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Alaska Fisheries Science Center
Resource Assessment and Conservation Engineering Division

Pacific cod (*Gadus macrocephalus*) Workshop – Field Efforts and Current Research 2023

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Pacific cod (*Gadus macrocephalus*) Workshop – Field Efforts and Current Research 2023

by

Kimberly M. Rand[1], Alexandra Dowlin[2], Charlotte Levy[3],
Susanne McDermott[2], Julie Nielsen[4], Bianca Prohaska[2], and Sean Rohan[2]

[1]Lynker
202 Church Street S.E. #536
Leesburg, VA, 20175
Under Contract to
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Alaska Fisheries Science Center
7600 Sand Point Way N.E.
Seattle, WA 98115-6349

[2]National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Alaska Fisheries Science Center
Resource Assessment and Conservation Engineering Division
7600 Sand Point Way N.E.
Seattle, WA 98115-6349

[3]Aleutians East Borough
Anchorage Office
3380 C St., Suite 205
Anchorage, AK 99503

[4]Kingfisher Marine Research, LLC
1102 Wee Burn Dr.
Juneau, AK 99801

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Preface

A 2-day workshop was held at the Alaska Fisheries Science Center in Seattle, Washington, on November 28-29, 2023. The purpose of this workshop was to bring together scientists from various disciplines working on aspects of Pacific cod ecology, life history, distribution, stock assessment, and fisheries management. This workshop was funded by a joint project between the Alaska Fisheries Science Center (AFSC) and the Aleutian East Borough (AEB) (Disaster relief grant for Pacific cod tagging, Charlotte Levy, AEB lead P.I.) Over 30 scientists participated in the workshop both on-site and remotely. Day 1 focused on past, current, and future Pacific cod research in Alaskan waters. Day 2 focused on informal discussions regarding current and future field efforts and forming collaborations when research objectives aligned.

The Workshop included 18 oral presentations under the following categories: Larval and Juvenile Pacific cod, Habitat Modeling and Management, Life History, and Adult Pacific cod. All presenters submitted presentations and a summary of each presentation constitutes the body of this report. Each presentation is summarized by “Overview”, a synopsis of current and future research/objectives and “Future Needs” identified by the presenter that included future collaborations, data needs, and research that would benefit our knowledge of Pacific cod in Alaska waters.

During the course of the workshop, planned field efforts and the spatial extent of sampling were mapped for multiple surveys and the years 2024 and 2025 (Appendix 1). The Workshop Agenda (Appendix 2), Workshop Abbreviations found throughout this report (Appendix 3), and the Workshop Participants (Appendix 4) with contact information accurate as of February 2024, are included. If a coauthor was not in attendance at the workshop, their affiliation is noted in the presentation summary. Only minor editorial corrections (spelling, punctuation) were made to the Summary Presentations, after review by the presenters. When applicable, peer-reviewed references were included at the end of the presentations.

Contents

Introduction

The fishery for Pacific cod is one of the largest groundfish fisheries in Alaska and this species is a key component of the ecosystem. In recent years, warming ocean conditions, including a series of marine heatwaves in the North Pacific Ocean, contributed to significant decreases in abundance as well as distributional shifts of Pacific cod in the Gulf of Alaska and the Bering Sea. In the Gulf of Alaska, an unprecedented marine heatwave precipitated consecutive years of low recruitment, leading to a temporary fisheries closure in 2020. Record warm conditions in the Bering Sea contributed to a loss of sea ice and contraction of the Bering Sea cold pool, which was associated with a northward shift of the Pacific cod population into the Northern Bering Sea (NBS).

The low recruitment and distribution shifts of Pacific cod during recent warm years have contributed to a proliferation of research efforts directed towards Pacific cod populations, with an emphasis on improving understanding of responses to climate change. This research ranges from changing maturity, egg survival, early life history, and growth patterns to genetics, distribution shifts of juvenile and adult fish, and ecosystem impacts resulting from these water temperature changes.

Summary Presentations

LARVAL AND JUVENILE PACIFIC COD

Pacific cod: An Early Life History Perspective

Benjamin Laurel (presenter), Alisa Abookire, Steve Barbeaux, Zoe Almeida, Louise A. Copeman, Janet Duffy-Anderson, Thomas P. Hurst, Mike Litzow, Trond Kristiansen, Jessica A. Miller, Wayne Palsson, Sean Rooney, Hillary Thalmann, Lauren A. Rogers

Overview

The presentation titled "Pacific cod in the Anthropocene: an early life history perspective under changing thermal habitats" discussed the loss of thermal spawning habitat in the NE Pacific. This coupled with the apparent loss of both adults and pre-recruits, is strong evidence that Pacific cod distribution and productivity is bottlenecked at this life history stage in the Gulf of Alaska (GOA) and lower latitudes.

Thermal habitat metrics have broad applicability for Pacific cod in management (annual assessments and forecasting)

Warming results in bigger larvae and juveniles. Considering faster growth and changes in spawning timing (i.e. earlier), we would expect to see more size variation likely from multiple spawning events (Figure 1, below).

Research efforts should consider demographic shifts in the population in addition to other thermal habitat metrics for higher latitude regions e.g., Bering Sea juvenile summer growth, Chukchi Sea juvenile overwintering, etc (see *Future Needs*).

Review of early life stages

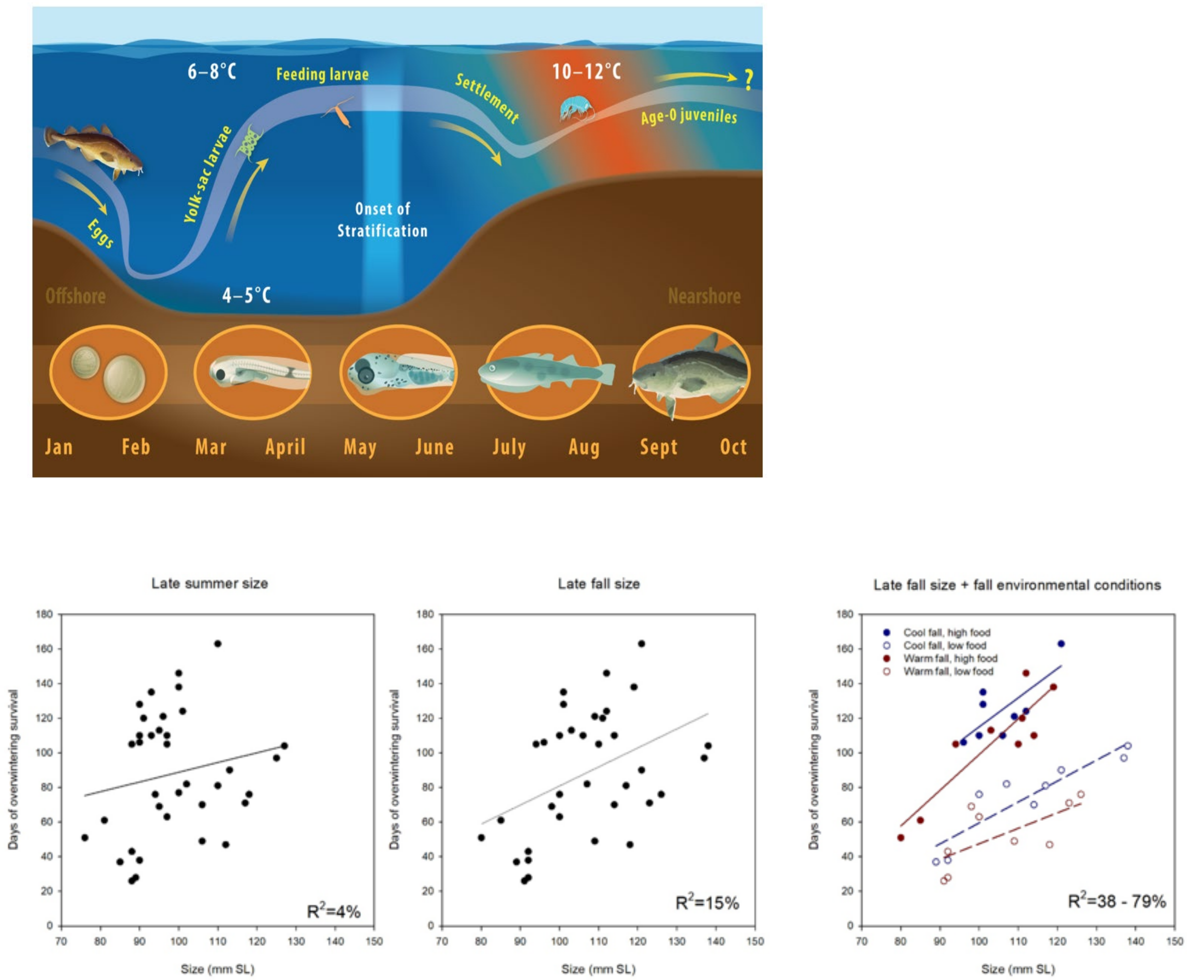


Figure 1. Top panel: Conceptual model of the first year of life of Pacific cod in the Gulf of Alaska along with optimal temperatures for growth and survival at the egg, larval, and juvenile phases. Eggs are spawned in the spring on the bottom substrates and hatched larvae advect to surface layers in the spring. Larvae develop and feed on zooplankton in the water column as they are transported to nearshore, coastal nursery habitats in the early summer. Post-settled juveniles shift to diverse epibenthic prey and gradually transition to deeper coastal waters through the early fall. Overwintering habitats have not been identified, but are dependent on temperature and food variability in the fall (bottom panel)

Future Needs

- Fall and winter sampling will be required to determine how changes in age-0 size structure is impacting overwintering survival to age-1.
- Maturity data are needed to validate predictions that faster, early growth resulting from marine heatwaves is leading to earlier age-at-maturity.

Pacific Cod Surveys, Data, and Current Projects from The EcoFOCI Program

Lauren Rogers (presenter)

Overview

An overview from the EcoFOCI (Ecosystems and Fisheries-Oceanography Coordinated Investigations) program on data, surveys, and samples that may be of interest, in the spirit of starting collaborations and optimizing the scientific value of our surveys. The following is organized by survey (when, where), followed by the types of data collected on the surveys, with figures focused on Pacific cod.

1. EcoFOCI Long-term larval fish sampling survey, Gulf of Alaska (1979-2023, odd years since 2011), May/June
    a. Catch-per-unit-effort (CPUE) (goes into Ecosystem Status Report, Ecosystem and Socioeconomic Profile)
    b. Lengths (Rogers analyzing)
    c. Age (Jessica Miller analyzing)
    d. Distribution
2. EcoFOCI Long-term larval fish sampling survey, Bering Sea (1991-2018, now even years), May/June
    a. CPUE
    b. Length
    c. Age (possible, but no aging work to date)
    d. Distribution
3. EcoFOCI Long-term larval fish sampling survey, Arctic (2010 - 2023, some earlier years), timing varies
4. Gulf of Alaska late-summer young -of-the-year (YOY) survey, August/September
    a. Diets (2013, 2015 processed; 2019, 2023 to be processed)
5. Ecosystem Monitoring and Assessment program (EMA), North Bering Sea Ecosystem Surface Trawl Survey
    a. CPUE YOY species (small mesh benthic trawl added in 2021)

Current research efforts are focused on examining widespread shifts in phenology of fish early life stages associated with warming in Alaska. Examining larval length-at-date as an indicator of phenology (age, developmental timing) and if larval length-at-date varies with temperature.

Possible Collaborations and data inquiries:

- Bering Sea Spring Larval Survey (May 2024) contact: Kelia Axler (kelia.axler@noaa.gov), Will Fennie (will.fennie@noaa.gov)
- Arctic Long-term larval fish sampling contact: Kelia Axler (kelia.axler@noaa.gov)
- Gulf of Alaska Late-summer YOY survey contact: Diets - Jesse Lamb (jesse.f.lamb@noaa.gov), CPUE - Lauren Rogers (lauren.rogers@noaa.gov).
- EMA North Bering Sea Ecosystem Surface Trawl survey contact: Benthic trawl - Dan Cooper (dan.cooper@noaa.gov).

