ATTACHMENT C **EVOSTC Annual Project Report Form**

Form Rev. 8.30.18

1. Program Number:

18120111-C

2. Project Title:

Modeling and stock assessment of Prince William Sound herring

3. Principal Investigator(s) Names:

PI: Trevor A. Branch.

Researchers: John Trochta, David McGowan

4. Time Period Covered by the Report:

1 February 2018 to 31 January 2019

5. Date of Report:

April 2019

6. Project Website (if applicable):

http://pwssc.org/herring-research-and-monitoring/

7. Summary of Work Performed:

The main aim of the modeling project is to improve the performance of the assessment model for Prince William Sound herring.

Assessment model: In previous years, the age structured assessment (ASA) model run by the Alaska Department of Fish and Game (ADF&G) was expanded and updated to include a Bayesian formulation which naturally weights the input data sources, and better characterizes uncertainty through estimating Bayesian posteriors, and this work was published (Muradian et al. 2017). The Bayesian age structured assessment (BASA) model has continued to evolve, now modeling ages starting at age-0 instead of age-3. The current model was run on the data up to and including 2018. The BASA model continues to provide a good fit to age composition data (Fig. 1), with an indication that there continues to be more young fish in the population than in any years since 2007. Estimated biomass in the population continued to be at record low levels, even though the model displays an apparent upward bias in biomass in the most recent year, with estimated biomass considerably above the mile-days of milt, and somewhat above the acoustic estimate (Fig. 2). A variety of sensitivity tests involving capping the model uncertainty in survey estimates, correlations in recruitment, and fixing sex ratio to 50:50 did not greatly alter these findings. Investigations are underway into possible retrospective bias in the model to see if additional adjustments to the model can better account for the observed decline in survey biomass estimates in 2018.

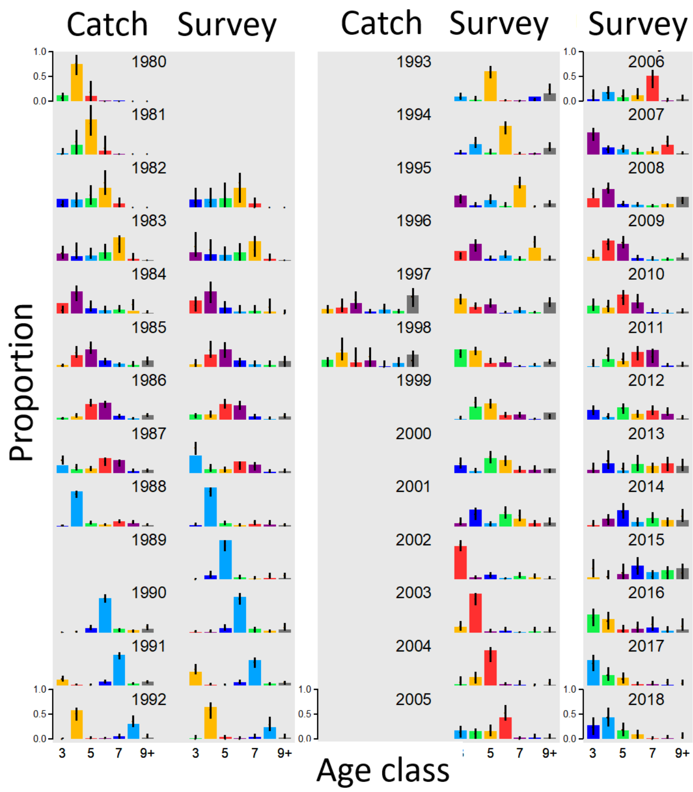

Figure 1. Fits of the BASA assessment model (points = median, lines = 95% credibility intervals) to the numbers at age data from catches and surveys (bars). Each color follows a single cohort as it ages through the fishery. Data are available only for ages 3 and above.

