FY 22-31 *PROJECT* PROPOSAL
LONG-TERM RESEARCH AND MONITORING PROGRAM

Does this proposal contain confidential information? ☐Yes ☒No

Project Number and Title

Gulf Watch Alaska Long-Term Monitoring Program: Herring Research and Monitoring Component

22220111-I Ecological interactions between Pacific herring and Pacific salmon in Prince William Sound, Alaska

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Project Abstract (maximum 300 words)

Since the collapse of the Pacific herring (*Clupea pallasii*) population in Prince William Sound (PWS), Alaska during the mid-1990s, hatchery production of pink salmon (*Oncorhynchus gorbuscha*) in PWS has increased dramatically. Importantly, ecological interactions between these species may have consequences for recruitment of both populations. We propose a retrospective analysis and focused field campaigns over a six-year period aimed at developing the following seven products. (1) Analyses of historical and current data describing each species co-occurrence in near-shore and off-shore habitats, (2) evidence of direct predation by each species on the other, (3) competition for dietary resources including estimates of age-0 herring and juvenile pink salmon body condition, and (4) prevalence of a key pathogen, viral erythrocytic necrosis. We propose constructing (5) a bioenergetic model to estimate the predatory demand of pink salmon on larval herring in southwestern PWS, a major migratory pathway for salmon. The model will be developed in collaboration with a post-doctoral associate funded by a separate Trustee Council mechanism. Incorporation of our results with environmental observations will lead to (6) a model to explain variation in marine survival of PWS pink salmon. Finally, we propose using data and relationships developed here to (7) construct a model to forecast PWS pink salmon returns. Our fieldwork and analyses will capture dynamics across ontogenetic shifts in herring and pink salmon during spring when age-1+ herring co-occur with pink salmon fry in nearshore waters, summer when emigrating pink salmon encounter larval herring over deeper waters, and late summer when age-0 herring rely on prey fields previously exploited by out-migrating juvenile pink salmon. Our field campaign is based on preliminary analysis of existing data, which will be formalized through the proposed retrospective analysis.

The project will support a M.S. student through the University of Alaska Fairbanks, Marine Biology program.

EVOSTC Funding Requested*

FY22	FY23	FY24	FY25	FY26	FY22-26 Total
$251,826	$397,535	$405,058	$347,194	$335,598	$1,737,212
FY27	**FY28**	**FY29**	**FY30**	**FY31**	**FY27-31 Total**
$244,480	$94,729	$0	$0	$0	$339,209
				FY22-31 Total	*$2,076,422*

**If the amount requested here does not match the amount on the budget form, the request on the budget form will considered to be correct.*

Non-EVOSTC Funds to be used, please include source and amount per source:

FY22	FY23	FY24	FY25	FY26	FY22-26 Total
$0	$0	$0	$0	$0	$0
FY27	**FY28**	**FY29**	**FY30**	**FY31**	**FY27-31 Total**
$0	$0	$0	$0	$0	$0
				FY22-31 Total	*$0*

1. EXECUTIVE SUMMARY (maximum ~1500 words, not including figures and tables)

We propose to resolve the role of pink salmon (*Oncorhynchus gorbuscha*) in regulating Pacific herring (*Clupea pallasii*, hereafter herring) production in Prince William Sound (PWS), Alaska (Fig. 1), and develop tools for predicting pink salmon marine survival. 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. Currently, PWS is home to the largest pink salmon hatchery program in the world and the herring population remains depressed (Pearson et al. 2012, Amoroso et al. 2017). There is growing interest in the ecological impacts of the large number of pink salmon released in PWS (Brenner et al. 2012, Pearson et al. 2012, Ward et al. 2017, Knudsen et al. 2021). Reports documenting the impacts of increased pink salmon releases in the North Pacific Ocean on other salmon populations (Connors et al. 2020, Kendall et al. 2020, Oke et al. 2020) 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 remain an injured resource.

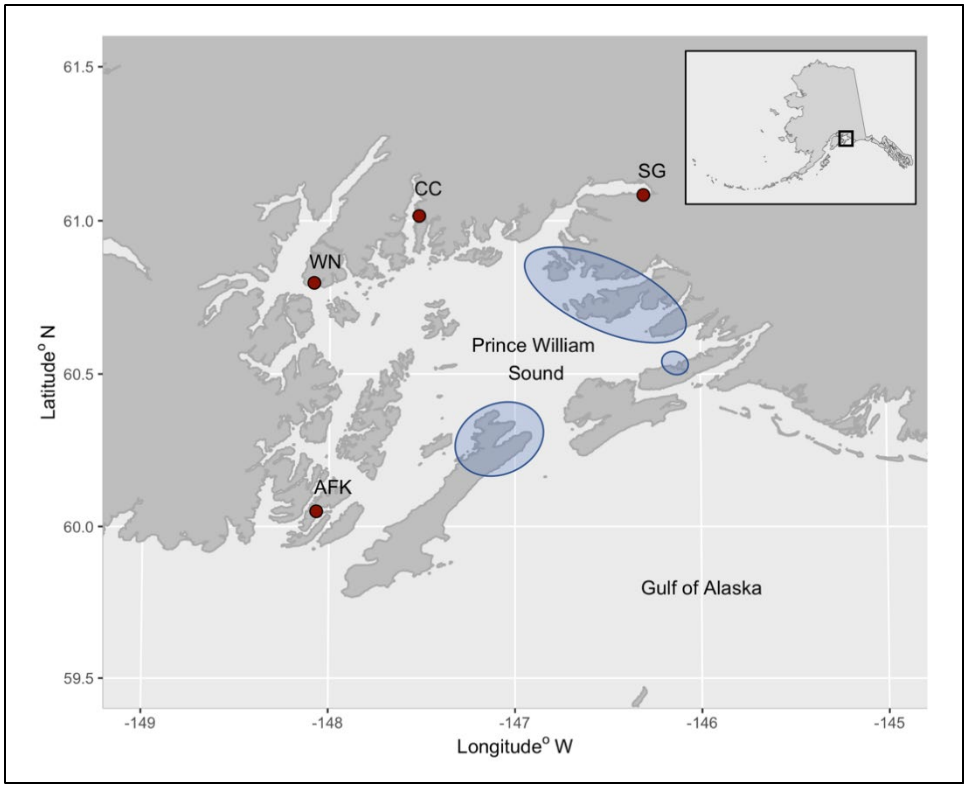

Figure 1. The Prince William Sound, Alaska study region. The location of pink salmon hatcheries (Solomon Gulch = SG, Cannery Creek = CC, Wally Noerenberg = WN, and Armin F. Koernig = AFK) are noted by the dark red circles. Location of the dominant regions of herring spawn for 2010-2019 are noted by the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

We propose a new, multi-faceted research effort that builds on past work (including EVOSTC projects), and develops new data specifically aimed at assessing the hypothesis of Deriso et al. (2008). We will also examine the countervailing effect of age-1+ (juvenile and adult) herring feeding on pink salmon fry. In addition, we will extend a key time series initiated by the Alaska Department of Fish & Game (ADF&G) on juvenile pelagic fishes in PWS including pink salmon, and an EVOSTC funded time series on PWS age-0 herring body condition. In addition, we will develop tools to forecast pink salmon marine survival.

Pink salmon and herring have distinct life histories that occasionally overlap in time and space, and they also share 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 with larger numbers of pink salmon adults returning in odd years. Newly emerged/released pink salmon fry forage and grow in nearshore habitats in spring before becoming large enough to emigrate seaward in summer. 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 and are advected into local currents where they feed and metamorphose, settling out in nearshore habitats during early summer. They rear in nearshore habitats until age-2 before moving into deeper waters. 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.

We hypothesize that there are three life history periods (and associated habitats) that set the stage for potential predation, dietary competition, and incidence of disease involving herring and pink salmon. Chronologically, the first period occurs in spring when newly emerged pink salmon fry occupy nearshore habitats and are vulnerable to predation by age-1+ herring. Competition for food may also be important during this period (Cooney et al. 2001a). The second period occurs one to two months later over deeper, offshore waters, when larger, emigrating juvenile pink salmon may prey upon larval herring. 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.

Our approach to examining these ecological interactions combines retrospective analysis of historical data, new field and lab data, and modeling. Specifically, we will (1) assess the spatial and temporal co-occurrence in sampled habitats of both species using historical and newly collected data, (2) examine prey availability in near-shore and off-shore habitats of PWS, (3) conduct dietary analysis using visual examination of stomach contents, DNA barcoding, and bulk and compound-specific carbon and nitrogen stable isotope (SIA and CSIA) techniques, and examine age-0 herring and juvenile pink salmon body condition, (4) examine the prevalence of a key pathogen, Viral Erythrocytic Necrosis (VEN), in both species, and (5) in collaboration with project 22220111-H, construct bioenergetic models to estimate larval herring predation by pink salmon. New data will be collected during near-shore purse seine (May and September) and off-shore surface trawl (June and early July) surveys. The purse seine surveys will extend a time series of age-0 herring body condition supported previously by EVOSTC, while the surface trawl surveys will extend an existing pink salmon time series initiated by ADF&G. By conducting these surveys over multiple years, we will capture replicate odd- and even-year adult pink salmon run cycles that are associated with larger and smaller returns of adults, respectively. Data from the surveys will allow us to (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 first year of the study includes resumption of the offshore surface trawl survey and a retrospective analysis of historical data on herring and pink salmon spatial and temporal dynamics aimed at informing our field efforts in years 2-6. The project will support a graduate student (M.S. program) at the University of Alaska Fairbanks (UAF) in years 2 and 3 of the study. The bioenergetic modeling will be done in collaboration with a post-doctoral associate funded externally through a separate EVOSTC proposal (22220111-H).

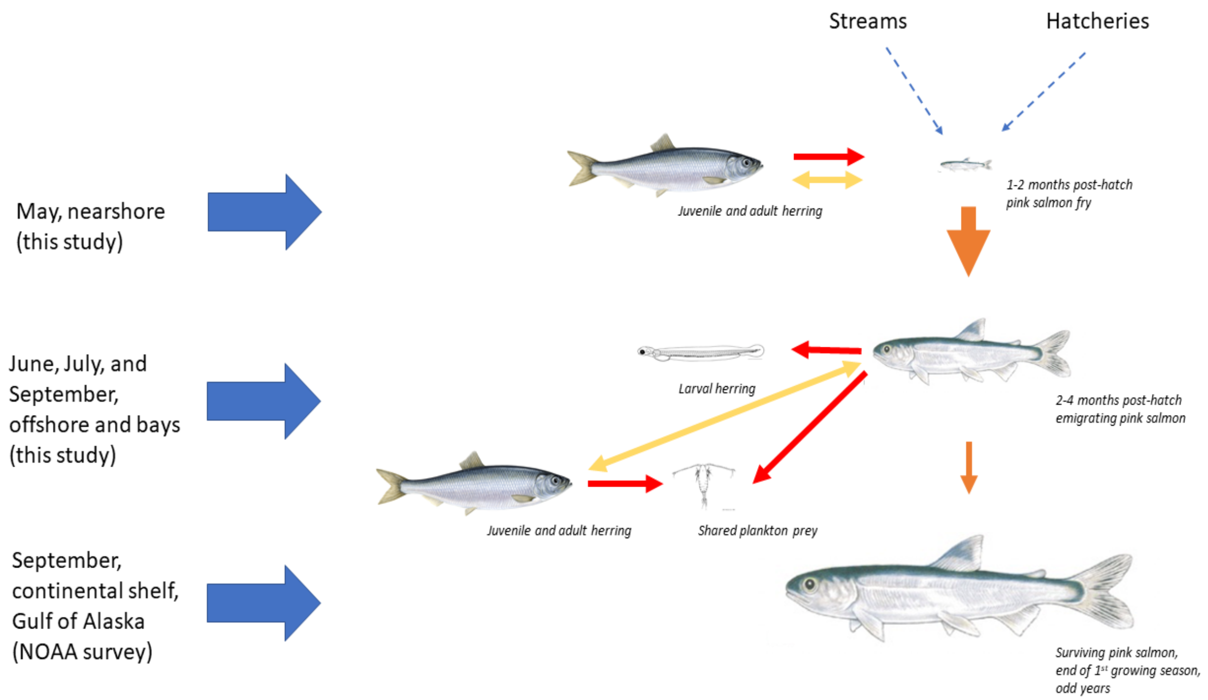

Figure 2. Illustration of potential ecological interactions between juvenile pink salmon and Pacific herring, highlighting habitat shifts and the survival progression during early life history of pink salmon in Prince William Sound, Alaska. Potential disease interactions are shown in yellow, predation and competitive processes are shown in red, and survival processes are shown in orange. This study is focused on carrying out field studies and data synthesis to evaluate a suite of hypotheses related to these interactions that may limit herring recruitment and physical and biotic variables controlling survival of pink salmon.

Earlier studies describing herring-salmon interactions

Previous work has generally relied on herring and salmon biomass/abundance information and correlative time series analysis to infer relationships between these species. For example, Trochta and Branch (2021 in review) found a direct correlation between adult pink salmon numbers and herring mortality. But like Deriso et al. (2008), the study did not identify causal mechanisms. Evidence for pink salmon limiting herring production through predation is supported by a single observation of adult pink salmon eating herring (Sturdevant et al. 2013). Conversely, previous work indicates herring may consume large numbers of young pink salmon (Willette 2001). Competition may be a factor if emigrating pink salmon forage on prey critical to juvenile herring (Cooney et al. 2001a). Measurements of recent age-0 herring energy content have revealed a conspicuous odd-even year pattern since 2007 (Fig. 3), suggesting a possible effect of increased juvenile pink salmon abundance during even years. Spillover and spillback of pathogens between herring and pink salmon may increase disease mortality for both species (Power and Mitchell 2004). Both species are natural hosts of VEN (Eaton 1990) and epizootics periodically occur among herring populations in nearshore areas of the NE Pacific (MacMillan and Mulcahy 1979, Meyers et al. 1986, Hershberger et al. 2009). Herring frequently mingle with juvenile pink salmon (Willette et al. 2001), creating opportunities for pathogen transmission within these high-density schools.

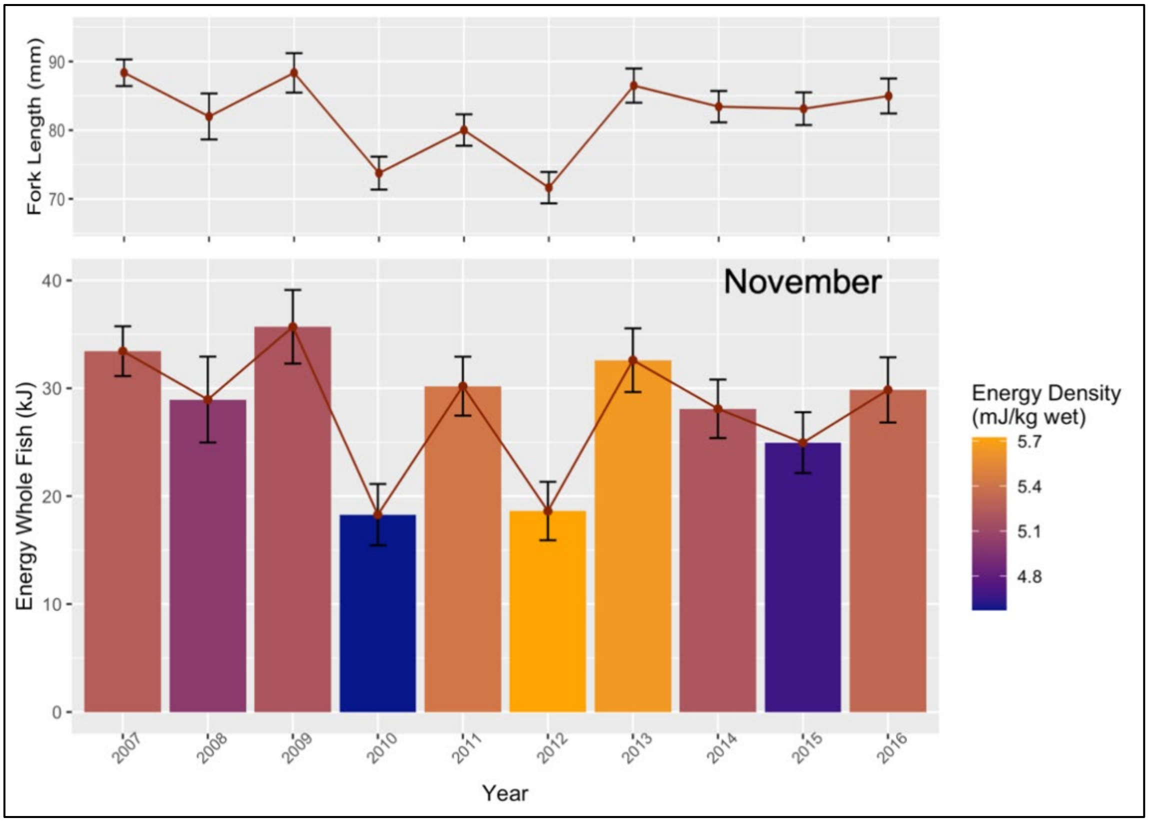

Figure 3. Total energy, energy density, and annual variation in length of juvenile (age-0) herring from Prince William Sound, Alaska at the start of the over-winter period (November) between 2007-2016. Data are from Gorman et al. (2018), error bars are 95% confidence intervals based on a linear model predicting energy whole fish (kJ) or length (mm) as a function of year. A conspicuous odd-even year pattern is evident in the total energy estimates, due to annual variation in body size of age-0 herring. An exception occurred during 2015, the year of the North Pacific marine heatwave.

