***Exxon Valdez* Oil Spill Trustee Council**

Long-Term Research and Monitoring, Mariculture, Education and Outreach

Annual Project Reporting Form

Project Number: 25220111-I

Project Title: Ecological interactions between Pacific herring and Pacific salmon in Prince William Sound

Principal Investigator(s): Pete Rand (lead PI) and Rob Campbell (co-PI), Prince William Sound Science Center; Kristen Gorman (co-PI), University of Alaska Fairbanks; and Ron Heintz (co-PI), Sitka Sound Science Center

Reporting Period: February 1, 2025 – January 31, 2026

Submission Date: March 1, 2026

Project Website: https://gulfwatchalaska.org/

Please check all the boxes that apply to the current reporting period.

☒ **Project progress is on schedule.**

☐ **Project progress is delayed.**

☐ **Budget reallocation request.**

☐ **Personnel changes.**

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1. Summary of Work Performed:

I. Review of study motivation and scientific objectives following the original proposal's Executive Summary and Project Design including updated references and study details:

This project seeks to resolve the role pink salmon (*Oncorhynchus gorbuscha*) play in regulating Pacific herring (*Clupea pallasii*, hereafter herring) production in Prince William Sound (PWS), Alaska (Fig. 1), and develop tools for predicting pink salmon survival. In 2008, Deriso et al. (2008) hypothesized that increased production of PWS pink salmon may be constraining the production of herring and limiting recovery of the PWS herring population. Despite dramatic increases in the hatchery production of PWS pink salmon during the early 1980s that has continued since the herring collapse of the mid-1990s (Amoroso et al. 2017), Deriso's hypothesis remains unresolved (Pearson et al. 2012). Currently, PWS is home to the largest pink salmon hatchery program in the world and there is growing interest in the ecological impacts of the large number of these released fish (Brenner et al. 2012, Pearson et al. 2012, Ward et al. 2017, Knudsen et al. 2021). Recently, reports documenting the impacts of increased pink salmon releases on other salmon populations (Connors et al. 2020, Kendall et al. 2020, Oke et al. 2020, Rand and Ruggerone 2024) and ecosystem processes (Kaga et al. 2013, Springer and van Vliet 2014, Batten et al. 2018, Ruggerone and Irvine 2018) have motivated the *Exxon Valdez* Oil Spill Trustee Council (EVOSTC) to request information on ecological interactions between pink salmon and herring in PWS, in an effort to explain why herring populations have not recovered to pre-spill numbers.

The project described here began in 2023 and is a multi-faceted field and laboratory research effort that builds on past work (including EVOSTC projects), and develops new data specifically aimed at assessing Deriso's hypothesis. We also examine the countervailing effect of age-1+ (juvenile and adult) herring feeding on pink salmon fry. In addition, the project provides for the resumption of a fisheries survey originally initiated by the Alaska Department of Fish & Game (ADF&G) on juvenile pelagic fishes including pink salmon, the extension of an EVOSTC funded data series on age-0 herring body condition, a bioenergetic analysis to estimate the predatory demand of pink salmon on larval herring to understand how this process may affect herring recruitment, and an analysis of factors affecting pink salmon survival.

Pink salmon and herring have distinct life histories that occasionally overlap in time, space, and for shared dietary resources, producing opportunities for ecological interactions. Pink salmon are semelparous with an obligate two-year life history and a conspicuous odd- and even-year return pattern by adults with larger numbers of pink salmon returning to spawn in odd years to the PWS region. Newly emerged pink salmon fry forage and grow in nearshore habitats in spring before becoming large enough to emigrate seaward in summer as smolts. Adults return in late summer to spawn in natal streams 12-13 months later. In contrast, herring are iteroparous and longer lived. They spawn on beaches in early spring. Herring larvae hatch a few weeks later than pink salmon and are advected into currents until they metamorphose and settle out in nearshore habitats during early summer. They rear in these nursery habitats until age-2 or 3 until they reach sexual maturity (Hay et al. 2008). After spawning, adult herring forage over deeper waters including migrations outside PWS to the Gulf of Alaska (GOA) before shoaling in bays and fjords during winter.

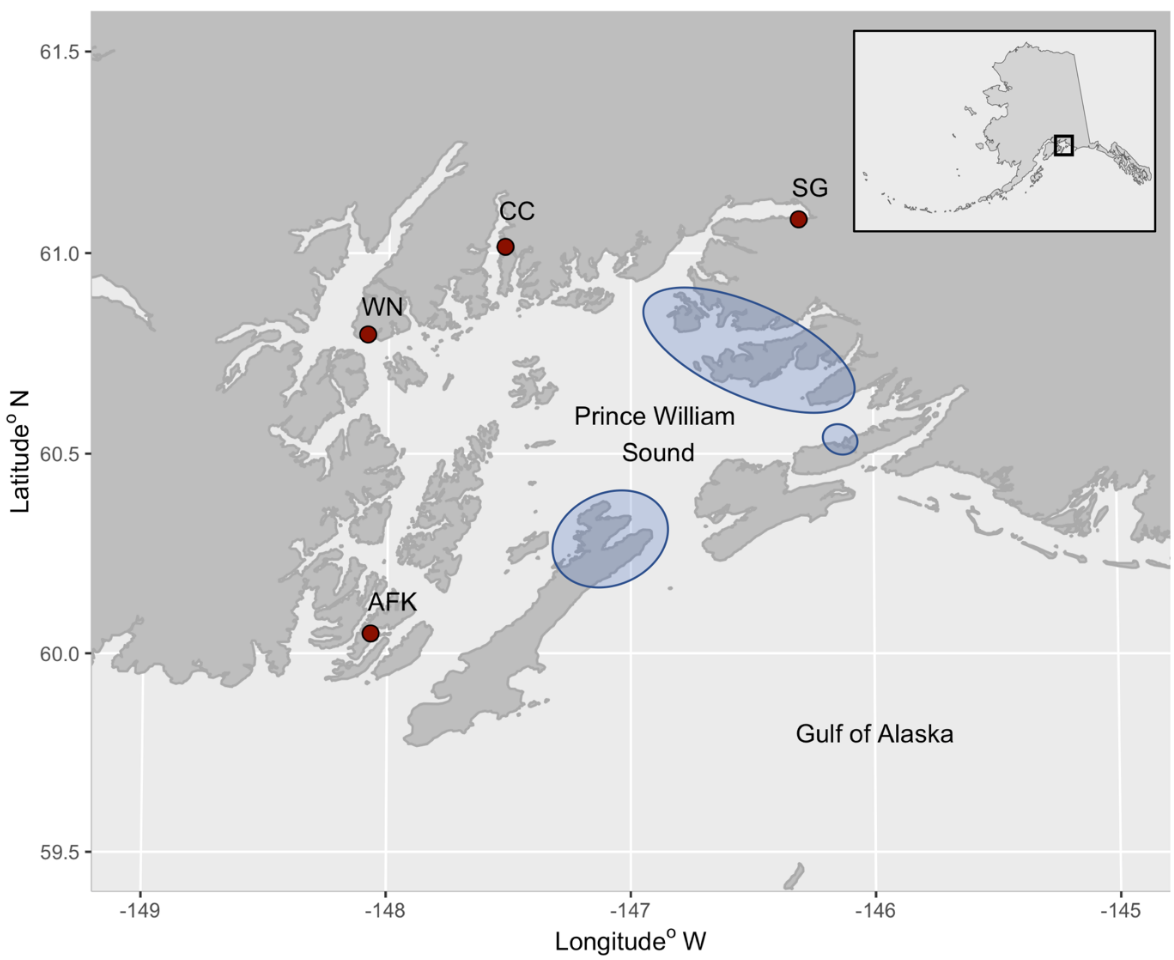


Figure 1. The Prince William Sound, Alaska study region. The location of pink salmon hatcheries (Solomon Gulch = SG, Cannery Creek = CC, Wally Noerenberg = WN, and Armin F. Koernig = AFK) are noted by the dark red circles. Location of the dominant regions of herring spawn for 2010-2019 are noted by the blue ovals following Pegau et al. (2019).

We hypothesize that there are three life history periods (and associated habitats) that set the stage for ecological interactions between herring and pink salmon including predation, competition, and disease transmission that may have important recruitment consequences for both species. Chronologically, the first period occurs in spring when newly emerged pink salmon fry occupy nearshore habitats and are vulnerable to predation by age-1+ and older herring. Competition for food may also be important during this period (Cooney et al. 2001). The second stage occurs one to two months later over deeper, more offshore waters, when larger, emigrating juvenile pink salmon (smolts) may prey upon larval herring originating from major spawning areas (particularly in the well documented spawning area at Hell's Hole in Gravina Bay, eastern PWS, McGowan et al. 2021) that are advected in anticyclonic (i.e., counter clockwise) currents that tend to disperse larvae to the west and southwest regions of PWS (Niebauer et al. 1994). Critically, the co-occurrence of these species during the first and second time periods presents opportunities for disease transmission that can affect each species' survival. The third stage occurs during summer and early fall when age-0 herring rely on prey fields previously exploited by out-migrating juvenile pink salmon. Figure 2 represents a conceptual diagram of these potential ecological interactions and the sampling underway to address these interactions.

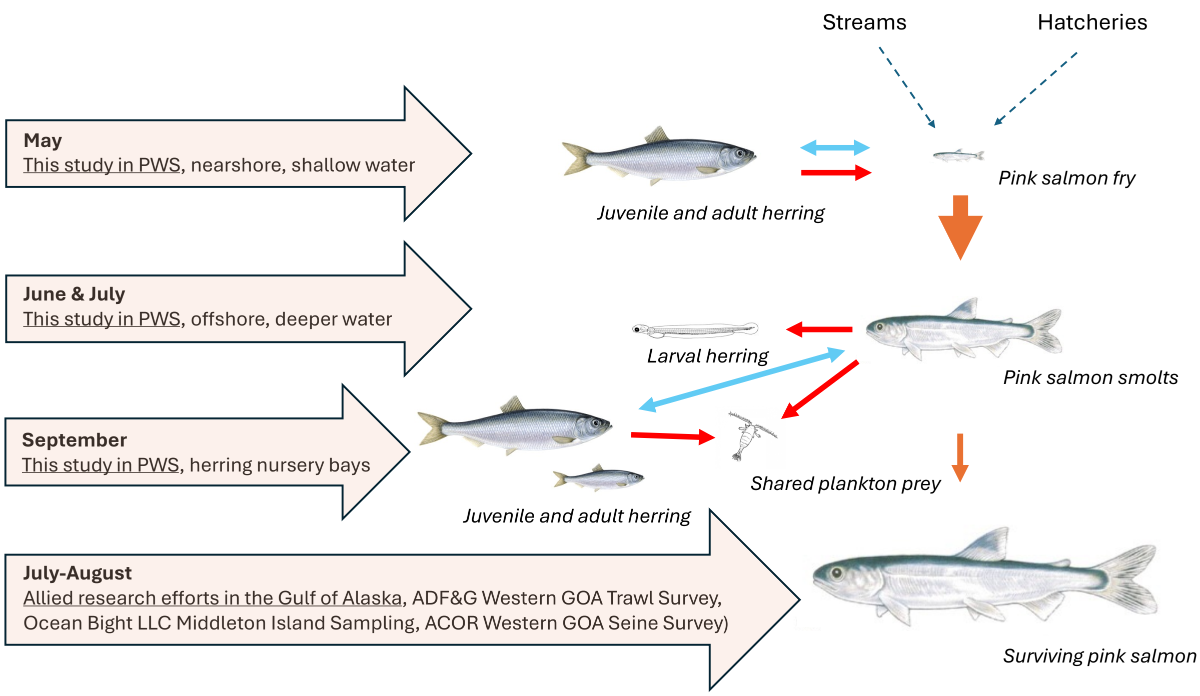


Figure 2. Illustration of potential interactions between juvenile pink salmon and Pacific herring, highlighting habitat shifts and the survival progression during early life history of pink salmon in Prince William Sound (PWS) and the Gulf of Alaska (GOA). Potential disease interactions are shown in light blue, predation and competitive processes are shown in red, and survival processes are shown in orange. ADF&G is the Alaska Department of Fish & Game and ACOR is the Alaska Coastal Observations and Research.

Our approach to examining ecological interactions between herring and pink salmon combines retrospective analyses, new field and lab data collected over a six-year period (2023-28), and modeling exercises. Specifically, we will (1) assess the spatial and temporal co-occurrence of both species using retrospective and newly collected data, (2) examine prey availability, (3) conduct dietary analysis using gut contents, DNA barcoding, and bulk carbon and nitrogen stable isotope analysis (SIA) and compound-specific stable isotope analysis (CSIA) techniques, (4) examine the prevalence of a key pathogen, Viral Erythrocytic Necrosis (VEN), in both species, and (5) construct bioenergetic models to estimate larval herring predation by pink salmon. New data will be collected by purse seine, beach seine, and cast net (May and September) and surface trawl (June and July) during field surveys. The surface trawl surveys will resume an existing pink salmon time series initiated by ADF&G, while the combined effort involving the other capture methods will extend a time series of age-0 herring condition supported by prior EVOSTC programs. By conducting these surveys over multiple years, we will capture replicate odd and even year pink salmon run cycles, as well as (6) examine the influence of environmental covariates on pink salmon survival, and (7) develop a tool for forecasting future pink salmon returns. These latter two analyses will directly aid management of pink salmon populations in PWS. The early years of the study includes a resumption of the surface trawl survey and a retrospective analysis of existing data on herring and pink salmon spatial and temporal dynamics aimed at informing our field efforts during later years of the study. The project supports a graduate student (MS program) at the University of Alaska Fairbanks (UAF) in year 2 (UAF spring, fall semesters 2024) and 3 (spring, fall semesters 2025) of the EVOSTC program (FY23-25). The bioenergetic modeling will be done in collaboration with a research associate to be funded by co-PI Heintz's portion of the study. The bioenergetic modeling work will begin in FY26 now that we have some preliminary data from FY23-25. The salmon survival and forecast modeling exercises are planned for FY28-29 and will also synthesize data collected during this study.

II. Brief summary of work performed in FY25 to address scientific objectives:

We have successfully completed a third field season during 2025. We continue to make progress processing lab samples at affiliated labs. At PWSSC, we are identifying and quantifying plankton and nekton from our towed bongo net and identifying prey in gut contents and carrying out calorimetry to measure energy content of juvenile salmon. At UAF laboratories, we are measuring energy content of herring and carrying out stable isotope analyses of herring and salmon. We have also executed contracts and agreements to process our samples at collaborating labs (ADF&G [otolith removal and hatchery- or wild-origin determination], NOAA [DNA metabarcoding of gut contents], and USGS [Viral Erythrocytic Necrosis, VEN prevalence) during 2023-25. In this report, we provide data summaries and preliminary statistical analyses, highlighting results from 2025, but drawing on data collected in our first two field seasons that provide some new insights into ecological dynamics that are relevant to our main set of research hypotheses. We provide a brief summary here, but we provide additional detail on collected data and preliminary results and analyses related to each of our study objectives and hypotheses in the main body of this report (Section III, below). While it is difficult to make robust inferences from our data after three years (i.e., two odd-year returns and one even-year return for pink salmon) of a planned six-year field campaign (i.e., three odd- and three even-year pink salmon returns), we present some key research findings to date that demonstrate our progress in meeting our overall study objectives:

- *Predation*
    - *Adult and juvenile herring are consuming pink salmon fry* - While we have not found any evidence of predation on juvenile pink salmon based on our visual examination of herring diets and our results from stable carbon and nitrogen isotope analyses, our DNA metabarcoding results from 2023 and 2024 support the hypothesis that herring rely on early life stages of pink salmon as a prey resource.
    - *Juvenile pink salmon are consuming herring larvae* - Gut content analyses (2023-2025) and DNA metabarcoding results (2023, 2024) have revealed that outmigrating pink salmon smolts consume herring larvae and consumption of herring larvae is more likely during some periods (early June) and in some years (2024).
    - Stable isotope analysis suggests that if adult herring are consuming pink salmon fry, it is likely to be a minor contributor to their diet given that adult herring appear isotopically distinct from outmigrating pink salmon smolts. We are producing stable isotope data for herring larvae directly that we will relate to the isotope values of pink salmon to quantitatively estimate the proportion herring larvae contribute to the diet of pink salmon.

