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

22120111-C: Modeling and stock assessment of Prince William Sound herring

Primary Investigator(s) and Affiliation(s)

Trevor A. Branch, Associate Professor, School of Aquatic and Fishery Sciences, University of Washington

Date Proposal Submitted

August 13, 2021

Project Abstract (maximum 300 words)

Pacific herring play a central role in the Prince William Sound ecosystem, and sustained valuable fisheries, but collapsed in 1993 and have not recovered. Rebuilding herring is a core goal of this program, and stock assessments are used to assess their past and present status to determine if fisheries can reopen safely. Over the past ten years we created a Bayesian age-structured assessment model (BASA), expanded it to fit to new time series and disease data, placed Prince William Sound herring in the context of global herring populations, and examined factors affecting recruitment, natural mortality, spawning location, and spawn timing in this population. Over the next ten years we propose to revise and expand BASA and conduct annual stock assessments of Prince William Sound herring. In addition, we propose to review best practices for managing highly variable fish populations and use this information to provide advice for management of Prince William Sound herring. The main tool we will use is a management strategy evaluation that comprises an operating model of truth that generates data mimicking those available in reality, the data are fed into BASA, and then a harvest control rule is used to set catches in the next year. By repeating this process, we can (1) evaluate different harvest control rules, (2) assess the trade-offs between cost and frequency of future surveys, (3) and test the robustness of the management system and BASA to misspecification. Unless higher priorities arise, we also propose to develop a spatial model of herring to capture key components of fishing, spawning, and movement; and to develop a simplified ecosystem model focusing on key competitors and predators (humpback whales, pink salmon, and pollock) to allow for more holistic predictions of herring abundance. Our proposal will provide useful advice to better manage Prince William Sound herring.

EVOSTC Funding Requested* (must include 9% GA)

FY22	FY23	FY24	FY25	FY26	FY22-26 Total
$141,717	$142,324	$157,049	$159,716	$164,729	$765,536
FY27	**FY28**	**FY29**	**FY30**	**FY31**	**FY27-31 Total**
$167,963	$166,322	$183,648	$186,650	$192,636	$897,219
				FY22-31 Total	*$1,662,756*

**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)

Key hypotheses and overall goals

1. Conduct annual stock assessments of Prince William Sound herring using the Bayesian age-structured stock assessment model (BASA).
2. Review best practices globally for managing highly variable fish populations.
3. Create a management strategy evaluation (MSE) framework for Prince William Sound herring.
4. Evaluate alternative harvest control rules for setting herring catches.
5. Evaluate tradeoffs between cost and frequency of surveys and other types of data collected for use in the stock assessment.
6. Test the robustness of the management process to misspecification in parameter values or relationships assumed in the stock assessment model.
7. Create a spatial model of Prince William Sound herring.
8. Create a model of intermediate complexity (MICE) that captures key interactions between humpback whales, pink salmon, Alaskan pollock, and herring.

Background and history

Stock assessments have been conducted on Prince William Sound herring over many years, most recently using a Bayesian age-structured stock assessment model (BASA) developed as part of this project (Muradian et al. 2017). The newest iteration of the model incorporates rapid and efficient Bayesian algorithms, enabling the assessment to be run in just a few hours (Monnahan et al. 2017, Monnahan & Kristensen 2018, Monnahan et al. 2019). In addition, the model now fits to a new age-1 aerial survey index, and after thorough simulation testing, incorporates disease data through seroprevalence (antibody) data (Trochta 2021, Trochta et al. in review).

The next step in this project involves ensuring that harvest control rules, data collection, and the assessment model itself are robust to uncertainty through the development of a management strategy evaluation (MSE) framework. An MSE involves modeling and testing key components of the management system: data collection (how are data collected, what data are available, and how frequently are data collected), stock assessment (what is the estimated status of the population), and the harvest control rule (how are catches set, and under what circumstances is the fishery closed). Testing in an MSE involves developing an **operating model** that acts as the underlying truth, but this truth is not known perfectly by the assessment or management team. Instead, **simulated data** (survey biomass indices, age composition, etc.) are generated with uncertainty from the operating model, and only these data can be used to assess the status of the population, thus mimicking the process in the real world where we only have access to uncertain data and are trying to infer the underlying truth. An **estimation model** (typically the stock assessment model) then assesses the status of the population from the generated data, and the resulting estimates of population status are fed into the **harvest control rule**, that sets where and how any catches will be taken from the population. The catches are fed back into the operating model ("truth") which is updated by one year, and the cycle repeats (generate data, run assessment, apply control rule, remove catches from the operating model) for a number of years, comprising one simulation. This process is repeated a large number of times (1000), with each such simulation differing in annual recruitment and drawing from the uncertainty in model parameter estimates in the operating model. Once the simulations are completed, **performance metrics** are used to assess the management system, typically including measures such as average short-term and long-term catch, proportion of years with fishery closures, variability in catch, population depletion, catch rates, and economic performance.

MSEs have been used in other fisheries and in whale populations to assess the performance of management systems, most often in deciding which harvest control rule provides the best balance between catch and depletion (Butterworth 2007, Plagányi et al. 2007, Punt & Donovan 2007, Rademeyer et al. 2007). In this context MSEs are often called "management procedures". For example, southern bluefin tuna catches are now set automatically every three years based on a harvest control rule thoroughly tested over the course of a decade of MSE simulations that were aimed at identifying a rule that would be robust to a variety of scenarios (Kurota et al. 2010, Hillary et al. 2016a, Hillary et al. 2016b).

Injured resources and services

Pacific herring in Prince William Sound is one of the key resources identified by the *Exxon Valdez* Oil Spill Trustee Council (EVOSTC) as injured by the oil spill. This proposal integrates multiple proposed components (aerial survey, acoustic survey, disease, salmon and pollock monitoring, humpback whales, age composition, genetics, and movements), to assess the current status of this population, and to ensure that future management is based on the best available scientific advice.

2. RELEVANCE TO THE INVITATION (maximum 300 words)

Management, assessment, and rebuilding of herring is at the core of the invitation and this proposal. Global reviews of harvest control rules, incorporation of uncertainty in setting catches, and performance metrics will ensure that herring management can be informed by current best scientific practices. The planned management strategy evaluation will ensure that any rules used for setting catches have been thoroughly simulation tested; are based on the best available science; and consider tradeoffs between jobs, food security, and community needs, while also maintaining a long-term sustainable herring population.

This proposal directly addresses the overarching goals of the long-term research and monitoring program: provide sound scientific products that inform management agencies and the public, monitor changes in herring stocks and their current status, and provide critical data to support EVOSTC-funded programs (all products will be annually deposited in the data management website for wide use).

In particular, this project has relevance to the following requirements listed by the EVOSTC: (1) support herring population modeling, (2) shed light on factors limiting the recovery of herring including top-down and bottom-up factors, (3) use retrospective studies and long-term data sets, (4) continue monitoring herring abundance, (5) include the role of disease, (6) examine the role of humpback predation, (7) assess the impacts of hatchery and wild pink salmon and other interacting species on herring, (8) predict factors that influence recruitment, and (9) continue to develop and refine the age-structured assessment model for future adoption and implementation by the Alaska Department of Fish and Game (ADF&G). The project also falls under the topic of continued synthesis and modeling.

Recipients of benefits from this research include fishing communities, ecological predators, management agencies, and of course the herring themselves.

3. PROJECT HISTORY (maximum 400 words)

This is a continuing project from the Herring Monitoring project "Modeling and stock assessment of Prince William Sound herring" (EVOSTC project 21120111-C). During the course of that project, three scientific papers were published, three more are currently in review, and one is in prep. In addition, two graduate students were funded and have graduated: MS: Melissa Muradian (Muradian 2015) and PhD: John Trochta (Trochta 2021); and three years of postdoc funding were used for David McGowan and Beatriz Dias combined. Numerous presentations were given at different fora including the Alaska Marine Science Symposium (AMSS), and many popular articles were written for Delta Sound Connections. In addition, principal investigator (PI) Branch communicates science in the project through active social media outreach on Twitter (@TrevorABranch), with 13,400 followers and 38 million views of his tweets during 2015-2020.

