Forage Fish Ecology in the GOA and BSAI

Report for the NPFMC Ecosystem Committee
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1 Introduction

In 2021 the Ecosystem Committee (committee) tasked Council staff with preparing a summary of recent research on forage fish ecology in the Gulf of Alaska and Bering Sea/Aleutian Islands. The purpose of the paper is to provide information to the committee to allow them to determine whether there is a role for the committee or Council in understanding forage fish ecology throughout the State of Alaska.

The application of ecological data to fisheries management has received increasing attention in recent years. Forage fish are often considered the cornerstone of marine ecosystems, and understanding of forage fish ecology has important implications for how commercial fish stocks are managed. Forage fish are considered juvenile age classes of some commercially important fishes (Pacific cod, Walleye pollock, salmon), squids, shrimps, pacific herring, and small adult fishes. They are important, but poorly studied part of the marine ecosystems in Alaska. The forage fish groups in Alaska are identified in the Fishery Management Plan or Groundfish of the Bering Sea and Aleutian Islands and the Fishery Management Plan for Groundfish of the Gulf of Alaska and are considered ecosystem species in both FMPs (Table 1).

Table 1. Forage fish families and common names in the BSAI and GOA FMPs.

Family	Common names
Osmeridae	Smelts, eulachon, capelin
Ammodytidae	Sand lances
Trichodontidae	Sandfishes
Stichaeidae	Pricklebacks
Pholidae	Gunnels
Myctophidae	Lanternfishes
Bathylagidae	Blacksmelts
Gonostomoatidae	Bristlemouths
Euphausicea	Krill

2 Regional Programs

2.1 Gulf of Alaska Project

The Gulf of Alaska Project was an integrated ecosystem study examining the physical and biological mechanisms that determine the survival of juvenile groundfishes in the Gulf of Alaska. From 2010 to 2014, oceanographers, fishery biologists, and modelers studied the "gauntlet" faced by commercially and ecologically important groundfishes during the first year of life as they are transported from offshore areas where they were spawned to nearshore nursery areas. Species of focus included walleye pollock, Pacific cod, Pacific ocean perch, sablefish, and arrowtooth flounder. The Gulf of Alaska Project included a retrospective analysis to incorporate and build on previous research, including for forage fish.

The middle trophic level (MTL) component of the GOA Project focused on early life survival of five focal groundfish species and was organized around two spatial dimensions, eastern GOA (eastern GOA regulatory region) and western GOA (central GOA regulatory region). Studies were conducted in spring, summer, and fall of 2011 and 2013. Summer and fall midwater trawl surveys and ecosystem surveys at 5 inshore sites in each region connected the offshore and inshore work. Acoustic and oceanographic data were collected at the same time.

Pacific cod (*Gaddus macrocephalus*) and walleye pollock (*Gaddus chalcogrammus*) were regularly encountered in inshore and offshore work. Age-0 pollock were abundant in the offshore midwater in the summer of 2013 and displayed distinct vertical patterns that were associated with bottom topography. Age-0 and older juvenile pollock were also seen inshore. Age-0 Pacific cod were ubiquitous and abundant in nearshore habitats. In 2011, pollock and cod were both largely absent from the offshore, attributed to low productivity resulting from the lack of a spring phytoplankton bloom, but were abundant inshore. In 2013, Pacific cod and pollock were common offshore, but abundance was reduced inshore. This variability suggests a degree of uncoupling between the inshore environment and offshore processes.

The MTL research also suggests that the GOA population of capelin (*Mallotus villosus*) is concentrated in the central GOA. Capelin occurred in abundance in the offshore acoustic survey, but densities in the western study area (Central GOA regulatory area) were much higher, centered around Kodiak Island. Pacific herring (*Clupea pallasii*) occurred mainly in the eastern region, offshore and inshore.

The results of the GOA Project indicates that the GOA nearshore likely has an important nursery role for age-0 Pacific cod, suggesting that information regarding the abundance or condition of age-0 Pacific cod in these areas may provide a meaningful predictor of recruitment. Early, small scale studies in Kodiak successfully predicted age-1 abundance (Laurel et al. 2016). However, a useful age-0 survey would have to be conducted in a very broad geographical scale and occur in both summer and fall. The MTL work also provided new insights into processes that influence the survival of age-0 groundfishes. The absence of age-0 pollock in 2011 offshore was linked to lower productivity in the GOA described by the Lower Trophic Level (LTL) component of the GOA Project. In contrast, good conditions in the offshore in 2013 were not reflected in the nearshore work, where age-0 Pacific cod were in low abundance and low condition. A greater understanding of how large annual cohorts may affect subsequent year-class strength is important for understanding groundfish population dynamics.

The authors of the GOA Project also identified the potential for stock structure in both walleye pollock and Pacific cod in the GOA. There appears to be some degree of uncoupling between individuals in the inshore versus offshore environments, and it is possible that both species have inshore and offshore spawning populations that may have different population trajectories. The authors suggest that identifying Pacific cod spawning grounds in the GOA, and genetic testing of Pacific cod and walleye pollock are priorities for future research.