Much of the EVOSTC work directed towards quantifying herring and pink salmon interactions was conducted during the Sound Ecosystem Assessment (SEA) program between 1995-1997. The SEA program focused on predator controls of juvenile pink salmon (Cooney et al. 2001a, Willette et al. 2001). They found that herring predation could account for ~25% of the pink salmon consumed in near-shore waters (Cooney et al. 2001a, Willette et al. 2001). SEA did not consider other interactions. This was partially due to the difficulty of visually recognizing larval herring in juvenile salmon stomach contents, but newer methods obviate this limitation.

Need for pink salmon management tools

While the SEA program and later studies have improved our understanding of pink salmon production in PWS, conditions have notably changed since the 1990s. Cooney et al. (2001b) conjectured that PWS can alternately take the form of a 'lake' or 'river' based on retention or export of productivity, respectively, as a function of downwelling. Given the positive relationship between growth and survival of pink salmon (Walters et al. 1978, Jaenicke and Celewycz 1994, Willette 1996, Murphy et al. 1998, Mortensen et al. 2000, Cross et al. 2009, Moss et al. 2009) the feeding and growing conditions that result from 'lake' or 'river' conditions in PWS are expected to shape survival. (Kline et al. 2008, Kline 2010). In addition, recruitment success for pink salmon is influenced by the timing of migration from PWS into the GOA (Armstrong et al. 2008, Malick et al. 2011).

Currently, forty percent of the 1.4 billion pink salmon released globally are produced from PWS hatcheries (Amoroso et al. 2017), and herring populations have remained at low levels. Moreover, recent marine heatwaves presage future changes in the region (Bond et al. 2015, Arimitsu et al. 2021a, Suryan et al. 2021). Increasing temperatures and drought conditions in PWS may lead to pre-spawn mortality events (P.S. Rand, unpubl. obs.) and recent patterns in marine survival rates of hatchery-origin pink salmon indicate a recent, sharp decline that may be related to ongoing climatological changes (Fig. 4). We propose to analyze past data on pink salmon survival by considering biological and environmental covariates to explain variation in marine survival and evaluate a suite of additional covariates measured during this study with the aim of developing a survival model and a forecast tool for use in fishery management. Performance of this model will be compared to the current, simple model based on a running average of recent escapement used by ADF&G.

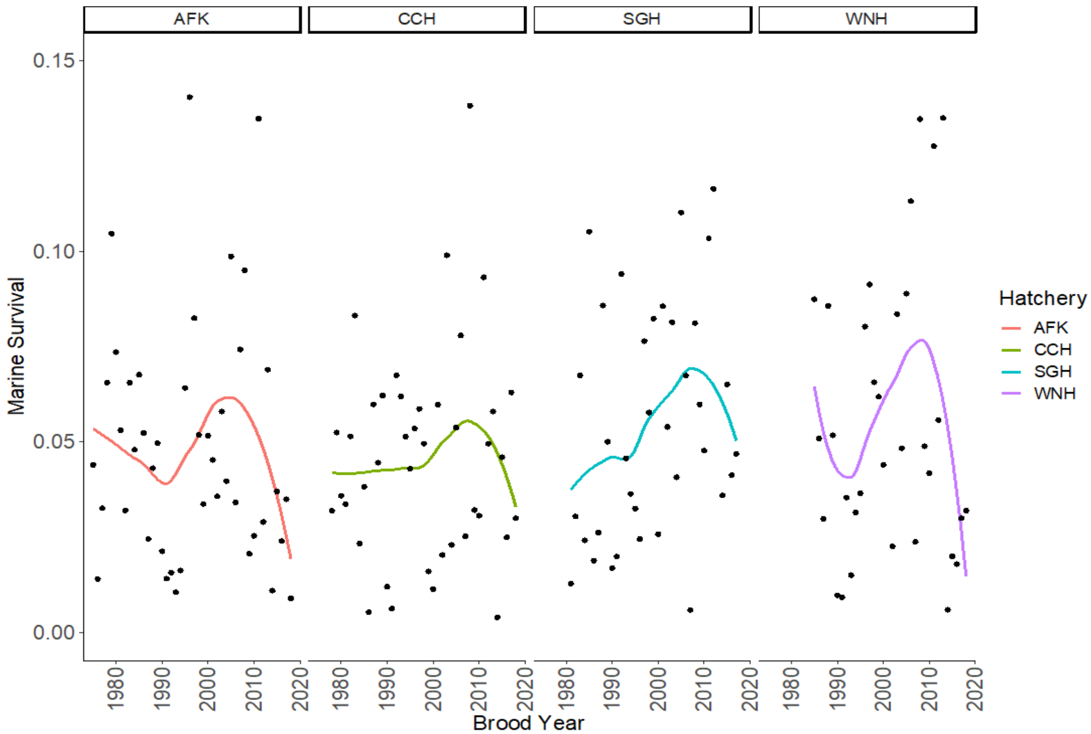

Figure 4. Marine survival rates (returns as a proportion of total releases) of hatchery pink salmon during brood years 1978-2018 for Armin F. Koernig Hatchery (AFK), Cannery Creek Hatchery (CCH), Soloman Gulch Hatchery (SGH), and Wally Noerenberg Hatchery (WNH) in Prince William Sound. Data are fit to a loess model. Note recent decline in survival across all four hatchery stocks.

2. RELEVANCE TO THE INVITATION (maximum 300 words)

The goals of the EVOSTC Herring Research and Monitoring (HRM) program have been to monitor changes in PWS herring stocks and the PWS ecosystem. The program is centered on a population model, and projects that produce data and information useful to this model. The EVOSTC FY22-31 Invitation for Proposals encourages new research that "sheds light on factors limiting the recovery of herring, including bottom-up and top-down forces", and, in particular, research focused on early life stages of herring. The project outlined here responds directly to item 10 of the HRM Component of the FY22-31 LTRM Program Invitation: An examination of the role of hatchery-produced pink salmon, wild pink salmon, on herring ecology in PWS and the GOA. The issue of herring-pink salmon ecological interactions in PWS is recognized and research has primarily focused on time series analyses (e.g., Deriso et al. 2008, Ward et al. 2017, Trochta and Branch 2021 in review). The ecological impacts of hatchery salmon production have been the focus of recent studies (Pegau et al. 2013, Springer and van Vliet 2014, Batten et al. 2018, Knudsen et al. 2021); however, directed studies of ecological mechanisms by which herring and pink salmon interact are lacking. Further, the project addresses other EVOSTC projects of interest in the FY22-31 Invitation including: monitoring and providing information on population trends of pink salmon (b 1), relationships between physical and biological oceanographic factors and environmental food web drivers including spatial and temporal patterns of these factors and relationships that could affect PWS herring (e 5), disease incidence in herring and salmon (e 7 and 8), and juvenile herring recruitment success (e 11). The proposed project would contribute to these areas of research through retrospective analysis, direct observation, and modeling of herring and pink salmon ecological interactions.

3. PROJECT HISTORY (maximum 400 words)

This is a new research project that builds on existing datasets produced with EVOSTC funding (Damage Assessment and restoration programs: SEA, the Alaska Predator Experiment [APEX], Gulf Watch Alaska [GWA], and HRM), and other sources (ADF&G, National Science Foundation [NSF], National Oceanic and Atmospheric Administration [NOAA], North Pacific Research Board, National Center for Ecological Analysis and Synthesis [NCEAS]). These data will be combined to evaluate the spatial and temporal distribution of herring and pink salmon in PWS to assess the potential for predation, dietary competition, and describe disease prevalence in the two species. Further, this study will advance our knowledge of these ecological interactions by taking advantage of new approaches to detect predation on target species using DNA barcoding, evaluate diet composition using compound-specific stable isotope analysis (CSIA), and assess disease prevalence, which will represent the first study of its kind in PWS. The study also uses bulk carbon and nitrogen stable isotope analysis (SIA) techniques that have been used in past EVOSTC studies of age-0 juvenile herring. Dramatic environmental perturbations have recently taken place in the form of marine heatwaves in the GOA and PWS region, and there is growing concern that these types of climate events will happen with greater frequency in the future. This study will help address how these past and future environmental changes can affect populations dynamics of herring and pink salmon.

Lead- and co-investigator, Rand and Campbell (both at Prince William Sound Science Center [PWSSC]), have led EVOSTC projects in recent years focusing on biological oceanography and juvenile and adult herring that are relevant to the current proposal (18120114-G, 16120111-E, 16120111-F), and have produced reports annually for the EVOSTC, publications (e.g., Campbell 2018, Rand 2018), and website summaries (https://gulfwatchalaska.org/monitoring/environmental-drivers/oceanographic-conditions-in-prince-william-sound/, https://pwssc.org/adult-biomass-surveys/). Data produced by these projects have contributed to recent modeling efforts and published syntheses (Arimitsu et al. 2021a, Suryan et al. 2021, Trochta and Branch 2021 in review).

Co-investigators Heintz (Sitka Sound Science Center [SSSC]) and Gorman (UAF) worked together previously on EVOSTC funded projects focused on over-winter energetics of juvenile herring (2007-2016 [16120111-L, 16120111-M]). This past research produced a suite of data products and manuscripts, with additional papers forthcoming (Gorman et al. 2017a, Heintz et al. 2017a, Gorman et al. 2018, Sewall et al. 2018, Sewall et al. 2019, Arimitsu et al. 2021a, Sewall et al. 2021 in press, Heintz et al. in prep), final reports (Gorman et al. 2017b, Heintz et al. 2017b, Heintz et al. 2020), public presentations (Gorman et al. 2016, Heintz et al. 2016, Gorman 2018, Arimitsu et al. 2020, Arimitsu et al. 2021b), and website pages (https://pwssc.org/exploring-changes-in-herring-energetics-over-winter-months/, https://pwssc.org/growth-and-energy-allocation-in-overwintering-herring/, https://pwssc.org/fatty-acid-analysis-as-evidence-for-winter-migration-of-age-0-herring/.

4. PROJECT DESIGN

A. Objectives and Hypotheses

This proposal focuses on the herring population of PWS, Alaska, an injured resource that has not recovered since collapsing after the 1989 *Exxon Valdez* Oil Spill. This is a new project that will contribute to our understanding of herring life history, including factors that may be responsible for preventing stock recovery. Our focus is specifically on ecological interactions (predation, competition, and disease) between age-0 and age-1+ herring and juvenile pink salmon and increasing our understanding of environmental and biotic drivers of growth and survival in juvenile pink salmon. The work is distinguished from previous efforts such as the SEA program in that current pink salmon production in PWS is much higher than when the SEA program was conducted, which might lead to more intense ecological interactions between herring and pink salmon. In addition, the project employs new laboratory approaches that have not been used previously to understand herring and pink salmon ecological interactions, i.e., DNA barcoding, CSIA, concurrent sampling of each species for VEN. Further, GOA ocean-climate changes have been marked in recent years and future fisheries management will need to consider environmental variability in stock management models. Our primary hypotheses are:

1. **HERRING PREDATION ON SALMON FRY:**
    a. Age-1+ (juvenile and adult) herring co-occur with, and feed on, pink salmon fry (~1-2 months post emergence/release) in near-shore habitats during May in PWS.
2. **SALMON PREDATION ON LARVAL HERRING:**
    a. Emigrating, larger juvenile pink salmon (~2-3 months post emergence/release) co-occur with, and feed on, larval herring (age-0) in pelagic habitats off-shore during June and early July in PWS.
    b. Juvenile pink salmon predation pressure meets or exceeds larval herring available in PWS migratory corridors, which will be evaluated using bioenergetic models.
3. **HERRING-SALMON COMPETITION:**
    a. Age-0 herring and juvenile pink salmon selectively consume similar prey items. However, prey may be consumed at different time periods, i.e., during outmigration of juvenile pink salmon in June and July, and during summer growth by settled age-0 herring (late July-September).
4. **DISEASE PREVALENCE:**
    a. Both age-1+ herring and juvenile salmon in near-shore and off-shore habitats are infected with the VEN disease pathogen.

b. VEN prevalence increases in both species when age-1+ herring and pink salmon co-occur in near-shore habitats.
c. VEN prevalence in age-0 herring sampled in September is higher during even years when the abundance of juvenile natural-origin pink salmon in PWS is higher.

5. **SALMON SURVIVAL COVARIATES:** Marine survival and annual returns of adult pink salmon (natural- and hatchery-origin) are influenced by the following environmental and biotic factors with the effect indicated as either positive (+) or negative (-):

   a. Surface trawl catch per unit effort (CPUE) of juvenile pink salmon by origin in year-1 (+)
   b. Degree of oceanic subsidy revealed by carbon and nitrogen stable isotope values of PWS juvenile pink salmon and their prey (+)
   c. PWS surface water temperature during May-July (-)
   d. Large-bodied zooplankton density in PWS during May-July (+)
   e. Prevalence of VEN (-)
   f. Size and energy density of juvenile pink salmon (+)
   g. Pink salmon escapement at year-2 into PWS streams (+ or -)
   h. Herring recruitment (+ or -)

Based these hypotheses, our research objectives detailed below provide the framework for our procedural and scientific methods:

1. Conduct a retrospective analysis of historical data to examine spatio-temporal overlaps in occurrence by herring and pink salmon in PWS.
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.
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 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*
      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*
      iii. Quantify the prevalence of VEN for both species in May and age-0 herring in September. *Disease hypothesis. Note: Disease analysis to be conducted by an allied EVOSTC long-term research and monitoring (LTRM) proposal by P. Hershberger*
      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, June, and July (see 3a, ii and 3b, ii). *Competition hypothesis*

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*
   ii. Determine whether pink salmon fry 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*
   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 to be conducted in an allied EVOSTC LTRM proposal by P. Hershberger*
   iv. Produce bioenergetic model estimates of larval herring consumption by juvenile pink salmon to be led by a post-doctoral associate funded by a separate EVOSTC mechanism (22220111-H). *Predation hypothesis – pink salmon forage on herring*

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 CPUE and body size of PWS hatchery pink salmon captured in the NOAA GOA survey, as well as bulk SIA data produced by Objective 3b, ii noted above.
   b. Develop predictive models of pink salmon survival, and evaluating their performance compared to the current model used by ADF&G to manage the PWS commercial pink salmon fishery.

B. Procedural and Scientific Methods

Methods for Objective 1

<u>Retrospective Analysis (Year 1)</u>

To address Objective 1, we will conduct an exhaustive literature review and data synthesis effort. We will collate information on herring and pink salmon life history-specific (i.e., larval, age-0, age-1+ including adults) distributions (both in time and space) in PWS and diet from past programs including those funded by EVOSTC, i.e., Natural Resources Damage Assessment and SEA programs (e.g., Cooney and Coyle 1985, Cooney 1989, 1993, Cooney et al. 1994, Brown et al. 1996, Norcross et al. 1996, Paul and Paul 1998, Paul et al. 1998, Brown et al. 1999, Foy and Norcross 1999b, a, Foy and Paul 1999, Paul and Paul 1999, Stokesbury et al. 1999, Brown and Norcross 2000, Norcross and Brown 2000, Stokesbury et al. 2000, Cooney et al. 2001a, Cooney et al. 2001b, Norcross et al. 2001, Paul et al. 2001, Sturdevant et al. 2001, Willette 2001, Willette et al. 2001, Stokesbury et al. 2002), EVOSTC Gulf Watch Alaska (McKinstry and Campbell 2018, Arimitsu et al. 2021a), EVOSTC HRM program (Kline and Campbell 2010, Kline 2013, Gorman et al. 2017b, Heintz et al. 2017b, Gorman et al. 2018, Sewall et al. 2018, Pegau et al. 2019, Sewall et al. 2019, Heintz et al. 2020, Heintz et al. in prep); ADF&G salmon programs (e.g., Brenner et al. 2012, Knudsen et al. 2021); past research funded by NSF and NOAA's Global Ocean Ecosystems Dynamics (GLOBEC) program (Boldt and Haldorson 2003, Cross et al. 2005, Cross et al. 2008, Kline et al. 2008, Kline 2009, 2010); NPRB funded projects (Batten et al. 2018); NCEAS projects (Ward et al. 2017, Connors et al. 2020) and other studies as they are encountered in the literature .

We aim to initially focus on developing preliminary maps of spatial and temporal overlap in the life history-specific distributions of herring and pink salmon based on our collated datasets. During proposal preparation we have made some initial progress on this objective by summarizing purse-seine and surface trawl catches in ADF&G surveys conducted during 2002-2010 and 2011-2015 (see Figs. 5, 6 and Table 3). If our datasets are comprehensive for a given life history stage, we will quantitatively explore distributional overlaps between herring and pink salmon in PWS using the spatio-temporal modeling package, Vector Autoregressive Spatio-Temporal (VAST) described by Thorson (2019) implemented in the R language environment (e.g., Kristensen et al. 2016, Godefroid et al. 2019, Thorson 2020). The retrospective VAST modeling exercises will be a primary focus of the M.S. graduate student program supported by this project. Our results from these retrospective analyses may lead to some adjustments in our field study proposed here. Results from our retrospective analysis will be compared with the data we generate over the six-years of field sampling in an analysis to be completed as part of the synthesis effort at the end of the project.