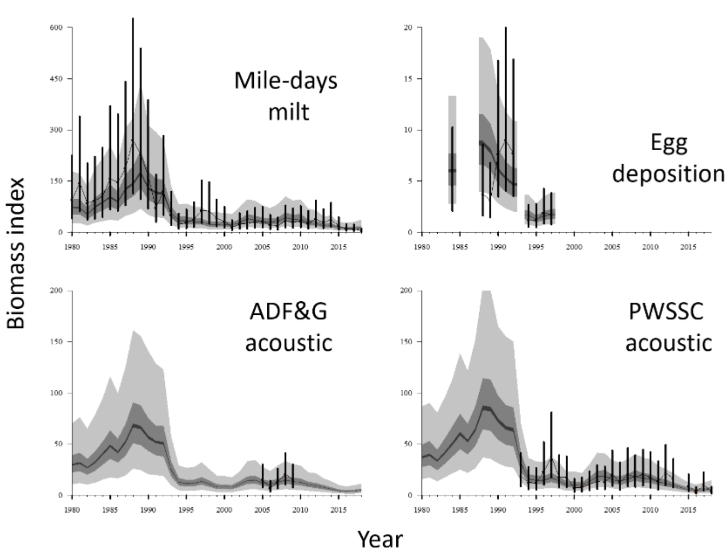

Figure 2. Estimated biomass from BASA (points and lines showing 95% credibility intervals) compared to indices of biomass in the population (shading). Both mile-days of milt and the Prince William Sound Science Center acoustic survey declined in 2018 to record lows, resulting in low estimates of biomass (9,430 t, 95% CI 5,860-15,630 t), well below those at which the fishery should be reopened.

Global herring meta-analysis: The meta-analysis on global herring populations has been revised and is being resubmitted to *Fish and Fisheries* (Fig. 3). It includes data from 62 herring populations from the two species, one in the North Pacific and the other in the North Atlantic, with data on catches, adult biomass, and recruitment by year obtained for most populations. Although many herring populations have collapsed, the median duration of collapse is only 7 years and fewer than 10% of populations remained collapsed for more than 20 years (one of which is Prince William Sound). A variety of factors were examined to find explanations for periods of collapse, with high variability in sea surface height anomaly associated with shorter collapse durations (Fig. 4). Catches were generally higher for populations with higher biomass and recruitment.