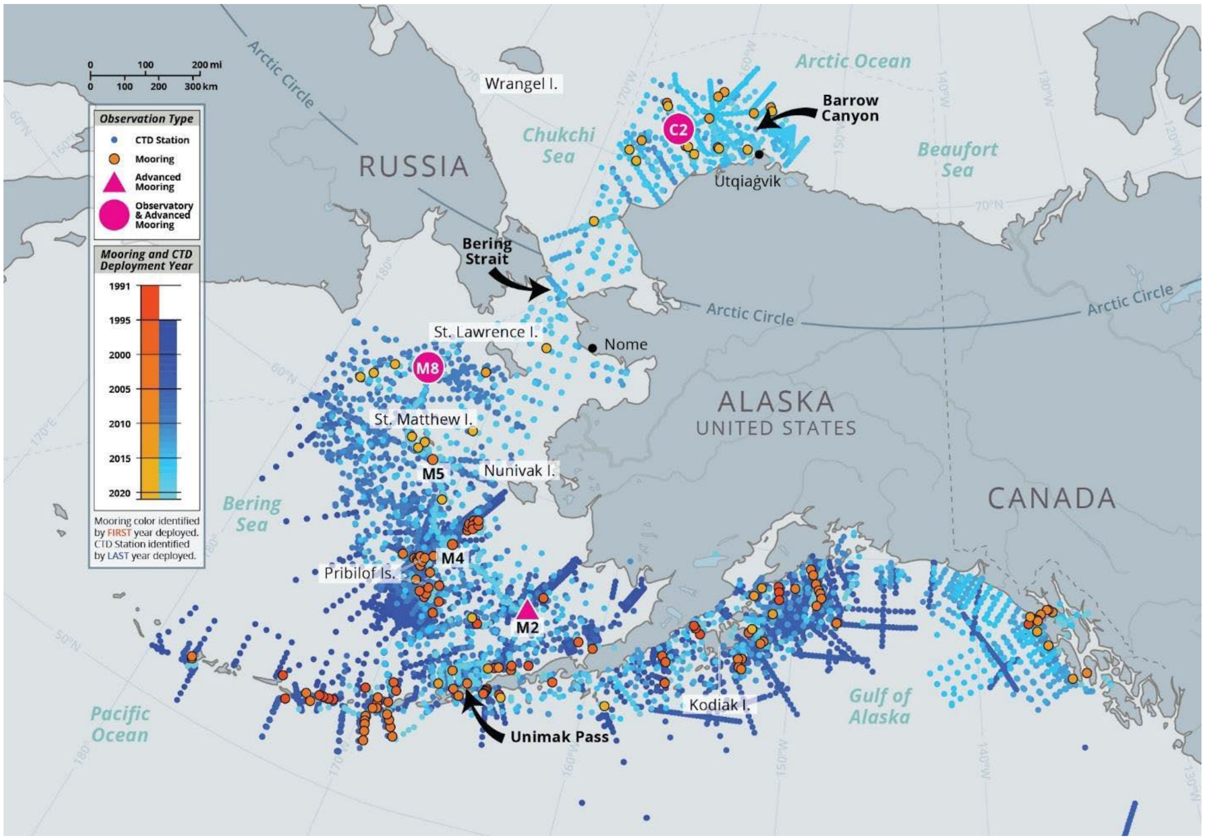


Figure 1. Snapshot of the EcoFOCI Ecosystem Surveys (Tabisola et al., 2021).

Tabisola, H., J. Duffy-Anderson, C. Mordy, and P.J. Stabeno (2021): EcoFOCI: A generation of ecosystem studies in Alaskan waters. Oceanography, 34(4), 34–35, doi: 10.5670/oceanog.2021.supplement.02-15

Future Needs

- Additional data/sampling possibilities from the EcoFOCI platforms:
    - Genetics sampling (Gulf of Alaska, #1 above)
    - Genetics sampling (Bering Sea, #2 above)
    - Age analysis (Bering Sea)

Pacific Cod Individual-Based Model (IBM) in the Gulf of Alaska

William Stockhausen (presenter), Katharine Miller (AFSC), Johanna Page (AFSC), Albert Hermann (CICOES), Ken Coyle (UAF), David Hill (OSU), Darcie Neff (Alaska BioMap, Inc.), Karen Endres (Stone Garden Farms, LLC)

Overview

Compare predictions from Individual-Based Model (IBM) for Pacific cod developed for the Gulf of Alaska (GOA) Integrated Ecosystem Research Program (IERP) with field observations to validate the IBM model and/or enhance model development by improving model processes.

Conducted broad-scale field sampling within 13 IBM comparison zones across the GOA in potential nearshore nursery areas for juvenile Pacific cod to validate early benthic juvenile abundance predictions from the IBM.

- Result: Low correlation with young-of-the-year (YOY) abundance and IBM may be the result of mismatch between IBM year (2020) and sampling year (2021) due to the pandemic-related canceled survey. Future analyses will have direct correspondence between years.

Currently Modeling

- Use size and daily ages of field-collected juvenile Pacific cod to evaluate dispersion and growth rates predicted by the IBM from spawning sites to nearshore settlement areas and make recommendations for IBM updates
- Model the nearshore habitat conditions associated with juvenile Pacific cod abundance and condition to inform Essential Fish Habitat.
- The 2021 3-km central GOA (CGOA) Regional Ocean Modeling System (ROMS) model run completed with high resolution freshwater influxes
- Incorporate small-scale habitat quality into settlement predictions
- run IBM for 2021
- Project sizes-at-settlement to field dates for better comparison with field data

Future work

- Conduct field sampling in 2024, 2025
- Run 3-km CGOA ROMS model hindcasts for 2022-2025
- Run IBM for 2022-2025
- Compare IBM predictions with field observations

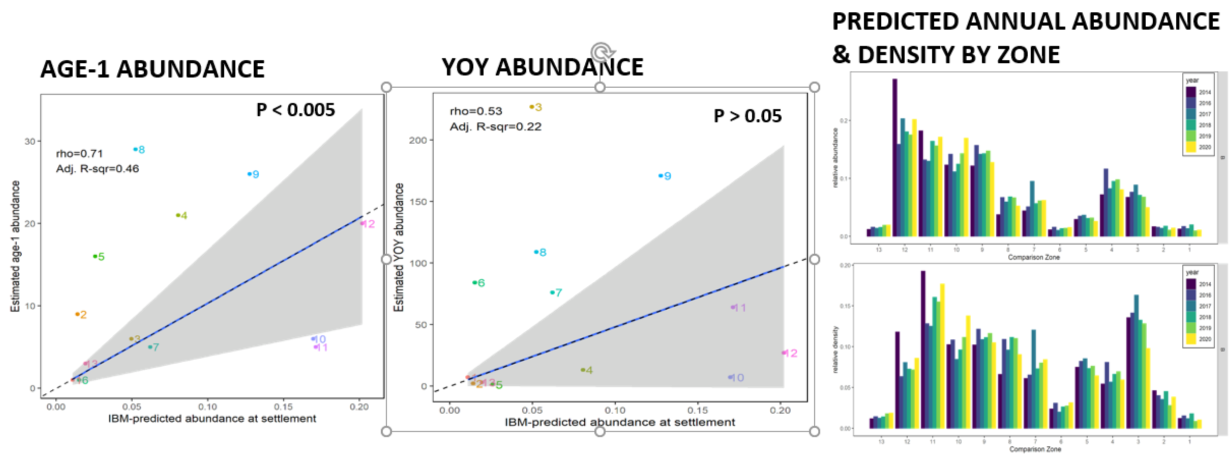


Figure 1. Results showing correlation between the IBM using 2020 ROMS model output and 2021 field results.

Future Needs

- Daily aging of juvenile Pacific cod otoliths is difficult and time intensive. A companion study (Age & Growth Lab AFSC, PSMFC, UAF) is developing a method to rapidly age cod otoliths using Fourier Transform Near Infrared Spectroscopy. This newly developed method will be used to estimate daily ages of field-caught fish.

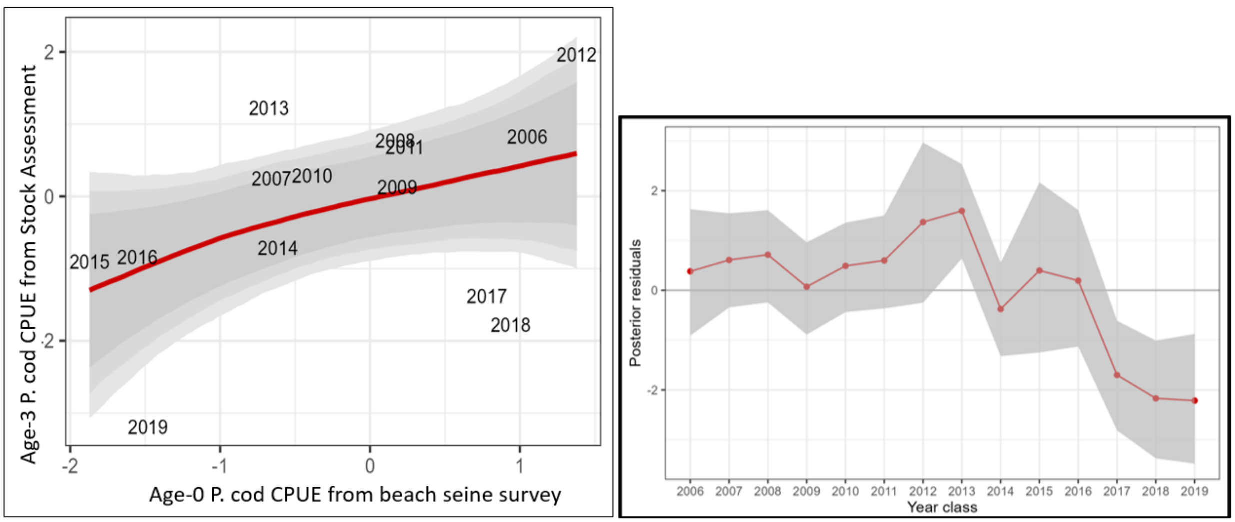
Pacific Cod Age-0: Improving Understanding of Recruitment Success

Alisa Abookire (ACOR; presenter), Mike Litzow (AFSC), Benjamin Laurel (AFSC),
Ingrid Spies (AFSC), and Pete Hulson (AFSC)

Overview

The presentation was titled “Improving Understanding of Recruitment Success in a Warming Gulf of Alaska: Building a 5-year Survey of Age-0 Pacific cod”.

The main goals of this project are to determine if age-0 abundance can forecast year class strength, to understand the effects of temperature on age-0 abundance and condition, and to assign natal stock of origin using genetics.



Model residuals

Figure 1. Forecasting year class strength for Pacific cod.

From 2006 to 2016, abundance of age-0 Pacific cod had high predictive skill for age-3 Pacific cod abundance, as reported in the Stock Assessment report. In 2017, 2018, and 2019 the number of age-3 Pacific cod was much lower than would have been predicted based on age-0 abundance from the previous 11 years. This suggests a new control on the population, and the model residuals also demonstrate a switch from positive residuals to negative residuals starting in 2017. Initially, the number of age-0 cod was a good predictor of the number of age-3 cod, but starting in 2017, a new control on cod population is occurring after August of the first year.

The altered relationship between age-0 and age-3 Pacific cod suggests a recent change in population control. Warm winter and/or early spring temperatures negatively affect cod survival. Warmer summer temperatures positively benefit age-0 cod by increasing body condition, which may improve overwintering success. However, there is likely a temperature trade-off and the effects of warm temperatures are life-stage specific.

We are currently using genetics to determine what spawning aggregations contribute to the nursery areas in the western Gulf of Alaska and if there are juveniles from multiple spawning aggregations utilizing the same nursery areas.

Peer-reviewed papers referenced in presentation

Abookire, A.A., M.A. Litzow, M.J. Malick, and B.J. Laurel. 2022. Post-settlement abundance, condition, and survival in a climate-stressed population of Pacific cod. Can. J. Fish. Aquat. Sci. 79(6):958-968. doi.org/10.1139/cjfas-2021-0224

Laurel, B.J., and L.A. Rogers. 2020. Loss of spawning habitat and prerecruits of Pacific cod during a Gulf of Alaska heatwave. Can. J. Fish. Aquat. Sci. 77(4): 644–650. doi:10.1139/cjfas-2019-0238.

Laurel, B., A. Abookire, S. Barbeaux, L. Almeida, L. Copeman, J. Duffy-Anderson, T. Hurst, M. Litzow, T. Kristiansen, J. Miller, W. Palsson, S. Rooney, H. Thalmann, and L. Rogers. 2023. Pacific cod in the Anthropocene: an early life history perspective under changing thermal habitats. Fish and Fisheries.

Litzow, M.A., A.A. Abookire, J.T. Duffy-Anderson, B.J. Laurel, M.J. Malick, and L.A. Rogers. 2022. Predicting year class strength for climate-stressed gadid stocks in the Gulf of Alaska. Fish. Res. 249: 106250. doi:10.1016/j.fishres.2022.106250.

Litzow, M.A., M.J. Malick, A.A. Abookire, J. Duffy-Anderson, B.J. Laurel, P.H.Ressler, and L.A. Rogers. 2021. Using climate attribution statistic to inform judgments about changing fisheries sustainability. Sci. Rep. 11, 23924. doi:10.1038/s41598-021-03405-6.

Future Needs

- Determine what parameters control overwintering success of age-0 and age-1 Pacific cod.
- Determine the best way to measure body condition of age-1 Pacific cod.

Molecular Response of Larval Pacific Cod to Warming and Acidification

Laura Spencer (presenter), Emily Slesinger (AFSC, Newport), Benjamin Laurel, Tom Hurst (AFSC, Newport), Louise Copeman (AFSC, Newport), MaryBeth Hicks (AFSC, Newport), Ingrid Spies, Steven Roberts (UW, SAFS)

Overview

Warming temperatures may cause high mortality in larval Pacific cod by a combination of heightened immune activity and lipid dysregulation.

It is unclear if immune activity is a temperature-dependent response, or reflective of infection.

Larval Pacific cod lipid metabolism is sensitive to both warming and acidification where

- Warming = broad changes to variety of lipid metabolism processes
- Acidification = decreased lipid digestion in intestine

Larval Pacific cod visual activity is sensitive to warming, and one possible explanation is that enables enhanced foraging.

Combined warming and acidification impacts similar genes and processes as warming alone, but the responses are more muted.