Methods for Objectives 2 and 3

<u>Field Sampling: Nearshore Purse Seine Surveys (Years 2-5)</u>

We plan to randomly sample the southwestern PWS region (see Fig. 5) with a purse seine used for herring age-sex-length sampling by ADF&G (Haught 2020) and focus on the transition from near-shore to off-shore habitats in waters between the 20 m and 40 m isobaths (Willette et al. 2001). This gear was effective at sampling both juvenile salmon and herring in these habitats during the earlier ADF&G study (2002-2010). We intend to resample sites (randomly selected) that were sampled during ADF&G survey (described below, Fig. 5). This sampling scheme may be revised pending our retrospective analysis, but existing survey data indicate southwestern PWS to be a region where co-occurrence has been documented, likely due to elevated densities of pink salmon produced in hatcheries (Figs. 1 and 5). Should we find that sampling the earlier ADF&G purse seine sites is insufficient for reaching our sample size goals, we will plan to target additional sites that may allow us to sample both species (e.g., close to hatcheries), as well as each species individually (e.g., northeastern PWS and possibly Valdez arm). We will also plan to use jig gear to sample herring at purse seine sites should herring be present, but sample sizes low using the purse seine. At each purse seine sampling site, we will also deploy a bongo net to sample zooplankton.

Sampling will be conducted in May, approximately 1-2 months post emergence/release for pink salmon and repeated in early September (i.e., two purse seine cruises per year) over four years (2023-2026, see Table 1 for a schedule of field sampling events). We expect sampling in May will follow the release of pink salmon from PWS hatcheries. However, we will seek information from the Prince William Sound Aquaculture Corporation (PWSAC) and the Valdez Fisheries Development Association (VFDA) as to the planned timing of their hatchery releases each year to ensure that our fieldwork in May will occur after pink salmon fry are released and therefore potentially interacting with herring at the time of sampling. Catch from the purse seine surveys will be used to examine:

(1) the probability of species co-occurrence (i.e., the likelihood that they are captured in the same seine haul in a sampling area) to address Hypothesis 1a and Objective 2,

(2) determine age-1+ herring are feeding on pink salmon to address Hypothesis 1a and Objective 3a, i using stomach content analysis, DNA barcoding, and CSIA approaches, and documenting body size differences between the species,

(3) prey availability and diet competition between pink salmon fry (sampled in May) and age-0 herring (sampled in September) addressing Hypothesis 3a and Objectives 3a, ii and 3a, iv using zooplankton sampling, stomach content analysis, bulk SIA and CSIA approaches,

(4) the prevalence of VEN in both juvenile pink salmon and age 1+ herring to address Hypothesis 4a, b and Objective 3a, iii in collaboration with P. Hershberger (GWA-LTRM herring disease program),

(5) the prevalence of VEN in age-0 herring sampling in September to address Hypothesis 4c and Objective 3a, iii in collaboration with P. Hershberger (GWA-LTRM herring disease program).

Table 2 outlines the specific lab analyses employed to address each hypothesis. By sampling over four years, we will be able to examine our hypotheses for two-odd and two-even pink salmon brood years. Pink salmon data will be analyzed according to origin (natural or hatchery) based on otolith analysis. The early fall sampling during September is intended to provide data on age-0 herring after settlement to determine if there is overlap between their diets and those of juvenile pink salmon that we document earlier in the season (during May, June, and July) and further evaluate disease prevalence. In addition, sampling age-0 herring in September will extend a time series on body condition of age-0 herring using stable isotope data to further evaluate even/odd year signals in energy content as described above and in Figure 3.

We analyzed catch records in the ADF&G purse seine survey conducted during 2002-2010 in this region (S. Haught, unpubl. data, Fig. 5) to estimate the number of sites and fish to sample for the near-shore survey work. Previous work on disease has determined a minimal sample size of 60 individuals provides a reliable indicator of disease prevalence in a sampled population (Hershberger et al. 2009). A power analysis revealed that sample sizes of at least 50 are required to test for differences in origin composition (natural and hatchery) across sampling sites in PWS for adult pink salmon (Knudsen et al. 2021). Based on these studies, we aim to achieve a sample size of 60 individuals per site or sampling event. However, analysis of herring catches in the ADF&G purse seine dataset during years of low herring abundance (years prior to 2008 and after 2009, Fig. 5, Table 3) indicates it will likely be necessary to pool samples over different seine hauls to meet this sample size goal. In a low herring abundance year, we will require approximately 13 hauls for age-1 herring and seven hauls for adult herring (Table 3, applying an average catch rate over the June-July sampling period). We propose to randomly select a minimum of 13 sites to sample each month to provide a minimum of 60 age-1 herring. Sites will be selected with replacement from those visited by ADF&G during 2002-2010, preserving our ability to make historical comparisons (Fig. 5). Although sampling effort can vary based on sea conditions, we expect to be able to sample approximately four sites per day, so a cruise consisting of four sampling days with allowances for weather should allow us to reach our sampling goal of 60 age-1+ herring per month if we experience a low recruitment year. We will charter 15 days (four sampling days, two transit days and one and a half weather days per month) of ship time each year for this work. If herring abundance is high, we intend to conduct comparisons in our measurements across sites and months. If herring abundance is low, we will focus on comparisons between months and regions (samples pooled across multiple sites in an area).

For each purse seine haul, we will quantify total catch (number of individuals) of each of our target groups (juvenile pink salmon, age-1+ herring) along with site characteristics (GPS coordinates of site, water depth, tide phase, time of day, weather conditions, CTD cast data, one zooplankton haul). Disease sampling will be conducted onboard the vessel at the time of capture based on a random sample of captured individuals. Stomachs will be removed from a subset of those fish immediately after capture, labeled and preserved in 5% ethanol. The remaining tissues and unsampled fish will be labeled and stored frozen for subsequent laboratory analysis (described in more detail below). Zooplankton samples collected at each seine site will be stored frozen for subsequent determination of species composition, as well as isotopic and calorimetric analysis.

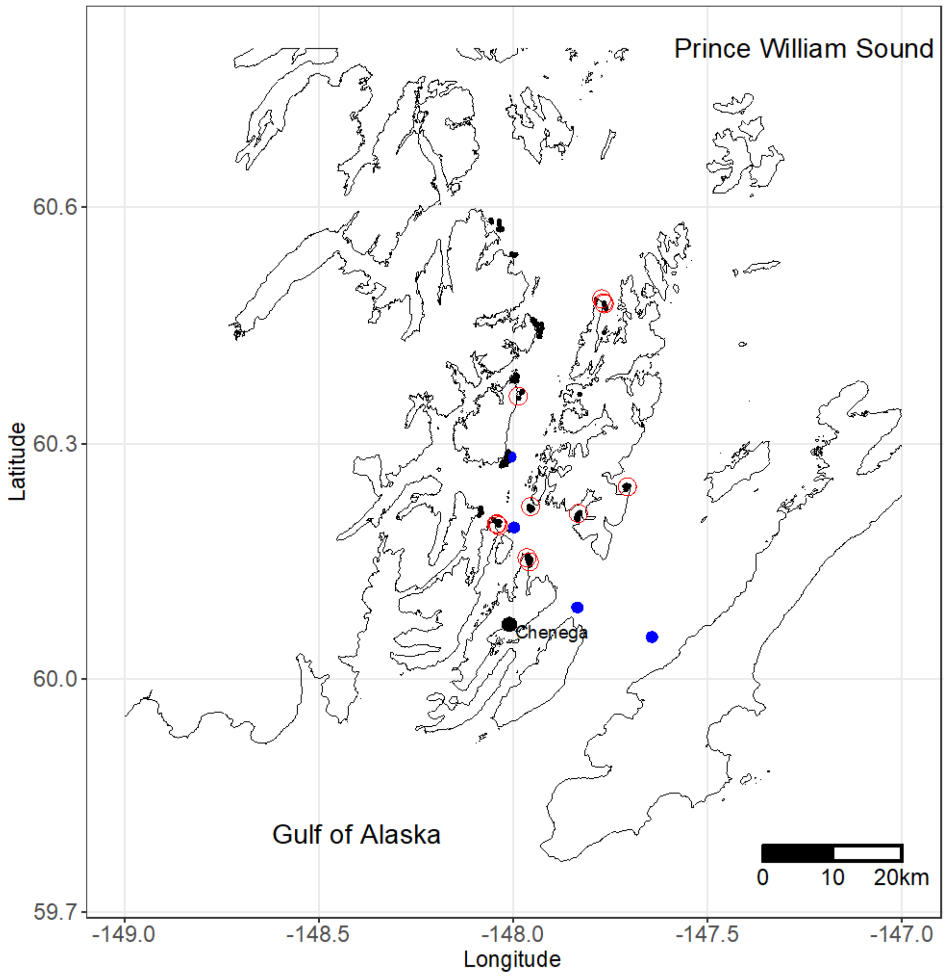

Figure 5. Sites (small, filled black circles) sampled as part of the western Prince William Sound juvenile salmon seine survey conducted during 2002-2010 by Alaska Department of Fish and Game (ADF&G; S. Haught, unpubl. data). Sites with red, unfilled circles indicate cases where more than a dozen herring and juvenile salmon co-occurred in the same seine haul. Only survey data from June and July were analyzed. Our proposed deeper water trawl sites established by ADF&G during 2011-2015 (4 sites, larger blue, filled circles) are also shown.

<u>Field Sampling: Off-Shore Trawl Surveys (Years 1-6)</u>

During summer (June and early July, see Table 1 for a schedule of field sampling events), we propose to sample emigrating, natural- and hatchery-origin juvenile pink salmon, age-1+ herring (opportunistically), and their prey through the major migratory corridor in southwestern PWS. Catch from these offshore trawl surveys will be used to examine the following:

(1) pink salmon predation on larval herring addressing Hypotheses 2a, b and Objective 3b, i and 3b, iv using stomach content analysis, DNA barcoding, and CSIA approaches

(2) prey availability and diet competition between juvenile pink salmon and age-0 herring to address Hypothesis 3 and Objective 3b, ii using zooplankton sampling, stomach content analysis, bulk SIA and CSIA approaches

(3) VEN prevalence among juvenile pink salmon and any age-1+ herring caught addressing Hypotheses 4a, b and Objective 3b, iii in collaboration with P. Hershberger (GWA-LTRM herring disease program)

(4) abundance of emigrating juvenile pink salmon and other co-variates (i.e., bulk SIA and other environmental parameters) that are critical for building survival and fishery forecast models for natural- and hatchery-origin pink salmon to address Hypothesis 5 and Objective 4a

Again, Table 2 outlines the specific lab analyses employed to address each hypothesis. We propose to sample four sites (shown with blue dots in Fig. 5). These sites are located in passages in SW PWS and are intended to serve as an index of abundance of juvenile pink salmon emigrating from PWS. We will lag this sampling one and two months (June and early July each year) after the early purse seine survey in May to account for ontogenetic shifts in juvenile pink salmon. Because age-0 herring are thought to metamorphose and settle in bays in July, we intend to conduct our July sampling early in the month to capture the period when larvae are still being advected in offshore currents and vulnerable to predation by juvenile pink salmon. We intend to capture juvenile pink salmon that are ~2-3 months post emergence/release. We propose to replicate trawls (n = 3) to estimate abundance of juvenile salmon and their prey. Sites will be visited once in June and once in July over a 6-year period (2022-2027), producing data for three even-year and three odd-year broods of pink salmon. We intend to rely on the PWSSC research vessel (R/V *New Wave*) for this work (15 days of ship time per year) and deploy a modified sweeper trawl (14 m headrope, 11.5 m wings, 22 m length, 38 mm mesh, 12 mm mesh on the cod end) to sample epipelagic fishes in surface waters (<10 m depth). Buoys or floats may be used to ensure the trawl is sampling near the surface. These will be 20-minute, high-speed tows. Two acoustic pingers (10 kHz, 132 dB) will be attached to the trawl to deter marine mammals. We will generally follow protocols used in the Southeast Alaska Coastal Monitoring (SECM) survey (Piston et al. 2020) to characterize catches for each of the dominant taxonomic fish groups likely to be encountered, including all salmon species, age-1+ herring, and other pelagic fishes. Catch and CPUE data for the non-target taxonomic groups will be made available to other GWA-LTRM PIs. Detailed event logs and specimen forms will be modeled after that used by Piston et al. (2020). For the purposes of our study CPUE will be calculated for juvenile pink salmon and age-1+ herring (number of individuals captured per min of trawl or over area swept by trawl). CPUE will be averaged over the three trawl replicates per site.

As described above for the purse seine survey, age-1+ herring will likely be observed less frequently than juvenile salmon in catches. To understand this better, and to provide some context for patterns of abundance of juvenile salmon observed at these sites in the past, we analyzed surface trawl data obtained from a field survey conducted by ADF&G during 2011-2015 (S. Haught, unpubl. data). This survey was intended to be a long-term monitoring effort, but funding for the program ended in 2015. Herring were captured infrequently in this surface trawl survey – among a total of 46 trawls, only 5 trawls captured juvenile or adult herring (~10% of the trawls, compared to over 30% in the purse seine survey described above). Our focus with this component of the study is on juvenile salmon and larval herring (larval herring sampling described below), but we intend to opportunistically sample and preserve age-1+ herring if captured during this survey. We will also plan to use jig gear to sample herring in schools observed with the vessel's sonar during trawl surveys or HRM's age-1 PWS aerial survey project (Pegau). Procedures for processing samples after collection will follow the methods outlined for purse seine surveys described above.

Because of our intention to use these data to estimate abundance of juvenile pink salmon and for incorporation as a covariate for forecasting returns to inform fisheries management, we explored patterns of juvenile salmon CPUE estimated during this early trawl survey period (2011-2015, no sampling data were available from 2012, S. Haught, unpubl. data). The species of salmon captured were not identified (we will identify to species in the work outlined in this proposal, see below) but total number of juvenile salmon were recorded. We estimated CPUE of total juvenile salmon (number of salmon captured per trawl minute). We assume the majority of the catches were juvenile pink salmon (R. Brenner, pers. comm.), and we noted the highest catches over the time series occurred in 2014, the year class that returned in record abundance in 2015 (Fig. 6). Although there is uncertainty in the salmon species catch composition in this data series, these data provide evidence that a survey of this type could capture variability in annual abundance of juvenile pink salmon emigrating from PWS that would be useful in fishery forecasting.

In addition to sampling juvenile pink salmon with a surface trawl, we will also collect larval herring and characterize prey available at these sites using a Methot or similar trawl designed to capture micronekton prey of salmon (Brodeur et al. 2011). We plan to make long tows (20 minutes) to integrate over patchiness typically observed in salmon prey species. We plan to conduct three tows per site to estimate mean and variance of different prey groups. This will provide densities (expressed volumetrically based on a flow meter in the net) for major prey categories similar to that described by Cross et al. (2005). A PWSSC lab technician will identify and enumerate the prey in each taxonomic group. These prey samples will also be analyzed for stable carbon and nitrogen isotopes to characterize sources consumed by pink salmon to compare with results from pink salmon tissue described above (see also Table 2).

Study co-principal investigator (PI) Campbell will characterize physical parameters at each trawl site (including temperature, salinity, and turbidity) using a conductivity and temperature at depth (CTD) profiler. Data produced for densities of larval herring will be compared with predatory demand estimates from the bioenergetic model simulations (described below). These data will also be shared with PI Cypher (project 22220111-H) to provide additional years data (2022-2024) for her project focused on larval herring ecology.

Table 1. Survey schedule for sampling in Prince William Sound, Alaska, and primary ecological actions to be examined during each survey. PS = pink salmon, Fry = newly emerged/released pink salmon, Emigrant = juvenile pink salmon emigrating from Prince William Sound, Larvae = larval age-0 herring, Age-0 = settled age-0 herring, Age 1+ = older age classes of juvenile and adult herring.

Year	2022		2023				2024			
Month	June	Early July	May	June	Early July	September	May	June	Early July	September
Survey	Trawl	Trawl	Purse Seine	Trawl	Trawl	Purse Seine	Purse Seine	Trawl	Trawl	Purse Seine
HYPOTHESES										
Predation	Emigrants consume Larvae	Emigrants consume Larvae	Age-1+ consume Fry	Emigrants consume Larvae	Emigrants consume Larvae		Age-1+ consume Fry	Emigrants consume Larvae	Emigrants consume Larvae	
Competition			Fry and Age-1+ diets	Emigrant diets	Emigrant diets	Age-0 diets	Fry and Age-1+ diets	Emigrant diets	Emigrant diets	Age-0 diets
Disease	Emigrants, Age-1+	Emigrants, Age-1+	Fry, Age-1+	Emigrants, Age-1+	Emigrants, Age-1+	Age-0	Fry, Age-1+	Emigrants, Age-1+	Emigrants, Age-1+	Age-0
PS relative abundance										
Adults	Low		High				Low			
Fry/Emigrants	High		Low				High			

Table 1. Continued.

