uncertainty in many of the model's components (e.g., diet proportion, total consumption), forage species have higher uncertainty than other species. A key assumption of the model is that, because we have higher certainty about groundfish consumption inputs (biomass, consumption rate, and diet) compared to forage species biomass and production, it's better to use groundfish (primarily) to estimate forage fish production.

(Aydin et al. 2007) models indicate that priority forage species and predators of key prey species differ among Alaska's LMEs, as well as highlighting the importance of forage species lacking effective monitoring. For example, myctophids and squids are relatively more important in the Aleutian Islands than in the EBS and GOA, most likely due to differences in bathymetry among the ecosystems. The models also highlight differences among ecosystems regarding which species are the primary predators for forage species. In the GOA, capelin are primarily consumed by groundfish (arrowtooth flounder, pollock, P. cod), and to a lesser extent by marine mammals, seabirds, and squid which are the primary capelin predators in the EBS and Aleutian Islands. In all three ecosystems, shrimp stand out as critical prey but remain among the more data-limited forage species (Whitehouse and Aydin 2020). This example demonstrates how an ecosystem model can be used to identify priority forage species for improved monitoring within an LME.

Additional ecosystem models are operational or in development for Alaska's LMEs. Examples include new and updated Ecopath models for the EBS, NBS, and western and eastern GOA; the

CEATTLE model for the EBS and NBS (Holsman et al. 2016) and its counterpart Rceattle for the GOA (Adams et al. 2022) that provide model outputs of environmental impacts on natural mortality, recruitment, and growth for pollock and other groundfish species; a whole-ecosystem model (Atlantis) developed for exploring mechanistic linkages between environmental and fishing mortality stressors and ecosystem processes in the GOA (Rovellini et al. 2025); and EcoState, a state-space mass-balance model (Ecopath with Ecosim) fitted to time series data (biomass indices and fisheries catches), that incorporates both bottom-up and top-down interactions (Thorson et al. 2025).

2.7. Integrating multiple datasets

Spatial and temporal fluctuations in the distributions of forage species affect their availability as prey to predators and monitoring. There is limited information on forage species due to a lack of directed fisheries (see Section 1.1), and nearly all existing AFSC surveys are not designed to sample them (see Section 2.1). Detecting temporal changes in distributions and abundances of forage species is further complicated by their aggregation behavior and variable ontogenetic habitat use that may span large spatial domains. Most studies of forage species in the Northeast Pacific have been limited by one or more of the following factors: temporal duration (typically ≤ 3 years); spatial coverage (e.g., study area of ~10s to 100s km vs. the population's range of ~1,000s km); sampling biases associated with fixed-depth gear, trawl selectivity, temporal sampling (e.g., differences in diel catch rates), and/or uncertainties in acoustic identification of small pelagic fish without directed trawling; and indirect sampling (e.g., abundance inferred from predator diets) (McGowan et al. 2020). Accordingly, there are limitations associated with using data from surveys designed for commercial species to assess non-targeted forage species, as the spatial coverage of the survey and sampling gear used may not be appropriate to quantify small pelagic fish occurrence and density.

Improved monitoring of forage species can be achieved in the absence of directed surveys by integrating multiple, independent data sources to compensate for their individual limitations. (McGowan et al. 2020) demonstrate a recent example from the GOA for capelin where CPUE data, from multiple AFSC surveys with different sampling gear and designs, were normalized and synthesized to characterize capelin spatial patterns. This approach identified core areas where capelin concentrate in years of low and high abundance over the continental shelf and in nearshore waters along the GOA. These core areas could be prioritized to improve monitoring of capelin.

Improved indices of relative abundance can also be developed through integration of multiple survey- and predator diet-based indices. A dynamic factor analysis (DFA), a type of principal components analysis for time series data, has been used in the GOA to detect common trends in relative abundance of capelin and sand lance from prey composition of predator diets for multiple groundfish and piscivorous seabirds (Zador and Yasumishii 2016). The capelin DFA index has been used as an ecosystem indicator for the western GOA, but it is limited by the lack of groundfish diet data in even years (see Section 2.1) and does not explicitly incorporate spatial information in the model. Similarly, recent research has extended DFA to allow expert knowledge about system linkages to be incorporated into a dynamic structural equation model (DSEM; (Thorson et al. 2024). DSEM has subsequently been used to synthesize information about forage indicators in the Bering Sea ESR (Siddon 2024).

Advances in spatiotemporal models now enable analysts to incorporate surveys of different data types in a single modeling framework to estimate shifts in habitat use and abundance trends of data-rich or -limited focal species. Spatiotemporal models have been fit to multiple, independent surveys that employ different gear and/or report different measurement units (e.g., presence/absence, count, biomass, CPUE) to estimate shifts in distribution, changes in the effective area occupied, or relative abundance (Perretti and Thorson 2019, Grüss and Thorson 2019). Environmental data can also be incorporated in these generalized linear mixed effects models as covariates to improve the precision of model estimates (Thorson et al. 2017, Perretti and Thorson 2019). A recent study combined survey-based CPUE data with predator diet-based indices of prey biomass (Grüss et al. 2020, Ng et al. 2021) to estimate a recruitment index for snow crab in the EBS (Grüss et al. 2023), demonstrating a promising approach for synthesizing multiple survey- and diet-based indices within an index standardization model for forage species in Alaska's LMEs.

Objective 3: Identify Major Scientific Goals and Knowledge Gaps

Separate breakout groups were organized by the three NPFMC FMP areas (GOA, BSAI, and Arctic) to discuss their respective data needs and management uses for prey species information. Priority forage species for each area were identified and discussed based on their management and ecological importance to highlight key knowledge gaps.

3.1. Gulf of Alaska

The GOA is a shelf ecosystem consisting of a shelf (< 200 m) and a shelf edge (200–300 m). The shelf is habitat for several prey species including age-0 pollock, herring, capelin, zooplankton, and juvenile salmon. The shelf edge and upper slope are habitat for several commercially important groundfish species that rely on these forage species as prey for their diets (Laman et al. 2022, Pirtle et al. 2023). Some of these groundfish species migrate to shallower waters to breed, and thus use different prey bases depending on the season.

In this section, GOA forage species are prioritized based on four different perspectives: spatial, temporal, ESRs, and predators. For the spatial perspective, the GOA was divided into subregions: western GOA, central GOA, and SEAK. The SEAK discussion was expanded to compare forage species between nearshore and offshore waters. In all GOA subregions, capelin, herring, eulachon, and sand lance are key forage species. Juvenile groundfish like age-0 pollock, euphausiids, and benthic invertebrate prey (e.g., polychaetes and other infauna and epifauna) were also identified as important forage species. Benthic prey was identified as a significant data gap for this region and other region, both in terms of their availability to predators and in terms of their contribution to predator diets.

A temporal perspective prioritizes forage species based on their seasonal availability to predators, as well as shifts in what predators eat depending on their life history stage. For example, seabirds need access to forage species especially in the winter, but groundfish predators are consuming forage species year-round. A full-year food web characterization is needed, and data on stomach contents and prey distributions could be used to fill in some data gaps without requiring new survey data. Some samples and data already exist outside the primary summer survey season, such as macrozooplankton information from winter acoustic surveys and EcoFOCI surveys in spring and fall. With additional staff time and resources, these data could be processed and methods developed to determine the usefulness of existing data and/or potentially identify and prioritize additional data collection needed to develop useful data products (e.g., collection of predator stomachs during winter surveys). Seasonal and interannual data on stomach contents and predator-prey overlap could be used to determine priority species, but disparate survey data need to be combined carefully in order to create a meaningful index.