The GOA Project also provided new information regarding capelin and Pacific herring in the GOA, and underlined the general value of the inshore habitat for young fish. The inshore surveys provided a broad temporal and spatial description of the inshore GOA and the data serve as a baseline for future work.

In addition to the final reports for each of the project components, the GOA Projected resulted in several peer-reviewed publications. Publications are listed for each project on the NPRB website and listed below in Table 2.

Table 2. Publications from the NPRB GOA IERP Project.

Waite, Jason N., and Franz J. Mueter. 2013. "Spatial and Temporal Variability of Chlorophyll-a Concentrations in the Coastal Gulf of Alaska, 1998–2011, Using Cloud-Free Reconstructions of SeaWiFS and MODIS-Aqua Data." Progress in Oceanography 116 (September): 179–92. doi:10.1016/j.pocean.2013.07.006.
Waite, Jason N., and Franz J. Mueter. 2013. "Spatial and Temporal Variability of Chlorophyll-a Concentrations in the Coastal Gulf of Alaska, 1998–2011, Using Cloud-Free Reconstructions of SeaWiFS and MODIS-Aqua Data." Progress in Oceanography 116 (September): 179–92. doi:10.1016/j.pocean.2013.07.006.
Zimmermann, Mark, Jane A. Reid, and Nadine Golden. "Using smooth sheets to describe groundfish habitat in Alaskan waters, with specific application to two flatfishes." Deep Sea Research Part II: Topical Studies in Oceanography (2015).
Moss, Jamal H., Marilyn F. Zaleski, and Ron A. Heintz. "Distribution, diet, and energetic condition of age-0 walleye pollock (Gadus chalcogrammus) and pacific cod (Gadus macrocephalus) inhabiting the Gulf of Alaska." Deep Sea Research Part II: Topical Studies in Oceanography 132 (2016): 146-153.
Aguilar-Islas, Ana M., Marie JM Séguret, Robert Rember, Kristen N. Buck, Peter Proctor, Calvin W. Mordy, and Nancy B. Kachel. "Temporal variability of reactive iron over the Gulf of Alaska shelf." Deep Sea Research Part II: Topical Studies in Oceanography 132 (2016): 90-106.
Strom, Suzanne L., Kerri A. Fredrickson, and Kelley J. Bright. "Spring phytoplankton in the eastern coastal Gulf of Alaska: Photosynthesis and production during high and low bloom years." Deep Sea Research Part II: Topical Studies in Oceanography 132 (2016): 107-121.
Stabeno, P. J., N. A. Bond, N. B. Kachel, C. Ladd, C. W. Mordy, and S. L. Strom. "Southeast Alaskan shelf from southern tip of Baranof Island to Kayak Island: Currents, mixing and chlorophyll-a." Deep Sea Research Part II: Topical Studies in Oceanography 132 (2016): 6-23.
Doyle, Miriam J., and Kathryn L. Mier. "Early life history pelagic exposure profiles of selected commercially important fish species in the Gulf of Alaska." Deep Sea Research Part II: Topical Studies in Oceanography 132 (2016): 162–193.
Ladd, Carol, Wei Cheng, and Sigrid Salo. "Gap winds and their effects on regional oceanography Part II: Kodiak Island, Alaska." Deep Sea Research Part II: Topical Studies in Oceanography 132 (2016): 54-67.
Ladd, Carol, and Wei Cheng. "Gap winds and their effects on regional oceanography Part I: Cross Sound, Alaska." Deep Sea Research Part II: Topical Studies in Oceanography 132 (2016): 41-53.

2.1.1 GOA marine heatwave effects on Pacific cod

In 2014-2016 an unprecedented warming event in the North Pacific Ocean triggered changes in the ecosystem of the GOA. The extraordinary heatwave, known as "The Blob", was noteworthy in its geographic extent, depth range, and persistence. In 2017, a groundfish survey indicated that GOA Pacific cod had experienced a 71% decline in abundance from the previous 2015 survey. Barbeaux et al. (2020) demonstrated that an increase in metabolic demand during the extended marine heatwave and reduced prey supply can explain the decline in the GOA Pacific cod biomass. Increased mortality due to the heatwave, along with concurrent low recruitment suggested that the recovery would be slow, and likely affect commercial fishery management for several years.

The marine heatwave and coincident decline in GOA Pacific cod stocks prompted several organizations to encourage the Council to identify needs and opportunities to manage fisheries in the context of environmental change. Peterson Williams et al. (2021) conducted conversations and directed interviews with commercial fishers, Alutiiq fishers, and fishery managers to explore early warning signs and management challenges preceding the decline of Pacific cod, and recommend tools to enhance the adaptive capacity of management to address climate related changes.

2.2 Bering Sea

The Bering Sea project was a collaborative program to understand the ecological connections between climate, physical oceanography, plankton, fishes, seabirds, marine mammals, humans including traditional knowledge and economic outcomes, and how climate change and dynamic sea ice cover is affecting them. The Bering Sea project was a partnership between the North Pacific Research Board and the National Science Foundation.