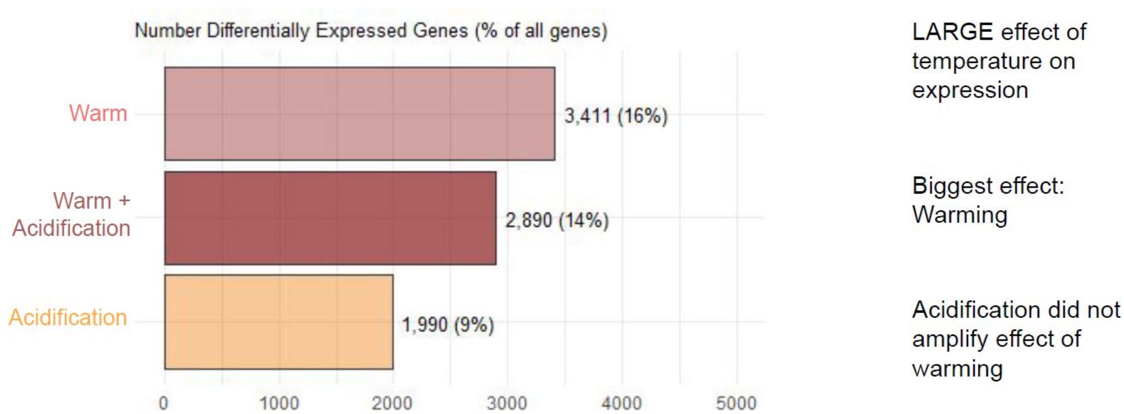


Figure 1. Results from the differential gene expression analysis of larval Pacific cod.

Future Needs

- Juvenile study of Pacific cod in more extreme temperatures (including cold exposure)

Management Stock Structure of Pacific Cod in the Gulf of Alaska

Lorenzo Ciannelli (presenter), Pete Hulson, Ingrid Spies, Steve Barbeaux, Lauren Rogers, William Stockhausen, Albert Hermann (CICOES)

Overview

The spatial structure of a population can be defined through different disciplinary lenses that include demographic (spatial structure), oceanographic (condition and habitats), ecological (life history traits), genetic (variations in genetic expression), and socio-economic (harvest technologies, food security, policy).

Within this framework we proposed several objectives using the EcoFOCI midwater summer surveys (odd years), the AFSC annual bottom trawl survey, and NMFS Observer data for winter distribution with emphasis on juveniles (YOY) stages:

1) Perform empirical retrospective analyses (1990s-current) of Pacific cod distribution over different life history stages.
    a) Simulate cod spawning, dispersal, foraging, growth and survival from spawning, in spring, to juvenile settlement in the summer
2) Refine mechanistic feeding and transport model of cod movement and survival during early life-history stages, and conduct simulation scenarios for assessing habitat connectivity
    a) Currently: build on dispersal and foraging model built by Giancarlo Correa for the Bering Sea and Hinckley et al. 2019 (https://doi.org/10.1016/j.dsr2.2019.05.007).
3) Build scenarios and assess consequences of multi-stock configurations for Pacific cod in the GOA and BS (i.e. NBS/EBS)
    a) Use stock-synthesis to parameterize a spatially-explicit stock assessment model that combines the GOA and BS regions to estimate regional abundance and to evaluate the impact on management reference points with different levels of exchange between the two regions and different spatial configurations.
    b) Apply estimation models that include: current assessment framework, GOA and BS separately (current models), GOA and BS combined, and GOA with spatial structure.

Future Needs

- Data on juvenile Pacific cod distributions in addition to the EcoFOCI late summer survey data such as surveys along the Alaska Peninsula in the coastal areas by ADFG.
- Collaboration between groups focusing on genetics and the satellite tagging study will continue to improve our understanding

Ontogenetic Habitats for Pacific Cod Along the Coast of Washington

Trond Kristiansen (presenter), Benjamin Laurel, Lorenz Hauser, Kathryn C. Meyer, Parker MacCready (UW, School of Oceanography)

Overview

The presentation was titled "Ontogenetic Habitats for Pacific Cod Along the Coast of Washington Under Climate Change Using High-Resolution Ocean Climate Downscaling". Pacific cod habitat suitability projections for the Salish Sea/Puget Sound (Washington) requires high-resolution climate projections. Climate projections from the IPCC CMIP6 models are too coarse to provide important physical processes for coastal regions. Statistical downscaling provides a quick approach to assess impacts of climate change from a range of CMIP6 models across a selection of climate scenarios.

Preliminary results are:

- Pacific cod habitat suitability will decrease considerably for the Puget Sound region in the future, as warming continues.
- Egg hatching success is limited to regions where the temperature is around 5°C, which is only found at very deep depths near shelf edge.
- Spawning habitat area decreases with continued warming and declines in oxygen.

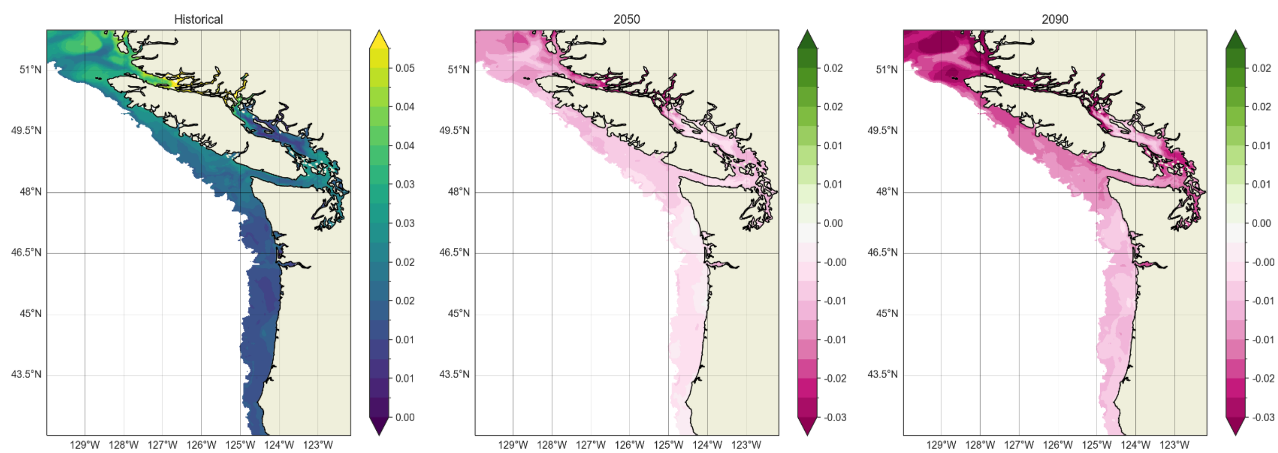


Figure 1. Differences in Pacific cod habitats now (1993-2020) and in the future (2041-2060) using an index comprised of survival through the egg stage during winter/spring, juvenile growth during summer, and female adult habitat conditions during spawning.

Future Needs

- The spatial and temporal modeled survival of juvenile Pacific cod could be improved by including prey availability.

Climate-Enhanced Stock Assessment Models for Pacific Cod

Krista Oke (presenter), Pete Hulson, Steve Barbeaux, Brad Harris (Fisheries, Aquatic Science, & Technology (FAST) Laboratory, Alaska Pacific University)

Overview

The presentation was titled "Sneak Peek: Climate-enhanced Stock Assessment Models for the Gulf of Alaska and Bering Sea Pacific Cod". Direct incorporation of ecosystem indicators into assessment models remains a challenge. Pacific cod provide a good test case for development and testing of ecosystem-informed stock assessment models, in part due to their sensitivity to ecosystem conditions and in part due to assessment model development that has included time-blocks and temperature parameters. Project goals are:

- Explore potential ecosystem indicators and determine most appropriate temperature metrics
- Explore alternative model parameterizations with ecosystem links
    - Could ecosystem-informed models have predicted GOA collapse?
- Investigate ecosystem indicators' impacts on recruitment
- Investigate relationships between temperature and growth
- Compare ecosystem responses in GOA and EBS

Future Needs

- This project is just getting underway, more to come!
- Identify ecosystem indicators of interest, inclusive of indicators already in use (*e.g.*, in assessment or ESP) and newly proposed indicators based on other research

Overview of Pacific Cod in Alaska State Waters Fisheries

Janet Rumble, Nat Nichols and Cassandra Whiteside (ADFG, Kodiak),
Rhea Ehresmann and Alex McCarrel (ADFG, Sitka), Aaron Baldwin (ADFG, Juneau),
Laura Coleman (ADFG, Ketchikan), Martin Schuster and Andy Pollak (ADFG, Homer),
Ethan Nichols and Asia Beder (ADFG, Dutch Harbor)

Overview

There are three Alaska Pacific cod fisheries:

1. Federal: Federal waters (3–200 nmi) guided by North Pacific Fishery Management Council (NPFMC) process. Harvest deducted from federal Total Allowable Catch (TAC).
2. Parallel: State waters (0–3 nmi) concurrent with adjacent federal fishery and generally adopt federal regulations and management measures as guided by the Alaska Board of Fisheries (BOF) process. Harvest deducted from federal TAC.
3. State-Waters (Guideline Harvest Level): State waters (0–3 nmi) guided by the BOF process. Harvest deducted from state GHL.

In 2023, there was 64.5 million pounds available for state-waters fisheries. Port sampling, surveys, logbooks, and fish ticket information is collected from the fisheries along with genetic samples that are given to NOAA/NMFS.

Board of Fisheries process guides regulations; proposals can be submitted by the public/groups/ADFG. This public process includes:

- Local Advisory Councils
- Public Testimony
- Committee Meeting

The BOF members are appointed by the Alaska Governor and Alaska State Legislature. Regulations can be effective within 6 months of passing.

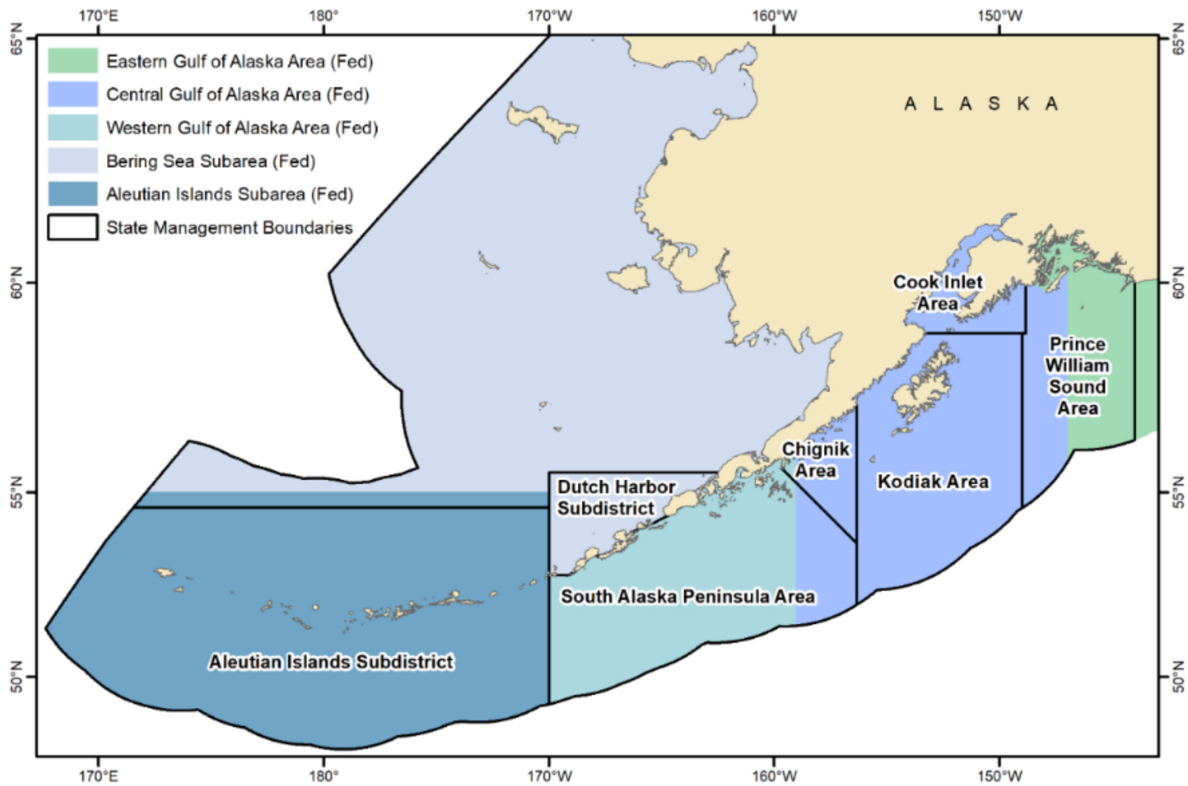


Figure 1. Federal fisheries management areas with state management boundaries.

Future Needs

- Potential avenue of research, data available: port sampling (biological/effort), logbooks (locations of harvest), fish ticket information (average weights, effort), genetic samples collected for NOAA/NMFS.

Changes in Pacific Cod Weight-at-age With Temperature and Oxygen

Jennifer Bigman (presenter), Lewis Barnett, Krista Oke, Benjamin Laurel, Kelly Kearney (AFSC), Kirstin Holsman (AFSC), Darren Pilcher (CICOES), Wei Cheng (CICOES), Albert Hermann (CICOES), Lauren Rogers

Overview

Changing environmental conditions elicit shifts in size and growth (i.e. warmer water = faster growth and smaller sizes at maturity). The main question is whether faster growth for younger age classes, and thus larger size-at-age for these age classes, will offset the smaller size-at-age for older age classes (maturity & post-maturity).

Preliminary observations:

- We observed different patterns of Pacific cod weight and temperature/oxygen effects for different age classes.
- With temperature, we observed a somewhat positive relationship (i.e. higher temperatures equal larger weights) for ages 4-14; however, we noted older age classes did not show this relationship.
- We did not observe a relationship between oxygen and growth for most age classes.