- *Competition*
  - We have generated paired data on herring and juvenile pink salmon dietary habits and prey availability across a network of sites in May, June, and July during 2025 that complements our results described in previous annual reports (2023-2024). We have carried out prey counts across 17 different taxonomic groups. These data will allow us to evaluate prey selectivity, dietary overlap, and potential competition for shared prey resources between these two species.
  - Overlap in isotopic signatures measured in 2023 of juvenile pink salmon sampled during May-July and juvenile herring sampled in September indicate that these two species potentially share dietary, and this overlap may be regionally specific. We are awaiting the 2024 and 2025 salmon isotope data to further evaluate this relationship. Wild juvenile pink salmon may have a more diverse diet than their hatchery conspecifics given the variability we observed in their isotopic signatures. Isotope values between age-0 herring sampled in 2023 and 2024 appear shifted between these two years, perhaps in response to the larger outmigration of salmon smolts in 2024. These isotope data will be coupled with our data on consumed prey and prey availability to better understand relationships between prey switching and age-0 herring condition.
- *Disease*
  - Our VEN sampling is on-going, and we report here the highly variable temporal and spatial patterns we are finding in VEN prevalence in herring. Our 2025 sampling has revealed a much higher prevalence of VEN during May in herring compared to the two previous years. We have only detected one VEN positive juvenile pink salmon (collected by beach seine in Sheep Bay in June 2025), so based on our sampling the prevalence of VEN for this species is very low.
- *Pink Salmon Trawl CPUE, development of survival/fishery forecast model*
  - We have extended our times series on CPUE for juvenile pink salmon to include year 2025, We have carried out preliminary analysis of abundance patterns during 2023-2025 and combined our data with previous catch data from an earlier ADF&G trawl survey. Taken together, these data reveal an even/odd year pattern,

indicating a strong run of pink salmon smolts in even years, a pattern expected given the strong adult pink salmon returns observed in PWS in odd years. We found a significantly higher contribution of hatchery-origin pink salmon in our surface trawl catches in 2023 (73.2%) compared to the two subsequent years (62.2% in 2024; 59.8% in 2025). Additional years of data on trawl catches will allow us to describe patterns of abundance of even and odd brood years of juvenile wild- and hatchery-origin pink salmon.

- After adding data we collected during 2025, we have begun to explore patterns in body size and energy density of juvenile pink salmon smolts that may help explain interannual patterns of marine survival. Our preliminary analyses suggest only subtle differences between wild- and hatchery-origin smolts (e.g. hatchery-origin smolts tend to be only marginally larger in body mass), but specific hatchery populations appear to be responding differently across years (2023-2025) that may be related to changes in hatchery operations (e.g., release timing) or differences in rearing conditions experienced by fry prior to release (e.g., interannual changes in sea surface temperatures in net pens managed by the different hatchery programs). Continued sampling in future years will help us better describe these dynamics and help us develop a fishery forecast model.

Our study has provided notable educational and training opportunities for UAF graduate (Borksy, Lavier assisted with September 2025 sampling) and undergraduate (Pence) students, as well as PWSSC seasonal field and lab assistants (Anderson, Carter, and Becker). Of note, Trish Pence is a UAF undergraduate who greatly assisted with lab processing of fish samples for stable isotope analysis this year at UAF. In terms of progress on addressing our primary hypotheses, Borsky's MS thesis work on spatio-temporal modeling of herring and salmon in PWS is progressing and we expect this project to wrap up by Spring 2027. We have conducted more public outreach on this project, including a number of events involving school groups in Cordova, and presentations made at a professional society meeting (Borsky, Gorman, and Rand all had individual posters presented at AMSS in January 2026).

III. Detailed summary of work performed (FY25):

The focus of our study is in the southwestern region of PWS, an area important as a major migratory corridor for juvenile salmon produced throughout PWS (Willette 1996, Sturdevant et al. 1999, Sturdevant et al. 2001) and also an area thought to serve as important habitat for different life stages of herring (see Bishop and Eiler 2018, Gorman et al. 2018, Bishop and Bernard 2021). Of note, we continued to sample eastern PWS (Sheep and Simpson bays) in June 2025, after extending our sampling to the region in May 2024. Going forward, we plan to extend our May sampling to the western or northwestern region of PWS to provide additional resolution on species interactions that may be occurring outside the southwest region. Overall, our field work is timed with important ontogenetic stages of these two species, described in detail above (and in our original proposal). During FY25 we conducted six research cruises during May, June, July, and September 2025 (Table 1, Fig. 3). During our first cruise in May 2025, we employed a beach seine that allowed us to better sample the nearshore environment. This approach allowed for sampling salmon fry more effectively, including mixed schools of both salmon fry and herring (Table 2). We plan to continue using both the beach and purse seines during May cruises in the future to comprehensively sample both the nearshore and deeper, offshore regions along the PWS coastline and embayments. Due to a ship mechanical issue aboard the *R/V Solstice* that required our research team to return to port in Cordova one day early in May 2025, we were unable to sample nearshore habitats in eastern PWS during our first May cruise. To maintain consistent sampling effort across years, we chartered a private vessel (a commercial bowpicker, *Dorothy G*) that allowed us to sample nearshore habitat in Sheep and Simpson Bays in eastern PWS in June 2025 (Table 1). We were unable to sample during our first surface trawl cruise in June 2025 – our trawl was severely damaged during our first sampling day of the cruise (reflected in an abbreviated cruise duration indicated in Table 1). The cause of the damage was floating debris that became entrained in or gear and separated the webbing from the cork and lead lines. The trawl was repaired shortly after this cruise and we were able to resume our cruise schedule later in June (Table 1). The trawl required additional mending following the second surface trawl cruise, and further repair on board the *R/V New Wave* during our final surface trawl cruise in July. We included a separate budget line in Year 5 of our original budget for a new surface trawl – we are currently having a net maker fully repair our existing trawl and fabricate a new one so we will have a back-up in the event we encounter these gear problems in the future so we won’t miss future sampling opportunities.

Table 1. Research cruises during 2025 for the Salmon-Herring Interactions Project in Prince William Sound, Alaska, including vessel, gear type, month, dates, and participants. ADF&G = Alaska Department of Fish and Game, UAF = University of Alaska Fairbanks, and PWSSC = Prince William Sound Science Center.

Vessel	Gear type	Month	Dates	Participants
Solstice	Purse and beach seine, nearshore	May	5/29/25 – 6/1/25	Gorman (UAF), Anderson (PWSSC), ADF&G crew
New Wave	Surface trawl, offshore	June	6/10/25 – 6/10/25	Campbell, Rand, Carter (all PWSSC)
Dorothy G	Beach seine, nearshore	June	6/16/25 – 6/17/25	Rand, Anderson, Becker, Carter (all PWSSC)
New Wave	Surface trawl, offshore	June	6/23/25 – 6/25/25	Campbell, Rand, Anderson (all PWSSC)
New Wave	Surface trawl, offshore	July	7/7/25 – 7/8/25	Campbell, Anderson, Becker (all PWSSC)
Solstice	Cast net, nursery bays	Sept	9/11/25 – 9/17/25	Gorman and Lavier (UAF), ADF&G crew

Table 2. Catches of herring and juvenile pink salmon in nearshore habitats, May, June, and September cruises 2025.

Cruise	Date	Site	Set	Gear[a]	Adult Herring	Juvenile Herring	Juvenile Pink Salmon	Totals
Solstice	5/29/25	Mummy Bay	1	BS	0	0	131	**131**
			2	PS	2	0	0	**2**
			3	PS	0	0	0	**0**
	5/30/25	Shelter Bay	1	BS	1	0	0	**1**
			2	BS	0	0	0	**0**
			3	BS	0	0	0	**0**
			4	BS	0	1765	0	**1765**
			5	BS	0	0	0	**0**
	5/31/25	Fox Farm	1	PS	0	16	0	**16**
			2	CN	0	10	0	**10**
	5/31/25	Outside Sawmill Bay	1	BS	0	85	321	**406**
	6/1/25	Squire Island	1	BS	0	0	0	**0**
			2	PS	11	22	6	**39**
Dorothy G	6/16/25	Simpson Bay	1	BS	0	100	30	**130**
	6/17/25	Sheep Bay	1	BS	0	1	39	**40**
			2	BS	0	1	7	**8**
			3	BS	0	7	1	**8**
Solstice	9/3/25	Zaikof Bay	1	CN	0	126	0	**126**
	9/4/25	Whale Bay	1	CN	0	550	0	**550**
	9/5/25	Deer Cove	1	CN	2	162	0	**162**
	9/6/25	Lower Herring Bay	1	CN	0	136	0	**136**
	9/7/25	Simpson Bay	1	CN	0	257	0	**257**

[a] BS = Beach seine, PS = Purse seine, CN = Cast net

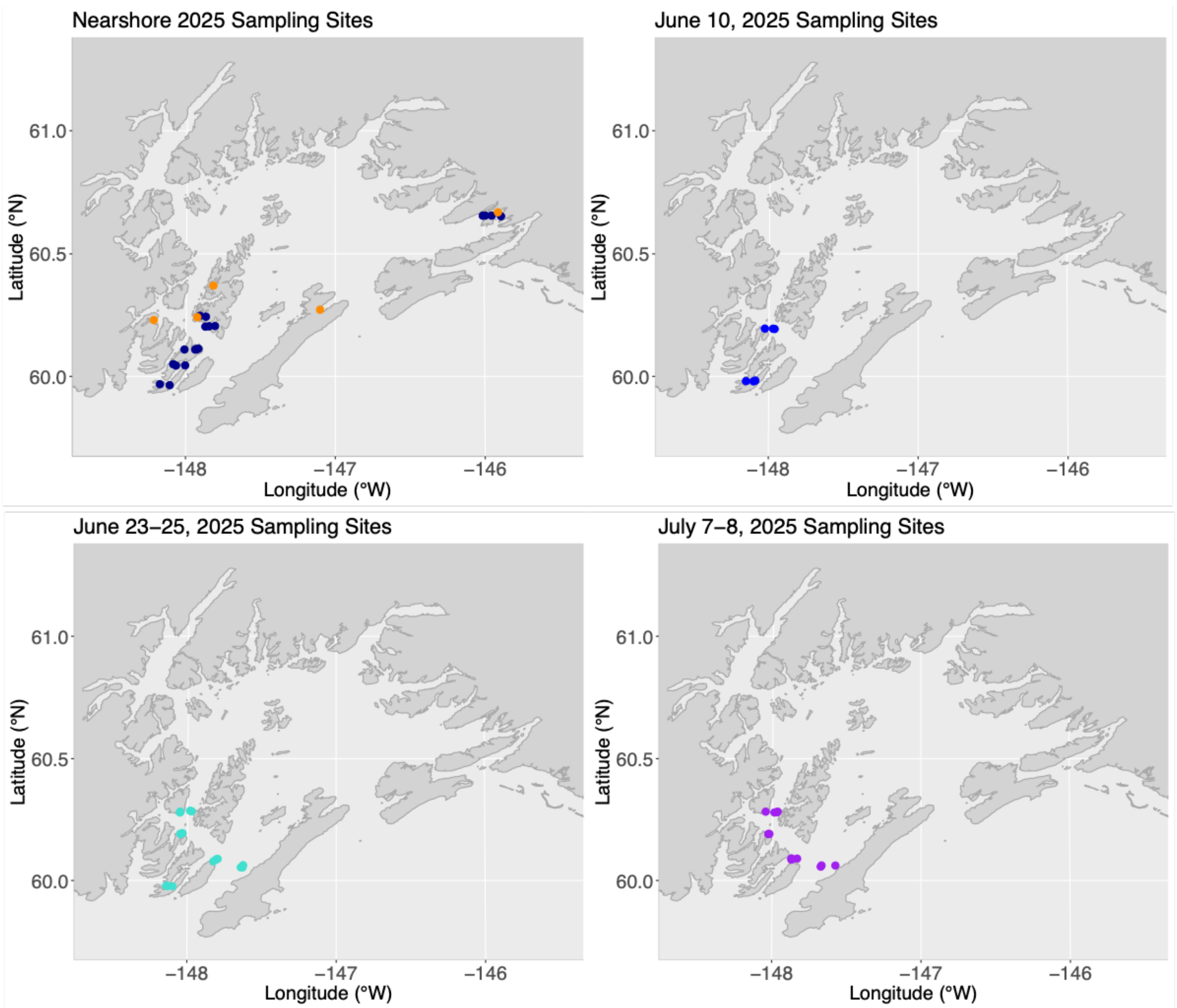


Figure 3. Herring and salmon sampling sites in Prince William Sound, Alaska during 2025. Purse seine (nearshore, May and early June, dark blue), cast net (nursery bay, September, orange), surface trawl (offshore, early June, blue; late June, turquoise; early July, purple). Trawl cruise sites are for start locations only.

The following is a list of objectives we outlined in our original proposal with details on progress in addressing these objectives during FY25:

1. Conduct a retrospective analysis of historical data to examine spatio-temporal overlaps in occurrence by herring and pink salmon in PWS.

Results. This work is being conducted as part of Alex Borsky's MS thesis program in the College of Fisheries and Ocean Sciences (CFOS, Marine Biology program), UAF under the supervision of co-PI Gorman. PI Rand and co-PI Heintz also serve on Alex's graduate committee at UAF along with Prof. Katrin Iken (EVOSTC nearshore PI). As described in our original proposal, this analysis is the primary focus of the graduate student training and research supported by the project. The first two years of Alex's graduate program (UAF spring, fall semester 2024 and spring, fall semester 2025) were supported by funding from this project (FY23-25), the third year (FY26) is supported by a graduate research fellowship funded by the Oil Spill Recovery Institute ($60,000). Alex is additionally supported by a $10,000 award from UAF's Northern Gulf of Alaska Applied Research Award.

Over the past year, Alex has continued to make good progress in his graduate program by completing his comprehensive exam requirements including a proposal presentation and oral exam. Alex advanced to candidacy in his MS program in December 2025. Alex made significant progress over the past year conducting a comprehensive literature review to identify data sources for his spatio-temporal modeling exercises. Alex conducted his search using *Web of Science* All Databases resulting in a total of 442 unique results across four different search terms (Table 3). All resulting publications were thoroughly reviewed for available data and external links to supplementary data. For a prospective dataset to be included in further analyses, the following criteria were used to determine its viability: (i) the dataset must include either Pacific herring or pink salmon catch data, preferably from fishery-independent surveys; (ii) data must contain spatial attributes for the location of the event (e.g. latitude/longitude); and (iii) data must include a temporal attribute of the event. Additional regional databases and online data repositories including Alaska Ocean Observing System (AOOS) Ocean Data Explorer, DataONE, *Exxon Valdez* Oil Spill Trustee Council (EVOSTC) Restoration Project Search, and Biological and Chemical Oceanography Data Management Office (BCO-DMO) were reviewed for relevant datasets.

Table 3. Summary of Web of Science search results in All Databases for the retrospective analysis.

Search No.	Date of Search	Keywords	No. of Results
1	11/10/2025	"pink salmon" and "herring" and "Prince William Sound"	34
2	11/11/2025	"Prince William Sound" and "pink salmon"	171
3	11/21/2025	"Prince William Sound" and "Pacific herring" or "herring"	294
4	12/9/2025	"Prince William Sound" and "spatiotemporal models" or "spatio-temporal models"	3

In total, 11 different data sources were identified for historical herring catches including a 33-year time series from 1954 to 2024 consisting of nearly 7350 individual observations for sampling effort including both positive and negative catch encounters (Table 4). Sampling effort for pink salmon was lower, with a total of four data sources identified including a 24-year time series from 1999 to 2024. An additional 10 datasets identified from DataONE repositories are still under review for viable datasets. Further, we are beginning to review zooplankton datasets for PWS, which have been funded through other EVOSTC projects (R. Campbell, pers. comm.).

Table 4. Summary of historical fisheries datasets identified to be used in retrospective analyses.

Agency/Program[a]	Data Name	Source
USGS	Alaska Forage Fish Database	Turner et al. 2024
NOAA	Nearshore Fish Atlas of Alaska	Alaska Fisheries Science Center (AFSC) 2026
ADF&G	Purse Seine Fry Surveys	Courtesy of ADF&G, Jenni Morella
ADF&G	Trawl Fry Surveys	Courtesy of ADF&G, Jenni Morella
GLOBEC	R/V Pandalus Surveys	Boldt et al. 2006
SEA	Mark Willette Diet Study and expanded dataset for herring and pink salmon	Courtesy of ADF&G, Heath Kimball
NOAA	Ichthyoplankton Information System	AFSC 2025
GWA	Pelagic Ecosystems Forage Fish Component	Arimitsu et al. 2017
EVOSTC	Herring Program Surveys	Bishop 2019
EVOSTC	Prince William Sound (PWS) Herring Aerial Surveys	Donnelly et al. 2024, Pegau pers. comm.
EVOSTC	PWS Herring Acoustic Surveys	Rand pers. comm.
PWSAC	PWS Hatchery Release Data	Rand pers. comm.