Year	2025				2026				2027	
Month	May	June	Early July	September	May	June	Early July	September	June	Early July
Survey	Purse Seine	Trawl	Trawl	Purse Seine	Purse Seine	Trawl	Trawl	Purse Seine	Trawl	Trawl
HYPOTHESES										
Predation	Age-1+ consume Fry	Emigrants consume Larvae	Emigrants consume Larvae		Age-1+ consume Fry	Emigrants consume Larvae	Emigrants consume Larvae		Emigrants consume Larvae	Emigrants consume Larvae
Competition	Fry and Age-1+ diets	Emigrant diets	Emigrant diets	Age-0 diets	Fry and Age-1+ diets	Emigrant diets	Emigrant diets	Age-0 diets		
Disease	Fry, Age-1+	Emigrants, Age-1+	Emigrants, Age-1+	Age-0	Fry, Age-1+	Emigrants, Age-1+	Emigrants, Age-1+	Age-0	Emigrants, Age-1+	Emigrants, Age-1+
PS relative abundance										
Adults	High				Low				High	
Fry/Emigrants	Low				High				Low	

Table 2. Laboratory derived data sets used to test hypotheses about herring and pink salmon ecological interactions in Prince William Sound, Alaska. Left two columns identify specific sample collections by survey type and life stage, remaining column headings show which hypotheses are to be examined. Entries list datasets employed to test the hypotheses. Abbreviations: DNA = DNA Barcoding, SIA = Bulk carbon and nitrogen stable isotope analysis, CSIA = Compound-specific carbon and nitrogen isotope analysis. See methods for detailed descriptions of analytical methods used to develop datasets.

Survey	**Species or life stage**	**Herring eating pink salmon Hypothesis 1a**	**Pink salmon eating herring Hypothesis 2a**	**Bioenergetic model Hypothesis 2b**	**Competition Hypothesis 3a**	**Disease prevalence Hypotheses 4a, 4b, and 4c**	**Pink salmon survival modeling Hypothesis 5**
Purse Seine – May	Pink Salmon fry	Length/weight, CSIA			Stomach contents, SIA, CSIA	Origin, VEN prevalence	
	Juvenile herring (Age-1)	Length/weight, Stomach contents, DNA, CSIA			Stomach contents, SIA, CSIA	VEN prevalence	
	Adult herring (Age-2+)	Length/weight, Stomach contents, DNA, CSIA				VEN prevalence	
	Zooplankton				SIA, CSIA		SIA
Purse seine - September	Juvenile herring (Age-0)				Length/weight Stomach contents, SIA, CSIA	VEN prevalence	
	Zooplankton				SIA, CSIA		
Surface trawls – June and July	Pink salmon		Stomach contents, DNA, CSIA	Abundance, Length/weight, Stomach contents, origin, SIA,	Length/weight, Stomach contents, SIA, CSIA	Origin, VEN prevalence	Abundance, Length/weight, Origin, SIA

Survey	**Species or life stage**	**Herring eating pink salmon Hypothesis 1a**	**Pink salmon eating herring Hypothesis 2a**	**Bioenergetic model Hypothesis 2b**	**Competition Hypothesis 3a**	**Disease prevalence Hypotheses 4a, 4b, and 4c**	**Pink salmon survival modeling Hypothesis 5**
				CSIA, Calorimetry			
	Larval herring		CSIA	Abundance, Length/weight, SIA, CSIA, Calorimetry	Length/weight, SIA, CSIA		
	Juvenile and adult herring (Age-1+)					Length/weight, VEN prevalence	
	Zooplankton			Length/weight	Length, weight, SIA, CSIA		SIA

Table 3. Summary of catch data from the Alaska Department of Fish and Game purse seine survey during 2002-2010. Years of relatively high abundance of herring (2008 and 2009) are contrasted with years with lower herring abundance in the time series.

Herring abundance level	Month	Number of individual seine hauls	Mean pink salmon catch/haul	Mean juvenile herring catch/haul	Mean adult herring catch/haul
Low	June	32	335	9	13
Low	July	33	116	0	549
High	June	107	574	7	148
High	July	26	922	530	148

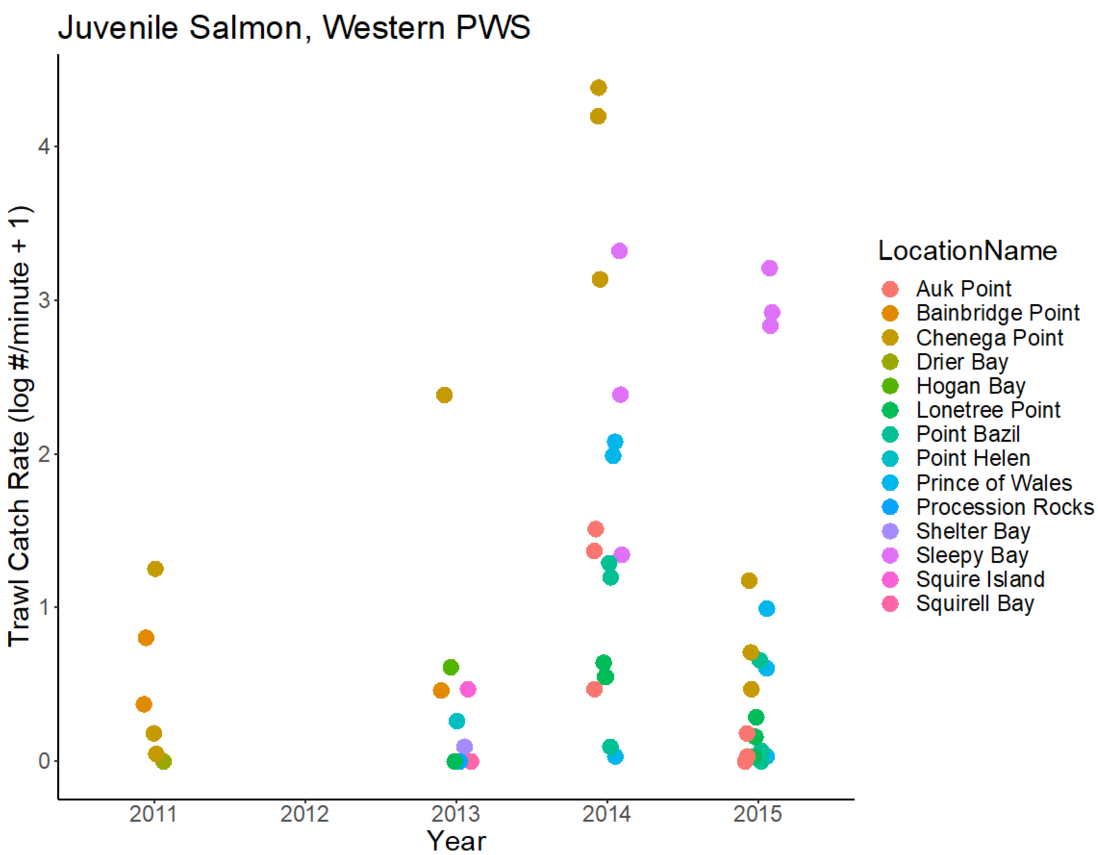

Figure 6. Catch rate of juvenile salmon in the Alaska Department of Fish and Game surface trawl survey, 2011-2015 (no data were available during 2012), color coded by site in Prince William Sound. The overall means (SE) are included in dark grey.

<u>Common Laboratory Analyses: Near-Shore Purse Seine and Off-Shore Surface Trawl Survey Samples</u>

Several key laboratory analyses will supplement field observations of abundance, distribution, and body size of herring and pink salmon and be used to address specific hypotheses (see Table 2). Importantly, our laboratory analyses require only small amounts of tissue, thus samples can be easily sub-sampled as needed. Sample size goals and field and laboratory processing will follow that described above for the purse seine survey. Priorities for sample processing will focus on Hypotheses 1a, 2a, 3a, 4a, and 5. Samples for stomach contents and VEN prevalence will be collected at sea. The origin of juvenile pink salmon (natural or hatchery), based on otolith analysis, will be used for survival modeling and to help understand physical and ecological differences that exist between these two eco-types (e.g., size, growth, diets, disease prevalence). Diet analysis will involve a combination of visual analysis of stomach contents, DNA barcoding, and bulk carbon and nitrogen SIA and CSIA approaches. Diet composition estimates from both stomach content analysis, bulk SIA and CSIA of juvenile pink salmon captured in trawl surveys will be used for predation and competition hypotheses and in the bioenergetic simulations, described more fully below. We will apply bulk SIA on herring and pink salmon tissues and zooplankton to quantify oceanic subsidies (Table 2).

Salmon Origin

Saggital otoliths will be removed from all pink salmon in the lab, labeled and stored dry in trays. Otoliths will be analyzed by the Cordova ADF&G otolith laboratory to determine if fish originated from hatcheries or wild streams. Origin determination is possible because hatcheries routinely impart thermal marks in the otoliths of pink salmon during incubation. In this way, all hatchery fish can be distinguished from their wild conspecifics. We will compare length and weight of juvenile pink salmon by origin. This will allow us to determine how origin might affect their vulnerability to herring predators in the purse-seine sampling. Origin of juvenile pink salmon will also be evaluated as a factor that may affect rates of predation on herring larvae in the surface trawl survey, particularly if we see differences in size or diets between natural- and hatchery-origin individuals. Quantifying size differences, diet, and abundance for natural- and hatchery-origin pink salmon will also allow us to gauge their relative contribution to competitive interactions and subsequent survival.

Analysis of Stomach Contents

In general, processing for juvenile pink salmon fish size, diet content, and preparation for bulk SIA and CSIA in the context of the predation and oceanic subsidy hypotheses will be conducted in the PWSSC laboratory. Similar analyses for the herring-pink salmon diet competition hypothesis will be conducted by UAF and SSSC laboratories. Length and weight of all individuals will be measured. Stomach contents, preserved in ethanol will be examined by lab technicians following procedures described by Sturdevant et al. (1999) and Armstrong et al. (2005) with a focus on identifying to the lowest taxon practical, including fish species and life stage. After removing stomach contents, the stomach will be returned to the carcass of the fish. Prey will be counted, and the total mass of the stomach contents recorded. After counting prey, the samples will be retained for DNA barcoding and shipped to a separate lab to detect the specific presence of herring and pink salmon DNA (Andrew Whitehead Lab, UC Davis). Stomach contents will be expressed as a percent of total mass and the data will be used to examine hypotheses relating to herring predation of pink salmon fry (Hypothesis 1a), juvenile pink salmon predation of larval herring (Hypothesis 2a), and juvenile herring-pink salmon diet competition (Hypothesis 3). In addition, the composition of prey in stomach contents of juvenile pink salmon caught in surface trawls will be used for the bioenergetic modeling (Hypothesis 2b).

DNA Barcoding

It is important to recognize the limitation of applying traditional diet analysis to identify larval and juvenile fishes that rapidly break down in predator stomachs. DNA barcoding has dramatically increased our ability to detect certain prey items in diet studies to the species level. DNA barcoding is based on amplification of DNA of specific prey in the stomach contents of predators to assign diet composition to the species level. Recent studies have demonstrated the power of this approach in detecting specific prey items in fish diets (e.g., Côté et al. 2013, Sousa et al. 2016). We intend to use this approach in this study to verify the presence specifically of pink salmon in herring diets (Table 2) for fish caught in purse seines (Hypothesis 1a) and specifically herring in pink salmon diets for fish caught in surface trawls (Hypothesis 2a). Note this method will only provide data on presence or absence of these two specific species and hence can only be used to estimate frequency of occurrence.

Bulk Stable Isotope Analysis (SIA)

Analysis of bulk stable carbon ($^{13}C/^{12}C$, $\delta^{13}C$) and nitrogen ($^{15}N/^{14}N$, $\delta^{15}N$) isotopes will be used to characterize dietary niches under Hypothesis 3a, and to assess the extent to which carbon consumed by pink salmon has advected into PWS from the GOA under Hypothesis 5. These analyses have been used extensively in previous studies of PWS herring and pink salmon diets (Kline 1997, 1999b, a, 2000, 2001, Kline et al. 2008, Kline 2010, Kline and Campbell 2010, Gorman et al. 2018, Heintz et al. in prep), as the ratio of the heavy to light isotopes in a sample serve as time-integrated, biogeochemical parameters that reflect assimilated prey (Deniro and Epstein 1978, 1981, Peterson and Fry 1987).

Muscle tissue samples collected for bulk SIA will be dried and pulverized and 0.1-0.2 mg of dried tissue will be transferred to a tin capsule and shipped to UAF – Alaska Stable Isotope Facility where carbon and nitrogen mass spectrometric analyses will be performed. Results will be produced for %C, %N, and the ratios of $^{13}C/^{12}C$, and $^{15}N/^{14}N$ with the heavy to light isotope ratios reported using delta notation, $\delta^{13}C$ and $\delta^{15}N$, respectively, calculated using the following equation: $\delta^{13}C$ or $\delta^{15}N = ([Rsample/Rstandard]-1) \times 1000$, where Rsample is the ratio of the heavy to light isotope for either $^{13}C/^{12}C$ or $^{15}N/^{14}N$, and Rstandard is the heavy to light isotope ratios for international standards – Vienna PeeDee Belemnite for carbon and atmospheric N_2 (Air) for nitrogen. We will rely on $\delta^{13}C$ values as a measure of oceanic carbon subsidies as described in Kline et al. (2010) and Gorman et al. (2018). Values of $\delta^{15}N$ will provide information on trophic position. These data will be used to address Hypotheses 3a and 5 including estimates of body condition (see Gorman et al. 2018). Construction of dietary niche metrics using SIA is described below.

Compound-Specific Stable Isotope Analysis (CSIA)

An important limitation of DNA barcoding is that it does not provide for quantitative assessments of diet composition, only presence or absence. Similarly, visual analysis of stomach content analysis provides estimates of composition that are biased towards the most recently ingested prey and those that are least digestible. We plan to supplement our visual observations of stomach contents with CSIA. This approach measures the $\delta^{13}C$ or $\delta^{15}N$ values of essential amino acids, which are only available through dietary intake. The CSIA approach provides considerably more power to standard bulk isotope analysis to resolve food web baselines or prey discrimination and can be used in multivariate mixing models to estimate diet composition (Whiteman et al. 2019). Initial sample preparation is similar to that of bulk SIA, and analyses will be conducted at the Alaska Stable Isotope Facility at UAF. We will also additionally obtain zooplankton prey to be used as end members in our isotopic mixing models (see details below). Mixing model results will provide quantitative estimates of diet composition.

Data from these analyses will be used to determine if herring are eating pink salmon in nearshore habitats in SW PWS (Hypotheses 1a), if pink salmon are eating larval herring in deeper water habitats in SW PWS (Hypothesis 2a), and dietary overlaps in SW PWS (Competition Hypothesis 3a). Diet compositions derived from CSIA also will be used to construct bioenergetic models (Hypothesis 2b). Based on results of our retrospective analysis, we may consider expanding sampling into other regions of PWS and broaden the scope of our study to include other regions in PWS.

VEN Prevalence

The field sampling and later laboratory analyses related to VEN prevalence will be conducted by Dr. Paul Hershberger, a U.S. Geological Survey (USGS) scientist leading the PWS herring disease program project (22120111-E) and a collaborator on this project. The details of field and laboratory protocols are detailed in the herring disease program proposal (Hershberger et al., project 22120111-E). Following disease sampling onboard, we will place individual salmon and herring in bags with a small amount of water and freeze them for later laboratory analyses. Each individual will be bagged and labeled uniquely so we can later relate our measurements of size, energetic conditions, and diet to the disease state of each individual. These data will be used to address Hypotheses 4a, b, and c.

Calorimetry

Energy content of juvenile salmon collected in purse seines and surface trawls will be determined through microbomb calorimetry measurements at PWSSC. These data will be used as covariates in the development of survival models (Hypothesis 5). In addition, energy densities of pink salmon collected in surface trawls will be important to the bioenergetic simulations required under Hypothesis 2b. Samples will be prepared by drying to a constant weight at 60 ^{o}C. Dried tissue will be ground in a mill, and tissue will be pressed into pellets and ignited with oxygen in a Parr microbomb calorimeter following methods outlined by Gorman et al. (2018). We also note that estimates of energy density also can be developed from the bulk SIA data, and we plan to supplement calorimetric analyses with these data (see Kline 2010, Gorman et al. 2018).

Methods for Objective 4

<u>Collaboration with NOAA: GOA Field Sampling</u>

Data collected during the purse seine surveys and trawl surveys will be combined with information on salmon returns to develop models describing pink salmon survival to examine Hypothesis 5. Specific modeling methods to be applied to these data are described below under **Statistical Methods for Objective 4a** in the data analysis section.