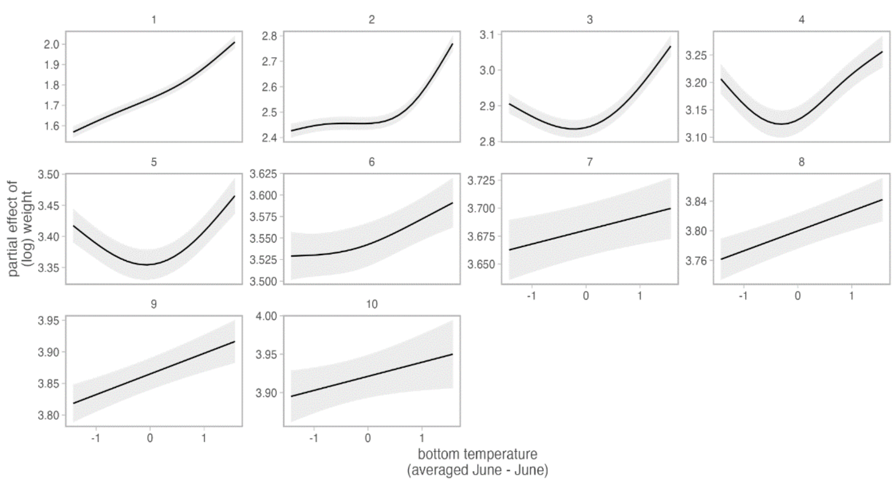


Figure 1. Using spatiotemporal generalized additive mixed models, this shows the relationship between temperature (from the Bering 10k ROMS hindcast) and (the partial effect of) weight for each age class for Pacific cod (numbers above the graph correspond to age).

Future Needs

- Examine additional species to compare contrasting life histories and ecologies and possibly extend to the Gulf of Alaska.

<u>ADULT PACIFIC COD</u>

Genetic Data: Stock-specific Survival and Natal Homing of Pacific Cod in Alaska

Sara Schaal (presenter), Wes Larson, Claire Tobin, Johanna Vollenweider, Katharine Miller, Jacek Maselko, Susanne McDermott, Lorenz Hauser, Ingrid Spies

Overview
The presentation was titled "Genetic Data Reveal Putative Stock-specific Survival and Natal Homing of Pacific cod Across Alaska".

GT-seq panel: The panel of genetic markers that differentiate stocks of Pacific cod in this study can identify four genetically distinct groups: eastern Gulf of Alaska (EGOA), western GOA (WGOA)/ Eastern Bering Sea (EBS), Aleutian Islands, and Northern Bering Sea (NBS).

Juvenile Life Stage: what is the stock-specific habitat use by juvenile Pacific cod? Hypothesis: westward advection in the Alaska Current will cause EGOA juveniles to mix with WGOA juvenile habitat, whereas EGOA juveniles will exhibit local retention.

- Overall there was a signal of westward advection of EGOA individuals into the central and western GOA.
- One exception was that a large proportion of WGOA/EBS juveniles were identified in the EGOA.
- Putative differential survival of WGOA/EBS individuals somewhere between the juvenile stage and maturity.

Adult Life Stage: Is there seasonal variation in stock-specific adult habitat use in Pacific cod? Hypothesis: Genetic stock proportions of summer caught Pacific cod adults will show mixing of multiple stocks at each location due to summer movement to feeding grounds.

Summer Captured Adult Pacific cod Conclusions:

- Overall, some seasonal movement between spawning groups (i.e. EBS and WGOA); however, the major exception is in the NBS where individuals found in Norton Sound were mostly WGOA/EBS individuals indicating seasonal movement up the Alaskan coast by WGOA/EBS individuals.
- Evidence for natal homing due to the movement we see in the summer that was not found on spawning grounds in the winter.

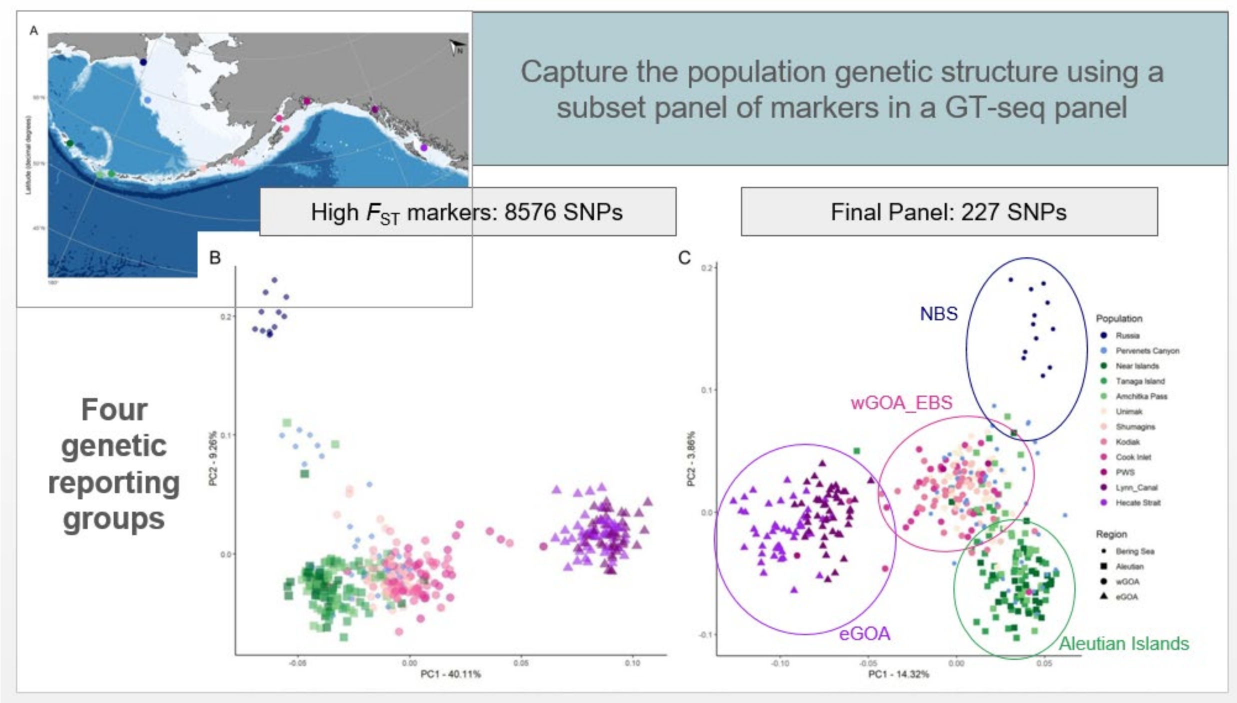


Figure 1. Sampling design and analysis of low-coverage whole genome data for Pacific cod populations across the GOA and BS. A) map of sampling locations of pacific cod with colors corresponding to the sampled population. B) principal component analysis (PCA) of the highly differentiated loci found in the genome (i.e., high F_{ST} markers) with colors again matching the sampled population and shape the sampling region and C) PCA of the panel of markers designed from the high F_{ST} markers showing we can still differentiate the four main genetic groups found in the first PCA: EGOA, WGOA/EBS, Aleutian Islands, and NBS.

Future Needs

- Juveniles from the EBS and NBS; in the process of obtaining samples in 2024 from the EBS survey, but because the NBS survey was canceled we are still looking for ways to get samples from far north.
- Adults from the NBS (summer): because of the interesting signal in the NBS we wanted to see if this was temporally stable and check samples around St. Lawrence Island and Norton Sound in future years.

Evolution at the Rear Edge of Distribution Shifts for Pacific Cod

Lorenz Hauser (presenter)

Overview

The presentation was titled "Evolution at the Rear Edge of Distribution Shifts: Implications for Adaptation to Climate Change".

Species change their distribution not always as a shifting single population, but as a complex process of colonization at the leading edge and extinction at the rear edge. For example, Pacific cod were continuously distributed in the North Pacific prior to last glaciation approximately 100,000 years ago, and subsequently retreated southward as the ice sheet expanded. Remaining populations survived as refugial populations in ice-free areas and slowly differentiated through genetic drift and local adaptation. As the glaciers retreated, those populations came into secondary contact and expanded northward in a series of colonization steps. The genetic signature of these recolonization patterns is still visible today, with relatively homogenous populations at the leading edge in northern latitudes (e.g. Bering Sea) which is now the center of distribution of Pacific cod, and genetically differentiated populations at the rear edge in the Salish Sea and South Korea (Figure 1). These southern populations comprise about two-thirds of the between population differentiation of Pacific cod, and may harbor genetic diversity instrumental for climate change, given that they spawn at much higher temperatures than northern distributions of cod.

Recently, Gulf of Alaska Pacific cod were adversely affected by marine heat waves during 2014-2016 and 2019. We hypothesize that warm-adapted cod could potentially provide a source of warm-adapted fish for the Gulf of Alaska and areas north where waters continue to warm. However, these peripheral rear edge populations are also under threat from climate change and other environmental pressures and are thus in urgent need of conservation.

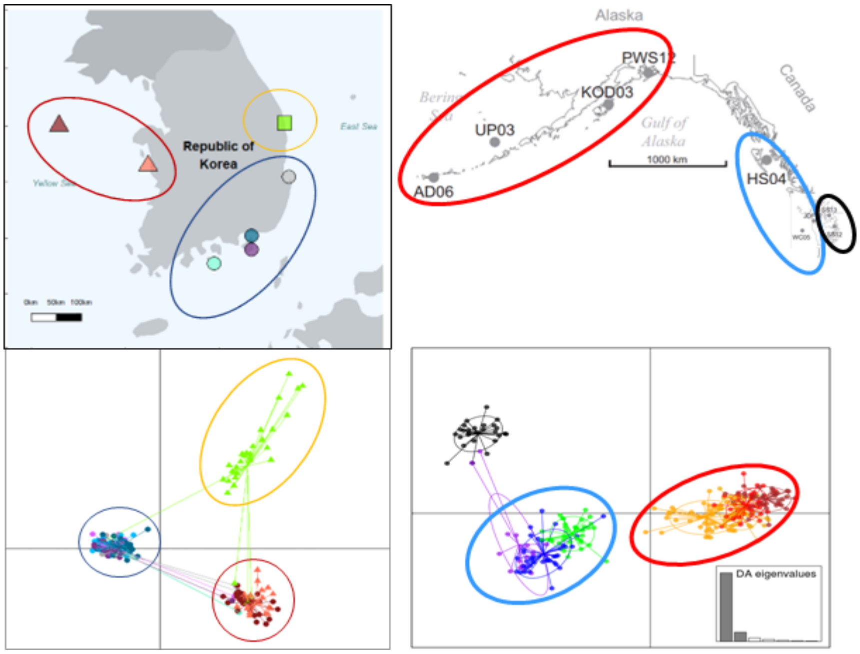


Figure 1. Population structure of Pacific cod at the southern edge of the distribution in Korea (left) and the Salish Sea (right). Color coding in the maps (top) is also used in the principal components analysis (PCA) (bottom left) and discriminant analysis of principal components (DAPC) (bottom right). Lines between clusters show individuals that are assigned to the wrong population, i.e. dispersers. All dispersers migrated from the periphery into the core populations. Note the high level of differentiation along the southern U.S. and B.C. range compare to the homogeneity in the Eastern Bering Sea (EBS) / (Aleutian Islands) AI group. From Fisher et al. 2022 (left) and Drinan et al. 2018 (right).

Peer-reviewed papers referenced in presentation

Fisher, M. C., Helser, T. E., Kang, S., Gwak, W., Canino, M. F., & Hauser, L. (2022). Genetic structure and dispersal in peripheral populations of a marine fish (Pacific cod, *Gadus macrocephalus*) and their importance for adaptation to climate change. *Ecology and Evolution*, 12, e8474. https://doi.org/10.1002/ece3.8474

Drinan DP, Gruenthal KM, Canino MF, Lowry D, Fisher MC, Hauser L. Population assignment and local adaptation along an isolation-by-distance gradient in Pacific cod (*Gadus macrocephalus*). *Evol Appl*. 2018; 11: 1448–1464. https://doi.org/10.1111/eva.12639

Future Needs

- Samples pre- and post- heatwave from the GOA, the EBS, and Washington coast.
- Continuing sampling of spawning populations for genetic monitoring.
- Environmental data to document warming trends and other environmental changes.

Can Pacific Cod Avoid Freezing?

Christina Cheng (presenter)

Overview

The presentation was titled "Can Pacific cod Avoid Freezing? Evaluation of its Antifreeze Protein Genotype and Phenotype".

The Cheng-DeVries laboratory conducts research on gadids and the evolutionary history of antifreeze glycoproteins (AFGPs) across the gadid phylogeny. This requires determining the functional status of the AFGPs phenotype and genotype. Results can inform whether the habitat use of a gadid species can include icy freezing polar waters.

Current study - AFGP genotype and phenotype of the Pacific cod (Pcod).