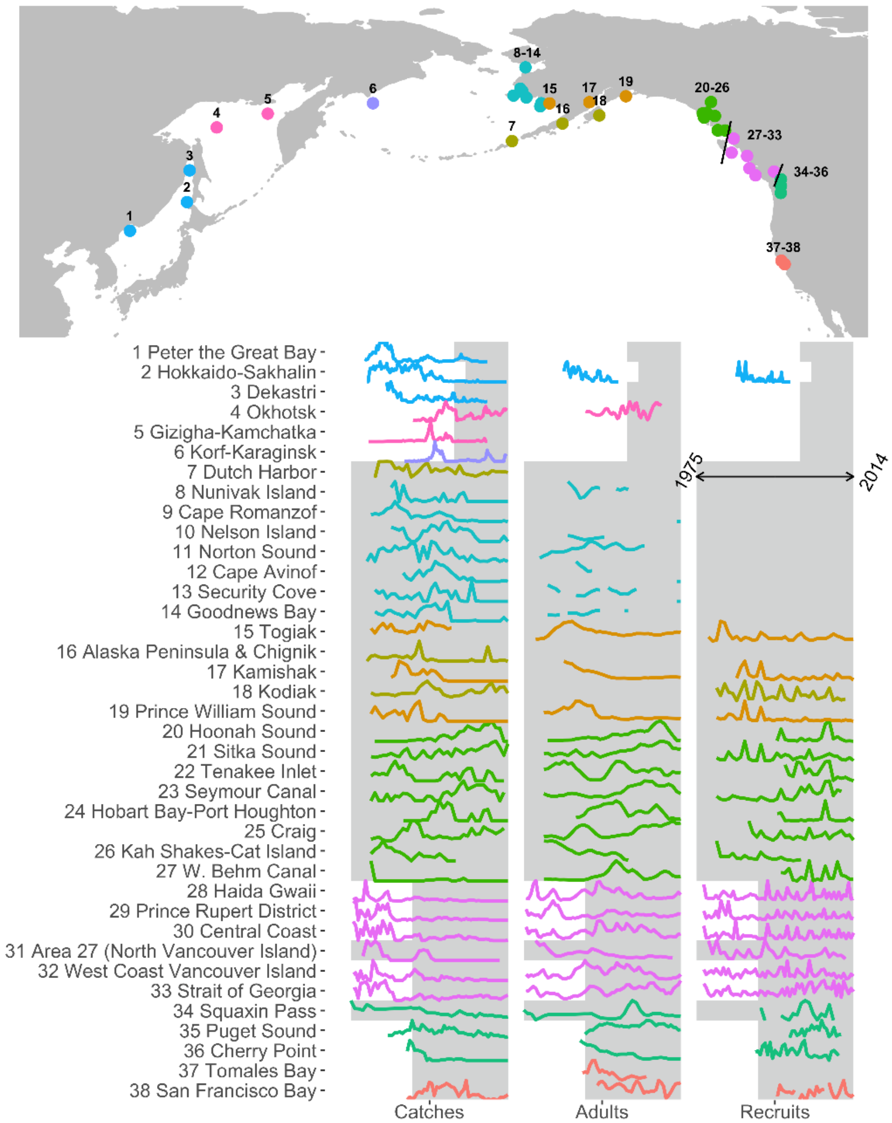

Figure 3. Summary of information available for 38 herring populations in the North Pacific for catches, adult biomass, and recruitment. This is part of the meta-analysis paper to be resubmitted to *Fish and Fisheries*. Gray shading shows the period 1975-2014 for each time series.

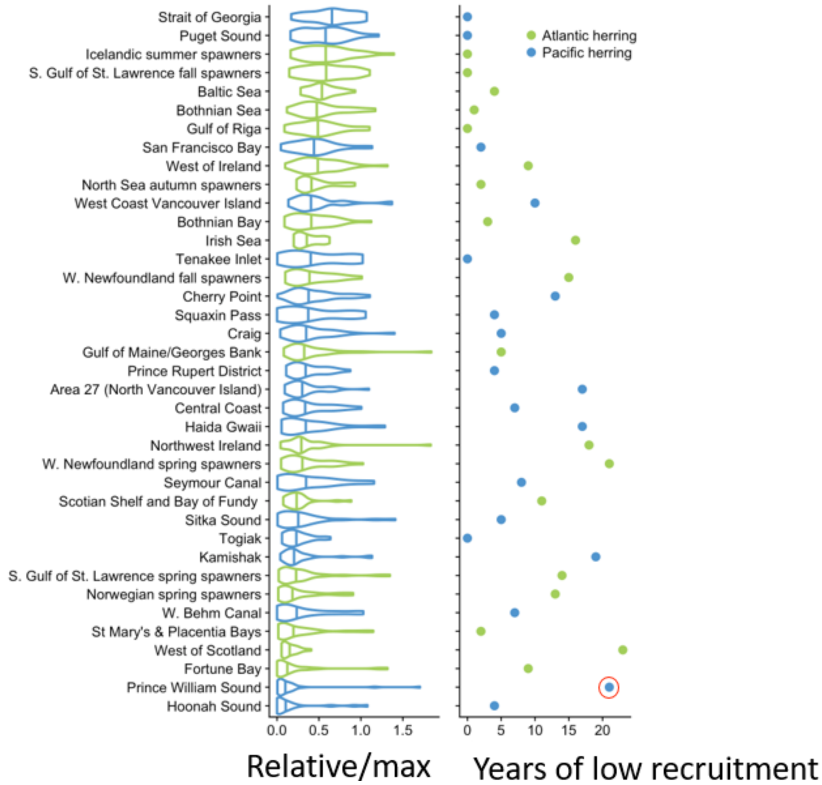

Figure 4. Average Prince William Sound herring recruitment, standardized to the maximum, is much lower than all other herring populations except one, and the number of years of poor recruitment (right panel) is the second highest in the collected data set.