ESRs offer another temporal perspective for identifying priority species. ESRs highlight datasets for species that are not necessarily the focus of a particular survey but are known to be ecologically important (e.g., euphausiids), and/or of specific importance to groundfish. ESRs offer opportunities to combine data across multiple surveys and predator diet data, as predators can be an effective sampling device for their target forage species (e.g., Gunther et al. 2024). Forage species described in the GOA ESR include zooplankton (e.g., euphausiids), herring, capelin, juvenile pollock, juvenile salmon, sand lance, and eulachon (Ferriss 2023).

From the predator perspective, the most important forage species should be those most prevalent in predator diets and/or with the largest nutritional contribution to predator diets. In this discussion, four key forage species were identified based on their prevalence in predator diets: herring, capelin, eulachon, and sand lance. Based on seabird diets, key forage species also include juvenile salmon, sablefish, and hexagrammids. Abundant and commercially important groundfish predators of forage species in the GOA consume juveniles of other groundfish species such as age-0 pollock.

Taken together, the forage species identified as the highest priority for data needs to support management in the GOA were capelin, eulachon, herring, juvenile gadids (age-0 pollock and P. cod), sand lance, and euphausiids.

Data gaps for these and other forage species were also identified. Abundance and distribution data for these species from most individual surveys are limited either in their spatial extent, temporal coverage, and/or biased sampling gear (see Section 2.1). For example, herring and other forage species surveys conducted in nearshore waters by ADF&G and USGS cover relatively small areas in coastal waters, compared to the much broader coverage of trawl surveys that target groundfish.

Estimates of capelin abundance from directed surveys (i.e., summer GOA pollock acoustic-trawl survey) are too short to provide reliable indices of abundance (< 10 years), requiring predator diet-based indices to be used as indicators of longer term (decadal) shifts in relative abundance. Most AFSC groundfish and ecosystem surveys do not incorporate trawl selectivity corrections in their survey estimates to account for low retention of small pelagic fishes, leading to biased density estimates. Similarly, euphausiids are not adequately captured in the most widely used zooplankton sampling gear. Diet data also primarily come from the summer surveys, and seasonal diet data could improve our ability to distinguish which forage guilds are important and when (Yang et al. 2006). Predator diets have already been successfully used to develop new indices for forage species (e.g., Sydeman et al. 2022) and could be further developed and integrated with existing survey data.

Data gaps in euphausiid abundance could be filled by analyzing existing acoustic data from surveys not targeting macrozooplankton. For example, backscatter indices from EcoFOCI spring and late-summer surveys (early 2000s to present) could be combined with summer MACE euphausiid indices and the NGOA LTER data (2016 to present) to get a three-season index for the GOA.

Data gaps also exist for polychaetes, infaunal and epifaunal benthic prey, and their predators, yet there was discussion around why benthic prey may not be prioritized as a research target. One consideration is that they are viewed as a more stable prey source compared to pelagic prey species (Yeung and Yang 2025) so their population dynamics may not require annual tracking.

With the exception of herring, information on spawn timing, locations, and migratory paths of nearshore forage species in the GOA are limited or unavailable. Spawning migrations from offshore to nearshore waters represents a significant transfer of energy from productive shelf habitat to coastal ecosystems, making dense aggregations of energy-rich prey seasonally available to central-place and other coastal predators (e.g., Womble and Sigler 2006, Womble et al. 2009). Directed sampling of these migratory pulses are rare and often limited to a specific area, such as the spring spawning run of eulachon in SEAK (Marston et al. 2002, Sigler et al. 2004). In the absence of consistent directed monitoring of capelin, their potential spawning habitat was identified from the Shore-Zone Coastal Habitat Mapping System and combined with larval movement simulations to better understand connectivity between capelin nearshore spawning areas and observed offshore distributions (McGowan et al. 2020). Yet the proportion of capelin that are retained in nearshore waters and their migration paths returning to spawning areas (e.g., Olafsdottir and Rose 2012, 2013) remains unknown.

3.2. Bering Sea and Aleutian Islands

The BSAI is defined by two distinct oceanographic regions: the North Pacific continental shelf, which includes waters < 200 m and the Bering Sea deep sea basin. The on- and off-shelf regions are characterized by differences in water column structure, currents, and species composition, thus priority forage species vary between the regions.

Forage species play a critical role in the BSAI food web, yet remain understudied relative to the commercially important or protected species they support. One ubiquitous forage species is juvenile pollock. Pollock support the largest U.S. commercial fishery by volume, and as juveniles are a critical prey resource for larger fish (including adult pollock), seabirds, and marine mammals (Hatch and Sanger 1992, Zeppelin and Ream 2006). Furthermore, pollock biomass is predicted to decline as a result of warming water temperatures (Mueter et al. 2011, Ianelli et al. 2016, Spencer et al. 2016).

Priority forage species in the Bering Sea, identified by predator diet analyses (Lang et al. 2005, Yang 2007, Zeppelin and Orr 2010, Boldt et al. 2012) and food web models (Aydin and Mueter 2007, Whitehouse and Aydin 2020), include other juvenile groundfish (e.g., P. cod), juvenile salmon, and key species within the FMP forage group (capelin, sand lance, eulachon, herring, myctophids, bathylagids, euphausiids, and squids). There are bycatch-related concerns for herring as a Prohibited Species (Vollenweider et al. 2024), as well as for the incidental catch of squid as an “ecosystem component” (Amendment 106 of BSAI FMP; effective date 8 August 2018; Federal Register, Volume 83, Number 130, 6 July 2018, p. 31460–31470). Squid are also a key prey species in the Aleutian Islands, and while their abundance is known to fluctuate between warm and cold years in other regions (Reuter and Gaichas 2006), their relative abundance in the Aleutian Islands is unknown. Squid are also potentially vulnerable to the biennial effect of predation by and competition with East Kamchatka pink salmon (*Oncorhynchus gorbuscha*) in the Aleutian Islands; this biennial effect can also be seen in Atka mackerel otolith growth, densities of diatoms and copepods, and reproductive success of puffins (summarized in (Ortiz and Zador 2023).

Three research topics related to forage species ecology and their importance for management were identified as priorities for the BSAI.

The first topic focused on the current and future impacts of environmental variability on forage species. How will forage species respond to long-term shifts in environmental conditions operating across large spatial scales, including but not limited to changes in temperature, precipitation, and wind patterns? Which species are expected to be "winners" versus "losers" given the ongoing and expected changes in the BSAI ecosystem? Do we expect forage species to respond in a similar way to changes in their environment (e.g., loss of sea ice, marine heat waves), or to respond in different ways, potentially buffering impacts on predators? This line of research requires improved information regarding changes in abundance, distribution, migration timing, and condition.

A second topic focused on resolving uncertainty in the role of forage species in general in the BSAI ecosystems. How often are forage species "limiting" in the food web(s) of the BSAI? In other words, does lack of forage constrain predators in the BSAI, particularly managed or protected species? From a predator perspective, how trophically interchangeable are different forage species?

A final set of questions focused on better characterizing habitat needs and ecosystem roles of currently understudied species, such as myctophids and squids, which primarily occupy off-shelf habitat. While there are a number of on-shelf surveys, relatively little is known about forage species in off-shelf regions. There is little data on bathylagid, myctophid and cephalopod species which are essential prey for fish, seabirds and marine mammal predators. Northern smoothtongue (*Leuroglossus schmidti*) and gonatid squid are the primary prey taxa of northern fur seals on Bogoslof Island, the only breeding site in Alaska where the population is increasing (Zeppelin and Orr 2010).