A collaboration with the National Marine Fisheries Service (NMFS) will provide additional samples and data from outside PWS. We will obtain samples of juvenile pink salmon from surface trawls in the Western GOA survey that will be carried out during August and September in odd years beginning in 2023 (J. Moss, NMFS, pers. comm.). This collaboration provides a significant amount of leveraged support for this project given the cost of conducting GOA research cruises. Otoliths from juvenile pink salmon will be analyzed to determine origin. In addition, we will measure body size, energetic condition, and diet composition of collected individuals (n = 50 per trawl site). While this will only provide data on even-year returning pink salmon (field years 2023, 2025, 2027), it will produce estimates of CPUE at an older life stage to be used in our data synthesis and allow us to describe characteristics of surviving salmon at a later endpoint (Fig. 2). Obtaining data on pink salmon in these locations later in the season was found to be particularly important in explaining variability in survival to the adult stage in earlier NOAA GLOBEC studies (e.g., Cross et al. 2009). We will also estimate the $\delta^{13}C$ in salmon tissue and their prey (zooplankton sample from bongo net tows collected during the NMFS cruise) as described above to compare with results from our PWS sampling.

Consultation Services

To ensure that our field and laboratory methods described above are consistent with other similar studies in the GOA, Dr. Ric Brodeur, retired Research Fishery Biologist with NMFS, will be contracted during the first year of the project to assist in developing protocols for fieldwork and the visual diet composition laboratory analyses. Dr. Brodeur has extensive experience in studies of juvenile salmon ecology in the GOA and California Current systems and will be invaluable in refining protocols to ensure that our methods are comparable to that used by other entities in Alaska and the US West Coast. We will also continue communications with Jim Murphy at NOAA and Andy Piston at ADF&G to apply knowledge gained through the Southeast Alaska Coastal Monitoring (SECM) survey.

C. Data Analysis and Statistical Methods

Statistical Methods for Objective 1

Synthesis of the retrospective data will include developing maps that depict the joint distributions of herring and pink salmon for each month both species are found in PWS. Distributions will be determined by also considering the depths over which pink salmon and herring are sampled in previous datasets. These maps will initially be conceptual in nature and not quantitative. Their purpose is to inform the field surveys beyond the data summaries provided in this proposal so that we can maximize the likelihood of sampling interacting herring and pink salmon. Additionally, should we collate sufficient data for particular life stages (i.e., juveniles), we will conduct a quantitative analysis of these retrospective data using a VAST model. VAST models can be extremely useful for identifying interactions between species (e.g., Godefroid et al. 2019), but they are data and computationally intensive. Typically, they require gridded survey data including catch and environmental observations. However, disparate data sets can be combined, and we will explore the possibility of using the collated retrospective data recorded in previous reports and the published literature for this purpose. The VAST modeling exercises will be a primary focus of the M.S. student project supported by the project during years two and three of the study (2023-2024). This student will be primarily supervised by Co-PI Gorman (UAF Marine Biology research faculty), while Rand (Lead PI) and Heintz (Co-PI) will serve as committee members.

Statistical Methods for Objective 2

To address the probability of co-occurrence of salmon and herring in PWS, we will determine the probability of co-occurrence based on catch results from our purse seine survey during 2023-2026. Given the likelihood of zero counts in some of the purse seine hauls, and the likelihood that responses might be non-linear, we propose to apply the Delta-model approach of Lo et al. (1992), which includes two analytical stages: 1) modeling the presence/absence of both species using a binomial response variable, and 2) modeling the number of occurrence (counts of each species in each purse seine haul) at sites where both species are present. For both stages, we will include a suite of covariates, including site or area location, depth of site, seas surface temperature, salinity, month of sampling, and all possible interaction terms. To address the potential for non-linear interactions, we propose to apply either Generalized Additive Models (GAM, Hastie and Tibshirani 1986) or Boosted Regression Trees (BRT, Elith et al. 2008). Both approaches are available in R statistical packages (mcgv for GAM, and gbm for BRT). A best fit model to predict presence and absence of both species will be determined based on information theory criteria (AIC). After we define the probability of presence for both species in the study area, we will model the number of observations at sites or areas where the species are predicted to be present assuming different error distributions (negative binomial or Poisson). Ultimately, predictions of counts for both species within the co-occurrence area will be made using both GAM and BRT models, and the results will be projected on a spatial grid of the sampling region, including a description of the covariates determined to be significant for each model. This analysis will determine if the species co-occur at a rate higher than what would be expected by chance, and the extent of temporal and spatial overlap in their distributions. An application of this approach involving occurrence of two species in a tropical purse seine fishery (Escalle et al. 2016) provides an example of how the approach will be applied in this study.

We plan to complete an additional analysis comparing our retrospective data with the field data collected for this study. This analysis would be completed as part of the synthesis of the project at the end of the study. We will apply the modeling framework described below and will also consider applying the VAST modeling approaches we develop as part of Objective 1 (details above) to explore both the past and current datasets to understand if co-occurrence of herring and pink salmon in PWS have shifted over time.

Statistical Methods for Objectives 3a

The primary purpose of the May near-shore purse seine sampling is to assess the co-occurrence of juvenile pink salmon and age-1+ herring, and the interacting mechanisms such as predation of pink salmon fry by age-1+ herring in PWS (Hypothesis 1a, Objective 3a, i). Additionally, during this time, we aim to characterize the diets of pink salmon fry to build our dataset regarding dietary competition (Hypothesis 3a) between herring and pink salmon. We will determine the probability of herring consuming salmon by relying on results from the visual examination of stomach contents, DNA barcoding analyses, CSIA, and whether there is a relationship between the presence of juvenile salmon in herring diets to the abundance of juvenile pink salmon (# of individuals counted in each haul) using a generalized linear model (GLM) approach.

Multivariate analysis of the observed age-0 herring and juvenile pink salmon diets will be used to identify the degree of diet similarity and the prey items most responsible for that similarity. Diet contents of pink salmon and herring will be compared using Bray-Curtis similarity matrices and Analysis of Similarity (ANOSIM). Non-metric multidimensional scaling (NMDS) will be used to visualize overall similarity by calculating centroid distances and plotting 95% confidence intervals for centroid locations. A similarity percentage routine (SIMPER) will be used to identify which prey species contribute to overall similarity in the diets of Pacific herring and pink salmon. Electivity indices (e.g., Ivlev 1975, Chesson 1983) will be used to evaluate the degree with which these shared items are selected from the prey field versus their being consumed in proportion to their abundance. In addition to the electivity indices we will conduct a chi-square goodness-of-fit analysis to determine if the proportion of prey in the diet is equal to that of the prey field (Byers et al. 1984). If shared prey items are actively selected, then there is evidence that their availability is somehow limited and therefore competition exists. If sufficient samples exist these analyses will be conducted on samples of herring and pink salmon that were caught together (sympatric) or alone (allopatric) to further examine if the presence of pink salmon influences herring diet (Sturdevant et al. 2001).

Carbon and nitrogen stable isotope data will also be used to independently determine a number of metrics related to trophic interactions between co-occurring pink salmon and herring (including the direct consumption of larval herring by pink salmon, see details below). We will make use of a number of recently developed Bayesian packages in the R language environment to explore trophic positions of pink salmon relative to herring (Quezada-Romegialli et al. 2018), dietary niche overlap between the two species (Jackson et al. 2011), as well as develop quantitative estimates of dietary proportions using isotopic mixing models (Stock et al. 2018). Of note, these statistical approaches can also incorporate CSIA data (e.g., Gibbs et al. 2020). These analyses combined with those described previously will allow for a thorough examination of the consumption of pink salmon by age-1+ herring, and potential resource limitations imposed by pink salmon on herring.

We will use GLM to quantify spatial and temporal patterns of VEN infection prevalence and intensity (i.e., percentage of erythrocytes with inclusion bodies) in age-1+ herring and in juvenile pink salmon sampling in May, and age-0 herring sampled in September. Potential covariates include time-lagged infection prevalence from previous surveys, surface water temperature and salinity (Campbell 2018), and whether or not sampled schools contain both herring and salmon. Data from a VEN temperature study (described in the herring disease program proposal led by Hershberger et al., 22120111-E) will be used to identify key temperature thresholds that increase or decrease susceptibility to infection. High correlations in infection prevalence between co-occurring pink salmon and Pacific herring will support the hypothesis that spillover/ spillback is occurring. Annual trends in VEN prevalence will be quantified by examining infection prevalence in age-0 and age-1+ herring and pink salmon in both purse seine and trawl surveys. Key findings from this study will be used to develop hypotheses to test experimentally as part of the herring disease program at the U.S. Geological Survey-Marrowstone Marine Field Station.

Statistical Methods for Objectives 3b

We will apply the same GLM modeling approach describe above to determine the association of the two species in the trawl and micronekton catches (in this case, we will be examining co-occurrence of older juvenile pink salmon and densities of larval herring) and test for presence of herring DNA in the stomachs of juvenile salmon. Similarly, we will apply the same multivariate diet and stable isotope approaches described above to samples collected during trawl surveys to characterize diet composition of juvenile pink salmon to address our diet competition hypothesis. Similar statistical methods regarding VEN prevalence will be applied using the trawl survey data.

Within the context of bioenergetic model simulations that will be the focus of a post-doctoral associate project (22220111-H), we will address the predatory impact of juvenile salmon on herring larvae by estimating predatory demand on key prey taxonomic groups. We will apply the model used by Cross et al. (2005) and estimate predatory demand at each trawl site relying on the following inputs:

1. Density of pink salmon predators (based on catches and area swept by trawl).
2. Diet composition (prey categories follow Cross et al. 2005).

3. Caloric content of predator (estimated in this study) and prey items (based on literature values and those determined in this study).

4. Temperature based on CTD measurements at each site.

5. Daily growth rate based on changes in mean size of pink salmon captured over May-July period in this study.

Estimates of predatory demand (in units g km^{-2} d^{-1}) will be compared to estimates of prey densities estimated in our micronekton trawl collections. We will assume our sampling represents the top 10 m of the water column. We will examine predation pressure on various taxonomic groups but compare predation on larval herring to larval herring abundance. We have conferred with PI Cypher (project 22220111-H) and will share data with her on larval herring collected during 2022-2024, and we intend to work with her in the field starting in 2025 when her research project begins to continue sampling micronekton in our western PWS study area to accomplish objectives in both of our studies. We have defined the level of significant top-down predation as a consumption rate that meets or exceeds standing stock biomass (Rand et al. 1995, Rand and Stewart 1998, Cross et al. 2005). We will use bulk SIA and CSIA approaches to determine if juvenile pink salmon are directly consuming herring. We anticipate the isotopic analyses described earlier to contribute to this objective as well, in particular isotopic mixing model analysis (Stock et al. 2018) using the CSIA data specifically from sampling larval herring and juvenile pink salmon.

Statistical Methods for Objective 4a

We will adopt a GLM approach to determine which covariates describe survival rates estimated for the four separate hatchery-origin stocks of pink salmon. The response variable will be marine survival estimates for hatchery-origin pink salmon produced annually by PWS regional aquaculture groups, PWSAC and VFDA. We intend to analyze each hatchery stock separately and in combination. We will evaluate two separate GLMs: 1) an analysis focused on explaining variability in marine survival and pink salmon returns during 1978-2025 using only covariates that have been consistently measured over the entire period, and 2) a model that incorporates additional covariates measured in this study.

We intend to include the following covariates in the GLM model: surface water temperature (Campbell 2018), zooplankton biomass (McKinstry and Campbell 2018), mean size and abundance of released hatchery-origin pink salmon, lagged pink salmon escapement to PWS (reflecting relative strength of even and odd year runs, ADF&G data), and measures of herring and pollock recruitment (HRM and ADF&G data). We will also include other variables that might be relevant that are measured through the GWA program, including measures of abundance of other forage fishes and humpback whales (e.g., Chenoweth et al. 2017). We anticipate that differences in even and odd year returns will be an important variable in the model. In a preliminary analysis of this data set, we observed significantly higher rates of survival for odd years (Fig. 7). A mechanism to explain this observed difference in survival between even and odd year returns is “predator swamping”, whereby abundant wild juvenile salmon produced by strong returns in odd years join with hatchery produced juveniles and jointly overwhelm predators, effectively buffering predation losses more than would be the case for even years. Density-dependent growth (that is, lower growth leading to lower survival for odd years because of higher overall densities) would countervail this effect, but these data on marine survival suggests otherwise.

For the period of this study (n = 6 years, representing three years for each even/odd year brood line) we will develop a more complex GLM that will include variables described above along with other variables measured in this study, including juvenile pink salmon trawl CPUE, salmon dietary data (stomach fullness, energy density of consumed prey, prevalence of herring consumption), bulk stable isotope data for juvenile pink salmon describing the degree of oceanic subsidies each year, observed sizes/growth of juvenile pink salmon observed during June and July in PWS, sizes/growth of young pink salmon through August and September in the GOA (even year returns only, relying on NOAA GOA cruise samples), and additional data on herring and pollock recruitment generated in other proposed LTRM studies (A. Cypher, PWSSC, and W. Rhea-Fournier, AD&G, LTRM PIs). We will rely on AIC to determine which model best fits the data. A similar best fit model approach was used to develop the forecast model based on SECM data (Wertheimer et al. 2013, Orsi et al. 2016).

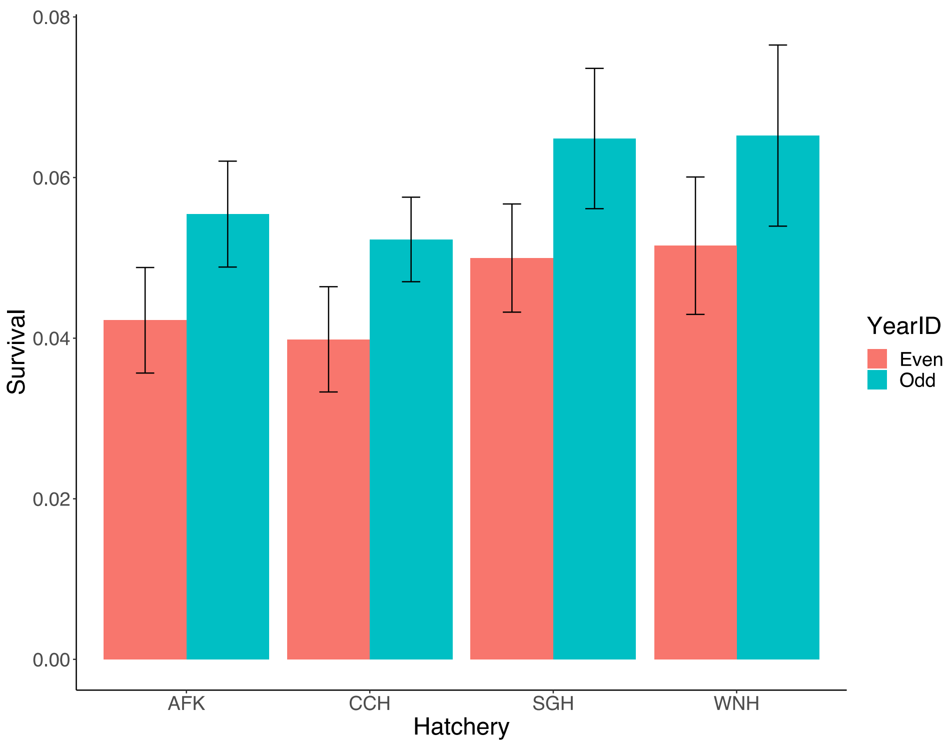

Figure 7. Marine survival rates during even and odd brood years for released pink salmon across the four hatchery programs (Armin F. Koernig Hatchery [AFK], Cannery Creek Hatchery [CCH], Soloman Gulch Hatchery [SGH], and Wally Noerenberg Hatchery [WNH]) in Prince William Sound. Bars represent 1 standard error of the mean.

Statistical Methods for Objective 4b

There is growing interest in incorporating ecosystem indictors in fishery forecast models as our climate changes (e.g., Cury and Christensen 2005, Jennings 2005). These models, known collectively as environmental-based forecasts (EBFs), have proven useful tools in the context of fishery management by accounting for important changes, particularly through the use of climate indices that reflect changes in oceanography that can affect salmon growth and survival. A number of models have been applied to North Pacific salmon (e.g., Mantua et al.

1997, Burke et al. 2013, Murphy et al. 2019), although the performance of many forecast approaches has been shown to be ephemeral given the complex dynamics in salmon ecosystems (Gosselin et al. 2021, Wainwright 2021). There has clearly been success in forecasting pink salmon in southeast Alaska through the SECM survey judging by sustained accuracy of the pre-season forecasts. The probability of success in his example from southeast Alaska is certainly increased by the incorporation of annual trawl CPUE estimates of emigrating pink salmon. By adopting this general approach in PWS, we have confidence that our resulting forecast model will help improve the accuracy of future forecasts. The long-term commitment by the EVOSTC to ecosystem monitoring and ecosystem process studies will provide future opportunities to modify or adapt this forecast model approach by incorporating additional metrics that track changing ecosystem processes in PWS and the GOA.

Performance of the three separate forecast models will be assessed based on their accuracy of predicting trends in marine survival and total run sizes of PWS pink salmon. The current forecast model used by ADF&G applies an exponential smoother, which is similar to a two-year running average forecast but results from earlier years can have some influence on predictions (Haught 2021). We will compare the performance of this model with the retrospective model described above that incorporates additional ecosystem covariates measured over the period 1978-2027. Attention in this analysis will focus on whether the incorporation of ecosystem covariates during the recent marine heatwave will result in an improvement in forecast prediction relative to the current, running average approach. Finally, we will use the best fit GLM to the six years of data collected in this study to compare performance with these other models during 2022-2027. This will help determine the contribution of data produced from an annual trawl survey to improving the accuracy of the pre-season forecast. Based on the success of the SECM survey, we anticipate incorporating juvenile pink salmon CPUE from surface trawl data and ancillary oceanographic variables we describe in this proposal will improve our ability to predict survival and run sizes for PWS pink salmon, and that this could become a tool to inform fisheries management in the future.