[a] USGS = U. S. Geological Survey, NOAA = National Oceanic and Atmospheric Administration, ADF&G = Alaska Department of Fish and Game, GLOBEC = Global Ocean Ecosystem Dynamics, SEA = Sound Ecosystem Assessment, GWA = Gulf Watch Alaska, EVOSTC = *Exxon Valdez* Oil Spill Trustee Council, PWSAC = Prince William Sound Aquaculture Corporation

Now that we have a near final retrospective dataset identified, we are beginning to quantitatively explore these data using a spatio-temporal framework. Importantly, there has been significant recent improvements in the statistical packages available for conducting species distribution modeling that allow for an easier specification of model structures (e.g., Anderson et al. 2025, Thorson et al. 2025). Using these resources, we plan to assess fluctuations in herring and salmon distribution and abundance using approaches in the sdmTMB (Anderson et al. 2025) and Vector Autoregressive Spatio-Temporal (VAST) (Thorson et al. 2025) model frameworks to evaluate a series of single species spatio-temporal models for herring and salmon, separately, focusing on early life stages of both species and herring adults, and a joint species distribution model including both species, as well as a model including both species and the PWS zooplankton prey base as an environmental covariate. We envision these analyses as an approach to i) evaluate a potential odd-even year pattern in herring abundance at different life stages over time that is hypothesized to amplify in more recent time periods in association with the increased production of hatchery pink salmon in PWS since the late 1980's when hatchery releases began exceeding 600 M fry, ii) assess shifts in regional distribution and abundance for each species over time, and iii) examine spatial and temporal patterns of co-occurrence that might be correlated with changes in abundance of each species or zooplankton. Of note, Alex is currently taking two quantitative fisheries classes to further his knowledge in fisheries modeling including spatio-temporal modeling (Modern Applied Statistics for Fisheries, Estimation of Fish Abundance). Alex will be attending a spatio-temporal modeling workshop held by ADF&G in Juneau during March 2026. We plan to conduct initial analysis of our data in preparation for the start of our field season in FY26 to inform any potential adjustments to our field sampling program as part of this larger study in the second half of the program (FY26-28).

Below are preliminary distribution maps for the time series of data we have pulled together over the past year for both herring and pink salmon. These data were presented by Borsky at the Alaska Marine Science Symposium in January 2026 (Fig. 4).

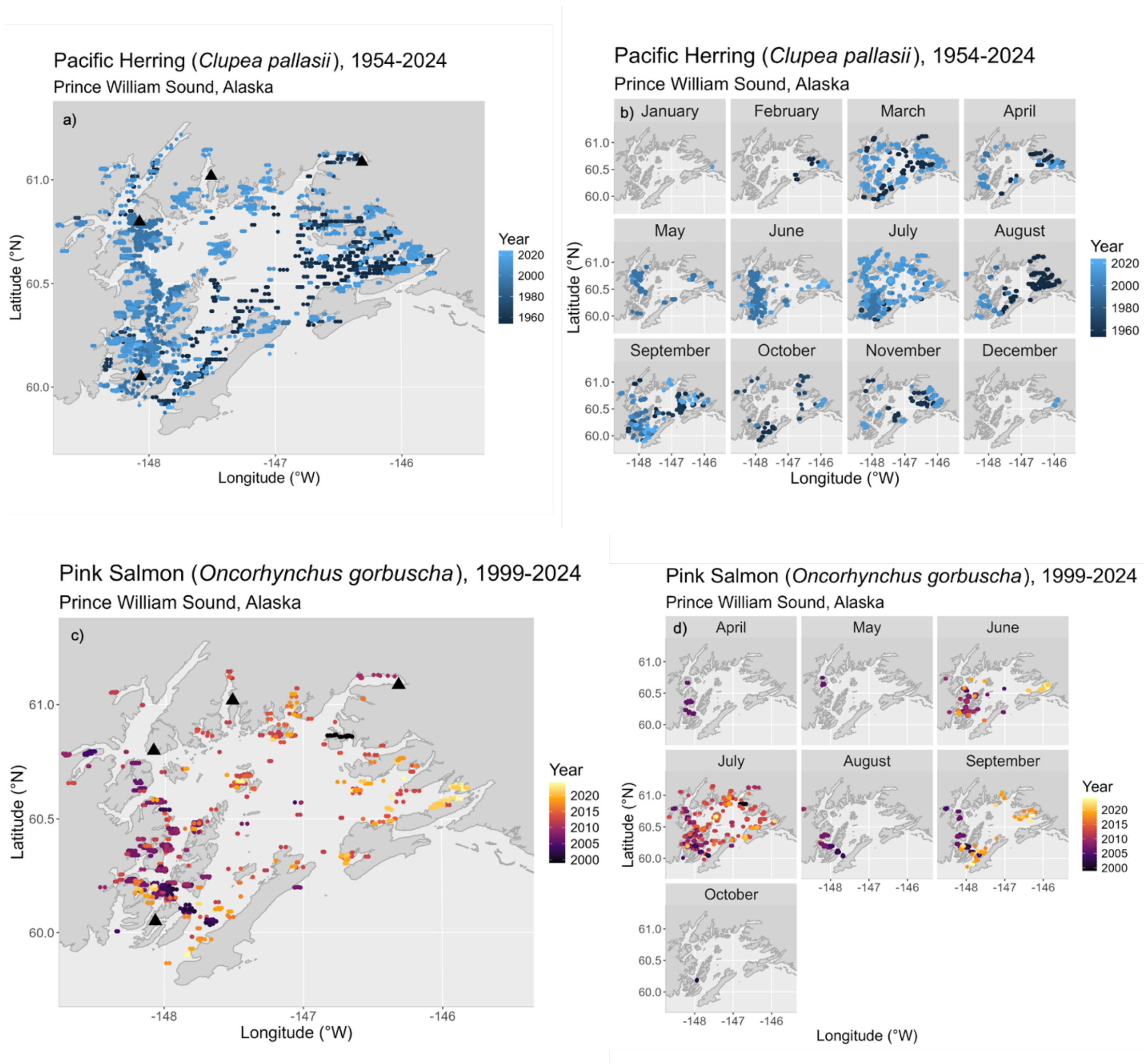


Figure 4. Combined overall and seasonal historical survey data for Pacific herring (juvenile and adult life stages, a & b, 1954-2024) and pink salmon (juvenile stages, c & d, 1999-2024) conducted throughout Prince William Sound, Alaska. Data points represent unique sampling events and may include either a positive or zero encounter.

2. Conduct field sampling to determine current probabilities of co-occurrence of herring and juvenile pink salmon in near-shore and off-shore habitats of PWS. These field data will be compared with the retrospective analysis we develop in Objective 1.

Results. Our catches to date (May-July during 2023-2025) indicate that these two species do occur in mixed schools (Fig. 5). Our updated dataset including 2025 indicates that 29% of our sets in May – July included the co-occurrence of herring and salmon (Fig. 5). We include detailed catch numbers for the May-June nearshore surveys in Table 2. We include catches of herring in our September cruise in 2025 (this is a period following the emigration of juvenile pink salmon from PWS) to address a different research hypothesis (see 3.a, iv section below). We expect that MS student Borsky will incorporate these new field data on herring and salmon catches from years 1-3 in his spatio-temporal analysis.

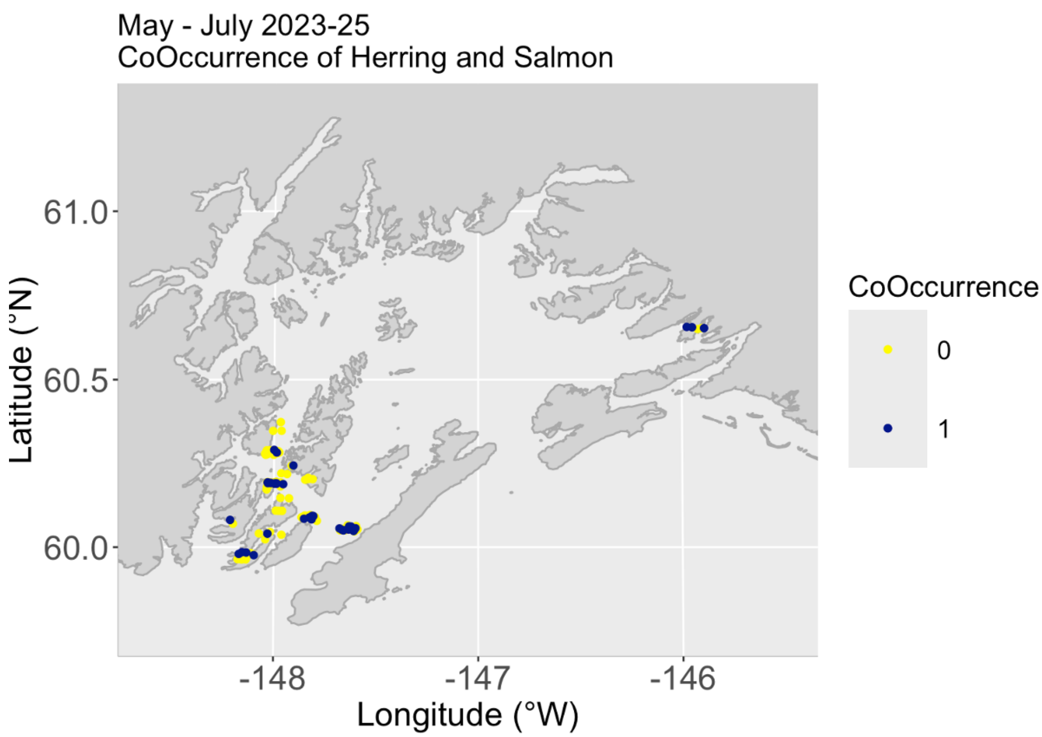
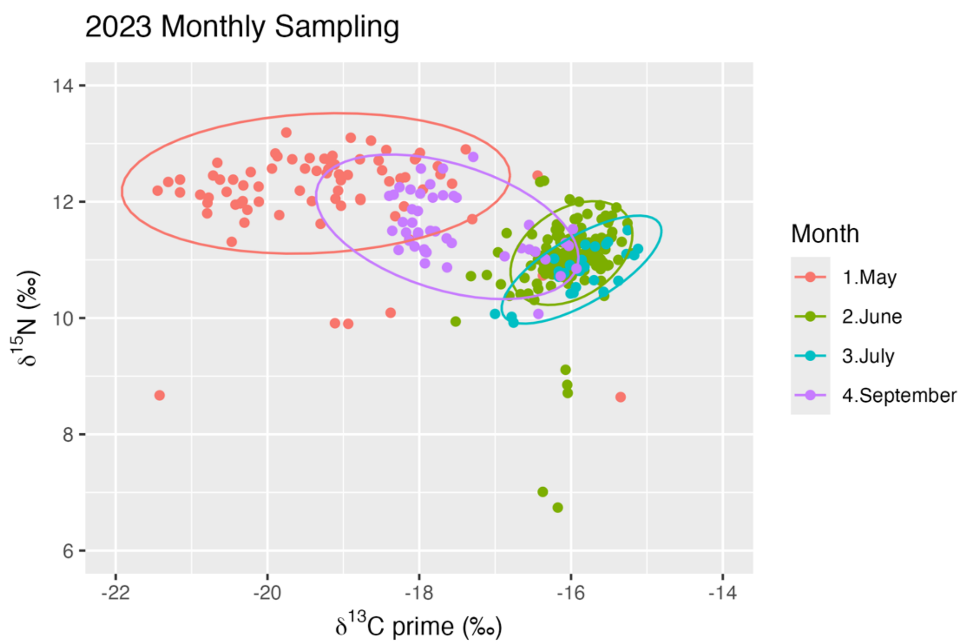


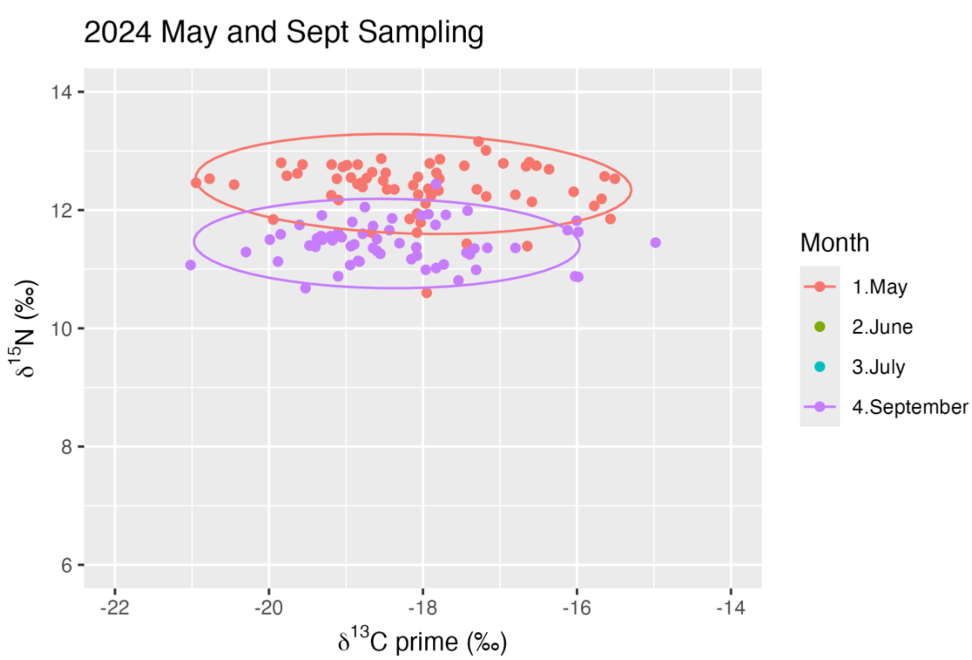
Figure 5. Co-occurrence of herring (adults, juveniles, *or larvae) and salmon (fry* and smolts*) in sets conducted May – Ju*ne*, 2023-25 in Prince William Sound, Alaska. Sampling sites where herring and juvenile pink salmon co-occurred (*blue*) and did not co-occur (yellow) are indicated.*

3. Assess ecological interactions between herring and pink salmon that occur in both near-shore and off-shore habitats:
   a. Near-shore habitats (purse seine/cast net sampling in May and September)
      i. Determine whether herring (age-1+) consume pink salmon fry in May using stomach content analysis, DNA barcoding, and bulk SIA and CSIA. *Predation hypothesis – herring forage on pink salmon*

Results. As documented in our past annual reports, we did not observe any prey fishes in the diets of herring captured during our late May cruises in 2023 (n = 72 examined stomachs) and 2024 (n = 27 examined stomachs). We observed three individuals with a single fish in their stomach in our 2025 herring collections (3 out of a total of 59 examined, or 5% of our samples). It was not possible, however, to determine the species of these consumed fish in these cases given the advanced state of digestion. Diets of herring have been composed mostly of copepods, euphausiids, and pteropods. Our collaborating lab (National Oceanic and Atmospheric Administration [NOAA] Ted Stevens Marine Institute, Dr. Wes Larson and colleagues) extracted DNA from gut contents of herring to identify prey fishes in their diet. Results of this analysis (results updated from our previous annual report) has revealed a moderate prevalence of pink salmon DNA in herring captured in 2023 (19 out of a total of 60 herring, or 32%) and a very high percentage of pink salmon DNA detections in our 2024 herring collections (20 out of a total of 21 herring, or 95%) suggesting that herring feeding on young salmon fry may be prevalent. The mean proportion of DNA reads of pink salmon, however, was relatively low compared to other prey fishes in herring stomachs (particularly rockfish, *Sebastes* spp., and walleye pollock, *Gadus chalcogrammus*), suggesting their overall contribution to the diets of herring is lower than these other prey fishes.

SIA results indicate that adult herring and salmon fry appear to be isotopically distinct (2023), suggesting little reliance by adult herring on young salmon (see Fig. 6), which correlated with our observations of mean proportions of DNA reads being low for pink salmon relative to other fish species. We are awaiting SIA data for salmon fry collected in 2024, these samples are in process now at UAF (spring 2026). The salmon fry collected in 2025 will be sent to UAF for SIA analysis as soon as all otolith and energetic analyses have been completed by PWSSC.