3.3. Arctic

Much of what is known about Arctic forage species has been learned from collaborative ecosystem studies, such as NPRB IERPs, and several nearshore projects. Juvenile Arctic cod are the keystone species of the Arctic, with a broad distribution and an abundance that is orders of magnitude greater than any other species (Logerwell et al. 2015, De Robertis et al. 2017b, Levine et al. 2023). *Calanus glacialis*, a lipid-rich copepod, are integral prey for juvenile Arctic cod, conferring good body condition and likely enhancing growth and survival when they are available (Copeman et al. 2020). Other species in lower abundance, but known to be important forage for marine mammals and seabirds, include capelin, which vary in abundance year to year with changing oceanographic conditions, as well as saffron cod (*Eleginus gracilis*), an important forage species in coastal regions (Johnson et al. 2010, Logerwell et al. 2015, De Robertis et al. 2017b, Levine et al. 2023). Arctic sand lance (*Ammodytes hexapteru*s) may also be relatively important prey as their prevalence is increasing in the U.S. (Baker et al. 2022) and Canadian (Falardeau et al. 2017) Arctic.

AFSC's involvement in Arctic research has been limited to short-term studies primarily from external funding sources and there is little ongoing field research. Consequently, there are limited time series and many research gaps exist, despite the increasing interest in transportation, infrastructure and fisheries. Though progress has been made to understand mechanisms structuring juvenile Arctic cod abundance, continued monitoring of their abundance is needed to better understand how this key species is responding to environmental changes in this region. Research has primarily focused on juvenile stages of Arctic cod and other forage species, and an understanding of juvenile survival to recruitment is lacking. Further, reproduction and spawning dynamics of this critical species is starting to be understood through modeling efforts and otolith analysis (Vestfals et al. 2021, Chapman et al. 2023), though direct observations of spawning or spawning-capable fish are yet to be made. In addition, assessing Arctic cod productivity is limited by difficulties in locating adult fish and estimating their abundance, as well as by a lack of knowledge about other ecological aspects of this life stage. Arctic cod have garnered interest for commercial fisheries, but other stock assessment parameters needed to manage a potential fishery (e.g., natural mortality) have yet to be addressed.

Another area of concern is the movement of sub-Arctic species into the Arctic, with recent observations of large numbers of juvenile pollock and P. cod. Potential for survival and reproduction and cascading effects on the ecosystem are of extreme interest, with applications to commercial fisheries. Similarly, delineation of Arctic sand lance from their GOA congeners is needed to understand sub-Arctic intrusions, though it remains difficult to discriminate among species morphometrically.

Extending existing datasets with a focus on keystone species using an integrated sampling approach should be prioritized over stand-alone one-year studies. Further development of mechanistic links between forage species and oceanographic conditions require long-term datasets and would be productive in predicting the future of forage species. Lastly, AFSC studies of the Chukchi Sea have been limited to U.S. waters, which is one-third of the Chukchi shelf. International collaboration to extend research beyond borders are needed to significantly enhance our understanding of forage species in the Arctic.

Objective 4: Recommendations to AFSC Leadership Regarding Future Research Priorities

4.1. Identify scientific information needed for ecosystem-based fisheries management

One goal of the breakout groups was to identify unmet management needs and data gaps in order to prioritize information needed for EBFM. Research recommendations are organized into three management needs:

1. Understand and report direct and indirect fishery impacts on forage species.
2. Understand the impact of changes in forage species on their managed predators.
3. Measure ecosystem status to support sustainable fisheries.

Recommendations provided will benefit from addressing these overarching needs:

- Collaborate on combining prey data across predator groups (seabirds, mammals, fishes) and reporting those data by supporting connections within and outside NOAA.

- Centralize forage species information by making forage data more easily shared and accessible.

Management Need 1: Understand and report direct and indirect fishery impacts on forage species

There are reporting tools in place to record fishery impacts on forage species. For example, NMFS, through the NPFMC process, provides a biennial report, Status of Forage Species, for the BSAI and GOA management areas. These reports include the status of forage species populations and forage fish bycatch. Squids reclassified as Ecosystem Components and herring Prohibited Species bycatch are examples of recent forage species topics included in the 2021 BSAI forage report (Vollenweider et al. 2024). Direct fishery impacts to herring are also reported by both ADF&G as the managing body and by NMFS through their fisheries catch and landings reports[5] as Prohibited Species for BSAI and GOA fisheries.

A potential tool for reporting fishery impacts on forage species is EFH Component 7, prey species (50 CFR 600.815(a)(7)[6]). Within each FMP, the prey component of EFH is included in the text descriptions of species' habitats (see Appendix D in the BSAI[7] and GOA[8] Groundfish FMPs and Appendix F in the BSAI Crab FMP[9]), however, where data are limited, the prey information is sparse. There is potential to increase prey information that could be used to assess fishing effects on their habitat similar to the fishing effects estimated on FMP species core EFH areas.

This breakout group developed the following recommendations to fill in the gaps needed for understanding direct and indirect fishery impacts on forage species:

- **Monitor abundance and species-composition**: This requires performing surveys and creating a network for data sharing.
- **Estimate status of forage community relative to ecosystem requirements:** Assess the abundance and composition of the forage community relative to predator requirements**.**
- **Identify habitat utilization for forage species**: This answers the question of which prey are available in small-scale areas for species of interest (e.g., Atka mackerel or Steller sea lions).
- I**mprove EFH component 7**: Expand prey species information in the FMPs. As stated above, prey information in EFH descriptions is limited and can be improved with species or species guild distribution maps. Prey species maps can be overlaid with the ensemble species distribution model maps prepared for the 2023 EFH 5-year Review (Laman et al.

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[5] https://www.fisheries.noaa.gov/alaska/commercial-fishing/fisheries-catch-and-landings-reports-alaska
[6] https://www.govinfo.gov/content/pkg/CFR-2019-title50-vol12/xml/CFR-2019-title50-vol12-part600.xml#seqnum600.815
[7] FMP for Groundfish of the BSAI Management Area Appendices, October 2024 (https://www.npfmc.org/wp-content/PDFdocuments/fmp/BSAI/BSAIfmpAppendix.pdf)
[8] FMP for Groundfish of the GOA Appendices, October 2024 (https://www.npfmc.org/wp-content/PDFdocuments/fmp/GOA/GOAfmpAppendix.pdf)
[9] FMP for BSAI King and Tanner Crabs, October 2024 (https://www.npfmc.org/wp-content/PDFdocuments/fmp/Crab/CrabFMP.pdf)

2022). Filling this data gap would meet EBFM intentions, although mapping prey species distribution is not a requirement of EFH regulations.

In order to produce prey species maps, research focus should include both offshore and nearshore data, of which the latter is limited. Nearshore prey habitat data includes forage species and early life history stages of FMP species. When mapping species distribution for the data limited species, distribution maps of combined guilds could act as proxy for individual species, similar to mapping species complexes of FMP species (Laman et al. 2022). These maps could be included as dynamic prey field covariates in species distribution models currently used to map EFH for managed species (e.g., active project by (Siple et al. In prep) and in process studies to understand ecological mechanisms driving distribution and abundance of species in nearshore/offshore habitats. Information may already be available to initiate development of these maps (e.g., Grüss et al. 2020).

- **Treat impacts on forage species as "fishing effects" in EFH**: Removal of an EFH component (i.e., prey species) through commercial fishing is an effect on an FMP species' EFH. Currently the evaluation of fishing effects on EFH focuses on the impacts to benthic habitat within a core EFH area for each species or species complex. Future discussion can evaluate correlations of life history parameters with forage species catch data. However, understanding predator-prey relationships and distribution overlap is necessary for evaluations to be credible.

Management Need 2: Understand the impact of changes in forage species on their managed predators

Predator-prey relationships inform EBFM and there are several gaps where research could be directed. Existing reporting tools include stock-specific tools like ESPs and risk tables in the stock assessments. ESRs report at the community level.