Incorporating viral hemorrhagic septicemia virus (VHSV) antibody data into the model: One currently poorly-modeled component of the BASA model is the incorporation of disease data. New antibody detection data have been obtained from the disease component of this larger project (Principal Investigator [PI] Paul Hershberger, Project 18120111-E). In brief, herring retain antibodies to VHSV, and thus if a disease outbreak hits the population, all individuals will be exposed and harbor antibodies at a proportion related to the prevalence of the disease outbreak. New recruits will not have antibodies, and thus an age-specific antibody prevalence can be used to estimate the ages affected by VHSV, and the prevalence of VHSV in the population. An initial simulation study with no sampling variability suggested it is possible to estimate VHSV prevalence by year and age from the antibody data (Fig. 5). A more complete age-structured model has been developed to simulation test what kinds of information can be obtained from antibody data (notably disease prevalence by year, by age, or by year and age), and to test how much information can be extracted given the inter-annual variability in the data collected to date.

		Age of herring									
Year	Disease	0	1	2	3	4	5	6	7	8	9+
2005	0.9	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
2006	0	0.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
2007	0	0.00	0.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90	0.90
2008	0	0.00	0.00	0.00	0.90	0.90	0.90	0.90	0.90	0.90	0.90
2009	0	0.00	0.00	0.00	0.00	0.90	0.90	0.90	0.90	0.90	0.90
2010	0.2	0.20	0.20	0.20	0.20	0.20	0.92	0.92	0.92	0.92	0.92
2011	0.5	0.50	0.60	0.60	0.60	0.60	0.60	0.96	0.96	0.96	0.96
2012	0	0.00	0.50	0.60	0.60	0.60	0.60	0.60	0.96	0.96	0.96
2013	0	0.00	0.00	0.50	0.60	0.60	0.60	0.60	0.60	0.96	0.96
2014	0.2	0.20	0.20	0.20	0.60	0.68	0.68	0.68	0.68	0.68	0.97
2015	0.1	0.10	0.28	0.28	0.28	0.64	0.71	0.71	0.71	0.71	0.71
2016	0.2	0.20	0.28	0.42	0.42	0.42	0.71	0.77	0.77	0.77	0.77

Figure 5. Simulated antibody prevalence if the mortality from non-VSHV causes is 0.2, mortality from VHSV is 0.6, and there were disease outbreaks affecting 90% of the population in 2005, 20% in 2010, 50% in 2011, 20% in 2014, 10% in 2015, and 20% in 2016.

Factors affecting Prince William Sound herring: We (Trochta and Branch) conducted a new study that examines the effect of a wide variety of factors on Prince William Sound herring recruitment and mortality. Factors examined included oceanographic variables, potential competitors and predators, river discharge and more. Adult mortality was most closely associated with walleye pollock numbers and winter North Pacific gyre oscillation, while walleye pollock (age-1), juvenile hatchery pink salmon, and a regime shift are most closely associated with herring recruitment. The results were presented in a poster at the Alaska Marine Science Symposium in 2019 (Fig. 6) and are being written up for publication.

Individual models with mortality covariates	DIC	WAIC	$D_{\infty\|SEL}$
null model (no covariates)	268.9	223.3	87.4
Freshwater discharge (Age 0)	269.8	223.5	87.0
Walleye pollock Age 1 (Age 0)	268.9	223.4	86.8
Winter air temperature (Age 0)	269.3	223.3	87.0
Winter mean sea level (Age 0)	268.5	223.6	86.7
Winter SST (Age 0)	269.4	223.7	86.8
Hatchery juvenile pink salmon (Age 0)	268.9	223.8	86.7
Freshwater discharge (Age 1)	269.4	223.7	87.2
Humpback whale numbers (Age 1-2)	267.4	224.1	86.6
Total pink salmon returns (Ages 1-2)	267.7	223.9	86.5
Disease-Ich. hof. & VHS virus (Ages 3+)	267.0	222.4	85.2
Arrowtooth flounder spawning biomass (Ages 3+)	269.3	224.7	86.6
Pacific cod spawning biomass (Ages 3+)	258.1	213.9	86.2
Walleye pollock spawning biomass (Ages 3+)	246.7	202.0	84.6
Summer NPGO index (Ages 3+)	256.1	208.7	84.5
Summer PDO index (Ages 3+)	261.2	216.3	86.8
Summer upwelling index (Ages 3+)	272.5	227.9	86.7
Total pink salmon returns (Ages 3+)	270.7	225.8	87.1
Winter NPGO index (Ages 3+)	251.6	204.9	81.1
Winter PDO index (Ages 3+)	271.4	226.8	87.4