2023 Monthly Sampling
δ15N (‰)
δ13C prime (‰)
14
12
10
8
6
-22
-20
-18
-16
-14
Month
1.May
2.June
3.July
4.September


2024 May and Sept Sampling
δ15N (‰)
δ13C prime (‰)
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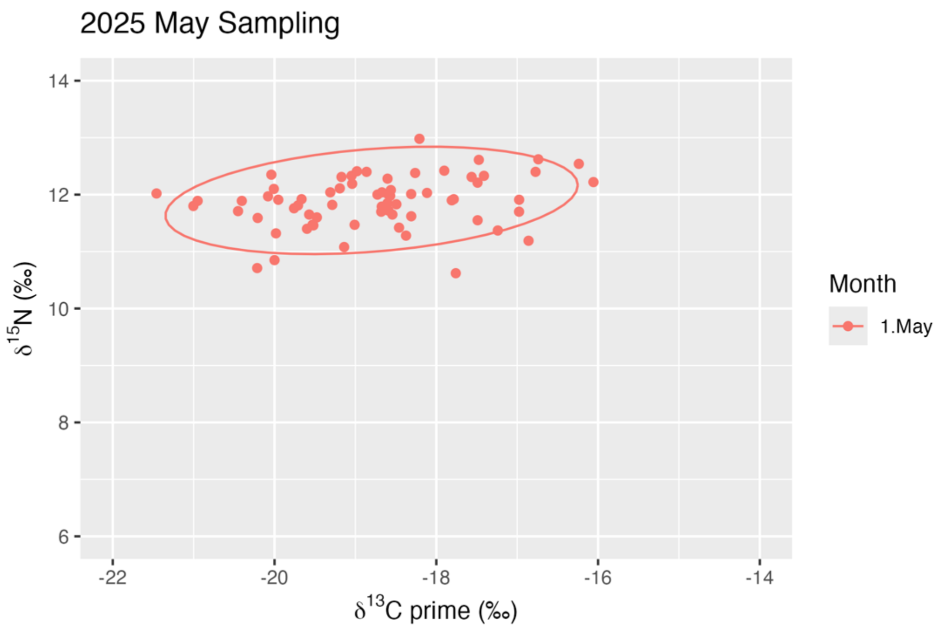

Figure 6. Carbon and nitrogen stable isotope variability of adult herring (sampled in May), outmigrating salmon fry (sampled in June and July), and age-0 herring (sampled in September) during a) 2023, b) 2024, and c) 2025. Some isotope data for months and years are forthcoming. Ellipses represent 95% confidence levels. Values for δ^{13}Cprime are lipid corrected following methods outlined by Gorman et al. 2018.

ii. Determine pink salmon fry and age-1+ herring diet composition in May using stomach content analysis, DNA barcoding, bulk SIA and CSIA, as well as determine prey availability using zooplankton nets during purse seine sampling. *Competition hypothesis*

Results. We have now completed prey counts on a total of 27 herring captured in our May 2024. We have an additional collection of stomachs from juvenile pink salmon collected in eastern PWS (Simpson and Sheep Bays, N = 71) during May 2024. We are planning on analyzing diets on a subset of those pink salmon collections in spring 2026. We have completed diet analysis on 41 herring and 23 pink salmon collected during our May 2025 cruise. Diets of both species were composed mostly of copepods and euphausiids. We have obtained SIA data for herring collected in May 2023-25: these data are described in more detail below. We have completed counts by taxonomic group for all the plankton samples collected during 2023-2025 (described in more detail below).

The beach seining completed during May 2025 was very successful (Table 2) and we plan to continue this sampling approach in 2026. We process our beach seine catches using the same protocols as we have been using in our purse seine catches.

iii. Quantify the prevalence of viral erythrocytic necrosis (VEN) for both species in May and age-0 herring in September. Disease hypothesis. Note: VEN analysis is conducted by the disease program (project 25120111-C, PI Hershberger). *Disease hypothesis*

Results. We found a markedly higher prevalence of VEN in captured herring in our May cruise in 2025 (94 out of a total of 153, or 61.4% of the herring sample collected were VEN positive) than previous years (1.5% in 2023, and 35.6% in 2024). VEN prevalence in herring during our September cruises have been uniformly low (4.4% in September 2023, 2.2% in September 2024, and 4.1% in September 2025). We have documented the first case in our study of a VEN positive sample in juvenile pink salmon (1 out of a total of 545 sample, or 0.2% of the pink salmon analyzed). The single VEN positive juvenile pink salmon was captured by beach seine in Sheep Bay in eastern PWS in June 2025. VEN results were generated by the U. S. Geological Survey (USGS) Marrowstone lab (P. Hershberger and C. Grady, unpubl. data). The interannual and seasonal variability in VEN prevalence we have detected thus far is important to note as it suggests VEN dynamics are not static and vary across years, seasons, and locations. Additional sampling for VEN in future years will help us better understand this variability and how it might be related to cooccurrence of the two species.

iv. Determine age-0 herring diet composition and body condition in September using stomach content analysis, DNA barcoding, and bulk SIA and CSIA to determine the degree of dietary overlap with juvenile pink salmon diets measured in May (see 3a, ii and 3b, ii). *Competition hypothesis*

Results. We are currently analyzing prey in stomachs of herring collected in September 2025. We anticipate these results will be generated by spring 2026. The diets of juvenile herring in September 2023 consisted mostly of small copepods, while the diets observed in September 2024 were more diverse, with dominant prey types including small copepods, larvaceans, and pteropods. It is interesting to note that this diet variability coincides with odd (low) - even (high) year outmigration patterns by pink salmon where during 2024 diets were more diverse potentially reflecting greater competition and possible prey switching. We have completed the counts of plankton collected during this September 2025 cruise (Zaikof Bay, Whale Bay, Deer Cove, Lower Herring Bay, and Simpson Bay). We will compare diet results with these zooplankton data to assess prey availability relative to herring diets to better understand the possibility of density-induced prey switching by herring. The results of counts of prey availability in May and September (from our bongo net sampling), along with results from June and July surveys, are included below (Section 3b. ii).

SIA data suggest that age-0 herring collected in September 2023 and 2024 appear somewhat isotopically segregated between years (Fig. 7) with the 2024 age-0 herring showing more variation in carbon values perhaps reflective of a broader diet in 2024. We are still in the process of producing the September 2025 SIA data for juvenile herring. Further, we are currently working on energy estimates (bomb calorimetry and C/N ratios) for age-0 herring and will evaluate how energy density varies between years in association with outmigration abundance of salmon as past work has shown that energy and growth appear to be lower in years of high salmon outmigration in PWS (Gorman et al. 2018, Arimitsu et al. 2021). We had hoped to make more progress on this in spring and summer 2025, but the bomb calorimeter at UAF was inoperable for much of the last six months. The machine was fixed over the winter 2025-26 holiday and we are now actively working on the age-0 herring energy dataset.

We are evaluating bulk and compound-specific isotopic variability between adult herring, salmon fry, and age-0 herring (Figs. 6, 7, 8). We have a complete dataset for 2023 for both species, a complete dataset for herring collected in 2024, and a partial dataset for herring collected in 2025. We are now working on the SIA data to complete the 2024 dataset. The salmon collected in 2025 will be sent to UAF for stable isotope processing as soon as all prior analyses (otolith removal, energy content) are completed by PWSSC. Available data suggest that adult herring are isotopically distinct from salmon fry (2023), providing support for low dietary reliance on salmon fry by adult herring in PWS (Fig. 6). Salmon smolts sampled in June and July 2023 mainly overlapped in isotopic values, however sample sizes were smaller for July (Fig. 6). Some age-0 herring overlapped in isotopic values with juvenile pink salmon (2023), while other age-0 herring were more isotopically distinct (Fig. 6). We will evaluate spatial variability in these isotope data. We know from past studies that age-0 herring collected from northeastern PWS have different $\delta^{13}C$ values than those from elsewhere in PWS (Gorman et al. 2018). CSIA data indicate that species and age classes perhaps are relying on different sources of primary productivity (Fig. 8), while juvenile herring may rely on higher trophic level prey based on non-essentially amino acids such as aspartic acid and glutamic acid (Fig. 9, note: leucine is an essential amino acid, see also Fig. 6). We recognize that the CSIA data are based on very small sample sizes at this point so results should be considered preliminary, but we will continue to explore these ideas with further analysis as justified. Additional CSIA data are being produced for 2023 and 2024 during spring 2026.

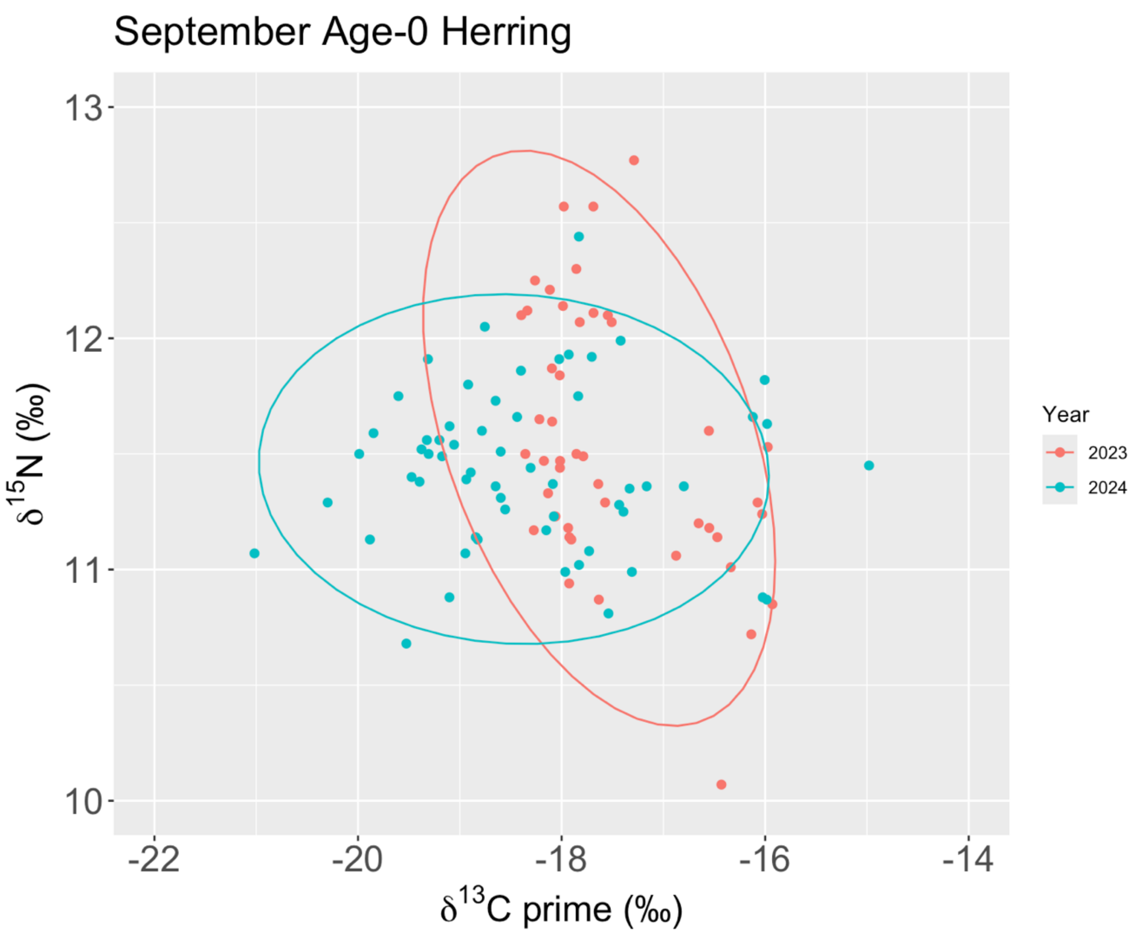

Figure 7. Carbon and nitrogen stable isotope variability of age-0 herring sampled in September 2023 (pink) and 2024 (green). Ellipses represent 95% confidence levels.

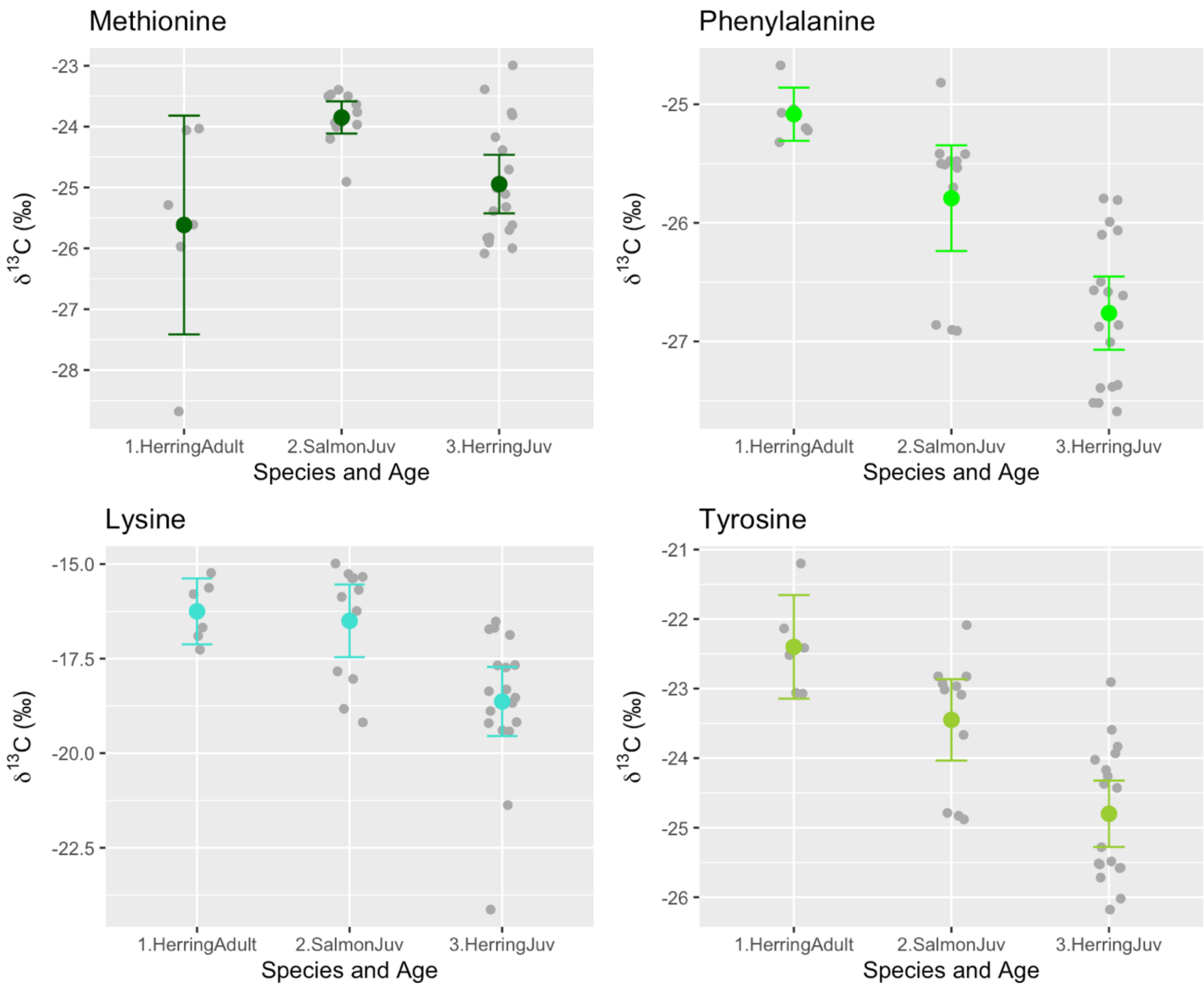

Figure 8. Compound-specific carbon isotope variability of adult herring, outmigrating salmon fry, and age-0 herring sampled throughout the summer of 2023. All compounds suggest some discrimination among species or age classes.

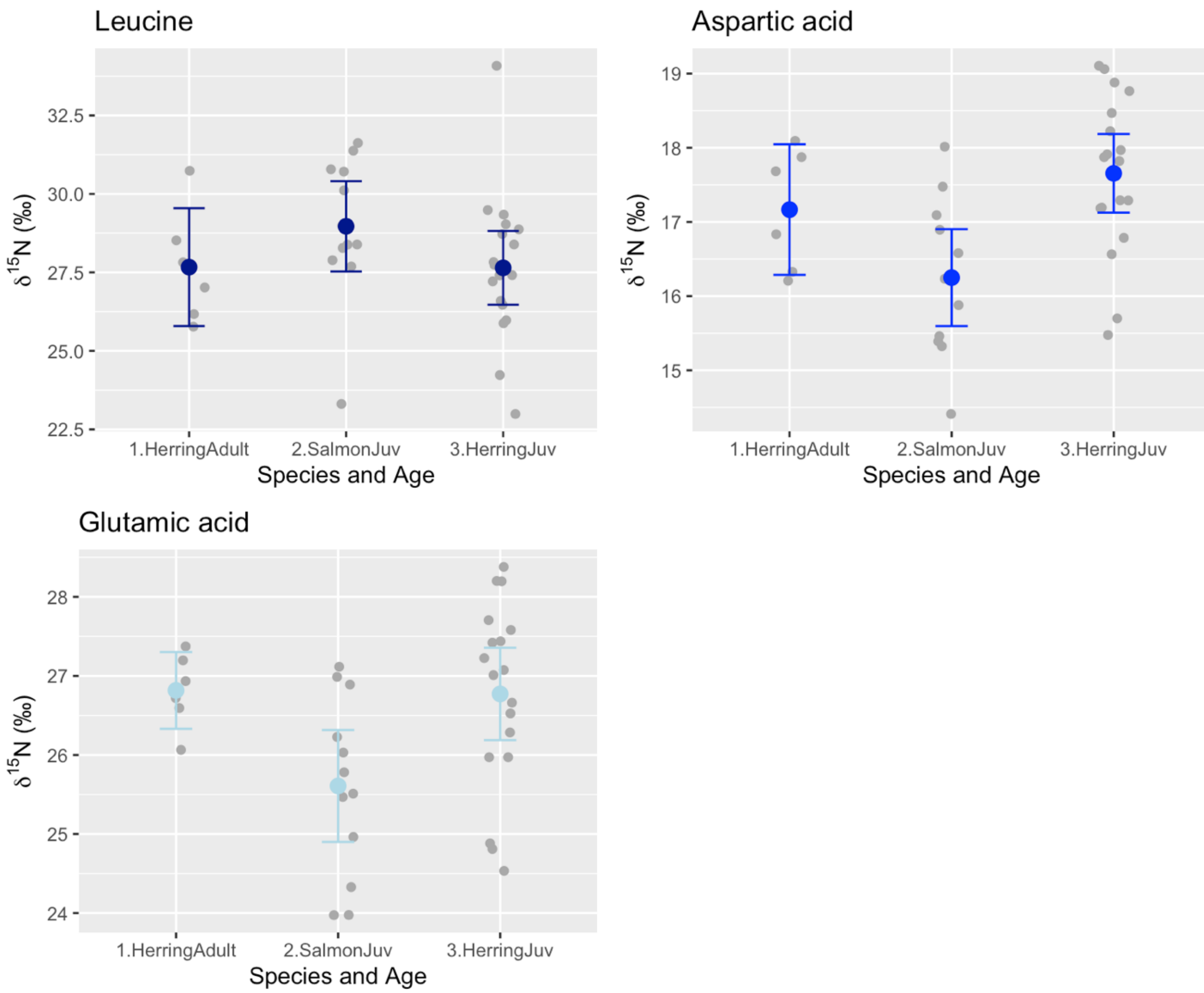

Figure 9. Compound-specific nitrogen isotope variability of adult herring, outmigrating salmon fry, and age-0 herring sampled throughout the summer of 2023. Both aspartic acid and glutamic acid suggest juvenile herring sampled in September may be foraging at a higher trophic level than juvenile salmon sampled in June and July. Note: leucine is an essential amino acid derived directly from the diet, therefore it is not surprising that there are no differences among species or age classes as herring and salmon forage within the same trophic levels.