The following recommendations can address the role of prey population dynamics on predator stocks:

- **Produce synoptic versions of zooplankton indicators**: ESPs and ESRs include zooplankton indicators from multiple surveys (i.e., EcoFOCI survey, Seward Line Survey, Southeast Coastal Monitoring Survey, and continuous plankton recorder (CPR) in the GOA[10], EcoFOCI survey, BASIS survey, MACE acoustic-trawl surveys, and CPR in the EBS). Planktivorous seabird reproductive success on USFWS monitored colonies in the GOA, AI, and EBS is also used as an indicator of zooplankton availability. Several ESPs also use different zooplankton indicators based on the timing of larvae for a given stock and the indicator availability (CPR indicators for sablefish, small and large copepods for GOA pollock and P. cod from EcoFOCI). It would be helpful if a more synoptic version of these zooplankton indicators were available to evaluate. This is also identified as a research gap in many of the ESPs.
- **Understand connections between prey population dynamics and predator productivity**: There are several research opportunities on the impact of variability of abundance, distribution, and nutritional quality of forage species to reproductive success

[10] https://www.cprsurvey.org/

and growth of individual managed groundfish and species of conservation concern. Examples are the linkages between the dramatic population decline of P. cod in the GOA and their prey availability (Barbeaux et al. 2020), seabird colony die-offs (Piatt et al. 2020), and large declines in marine mammal populations (Gabriele et al. 2022).

- **Attribute changing productivity to forage species**: Where possible, identify changes in predator productivity with respect to changes in forage species populations. It is hypothesized that the decline of the western stock of Steller sea lions may be linked to reduced availability of forage species (Trites and Donnelly 2003). Variation in northern fur seal productivity at the three eastern Pacific stock breeding colonies are associated with different prey assemblages of forage fish species (Zeppelin and Ream 2006, Musbach et al. 2024). Monitoring of both predator and prey populations are needed to evaluate these linkages.

Management Need 3: Measure status of ecosystem to support sustainable fisheries

Measuring the ecosystem status can include system-level MSY, trophic trade-offs, prey base and availability, energy flow/trophic transfer, food web stability, and environmental variability monitoring and projections. There are annual ESRs for the EBS, Aleutian Islands, and GOA that are a consistent way to communicate information on ecosystem status and trends. The ESRs include relative abundance indices for forage species like euphausiid and pelagic forage fish biomass to track interannual trends. Another reporting tool is the Fishery Ecosystem Plan (FEP), either as a statewide implementation plan (e.g., the Alaska Plan) or at the management region level (e.g., the Bering Sea FEP).

The following recommendations can continue to inform and add to status reports:

- **Determine the quantity and quality of prey for species of commercial and conservation importance to achieve fitness, reproductive success and growth**: Connect prey quantity and quality to predator fitness, reproductive success, and growth. One pathway is combining spatially and temporally variable datasets at the LME and population levels. Another is to develop benthic prey community (infaunal and epifaunal) information as ecosystem indicators to be used in products like ESRs similar to the pelagic forage fish density index for the EBS (Siddon 2024).
- **Define the general structure and characteristics of energy transfer through the food web**: There is a dynamic relationship between the prey community and the environment, and spatiotemporal variation of benthic and pelagic productivity within LMEs. Understanding the energy transfer through the food web could provide predictions and trigger early warnings of shifts in the prey community and the potential impacts to their predators.
- **Understand predator removals**: Part of understanding the general structure of the food web is also understanding top-down effects through predator removals. Examples include northern fur seals in the CEATTLE model and ice seals in the northern Bering Sea Ecopath with Ecosim.
- **Parameterize ecosystem models**: Ecosystem models can be updated by including the availability of forage species as well as a component representing competition for prey resources. For example, EcoState is a new state-space mass balance model which is fitted

directly to biomass indices for both exploited and forage species (Thorson et al. 2025). This model then allows forage indices to be used to understand changes in productivity and growth for commercially important species.

- **Improve ROMS-NPZ**: The focus of this recommendation could be to validate euphausiids by monitoring distribution, abundance, species composition, and condition. This could identify regime changes and small-scale turn-over, project distribution and abundance, and be overlaid with fishery or community use areas. Combining datasets by building data assimilation could fill gaps for otherwise data limited times or locations from single-source studies.

4.2. Improving surveys or collecting new data, and combine survey, opportunistic, and fishery data

Congress participants identified priorities for sustaining and expanding existing surveys and establishing and/or supporting new data series and collaborations. The following approaches for improving monitoring in the next 5–7 years would address knowledge gaps for priority forage species:

- Minor to moderate changes to existing surveys.
- Analytic approaches using existing data.
- Potential new data sources.
- Opportunities for expanding collaborations within and outside AFSC and improvements in information sharing.

For each approach, potential opportunities and/or specific actions that were identified during this breakout session are highlighted and briefly discuss their advantages and expected challenges.

Potential minor to moderate changes to existing surveys

Given the high cost of fisheries surveys, in many instances minor to moderate changes to existing surveys may be the most cost-effective approach to address data gaps and capture better information on forage species. Some of these modifications may be relatively simple such as making minor adjustments to the areas sampled to improve spatial coverage of forage species hot spots, adjusting a survey design (e.g., sampling resolution, gear) to better account for potential sampling bias, and adopting more efficient electronic tools that may allow for increased biological sampling of forage species in the catch (Link et al. 2008).

There are multiple instances in the past decade where modifications to existing AFSC surveys improved information on forage species. The MACE program transitioned survey gear in all acoustic-trawl surveys to use a smaller midwater trawl with a finer mesh codend liner to improve retention of juvenile pollock and other small pelagic fishes (Jones et al. 2022, McCarthy et al. 2022, Stienessen et al. 2025). MACE also improved coverage of known capelin hot spots in the summer GOA pollock acoustic-trawl survey by extending some transects to shallower waters over Albatross Bank (Levine et al. 2024) where capelin were known to concentrate (McGowan et al. 2019c). BASIS has temporarily incorporated different sampling approaches in its design to expand coverage below the surface trawl's footrope (~20 m) by including opportunistic acoustic sampling with directed midwater trawls between stations (Parker-Stetter et al. 2013, De Robertis et al. 2014, McKelvey and Williams 2018) and more recently explored adding obliquely towed midwater trawls at predetermined stations (Spear et al. 2023).

Additional improvements in existing surveys may be achieved through the expanded use of pilot studies designed to improve sampling efficiency or address/reduce sampling biases related to the availability and retention of forage species. These include gear comparison studies (De Robertis et al. 2017a, 2021), pilot studies for incorporating uncrewed surface vessels (USVs) in existing surveys (Handegard et al. 2024), and evaluations of new sampling tools such as eDNA (Rourke et al. 2022, Shelton et al. 2022, Guri et al. 2024) or cameras (Lauth et al. 2004). Gear studies can also be used to augment survey data by better quantifying the probability that forage species are available and retained in active surveys. Improved quantification of size and species selectivity will improve density and abundance estimates of forage species captured intentionally during targeted surveys and incidentally during surveys designed for other species (Nakashima 1990, Williams et al. 2011, De Robertis et al. 2017a, 2017b, 2021). They can also provide a basis for data collected with different gears to be combined via gear comparisons (i.e., joint sampling with different gears, (Parker-Stetter et al. 2013), and methods to estimate the degree of escapement from trawls (e.g., recapture nets, trawl cameras, and comparison of acoustics and trawl catches, (Somerton et al. 2011, De Robertis et al. 2017a, 2021). In MACE acoustic-trawl surveys, characterizing the size- and species-specific escapement of a midwater trawl has subsequently allowed for backscatter to be apportioned to all species in the catch using the selectivity-corrected trawl data, resulting in improved abundance estimates of juvenile (and subsequently adult) groundfish and other forage fish species that co-occur with targeted species (e.g., Williams et al. 2011, De Robertis et al. 2017a, 2021, Levine et al. 2024). This has improved not only ongoing surveys, but facilitated reanalysis of historical winter and summer GOA survey data to provide more accurate time series for pollock, Pacific ocean perch (*Sebastes alutus*) and capelin (McGowan et al. In prep). Improved understanding of the locations in a trawl gear where escapement is highest (Nakashima 1990, Williams et al. 2011, 2015) can also be used to design improved sampling gear (De Robertis et al. 2023).