- **Genotype** - We curated the AFGP gene family from genome assembly and analyzed the functionality of AFGP genes.
    - Results: The Pacific cod genome has 9 copies of AFGP gene; two of them appear functional.
- **Phenotype** - We used 85 samples of Pacific cod plasma (from EBS, collected in June 2022) to determine two contributions to plasma freezing point (FP): (i) the equilibrium (*i.e.* colligative) FP due to dissolved small osmolytes in the plasma, and (ii) the hysteresis FP due to antifreeze protein if present. The sum of the values of (i) and (ii) equals the plasma FP, *i.e.* the temperature at which cod blood, and therefore the fish, will freeze.
    - Results: The majority of the 85 summer EBS pcods have little or no antifreeze activity. Among the small fraction of individuals that have antifreeze, the highest level observed can prevent freezing to about -1.26C (Figure 1). This is 0.67C higher than the freezing waters (-1.93C) of Arctic marine habitats.
- **Conclusion** - Based on current data, high Arctic freezing habitats will be out of reach for the Pacific cod.

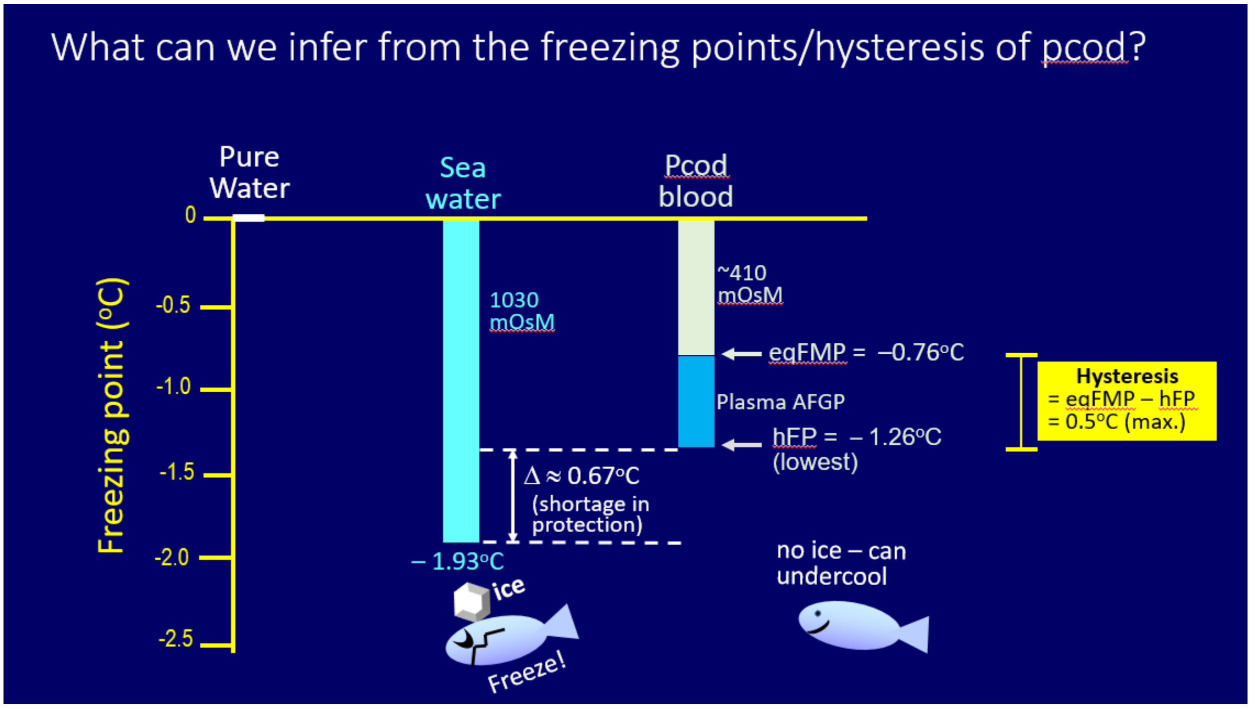


Figure 1. Plasma freezing point/hysteresis of Pacific cod (n=85) from EBS summer collection, illustrating the level of the species' freeze avoidance capacity. Seawater FP is -1.93C. Mean equilibrium freezing/melting point (eqFMP) due to dissolved small osmolytes is -0.76C. The highest level of AFGPs observed further depresses the plasma FP by 0.5C, to a hysteresis FP (hFP) of -1.26C. This is 0.67C higher than the FP of seawater (-1.93C), and thus Pacific cod will freeze and die if seawater reaches freezing and especially if ice is present in the water column.

Future Needs

- Repeat the same analyses for samples collected from winter individuals.
    - The current results and inference were derived from summer individuals of Pacific cod. Most northern fishes that have antifreeze protein exhibit a seasonal migration cycle. It is unknown whether cod AFGPs synthesis is seasonal. If it is upregulated in the winter, it would enhance the freezing avoidance capacity.
- Genotyping analyses of both summer and winter Pacific cod.
    - Only a fraction of the summer EBS cod had antifreeze activity that will allow us to determine which particular genetic stock/s express this protective trait.

Physiological Stress of Pacific Cod in the Eastern Bering Sea

Bianca Prohaska (presenter), Anita Kroska (Alaska Pacific University),
Nathan Wolf (Alaska Pacific University)

Overview

Stress physiology in bony fishes has been measured in previous work primarily using blood plasma and measuring cortisol. To measure this stress hormone, a laboratory analysis is required. For more immediate results, a secondary stress response is measured which is glucose, lactate, pH, and hematocrit. To determine if the measured stress hormone is a result of environmental stress, we are developing a method to extract cortisol from epidermal mucus. If successful, the strengths are:

- Complement to plasma collections
- View cortisol levels over a different temporal window allowing comparative assessment
- Useful for habitat mapping such as temperature, food availability, etc.

Opportunistic project measured stress responses between rod/reel and trawl captured fish using lactate, pH, glucose, hematocrit and stored plasma (cortisol). The results showed less acute stress with a rod/reel combination than trawl capture. This can affect the post-release survivorship of tagged fish.

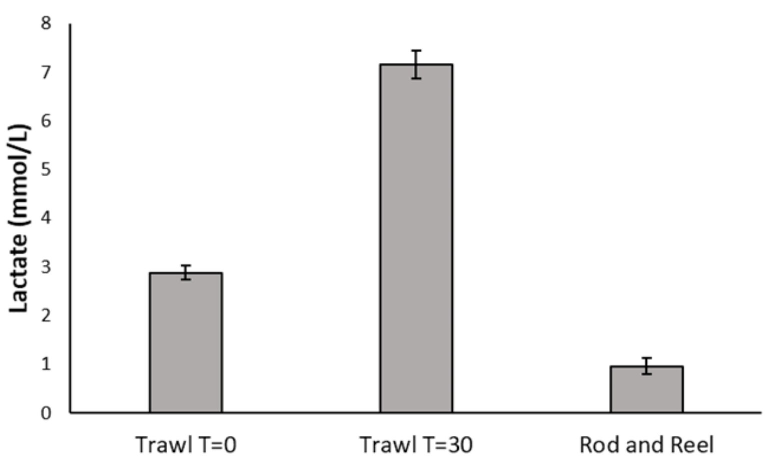


Fig. 1. Preliminary results of plasma lactate (mmol/l) in Pacific cod blood immediately after trawl capture (Trawl T=0), after trawl capture and 30 minutes in an onboard holding tank (Trawl T=30), and after a 1-2-minute rod and reel capture (Rod and Reel).

Future Needs

- Funding to analyze stored plasma and mucus samples - Purchase ELISA Kits and lab materials.
- Funds to continue collecting/analyzing samples from different regions/over different temporal scales.

Overview of Pacific Cod Satellite Tagging in Alaskan Waters

Julie Nielsen (presenter), Susanne McDermott, Charlotte Levy, Kimberly Rand

Overview

Seasonal movement of Pacific cod in Alaskan waters is not well understood in many areas. Migration timing, extent, pathways and the proportion of the cod population that migrates. With warming ocean conditions, Pacific cod distribution patterns are changing in Alaska waters. Outstanding questions:

- Bering sea: Northward shift
  - Year-round or seasonal?
- Gulf of Alaska: Large population decline
  - Migration into Bering sea waters?

Pacific cod satellite tagging projects highest priorities are:

- Quantify seasonal connectivity between management areas
  - Between the Northern Bering Sea (NBS) and Eastern Bering Sea (EBS)
  - Between the EBS and Gulf of Alaska (GOA)
  - Western/Central (WGOA/CGOA)
- Movement out of NMFS managed areas, movement into/out of Russian waters, northward shift to NBS and Arctic waters
- Effects of warming waters on seasonal shifts in distribution
- Fish activity patterns, including diel, seasonal, geographic, and diet

To answer these questions, we use Pop-up Satellite Archival Tags (PSATs) that are attached to Pacific cod for a predetermined length of time. After the tag is released from the fish and floats to the water surface, the tag transmits depth, temperature, light, and (sometimes) acceleration data to the Argos satellite network. The data are then used to reconstruct the path of the fish with a Hidden Markov model (HMM) on a 3-km grid of the study area. The model produces location probability surfaces (e.g., the probability that the fish occupied each study area grid cell) for each day. These probability surfaces are then used to derive products that allow visualization of the reconstructed pathway such as Viterbi point estimates that represent the most probable sequence of grid cells occupied and error polygons that encompass the highest 50% and 99% of the probability each day (Figure 1).

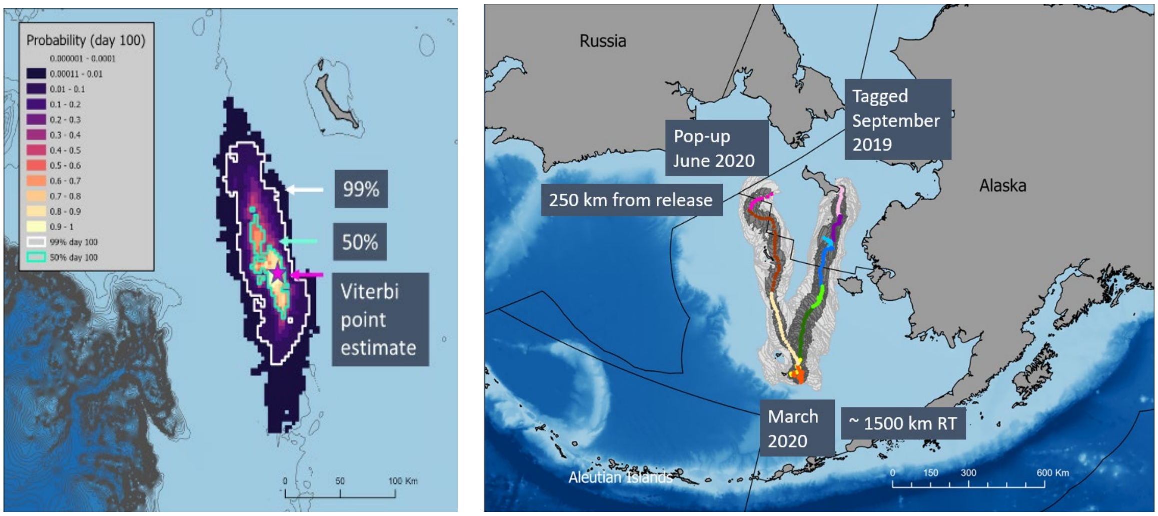


Figure 1. Example of the Hidden Markov model results, with Viterbi point estimate (star), 50% and 99% probability polygons on day 100 (left) and an estimated travel path for a tagged Pacific cod (right).

Results to date for 2019, 2021 and 2022 NBS tagging (summer to winter and annual movement):

- No evidence of cod overwintering in the NBS; movement out of NBS related to dropping temperatures and sea ice advance
- Substantial seasonal connectivity between the NBS and EBS
- Some seasonal connectivity between the NBS/EBS and the WGOA
- Some connectivity with Russia year-round
- Limited connectivity with the Aleutian Islands
- Site fidelity to summer foraging areas in NBS

Results to date for 2021, 2022, and 2023 WGOA (winter spawning to summer foraging)

- Extensive seasonal connectivity between WGOA and northern waters (EBS, Russia, Chukchi Sea)
- Shumagin Islands seems to be eastward extent for connectivity between WGOA and EBS
- Magnitude of connectivity may vary by year (warm vs. cold?)
- Limited connectivity between CGOA and WGOA (or EGOA)
- Limited connectivity with the Aleutian Islands
- Some proportion of fish do not migrate out of the tagging vicinity, resident fish

Future Needs

- More release platforms in the summer (GOA and EBS) for 2024.
- More releases in years with different temperature regimes (in progress).
- Link movement patterns with genetic information, otolith chemistry (in progress).
- Link movements of adults to early life history: the "conceptual model" of Pacific cod.
- Use movement data in bioenergetic models, larval drift from spawning locations (IBMs), habitat preference models, etc.