b. Off-shore habitats (trawl sampling in June and July)
    i. Determine whether larger, emigrating pink salmon fry feed on larval herring in June and July using stomach content analysis, DNA barcoding, and bulk SIA and CSIA. *Predation hypothesis – pink salmon forage on herring*

Results. We completed a preliminary analysis comparing two methods applied to detect the presence of herring in the diets of juvenile pink salmon collected during this grant period. Here we focus on our four surface trawl sites (Chenega Island, Prince of Wales, Sleepy Bay, and Point Bazil). We examined prey from a total of 207 individual pink salmon (collected during 2023-2025) and estimated the total number of larval fishes (unidentified) and the number of larval herring based on morphology and pigment patterns. For each processed stomach, we estimated the total mass of prey (blotted dry) and, for this preliminary analysis, we assumed an average larval herring was 5 mg in mass (used to quantify the mass contribution of herring larvae to total prey mass in the gut). The DNA metabarcoding analysis was conducted at the NOAA lab in Juneau. We extracted DNA from 71 individual pink salmon stomachs collected in 2024 (in addition to 49 that were already processed from our 2023 pink salmon collections). We are planning to ship preserved stomach contents from additional 2024 pink salmon collections (in an effort to increase sample sizes for that year) in addition to 2025 collections to the NOAA lab during Spring 2026. Here we report results based on three years of microscopy data and two years of DNA metabarcoding results.

Based on our microscopy analysis, larval fishes were observed in 51 individual pink salmon (24.6%), and 17 (8.7%) had consumed larval herring (Figs. 10 and 11). Many of the unidentified larval fishes were of a form that resembled herring larvae (elongated body form), but advanced digestion made it impossible for us to clearly identify them to species (they closely resemble other larval fishes that we have observed in our plankton net collections, including northern smoothtongue *Leuroglossus schmidti* and capelin *Mallotus villosus*). We observed the highest amount of herring predation in June 2024 – during that period, the mean total mass of larval herring represented on average 8% of total prey mass in the diet of juvenile pink salmon (range across individuals: 1.9-29.2%). Based on our metabarcoding results, a total of 49% of the individuals had positive detections of herring DNA in their gut contents (Fig. 11). Herring represented a total of 43.6% of the DNA reads, indicated they were a dominant component of their prey fish diet.

We applied generalized linear models (using presence/absence and count/DNA read data) to explain variation in larval herring presence in diets. We applied models separately to the microscopy data (2023-2025) and the metabarcoding data (2023-2024). Explanatory variables included: Year, Day of Year, Origin, Total Length, and Site. Five candidate models were fit to each dataset using maximum likelihood estimation, and the best model was determined based on the Akaike information criterion (AIC).

Based on our nekton collections (catches from a towed bongo plankton net, described in more detail in a section below), we observed densities of larval herring to vary from nil to 0.24 individuals/m^3. We captured fewer herring larvae in 2023 (mean: 0.01 individuals/m^3) compared to 2024 (0.04 individuals/m^3) and 2025 (0.04 individuals/m^3).

We observed a seasonal decline in larval herring abundance. Mean densities of larval herring (averaged over all three years) were highest in early June (0.07 individuals/m^3), moderate in late June (0.04 individuals/m^3), and lowest in July (0.01 individuals/m^3).

Figure 10. Example of a herring larvae (~4.5mm) identified in a pink salmon stomach collected from Chenega Point in southwestern Prince William Sound in June 2025.

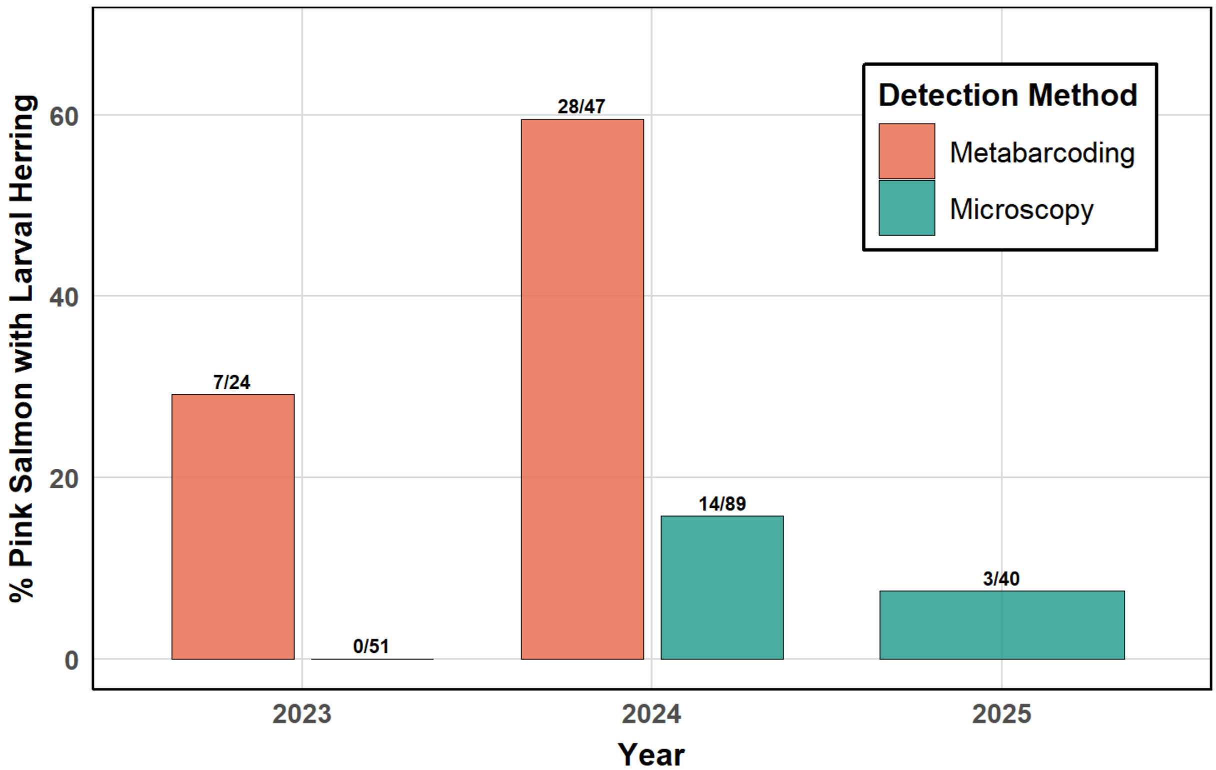

Figure 11. Percent of pink salmon stomachs with larval herring by year (2023-2025) and by detection method.

The best fit model (general linear model [GLM] binomial model, based on AIC) for both microscopy and metabarcoding datasets included the following covariates: Year, Day of Year, and Origin. The Year effect indicated a high incidence of larval herring predation in 2024 relative to the other years (Fig. 11), and the Day of Year effect indicated an overall decline in incidence of herring in diets over the season, which tracks the declining temporal trend in larval herring abundance in our study area described above. The temporal variables were most important, and the effect of pink salmon origin was marginal (microscopy data) and not significant (metabarcoding data). Sampling site was not a significant factor.

The best fit model applied to the microscopy data (count model) was the same as the binomial model (described above) and included the following covariates: Year, Day of Year, and Origin

(Table 5). We also observed the same temporal patterns as described above for the binomial model (Fig. 12), but origin had a stronger effect: hatchery-origin pink salmon consumed 13.1 times ($p = 0.002$) more herring larvae than wild pink salmon (Table 5).

*Table 5. General linear model (GLM) results using count/DNA read data. Predictor variables to explain variation in microscopy data (# larvae observed per stomach) and metabarcoding data (# DNA reads per stomach) are listed in the first column. Effect sizes (RR = relative rates) and p-values are included for each data type. *** indicates high statistical significance, ** indicates strong statistical significance.*

Predictor Variable	Microscopy	Metabarcoding
Year (2024 vs. 2023)	$p<0.001^{***}$, peak in 2024	$p<0.001^{***}$, peak in 2024
Day of Year (per 10 days)	RR = 0.33 ($p<0.001^{***}$), 67% decline	RR = 0.24 ($p<0.001^{***}$), 76% decline
Total Length (per 10 mm)	RR = 0.87 (p=0.71), No effect	RR = 1.31 ($p<0.001^{***}$), 31% more reads
Site (4 PWS surface trawl sites)	p=0.15, Not significant	$p<0.001^{***}$, Point Bazil 95% higher
Origin (hatchery vs. wild)	RR=13.1 ($p=0.002^{**}$), 13.1X more larvae	RR=0.98 ($p<0.001^{***}$), 2% fewer reads
Sample size	N -= 179 fish	N = 71 fish
Model Type	Negative Binomial GLM	Poisson GLM
Best Model	Origin + Year + DOY	Full model (all predictors)

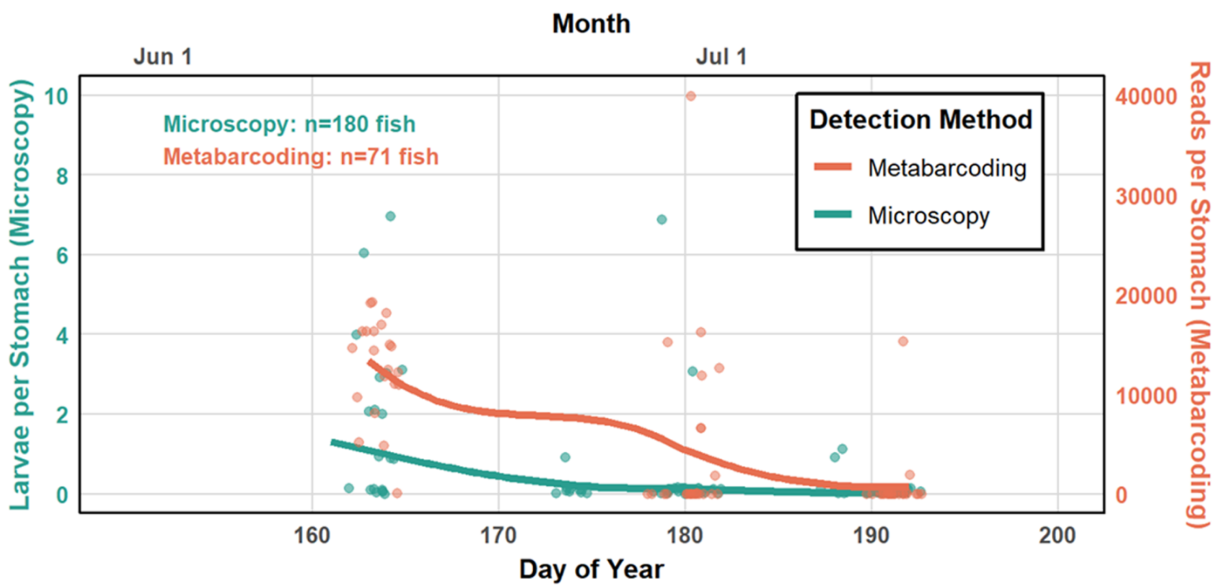

Figure 12. Pattern in larval herring counts by month/day of year, all years combined for both analytical methods.

The best fit model applied to the metabarcoding data was the full model that included the following covariates: Year, Day of Year, Origin, Total Length, and Site (Table 5). We document the same temporal patterns as described above for the binomial model (Fig. 12**)**. The effect of Origin was significant but not consistent with results from the microscopy data, with wild pink salmon showing higher herring DNA read counts compared to hatchery-origin pink salmon, but the effect size was very small (2% fewer reads, p = 0.001, Table 5). For every increase in 1 standard deviation in total length of pink salmon (~ 20 mm), herring DNA read counts increase by 31% (Total Length effect, Table 5). The effect of sampling site on herring DNA read counts (Site effect) was stronger in this model. The sites ranked by effect size are as follows: Point Bazil>Prince of Wales>Sleepy Bay>Chenega.

Year and Day of Year explained much of the variation in incidence of larval herring predation (both methods). Our results indicate a strong seasonal decline in larval herring consumption that appears to track larval herring availability. The year 2024 was exceptional, with 2-6 times higher incidence of larval herring consumption compared to other years. Metabarcoding appears to be a much more sensitive indicator of larval herring predation given the higher likelihood of detections compared to visual observations of prey with a microscope. Herring larvae appear to be an important food resource for both wild and hatchery juvenile pink salmon but only during a limited period of time, and this likely depends on the strength of herring year classes.

Stable isotope values of wild and hatchery salmon fry suggest that wild fish are consuming perhaps a more variable diet, and that hatchery fish are likely reflecting a less variable diet they were fed while in captivity (Fig. 13). We are processing salmon collected in 2024 for SIA currently, and we intend to examine differences in isotopic niches between salmon of different origins with additional years of data.

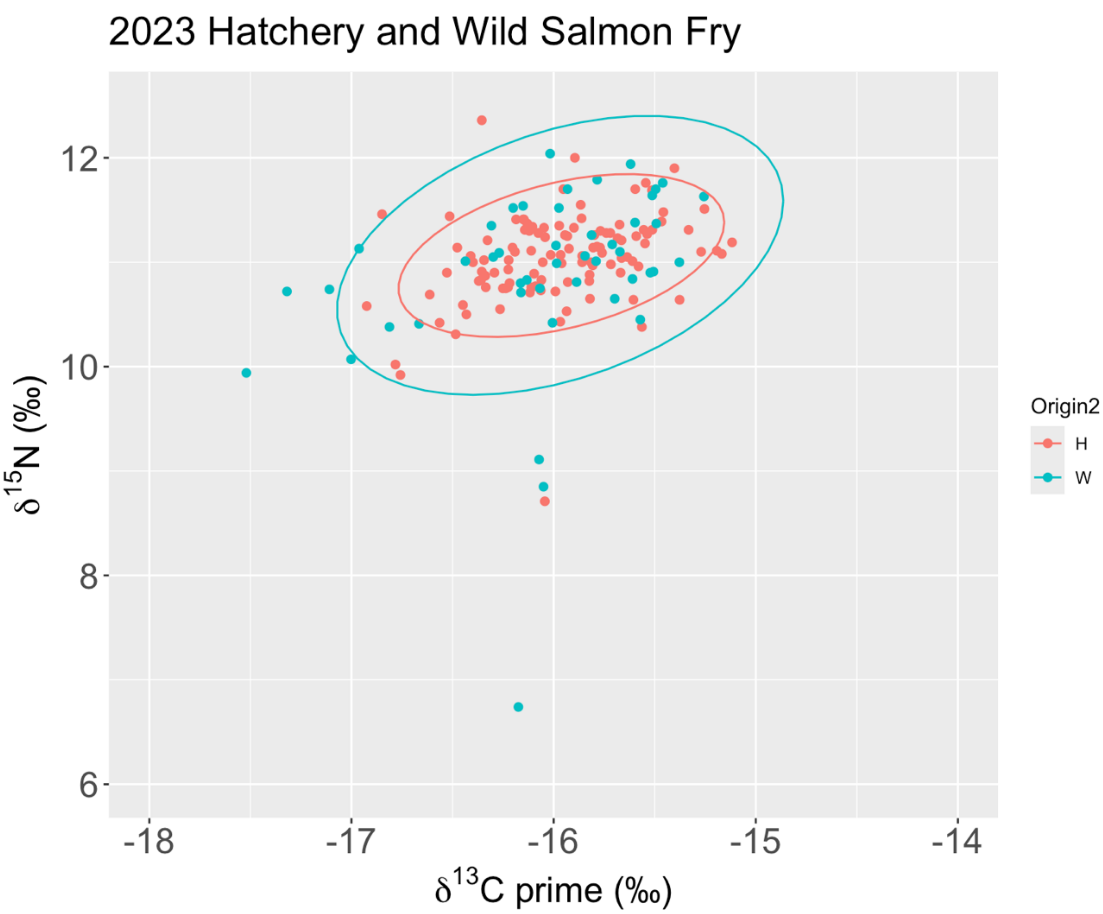

Figure 13. Carbon and nitrogen stable isotope variability of outmigrating hatchery and wild salmon smolts collected during June and July 2023. Ellipses represent 95% confidence levels.

ii. Determine whether juvenile pink salmon offshore in June and July consume similar prey as age-0 herring in September (see Objective 3a, iv) using stomach content analysis, DNA barcoding, and bulk SIA and CSIA. Also, determine prey availability using zooplankton nets during trawl sampling. *Competition hypothesis*

Results. We have now completed prey counts on a total of 70 pink salmon collected during our June and July cruises in 2025. Diets of both species were composed mostly of copepods and euphausiids. The dominant prey item (by numbers) was copepods, but diet composition varied markedly by site and year. We present results in the form of plots for pink salmon collected at our surface trawl sites for the three years of study (Fig. 14). The majority of pink salmon stomachs analyzed had at least some prey items. Empty stomachs were most frequently observed during 2023 (proportion empty at Point Bazil was 0.7, 0.2 at Prince of Wales and 0.17 at Chenega), and at Sleepy Bay trawl site in 2024 (proportion empty, 0.18). We intend to compare these diet compositions to age-0 herring diets sampled in September to quantify dietary overlap.