Opportunistic data collection during existing surveys may also help address data gaps. Most stomachs provided to the REEM Program's groundfish diet database to support predator food-habits research are collected during summer bottom trawl surveys. Stomach collections from surveys conducted in fall/winter/spring (e.g., winter acoustic-trawl surveys) would expand the database's seasonal coverage.

In addition, opportunistic acoustic data should continue to be collected during non-MACE surveys conducted on NOAA ships to provide information on macrozooplankton (i.e., euphausiid) distributions (see below). Emerging research is highlighting the potential for utilizing eDNA samples to inform classification of acoustic data (Shelton et al. 2022). The breakout session discussed the potential for analyzing opportunistically collected acoustic data from oceanographic or marine mammal surveys where trawling is not conducted by eDNA samples that could be collected from conductivity-temperature-depth (CTD) casts throughout the survey. The feasibility of expanding this opportunistic sampling to collect broadband acoustic data should also be explored to potentially support future analyses that utilize developing methods for classifying these data into more informative categories without the availability of trawl-based biological data. One such approach, automatic probabilistic echo solving (APES, (Urmy et al. 2023), uses a probabilistic, Bayesian inverse method that informs priors with direct samples from trawl catches or other potential sources (e.g., camera drops, eDNA) to reduce uncertainty in species identification. It should be noted that opportunistically collected acoustic data lacking direct samples (i.e., trawl samples for fish, net samples for zooplankton) is not a substitute for a traditional acoustic-trawl survey. Nonetheless, these data may provide high-resolution, spatially-indexed measures of relative density for different categories of potential prey (e.g., small pelagic fish with swim bladders, mesopelagics, and macrozooplankton) with supplemental data sources indicating species composition; these data could potentially facilitate identifying areas where forage species are concentrated, and track changes in their distribution and availability to predators.

Analytic approaches using existing data

There is the analytic capability and data availability to utilize multiple survey- and diet-based datasets to compensate for their individual limitations (see sections 2.3, 2.5, 2.7); however, combining disparate datasets is not normally a planned work product. There are a variety of analytic approaches using existing data sources that can be used to reduce uncertainty by improving knowledge of forage species migration patterns, identifying EFH and core areas to inform survey design, and developing indices of abundance. Observer bycatch data can be used for year-round and not just seasonal forage species information. (Tojo et al. 2007) used observer data tracking herring as a Prohibited Species in the EBS to characterize seasonal migration patterns of herring from nearshore spawning grounds in Alaska state waters, where they can be harvested, to overwintering grounds over the continental shelf, where they are protected in U.S. federal waters but caught as bycatch in groundfish fisheries. Observer data collected for herring during pollock A-season could resolve or reduce winter data gaps, though directed off-season sampling may still be needed. Model-based estimates of key forage species densities, based on groundfish diets, are being used to identify forage species hot spots to inform EFH species distribution models (P. Gerson, Oregon State University, pers. comm.). Capelin core areas in the GOA were identified using normalized CPUE data from multiple non-directed surveys with different sampling gear and designs to characterize capelin spatial patterns while compensating for the individual limitations of each data source (McGowan et al. 2020).

Improved indices of abundance have been developed through model-based integration of predator diet-based indices to be used as ecosystem indicators of capelin and sand lance abundance in GOA ESRs (Zador and Yasumishii 2016). Spatiotemporal models allow multiple surveys of different data types to be incorporated within a single modeling framework to estimate shifts in habitat use and abundance trends of data-rich or -limited focal species (Perretti and Thorson 2019, Grüss and Thorson 2019, Gaichas et al. 2023). Model-based indices of prey biomass, derived from predator diet data, can serve as abundance indices for forage species (Grüss et al. 2020, Ng et al. 2021, Gaichas et al. 2023). Index standardization models, that combine survey-based CPUE data with predator diet-based indices of prey biomass, are currently in development and offer a promising tool for improved monitoring of forage fish and other data-limited species (e.g., Turner et al. 2024). To support creation of more useful index standardization models for monitoring forage species abundance trends, research priorities should include: continued development of multi data source models that utilize spatially-indexed survey, diet-based, and/or fisheries-dependent inputs; improvements in the use of diet data, including improved estimation of digestion rates and catchability coefficients to further develop diet-based indices of abundance, and their inclusion in multivariate analyses with survey-based data sources.

Another data gap discussed for the GOA is the need for improved information of euphausiid distribution and abundance. Euphausiids are a priority species, however the gear used for surveys do not capture them adequately. There are decades of archived acoustic data from surveys conducted on calibrated NOAA ships and other research vessels that could inform euphausiid distribution. Three sources were discussed: EcoFOCI spring and late-summer surveys (early 2000s–present); MACE summer euphausiid index (2013–2023 odd years); and Northern GOA LTER data (2018–present). A research priority could be combining and analyzing these datasets for a 3-season index. All of these data sources include net samples to help infer species and possibly length composition: 60 cm bongos and Tucker trawls for EcoFOCI surveys, Methot trawls for MACE surveys, and 60 cm bongos for the LTER surveys.

New data sources

Existing data sources and advanced analytics are insufficient for addressing all data gaps identified by this Congress. Available ship-time and staff are limited, and current budget constraints make it unlikely that there will be new surveys designed to improve monitoring of forage species in Alaska LMEs in the near future. Nonetheless, we have identified the following potential data sources that would address priority data gaps:

- Nearshore surveys. Nearshore surveys (e.g., USGS and ADF&G surveys, NOAA beach seine) and targeting areas around freshwater input in the EBS. These areas are likely sensitive to long-term shifts in environmental variability or terrestrial contaminants (i.e., pollution). These areas may be important for forage fish rearing or EFH.
- Deploying acoustic moorings (De Robertis et al. 2018) at key forage species hot spots or migration paths for extended monitoring.
- Off shelf survey data collection in the EBS, including from surveys conducted by other countries outside U.S. waters.
- Adding fish collections on non-NOAA survey vessels in the Arctic, recognizing that most survey boats currently operating in the Arctic are not equipped for trawl operations.
- More bongo sampling during June and July in the EBS and/or GOA, even if limited to collecting bongo data in hot spots on groundfish survey boats.
- More seasonal data to link up with tracks for Steller sea lions.
- Development of a new research tool for sampling euphausiids to better monitor their distribution and habitat associations.

In addition, we identified key elements to be included in the design of future sampling targeting forage species within existing or in new surveys if resources become available:

- Integrated survey design that collects physical and biological oceanographic data with fish and seabird/marine mammal sampling to better understand potential drivers of forage species distribution and abundance.