D. Description of Study Area

The PWS study region is within the *Exxon Valdez* spill area. We plan to sample the southwestern region in particular, in both near-shore and more off-shore habitats (see Fig. 1). The north, east, south, and west bounding coordinates for the sampling area are: 61.5, -145.5, 59.8, -148.9. In addition, we will obtain samples from coastal GOA from a NMFS research cruise (coordinates of study area include the Seward and GAK lines. Station GAK-1 at 59.845 N 148.5 W, and the survey line extends across the continental shelf.

5. COORDINATION AND COLLABORATION

A. With the Alaska SeaLife Center or Prince William Sound Science Center

This project will be managed by PWSSC (Program Manager S. Pegau, lead PI Rand) and will coordinate directly with PWSSC researchers working on PWS environmental drivers (Campbell, project 22120114-G). Of particular note, this project was revised to include both the juvenile pelagic fish survey led by Rand, and the predation and competition project led by Heintz and Gorman. Thus, all project PIs (Rand, Campbell, Heintz, and Gorman) are now fully integrated into one project to streamline coordination and collaboration. This project is part of the HRM package being proposed by PWSSC and will integrate with that program to the fullest extent possible by participating in annual meetings and working with other project PIs (Branch, Cypher).

B. Within the EVOSTC LTRM Program

Environmental Drivers Component

Co-PI Dr. Rob Campbell is a PI in this component and will be contributing PWS data and expertise to explore how environmental drivers affect herring and juvenile pink salmon in our project. Additionally, the project will use data produced by GWA-LTRM PIs Hopcroft and Danielson for use in our modeling efforts.

Pelagic Monitoring Component

We have consulted with Dr. Mayumi Arimitsu on our planned study, and we intend to collaborate closely with her to make sure our work complements the other projects focusing on forage fishes in the Pelagic Component of the GWA-LTRM program. In particular, Dr. Arimitsu is proposing to analyze past and future samples of juvenile pink salmon collected by rhinoceros auklets (*Cerorhinca monocerata*) at Middleton Island in the GOA. This will provide an opportunity to examine prey selectivity by contrasting characteristics of juvenile pink salmon preyed on by these seabirds (including size, energetic condition, and origin) to those we have collected in our surface trawl survey during 2022-2027.

Nearshore Monitoring Component

We plan to acquire temperature data from the nearshore monitoring component project (Coletti et al., project 22120114-H) to describe growth of pink salmon in very nearshore habitats.

Lingering Oil Monitoring Component

Because lingering oil data are collected once in a 5-year period and the oil is not currently bioavailable, we do not anticipate incorporating these data into our project. We look forward to status reports from the Lingering Oil Component.

Herring Research and Monitoring Component

This study is fully integrated in the HRM Component of the GWA-LTRM program. The project will work closely with a post-doctoral associate on bioenergetic analysis (proposed project 22220111-H). We are collaborating closely with Paul Hershberger (GWA-LTRM PI) on the disease aspects of this project. We have consulted with Dr. Hershberger and Dr. Maya Groner as this proposal developed, and they contributed to the study design. Dr. Hershberger is included in this proposal as a collaborator. Our focus on sampling for larval herring will complement the work of Dr. Alysha Cypher (GWA-LTRM PI). We intend to share data we produce on distribution and abundance of larval herring during the first three years of the project (2022-2024), and then work with her in the field for the remaining years of the grant period to continue sampling larval herring in southwestern PWS. We will rely on data regarding herring recruitment success measured by Morella (GWA-LTRM PI) and used by Branch (GWA-LTRM PI) in the work we propose here, and data we generate on mechanisms of interaction (predation, competition, and disease) between herring and juvenile pink salmon can be incorporated into the MICE ("models of intermediate complexity") being developed by Dr. Branch. Dr. Scott Pegau (GWA-LTRM PI) will estimate juvenile herring abundance from aerial surveys, and we will work with him to better understand herring distributions in June and early July to help target herring in our off-shore trawl surveys. This coordination will allow for additional ground-truthing of aerial survey observations using the purse seine and trawl data.

Synthesis and Modeling Component

We will be providing a synthesis of EVOSTC-funded and other research on the spatial distribution of herring and pink salmon in PWS. We will also share data with the herring population modeling project (Branch, 22120111-B) to coordinate our results with their proposed Model of Intermediate Complexity (MICE), as well as coordinate on any information we produce that is useful to the PWS herring population model directly. The abundance of forage fish species from trawl surveys will contribute to predator-prey studies in PWS (PIs Arimitsu and Piatt, Moran and Straley, Bishop and Schaefer). Diet, trophic, and bioenergetic relationships from our study will be important contributions to GWA-LTRM cross-component synthesis and modeling efforts (Program Management project, 2222LTRM), including the development of mass-balanced ecosystem models for PWS (Ecopath/Ecosim, PIs Hopcroft and Dias).

Data Management Project

All model outputs and raw observational data will be provided to the Data Management project by posting on the Alaska Ocean Observing System (AOOS) Research Workspace and making publicly available on the GOA Data Portal within required timeframes.

C. With Other EVOSTC-funded Projects (not within the LTRM Focus Area)

As the EVOSTC funds future projects outside the GWA-LTRM program we will evaluate their applicability to our project and coordinate as appropriate. Project 21210128 and proposed seabird survey work by Bishop and Schaefer (PWSSC) may have an interest in our maps as indicators of potential prey for seabirds.

D. With Proposed EVOSTC Mariculture Focus Area Projects

We look forward to working with the EVOSTC's Mariculture Program and projects they embark on. We anticipate they will be interested in GWA-LTRM datasets, and we expect there will be opportunities for coordination and collaboration. We will be using data developed by entities conducting aquaculture in the region and these entities will have a direct interest in our results. To the extent that mariculture projects will use integrated multi-trophic approaches involving salmon aquaculture, they may have interest in our results.

E. With Proposed EVOSTC Education and Outreach Focus Area Projects

The GWA-LTRM program will develop an outreach plan that includes coordination and collaboration with the Trustee Council's Education and Outreach Program and projects. We look forward to participating in education and outreach opportunities where our project findings can contribute to a better understanding of the GOA ecosystem by the general public. We intend to work with several educators, including Lauren Bien and Haley Hoover of PWSSC, to provide education and outreach for our project, including a new webpage on PWSSC.org described our project and findings, newsletter articles for *Delta Sound Connections*, articles for Breakwater, public radio interviews, and presentations as part of the community lecture series managed by PWSSC in Cordova.

F. With Trustee or Management Agencies

We will be relying on ADF&G and PWS private-non-profit salmon hatcheries (PWS Aquaculture Corporation and Valdez Fisheries Development Association) for data on pink salmon releases and returns to PWS hatcheries along with information on the numbers of spawning female herring and their ages. J. Morella at ADF&G Cordova will be our primary contact for these data as he is the area research biologist and an PI involved with the HRM program (project 22170111-F).

We anticipate that the data produced by the proposed project will be of primary use to ADF&G. The agency has statutory authority over both herring and pink salmon production in PWS. This project is meant to determine the most likely mechanisms of interaction between pink salmon and herring, and further research would be needed to confirm our results prior to any potential management actions being taken by ADF&G.

In a letter to the GWA Management Team dated 13 December 2020, ADF&G articulated support for a EVOSTC project to "… create an outmigration index of salmon and other species that could be used to forecast future returns and associated availability for harvests". The letter went on to describe the value of a project like the one proposed here: "As major components of the Prince William Sound fish community, research on salmon … abundances will provide a variety of ecological information to support other Gulf Watch research initiatives – including their interactions with herring and their role as prey, predators, and competitors to birds, whales, and other community members – while also directly informing management". We intend to communicate with ADF&G biologists and fishery managers over the course of this study period to convey new knowledge generated from this study and our proposed work on fishery forecast modeling will help inform PWS fishery management.

G. With Native and Local Communities

The GWA-LTRM program and this project are committed to involvement with local and Alaska Native communities. Our vision for this involvement will include active engagement with the Education and Outreach Focus Area (see above), program-directed engagement through the Program Management project (2222LTRM), and project-level engagement. During the first year of the funding cycle (FY22), the GWA-LTRM program will reach out to local communities and Alaska Native organizations in the spill affected area to ask what engagement they would like from us and develop an approach that invites involvement of PIs from each project, including this one. Our intent as a program is to provide effective and meaningful community involvement that complements the work of the Education and Outreach Focus Area and allows communities to engage directly with scientists based on local interests.

Lead PI Rand and co-PI Gorman on this project are also currently working closely with the Native Village of Eyak and the Ahtna Intertribal Resource Commission on field studies in the Copper River drainage, and there may be opportunities for Alaska Native community members to also be involved in these PWS surveys, providing new opportunities for tribal members to gain experience in the field.

6. DELIVERABLES

We anticipate that this project will produce several peer reviewed reports and manuscripts, a series of maps, metadata and datasets describing herring and pink salmon co-occurrence, diet, disease, and modeling exercises. Importantly, the project will extend an existing pink salmon time series initiated by ADF&G, and a time series of age-0 herring condition supported by prior EVOSTC funding. Specifically, we envision the following products:

1. Datasets and associated metadata include:
    a. Maps will depict the monthly joint spatio-temporal distributions of pink salmon and herring

   b. Herring and pink salmon body size and co-occurrence data from surveys
   c. Zooplankton and micronekton (including larval herring) and other environmental data from surveys
   d. Herring and pink salmon diet data from surveys including stomach contents and DNA barcoding
   e. Herring and pink salmon bulk SIA and CSIA data that reflect assimilated prey
   f. Herring and pink salmon VEN prevalence data
   g. Derived energy density metrics of herring, pink salmon, and selected prey items from surveys
   h. Estimates of abundance of juvenile salmon (pink salmon and other salmonids) during emigration from PWS
2. Reports
   a. Annual reports (FY22-27)
   b. Final project report (FY28)
3. Tentative titles for 4-5 manuscripts include:
   a. A synthesis of spatiotemporal distributions of herring and pink salmon in PWS, Alaska
   b. Predatory interactions and potential biomass removal of herring by pink salmon in PWS, Alaska
   c. Dietary overlap between herring and pink salmon in PWS, Alaska
   d. Models of pink salmon survival in PWS, Alaska
   e. Forecasting pink salmon production and return strengths in PWS, Alaska
4. Outreach materials
   a. PWSSC, SSSC, and UAF website materials
   b. Articles for PWSSC's Delta Sound Connections and Breakwater Newsletter.
   c. Presentations to Cordova and Sitka Lecture Series
   d. Presentations at AMSS and other professional meetings.

We intend to primarily use the R language environment for analyses and all data and R code will be made available on GitHub (e.g., https://github.com/gormankb), as well as the AOOS Research Workspace and DataONE repositories.

7. PROJECT STATUS OF SCHEDULED ACCOMPLISHMENTS

Project milestones and tasks by fiscal year and quarter, beginning February 1, 2022. Fiscal Year Quarters: 1= Feb. 1-April 30; 2= May 1-July 31; 3= Aug. 1-Oct. 31; 4= Nov. 1-Jan 31.

	FY22				FY23				FY24				FY25				FY26			
Milestone/Task	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Milestone 1. Retrospective analysis on salmon-herring co-occurrence and interactions in PWS (Objective 1)																				
Obtain additional data from past studies in PWS	X	X																		
Summarize/analyze data			X	X	X	X	X	X	X	X	X	X								
UAF Masters student					X	X	X	X	X	X	X	X								
Milestone 2. Conduct Field Surveys and Lab Work (Objectives 2 & 3)																				
Hiring field/lab techs - PWSSC	X	X			X	X			X	X			X	X			X	X		
Hiring field/lab techs - SSSC													X	X			X	X		
Purchase equipment/supplies/prep	X	X			X	X			X	X			X	X			X	X		
PWS offshore surface trawl survey		X				X				X				X				X		
PWS bay purse seine survey						X	X			X	X			X	X			X	X	
PWSSC lab work and working with lab contractors (plankton, diets, stomach DNA, salmon isotopes, salmon otoliths, salmon calorimetry, VEN sampling)			X	X	X		X	X	X		X	X	X		X	X	X		X	X
UAF lab work (herring and salmon isotopes, bulk and CSIA)							X	X	X		X	X	X		X	X	X		X	X
SSSC lab work (herring and salmon diets)							X	X	X		X	X	X		X	X	X		X	X
UAF Masters student					X	X	X	X	X	X	X	X								
Milestone 3. Annual Data Analysis (Objectives 2 & 3)																				
Analyze results from PWS trawl survey				X	X	X		X	X	X		X	X	X		X	X	X		X
Analyze results from PWS purse seine survey								X	X	X		X	X	X		X	X	X		X
Milestone 4. Data Analysis, modeling, synthesis (synthesis of all Objectives 1-4)																				
Synthesize field data, develop; bioenergetic model simulations, and forecast model development (support from PWSSC postdoc, funded separately)																	X	X	X	X
Reporting																				
Annual reports					X				X				X				X			
Deliverables																				
Peer reviewed paper												X				X				
Data posted online					X				X				X				X			

Milestone/Task	FY27				FY28				FY29				FY30				FY31			
	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Milestone 2. Conduct Field Surveys and Lab Work (Objectives 2 & 3)																				
Hiring field/lab techs – PWSSC	X	X																		
Hiring field/lab techs – SSSC																				
Purchase equipment/supplies/prep	X	X																		
PWS offshore surface trawl survey		X																		
PWS bay purse seine survey																				
PWSSC lab work and working with lab contractors (plankton, diets, stomach DNA, salmon isotopes, salmon otoliths, salmon calorimetry, VEN sampling)	X		X	X	X															
UAF lab work (herring and salmon isotopes, bulk and CSIA)	X																			
SSSC lab work (herring and salmon diets)	X																			
UAF Masters student																				
Milestone 3. Annual Data Analysis (Objectives 2 & 3)																				
Analyze results from PWS trawl survey	X	X		X	X	X														
Analyze results from PWS purse seine survey	X	X																		
Milestone 4. Data Analysis, modeling, synthesis (synthesis of all Objectives 1-4)																				
Synthesize field data, develop bioenergetic model simulations, and forecast model development (support from PWSSC postdoc, funded separately)	X	X	X	X	X	X	X	X												
Reporting																				
Annual reports	X				X															
Final report									X											
Deliverables																				
Peer reviewed paper							X	X												
Data posted online	X				X				X											

8. Budget

A. Budget Forms (Attach)

Please see Gulf Watch Alaska Long-Term Research and Monitoring workbook.

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	
Travel	$11,223	$15,539	$14,459	$11,998	$10,764	$63,983	
Contractual	$65,706	$98,644	$100,119	$98,774	$97,674	$460,917	
Commodities	$12,050	$4,250	$4,250	$4,250	$3,250	$28,050	
Equipment	$22,000	$22,775	$23,913	$2,000	$0	$70,688	
Indirect Costs (varies by proposer)	$7,755	$22,032	$22,218	$16,441	$13,723	$82,168	
SUBTOTAL	$231,033	$364,711	$371,613	$318,527	$307,888	$1,593,773	
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	

Budget Category:	Proposed FY 27	Proposed FY 28	Proposed FY 29	Proposed FY 30	Proposed FY 31	5-YR TOTAL PROPOSED	ACTUAL CUMULATIVE	TEN YEAR TOTAL
Personnel	$138,043	$60,433	$0	$0	$0	$198,476		$1,086,442
Travel	$12,127	$8,599	$0	$0	$0	$20,726		$84,709
Contractual	$58,602	$10,100	$0	$0	$0	$68,702		$529,619
Commodities	$2,392	$0	$0	$0	$0	$2,392		$30,442
Equipment	$0	$0	$0	$0	$0	$0		$70,688
Indirect Costs (varies by proposer)	$13,130	$7,776	$0	$0	$0	$20,905		$103,074
SUBTOTAL	$224,294	$86,907	$0	$0	$0	$311,201		$1,904,974
General Administration (9% of subtotal)	$20,186	$7,822	$0	$0	$0	$28,008	N/A	$171,448
PROJECT TOTAL	$244,480	$94,729	$0	$0	$0	$339,209		**$2,076,422**
Other Resources (In-Kind Funds)	$0	$0	$0	$0	$0	$0		**$0**

B. Sources of Additional Funding

Non-EVOSTC Funds to be used, please include source and amount per source:

FY22	FY23	FY24	FY25	FY26	FY22-26 Total
$0	$0	$0	$0	$0	$0
FY27	**FY28**	**FY29**	**FY30**	**FY31**	**FY27-31 Total**
$0	$0	$0	$0	$0	$0
				FY22-31 Total	$0

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Rand, P. S., D. J. Steward, B. F. Lantry, L. G. Rudstam, O. E. Johannsson, A. P. Goyke, S. B. Brandt, R. O'Gorman, and G. W. Eck. 1995. Effect of lake-wide planktivory by the pelagic prey fish community in Lakes Michigan and Ontario. Canadian Journal of Fisheries and Aquatic Sciences 52:1546-1563.