Key scientific outputs during the past ten years include the following: annual stock assessments of Prince William Sound herring (Muradian et al. 2017), which is the first Bayesian assessment of herring in the region. The model was continuously improved in terms of efficiency and applicability, including the following: (1) Converted the model from an Excel-based maximum likelihood model used by ADF&G to a Bayesian age-structured assessment model (BASA); (2) Changed the starting age in the model to 0 instead of 3 to fit to the new age-1 aerial survey index; (3) Investigated the impact of different assumptions about maturity and selectivity; (4) Updated the Bayesian algorithm to the No-U-Turn-Sampler (NUTS) algorithm to improve efficiency and reduce runtime; and (5) Estimated additional mortality from disease using seroprevalence data.

In addition to the work on the stock assessment, this project previously assessed the value of past sampling programs (Muradian et al. 2019); conducted a meta-analysis of all global herring catches, recruitment, and biomass trends to examine what factors lead to herring declines and failure to recover (Trochta et al. 2020); assessed key factors influencing mortality and recruitment in Prince William Sound herring (Trochta & Branch in review); simulation tested the usefulness of viral hemorrhagic septicemia virus (VHSV) antibody data in estimating disease mortality (Trochta et al. in review); incorporated antibody data into the stock assessment (Trochta et al. in review); assessed the spatial and timing shifts in spawn locations in Prince William Sound herring (McGowan et al. in review); and estimated which covariates best predict shifts in spatial timing of Prince William Sound herring spawning (Dias et al. in prep).

Each year, stock assessment results and other research findings were presented to the annual PI meetings, included in annual reports, presented at conferences, and uploaded to the data portal.

4. PROJECT DESIGN

A. Objectives

The key objectives of the proposed work are as follows:

1. Conduct annual stock assessments of Prince William Sound herring using BASA.

2. Review best practices globally for managing highly variable fish populations.
3. Create an MSE framework for Prince William Sound herring.
4. Use the MSE framework to evaluate alternative harvest control rules for setting herring catches.
5. Use the MSE framework to evaluate tradeoffs between cost and frequency of surveys and other types of data collected for use in the stock assessment.
6. Use the MSE framework to test the robustness of the management process to misspecification in parameter values or relationships assumed in the stock assessment model.
7. Create a spatial model of Prince William Sound herring that can account for subpopulation structure, and spatial structure in catches and spawning locations.
8. Create a model of intermediate complexity (MICE) that captures the most important predators and competitors of herring in Prince William Sound, adding humpback whales, pink salmon, and Alaskan pollock interactions to the herring model.

These objectives each directly further the EVOSTC's mission of recovering injured natural resources (named herring), accounting for species that rely on herring or compete with herring, and ecosystem services (fishing) resulting from herring, by improving the accuracy of herring stock assessments, and possibly identifying more effective harvest control rules. In addition, the modeling project integrates a wide variety of projects proposed for the next ten years, for example the monitoring efforts (aerial surveys, hydroacoustic surveys), ageing data, biological data (maturity and weight-at-age), disease collection, tagging, humpback whale surveys, and proposed surveys for pink salmon and pollock diet in Prince William Sound.

B. Procedural and Scientific Methods

1. Annual stock assessments of Prince William Sound herring

Conduct annual Bayesian stock assessments of Prince William Sound herring, updating with new data for the aerial milt survey, acoustic survey, proportions-at-age in the survey, and annual empirical weight-at-age. The assessment model would provide estimates of current spawning biomass and relative spawning biomass, annual recruitment, and the probabilities that spawning biomass is above key management reference points. Results would be reported annually to the project PI meetings; the results, input data, and BASA code for running the model will be posted to the data management website; and a 5-page executive summary of results made available in a format suitable for fishing industry, ADF&G managers, and other interested groups (e.g., Fig. 1).

The assessment model will be regularly updated to incorporate the latest advances in fisheries stock assessment, as was done over the past ten years during the long-term herring monitoring project under EVOSTC. Notably, as new methods are developed to detect the prevalence of diseases such as VHSV and *Ichthyophonus*, these data could be included directly in the stock assessment, given promising simulation testing and the inclusion of antibody data in the stock assessment (Trochta 2021).

The annual stock assessments could also be run by ADF&G scientists with a suitable background in AD Model Builder and Bayesian age-structured models. In the past we have conducted informal trainings with a select group of biometricians, and we anticipate this will continue, such that by the end of the project, annual Prince William Sound stock assessments could be run by ADF&G using BASA. In addition, a "how-to" manual will be made available to assist in the transfer of knowledge and enhance the ability of ADF&G to adopt the methods developed in this project if biometricians with suitable backgrounds are not immediately available. This would also bridge any gaps resulting from personnel turnover at either the University of Washington or ADF&G.

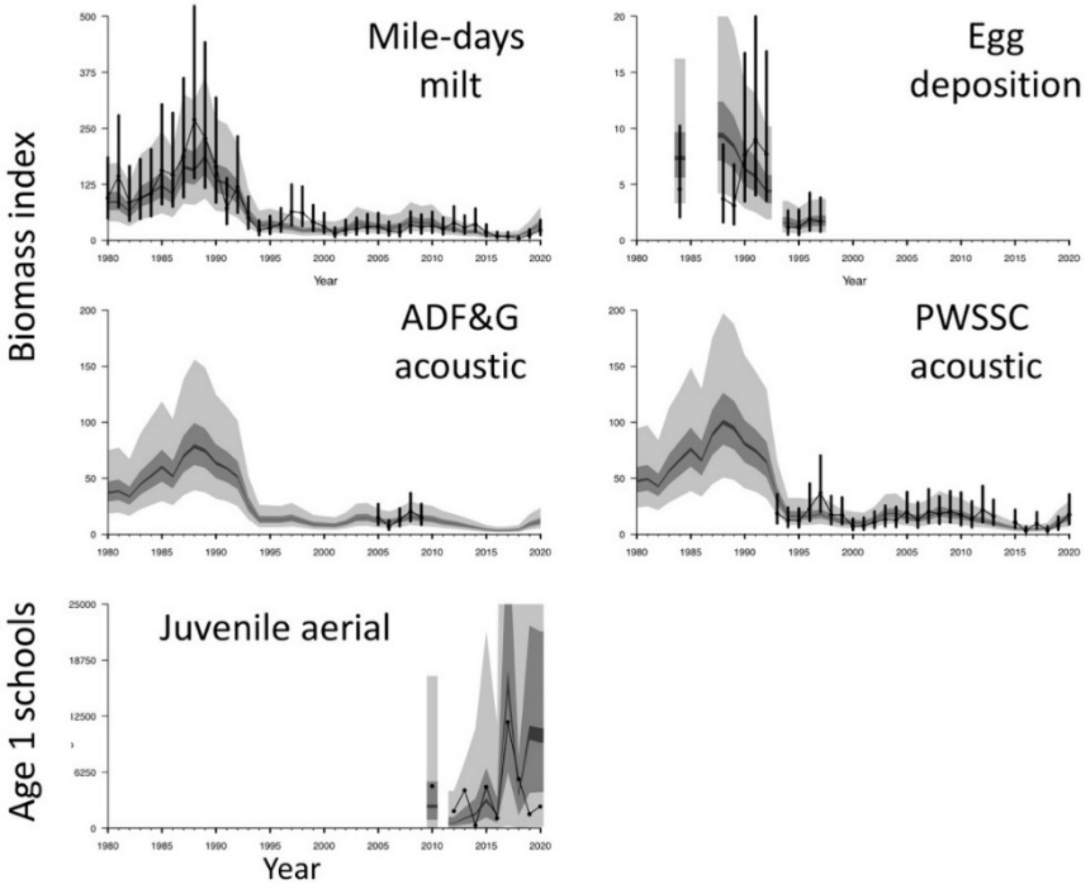

Figure 1. Estimated survey biomass from Bayesian age structured assessment (shading showing 50% and 95% posterior predictive intervals in dark and light gray, respectively) compared to indices of biomass in the population (points and lines showing observation coefficient of variation). Continuing increases in both acoustic and milt indices for 2020, resulted in increased biomass (21,000 t, 95% confidence interval 14,390-30,950 t), which is above the lower cut-off for fishing, but with a wide range of uncertainty.