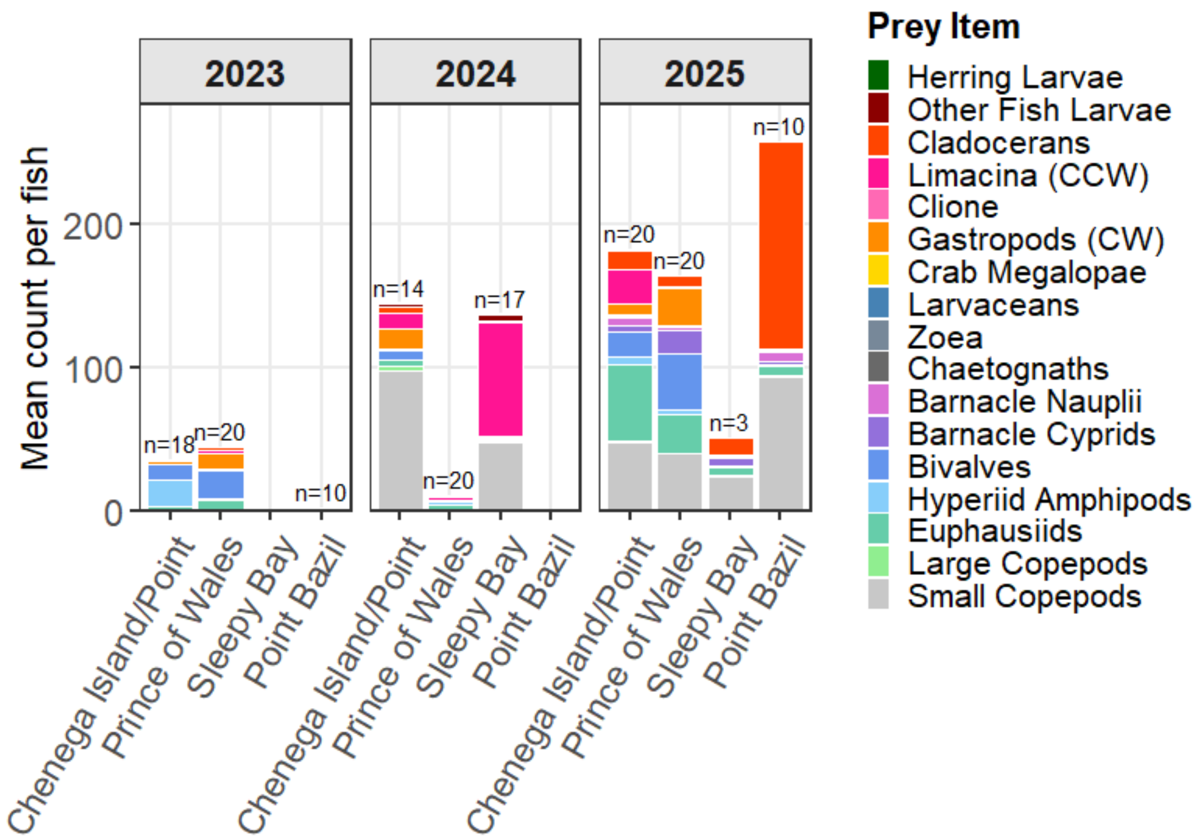

Figure 14. Composition of prey items in diets (mean prey count per fish) of juvenile pink salmon captured during 2023-2025 during our June and July surface trawl surveys. Sample sizes at each site in each year are provided above the columns.

The diet data described above will be compared to prey availability measured by our towed plankton net to evaluate overlap and potential competition for shared prey resources. We have fully worked up plankton collections for all cruises completed to date during 2023-2025. We quantified counts in 17 separate taxonomic categories, applying the same categories used in earlier Global Ocean Ecosystem Dynamics (GLOBEC) studies to allow comparisons to earlier results; we additionally discriminated herring larvae from other fish larvae where possible (Fig. 15). We present results from bongo plankton collections (densities, log #/m^3, 333 um mesh net ring) from all cruises across all three study years (Fig. 16). We were unable to make collections during our early June 2025 surface trawl cruise because our surface trawl was damaged at our first survey site (described above).

Given we now have three years of plankton count data, we have begun some exploratory analysis to understand interannual patterns of prey in our main study area (surface trawl sites) in southwestern PWS. We fit an analysis of variance (ANOVA) model including mesh size (we have counts for both the 333 um and 500 um mesh rings) and month as covariates alongside year. The response variable was total prey count (log_{10} transformed plankton and nekton counts). This model revealed a significant year effect ($F_{2,109} = 5.00$, $p = 0.008$), alongside strong effects of mesh size ($p < 0.001$) and month ($p < 0.001$). After accounting for these sampling factors, 2023 had the highest adjusted mean prey density (emmean = 2.65), followed by 2025 (2.43) and 2024 (2.15). Pairwise Tukey contrasts indicated that 2023 was significantly higher than 2024 ($p = 0.0007$), while 2025 was intermediate — not significantly different from 2023 ($p = 0.204$) but marginally higher than 2024 ($p = 0.062$). Taken together, these results suggest that total prey availability was lowest in 2024 and recovered somewhat in 2025 to levels more comparable to 2023. We posit this may be a food web response to varying levels of planktivory from juvenile pink salmon and larval herring, although we cannot rule out other explanations, including differences in environmental factors across years. We explore interannual patterns of abundance of juvenile pink salmon in our study area based on trawl catch per unit effort (CPUE) in a section below. We intend to characterize environmental conditions at all our sampling sites based on our conductivity and temperature at depth (CTD) data and include environmental covariates in future analyses.

May 2023, Site 9, 500 um Bongo

Figure 15. Example of preserved herring larvae collected in May 2023 using a bongo plankton net.

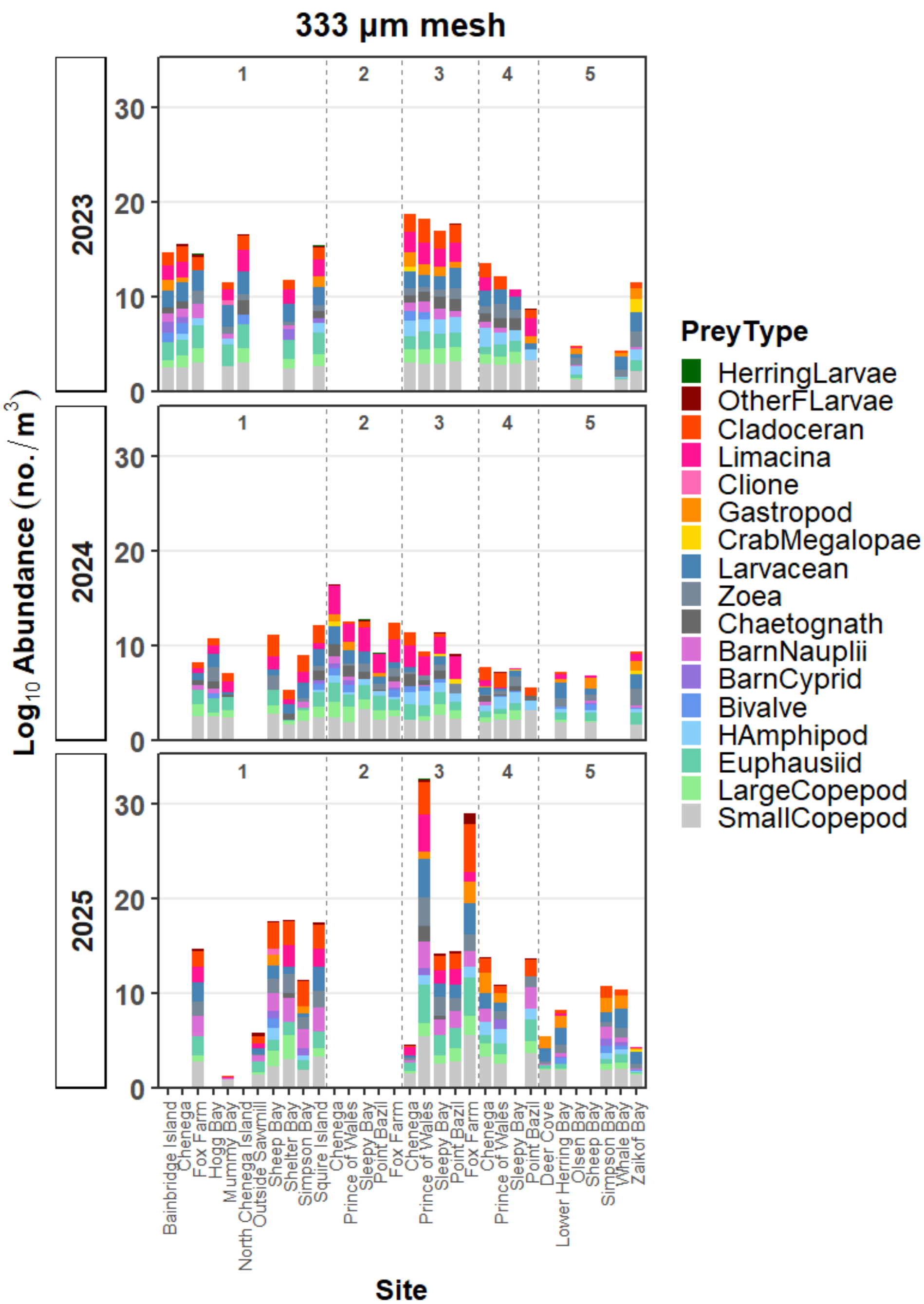

Figure 16. Densities (log #/m³) derived from microscope counts of individual plankton and nekton prey types collected with a bongo net at all sampling sites during 2023-2025. Data shown

are collections made in the finer mesh (333 um) plankton ring of the bongo net. Numbers appearing between the vertical, broken lines refer to cruise periods (1 – late May-early June, nearshore sampling, 2 – early June, offshore sampling, 3 – late June, offshore sampling, 4 – July, offshore sampling, 5 – September, juvenile herring sampling).

iii. Quantify the prevalence of VEN in juvenile pink salmon and age-1+ herring opportunistically caught during June and July. Disease hypothesis. Note: Disease analysis conducted by the disease program (project 25120111-C, PI Hershberger). *Disease hypothesis*

Results. No juvenile salmon have tested positive for VEN in these surface trawl surveys in June and July during 2023-2025, and we did not capture enough herring in these surveys to estimate VEN prevalence.

iv. Produce bioenergetic model estimates of larval herring consumption by juvenile pink salmon originally planned to be led by a post-doctoral associate funded by a separate EVOSTC project (22220111-H). *Predation hypothesis – pink salmon forage on herring*

Results. This work will be conducted by co-PI Heintz (Sitka Sound Science Center [SSSC]) beginning in 2026-27 when we have three to four complete years of data. This will represent the start of the 'synthesis phase' of our project and provide support to build a bioenergetic model to simulate growth and consumption of pink salmon and evaluate trophic dynamics (described as the predation hypothesis in our original proposal), as well as assist in the development of a fishery forecast model.

4. Develop pink salmon models
   a. Evaluate a suite of covariates to improve our understanding of factors regulating marine survival of pink salmon, including data on trawl catch per unit effort (CPUE), body size, and body energy density of PWS hatchery pink salmon captured in our study and allied studies, as well as bulk SIA data produced by Objective 3b, ii noted above.
   b. Develop predictive models of pink salmon survival and evaluate their performance compared to the current model used by ADF&G to manage the PWS commercial pink salmon fishery.

Results. In addition to the diet composition and disease prevalence described earlier, we have now worked up size and energy densities measures for juvenile pink salmon in 2023 and 2024, and we are currently processing 2025 collections (carcasses were returned to us in September 2025 after otoliths were extracted by the ADF&G Otolith Lab). We collected individuals from all four hatcheries (Armin F. Koernig [AFK], Wally Noerenberg [WNH], Cannery Creek [CCH], and Solomon Gulch [SGH]), and wild fish during 2023-2025.

We explored body size and energy density (measured using microbomb calorimetry at the PWSSC lab) dynamics with an ANOVA model, with Year and Origin (wild and hatchery) as covariates. We further evaluated hatchery-specific patterns by applying a separate ANOVA with Year and Hatchery as covariates. We found fish to be significantly larger in 2024 compared to 2023 (ANOVA, $F = 17.98$, $p < 0.001$; EMMs: 3.74 g vs. 5.41 g averaged across origins, Fig. 17). Hatchery-origin pink salmon were significantly larger than wild fish overall ($F = 8.04$, $p = 0.005$; EMMs: 5.00 g vs. 4.16 g), indicating the body size of hatchery pink salmon was consistent across both years. The contrast in body size between 2023-2024 was significant for hatchery fish (2.08 g, $p < 0.001$) but not significant for wild fish (1.26 g, $p = 0.076$), and it should be noted that sample sizes of wild fish in 2023 was small ($n = 38$).

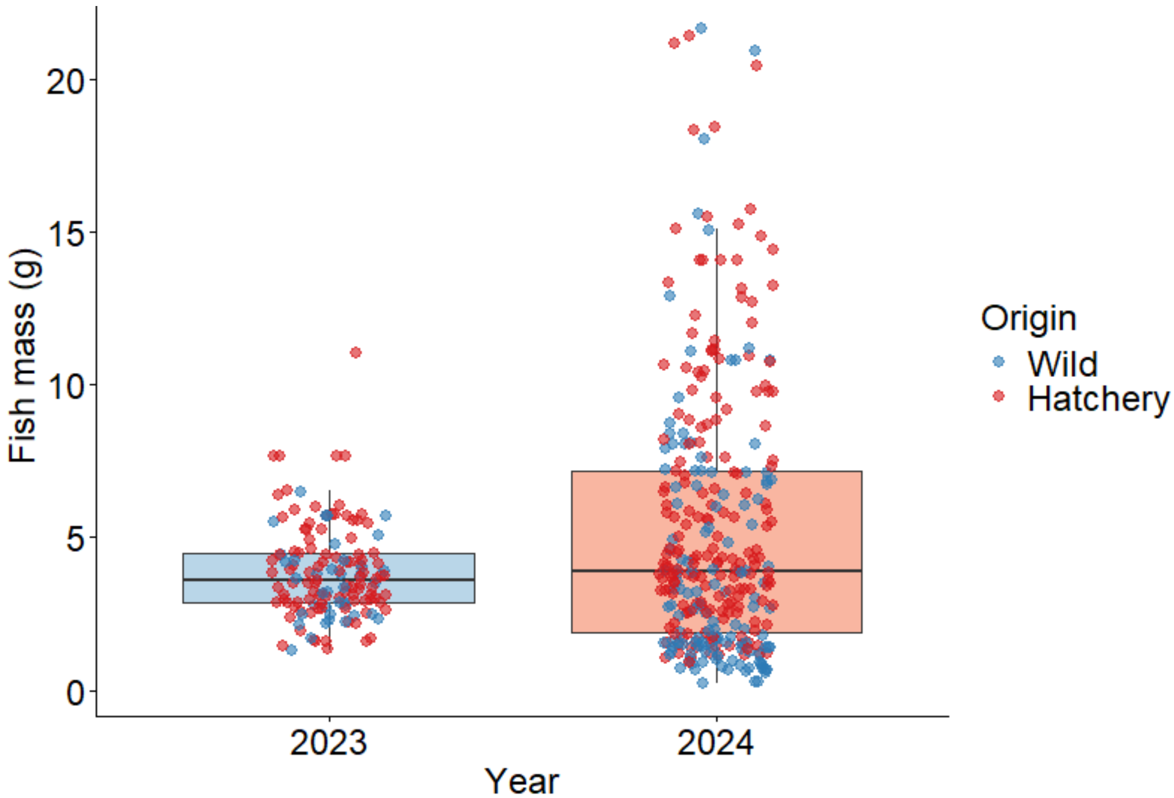

Figure 17. Fish mass (wet weight, in g) for trawl-captured juvenile pink salmon in 2023 and 2024, by origin.