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Sewall, F., B. L. Norcross, and R. A. Heintz. 2021 in press. Growth, Condition, and Swimming Performance of Juvenile Pacific Herring with Winter Feeding Rations. Canadian Journal of Fisheries and Aquatic Sciences. 10.1139/cjfas-2020-0293.

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Stokesbury, K. D. E., J. Kirsch, E. V. Patrick, and B. L. Norcross. 2002. Natural mortality estimates of juvenile Pacific herring (*Clupea pallasi*) in Prince William Sound, Alaska. Canadian Journal of Fisheries and Aquatic Sciences 59:416-423.

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Suryan, R. M., M. L. Arimitsu, H. A. Coletti, R. R. Hopcroft, M. R. Lindeberg, S. J. Barbeaux, S. D. Batten, W. J. Burt, M. A. Bishop, J. L. Bodkin, R. Brenner, R. W. Campbell, D. A. Cushing, S. L. Danielson, M. W. Dorn, B. Drummond, D. Esler, T. Gelatt, D. H. Hanselman, S. A. Hatch, S. Haught, K. Holderied, K. Iken, D. B. Irons, A. B. Kettle, D. G. Kimmel, B. Konar, K. J. Kuletz, B. J. Laurel, J. M. Maniscalco, C. Matkin, C. A. E. McKinstry, D. H. Monson, J. R. Moran, D. Olsen, W. A. Palsson, W. S. Pegau, J. F. Piatt, L. A. Rogers, N. A. Rojek, A. Schaefer, I. B. Spies, J. M. Straley, S. L. Strom, K. L. Sweeney, M. Szymkowiak, B. P. Weitzman, E. M. Yasumiishi, and S. G. Zador. 2021. Ecosystem response persists after a prolonged marine heatwave. Scientific Reports 11:6235.

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Trochta, J., and T. Branch. 2021 in review. This clears up nothing! Applying multiple Bayesian model selection criteria to ecological covariates in stock assessment. ICES Journal of Marine Science.

Wainwright, T. C. 2021. Ephemeral relationships in salmon forecasting: A cautionary tale. Progress in Oceanography 193:102522.

Walters, C. J., R. Hilborn, R. M. Peterman, and M. Staley. 1978. A model for examining early ocean limitation of Pacific salmon production. Journal of the Fisheries Research Board of Canada 35:1303-1315.

Ward, E. J., M. Adkison, J. Couture, S. C. Dressel, M. A. Litzow, S. Moffitt, T. Hoem Neher, J. Trochta, and R. Brenner. 2017. Evaluating signals of oil spill impacts, climate, and species interactions in Pacific herring and Pacific salmon populations in Prince William Sound and Copper River, Alaska. Plos One 12:e0172898.

Wertheimer, A. C., J. A. Orsi, E. A. Fergusson, and M. V. Sturdevant. 2013. Forecasting Pink Salmon Harvest in Southeast Alaska from Juvenile Salmon Abundance and Associated Biophysical Parameters: 2012 Returns and 2013 Forecast. NPAFC Doc. 1486, 23 pp.

Whiteman, J. P., E. A. Elliott Smith, A. C. Besser, and S. D. Newsome. 2019. A guide to using compound-specific stable isotope analysis to study the fates of molecules in organisms and ecosystems. Diversity 11:8.

Willette, M. 1996. Impacts of the Exxon Valdez oil spill on the migration, growth, and survival of juvenile pink salmon in Prince William Sound. American Fisheries Society Symposium 18:533-550.

Willette, T. M. 2001. Foraging behaviour of juvenile pink salmon (*Oncorhynchus gorbuscha*) and size-dependent predation risk. Fisheries Oceanography:110–131.

Willette, T. M., R. T. Cooney, V. Patric, D. M. Mason, G. L. Thomas, and D. Scheel. 2001. Ecological processes influencing mortality of juvenile pink salmon (*Oncorhynchus gorbuscha*) in Prince William Sound, Alaska. Fisheries Oceanography 10:14-41.

10. PROJECT PERSONNEL

Peter S. Rand, Ph.D.

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EDUCATIONAL BACKGROUND

Colgate University, Biology, B.A., 1987
SUNY College of Environmental Science and Forestry, Ecology, M.S., 1990
SUNY College of Environmental Science and Forestry, Ecology, Ph.D., 1994
University of British Columbia, Fisheries Science, Postdoctoral Fellow, 1995-1997

ACADEMIC/PROFESSIONAL WORK EXPERIENCE

Research Ecologist, Prince William Sound Science Center (2015-present)
Senior Conservation Biologist (2003-2015), Wild Salmon Center
Assistant Professor (1997–2003), Department of Zoology, North Carolina State University.

TEN RECENT PUBLICATIONS

1. E.E. Knudsen, **P.S. Rand**, K.B. Gorman, D. Bernard, and W.D. Templin. 2021. Hatchery-origin stray rates and total run characteristics for pink salmon and chum salmon returning to Prince William Sound, Alaska in 2013-2015. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 13:58–85. DOI: 10.1002/mcf2.10134.
2. Fukushima, M., and **P.S. Rand**. 2021. High rates of consecutive spawning and precise homing in Sakhalin taimen (*Parahucho perryi*). Environmental Biology of Fishes 104:41-52.
3. Connors, B., M.J. Malick, G.T. Ruggerone, **P.S. Rand**, M. Adkison, J.R. Irvine, R. Campbell, and K. Gorman. 2020. Climate and competition influence sockeye salmon population dynamics across the Northeast Pacific Ocean. Canadian Journal of Fisheries and Aquatic Sciences 77(6): 943-949.
4. Farley, E.V., J.M. Murphy, K. Cieciel, K. Howard, E.M. Yasumiishi, K. Dunmall, T. Sformo, and **P.S. Rand**. 2020. Response of pink salmon to climate warming in the northern Bering Sea. Deep Sea Research II.
5. **Rand, P.S.** 2018. Pacific herring response to surface predators in Prince William Sound, Alaska, USA. Marine Ecology Progress Series 600:239-244.
6. **Rand, P.S.,** and M. Fukushima. 2014. Estimating the size of the spawning population and evaluating environmental controls on migration for a critically endangered Asian salmonid, Sakhalin taimen. Global Ecology and Conservation 2:214-225.
7. Rand, P.S., M. Goslin, M.R. Gross, J.R. Irvine, X. Augerot, et al. 2012. Global Assessment of Extinction Risk to Populations of Sockeye Salmon Oncorhynchus nerka. PLoS ONE 7(4): e34065. doi:10.1371/journal.pone.0034065
8. **Rand, P.S.**, B.A. Berejikian, T.N. Pearsons, and D.L.G. Noakes. 2012. Ecological interactions between wild and hatchery salmonids: an introduction to the special issue. Environmental Biology of Fishes. DOI 10.1007/s10641-012-9987-3
9. **Rand, P.S.**, B.A. Berejikian, A. Bidlack, D. Bottom, J. Gardner, M. Kaeriyama, R. Lincoln, M. Nagata, T. Pearsons, M. Schmidt, W. Smoker, L. Weitkamp, and L. Zhivotovsky. 2012. Ecological interactions

between wild and hatchery salmonids and key recommendations for research and management actions in selected regions of the North Pacific. 94(1):343-358.

10. Zimmerman, C.E., **P.S. Rand**, M. Fukushima, and S.F. Zolotukhin. 2011. Reconstructing migratory and growth histories of Sakhalin taimen (*Parahucho perryi*). Environmental Biology of Fishes DOI 10.1007/s10641-011-9908-x

FIVE OTHER SIGNIFICANT PUBLICATIONS

1. Taylor, J.C., **P.S. Rand**, and J. Jenkins. 2007. Swimming behavior of juvenile anchovies (Anchoa spp.) in an episodically hypoxic estuary: implications for individual energetics and trophic dynamics. Mar. Biol. 152(4):939-957.
2. **Rand, P.S.**, S.G. Hinch, J. Morrison, M.G.G. Foreman, M.J. MacNutt, J.S. Macdonald, M.C. Healey, A.P. Farrell, and D.A. Higgs. 2006. Effects of changes to river discharge, temperature and future climate on energetics and mortality of adult migrating Fraser River sockeye salmon. Transactions of the American Fisheries Society. 135:655-667.
3. **Rand, P.S.** 2002. Modeling stomach fullness and growth potential of sockeye salmon in the Gulf of Alaska: Implications for high seas distribution and migration. Mar. Ecol. Prog. Ser. 234:265-280.
4. **Rand, P.S.** and D.J. Stewart. 1998. Prey fish exploitation, salmonine production, and pelagic food web efficiency in Lake Ontario. Can. J. Fish. Aquat. Sci 55(2):318-327
5. **Rand, P.S.**, D.J. Stewart, B.F. Lantry, L.G. Rudstam, O.E. Johannsson, A.P. Goyke, S.B. Brandt, R. O'Gorman, and G.W Eck. 1995. Effect of lake-wide planktivory by the pelagic prey fish community in Lakes Michigan and Ontario. Can. J. Fish. Aquat. Sci. 52(7):1546-1563.

AWARDS/SPECIAL RECOGNITION/HONORS

Chair, IUCN Salmonid Specialist Group
Fulbright Award, Japan Program
Research Fellowship Award, Japan Society for the Promotion of Science
Robert L. Kendall Publication Award, Best Paper in Transactions of American Fisheries Society
James W. Moffett Publication Award, Most Significant Paper, US Geological Survey

RESEARCH COLLABORATORS (last 4 years)

L. Adelfio (USFS), M. Adkison (UAF), H. Araki (U Hokkaido), D. Bernard (ADF&G, ret.), R. Campbell (PWSSC), K. Cieciel (NOAA), B. Connors (DFO), K. Dunmall (DFO), E. Farley (NOAA), M. Fukushima (NIES), K. Gorman (UAF), K. Howard (ADF&G), J. Irvine (DFO), M. Kaeriyama (U Hokkaido), E. Knudsen (PWSSC), T. Linley (PNNL), M. Malick (NOAA), N. Mantua (NOAA), K. Miller (DFO), J. Murphy (NOAA), M. Piche (NVE), G. Reeves (USFS), G. Ruggerone (NRC), D. Schindler (UW), J. Savereide (ADF&G).T. Sformo (North Slope Bureau), M. Sloat (WSC), W. Templin (ADF&G), P. Westley (UAF), S. Wondzell (USFS), E.M. Yasumiishi (NOAA).

Robert William Campbell

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EDUCATION

Doctor of Philosophy, University of Victoria, School of Earth and Ocean Sciences (1999-2003)

Thesis: "Overwintering ecology of Neocalanus plumchrus"

Master of Science, Biology, Dalhousie University (1996-1998)

Thesis: "Reproduction of Calanus finmarchicus in the western North Atlantic: fecundity and hatching success"

Bachelor of Science (Hons), Biology, University of Toronto (1991-1996)

Thesis: "Simulation and bioenergetic modeling of Walleye (Stizostedion v. vitreum) populations"

APPOINTMENTS

2020 – present	Chief Science Officer, Prince William Sound Science Center
2007 – present	Oceanographer, Prince William Sound Science Center
2010 – present	Affiliate faculty, University of Alaska Anchorage
2004-2006	Post-doctoral researcher, University of Hamburg, Germany

RECENT RELEVANT PUBLICATIONS

Arimitsu, M., Piatt, J., Hatch, S., Suryan, R.M., Batten, S., Bishop, MA, Campbell, R.W., Coletti, H., Cushing, D., Gorman, K., Hopcroft, R., Kuletz, K.J., Marsteller, C.M., McKinstry, C., McGowan, D., Moran, J., Pegau, W.S., Schaefer, A., Schoen, S., Straley, J. and V.R. von Biela. 2021. Heatwave-induced synchrony within forage fish portfolio disrupts energy flow to top pelagic predators. Global Change Biol, doi: 10.1111/gcb.15556

Suryan, R.M., Arimitsu,M.L., Coletti, H.A., Hopcroft, R.R., Lindeberg, M.R., Barbeaux, S.J., Batten, S.D., Burt, W.J., Bishop, MA, Bodkin, J.L., Brenner, R., Campbell, R.W., Cushing, D.A., Danielson, S.L., Dorn, M.W., Drummond, B., Esler,D., Gelatt, T., Hanselman, D.H., Hatch, S.A., Haught, S., Holderied, K., Iken, K., Irons, D.B., Kettle, A., Kimmel, D.G., Konar, B., Kuletz, K.J., Laurel, B.J., Maniscalco, J.M., Matkin, C., MckKinstry, C.A.E., Monson, D.H., Moran, J.R., Olsen,D., Palsson, W.A., Pegau, W.S., Piatt, J.F., Rogers, L.A., Rojek, N., Schaefer, A., Spies,I.B., Straley, J.M., Strom, S.L., Sweeney, K.L., Szymkowiak, M., Weitzman, B.P., Yasumiishi, E.M. and S.G. Zador. 2021. Ecosystem response persists after a prolonged marine heatwave. Sci. Rep. 11:6235. doi: 10.1038/s41598-021-83818-5.

Campbell, R.W., Roberts, P.L. and J. Jaffe. 2020. The Prince William Sound Plankton Camera: a profiling in situ observatory of plankton and particulates. ICES J. Mar. Sci. doi:10.1093/icesjms/fsaa029.

Tomco, P.L., Zulueta, R.C., Miller, L.C., Zito, P.A., Campbell, R.W. and J.M. Welker. 2019. DOC export is exceeded by C fixation in May Creek: A late successional watershed of the Copper River Basin, Alaska. PLoS ONE 14(11): e0225271. https://doi.org/10.1371/journal.pone.0225271

Campbell, R.W. 2018. Hydrographic trends in Prince William Sound, Alaska, 1960–2016. Deep Sea Res. doi: 10.1016/j.dsr2.2017.08.014

McKinstry, C.A.E., and R.W. Campbell. 2018. Seasonal variation of zooplankton abundance and community structure in Prince William Sound, Alaska, 2009–2016. Deep Sea Res. doi: 10.1016/j.dsr2.2017.08.016

Crusius, J., Schroth, A.W., Resing, J.A., Cullen, J. and R.W. Campbell. 2017. Seasonal and spatial variabilities in the northern Gulf of Alaska surface water iron concentrations driven by shelf sediment resuspension, glacial meltwater, a Yakutat eddy, and dust. Global Biogeochemical Cycles. Doi: 10.1002/2016GB005493

Batten, S.D., Moffitt, S., Pegau, W.S. and R. Campbell. 2016. Plankton indices explain interannual variability in Prince William Sound herring first year growth. Fisheries Oceanography 25:420-434. doi: 10.1111/fog.12162

Schroth, A.W., Crusius, J., Hoyer, I. and R. Campbell. 2013. Estuarine removal of glacial iron and implications for iron fluxes to the ocean. Geophysical Research Letters. doi: 10.1002/2014GL060199.

Other Publications

Kattner, G., Hagen, W., Lee, R.F., Campbell, R.W., Deibel, D., Falk-Petersen, S., Graeve, M., Hansen, B.W., Hirche, H.J., Jonasdottir, S.H., Madsen, M.L., Mayzaud, P., Müller-Navarra, D., Nichols, P., Paffenhöffer, G.A., Pond, D., Saito, H., Stübing, D., and P. Virtue. 2007. Perspectives on zooplankton lipids. Can. J. Fish. Aquat. Sci. 64:1628-1639.

Irigoien, X., Harris, R.P., Verheye, H.M., Joly, P., Runge, J.A., Starr, M. Pond, D., Campbell, R.W., Shreeve, R., Ward, P., Smith, A.N., Dam, H.G., Napp, J., Peterson, W., Tirelli, V., Koski, M., Smith, T., Harbour, D., Strom, S. and R. Davidson. 2002. Copepod Hatching Success Rate in Marine Ecosystems With with High Diatom Concentrations - the Paradox of Diatom-Copepod Interactions Revisited. Nature. 419:387-389.

Mackas, D., et. al. 2013. Zooplankton time series from the Strait of Georgia: Results from year-round sampling at deep water locations, 1990–2010. Progress in Oceanography. 115:129-159.

Campbell, R.W and J.F. Dower. 2008. Life history and depth distribution of Neocalanus plumchrus in the Strait of Georgia. J. Plankton Res. 30:7-20.