2. Review best practices for managing highly variable fish populations

Prince William Sound herring are not unique among fish populations worldwide, and much can be learned from management in other regions. Previously, we examined whether Prince William Sound herring catch, abundance, and recruitment differed from all other herring populations through a global synthesis, finding that the duration of collapse and failure to recover is unusual (Trochta et al. 2020). Two possible reviews are considered, with emphasis on the first:

a) A review of the harvest control rules used to manage fish populations, with a special focus on stocks with large fluctuations in abundance that are similar in life history to herring (forage fish). Harvest control rules are used to set catches based on some relationship to spawning biomass levels or other indicators. This synthesis would provide advice and a recommended set of harvest control rules that could be tested through the management strategy evaluation framework outlined in the next section.

b) A review of how uncertainty in estimated biomass is incorporated into catch setting in other regions. Ideally, the more uncertainty there is in current stock status, the more precautionary future catches should be. BASA automatically produces a distribution of the uncertainty in stock status because it is a Bayesian model, unlike most stock assessments which rely more heavily on median point estimates. Few management agencies explicitly include uncertainty in setting catch, with the exception of Pacific Council regulations governing groundfish (e.g, Privitera-Johnson & Punt 2020), and it is highly relevant to management of herring to identify the optimal balance between risk and catch level given uncertain stock status.

The review or reviews will make use of available databases collated by the University of Washington and used in analyses of global fisheries management and their effect on marine fisheries (Hilborn et al. 2020, Melnychuk et al. 2021).

3. Create a management strategy evaluation framework for Prince William Sound herring

The main thrust of this proposal is to develop an MSE framework for Prince William Sound herring to answer a wide variety of questions. Since MSE has not previously been applied to this system, the framework opens a rich avenue for research that will directly benefit fisheries, managers, and the conservation of herring in this region, in addition to improving the robustness of the stock assessment and evaluating the cost-effectiveness of data collection and surveys. It is also likely that over the ten-year timeline of this proposal, some proposed projects will be expanded, reduced, or replaced with projects that have immediate management implications. Timeline uncertainties extend to the training of graduate students in the required work, since MSE work is highly technical. Notwithstanding these caveats, we propose the MSE projects listed below as core examples of the work planned for the duration of the proposal.

4. Evaluate alternative harvest control rules for setting Prince William Sound herring catches

Fisheries on Prince William Sound herring have not been conducted since 1998 due to low biomass levels in this population (Muradian et al. 2017). The current harvest control rule is as follows, with all numbers in short tons: *"5AAC 27.365. The minimum spawning biomass threshold is 22,000 tons, and no fishery may be opened if the estimated spawning biomass is below this threshold level. The department may allow, based upon age class strength, a harvest of herring at an exploitation rate between zero and 20 percent of the projected spawning biomass when that biomass is between 22,000 tons and 42,500 tons. The department may allow a harvest of herring at a maximum exploitation rate of 20 percent when the total projected spawning biomass is greater than 42,500 tons."* (ADF&G 2019-21 herring regulations, p. 26).

The lower threshold (22,000 tons) is approximately 25% of unfished spawning biomass, B_0; while the upper threshold above which a harvest rate of 20% may be allowed, was chosen to ensure a high probability (95%) that the spawning biomass is above the lower threshold. Occasionally, additional management decisions are added, such as keeping herring fisheries closed when recruit-age fish (ages 3 and 4) comprise more than 50% of the spawning biomass (Botz et al. 2014), i.e., the "based on age class strength" clause in the regulations.

We propose to develop and use MSEs to test a variety of alternative harvest control rules for setting catches and reopening the fishery, developed in coordination with key stakeholders (such as fishing industry, managers, communities, native Alaskans, and conservation groups). The review of harvest control rules in the previous section will provide advice on the kinds of rules used elsewhere. Possible harvest control rules could encompass a wide range of possibilities, with illustrative examples listed below:

a) **Current Rule**: retain the current harvest control rule, with no fishing below 22,000 tons, a 20% harvest rate above 42,500 tons, and a linear increase in harvest rate between 22,000 and 42,500 tons.

b) **Higher Harvest Rate**: retain the current harvest control rule but set the harvest rate at 30% (instead of 20%) when spawning biomass is above 42,500 tons.
c) **Lower Harvest Rate**: retain the current harvest control rule but set the harvest rate at 15% (instead of 20%) when spawning biomass is above 42,500 tons.
d) **Lower B_0**: B_0 is estimated from recruitment in an unfished population (R_0) multiplied by spawning biomass per recruit from average weight-at-age, maturity-at-age, and survival. Given there has been no fishing since 1998, a new B_0 estimate could be based on mean recruitment in the post-decline period, which would be substantially lower (perhaps 15,000–20,000 tons) than the existing estimate of R_0 (about 88,000 tons). A corresponding harvest control rule should have a higher threshold for fishing—no fishing allowed below 40% B_0 (recommended by Pikitch et al. 2012)—rising to 20% harvest rates allowed above an upper threshold such as 60% of B_0.
e) **Risk-averse biomass**: same scenario as Lower B_0, but the harvest control rule is based on the ratio of the lower 20th percentile of spawning biomass to unfished spawning biomass; instead of median spawning biomass.
f) **Fish at lower levels**: same scenario as Lower B_0 but set the threshold for no fishing at 25% of B_0, and the threshold for a harvest rate of 20% at 40% of B_0, as in the current harvest control rule.
g) **Age class diversity**: same scenario as current harvest control rule but no fishing allowed if more than 50% of spawning biomass is age-3 or age-4.

5. Evaluate tradeoffs between cost, survey frequency, and additional data collection

The MSE framework, once set up, can be used to evaluate the usefulness of different data streams for management of Prince William Sound herring. Resources are scarce and it is always worth assessing which kinds of data offer the greatest return for the investment given their costs. In a previous assessment, we examined the value of past sampling programs in informing the stock assessment (Muradian et al. 2019), concluding that past surveys for egg deposition were valuable despite their high cost, because they provided the only absolute estimate of abundance for the population, which anchored the stock assessment.

However, in projecting forward through time, harvest control rules are a form of feedback control: if catches are erroneously set too high, the population declines and the harvest control rule lowers future catches; conversely if catches are low, the population increases and the harvest control rule increases future catches. The key advantage of the MSE framework is that it allows for the evaluation of this feedback control loop, including the consequences of changes in data collection on future catch, profits, and biomass depletion. In contrast, the past work we did on this topic in Muradian et al. (2019) only evaluated the current usefulness of past data collection. Some examples of the kinds of evaluations that could be conducted are given below:

a) **Different survey frequency**: at present, aerial milt surveys and hydroacoustic surveys by the Prince William Sound Science Center are conducted annually. How would future catches and depletion change if the aerial survey was conducted every second year? If the hydroacoustic survey was conducted every second year? If the surveys alternated (e.g., aerial survey in even years and hydroacoustic survey in odd years)?
b) **New egg deposition diver surveys**: diver surveys were discontinued in Prince William Sound in the early 1990s because their trends diverged from the aerial survey and hydroacoustic survey, and they had wide uncertainty intervals. In other regions, diver surveys are the primary source of information about trends in abundance but they are expensive; reinstating diver surveys in Prince William Sound could be informative but the expense would need to be evaluated. The MSE could evaluate the usefulness of a new time series mimicking a diver series that provides absolute abundance estimates with higher uncertainty than for the indices of abundance from the aerial milt and hydroacoustic surveys.

c) **Aerial survey coverage**: what effect would it have on management of herring if the aerial milt survey missed some spawning aggregations due to herring spawning in new areas?

d) **Change sample size for numbers-at-age**: what is the effect of doubling or halving the number of fish collected during the surveys that are used to estimate the numbers-at-age in the population? What if these samples were only collected and analyzed every second year?

6. Test robustness of the management process to misspecification in the stock assessment

Fisheries stock assessment models involve specifying or estimating a wide range of parameters and relationships among parameters. For example, assumptions are often made about stock-recruitment relationships, variability in recruitment, fixing natural mortality at a particular value, and other such assumptions. In some fisheries, catches may be under-reported, affecting estimates of stock productivity (Rudd & Branch 2017). The MSE framework offers a natural method of evaluating the long-term impact of such forms of model misspecification on catches and biomass depletion levels. In brief, the parameters (or relationships) in the operating model ("truth") are systematically altered from those made in the estimation model, and then the management process is simulated through the MSE framework. In some cases, model misspecification corrects after a few years, because while the stock assessment provides biased estimates of some parameters, recommended harvest levels are little changed (e.g., Rudd & Branch 2017). Examples of the kinds of analyses that could be undertaken in this proposed component include the following:

a) **Natural mortality**: in almost all stock assessments, natural mortality is fixed at a constant value since there is little information in available data to estimate it. Here, the value for natural mortality could be fixed at 0.15, 0.2, 0.25, and 0.3 in the operating model ("truth"), while in the estimation model it is fixed at 0.2. Natural mortality could also be modeled as time-varying to incorporate both disease outbreaks (Trochta 2021) and changes in predation mortality estimated from stomach sampling and monitoring of predator populations.

b) **Stock-recruitment relationship**: the stock assessment assumes no relationship between spawning biomass and recruitment in Prince William Sound herring (Muradian et al. 2017, Trochta 2021). The MSE could evaluate the consequences the true relationship being a Beverton-Holt stock-recruitment relationship with steepness of 0.5, 0.75, and 0.9, or a variety of other alternative stock-recruitment relationships.

c) **Different variability in recruitment**: test the effect of a higher or lower amount of variability in recruitment than currently assumed in the estimation model.