- Focus on hotspots and season for forage species during life stages when their availability as prey is most important.
- Optimize sampling at spatial scales best-suited for forage species distribution patterns:
    - Fixed equally-spaced stations for oceanographic sampling, along with opportunistic stations located at observed forage species hot spots.
    - Continuous transects for pelagic fish, seabirds, and marine mammals, along with targeted midwater trawling for fish (O'Driscoll et al. 2002, McQuinn 2009). In the GOA, continuous sampling is especially important due to the complex bathymetry and circulation patterns that result in forage fish distributions that are structured at multiple spatial scales (McGowan et al. 2019a, 2019c).
- Selection of sampling gear(s) for pelagic fish should be optimized to balance trade-offs of covering the full water column while accounting for gear bias with available ship time.
- Utilize new technologies that augment or replace trawling and direct net sampling to optimize available ship time, minimize sampling biases, or expand sampled habitat; examples include using camera drops or towed sleds (Bryan et al. 2023, McGowan et al. 2025), open codend trawls (Williams et al. 2016), optical and acoustic zooplankton profiler (Giering et al. 2022), and eDNA sampling (Guri et al. 2024).
- Broadband acoustic data collection with multispecies classification approach (Bassett et al. 2018, Urmy et al. 2023).

Opportunities for collaboration and improvements in information sharing

There are multiple opportunities to increase collaboration within the AFSC and with outside partners. Several areas were identified where collaboration within AFSC could improve assessments and ecosystem services-related products. Some of these collaborations already exist informally; others would be new internal connections between divisions. Collaborative efforts within AFSC already exist or existed among several divisions. For example, a collaborative project among MML, RACE, and PMEL researchers linked predator behavior to survey data on prey distributions (e.g., Kuhn et al. 2015, 2020, Mordy et al. 2017). Coordination and collaboration among sampling and analysis efforts could improve temporal resolution in existing datasets (in the case of moored and autonomous sampling) and streamline workflows in existing facilities (e.g., wet labs and chemistry labs). Rapid assessments like those for zooplankton, larval fish, and lipids could also be improved with more collaboration among field teams. Increased cross-program and -division collaborations would also help ongoing at-sea staffing needs for conducting surveys.

Due to the nearshore distribution of several forage species in the GOA, data from several sources are required to obtain useful indices of abundance and distribution, assess predator needs and impacts, and identify habitat. This is an opportunity for community collaboration, including between the AFSC and Alaska Regional Office. Nearshore forage surveys can fill gaps in the Nearshore Fish Atlas that records fish species collected throughout SEAK using beach seines (Johnson et al. 2012). Prey species are an EFH component for groundfish species and can be used when mapping and understanding habitat needs. A data gap with the EFH mapper[11] effectively stops at Admiralty Island in SEAK but a value to management would be the ability to overlay both predator and prey species habitat within the nearshore environment. The Nearshore Fish Atlas offers missing nearshore fish data in the Inside Passage waters and could be coupled with habitat information from the Alaska ShoreZone mapper[12] (Grüss et al. 2021).

There are several examples of existing collaborations with other research institutions that improve management science for forage species in Alaska. These include partnerships between ADF&G and NOAA that combine data to obtain indices of abundance for herring (Ormseth 2020), link forage availability to predators during marine heat waves (Arimitsu et al. 2021a), track ecosystem changes across time series (Suryan et al. 2021), and improve abundance indices for forage species (McGowan et al. 2020). Collaborative projects such as Gulf Watch Alaska have provided forage monitoring data that can be shared across institutions (McKinstry and Campbell 2018). Collaborative efforts underway include the incorporation of forage data from seabird diets, humpback whale diets, eDNA, and bioenergetics. Sustained institutional support would improve research outcomes and ensuring impact, including the improvement of regular NOAA products such as ESRs, Forage Reports, and ESPs. New data sources may also be developed through external collaborations. For example, bycaught bird stomach data from commercial fisheries offers a large, unexplored sample of direct samples (S. Fitzgerald, AFSC emeritus, pers. comm.). Opportunities exist to build on active partnerships with the USFWS Alaska Maritime National Wildlife Reserve who have conducted colony-based monitoring of seabirds across Alaska's LMEs since the 1970s to better integrate their seabird food habits data with other indices of forage abundance.

Collaborations with other institutions have been an essential part for the ecosystem research programs that continue to be mutually beneficial to NOAA. These include ecosystem research programs in which AFSC and PMEL are already contributors and highly leveraged (NPRB IERPs, Gulf Watch Alaska, IYS, etc.). Efforts to model juvenile rearing habitat, spatial variability in forage abundance and condition, and inputs like drivers, thresholds, and energy pathways can include data and information from all of these sources. In particular, the absence of on-going Arctic surveys highlights the importance of seeking opportunities to continue collaborations with external partners from Arctic ecosystem research programs and fostering new partnerships to expand short-term projects in this region.

Applications for these collaborative projects are broad and include improvements to EBFM, development of robust ecosystem models, and improvements to EFH designations. All of these management efforts will benefit from consistent time series and good spatial coverage, which could be achieved in collaboration within and outside of the AFSC.

There is a need to centralize forage species information by making forage data more easily shared and accessible. Sharing monitoring data and collaborating on syntheses are most effective when there are shared goals and practices around data management, including support from AFSC and NOAA leadership to ensure that staff have the time and training necessary to make data available and accessible, share code, and develop strong project management practices (e.g., Lowndes et al. 2017). This will require staff and staff time dedicated to developing infrastructure and communication across NOAA and with non-NOAA collaborators. Existing data sharing

[11] https://www.fisheries.noaa.gov/resource/map/alaska-essential-fish-habitat-mapper

[12] https://alaskafisheries.noaa.gov/mapping/sz/

platforms could be leveraged for collaborative projects. Cross-program collaboration (datasets are often from different divisions) can be better supported by improving cross-AFSC access to data, and by building a framework for data documentation that provides credit and/or coauthorship for those who collect, process, and maintain data sources (e.g., DOI for data sources). An example data repository is the Alaska Forage Fish Database (Turner et al. 2024). Similar to the USGS North Pacific Pelagic Seabird database[13], the Forage Fish Database was developed by USGS and its partners to inform potential impacts of an oil spill on seabirds and forage fish in a given season and location. The AFSC should consider whether contributing data to such an external database would be sufficient, what modifications and security measures would be required to enter a formal partnership, or if an internal AFSC-supported repository for forage species information would be more effective to ensure data and analytic products are more readily available to NOAA and non-NOAA users.

4.3. Process and modeling

Gaps in knowledge and research priorities for forage species were identified and should be addressed by future process research at AFSC. While juvenile gadids are generally well represented in process research at AFSC, less is known about other key forage species such as euphausiids, capelin, herring, or sand lance. Even basic abundance, distributional, taxonomic, and early life history information is missing for some of the least studied forage species such as myctophids and squid. This is especially true in nearshore areas which are poorly studied and less monitored, despite their importance as EFH where major life events occur for many forage species (e.g., nurseries, spawning). Understanding the habitat characteristics required to support critical life stages is a priority for process studies, as well as which life history stages are most sensitive with impacts on survival and recruitment. Specifically, quantifying vital rates and thermal response curves of forage species, which have only been characterized for juvenile gadids (Laurel et al. 2023), will help answer remaining questions over whether thermal thresholds are being exceeded in juvenile rearing habitat or spawning areas in light of rising ocean temperatures. Consideration should be given to incorporating indirect effects resulting from temperature-driven changes in prey quality in process studies quantifying direct effects of thermal stress. EFH designations are also important for conserving or protecting sensitive habitats. Additionally, diet- and temperature-mediated impacts on energy allocation strategies and fish condition are needed, with measurements of the time integrated by different condition metrics (Fulton's condition index, energy content, lipid content, etc.). Subsequently, process studies are needed to understand the mechanistic linkages between body condition and their future performance. Experiments are needed to evaluate stationarity (Litzow et al. 2019) and determine if fish from different LMEs respond similarly to habitat perturbation or instead have endemic responses. As long-term warming continues and heatwaves become more common in Alaska's LMEs, a key question is whether the availability and quality of forage species will be able to sustain the increased metabolic demands of predators (Holsman and Aydin 2015, Piatt et al. 2020).