Individual models with recruitment covariates	DIC	WAIC	$D_{\infty\|SEL}$
1989 pulse/recovery	269.7	224.4	87.7
1989 regime shift	255.5	222.7	86.8
1980s trending shift	256.0	223.6	86.6
Walleye pollock Age 1	244.0	221.4	87.5
Hatchery juvenile pink salmon	256.8	222.5	87.2
Spring air temp	269.7	223.8	87.1
Spring mean sea level	268.6	222.9	87.0
Winter mean sea level	264.6	223.9	86.7

Lower values of each criterion imply better models/important factors and have darker cells. The best performing model for each criterion (i.e. the minimum) has a white value.

Figure 6. Covariates examined for adult mortality (left) and recruitment in the BASA model.

Semi-spatial recruitment models: A new collaboration between Alec MacCall (retired NOAA scientist), and the modeling group (Trochta, McGowan, Branch) has led to a study related to Prince William Sound herring. The key preliminary finding being investigated is whether interannual changes in where and even when herring spawn, as measured by two-dimensional milt coverage, explain changes in the stock-recruitment relationship. For example, even when habitat quality is similar in all places, if spawning (milt) is evenly spread across sites, recruitment is likely to be higher than if recruitment is unevenly spread, or there are fewer spawning sites. A primary benefit of this work is a potential improvement in forecasts from the herring age-structured model, particularly for management strategy evaluation. Additionally, this work will have relevance to other fish populations with spawning information over space and time. Preliminary results were presented at a Center for the Advancement of Population Assessment Methodology (CAPAM) conference by John Trochta.

Postdoc progress: The postdoctoral fellow (David McGowan) began work in the 1st quarter of 2018 with a review of the literature and reaching out to key scientists who work in Prince William Sound and on herring, and other related species. Initial results are described below.

Variability in Prince William Sound herring spawning in space and time: Aerial survey data collected within the Prince William Sound area in spring from 1980 to 2017 by ADF&G were examined. Data prior to 1980 were excluded due to unbalanced survey coverage during the 1970s (Stormy Haught, ADF&G). Observed mile-days of milt (MDM) were summed within 10 km^2 grid cells, and spawn patterns mapped by decade. Grid cells were subjectively grouped into regions (future work will examine a data-driven approach to defining region boundaries). In earlier years spawning was widely distributed, before a major contraction in the northwestern (NW) region in the 1990s and later in the southwestern (SW) region in the 2010s (Fig. 7). Initially there was a pronounced increase in the number of spawning areas (Fig. 8a) and cumulative spawn (Fig. 8b) in the NW region in the early 1980s (grid cells 27-42) that coincided with reduced spawning in southern areas of the eastern (ES) region (grid cells 45-54). Starting in 1991, spawning declined rapidly throughout the NW region and northern areas of the ES region (grid cells 64-69), preceding the collapse of spawning biomass in 1993 (Fig. 8).