7. Create a spatial model of Prince William Sound herring

Prince William Sound herring has always been assessed as a single population occupying the entire Sound. However, there are important spatial aspects of the herring population that may influence perceptions of stock status. Notably, fishing usually has been focused in small subregions in each year that shift over time; spawning locations have shifted from the western Sound to the eastern Sound (Fig. 2); and the timing of peak spawning has shifted (Fig. 2) in a manner that differs between the western and eastern Sound (Dias et al. in prep, McGowan et al. in review). In addition, many important factors that affect herring recruitment, mortality, and growth may differ by space. Over the ten-year span of this project, additional evidence may arise from genetics and tagging studies that highlights further spatial separation among components of Prince William Sound herring.

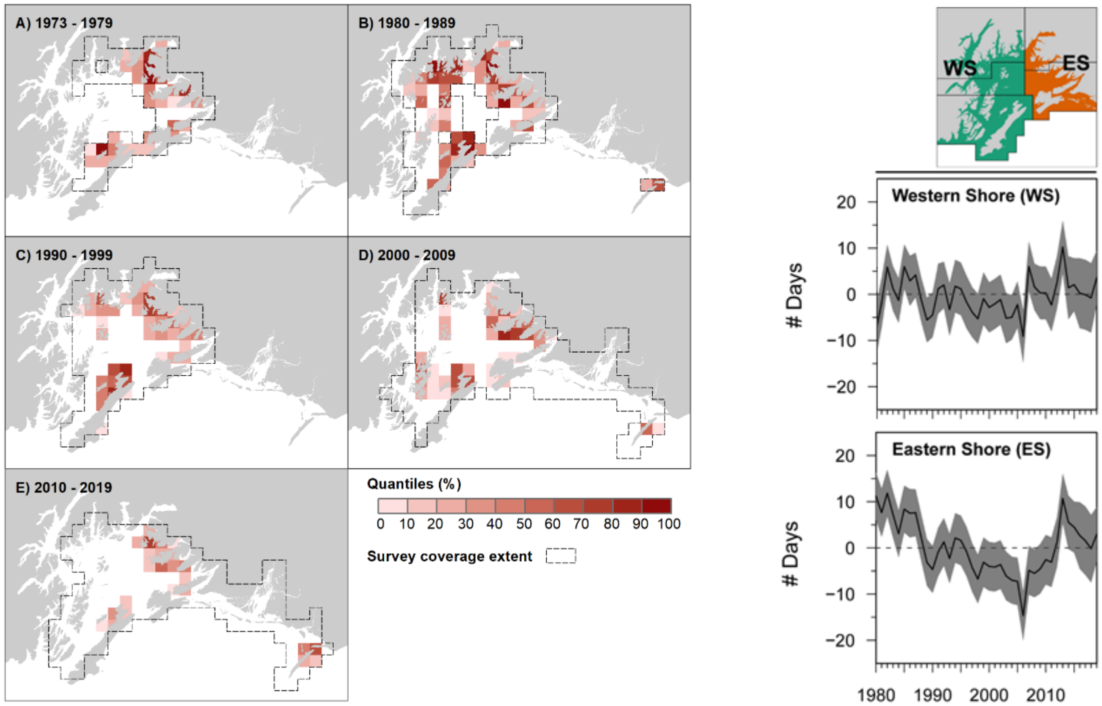

Figure 2. (left) Spatial shifts in spawning activity in Prince William Sound herring based on aerial surveys for milt. (right) The best-fitting model for changes in spawn timing (plotted here as deviations from the median) involves splitting the population into a western and eastern region (McGowan et al. in review).

Should sufficient evidence arise during this project that Prince William Sound herring comprises a portfolio of populations, it would be prudent to test whether this results in biased assessments of stock status. However, spatial models involve substantially work, and are technically far more difficult to run and create than single-population models, and therefore the idea outlined below should be considered a contingency plan. One option would be to build off the modeling framework in Punt et al. (2018), which examined the influence of different levels of spatial complexity on herring stock assessments.

The general idea would be to create an operating model that can be used within the MSE framework, that is spatially explicit, with two to five areas designed to capture key spatial components of fishing and spawning. Recruitment would differ by space and over time, and there would be movement among areas, as well as directed movement over time from one area to another to mimic the patterns observed in spawning locations (McGowan et al. in review). The estimation model would still consist of a single Sound-wide population. In this way, by tweaking the "truth" in the operating model, the MSE can test whether including or excluding space under a variety of hypotheses of movement and localized depletion from fishing, would result in bias in estimated stock status if a single population is assumed.

__8. Model of intermediate complexity (MICE) of interactions with key species__

Predation and competition from key species are likely to influence growth, survival, and recruitment in Prince William Sound herring. Previous work has shown that humpback whales may eat 21-77% of all herring in Prince William Sound in a single year, which is a major potential source of mortality, and potentially also disruptive to herring spawning aggregations (Moran et al. 2018, Straley et al. 2018). In addition, model selection criteria found support for an association between pink salmon abundance and higher herring mortality, and higher mortality associated with Alaskan pollock abundance in the Gulf of Alaska (Trochta 2021, Trochta & Branch in review), although these associations were not supported by all model selection criteria examined.

Developing a full ecosystem model of Prince William Sound herring is already planned by Beatriz Dias and the University of Alaska Fairbanks. Ecosystem models such as Ecopath with Ecosim (Christensen & Walters 2004) have been widely used, and are less complex than Atlantis ecosystem models (Fulton et al. 2011). However, it can be difficult to disentangle effects of any particular species on another species given the complexities of full ecosystem models, and Ecosim models in particular are hard to integrate within fisheries management (Plagányi & Butterworth 2004).

Instead of ecosystem models, we propose to develop a “model of intermediate complexity” (MICE) (Plagányi et al. 2014) that models only the abundance and interactions of the key species suspected of having strong interactions with herring: humpback whales, pink salmon, and Alaskan pollock. Population models will be developed for each population based on historical abundance estimates, likely age-aggregated for pink salmon and humpback whales, but possibly age-structured for pollock, and simulations conducted that examine the effect of predation or competition on Prince William Sound herring. A MICE model would also have the potential to be used as an operating model within the MSE framework, to examine how species interactions might influence the accuracy of mortality estimates and the stock assessment model.

C. Data Analysis and Statistical Methods

The stock assessment will be conducted using BASA (Muradian et al. 2017), which we developed using EVOST funding from 2013-2022. This has been progressively updated, with simulation testing showing that mortality from disease (VHSV) can be estimated within BASA (Trochta 2021); adding a much more efficient Bayesian algorithm called the No-U-Turn-Sampler (NUTS) to AD Model Builder software (Fournier et al. 2012), and thus allowing stock assessment models including BASA to use NUTS (Monnahan et al. 2017, Monnahan & Kristensen 2018, Monnahan et al. 2019); the expansion of the model to include age-0 so that the juvenile aerial survey can be included; and many other improvements (Trochta 2021). Using a Bayesian stock assessment model better accounts for uncertainty than other approaches (Punt & Hilborn 1997, Stewart et al. 2012, Magnusson et al. 2013), and is already used for assessments of two of the most important US fisheries in the North Pacific: Alaskan pollock and Pacific hake (which also now uses the NUTS algorithm).

The proposed MSE framework is a well-established method used to evaluate harvest control rules, data collection, and model assumptions in stock assessments, for species ranging from Pacific hake, to whales, to southern bluefin tuna, and beyond (Butterworth & Punt 1999, Plagányi et al. 2007, Punt & Donovan 2007, Rademeyer et al. 2007, Hillary et al. 2016b, Punt et al. 2016). The operating model may be coded in either AD Model Builder (Fournier et al. 2012) or Template Model Builder (Kristensen et al. 2016), while the estimation model will be the most up-to-date version of BASA (Muradian et al. 2017, Trochta 2021). Data generated from the operating model will mimic current data: aerial milt survey, hydroacoustic spawning biomass survey, and fishery-independent age-composition, and samples for age composition will be generated from a Dirichlet distribution as in Muradian et al. (2019). Future simulations will be based on 1000 sets of posterior draws of model parameters from the start year, with simulated recruitment to project each time series forward.