Process studies also have value in enhancing existing data sets and time series. In this vein, the food habits database produced by the REEM Program was cited explicitly (Section 2.3). Evaluation of differential digestion rates by species, life stage, and temperature would

[13] https://www.usgs.gov/centers/alaska-science-center/science/north-pacific-pelagic-seabird-database

significantly enhance the dataset, allowing for better comparability. These datasets are crucial for understanding trophic interactions and health of many commercially important species that consume forage species.

While already well integrated in many ways, there are opportunities for improved collaboration on process research within AFSC and with partners. For instance, moored and autonomous sampling could be used to increase the temporal resolution of sampling in regions and ecosystems that are typically surveyed annually or less frequently, which could be accomplished through further partnership with PMEL. A saltwater laboratories working group was recently formed to coordinate similar efforts across Divisions at the AFSC. Overall, increased collaboration among modelers, field teams, and experimental groups will be important for improved process understanding of forage species in Alaska's LMEs. Enhanced communication between these sometimes-disjunct groups is needed to identify data gaps that process research can fill and identify forage fish indicators that could be used in stock assessment and other models. Additionally, cross-divisional involvement and collaboration with partners on ecosystem research programs such as NPRB IERPs (including the upcoming Northern Bering Sea IERP) will contribute to integration and advancement of forage species research in Alaska.

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Appendix 1: Congress Meeting Agenda and Breakout Session Topics

Overview:

This Congress aims to improve the AFSC's state of knowledge regarding forage species in Alaska's large marine ecosystems by addressing the following objectives:

1. Identify species and species groups that serve important ecosystem roles as forage in Alaska large marine ecosystems.
2. Assess forage-related research efforts regarding these species at the AFSC and other institutions.
3. Identify major scientific goals for forage research across the AFSC and associated knowledge gaps, and identify paths to improve data collection, analysis, and information-sharing.
4. Provide specific recommendations to center leadership regarding (1) important ecological and management questions that could be addressed in the next 5-7 years and (2) organization of cross-program forage research.

Day1: Wednesday, March 30, 2022

9:00	Welcome and introductions (Olav Ormseth)
9:15	Q1: In Alaska LMEs, what are forage species and why are they important?
9:15 - 9:30	Overview of forage species in Alaska LMEs and fishery management (Olav Ormseth)
9:30 - 9:45	Management considerations - Ecosystem-based management (Jim Thorson)
9:45 - 10:00	Key predator-prey relationships (fishes, birds, marine mammals) (Bridget Ferriss)
10:00	Q2: What information currently exists and what are the key gaps?
10:00 - 10:15	Dedicated surveys - GOA and AI (Megsie Siple)
10:15 - 10:30	Dedicated surveys - EBS and Arctic (Olav Ormseth)
10:30 - 10:45	BREAK
10:45 - 11:00	Research programs outside the AFSC (Yumi Arimitsu, USGS)
11:00 - 11:15	Process studies ("hot spots", bioenergetics, fatty acids) (Rob Suryan, Lauren Rogers/Louise)
11:15 - 11:25	Fish predator food-habits research (Jon Reum)
11:25 - 11:35	Seabirds as samplers (Stephani Zador)
11:35 - 11:45	Marine mammals as samplers (Tonya Zeppelin, Katie Luxa)
11:45 - 12:00	Ecosystem modeling (Kerim Aydin, Andy Whitehouse)
12:00 - 12:10	Integrating multiple datasets (Dave McGowan)
12:10	Identify major themes and prepare for April 6 discussion Revisit goals #3/4
12:45	Adjourn

Day 2: Wednesday, April 6, 2022

Objectives: Discuss, get feedback, and achieve some consensus about Forage Congress Goals

9:00 - 9:15 Welcome and synopsis from last session (Dave McGowan)

9:15 - 9:30 Introduction of discussion themes and structure (Olav Ormseth)

9:30 - 10:15 Breakout groups #1: Regional focus

Goals:

- Discuss Objective #3 and #4 for different AFSC regions

Breakout groups (with one google doc per group)

A. Gulf of Alaska (Leads: Megsie Siple and Molly Zaleski)
B. Bering Sea-Aleutian Islands (Leads: Tonya Zeppelin and Lauren Rogers)
C. Arctic (Leads: Johanna Vollenweider and Jim Thorson)

Products from each group:

- Identify priority species for a given LME, based on management importance, trophic transfer
- Identify major research gaps

10:15 - 10:30 Each concurrent session presents back to full group (5 min per group)

10:30 - 10:45 COFFEE BREAK

10:45 - 11:30 Breakout groups #2: Process recommendations

Goals:

- Identify specific recommendations based on themes from Day #1

Breakout groups (with one google doc per group)

A. Improving surveys or collecting new data, and combine survey, opportunistic, and fishery data (Leads: Dave McGowan, Jim Thorson, Tonya Zeppelin)
B. Identifying unmet management needs, and prioritizing species based on these (Leads: Bridget Ferriss, Olav Ormseth, Molly Zaleski)
C. How to combine short-term targeted field and laboratory efforts (“process research”) and modeling (Leads: Johanna Vollenweider, Lauren Rogers)

Products

- Develop bulleted list of recommendations related to topic for each group

11:30 - 11:45 Each concurrent session presents back to full group (5 min per group)

11:45 - 12:15 Plenary discussion (Lead: Jim Thorson)

12:30 Adjourn

Appendix 2: Inventory of active and historical surveys that sample forage species in Alaska.

Table 2-1. -- Inventory of active and historical surveys that sample forage species in Alaska. Seasons are defined as: winter (W) = Jan-Mar; spring (Sp) = Apr-Jun; summer (Su) = Jul-Sep; fall (F) = Oct-Dec; year-round (All). Sampling gear are defined as: AC = acoustics; AR = aerial; BC = baited camera; BN = 60 cm bongo; BS = beach seine; BT = bottom trawl; CN = cast net; CPR = continuous plankton recorder; FN = fyke net; ME = Methot trawl; MT = midwater/pelagic trawl; OT = otter trawl; PS = purse seine; PT = plumb staff beam trawl; ST = surface trawl; TT = Tucker trawl.

Survey name	Spatial coverage	Years surveyed	Season	AFSC Division-Program or other institution	Gear	Key citation(s) for methods or data
LME: *Gulf of Alaska (GOA)*						
Spring larval survey	Western GOA	1979–present (odd years 2011–present)	Sp	RACE-EcoFOCI	BN, TT	Dougherty et al. 2010
Winter Shelikof Strait pollock acoustic-trawl survey	Shelikof Strait, Marmot Bay, Chirikof shelf break	1981–present (no surveys in 1982, 1999, 2011)	W	RACE-MACE	AC, MT, BT	Levine and Jones 2025
Summer GOA bottom trawl survey	GOA	1984–1999 (tri) 2001–present (odd years)	Sp-Su	RACE-GAP	BT, AC	Stauffer 2004
MML opportunistic food habits studies of Steller sea lions	GOA	1990–present		MML		
North Pacific Observer Program (domestic)	GOA	1991–present	All	FMA		AFSC 2021
Winter Shumagin Islands pollock acoustic-trawl survey	Shumagin Is., Sanak, Morzhovoi, Pavlof	1994–1996, 2001–present	W	RACE-MACE	AC, MT, BT	Levine and Jones 2025