We found that SGH and WNH fish were dramatically larger in 2024 compared to 2023, while AFK and CCH fish showed little change (Fig. 18). This was indicated in our statistical analysis as a significant interaction between Year and Hatchery ($F = 8.55$, $p < 0.001$). This may indicate differences in hatchery fry release timing, distance of our sampling sites from each hatchery release location, or environmental conditions experience by each separate hatchery population. Results from pink salmon collected during our 2025 cruises will help us further evaluate these body size patterns across years and origin groups.

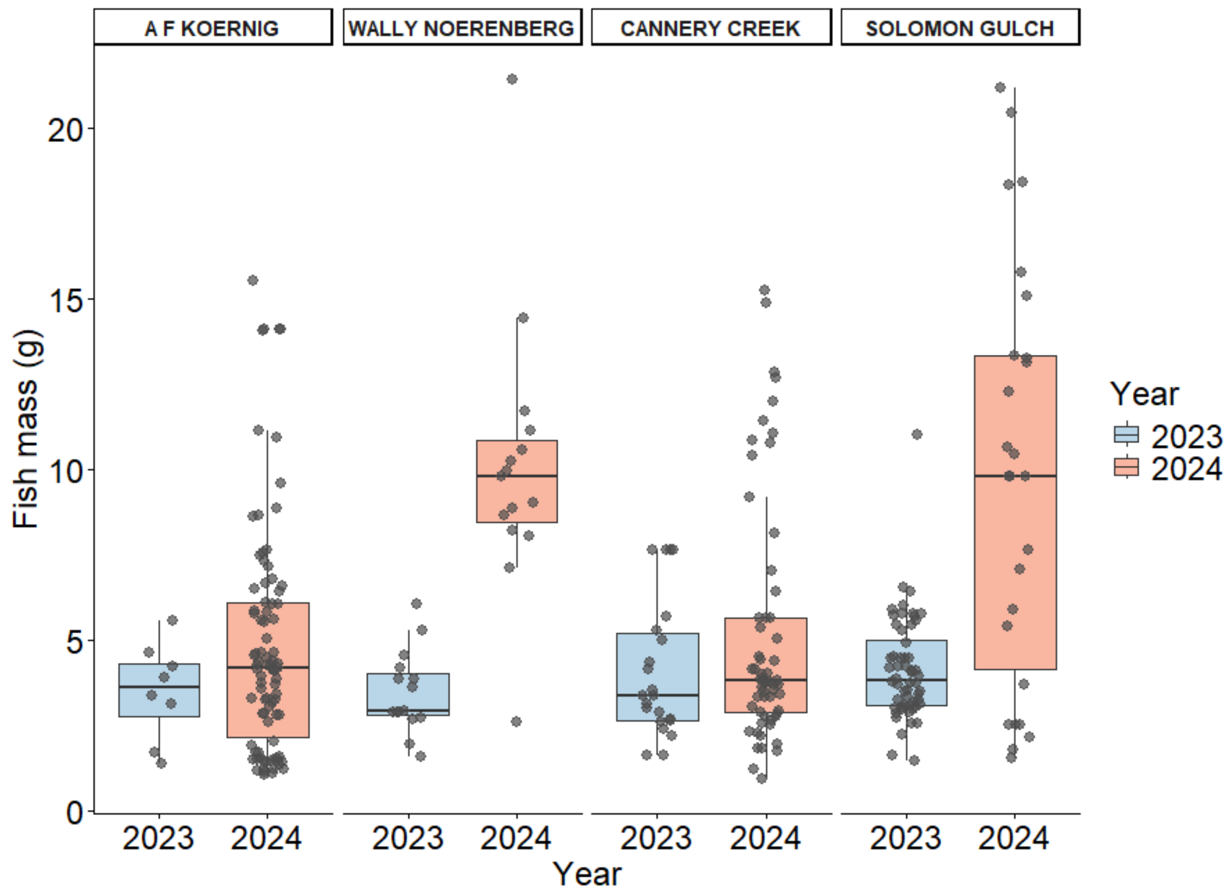

Figure 18. Fish mass (wet weight, in g) for trawl-captured juvenile pink salmon in 2023 and 2024, by hatchery origin.

We also found a significant year effect in our analysis of energy density as we report above for body size, but in the reverse direction (Fig 19). There was a strong and highly significant year effect ($F = 36.5$, $p < 0.001$), with 2023 fish having higher energy density than 2024 fish across both origin groups (wild and hatchery, grand means 19.5 MJ/kg vs. 18.7 MJ/kg, Fig. 19). We found no significant difference in energy density between wild and hatchery fish overall ($F = 0.12$, $p = 0.732$; wild mean = 18.9 and hatchery mean 19.0 MJ/kg). The Year X Origin interaction was also not significant ($F = 1.85$, $p = 0.175$) indicating the year-to-year decline was broadly similar for both origin groups.

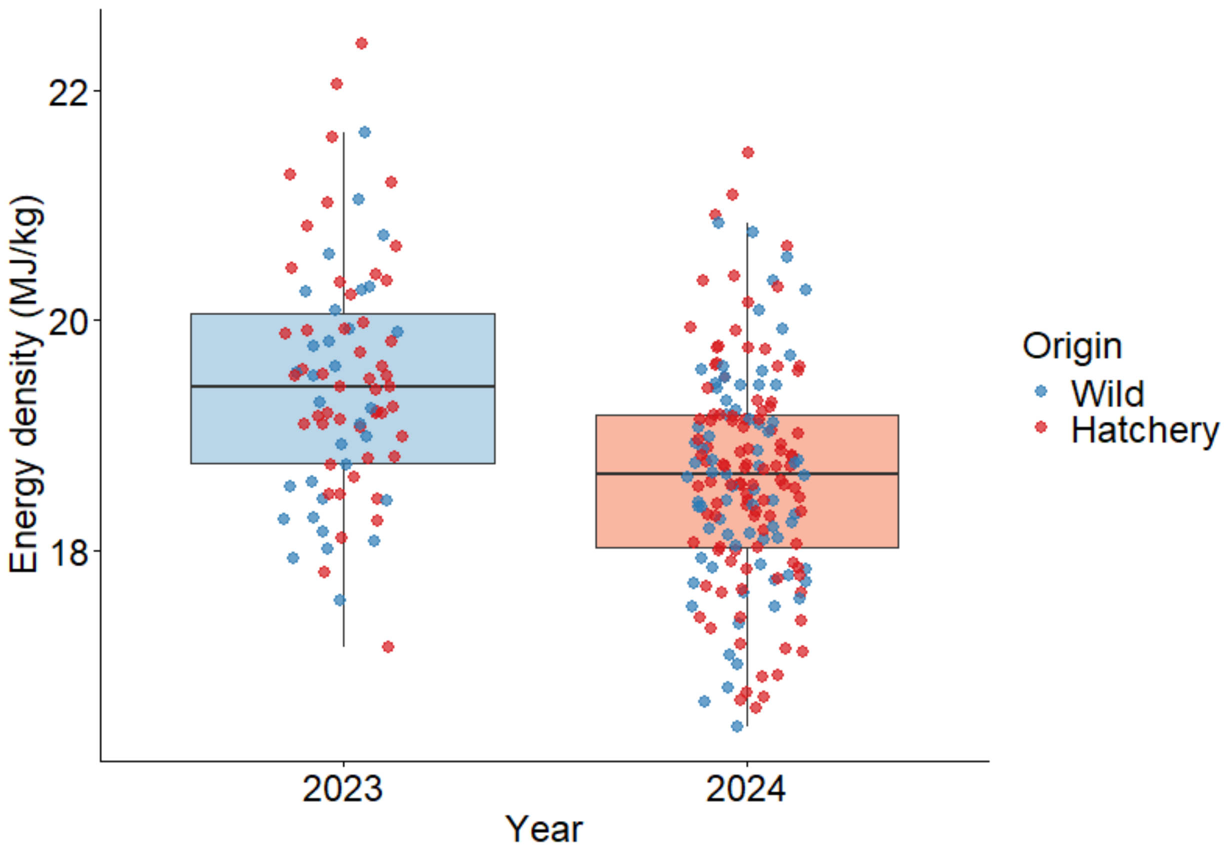

Figure 19. Energy density (MJ/kg) for juvenile pink salmon collected in 2023 and 2024 by surface trawl. Origin, determined by thermal marks, are plotted by color.

Among hatchery fish, there was no significant difference in energy density among the four hatcheries when averaged across years ($F = 1.07$, $p = 0.364$; all EMMs ranging narrowly from 19.0–19.4 MJ/kg, all pairwise contrasts non-significant, Fig. 20). However, there was a significant Year × Hatchery interaction ($F = 6.07$, $p < 0.001$, Fig. 20), indicating that hatcheries differed in how much their fish energy density changed between 2023 and 2024, suggesting hatchery-specific interannual variation in fish condition that warrants further examination. This pattern was driven by three hatcheries showing different patterns. CCH fish showed the largest and most significant year-to-year decline, dropping 1.99 MJ/kg from 2023 (20.3) to 2024 (18.3), $p < 0.001$. This was the steepest drop of any hatchery and largely responsible for the significant interaction term. In 2023, CCH fish had significantly higher energy density than SGH fish (contrast = 1.01 MJ/kg, $p = 0.014$), but by 2024 this difference had disappeared. AFK fish also showed a significant decline of 1.16 MJ/kg from 2023 (19.9) to 2024 (18.7, $p = 0.020$), a meaningful drop, although less dramatic than CCH fish. It should be noted that sample size for pink salmon originating from AFK during 2023 was very low ($n = 4$), making it difficult to draw inferences about that hatchery population. SGH fish showed a modest and non-significant decline of 0.48 MJ/kg ($p = 0.093$), suggesting a weaker or negligible year effect. WNH fish stood out as the exception, with essentially no change between years (−0.02 MJ/kg, $p = 0.965$), with nearly identical energy density in 2023 (19.4) and 2024 (19.4). By 2024, WNH fish were significantly higher in energy density than CCH fish (contrast = 1.10 MJ/kg, $p = 0.009$), a difference that did not exist in 2023.

In summary, the interaction reflects a pattern where three hatcheries declined substantially in energy density from 2023 to 2024 while WNH fish maintained consistent energy density across both years, diverging from the others, particularly from CCH, by 2024.

We now have three years of trawl CPUE data of pink salmon (and associated metrics, including origin, body size, energy densities, and stomach diet composition and fullness). We analyzed CPUE for pink salmon for the 3 years of trawl data (2023-2025). The even/odd pattern in pink salmon abundance is in the predicted direction; 2024 (even-year smolts, dominant cycle) had higher mean log CPUE (0.340) than 2023 and 2025 combined (0.278), but the difference is not statistically significant (ANOVA $p = 0.447$, one-tailed t-test $p = 0.275$, Fig. 21). We also applied a hurdle model, a modeling approach composed of two parts. The first part is a binomial model that tests whether P (any catch >0) differs between even and odd smolt years. The second model is a linear model (with one tailed t-test) that tests whether the catch magnitude differs conditional on fish being present, which removes zero inflation from the comparison. Results of the hurdle model adds some nuance: the detection frequency component shows a meaningful gap in the predicted direction (68% of tows caught fish in 2024 vs. 56% in odd-year smolt years), though again not significant ($p = 0.227$). Crucially, among tows that did catch fish, mean log CPUE was nearly identical between even and odd smolt years (0.499 vs. 0.496, $p = 0.491$). This suggests that the modest overall CPUE advantage in 2024 is driven entirely by more frequent detections, not higher catches when fish are present — potentially reflecting patchier distribution in odd-year smolt years rather than a difference in local density.

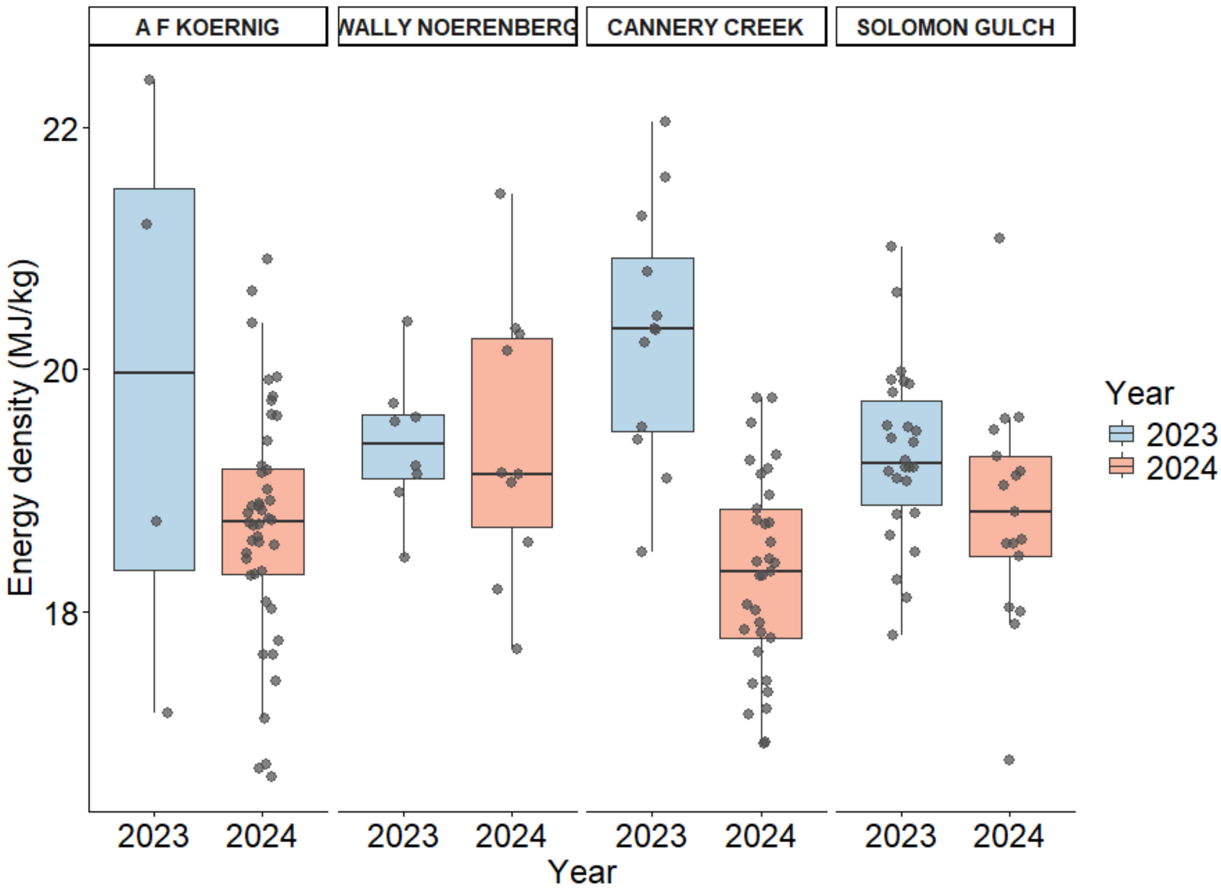

Figure 20. Plot showing interaction effect of hatchery and year on energy density (MJ/kg) of juvenile pink salmon capture in our surface trawl survey.

Hatchery-origin fish comprised the majority of pink salmon sampled at these trawl sites across all three years during the late-season survey window (Late June and July sampling periods combined). Sample sizes (number of individual fish sampled for origin using thermal marks) were 127, 292, and 256 fish in 2023, 2024, and 2025 respectively across the four surface trawl sites (Chenega Point, Prince of Wales, Sleepy Bay, and Point Bazil). The proportion of hatchery-origin fish differed significantly among years (binomial GLM with fixed site effect, likelihood-ratio test: $\chi^2 = 7.75$, df = 2, $p = 0.021$), with 2023 having a notably higher hatchery proportion (73.2%) than either 2024 (62.2%) or 2025 (59.8%). Pairwise contrasts indicated that 2023 differed significantly from 2025 (OR = 1.84, p = 0.027) and marginally from 2024 (OR = 1.66, p = 0.089), while 2024 and 2025 were indistinguishable (OR = 1.11, p = 0.850). With additional years of data, we hope to further explore even and odd year patterns in the relative abundance of wild- and hatchery-origin smolts in our study area.