D. Description of Study Area

The study encompasses the entirety of Prince William Sound, since herring are assumed to be a single population throughout this region, with a focus on regions where spawning was observed 1973–2019 (Fig. 3, McGowan et al. submitted), but excluding Kayak Island.

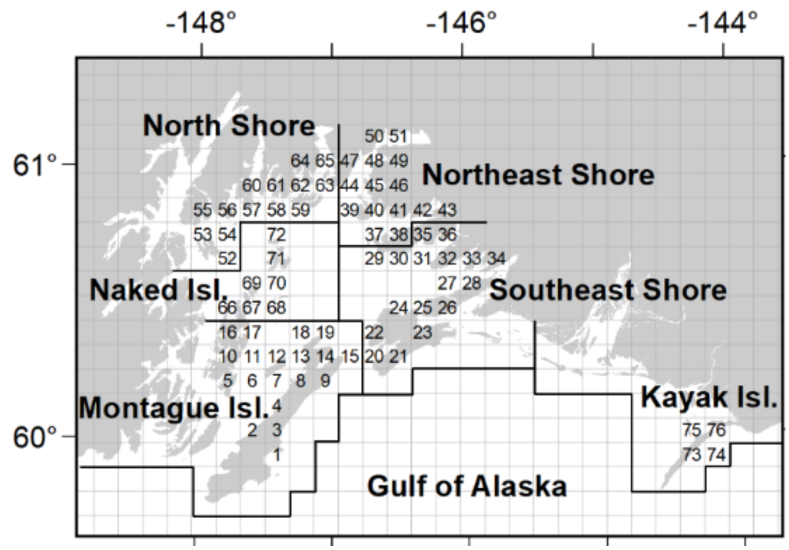

Figure 3. The entire region of Prince William Sound is included in this proposal, excluding Kayak Island region. Numbered 10×10 km cells are where spawning was observed during 1973–2019 (McGowan et al. submitted).

5. COORDINATION AND COLLABORATION

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

This project will be partnered with the Prince William Sound Science Center, as in the previous ten years.

B. Within the EVOSTC LTRM Program

Environmental Drivers Component

Long-term oceanographic data for Prince William Sound may be appropriate for incorporating into our modeling and we intend to collaborate with Environmental Drivers Component PIs to discuss these data streams.

Pelagic Monitoring Component

Time series and results will be used to inform the spatial model, and the parameterization of the MICE model.

Nearshore Monitoring Component

We look forward to future discussions with the Nearshore Component to evaluate potential collaboration.

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 the modeling effort. We look forward to status reports from the Lingering Oil Component.

Herring Research and Monitoring component

Almost all of the proposals in this component will result in data that will be used in the stock assessment or other modeling components. Below is a list of the PIs, projects, and relevance to the modeling project.

Hershberger, herring disease program (22120111-E): estimated seroprevalence data for VHSV, disease prevalence for VHSV and *Ichthyophonus* are used in the assessment to estimate annual natural mortality.

Heintz & Gorman, herring-salmon trophic interactions (22220111-I): ecological interactions between juvenile salmon and herring will be used in the MICE model.

Haught, surveys and age, sex, and size collection and processing (22170111-F): aerial milt survey used as an index of abundance in the stock assessment; numbers-at-age and weight-at-age also used in the stock assessment.

Cypher, interannual variation of Pacific herring larval growth in Prince William Sound (22220111-H): predictions of herring recruitment and estimates of survival in the stock assessment could also be related to indices of predator abundance for pink salmon that fluctuate every second year.

Cypher & Bishop, annual herring migration cycle and movement between Kayak Island and Prince William Sound (22160111-B): will inform the spatial model.

Rand, adult Pacific herring acoustic surveys in Prince William Sound (22120111-G): used as in index of abundance in the stock assessment.

Pegau, herring workshops (22220111-J): one workshop is planned on herring modeling approaches.

Pegau, aerial forage fish surveys (22220111-K): the index of age-1 herring schools is used in the assessment.

Lindeberg, Suryan, and Hoffman, program management (2222LTRM-A&B): logistics, coordination, science synthesis, meeting logistics, administration, community involvement for the Prince William Sound Science Center. Runs the planning and administrative portion of the modeling project.

Rand, ecological interactions between juvenile salmon and Pacific herring (22220111-L): diet data and ecological interactions between juvenile salmon and herring will be used in the MICE model.

Whitehead, history of oil and virus interaction and resisting disease (22170115): potential implications for spatial model, and incorporation of disease in the stock assessment.

Synthesis and Modeling Component

Multiple data streams from this project will be used in GWA-LTRM Synthesis and Modeling Component efforts (PI Suryan, 2222LTRM-A&B). Environmental driver and predator data will allow quantitative evaluation of bottom-up and top-down factors affecting estimated herring biomass. Herring biomass estimates will contribute to assessing changes in prey abundance and predator populations in PWS. Furthermore, these and the proposed MICE modeling efforts will be important contributions to the PWS and broader mass-balanced (e.g., Ecopath/Ecosim) and end-to-end ecosystem modeling efforts of the Synthesis and Modeling Component and collaborators. In the previous period, postdoc funding under this area enabled synthesis of variation in herring spawning locations and timing. Such a collaboration would be fruitful, if possible, near the end of the ten years to conduct similar synthesis work, although it is difficult to lay out the scope of the work before the new data have been collected.

Data Management Project

Stock assessment outputs and other products will be posted under the Gulf of Alaska data portal as in previous years.

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

Current EVOSTC-funded projects not within the long-term research and monitoring focus area do not intersect with the purposes of this project. As the EVOSTC funds future projects outside the focus area we will evaluate their applicability to our project and coordinate as appropriate.

D. With Proposed EVOSTC Mariculture Focus Area Projects

We look forward to evaluating the projects the EVOSTC funds within the mariculture focus area to determine the potential for coordination and collaboration. Our particular interest will be related to mariculture and herring mortality.

E. With Proposed EVOSTC Education and Outreach Focus Area Projects

The Gulf Watch Alaska long-term research and monitoring program will develop an outreach plan that includes coordination and collaboration with the education and outreach focus area that is funded by the EVOSTC. We anticipate participating as part of the overall program and look forward to our findings contributing to the general understanding of the Gulf of Alaska ecosystem by the general public.

Within the program we anticipate contributing articles to Prince William Sound Science Center's *Delta Sound Connections* publication and presenting our findings at conferences and public forums. In addition, the PI conducts a robust science communication outreach program through social media, to 13,000 followers on Twitter (@TrevorABranch), with tweets being viewed 38 million times since 2015.

F. With Trustee or Management Agencies

Stock assessment results will be shared with ADF&G and be used in management of Prince William Sound herring. The key contact here is Sherri Dressel. Results from this project will inform which covariates are used in the stock assessment to predict herring mortality and recruitment, following on from previous work on these relations (Trochta & Branch in review); and to continue work on the drivers of changes in spawn location and timing (Dias et al. in prep, McGowan et al. in review).

G. With Native and Local Communities

The Gulf Watch Alaska long-term research and monitoring 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 Gulf Watch Alaska long-term research and monitoring 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.

6. DELIVERABLES

1. Annual executive summaries of Prince William Sound herring stock assessments with key figures and numbers, starting in FY23.

2. One or more scientific papers reviewing best practices globally for managing highly variable fish populations.

3. Scientific paper with a management strategy evaluation of alternative harvest control rules for Prince William Sound herring.

4. Scientific paper evaluating tradeoffs between cost and frequency of data collection using the MSE for Prince William Sound herring.

5. Scientific paper testing the robustness of the management process to model misspecification.

6. [may be replaced by other urgent priorities] Scientific paper outlining a spatial model for Prince William Sound herring.

7. [may be replaced by other urgent priorities] Scientific paper outlining a model of intermediate complexity capturing key interactions between herring, humpback whales, pink salmon, and Alaskan pollock.