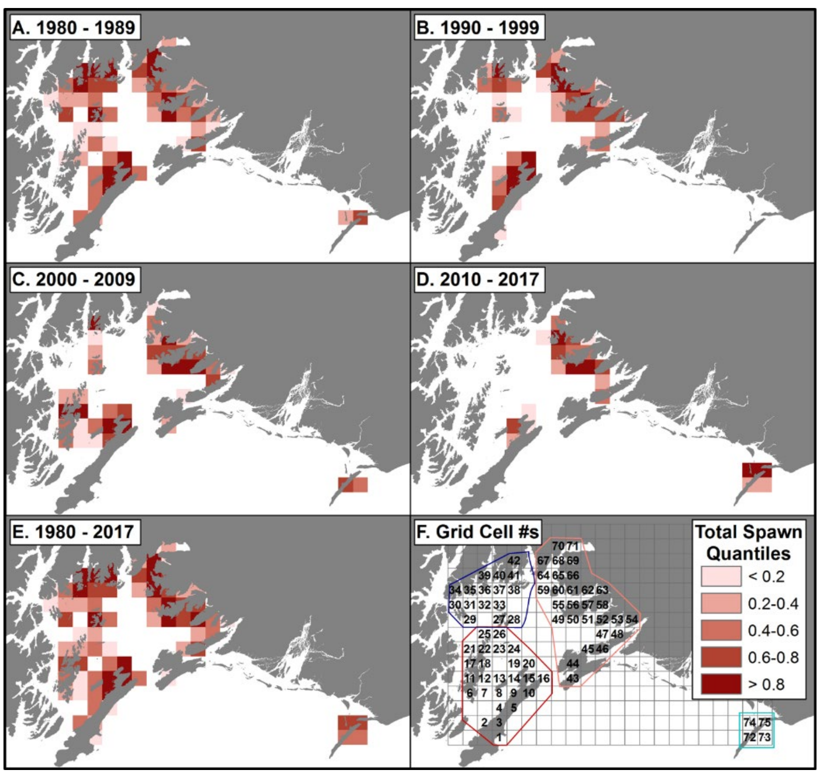

Figure 7. Distribution of spawning within Prince William Sound and along Kayak Island from 1980 to 2017. Spawn patterns are represented as quantiles of MDM that were summed within each 10 km^2 grid cell by decade (plots A-D) and for all years combined (plot E). In plot F, grid cell numbers (1-75) are grouped into the following regions: SW = southwestern PWS; NW = northwestern PWS; ES = eastern PWS; KY = Kayak Island.

The rapid increase in spawning biomass during the 1980s coincided with expansion of herring spawning activity and increases in cumulative spawn in the NW region (Fig. 8). Spawning in the NW region and northern areas of the ES region declined rapidly in the early 1990s as the population collapsed, and active spawning has rarely been observed in these areas over the past 25 years. The expanded use of the northern Prince William Sound for spawning in 1982 appears to have preceded the population's rapid increase in size through that decade, and this topic will be further investigated in FY19.