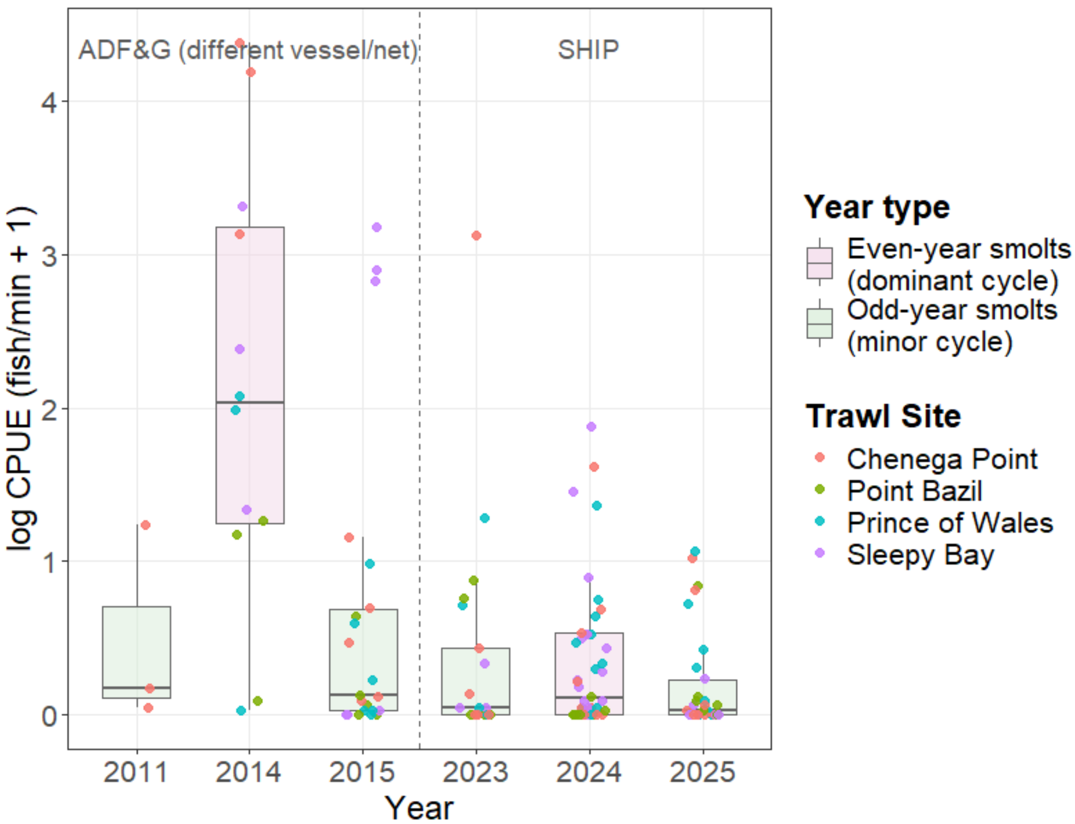

Figure 21. Trawl catch per unit effort for juvenile salmon (Alaska Department of Fish and Game [ADF&G] data in 2011, 2014, and 2015) and pink salmon (this study, during 2023-2025) color-coded by trawl station. Data from ADF&G were based on captures from a different surface trawl design (Nordic Rope Trawl 264) and deployed off the R/V Solstice, whereas juvenile salmon were captured with a Mamou-style surface trawl during 2023-2025 off the R/V New Wave. SHIP = Salmon-Hatchery Interactions Project.

To evaluate the longer time series, we included the early ADF&G catch data in the analysis, but added "SurveyEra" as an additive covariate in the ANOVA and the hurdle GLMs. This approach allows for estimation of the even/odd effect while accounting for the absolute CPUE shift from the gear/vessel change, rather than conflating the two. In this case, we applied a two-way ANOVA (log CPUE ~ YearType + SurveyEra) and found the YearType (even vs. odd year) effect to be significant ($F=5.41$, $p= 0.022$) with even-year smolts having significantly greater CPUE than odd-year smolts. The Hurdle Part 1 model (P(catch > 0), binomial GLM) indicated only marginal higher detection in even years ($z = -1.74$, $p = 0.081$), whereas the Hurdle Part 2 model (logCPUE given catch > 0) did show a significant YearType effect ($t = -2.40$, $p = 0.019$). The consistent direction across all three tests, and the significance of two of the three tests, provides reasonably strong support for the expected even/odd year cycle pattern across the full time series.

As noted in our annual report last year, the CPUE in 2014 was exceptionally high. Although the smolts for the earlier ADF&G time series were not keyed to species, we presume here the majority of smolts captured were pink salmon. This strong year class was certainly reflected in the run in 2015, which was one of the biggest runs on record (Knudsen et al. 2021). While it is difficult to compare these two trawl time series given the shift in vessel and trawl gear, our effort to control for survey era in the above analysis does provide some insight into the relative strengths of the even/odd year smolt run in PWS. With additional years of sampling of smolts (coupled with data on adult returns), combined with ocean-climate metrics, we intend to develop a fishery forecast model, similar to that developed as part of the Southeast Alaska Coastal Monitoring (SECM) survey in southeast Alaska.

We have documented other species of juvenile salmon captured in our surveys. These fishes occur at much lower frequency in our sampling compared to pink salmon (including sockeye salmon *O. nerka*, coho salmon *O. kisutch*, and chum salmon *O. keta*). In addition, we have also been documenting counts of other bycatch species of finfish (particularly *Gadidae* spp.) that we have been including as part of our ADF&G collection permit reports. We intend to include catches of these other species in data we ultimately share on the Research Workspace data repository.

In our original proposal we intended to compare our results to another trawl survey conducted in the western GOA by ADF&G. Our interest here is to compare our results to characteristics of surviving pink salmon smolts during later periods following their emigration from PWS (in locations in western GOA as the smolts migrate with the Alaska current, Fig. 2). We submitted an ADF&G Sample Request form during the first year of our study (2023), but unfortunately the effort was limited in 2023 and ADF&G did not collect enough juvenile pink salmon to share with us. They have additional samples collected from 2024 and 2025 that they are processing in-house, and we hope to be able to compare results across surveys, particularly for fish with PWS hatchery thermal marks (Fig. 2). In addition, the PIs met with Alisa Abookire (Founder and Executive Director of Alaska Coastal Observations and Research) at AMSS 2026 (and later over zoom) and learned that she has been carrying out beach seine surveys in the western GOA region, and she has been having pink salmon otoliths read by ADF&G to determine hatchery origin. We intend to collaborate with her to examine characteristics of surviving pink salmon in this region. Finally, Yumi Arimitsu (Ocean Bight LLC) has shared pink salmon origin data, mounted otoliths, and whole frozen pink salmon that were captured by nesting rhinoceros auklets (*Cerorhinca monocerata*) at Middleton Island as part of the GWA program (Fig. 2). She presents some of these results in her annual EVOSTC report. We intend to include some of these frozen samples in our 2026 shipment to the Cordova ADF&G otolith lab for reading this coming season. In our PWSSC lab freezer, we currently have 79 individual pink salmon collected in 2024 and 67 individual pink salmon collected in 2025 at Middleton Island. We intend to conduct comparisons (with measures including size, origin, energy density) between trawl-caught individuals in our study with pink salmon preyed on by rhinoceros auklets as part of Dr. Arimitsu's study.

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2. Products:

Peer-reviewed publications:

No new contributions for this reporting period.

Reports:

No new contributions for this reporting period.

Popular articles:

No new contributions for this reporting period.

Conferences and workshops:

No new contributions for this reporting period.

Public presentations:

Borsky, A., K. Gorman, P. Rand, and K. Iken. 2025. Spatio-temporal distributions of Pacific herring and pink salmon in Prince William Sound, Alaska. Poster presentation, Alaska Marine Science Symposium, Anchorage, Alaska, January.

Borsky, A., K. Gorman, P. Rand, and K. Iken. 2026. Evaluating interactions between Pacific herring and pink salmon using spatio-temporal models. Poster presentation, Alaska Marine Science Symposium, Anchorage, Alaska, January.

Gorman, Rand, and Heintz. 2026. Isotopic perspectives on ecological interactions berween Pacific herring and pink salmon in Prince William Sound, Alaska. Poster presentation, Alaska Marine Science Symposium, Anchorage, Alaska, January.

Rand, P., K. Gorman, K. Ledger, W. Larson, K. Anderson, J. Becker, and R. Campbell. 2026. Pacific herring as a prey resource for juvenile pink salmon in Prince William Sound, Alaska, Alaska Marine Science Symposium, Anchorage, Alaska, January.

Data and/or information products developed during the reporting period:

We developed a comprehensive Access database during the reporting period to manage and archive all the various data streams from the project. This database will continue to be updated as new data become available. This was a significant effort led by Borsky, Gorman, and Rand over the reporting period. This database and associated files are currently available on Research Workspace.

Data sets and associated metadata:

Currently, all available data for this project are archived on this project's Research Workspace shell. No data have been fully vetted and submitted with metadata to the Gulf of Alaska data portal or DataONE at this time. We plan to work on this for the 2023 and 2024 data in 2026. We plan to publicly disseminate the data for this project at the time datasets are published or at the end of the project as part of our data archiving requirement. All the retrospective data will be made publicly accessible once Borsky's thesis project has been completed.

To date, primary datasets on Research Workspace include: Cruise headers, Catch data (date, location, gear, catch information), Ocean station (date, location for CTD and bongo deployments), Fish attributes (species, life stage, length, mass, diet content, meta-barcoding data, stable isotope values, energy content information, VEN status, and otolith hatchery or wild determination), and Plankton counts.

Additional Products not listed above:

No new contributions for this reporting period.

3. Coordination and Collaboration:

The Alaska SeaLife Center or Prince William Sound Science Center

PIs Campbell and Rand both work at PWSSC. Campbell's oceanographic research platform, R/V *New Wave*, was used by this project in June and July to conduct trawl sampling.

EVOSTC Long-Term Research and Monitoring Projects

This project is a recently funded research project within the Herring Research and Monitoring component of the Gulf Watch Alaska Long-Term Research and Monitoring (GWA-LTRM) program. PI Rand coordinated with M. Arimitsu (GWA-LTRM Pelagic Component lead and PI of the forage fish project, 25120114-C) to share data and samples from rhinoceros auklet diets at Middleton Island, Alaska. We intend to compare data on size, origin, and energy density of juvenile pink and chum salmon in the diets of auklets to trawl-caught individuals processed as part of this project.

PIs Rand and Gorman are coordinating with Paul Hershberger (herring disease program [25120111-E] PI) to collect blood smears for disease screening for VEN.

Our project will produce key measures (e.g., rates of larval herring consumption by juvenile pink salmon) to be used in modeling herring dynamics as part of the herring modeling (25120111-C) project led by Trevor Branch.

Gorman and Borsky are coordinating with PI Campbell (PWS oceanographic project 25120114-G) to incorporate zooplankton sampling in our spatio-temporal modeling exercises.

EVOSTC Mariculture Projects

None.

EVOSTC Education and Outreach Projects

Krimson Anderson and Jasmine Becker (PI Pete Rand's research assistants at PWSSC funded by this project) hosted a workshop for the Community Coastal Experience, a Community Organized Restoration and Learning (CORaL) Network project, to help Alaskan adults explore career and internship pathways in marine and coastal research, environmental monitoring, and Alaska Native culture, history, and arts, on Thursday, June 19, 2025, in Cordova, Alaska.

Krimson Anderson served as an outreach participant at the CORaL Network Ocean Sciences Festival with an all-age children section, followed by an open adult/community session held on November 7, 2025, in Cordova, Alaska.

Individual EVOSTC Projects

Rand and Gorman keep in communication with the Data Management team (Adrienne Canino, Axiom) during this grant period.

Trustee or Management Agencies

We have been in communication with Ben Gray at the ADF&G office in Anchorage to coordinate our work with their western GOA trawl survey. This GOA survey has been delayed, but we hope to obtain results and/or samples beginning in 2026 and we intend to collaborate on future analyses of trawl CPUE and other biological measures made on juvenile salmonids in these surveys.

Project PIs are contracting with Jenni Morella at ADF&G in Cordova to process juvenile pink and chum salmon otoliths to determine origin. The project PIs are also contracting for ship time on the R/V *Solstice*, the ADF&G research vessel based in Cordova, for our cruises in May and September each year of the project. ADF&G staff have been instrumental in supporting our sampling efforts in May and September each year.

Project PIs are contracting with Dr. Wes Larson at NOAA Ted Stevens Marine Institute to conduct DNA metabarcoding of stomach contents of juvenile pink salmon and herring.

PIs Rand and Gorman are coordinating with Paul Hershberger (USGS; herring disease program [25120111-E] PI) to collect blood smears for disease screening for VEN.

Native and Local Communities

We stay in communication with the Prince William Sound Aquaculture Corporation (PWSAC) to help with the timing of our surveys. We obtain data from them each spring on number and timing of hatchery pink salmon releases to help us develop our cruise plan.

The development of a fishery forecast model is a high priority need identified by PWSAC. Rand has been in communication with Geoff Clark, the PWSAC general manager, and Steve Hilton, PWSAC production manager, on this project (PI Rand recently met with them in January 2026 to discuss this project). Mr. Clark is strongly supportive of our project as it may be a useful fishery forecast tool.

4. Response to EVOSTC Review, Recommendations and Comments:

No review, recommendations, or comments were provided in 2025. This project responded to comments in the FY24 annual report.

5. Budget:

The project is behind in spending because of the delay in the release of the NOAA grant in Year 1 (FY22), when this project began, resulting in a one-year delay to the start of field sampling and laboratory analysis (we started field work in 2023 not 2022). In addition, the delay in the release of Year 3 (FY24) NOAA grant funds until February 2025 caused additional work delays mainly for laboratory processing of samples. This project initially called for bioenergetic modeling to estimate the potential impact of pink salmon predation on herring with modeling planned to commence in Year 5 (originally FY26, after four years of sampling). It was to be funded under a proposal external to this project. The external proposal was not funded, consequently our plan has been adjusted to have Sitka Sound Science Center (SSSC) conduct the modeling with the work commencing a year earlier in Year 5 (FY26, after three years of sampling). Model development will require some time to set up, and the three years of data provide the input necessary to ensure the model will operate with the data being collected. Our revised plan is to develop the model during the current funding period and complete the analyses in the next 5-year funding period, once all the data are collected. This change will reduce potential effects on deliverables from the original proposal by partially compensating for the loss in funding for modeling that was link in a collaborating GWA-LTRM project proposal that the Trustees decided not to fund.

SSSC has the expertise and skill in place for this work. Staff include Heintz for oversight and a modeler, Tahvo Wilson. Heintz and Wilson are currently developing a similar model for Chinook salmon on the Yukon Delta, and Heintz has published previous modeling work on Pacific cod and Sablefish. Heintz and Wilson's work on the Chinook model will be complete in Year 7 (FY28). Funding to support the bioenergetic model building will be taken from the SSSC budget. SSSC funds were originally intended to assist with data collection and sample analyses, which were absorbed and completed by Rand and Gorman's portion of the project. Shifting the funds to cover Wilson's salary allows us to put more effort into the data analysis needed.

***EXXON VALDEZ* OIL SPILL TRUSTEE COUNCIL**

PROGRAM BUDGET PROPOSAL AND REPORTING FORM

Budget Category:	Proposed FY 22	Proposed FY 23	Proposed FY 24	Proposed FY 25	Proposed FY 26	5-YR TOTAL PROPOSED	ACTUAL CUMULATIVE
Personnel	$112,299	$201,472	$206,654	$185,064	$182,478	$887,967	$555,125
Travel	$11,223	$15,539	$14,459	$11,998	$10,764	$63,983	$45,974
Contractual	$61,706	$89,644	$91,119	$89,774	$88,674	$420,917	$205,392
Commodities	$16,050	$13,250	$13,250	$13,250	$12,250	$68,050	$28,478
Equipment	$22,000	$22,775	$23,913	$2,000	$0	$70,688	$31,405
Indirect Costs (varies by proposer)	$7,755	$22,032	$22,218	$16,441	$13,723	$82,168	$43,338
SUBTOTAL	$231,033	$364,711	$371,613	$318,527	$307,888	$1,593,773	$909,711
General Administration (9% of subtotal)	$20,793	$32,824	$33,445	$28,667	$27,710	$143,440	N/A
PROJECT TOTAL	$251,826	$397,535	$405,058	$347,194	$335,598	$1,737,212	
Other Resources (In-Kind Funds)	$0	$0	$0	$0	$0	$0	

COMMENTS:
This is the combined budget for the individual Rand and Campbell, Gorman, and Heintz budgets that follow. Rand and Campbell are associated with Prince William Sound Science Center (PWSSC), Gorman is affiliated with the University of Alaska Fairbanks (UAF), and Heintz is affiliated with the Sitka Sound Science Center (SSSC). This form contains the summary information only. Detail by year for each PI/organization can be found in the following four worksheets.

FY22-26	**Project Number: 25220111-I** **Project Title: Trophic Interactions** **PI(s): Rand & Campbell (PWSSC), Gorman (UAF), & Heintz (SSSC)**	**SUMMARY TABLE**