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																				
Stock assessment					X				X				X				X			
Reporting																				
Annual reports					X				X				X				X			
Deliverables																				
Peer reviewed paper: best practices								X												
Peer reviewed paper: harvest rules												X								
Peer reviewed paper: data frequencies																				X
Data posted online					X				X				X				X			

	FY27				FY28				FY29				FY30				FY31			
Milestone/Task	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Milestone																				
Stock assessment	X				X				X				X				X			
Reporting																				
Annual reports	X				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
Final report																				X
Deliverables																				
Peer reviewed paper: model robustness				X																
Peer reviewed paper: spatial model												X								
Peer reviewed paper: multispecies model																				X
Data posted online	X				X				X				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		$62,295	$65,827	$67,599	$69,421	$71,293	$336,435	
Travel		$4,509	$4,734	$8,719	$7,809	$8,199	$33,970	
Contractual/Tuition		$18,672	$19,606	$20,586	$21,616	$22,697	$103,177	
Commodities		$4,800	$800	$3,100	$3,100	$3,100	$14,900	
Equipment		$0	$0	$0	$0	$0	$0	
Indirect Costs Rate =	55.5%	$39,740	$39,606	$44,077	$44,583	$45,839	$213,844	
SUBTOTAL		$130,016	$130,573	$144,082	$146,528	$151,128	$702,327	
General Administration (9% of subtotal)		$11,701	$11,752	$12,967	$13,188	$13,602	$63,209	N/A
PROJECT TOTAL		$141,717	$142,324	$157,049	$159,716	$164,729	$765,536	
Other Resources (In-Kind Funds)							$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		$73,216	$75,194	$77,225	$79,314	$81,461	$386,410		$722,845
Travel		$5,754	$6,042	$11,128	$9,966	$10,464	$43,355		$77,325
Contractual/Tuition		$23,831	$25,023	$26,274	$27,588	$28,967	$131,683		$234,860
Commodities		$4,800	$800	$3,100	$3,100	$3,100	$14,900		$29,800
Equipment		$0	$0	$0	$0	$0	$0		$0
Indirect Costs Rate =	55.5%	$46,493	$45,530	$50,757	$51,271	$52,739	$246,789		$460,634
SUBTOTAL		$154,094	$152,589	$168,485	$171,239	$176,731	$823,137		$1,525,464
General Administration (9% of subtotal)		$13,868	$13,733	$15,164	$15,412	$15,906	$74,082	N/A	$137,292
PROJECT TOTAL		$167,963	$166,322	$183,648	$186,650	$192,636	$897,219		**$1,662,756**
Other Resources (In-Kind Funds)							$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*

No additional sources of funding or in-kind contributions are made to this project.

9. LITERATURE CITED

Botz, J., T. Sheridan, A. Wiese, S. Moffitt, and R. Brenner. 2014. 2013 Prince William Sound area finfish management report. Alaska Department of Fish and Game, Fishery Management Report No. 14-43, Anchorage.

Butterworth, D.S. 2007. Why a management procedure? Some positives and negatives. ICES Journal of Marine Science 64:613-617

Butterworth, D.S., and A.E. Punt. 1999. Experiences in the evaluation and implementation of management procedures. ICES Journal of Marine Science 56:985-998

Christensen, V., and C.J. Walters. 2004. Ecopath with Ecosim: methods, capabilities and limitations. Ecological Modelling 172:109-139

Dias, B.S., D.W. McGowan, R. Campbell, and T.A. Branch. in prep. Influence of environmental and population factors on spawn timing in Prince William Sound herring. Canadian Journal of Fisheries and Aquatic Sciences

Fournier, D.A., H.J. Skaug, J. Ancheta, J. Ianelli, A. Magnusson, M.N. Maunder, A. Nielsen, and J. Sibert. 2012. AD Model Builder: using automatic differentiation for statistical inference of highly parameterized complex nonlinear models. Optimization Methods & Software 27:233-249

Fulton, E.A., J.S. Link, I.C. Kaplan, M. Savina-Rolland, P. Johnson, C. Aimsworth, P. Horne, R. Gorton, R.J. Gamble, A.D.M. Smith, and D.C. Smith. 2011. Lessons in modelling and management of marine ecosystems: the Atlantis experience. Fish and Fisheries 12:171-188

Hilborn, R., R.O. Amoroso, C.M. Anderson, J.K. Baum, T.A. Branch, C. Costello, C.L. de Moor, A. Faraj, D. Hively, O.P. Jensen, H. Kurota, L.R. Little, P. Mace, T. McClanahan, M.C. Melnychuk, C. Minto, G.C. Osio, A.M. Parma, M. Pons, S. Segurado, C.S. Szuwalski, J.R. Wilson, and Y. Ye. 2020 Effective fisheries management instrumental in improving fish stock status. Proceedings of the National Academy of Sciences USA 117:2218-2224

Hillary, R.M., A.L. Preece, C.R. Davies, H. Kurota, K. Sakai, T. Itoh, A.M. Parma, D.S. Butterworth, J.N. Ianelli, and T.A. Branch. 2016a. Managing international tuna stocks via the management procedure approach. In: Edwards, C.T.T., and D.J. Dankel (eds), Management science in fisheries. Routledge, Taylor & Francis Group, London, p 147-162

Hillary, R.M., A.L. Preece, C.R. Davies, H. Kurota, K. Sakai, T. Itoh, A.M. Parma, D.S. Butterworth, J.N. Ianelli, and T.A. Branch. 2016b A scientific alternative to moratoria for rebuilding depleted international tuna stocks. Fish and Fisheries 17:469-482

Kristensen, K., A. Nielsen, C.W. Berg, H. Skaug, and B.M. Bell. 2016 TMB: automatic differentiation and Laplace approximation. Journal of Statistical Software 70:1-21

Kurota, H., K. Hiramatsu, N. Takahashi, H. Shono, T. Itoh, and S. Tsuji. 2010. Developing a management procedure robust to uncertainty for southern bluefin tuna: a somewhat frustrating struggle to bridge the gap between ideals and reality. Population Ecology 52:359-372

Magnusson, A., A.E. Punt, R. Hilborn. 2013. Measuring uncertainty in fisheries stock assessment: the delta method, bootstrap, and MCMC. Fish and Fisheries 14:325-342

McGowan, D.W., T.A. Branch, S. Haught, and M.D. Scheuerell. in review. Multi-decadal shifts in the distribution and timing of Pacific herring (*Clupea pallasii*) spawning in Prince William Sound, Alaska. Canadian Journal of Fisheries and Aquatic Sciences

Melnychuk, M.C., H. Kurota, P.M. Mace, M. Pons, C. Minto, G.C. Osio, O.P. Jensen, C.L. de Moor, A.M. Parma, L.R. Little, D. Hively, C.E. Ashbrook, N. Baker, R.O. Amoroso, T.A. Branch, C.M. Anderson, C.S. Szuwalski, J.K. Baum, T.R. McClanahan, Y. Ye, A. Ligas, J. Bensbai, G.G. Thompson, J. DeVore, A. Magnusson, B. Bogstad, E. Wort, J. Rice, and R. Hilborn. 2021. Identifying management actions that promote sustainable fisheries. Nature Sustainability https://doi.org/10.1038/s41893-020-00668-1

Monnahan, C.C., T.A. Branch, J.T. Thorson, I.J. Stewart, C.S. Szuwalski. 2019. Overcoming long Bayesian run times in integrated fisheries stock assessments. ICES Journal of Marine Science 76:1477-1488

Monnahan, C.C., and K. Kristensen. 2018. No-U-turn sampling for fast Bayesian inference in ADMB and TMB: Introducing the adnuts and tmbstan R packag. PLoS One 13:e0197954

Monnahan, C.C., J.T. Thorson, and T.A. Branch. 2017 Faster estimation of Bayesian models in ecology using Hamiltonian Monte Carlo. Methods in Ecology and Evolution 8:339-348

Moran, J.R., R.A. Heintz, J.M. Straley, and J.J. Vollenweider. 2018. Regional variation in the intensity of humpback whale predation on Pacific herring in the Gulf of Alaska. Deep-Sea Research II 147:187-195

Muradian, M.L. 2015. Modeling the population dynamics of herring in the Prince William Sound, Alaska. University of Washington

Muradian, M.L., T.A. Branch, S.D. Moffitt, and P.-J.F. Hulson. 2017. Bayesian stock assessment of Pacific herring in Prince William Sound, Alaska. PLoS One 12:e0172153

Muradian, M.L., T.A. Branch, and A.E. Punt. 2019. A framework for assessing which sampling programs provide the best trade-off between accuracy and cost of data in stock assessments. ICES Journal of Marine Science 76:2102-2113

Pikitch, E.K., P.D. Boersma, I.L. Boyd, D.O. Conover, P. Cury, T. Essington, S.S. Heppell, E.D. Houde, M. Mangel, D. Pauly, É. Plagányi, K. Sainsbury, and R.S. Steneck. 2012. Little fish, big impact: managing a crucial link in ocean food webs. Lenfest Ocean Program. Washington, D.C. 108 pp.