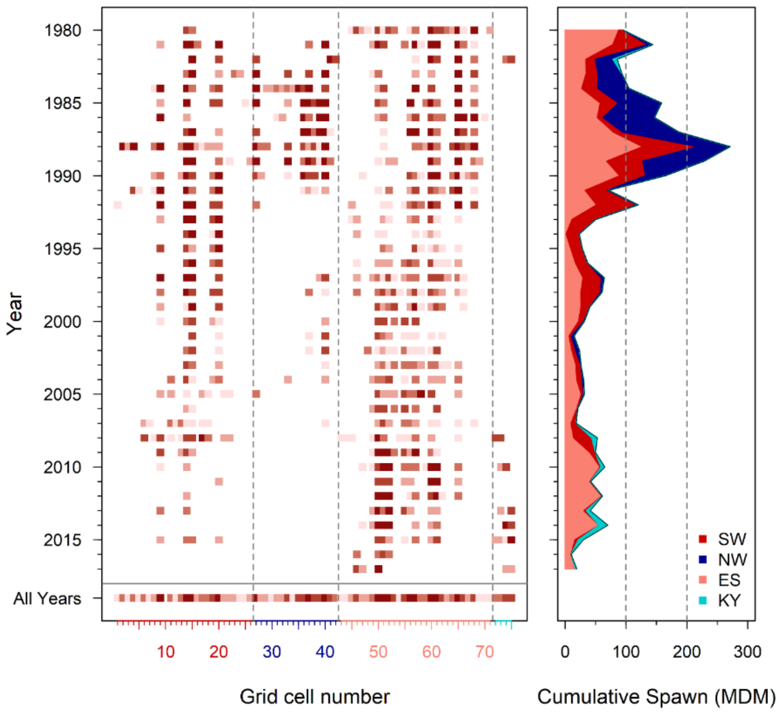

Figure 8. The left panel shows the distribution of spawning within Prince William Sound and Kayak Island from 1980 to 2017. Spawn patterns are represented as quantiles of MDM for all years. Grid cell numbers (1-75) and colors on x-axis correspond with cell locations and regions identified in Fig. 7F. The right panel shows annual cumulative spawn by region: SW = southwestern PWS; NW = northwestern PWS; ES = eastern PWS; KY = Kayak Island.

Spawn timing within Prince William Sound shows high interannual variability during periods of high and low spawning activity, with a trend towards earlier spawning (Fig. 9). It is unclear if the shift in spawn timing is related to environmental factors (e.g., temperature) or reduced spawning in more northern areas of Prince William Sound that are farther away from the primary access points to the Gulf of Alaska at Montague Strait and Hinchinbrook Entrance from where spawners are presumed to migrate. This topic will be further investigated in FY19.

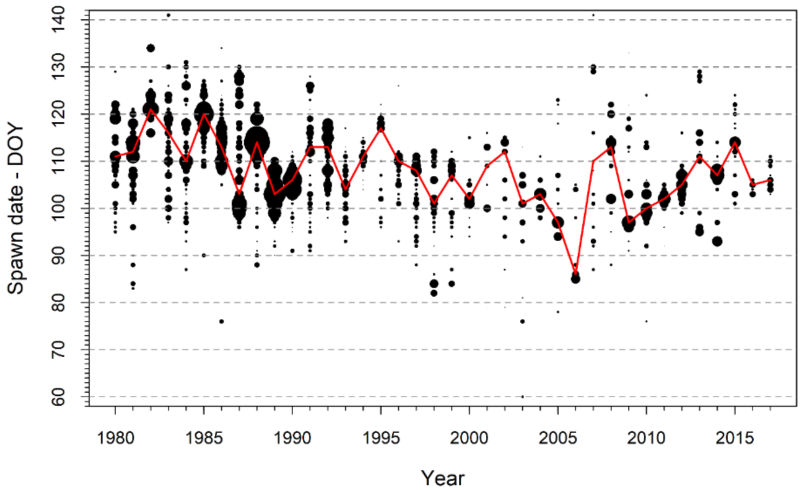

Figure 9. Interannual variations in spawn timing (day-of-year, DOY) observed within Prince William Sound and along Kayak Island from 1980 to 2017. The size of the points is relative to the daily total of MDM for each year. The date on which 50% of the total spawn (MDM) was observed for each year is used to represent changes in spawn timing by year.

Unanticipated delay: John Trochta, the principal graduate student working on the herring modeling, was awarded a Bonderman Travel Fellowship, involving an eight month leave of absence October 2017 to June 2018. Progress has therefore been slower on some of the components of this project.

8. Coordination/Collaboration:

A. Projects Within a Trustee Council-funded program

1. Within the Program

Close collaboration and coordination with the components of the Herring Research and Monitoring (HRM) program are an integral part of the modeling project, including assumptions going into the model, data collection (milt survey, acoustic survey, numbers at age, age at maturity, and other data). In addition, the development of the antibody data involves working closely with the disease component of the program.

2. Across Programs

a. Gulf Watch Alaska

The new postdoc David McGowan started work in 2018 and has been coordinating with Gulf Watch Alaska and the HRM program on a three-year broad-scale integrative project to predict herring recruitment and holistically combine all elements of the HRM and Gulf Watch Alaska programs.

b. Data Management

Data and model outputs are being uploaded as they become available to the Gulf of Alaska Data Portal.

c. Lingering Oil

Results from the lingering oil program will be included when relevant to the model.