Recent Collaborators (exclusive of co-authors already listed above)

Causey, Doug (UAA); Doroff, Angela (UAA); Gassó , Santiago (NASA); Gorman, Kristen (UAF); Heintz, Ron (NOAA, ret.); Rand, Pete (PWSSC); Sewall, Fletcher (NOAA); Sorum, Alan (PWSRCAC); Thomas, Andrew (U Maine); West, Mick (Ga. Tech)

Biographical Sketch
Ron Heintz. Research Director, Sitka Sound Science Center

Professional Preparation:

University of Illinois, Urbana IL	Ecology Ethology and Evolution B.Sc.	1979
University of Alaska, Fairbanks AK	Fisheries Biology M.Sc.	1985
University of Alaska, Fairbanks AK	Fisheries Biology Ph.D.	2010

Appointments
Present: Research Director Sitka Sound Science Center – Oversee research portfolio for the Sitka Sound Science Center, plan and develop research programs, identify and develop research partnerships, ensure completion of existing programs
2019- 2013: Program Manager NOAA Alaska Fisheries Science Center (AFSC)– Lead and supervise 24 scientists and contractors in the Recruitment Energetics and Coastal Assessment Program. The program conducted original research into the trophic ecology of forage fish in the Gulf of Alaska, Bering Sea and U.S. Arctic, monitored Prince William Sound for the presence of lingering *Exxon Valdez* oil, conducted surveys to evaluate the abundance and distribution of fish in near shore habitats and developed indicators of ecosystem status for large marine ecosystems in Alaska in conjunction with fishery oceanographic surveys.
2013 – 2000: Research Biologist Nutritional Ecology Laboratory, NOAA, Alaska Fisheries Science Center – Developed a bioenergetics research group ultimately consisting of 7 scientists and contractors. Research focused on cataloging the nutritional quality of Steller Sea Lion prey in the Gulf of Alaska, understanding the lipid phenology in forage species, and characterizing the nutritional subsidies to freshwater habitats offered by salmon returning to spawn.
1992 to 2000 - Research Biologist NOAA Alaska Fisheries Science Center - Conducted original research establishing the teratogenic effects of crude oil on fish embryos following the *Exxon Valdez* oil spill. Managed a database cataloging hydrocarbon concentrations in sediments, water and biota collected by Trustee scientists following the spill, helped to develop an algorithm for fingerprinting *Exxon Valdez* oil in sediments, water and biota.
1985 to 1995 - Research Biologist NOAA Alaska Fisheries Science Center – Conducted original research into the culture of Chinook Salmon at a remote research hatchery in southeastern Alaska. Developed methods for rearing fish to maturity in captivity and researched the optimal size at release for hatchery reared Chinook salmon.

Products related to this proposal
2018 – Invited by the Korean National Park Service to speak at the 10th Anniversary of the Hebei Spirit Symposium, Incheon S Korea
2018 – Guest Editor for Deep Sea Research II Special Issue on Lessons Learned from the *Exxon Valdez* Oil Spill
2017 – Guest Editor for Environmental Biology of Fishes Special Issue - New perspectives on the feeding ecology and trophic dynamics of fishes
2015 – Gold Medal for Scientific/Engineering Achievement awarded by Secretary of Commerce for work conducted on the Bering Sea Integrated Ecosystem Research Project

Other Research Products
I have authored or co-authored more than 70 peer-reviewed reports and completed more than 10 contract reports. Selected reports are listed below:

Sewall, F., B. Norcross, J. Vollenweider, and **R. Heintz**. 2019. Growth, energy storage, and feeding patterns reveal winter mortality risks for juvenile Pacific herring in Prince William Sound, Alaska, USA. Marine Ecology Progress Series 623:195-208.

Gorman, K. B., T. C. Kline, M. E. Roberts, F. F. Sewall, **R. A. Heintz**, and W. S. Pegau. 2018. Spatial and temporal variation in winter condition of juvenile Pacific herring (*Clupea pallasii*) in Prince William Sound, Alaska: Oceanographic exchange with the Gulf of Alaska. Deep-Sea Research Part II-Topical Studies in Oceanography 147:116-126.

Heintz, RA, E.C. Siddon, E.V. Farley and J. Napp. 2013. Correlation between recruitment and fall condition of age-0 pollock (*Theragra chalcogramma*) from the eastern Bering Sea under varying climate conditions. Deep Sea Research II 94:150-156.

Hunt, G. L. Jr., K. O. Coyle, L. Eisner, E. V. Farley, **R. A. Heintz**, F. Mueter, F. M. Napp, J. E. Overland, P. H. Ressler, S. Salo and P. J. Stabeno. 2011. Climate impacts on eastern Bering Sea food webs: A synthesis of new data and an assessment of the Oscillating control Hypothesis. ICES Journal of Marine Science. 68(6):1230-1243. DOI:10.1093/icesjms/fsr036

Heintz, R. A., S. D. Rice, et al. 2000. Delayed effects on growth and marine survival of pink salmon *Oncorhynchus gorbuscha* after exposure to crude oil during embryonic development. Marine Ecology Progress Series 208: 205-216.

Synergistic Activities

Ongoing - Participant in multiple graduate committees, currently on 2 Ph.D. committees at the University of Alaska Fairbanks and University of Idaho.

2018 – Convened special session on the impact of the *Exxon Valdez* on our current understanding of oil spill impacts at the Alaska Marine Sciences Symposium.

2013- 2017 Led multi-agency group characterizing ecological processes in Arctic lagoons near Point Barrow, Alaska

2016 – Convened a workshop on stomach content analysis at the American Fisheries Society Annual meeting. Workshop was published as a special issue of the Environmental Biology of Fishes.

2015-2019 - Senior Staff member of the North Slope Science Initiative

Research Interests

I have spent the last few decades conducting research in Alaska in a variety of fields ranging from aquaculture to toxicology and forage fish ecology. I have developed a deep understanding of the relationship between Alaska's fishing communities and the surrounding marine ecosystems. My current research interests are in applying this knowledge to diversify the economies of Alaska's fishing communities in order to increase their resilience in the face of warming conditions. The recent heat wave in the Gulf of Alaska demonstrated the extent to which Alaskans will need to adapt. My interests now lie in understanding how Alaskans will maintain food security and traditional livelihoods in the face of climate change.

Graduate Advisor

M.Sc. – Dr. William Smoker, University of Alaska, Fairbanks (retired)

Ph.D. – Dr. Michael Stekoll, University of Alaska, Fairbanks (retired)

Biographical Sketch
Kristen B. Gorman

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College of Fisheries and Ocean Sciences
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Fairbanks, Alaska 99775

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Professional Preparation

Dickinson College, Carlisle, PA	Biology	BS (1996)
Simon Fraser University Vancouver, Canada	Ecology & Evolutionary Biology	MSc (2005)
Simon Fraser University Vancouver, Canada	Ecology & Evolutionary Biology	PhD (2015)

Appointments

2018 Research Assistant Professor. University of Alaska Fairbanks, College of Fisheries and Ocean Sciences, Department of Marine Biology. Fairbanks, AK.

2014 Research Ecologist. Prince William Sound Science Center. Cordova, AK.

Publications (10 most relevant)

McMahon, J. **K.B. Gorman**, E.E. Knudsen, and P.A.H. Westley. *In prep, 2021*. Stable isotopes suggest trophic overlap between maturing adult hatchery and wild pink salmon in Prince William Sound, Alaska. *Marine Ecology Progress Series.*

Gorman, K.B., T.D. Williams and W.R. Fraser. *In prep, 2021*. Trophic interactions and individual variation in reproductive performance among *Pygoscelis* penguins at opposing range margins, part I. *In submission to Marine Ecology Progress Series.*

Heintz, R.A., **K.B. Gorman**, T.C. Kline Jr., F.F. Sewall, and W.S. Pegau. *In prep, 2021*. Influence of size on energy loss, ration size, and body composition in overwintering juvenile Pacific herring. *Journal of Experimental Marine Biology and Ecology.*

Guo, C. B. Konar, C. Walker, and **K. Gorman**. *In review, Feb 2021*. Environmental factors important to high-latitude nearshore estuarine fish community structure. *Deep-Sea Research II*.

Gorman, K.B., K.E. Ruck, T.D. Williams and W.R. Fraser. *In press, July 2021.* Advancing the sea ice hypothesis: trophic interactions among breeding *Pygoscelis* penguins with divergent population trends throughout the western Antarctic Peninsula. *Frontiers in Marine Science*.

Arimitsu, M., J. Piatt, S. Hatch, R.M. Suryan, S. Batten, M.A. Bishop, R.W. Campbell, H. Coletti, D. Cushing, **K. Gorman**, R.R. Hopcroft, K.J. Kuletz, C. Marsteller, C. McKinstry, D. McGowan, J. Moran, W.S. Pegau, A. Schaefer, S. Schoen, J. Straley, and V.R. von Biela. *In press, Feb 2021.* Heatwave-induced synchrony within forage fish portfolio disrupts energy flow to top pelagic predators. *Global Change Biology*, doi: 10.1111/gcb.15556.

Knudsen, E.E., P.S. Rand, **K.B. Gorman**, D.R. Bernard, and W.D. Templin. 2021. Hatchery-origin stray rates and total run characteristics for Pink Salmon and Chum Salmon returning to Prince William Sound, Alaska in 2013-2015. *Marine and Coastal Fisheries* 13:58-85. doi: 10.1002/mcf2.10134.

Connors, B., M. Malick, G. T. Ruggerone, P. Rand, M. Adkison, J. R. Irvine, R. Campbell, and **K. Gorman**. 2020. Climate and competition shape sockeye salmon population dynamics across the Northeast Pacific Ocean. *Canadian Journal of Fisheries and Aquatic Sciences* 77: 943–949.

Gorman, K.B., T.C. Kline Jr., M.E. Roberts, F.F. Sewall, R.A. Heintz, and W.S. Pegau. 2018. Spatial and temporal variation in winter condition of juvenile Pacific herring (*Clupea pallasii*) in Prince William Sound, Alaska: oceanographic exchange with the Gulf of Alaska. *Deep-Sea Research II* 147:116-126.

Gorman, K.B., T.D. Williams, and W.R. Fraser. 2014. Ecological sexual dimorphism and environmental variability within a community of Antarctic penguins (genus *Pygoscelis*). *PLoS ONE* 9(3): e90081.

Bestelmeyer, B.T., A.M. Ellison, W.R. Fraser, **K.B. Gorman**, S.J. Holbrook, C.M. Laney, M.D. Ohman, D.P.C. Peters, F.C. Pillsbury, A. Rassweiler, R. Schmitt, and S. Sharma. 2011. Analysis of abrupt transitions in ecological systems. *Ecosphere* 2(12):art129.

Other Publications and Products (5)

Horst, A.M., A.P. Hill, and **K.B. Gorman**. 2020. palmerpenguins: Palmer Archipelago (Antarctica) penguin data. R package version 0.1.0. https://allisonhorst.github.io/palmerpenguins/. doi: 10.5281/zenodo.3960218.

Gorman, K.B., S.L. Talbot, S.A. Sonsthagen, G.K. Sage, M.C. Gravely, W.R. Fraser and T.D. Williams. 2017. Population genetic structure and gene flow of Adélie penguins (*Pygoscelis adeliae*) breeding throughout the western Antarctic Peninsula. *Antarctic Science* 29(6):499-510.

Crossin, G.T., P.N. Trathan, R.A. Phillips, **K.B. Gorman,** A. Dawson, K.Q. Sakamoto, and T.D. Williams. 2012. Corticosterone predicts foraging behavior and parental care in macaroni penguins. *The American Naturalist* 180(1):E31-E41.

Gorman, K.B., D. Esler, R.L. Walzem, and T.D. Williams. 2009. Plasma yolk precursor dynamics during egg production by female Greater Scaup *(Aythya marila*): characterization and indices of reproductive state. *Physiological and Biochemical Zoology* 82(4):372-381.

Gorman, K.B., D. Esler, P.L. Flint, and T.D. Williams. 2008. Nutrient reserve dynamics during egg production by female Greater Scaup (*Aythya marila*): relationships with timing of reproduction. *Auk* 125(2):384-394.

Synergistic Activities (3 of 6 current projects)

Lead PI. Are expanding Pacific salmon populations in the Arctic produced from regional watersheds? Coastal Marine Institute/BOEM. 2020-2022.

Lead PI. Using otolith geochemistry to understand the ocean ecology of a changing Alaskan salmon system. National Science Foundation. 2020-2021.

co-PI. Implications of a declining trend in body size and condition on abundance of Sockeye Salmon in the Copper River, Alaska. North Pacific Research Board. 2019-2021.

Collaborators (last 48 months)

M. Adkison (UAF), M. Arimitsu (USGS), S. Batten (Alister Hardy Foundation), D. Bernard (ADF&G, retired), M.A. Bishop (PWSSC), R. Campbell (PWSSC), H. Coletti (NPS), B. Connors (DFO Canada), D. Cushing (Pole Star Ecological Research), K. Elliot (McGill U), W. Fraser (Polar Oceans Res Group), M. Gravely (USGS), C. Guo (UAF), S. Hatch (Institute for Seabird Research and Conservation), S. Haught (ADF&G), R. Heintz (NOAA), R.R. Hopcroft (UAF), J.R. Irvine (DFO Canada), T. Kline Jr. (PWSSC), E. Knudsen (USGS, retired), B. Konar (UAF), K.J. Kuletz (USFWS), T. Linley (PNNL), M. Malick (OSU), C. Marsteller (USGS), D. McGowan (NOAA), C. McKinstry (PWSSC), J. McMahon (UAF), K. Miller (DFO Canada), J. Moran (NOAA), S. Pegau (OSRI, PWSSC), J. Piatt (USGS), P. Rand (PWSSC), K. Ruck (VIMS), G.T. Ruggerone (NRC, Inc), K. Sage (USGS), F. Sewall (NOAA), A. Schaefer (PWSSC), S. Schoen (USGS), T. Sformo (North Slope Borough), S. Sonsthagen (USGS), J. Straley (UAS), R.M. Suryan (NOAA), S. Talbot (USGS), W.D. Templin (ADF&G), V.R. von Biela (USGS), C. Walker (Kachemak Bay Reserve), P.A.H. Westley (UAF), T. Williams (Simon Fraser U).

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August 9, 2021

To: Mandy Lindeberg - NOAA, GWA-LTRM Program Lead
Shiway Wang, EVOSTC Executive Director

Re: ***Letter of Commitment***

We are pleased to provide this letter of commitment for the proposed project "Ecological interactions between Pacific herring and Pacific salmon in Prince William Sound, Alaska", project number 22220111-I that is part of the Herring Research and Monitoring Component of the Gulf Watch Alaska Long-Term Research and Monitoring (GWA-LTRM) program and is led by principal investigator (PI), Peter S. Rand, Ph.D.

This proposal was drafted by the PI in response to the EVOSTC's FY22-31 Invitation for Proposals and subsequent request for final submission on August 13, 2021. The cost for this project over a ten-year period will be $1,904.974K (without EVOSTC GA). There are no outside matching funds listed.

This project proposal is part of the larger multi-agency GWA-LTRM program proposal package. This proposal is designed to ensure sharing of the Herring Research and Monitoring program results with the State's fisheries managers and other scientists.

Sincerely,

Katrina Hoffman, President & CEO
Authorized Representative of Prince William Sound Science Center
khoffman@pwssc.org 907-424-5800

RESILIENCE: OUR PATH TO THE FUTURE

UAF
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July 29, 2021

To: Mandy Lindeberg - NOAA, GWA-LTRM Program Lead
Katrina Hoffman - PWSSC, President and CEO
Shiway Wang, EVOSTC Executive Director

Re: Letter of Commitment

We are pleased to provide this letter of institutional commitment for the following University of Alaska Fairbanks projects proposed as part of the Gulf Watch Alaska Long-Term Research and Monitoring program:

- 22120114-I, Oceanographic Station GAK-1 Long Term Monitoring of the Alaska Coastal Current, principal investigator (PI) Seth Danielson, $1,558,434
- 22120114-H, Nearshore Ecosystems in the Gulf of Alaska, PIs Katrin Iken and Brenda Konar, $1,543,053
- 22120114-L, Seward Line, PIs Russell Hopcroft and Seth Danielson, $1,961,848
- 22220111-L, Ecological Interactions Between Pacific Herring and Pacific Salmon in Prince William Sound, PI Kristen Gorman, $426,792

This proposal was drafted by the PIs in response to the *Exxon Valdez* Oil Spill Trustee Council's (EVOSTC's) FY22-31 Invitation for Proposals and subsequent request for final submission on August 13, 2021. The costs listed above for each project are for the 10-year period from 2022 through 2031 and do not include EVOSTC general administration fees. UAF indirect costs have been included at the negotiated F&A rate for State of Alaska-sponsored, 25.0% of Modified Total Direct Costs.

These proposals represent a continued commitment of the successful long-term research and monitoring projects supported by the EVOSTC and various agencies and organizational investments.

Sincerely,

S. Bradley Moran, Dean
College of Fisheries and Ocean Sciences

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August 6, 2021

To: Mandy Lindeberg - NOAA, GWA-LTRM Program Lead
Katrina Hoffman - PWSSC, President and CEO
Shiway Wang, EVOSTC Executive Director

Re: Letter of Commitment

The Sitka Sound Science Center is pleased to participate in Project 22220111-I *Ecological interactions between Pacific herring and Pacific salmon in Prince William Sound, Alaska,* principle investigator Ron Heintz $115,896. The cost listed for the project is the total for fiscal years 2022 through 2028 and represents the cost to the Sitka Sound Science Center and does not include the 9% General Administration fee. Our indirect costs of 30.45% of the total direct cost was negotiated with the National Science Foundation. We can provide the letter the National Science Foundation stating the rate at your request. We recognize the value of Trustee Council science to the people of the Gulf of Alaska region and are pleased to be participating in your long-term and successful program.

Sincerely,

Lisa Busch

Executive Director

Sitka Sound Science Center