Plagányi, É.E., and D.S. Butterworth. 2004. A critical look at the potential of ECOPATH with ECOSIM to assist in practical fisheries management. African Journal of Marine Science 26:261-287

Plagányi, É.E., A.E. Punt, R. Hillary, E.B. Morello, O. Thébaud, T. Hutton, R.D. Pillans, J.T. Thorson, E.A. Fulton, A.M.D. Smith, F. Smith, P. Bayliss, M. Haywood, V. Lyne, and P.C. Rothlisberg. 2014. Multispecies fisheries management and conservation: tactical applications using models of intermediate complexity. Fish and Fisheries 15:1-22

Plagányi, É.E., R.A. Rademeyer, D.S. Butterworth, C.L. Cunningham, and S.J. Johnston. 2007. Making management procedures operational - innovations implemented in South Africa. ICES Journal of Marine Science 64:626-632

Privitera-Johnson, K.M., and A.E. Punt. 2020. Leveraging scientific uncertainty in fisheries management for estimating among-assessment variation in overfishing limits. ICES Journal of Marine Science 77:515-526

Punt, A.E., D.S. Butterworth, C.L. de Moor, J.A.A. De Oliveira, and M. Haddon. 2016. Management strategy evaluation: best practices. Fish and Fisheries 17:303-334

Punt, A.E., and G.P. Donovan. 2007. Developing management procedures that are robust to uncertainty: lessons from the International Whaling Commission. ICES Journal of Marine Science 64:603-612

Punt, A.E., and R. Hilborn. 1997. Fisheries stock assessment and decision analysis: the Bayesian approach. Reviews in Fish Biology and Fisheries 7:35-63

Punt, A.E., D.K. Okamoto, A.D. MacCall, A.O. Shelton, D.R. Armitage, J.S. Cleary, I.P. Davies, S.C. Dressel, T.B. Francis, P.S. Levin, R.R. Jones, H. Kitka, L.C. Lee, J.A. McIsaac, M.R. Poe, S. Reifenstuhl, J.J. Silver, J.O.

Schmidt, T.F. Thornton, R. Voss, and J. Woodruff. 2018. When are estimates of spawning stock biomass for small pelagic fishes improved by taking spatial structure into account? Fisheries Research 206:65-78

Rademeyer, R.A., É.E. Plagányi, and D.S. Butterworth. 2007. Tips and tricks in designing management procedures. ICES Journal of Marine Science 64:618-625

Rudd, M.B., and T.A. Branch. 2017. Does unreported catch lead to overfishing? Fish and Fisheries 18:313-323

Stewart, I.J., A.C. Hicks, I.G. Taylor, J.T. Thorson, C. Wetzel, and S. Kupschus. 2012. A comparison of stock assessment uncertainty estimates using maximum likelihood and Bayesian methods implemented with the same model framework. Fisheries Research 142:37-46

Straley, J.M., J.R. Moran, K.M. Boswell, J.J. Vollenweider, R.A. Heintz, T.J. Quinn II, B.H. Witteveen, and S.D. Rice. 2018. Seasonal presence and potential influence of humpback whales on wintering Pacific herring populations in the Gulf of Alaska. Deep-Sea Research II 147:173-186

Trochta, J. 2021. Modeling population collapse and recovery in herring. PhD dissertation. University of Washington

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

Trochta, J.T., T.A. Branch, A.O. Shelton, and D.E. Hay. 2020. The highs and lows of herring: A meta-analysis of patterns in herring collapse and recovery. Fish and Fisheries 21:639-662

Trochta, J.T., M.L. Groner, P.K. Hershberger, and T.A. Branch. in review. A better way to account for disease in fisheries stock assessment: the powerful potential of seroprevalence data. ICES Journal of Marine Science

10. PROJECT PERSONNEL

Principal investigator: Trevor A. Branch

Associate Professor, School of Aquatic and Fishery Sciences, Box 355020, University of Washington, Seattle, WA 98185, phone: 206-221-0776, email: tbranch@uw.edu

Professional Preparation

University of Cape Town	Zoology & Computer Science	BSc 1994
University of Cape Town	Zoology	BSc (Hons) 1995
University of Cape Town	Conservation Biology	MSc 1998
University of Washington	Aquatic and Fishery Sciences	PhD 2004

Appointments

2016–present, Richard C. and Lois M. Worthington Endowed Professor in Fisheries Management
2015–present, Associate Professor, School of Aquatic and Fishery Sciences, University of Washington
2010–15, Assistant Professor, School of Aquatic and Fishery Sciences, University of Washington
2006–10, Research Scientist, School of Aquatic and Fishery Sciences, University of Washington
2005–06, Research Scientist, Department of Mathematics & Applied Mathematics, University of Cape Town

Ten recent publications related to the project

Froehlich HE, Gentry RR, Lester SE, Cottrell RS, Fay G, Branch TA, Gephart JA, White ER, Baum JK (2021) Securing a sustainable future for US seafood in the wake of a global crisis. Marine Policy 124:104328

Gephart JA, Froehlich HE, Branch TA (2019) To create sustainable seafood industries, the United States needs a better accounting of imports and exports. Proceedings of the National Academy of Sciences USA 116:9142-9146

Hilborn R, Amoroso RO, Anderson CM, Baum JK, Branch TA, Costello C, de Moor CL, Faraj A, Hively D, Jensen OP, Kurota H, Little LR, Mace P, McClanahan T, Melnychuk MC, Minto C, Osio GC, Parma AM, Pons M, Segurado S, Szuwalski CS, Wilson JR, Ye Y (2020) Effective fisheries management instrumental in improving fish stock status. Proceedings of the National Academy of Sciences USA 117:2218-2224

Melnychuk MC, Kurota H, Mace PM, Pons M, Minto C, Osio GC, Jensen OP, de Moor CL, Parma AM, Little LR, Hively D, Ashbrook CE, Baker N, Amoroso RO, Branch TA, Anderson CM, Szuwalski CS, Baum JK, McClanahan TR, Ye Y, Ligas A, Bensbai J, Thompson GG, DeVore J, Magnusson A, Bogstad B, Wort E, Rice J, Hilborn R (2021) Identifying management actions that promote sustainable fisheries. Nature Sustainability https://doi.org/10.1038/s41893-020-00668-1

Monnahan CC, Branch TA, Thorson JT, Stewart IJ, Szuwalski CS (2019) Overcoming long Bayesian run times in integrated fisheries stock assessments. ICES Journal of Marine Science 76:1477-1488

Monnahan CC, Thorson JT, Branch TA (2017) Faster estimation of Bayesian models in ecology using Hamiltonian Monte Carlo. Methods in Ecology and Evolution 8:339-348

Muradian ML, Branch TA, Moffitt SD, Hulson P-JF (2017) Bayesian stock assessment of Pacific herring in Prince William Sound, Alaska. PLoS One 12:e0172153

Muradian ML, Branch TA, Punt AE (2019) A framework for assessing which sampling programs provide the best trade-off between accuracy and cost of data in stock assessments. ICES Journal of Marine Science 76:2102-2113

Trochta JT, Branch TA, Shelton AO, Hay DE (2020) The highs and lows of herring: A meta-analysis of patterns in herring collapse and recovery. Fish and Fisheries 21:639-662

White ER, Froehlich HE, Gephart JA, Cottrell RS, Branch TA, Bejarano RA, Baum JK (2020) Early effects of COVID-19 on US fisheries and seafood consumption. Fish and Fisheries 22:232-239

Five other significant publications (98 peer-reviewed publications in total)

Branch TA, Watson R, Fulton EA, Jennings S, McGilliard CR, Pablico GT, Ricard D, Tracey SR (2010) The trophic fingerprint of marine fisheries. Nature 468:431-435

Branch TA, Hilborn R, Haynie AC, Fay G, Flynn L, Griffiths J, Marshall KN, Randall JK, Scheuerell JM, Ward EJ, Young M (2006) Fleet dynamics and fishermen behavior: lessons for fisheries managers. Canadian Journal of Fisheries and Aquatic Sciences 63:1647-1668

Branch TA, Lobo AS, Purcell SW (2013) Opportunistic exploitation: an overlooked pathway to extinction. Trends in Ecology and Evolution 28:409-413