Pacific Cod Movement and Behavior Patterns Derived from Tagging Data

Susanne McDermott (presenter), Julie Nielsen, Kimberly Rand, Charlotte Levy (AEB),
Sean Rohan, Alexandra Dowlin

Overview

Using data from the Pop-up Satellite Tagged (PSATs) Pacific cod, we can use depth, temperature, light, and acceleration to examine cod behavior. Examples of behaviors we can examine are:

- Cod thermal environment during migration and spawning,
- Daily movement patterns in the water column as it relates to diet
- Barotrauma from tagging
- Day vs. night activity and time cod spend on the bottom vs. water column

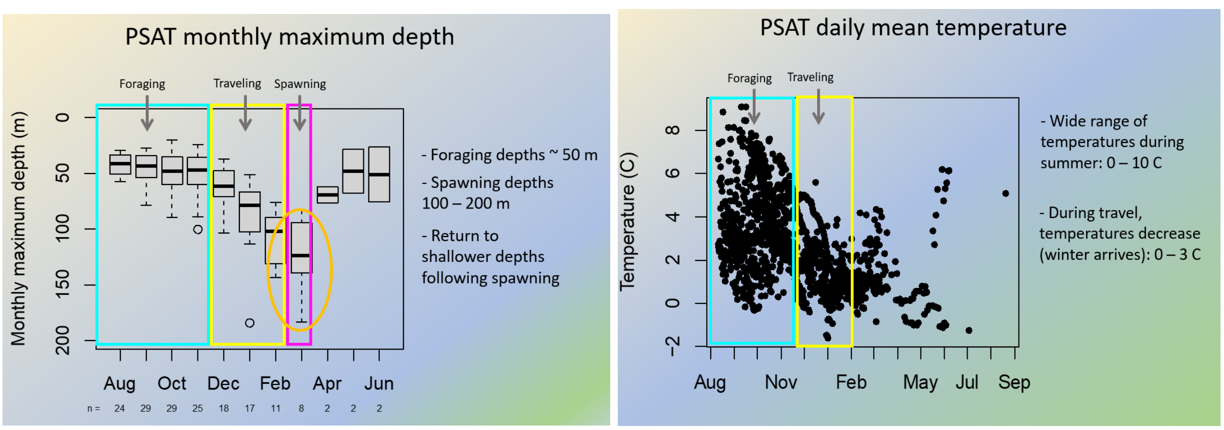


Figure 1. Examples of behavioral type data obtained from Pop-up Satellite Tagged (PSAT) Pacific cod. The left pane is the monthly maximum depth beginning in August and ending the following year in June. The right pane is the daily mean temperature. Sample sizes are shown in left pane only, below month, but is the same for temperature.

Summary of Pacific cod vertical movement and activity:

- Pacific cod stayed close to bottom during the summer months in Eastern Bering Sea (EBS)/Northern Bering Sea (NBS)
- Average distance from bottom = 1.75 m
- Differences in vertical movement for times of day
- Larger distance to bottom during the day (significant but only 0.5 m)
- Activities increased during the day in both areas
- Tilt sensor and knockdown show more activity during the daylight hours, which indicates foraging preferred during the daylight

Summary of Pacific cod temperature data:

- Large Temperature range during summer months
- Colder temperatures during migration in the fall
- Warmer temperatures during spawning
- Colder temperatures during April when fish are migrating towards summer foraging
- Cod will travel through the cold pool but stay above -1.3°C

Future Needs

- Compare multiple years and areas to understand Pacific cod's behavior during different climate scenarios and in different ecosystems.
- Continue to examine Pacific cod's depth distribution during the survey months in the summer to understand availability to trawl gear.

Selectivity and Trawl Interaction of Pacific Cod

Sean Rohan (presenter), Steve Barbeaux (AFSC), Alex DeRobertis (AFSC),
Stan Kotwicki (AFSC), Steve Lewis, Susanne McDermott (AFSC),
Julie Nielsen (Kingfisher Marine Research), Bianca Prohaska (AFSC)

Overview

Selectivity: Eastern Bering Sea Pacific cod bottom-trawl survey selectivity assumptions have changed over time. We used a relative selectivity ratio to examine paired longline fishery and bottom-trawl survey length samples from 2000-2022. There may be an avenue for combining survey and fishery data. Historical selectivity relationships in stock assessment.

- 2006–2015: Dome-shaped. Based on depth distribution from archival tags.
- 2016–2018: Asymptotic. Based on trawling experiments.
- 2019–2022: Ensemble with several asymptotic and one dome-shaped selectivity model.

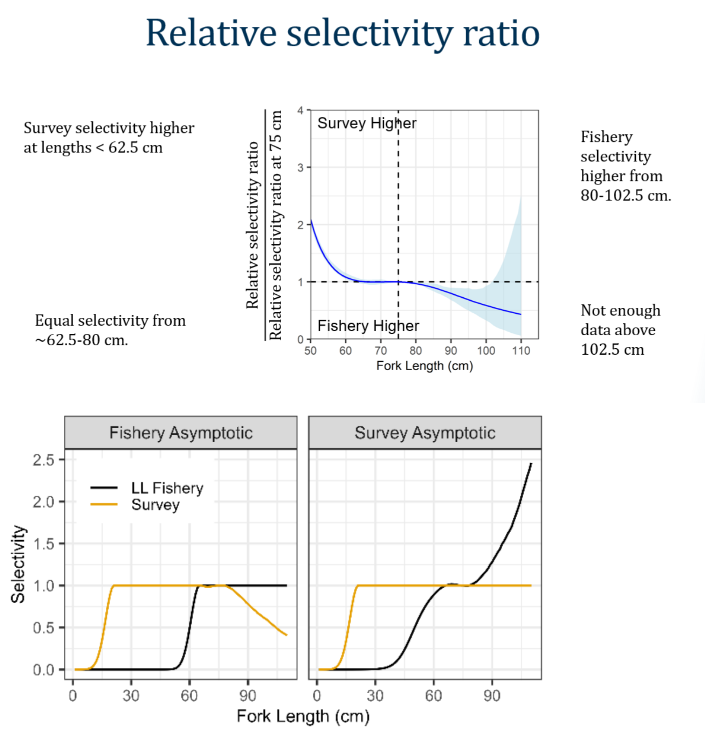


Figure 1. Selectivity ratio between the fishery and bottom-trawl survey divided by the relative selectivity ratio at 75 cm FL. At 75 cm, all models in the 2022 EBS Pacific cod stock assessment model ensemble had selectivity ≈ 1. The solid blue line shows mean fit from the binomial generalized additive mixed model, the ribbon denotes the 95% confidence interval based on two-stage bootstrap resampling, dashed vertical line denotes 75 cm fork length, and the dashed horizontal line denotes the expected value if relative selectivity ratio was equal to selectivity ratio at 75 cm.

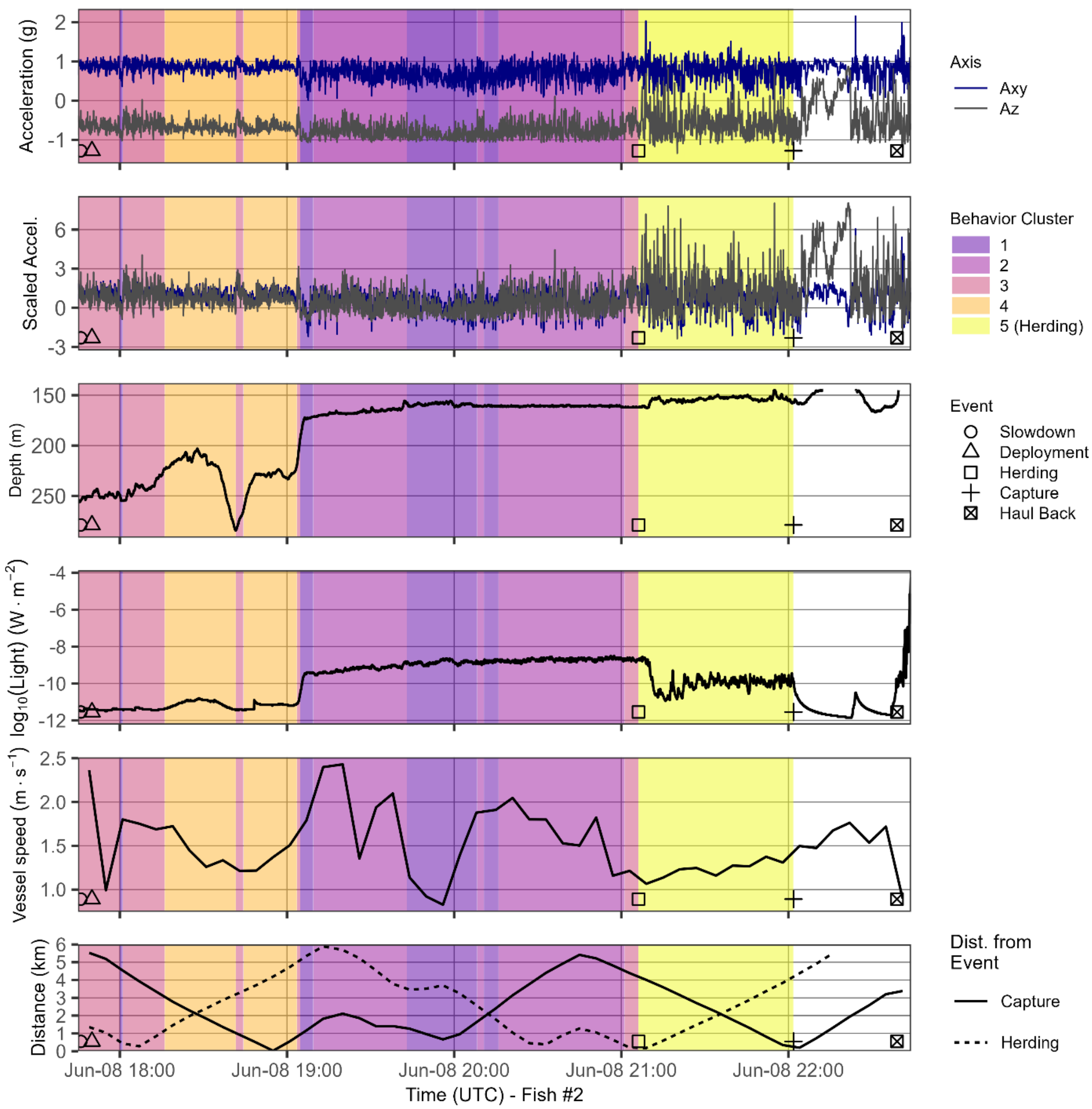


Figure 2. Archival tag and vessel time series for five hours leading up to capture of a pop-up satellite tagged Pacific cod. Panels show (from top to bottom): archival tag horizontal (A_{xy}) and vertical (A_z) accelerometer values (g-force), Z-score transformed (i.e., mean/standard deviation) accelerometer values, archival tag depth (meters), archival tag irradiance ($W \cdot m^{-2}$), vessel speed ($m \cdot s^{-1}$), and vessel distance from capture and herding locations. Fill color bands denote behavioral segments (i.e., phases) by behavioral clusters (i.e., behavior types). A behavioral cluster can occur multiple times in a time series. Symbols along the bottom of each panel show haul activity and fish behavior events (vessel slowdown, trawl gear deployment, onset of herding, capture, and haul back).

Using archival tags to observe Pacific cod reactions to trawl vessels and gear. We can use the vertical and horizontal acceleration data from Pop-up Satellite tagged Pacific cod to classify behavior. For example, we were able to identity fish speed, herding from a trawl net and capture/haul back in the haul net (Fig. 2). Pairing this information with the vessel location monitoring systems, we were able to obtain the speed and position of the vessel. This data offers insight into research examining Pacific cod behavior and survey net/vessel interactions, and those behaviors that might affect catchability.

Future Needs

- Fishing experiments to evaluate the effects of hook competition on longline selectivity based on size-dependent capture time.
- Fishing or tank experiments to characterize the swimming endurance of Pacific cod to evaluate what proportion of fish are capable of outrunning bottom trawl gear towed at ‘typical’ survey tow speeds.
- Additional pop-up satellite tag data from Pacific cod to better characterize behavioral reactions to trawl vessels.

Pacific Cod Stock Assessment 101

Steve Barbeaux (presenter)

Overview

Pacific cod (*Gadus macrocephalus*) in the waters of the northeastern Pacific are managed as three separate stocks; the Eastern Bering Sea (EBS), Gulf of Alaska (GOA), and Aleutian Islands stocks. The EBS and GOA stock assessments use population dynamics models to assess the impacts of fisheries on the stocks. Population dynamics is the study of change in an animal or fish population. The basis for fisheries management has long relied on assumptions of the ability of fish populations to compensate for new causes of mortality with increased productivity, termed the theory of surplus production. The theory presupposes that when fishing mortality reduces the biomass of a stock below carrying capacity, reduced competition and greater relative abundance of resources at this lower level allows the stock to increase productivity. Theoretically, the biomass of a stock can be held indefinitely at a level below carrying capacity, and the fishery can continue to operate on the corresponding surplus production. Where harvest is at its greatest while the sustainability of the stock is maintained is termed maximum sustainable yield (MSY), a common reference point in fisheries. Although simple in concept, determining the actual MSY of a stock given variability in the biology of a population, environmental drivers, interdependence with other species in the form of competition and predation, and interactions with other fisheries can become rather complicated as can the models used to estimate MSY or a proxy for this value.

The simplest useful population model is the logistic, in which a population has sigmoidal growth to the carrying capacity. More complex models may include age and/or length structure, natural and harvesting mortality, recruitment of new individuals into the population, individual growth, reproductive parameters, species interactions, spatial structure, and movement. A common feature of realistic models that have an equilibrium carrying capacity is that there is density-dependence in some population process that causes a reduction in the rate of increase as the population gets large.