Survey name	Spatial coverage	Years surveyed	Season	AFSC Division-Program or other institution	Gear	Key citation(s) for methods or data
Southeast coastal monitoring survey	Inside waters of N. SEAK	1997–present	Sp-Su	ABL	ST	Murphy et al. 1999
Late-summer small-mesh trawl survey	WGOA, CGOA	2000, 2001–2023 (odd years, no survey in 2021)	Su	RACE-EcoFOCI	MT	Dougherty et al. 2010
FIT-EcoFOCI acoustic-trawl surveys of Barnabus and Chiniak Troughs	CGOA	2000–2005 (no survey in 2003)	Su	RACE-FIT-EcoFOCI	AC, MT, BN	Hollowed et al. 2007, Logerwell et al. 2007, 2010a
Summer GOA pollock acoustic-trawl survey	GOA	2003, 2005, 2011–2023 (odd years)	Sp-Su	RACE-MACE	AC, MT, BT, ME	McGowan et al. 2025
Gulf Watch Alaska Predator / Prey survey	Prince William Sound	2006–present	All	ABL-RECA		Moran et al. 2018
Kodiak juvenile cod survey	Two Kodiak bays	2006–present	Su	RACE-FBEP	BS, BC	Abookire and Litzow 2021, Hulson et al. 2024
NOAA Pacific Seabird Necropsy Project	GOA	2007–present		AFSC-CSS		AFSC 2025
GOA IERP upper trophic level survey	EGOA, CGOA	2011, 2013	Su-F	ABL, U. of Washington	AC, MT, ST, BN	McGowan et al. 2019a
GOA Assessment Survey	shelf, slope, basin	2011–2017	Su	ABL	ST	Farley et al. 2005, Moss et al. 2016
Expanded juvenile cod survey	CGOA, WGOA	2018–present	Su	RACE-FBEP, ACOR	BS, BC	Abookire and Litzow 2021, Hulson et al. 2024
ADF&G/NMFS small-mesh bottom trawl survey for shrimp and forage fish	nearshore CGOA and WGOA,	1953–2020 (no survey in many years)		ADF&G, AFSC	BT	Watson 1987, Jackson 2003

Survey name	Spatial coverage	Years surveyed	Season	AFSC Division-Program or other institution	Gear	Key citation(s) for methods or data
Prince William Sound Herring Research and Monitoring	Prince William Sound	1973–present	W-Sp	PWSSC, ADFG, USGS	AR, PS, CN, AC	Brady 1987, Pegau 2013, Haught and Moffitt 2018, McGowan et al. 2021
Gulf Watch Alaska Middleton seabird diets	Middleton Island	1978–present	Sp-Su	ISRC-USGS - Gulf Watch		Hatch and Sanger 1992, Hatch 2013
USFWS - seabird chick diets	GOA	1990s–present	Su	USFWS - AMNWR		
USGS inshore surveys - Cook Inlet	Cook Inlet	1996–1999, 2016–present (no survey 2020)	Su	USGS	BS, MT	Abookire and Piatt 2005, Arimitsu et al. 2021b
USGS inshore surveys - SEAK outer coast, Icy Strait, Skagway	SEAK outer coast, Icy Strait, Skagway	1999, 2001–2002		USGS	BS, MT	Arimitsu and Piatt 2008
USGS inshore surveys - Glacier Bay	Glacier Bay	1999–2004		USGS	BS, MT	Renner et al. 2012, Arimitsu et al. 2016
USGS inshore surveys - Yakutat and Icy Bays	Yakutat and Icy Bays	2002, 2011		USGS	BS, MT	Arimitsu et al. 2016
USGS inshore surveys - Kenai Fjords	Kenai Fjords	2007, 2008		USGS	BS, MT	Arimitsu et al. 2012
USGS inshore surveys - Prince William Sound	PWS	2010, 2012–present		USGS, Gulf Watch	AC, BS, MT	Neher et al. 2015, Arimitsu et al. 2018, 2021a
North Pacific CPR Survey	GOA, Cook Inlet	2004–present	Sp-Su	The Marine Biological Association (Gulf Watch Alaska)	CPR	Batten et al. 2003, 2018

Survey name	Spatial coverage	Years surveyed	Season	AFSC Division-Program or other institution	Gear	Key citation(s) for methods or data
LME: *Aleutian Islands (AI)*						
North Pacific Observer Program (Domestic)	AI	1991–present	All	AFSC-FMA		AFSC 2021
MML opportunistic food habits studies of Steller sea lions	WAI, CAI, EAI	1990–present		AFSC-MML		
Summer Aleutians bottom trawl survey	AI	2002–present (even, no survey 2020)	Sp-Su	AFSC-GAP	BT, AC	Stauffer 2004
NOAA Pacific Seabird Necropsy Project	AI	2007–present		AFSC-CSS		AFSC 2025
USGS-USFWS-ISRC puffin diets	GOA, Alaska Peninsula, Attu	1978–2013	Su	USGS, USFWS, ISRC		Sydeman et al. 2017, Piatt et al. 2018, Schoen et al. 2018, Thompson et al. 2019
USFWS - seabird chick diets	AI	1990s–present	Su	USFWS - AMNWR		
USGS inshore surveys - Aleutian Islands	WAI, CAI, EAI	2006		USGS		Arimitsu and Piatt 2008
LME: *Eastern Bering Sea (EBS) and northern Bering Sea (NBS)*						
Summer EBS pollock acoustic-trawl survey	EBS	1979–present (even years 2010–)	Sp-Su	AFSC-MACE	AC, MT, BT, ME	Stienessen et al. 2025
Summer EBS shelf bottom trawl survey	EBS	1982–present (no survey 2020)	Sp-Su	AFSC-GAP	BT, AC	Stauffer 2004
Summer NBS bottom trawl survey	NBS	1982, 1985, 1988, 1991, 2010, 2017–present (no survey 2020)	Su	AFSC-GAP	BT, AC	Stauffer 2004

Survey name	Spatial coverage	Years surveyed	Season	AFSC Division-Program or other institution	Gear	Key citation(s) for methods or data
MML opportunistic food habits studies of northern fur seals	Pribilof Island, Bogoslof	1990–present		AFSC-MML		
North Pacific Observer Program (Domestic)	EBS	1991–present	All	AFSC-FMA		AFSC 2021
Bering-Aleutian Salmon International survey	EBS, NBS	2003–present	Su-F	AFSC-ABL	ST, AC	Farley et al. 2005, Andrews et al. 2016
NOAA Pacific Seabird Necropsy Project	EBS	2007–present		AFSC-CSS		AFSC 2025
Spring larval survey	EBS	2012–present (even years only, no survey in 2020)	Sp	AFSC-EcoFOCI	BN, TT	Dougherty et al. 2010
Arctic EIS	NBS	2012, 2013	Su	Various PI's, including AFSC	AC, BT, MT, ST	De Robertis et al. 2017b
USFWS - seabird chick diets	EBS	1990s–present	Su	USFWS-AMNWR		
North Pacific CPR Survey	Bering Sea slope	2004–present	Sp-Su	The Marine Biological Association	CPR	Batten et al. 2003
LME: *Arctic*						
Cooper Island beach and nearshore survey	Beaufort	2004–2007, 2009	Su	AFSC	BS, BT	Johnson et al. 2010
BOEM acoustic-trawl survey	Beaufort	2008	Su	Multiple institutions	AC, MT	Logerwell et al. 2010b, Parker-Stetter et al. 2011
BOEM/Arctic IERP	Chukchi	2012, 2013, 2017, 2019	Su	Various PIs, including AFSC	AC, MT	De Robertis et al. 2017b, Levine et al. 2023

Survey name	Spatial coverage	Years surveyed	Season	AFSC Division-Program or other institution	Gear	Key citation(s) for methods or data
North Slope Bureau Shell Baseline Studies Program	Beaufort, Chukchi	2012-2015		Various PIs, including AFSC	AC, BS, MT, OT, PT	Vollenweider et al. 2018
Elson Lagoon survey	Beaufort (Utqiaġvik)	1996, 2009–2017 (still active?)	Su	North Slope Borough Dep. of Wildlife Management	FN	Sformo et al. 2019

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