The Bering Sea project was built around five hypotheses addressing physical forcing effects on food availability, bottom-up forcing, dynamic ecosystem controls, effects of climate conditions on local systems, and climate impact on the abundance and distribution of commercial and subsistence fisheries. The fishes portion of the Bering Sea Project used acoustic surveys, surface trawl surveys, and bottom trawl surveys to collect data to examine pollock and cod distribution, functional foraging responses, and forage distribution and ocean conditions. The project resulted in several special publications in Deep-Sea Research Part II, several peer-reviewed articles, and project Final Reports. More information on this large, expansive project is available at the NPRB website.

Park-Stetter et al., (2013) examined acoustic and trawl data from a non-target survey to evaluate distributions of capelin, age-0 Pacific cod, and age-0 pollock in 2006-2010. Data were collected during the 2006-2010 Bering-Aleutian Salmon International Survey (BASIS) throughout the EBS. Although other species (Atka mackerel, Bering wolfish, Pacific sand lance, Pacific sandfish, rainbow smelt, threespine stickleback, age-1+ pollock, Arctic cod, age-1+ Pacific cod, ninespine stickleback, juvenile rockfish, adult rockfish, saffron cod) were captured, analysis focused on the three focal species identified above. Within the surface zone, capelin occurred throughout the EBS, but primarily in the middle shelf. Capelin were also present in the midwater zone in some years. Age-0 Pacific cod occurred primarily in the surface zone of the middle and outer shelf regions. Age-0 pollock were found in the EBS surface zone in all years, primarily in the middle and outer shelf regions. Parker-Stetter et al. (2013) suggested that annual abundance indices based on bottom or surface trawl data alone will not be sufficient to characterize forage fish distribution in the EBS in all years.

Yasumiishi et al., (2021) summarized climate-related changes in the distribution and biomass of small pelagic fishes in the EBS during late summer 2002-2018. Data from NOAA surveys from 2002-2018 show a shift northward for age-0 pollock, juvenile salmon, herring, and capelin during the 2002-2005 warm stanza compared to the 2006-2011 cold stanza in the EBS. However, little is known about temperature related changes in the distribution and biomass of pelagic fishes in the EBS over multiple climate stanzas. Yasumiishi et al., (2021) expanded upon priori analyses by including multiple climate stanzas: warm (2002-2005), cool (2006, 2008-2013), and warm (2014-2018). They report that biomass of herring, juvenile sockeye salmon, and age-0 pollock showed an increase with warming, while capelin showed a decrease with warming. Yasumiishi et al., (2021) concluded that the impact of temporal and spatial changes in summer sea temperature were positive, neutral, and negative on the distribution of fish in the EBS, depending on species. They noted that due to the importance of early life history on the survival of fish species and their importance as prey items for many marine fishes, birds, and mammals, further monitoring of pelagic forage fish is needed to track changes in the distribution and biomass of pelagic fishes during warming. They suggested that future studies should examine the relationship between early life history distribution and biomass of pelagic fishes in relation to estimates of year class strength, later determined by stock assessments or fishery catches.

2.3 Traditional Knowledge studies of forage fish ecology

Brown et al., (2002) documented qualitative ecological information about non-harvested fish age classes and species from resources users and area residents in Prince William Sound (PWS) and outer Kenai Peninsula (OK) in southcentral Alaska. Brown et al., (2002) conducted 48 oral interviews in 5 Alaskan communities and covered observations from as early as 1934. Survey questions fell into 6 categories: 1) life history stage and species, 2) fish behavior and school characteristics, 3) presence and behavior of co-occurring predators, 4) seasonal spatial distribution, 5) decadal shifts observed, and 6) observation and method activity. In PWS the spring spatial distribution of herring was different from summer and fall-winter, which were themselves similar. Spatial distributions of herring in the OK were significantly different from one another in all three seasons. Most observations concerned juvenile herring, but locations of herring spawning overlapped with adult herring. Pacific sand lance, capelin, capelin spawning, and eulachon were also observed and documented. Decadal shifts were observed with an increase in juvenile herring from the 1970s to the 1980s and a much more restricted distribution in the 1990s. Decadal shifts in the reported extent of juvenile herring distribution matched decadal trends in catches of adult herring in the PWS. Herring spawning locations prior to the 1970s that were not previously reported by ADFG were documented.

3 Conclusions

Two large ecosystem studies in the GOA and BSAI have included forage fishes in their studies, and resulted in descriptions of distribution, diet, energetic condition, and the effects of climate related changes on forage fish in those large marine ecosystems. Additional studies have included summaries of traditional and local knowledge on forage fish distribution and abundance going back several decades. Staff were not able to identify studies of forage fish on a statewide scale. Many authors have noted that juvenile and small adult fish are an important part of all marine ecosystems, and encouraged additional studies. Some authors, however, have noted that annual indices of abundance from surveys as currently conducted may not be sufficient to understand and predict responses of forage fish to changing climate, and suggested that a useful forage fish survey would have to be conducted in a very broad geographical scale and occur in both summer and fall.

4 References

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