Life history modeling is population dynamics modeling in which the life history characteristics such as recruitment, natural mortality, and growth are used to assess an appropriate management strategy. In this approach compensation remains a fundamental assumption, but origins and shape of production in relation to population size, mortality, growth, and recruitment is assessed. For EBS and GOA Pacific cod life history modeling is employed in the form of single species age-based stock assessment models. This approach uses data on the size and age of fish captured in scientific surveys and by fisheries to provide management advice and requires a large amount of data. At the very minimum these data include:

1. At least one index of stock size, such as a survey index or record of commercial fishery catch and effort.

2. Records of the total catch from each fishery targeting a stock over time.

3. Information on the number of fish caught at each age during annual surveys and by all relevant fisheries.

4. Information on the fecundity of the species.

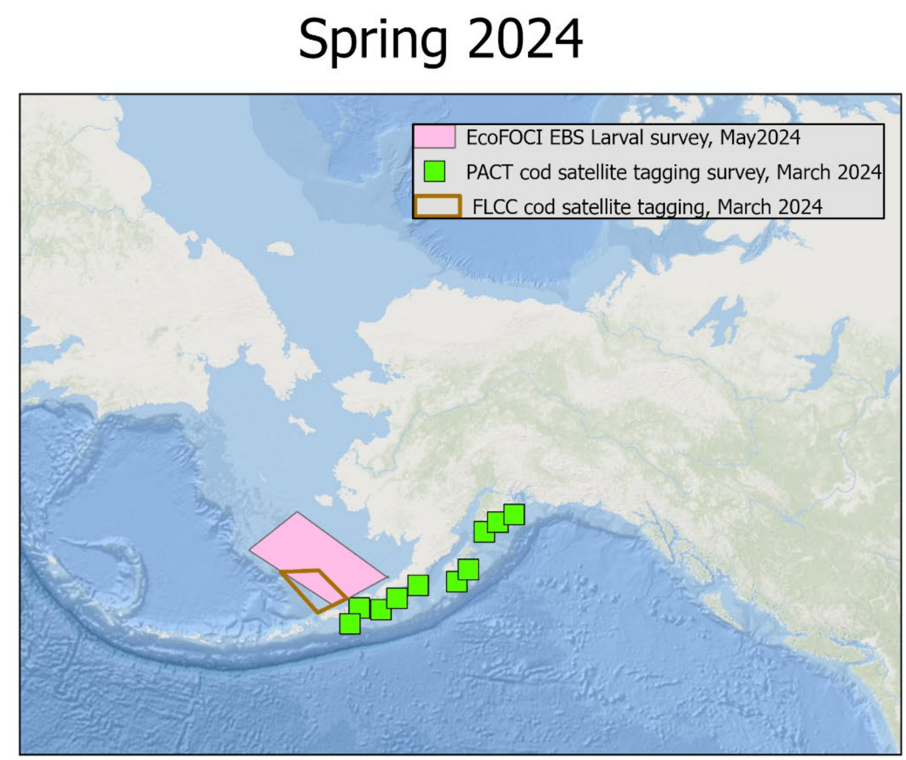
The performance of these complicated models also depends on the quality of information on a stock's natural mortality, growth, and reproduction provided by other scientific studies conducted on the stock. For Pacific cod these models provide estimates of a stock's current size, current and historic harvest rates, its management reference points associated with proxies for MSY, and forecasts of catch and biomass that managers can use to evaluate the risk associated with a range of harvest options. For EBS and GOA Pacific cod because we do not have a reliable stock recruitment relationship with spawning biomass an actual MSY cannot be calculated and therefore proxies are used. The proxy for MSY in this case is the fishing rate which reduces the spawning biomass per recruit to 35% of what it would be in an unfished state, termed $F_{35\%}$. As this value may be uncertain the EBS and GOA Pacific cod stocks are managed to $F_{40\%}$ as a buffer against uncertainty. Additional conservation measures are employed for these stocks with what is called a sloping control rule where an additional graduated reduction in the fishing rate is implemented when the stock drops below $B_{40\%}$. $B_{40\%}$ is defined as the long-term average biomass that would be expected under average recruitment and $F=F_{40\%}$. Further because Pacific cod are forage for the endangered western population of Steller sea lions (*Eumetopias jubatus*), to maintain a minimum level of forage for the sea lions a closure of the fisheries is enacted if the spawning stock biomass drops below 20% of the unfished spawning biomass.

For the Aleutian Islands Pacific cod an age-based stock assessment model has not been approved by the North Pacific Fisheries Management Council. This stock is therefore managed using a simpler approach where a random effects model is applied to the Aleutian Islands bottom trawl survey index. The random effects model considers the variability of the index over time to generate a best estimate of current biomass. As there are no reference points for estimating the production of the stock the stock is managed such that the fishing mortality rate is set to 75% of the estimated natural mortality rate.

Future Needs

- Updated Pacific cod maturity, continued research on spatial movement between management areas, early life history (YOY, juveniles) investigations

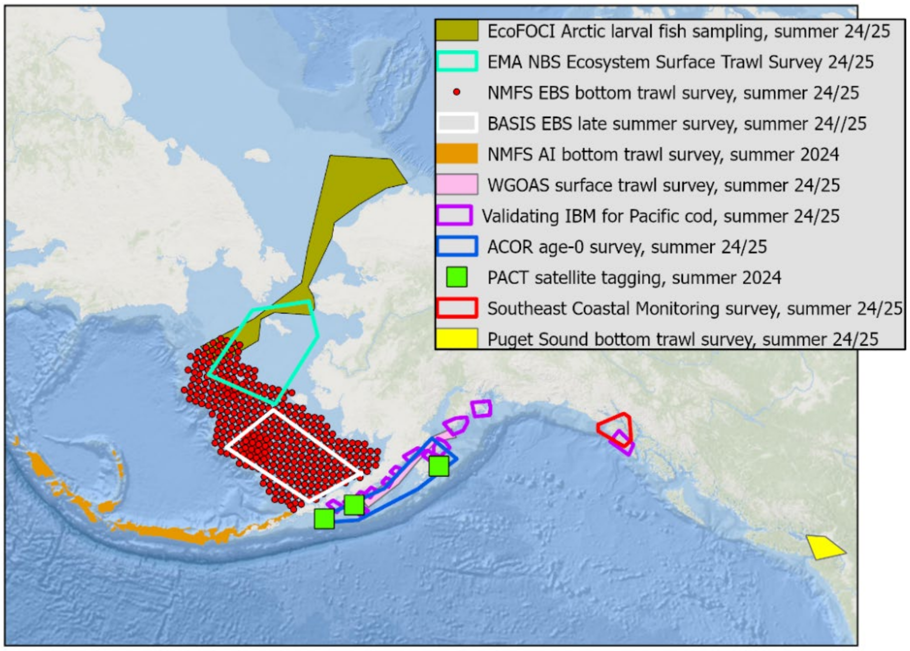
Appendix 1. Maps and Metadata of Future Field Efforts and Sampling



Spring 2024 field efforts involving Pacific cod research or general research surveys. Note: all abbreviation definitions are located in Appendix 2.

Event name	Life stage	Affiliation	Month(s) if known	Gear type	Lead and/or P.I.	Contact email
EcoFOCI EBS Larval Survey	Larval	NOAA	May-June 2024	Plankton Nets	Kelia Axler William Fennie	kelia.axler@noaa.gov, will.fennie@noaa.gov
PACT Satellite Tagging	Adult	AEB NOAA	Mid-March 2024	Crab Pots	Charlotte Levy Susanne McDermott	clevy@aeboro.org, susanne.mcdermott@noaa.gov
FLCC Satellite Tagging	Adult	FLCC	Mid-March 2024	Longline	Jim Armstrong	Jim@freezerlongline.biz

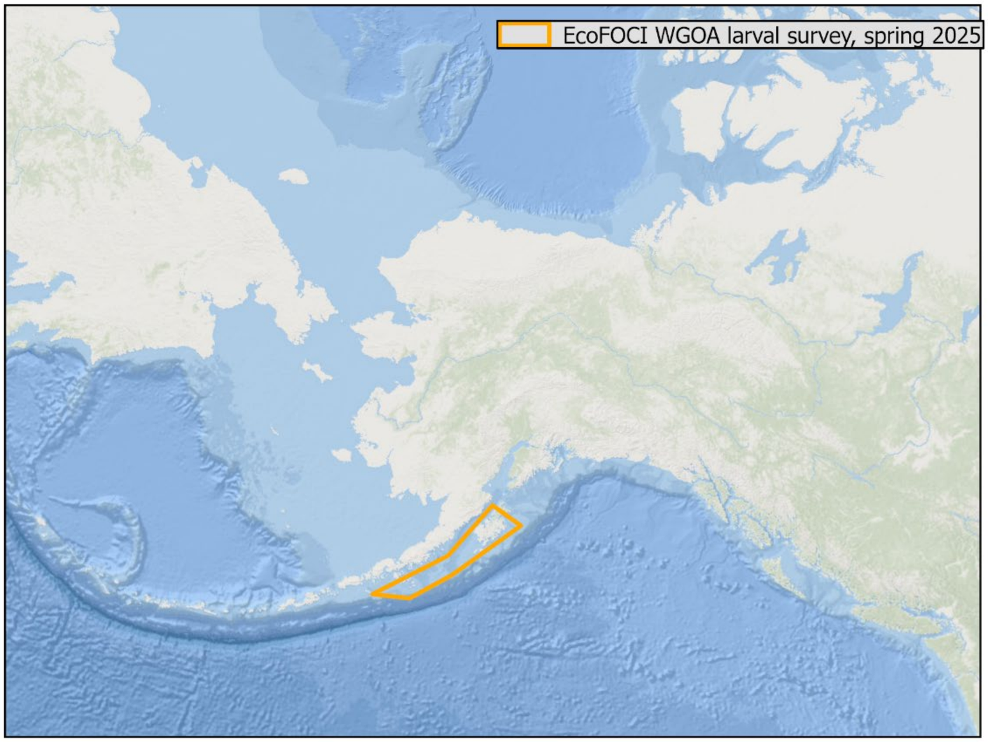
Summer 2024



Summer 2024 field efforts involving Pacific cod research or general research surveys. Note: all abbreviation definitions are located in Appendix 2.

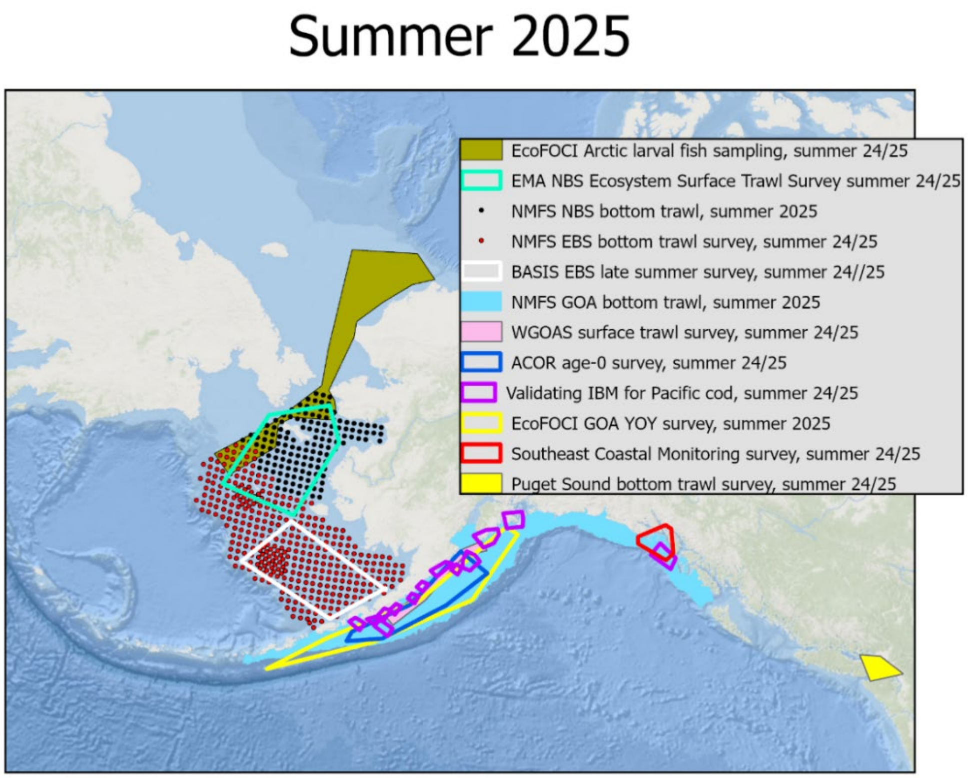
Event name	Life Stage	Affiliation	Month(s) if Known	Gear type	Lead Principal Investigator	Contact email
EcoFOCI Arctic Larval Fish Sampling	Juvenile	NOAA	August 2024	Bongo Tows, Beam Trawl	Kelia Axler	kelia.axler@noaa.gov
EMA NBS Ecosystem Surface Trawl Survey	Juvenile	NOAA	Aug-Sept 2024	Bongo Tows, Surface Trawl, Beam Trawl	Jim Murphy Dan Cooper (P cod)	jim.murphy@noaa.gov dan.cooper@noaa.gov (for samples)
NMFS EBS Bottom Trawl Survey	Adult	NOAA	Summer 2024	Bottom Trawl	Duane Stevenson	duane.stevenson@noaa.gov
BASIS EBS late summer survey	Juvenile	NOAA	Aug-Sept 2024	Surface Trawl, Beam Trawl	Ed Farley	ed.farley@noaa.gov
NMFS AI Bottom trawl survey	Adult	NOAA	Summer 2024	Bottom Trawl	Ned Laman	ned.laman@noaa.gov
WGOAS surface trawl survey	Juvenile	ADFG	June-Aug 2024	Surface Trawl	Ben Gray	ben.gray@alaska.gov
ACOR age-0 survey	Juvenile	ACOR	July-Aug 2024	Beach Seine	Alisa Abookire	alaskacor@gmail.com
PACT satellite tagging	Adult	NOAA AEB	Summer 2024	Crab Pots	Charlotte Levy Susanne McDermott	clevy@aeboro.org, susanne.mcdermott@noaa.gov
Validating IBM for Pacific cod	Juvenile	NOAA	June-July 2024	Beach seine, cameras	William Stockhausen Katharine Miller	katharine.miller@noaa.gov, william.stockhausen@noaa.gov
Southeast Coastal Monitoring Survey	Juvenile	ADFG	June-Aug 2024	Surface trawl, plankton	Andrew Gray	andrew.gray@noaa.gov
Puget Sound Bottom Trawl Survey	Adult	WDFW	Summer 2024	Bottom trawl	Kathryn Meyer	kathryn.meyer@dfw.wa.gov

Spring 2025



Spring 2025 field efforts involving Pacific cod research or general research surveys. Note: all abbreviation definitions are located in Appendix 2.