Sethi SA, Branch TA, Watson R (2010) Fishery development patterns are driven by profit but not trophic level. Proceedings of the National Academy of Sciences USA 107:12163-12167

Worm B, Hilborn R, Baum JK, Branch TA, Collie JS, Costello C, Fogarty MJ, Fulton EA, Hutchings JA, Jennings S, Jensen OP, Lotze HK, Mace PM, McClanahan TR, Minto C, Palumbi SR, Parma AM, Ricard D, Rosenberg AA, Watson R, Zeller D (2009) Rebuilding global fisheries. Science 325:578-585

Coauthors and collaborators on scientific papers in the past 48 months (*n* = 202)

Abrahms, B (NOAA); Acevedo, J (Chile); Adame, MF (Australia); Ahrens, R (Univ Florida); Al Harthy, S (Oman); Allison, C (UK); Amoroso, R (UW); Anderson, CM (UW); Anderson, SC (Simon Fraser Univ); Ashbrook, CE (UW); Atkinson, S (Univ Alaska); Baker, N (UW); Balcazar, N (Chile); Barlow, D (Oregon State Univ); Barnett, LAK (NOAA); Baum, JK (Univ Victoria, Canada); Bejarano RA (Univ Michigan); Bell, RJ (Univ Rhode Island); Benbai, L (Morocco); Berchtold, AE (Simon Fraser Univ); Black, A (Falkland Is); Bogstad, B (IMR, Norway); Broadley, A (Australia); Brodziak, JKT (NOAA); Brown, CJ (Australia); Brownell, RL (NOAA); Buchan, S (Chile); Calderan, SV (UK); Cerchio, S (New England Aquarium); Chato Osio, G (Italy); Chaves, LCT (Simon Fraser Univ); Chong, L (Univ Florida); Clapham, PJ (NOAA); Collie, JS (Univ Rhode Island); Collins, MA (UK); Connolly, RM (Australia); Converse, S (USGS); Cooper, AB (Simon Fraser Univ); Cope, JM (NOAA); Costello, C (UC Santa Barbara); Côté, IM (Simon Fraser Univ); Cottrell, RS (UC Santa Barbara); Cunningham, CJ (Univ Alaska); Dailey, C (Pacific Salmon Comm); Dann, TH (ADF&G); David, S (Nicholls State Univ); de Moor, CL (South Africa); Delgerjargal D (UW); DeVore, J (PFMC, USA); Dodhia, R (Microsoft); Donovan, GP (UK); Double, MC (Australia); Dréo, R (France); Drew, J (SUNY); Drinkwater, R (UW); Dulvy, NK (Simon Fraser Univ); Dunic, JC (Simon Fraser Univ); Enriquez-Paredes, LE (Mexico); Essington, TE (UW); Faraj, A (Morocco); Favaro, B (Simon Fraser Univ); Fay, G (Univ Massachusetts); Feist, BE (NOAA); Ferres, JL (Microsoft); Findlay, KP (South Africa); Fogarty, MJ (NOAA); Francis, FT (Simon Fraser Univ); Froehlich, HE (UC Santa Barbara); Fromentin, JM (France); Gavrilov, AN (Australia); Gedamke, J (NOAA); Gendron, D (Mexico); Gentry, RR (Florida State Univ); Gephart, J (American Univ); Hamel, O (NOAA); Harley, SJ (New Caledonia); Harms, J (NOAA); Haught, S (ADF&G); Haynie, AC (NOAA); Hay, DE (Canada); Hazen, E (NOAA); Hennessey, SM (UW); Hicks, A (IPHC); Hicks, RL (College William & Mary); Hilborn, R (UW); Hively, DJ (UW); Hodge, KB (Cornell Univ); Holland, DS (NOAA); Howard, BR (Simon Fraser Univ); Hulson, PJF (NOAA); Ivashchenko, YV (NOAA); Jackson, JA (UK); Jeffrey, KM (Simon Fraser Univ); Jenner, KCS (Australia); Jensen, OP (Univ Wisconsin-Madison); Kanaji, Y (Japan); Kato, H (Japan); Kell, LT (Spain); Kelly, N (Australia); Kleiber, D (Univ British Columbia); Kuriyama, PT (UW); Kurota, H (Japan); Lang, A (NOAA); Larue, M (New Zealand); Leaper, Russell (UK); Leroy, EC (Australia); Lester, SE (Florida State Univ); Li, B (NRC); Ligas, A (Italy); Little, LR (Australia); Lurcock, S (UK); Mace, PM (New Zealand); Maeda, H (Japan); Magnusson, A (ICES, Denmark); Malige, F (France); Malpica-Cruz, L (Simon Fraser Univ); Marquez, MC (writer); Mashburn, KL (Univ Alaska); Maslowski, N (Simon Fraser Univ); Matsuoka, K (Japan); Maunder, MN (IATTC); McCauley, RD (Australia); McClanahan, TR (Wildlife Conservation Society); McClure, MM (NOAA); McGowan, DW (NOAA); Melica, V (Univ Alaska Fairbanks); Melnychuk, MC (UW); Methot, RD (NOAA); Miksis-Olds, JL (Univ New Hampshire); Mildenberger, TK (Denmark); Miller, BS (Australia); Minto, C (Ireland); Mizroch, S (Blue Sea Research, Seattle); Moffitt, SD (ADF&G); Monnahan, CC (UW); Moore, M (WHOI); Muradian, M (UW); Okamura, H (Japan); Olson, P (NOAA); Pangerc, T (UK); Panicker, D (UW); Parma, AM (Argentina); Parsons, ECM (NSF); Pastene, LA (Japan); Patris, J (France); Pons, M (UW); Punt, AE (UW); Rabaiotti, D (UK); Ranasinghe, RA (Virginia Polytechnic); Restrepo, VR (ISSF); Ricard, D (Czech Republic); Rice, J (FOC, Canada); Rogers, T (Australia); Rojas-Cerda, C (Chile); Rosenbaum, HC (Wildlife Conservation Society); Royer, J-Y (France); Rudd, MB (UW); Samaran, F (France); Scheuerell, MD (USGS); Schnier, KE (UC Merced); Schultz, JA (Simon Fraser Univ); Seeb, JE (UW); Seeb, LW (UW); Segurado, S (Sust Fish Partnership); Shabangu, FW (South Africa); Sharma, R (Seychelles); Shelton, AO (NOAA); Shiffman, D (Marine Stewardship Council); Širović, A (Texas A&M Univ); Smith, M (UW); Smith, NS (Simon Fraser Univ); Spurr, R (UW); Stäbler, M (Germany); Stafford, KM (UW); Staniland, L (UK); Steen, D (FL Fish & Wildlife Cons Comm); Stewart, IJ (NOAA); Suydam, R (North Slope Borough, AK); Szuwalski, CS (NOAA); Taylor, MH (Germany); Thomisch, K (Germany); Thompson, GG (NOAA); Thorson, JT (UW); Thurner, S (UW); Torres, LG (Oregon State Univ); Torterotot, M (France); Tripovich, JS (Australia); Trochta, JT (UW); Thurner, S (UW); Turshwell, M (Australia); Warren, VE (New Zealand); White ER (Univ Vermont); Wild, A (Univ Texas); Williams, RS (Canada); Willson, A (UK); Wilson, JR (Nature Conservancy); Wolff, M (Germany); Wood, AG (UK); Wort, E (Univ Plymouth, UK); Ye, Y (FAO, Italy); Zerbini, AN (Cascadia Research); Zhong, M (Microsoft, Seattle)

OFFICE OF SPONSORED PROGRAMS
UNIVERSITY of WASHINGTON

July 27, 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 commitment for the proposed project "22120111-C: Modeling and stock assessment of Prince William Sound herring" led by principal investigator (PI), Trevor A. Branch, with internal University of Washington GC1 code of A167854. 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 $1,525,464 (without EVOSTC GA). There are no in-kind contributions of non-EVOSTC funds.

This project proposal is part of the larger multi-agency Gulf Watch Alaska Long-Term Research and Monitoring (GWA-LTRM) program proposal package. This package represents a continued commitment of the successful long-term research and monitoring projects supported by the EVOSTC and various agencies and organizational investments, that PI Branch has been involved with since 2012.

Indirect costs have been included at the negotiated F&A rate of 55.5% for the University of Washington. We reserve the right to negotiate the terms and conditions of the award should this application be funded.

Sincerely,

Daniel J. Lienard
Grant and Contract Analyst, Lead
Authorized Representative of the University of Washington
osp@uw.edu; (206) 543-4043