Event name	Life stage	Affiliation	Month(s) if Known	Gear type	Lead Principal Investigator	Contact email
EcoFOCI WGOA Larval Survey	Larval	NOAA	Spring 2025	Plankton Nets	Jesse Lamb	jesse.f.lamb@noaa.gov



Summer 2025 field efforts involving Pacific cod research or general research surveys. Note: all abbreviation definitions are located in Appendix 2.

Event name	**Life stage**	**Affiliation**	**Month(s) if Known**	**Gear type**	**Lead Principal Investigator**	**Contact email**
EcoFOCI Arctic Larval Fish Sampling	Juvenile	NOAA	Aug 2024/2025	Bongo Tows, Beam Trawls	Kelia Axler	kelia.axler@noaa.gov
EMA NBS Ecosystem Surface Trawl Survey	Juvenile	NOAA	Aug/Sept 2024/2025	Bongo Tows, Surface Trawl, Beam Trawl	Dan Cooper	dan.cooper@noaa.gov
NMFS NBS Bottom Trawl Survey	Adult	NOAA	Summer 2025	Bottom Trawl	Duane Stevenson	duane.stevenson@noaa.gov
NMFS EBS Bottom Trawl Survey	Adult	NOAA	Summer 2024/2025	Bottom Trawl	Duane Stevenson	duane.stevenson@noaa.gov
NMFS GOA Bottom Trawl Survey	Adult	NOAA	Summer 2025	Bottom Trawl	Ned Laman	ned.laman@noaa.gov
WGOAS Surface Trawl Survey	Juvenile	ADFG	June - Aug 2024	Surface Trawl	Ben Gray	ben.gray@alaska.gov
ACOR Age-0 Survey	Juvenile	ACOR	July/Early Aug 2024/2025	Beach seine	Alisa Abookire	alaskacor@gmail.com
Validating IBM for Pacific cod	Juvenile	NOAA	June/July 2024/2025	Beach Seine, Cameras	William Stockhausen Katharine Miller	Katharine.miller@noaa.gov, william.stockhausen@noaa.gov
EcoFOCI GOA YOY Survey	Juvenile	NOAA	Aug/Sept 2025	Bongo Tows, Midwater Trawl	Lauren Rogers Jesse Lamb	lauren.rogers@noaa.gov, jesse.f.lamb@noaa.gov
Southeast Coastal Monitoring Survey	Juvenile	ADF&G	June - Aug 2024/2025	Surface Trawl, Plankton	Andrew Gray	andrew.gray@noaa.gov
Puget Sound Bottom Trawl Survey	Adult	WDFW	summer 2024/2025	Bottom Trawl	Kathryn Meyer	kathryn.meyer@dfw.wa.gov

Appendix 2. Workshop Abbreviations

Abbreviations	Full Name
ACOR	Alaska Coastal Observations and Research
ADFG	Alaska Department of Fish and Game
AEB	Aleutians East Borough
AFSC	Alaska Fisheries Science Center
AI	Aleutian Islands
AK	Alaska
BC	British Columbia
BS	Bering Sea
CGOA	Central GOA
CICOES	Cooperative Institute for Climate, Ocean & Ecosystem Studies
DAPC	Discriminant Analysis of Principal Components
DFO	Fisheries and Oceans Canada
EBS	Eastern Bering Sea
EcoFOCI	Ecosystems and Fisheries-Oceanography Coordinated Investigations
EGOA	East Gulf of Alaska
FI	Farallon Institute
FLCC	Freezer Longline Conservation Cooperative
GOA	Gulf of Alaska
GOA	Gulf of Alaska
IBM	Individual Based Model
NBS	North Bering Sea
NE	Northeast
NGO	Non-governmental organization
NMFS	National Marine Fisheries Service
NOAA	National Oceanic Atmospheric Administration
OSU	Oregon State University
P cod	Pacific cod
PACT	Pacific cod Tagging
PCA	Principal Components Analysis
PMEL	Pacific Marine Environmental Laboratory
PSMFC	Pacific States Marine Fisheries Commision
ROMS	Regional Ocean Modeling System
UAF	University of Alaska Fairbanks
UW	University of Washington
WGOA	West Gulf of Alaska
YOY	Young of year Pacific cod

Appendix 3. Workshop Agenda

Alaska Fisheries Science Center, Seattle, WA, November 28-29, 2023

November 28	**Presenter**	**Presentation Title**
9:00	Susanne McDermott	Introduction and Welcome
9:15	Benjamin Laurel	An Early Life History Perspective Under Changing Thermal Habitats
9:30	Lauren Rogers	Larval Dynamics and Phenology of Pacific cod Spawning
9:45	William Stockhausen	Pacific cod IBM Validation
10:00	Alisa Abookire	Improved Understand of Recruitment Success in a Warming GOA
10:15	Laura Spencer	Physiological response to Ocean Acidification and Warming in larvae
10:45	Lorenzo Cianelli	Management stock structure of Pacific cod in the Gulf of Alaska
11:00	Trond Kristiansen	Pacific cod Habitats Under Climate Change
11:15	Krista Oke	Developing climate-enhanced stock assessment models for GOA and EBS
11:30	Janet Rumble	Pacific Cod Management in the state of Alaska
11:45	Jennifer Bigman	size-at-age with temperature and oxygen
1:30	Sara Schaal	Pacific cod genomics
1:45	Lorenz Hauser	Evolution at the rear edge of distribution shifts
2:00	Chris Cheng	Can Pacific cod avoid freezing? .
2:15	Bianca Prohaska	Physiological Stress of Pacific Cod in the Eastern Bering Sea
3:00	Julie Nielsen	Overview of Pacific Satellite tagging study in Alaskan Waters
3:15	Susanne McDermott	Pacific cod movement patterns derived from tagging data
3:30	Sean Rohan	Pacific cod trawl gear interactions and survey selectivity
3:45	Steve Barbeaux	Pacific cod Management 101
November 29	**No Presenters**	**Field Discussions**
9:00		*Introduction and welcome*
9:15	Pacific cod Field Effort All Life Stages	1. How can we best connect field efforts from different life history stages in one or multiple ecosystems? 2. Can we share field platforms? 3. Can we collect data for other projects? 4. Equipment availability and expertise for different collections? 5. Sharing of cooperative partners and interested parties that would like to collaborate on projects, especially from industry or NGOs 6. Stock assessment/ecosystem assessment goals
1:30	Pacific cod Synthesis and Future Work	1. Future field efforts and goals. 2. Habitat and species distribution modeling (including habitat-specific growth and mortality) 3. Climate change, physiology, reproductive success and distribution changes 4. Pacific cod prey studies and effect on the environment 5. Discussion of Conceptual model for Pacific cod 6. Gaps in knowledge and potential new research (NBS IERP)
4:00		*Final discussion and adjourn*

Appendix 4. Workshop Participants

Contact Last Name	Contact First Name	Affiliation	Contact Email
Abookire	Alisa	ACOR	alaskacor@gmail.com
Almeida	Zoe	Cornell	lza3@cornell.edu
Anderson	Sean	DFO	sean.anderson@dfo-mpo.gc.ca
Armstrong	Jim	FLC	jim@freezerlongline.biz
Axler	Kelia	AFSC	kelia.axler@noaa.gov
Baldwin	Aaron	ADFG	aaron.baldwin@alaska.gov
Baldwin-Schaeffer	Mabel	AFSC	mabel.baldwin-schaeffer@noaa.gov
Barbeaux	Steve	AFSC	Steve.Barbeaux@noaa.gov
Bigman	Jenny	AFSC	jennifer.bigman@noaa.gov
Brogan	John	AFSC	john.brogan@noaa.gov
Bush	Karla	ADFG	karla.bush@alaska.gov
Cheng-DeVries	Chi-Hing Christina	UIUC	c-cheng@illinois.edu
Ciannelli	Lorenzo	OSU	lorenzo.ciannelli@oregonstate.edu
Coleman	Laura	ADFG	laura.coleman@alaska.gov
DeVries	Arthur	UIUC	adevries@illinois.edu
Dowlin	Alexandra	AFSC	alexandra.dowlin@noaa.gov
Ehresmann	Rhea	ADFG	rhea.ehresmann@alaska.gov
Erickson	Jack	ADFG	jack.erickson@alaska.gov
Fennie	Will	AFSC	will.fennie@noaa.gov
Forrest	Robyn	DFO	robyn.forrest@dfo-mpo.gc.ca
Glass	Jessica	UAF	jrglass@alaska.edu
Goldstein	Esther	AFSC	esther.goldstein@noaa.gov
Haltuch	Melissa	AFSC	melissa.haltuch@noaa.gov
Hauser	Lorenz	UW	lhauser@uw.edu
Hicks	Mary Beth	AFSC Newport	marybeth.rew.hicks@noaa.gov
Holsman	Kirstin	AFSC	kirstin.holsman@noaa.gov
Hulson	Pete	AFSC	pete.hulson@noaa.gov
Hurst	Tom	AFSC Newport	thomas.hurst@noaa.gov
Keister	Julie	AFSC	julie.keister@noaa.gov
Kotwicki	Stan	AFSC	stan.Kotwicki@noaa.gov
Kristiansen	Trond	FI	trondkr@faralloninstitute.org
Laman	Ned	AFSC	ned.Laman@noaa.gov
Lamb	Jesse	AFSC	jesse.f.lamb@noaa.gov
Laurel	Ben	AFSC Newport	ben.laurel@noaa.gov
Levy	Charlotte	AEB, AFSC	clevy@aeboro.org
Matta	Beth	AFSC	beth.matta@noaa.gov
McDermott	Susanne	AFSC	susanne.mcdermott@noaa.gov
Meyer	Kathryn	WDFW	kathryn.meyer@dfw.wa.gov
Miller	Jessica	OSU	jessica.Miller@oregonstate.edu

Contact Last Name	Contact First Name	Affiliation	Contact Email
Miller	Katharine	AFSC	katharine.miller@noaa.gov
Neff	Darcie	AF Biomap	darcie@akbiomap.com
Neff	Darcie	AFSC	darcie.neff@noaa.gov
Neidetcher	Sandi	AFSC	sandi.Neidetcher@noaa.gov
Nielsen	Julie	KMR	julie.nielsen@gmail.com
Oke	Krista	APU/AFSC	krista.oke@noaa.gov
Pirtle	Jodi	AKRO	jodi.pirtle@noaa.gov
Prohaska	Bianca	AFSC	bianca.prohaska@noaa.gov
Rand	Kimberly	Lynker/AFSC	kimberly.Rand@noaa.gov
Rhea-Fournier	Whyatt	ADFG	wyatt.rhea-fournier@alaska.gov
Roberts	Steven	UW	sr320@uw.edu
Rogers	Lauren	AFSC	lauren.rogers@noaa.gov
Rohan	Sean	AFSC	sean.rohan@noaa.gov
Rooney	Sean	AFSC	sean.rooney@noaa.gov
Rumble	Janet	ADFG	janet.rumble@alaska.gov
Schaal	Sara	UAF	sara.schaal@noaa.gov
Schuster	Martin	ADFG	martin.schuster@alaska.gov
Seitz	Andy	UAF	acseitz@alaska.edu
Siple	Megsie	AFSC	margaret.siple@noaa.gov
Siwicke	Kevin	AFSC	kevin.siwicke@noaa.gov
Smith	Mason	AKRO	mason.smith@noaa.gov
Spencer	Laura	UW	laura.spencer@noaa.gov
Spies	Ingrid	AFSC	ingrid.spies@noaa.gov
Stevenson	Duane	AFSC	duane.stevenson@noaa.gov
Stichert	Mark	ADFG	mark.stichert@alaska.gov
Stockhausen	William (“Buck”)	AFSC	william.stockhausen@noaa.gov
Thalmann	Hillary	OSU	hillary.thalmann@oregonstate.edu
Timm	Laura	UAF/AFSC	laura.timm@noaa.gov
Vinson	Ana	ADFG	ana.vinson@alaska.gov
Vollenweider	Johanna	AFSC	johanna.vollenweider@noaa.gov
Yeager	Mallarie	AKRO	mallarie.yeager@noaa.gov
Monnahan	Cole	AFSC	cole.monnahan@noaa.gov
Chamberlin	Derek	AFSC	derek.chamberlin@noaa.gov

U.S. Secretary of Commerce
Gina M. Raimondo

Under Secretary of Commerce for
Oceans and Atmosphere
Dr. Richard W. Spinrad

Assistant Administrator,
National Marine Fisheries Service.
Janet Coit

May 2024

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National Marine
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Alaska Fisheries Science Center
7600 Sand Point Way N.E.
Seattle, WA 98115-6349