B. Projects not Within a Trustee Council-funded program

A collaboration between John Trochta, David McGowan, and Alec MacCall (retired, NOAA) was started to incorporate the spatio-temporal information of the aerial milt surveys into the age-structured assessment model. This project aims to simulation test the value of this spatial information to predict recruitment in the model. It uses Prince William Sound herring as an application since milt data here are mapped by day and year since the 1970s.

C. With Trustee or Management Agencies

Coordination with ADF&G scientists is ongoing and required for data inputs collected by ADF&G and used in the BASA stock assessment model. ADF&G staff are also providing data products to the post-doc project for other coastal herring populations in the Gulf of Alaska.

9. Information and Data Transfer:

A. Publications Produced During the Reporting Period

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

B. Dates and Locations of any Conference or Workshop Presentations where EVOSTC-funded Work was Presented

McGowan, D. W. 2019. Spatial and temporal variations in Pacific herring spawning in Prince William Sound. Poster presentation. Alaska Marine Science Symposium, Anchorage, AK.

Trochta, J. T., A. MacCall, D. McGowan, T. A. Branch. 2019. Incorporating spawn surveys in a semi-spatial stock-recruitment model. Center for the Advancement of Population Assessment Methodology (CAPAM) conference on Spatial Stock Assessment Models, La Jolla. Oral presentation, 1-5 October 2018.

Trochta, J. T. & T. A. Branch. 2019. Evaluating the effects of a changing ecosystem on Pacific herring (*Clupea pallasii*) in Prince William Sound, Alaska. Poster presentation. Alaska Marine Science Symposium, Anchorage, AK.

C. Data and/or Information Products Developed During the Reporting Period, if Applicable

Stock assessment of Prince William Sound herring for 2018.

D. Data Sets and Associated Metadata that have been Uploaded to the Program's Data Portal

Uploaded the most recent version of the BASA model and results using 2018 data (Dec. 2018). Metadata on the workspace summarizes the data sets and how to run the model, while detailed instructions and descriptions are contained within READ_ME files and line comments within the code. The upload includes: AD Model Builder files to run model, R code to pre-process data for model & post-process model output, figures and tables of key model output (fits to data, estimates of biomass and recruitment, parameter estimates), and raw model output (read in by R code to produce figures and tables).

10. Response to EVOSTC Review, Recommendations and Comments:

The Science Panel requests for future reports and proposals to please clarify that ADF&G is now using the model from this project. Timeline products:

What juvenile data (ages 0-2) are now being incorporated into the model?

The current BASA model was changed to start with age 0, but does not currently fit to any juvenile data. We ran a test series of model fits that included the aerial surveys of age 1+ schools in 2015 (only four data points were available), but this did not improve predictions for age-3 recruits. However, as the length of these surveys continues to grow, these and other juvenile data can be easily reincorporated into the most recent model.

How are these data collected and have scaling issues of juvenile to adult data been adequately addressed?

When the model fits to juvenile data, these data are scaled using an estimated catchability parameter, so that the trend is captured but the absolute magnitude is scaled up and down automatically to match the adult surveys.

Can apparent increases in mortality of herring at ages 1-2 be distinguished from selectivity/catchability issues among aerial and acoustic surveys? The answers affect interpretation of the age(s) at which year class strength is determined.

These are currently not incorporated into the BASA model, so the question cannot be addressed from the modeling perspective yet. It seems unlikely that changes in mortality could be estimated precisely enough from the aerial and acoustic surveys.

Regarding the antibody paper, is the PI working closely with Hershberger to get this done?

We have the most up-to-date antibody data from Hershberger. Initial simulations suggested that it should be possible to estimate disease prevalence by year and age, but the actual data are much more ambiguous than the simulated data we tested. We are developing a more advanced age-structured simulation model to test how much information can be obtained from the noisier actual antibody data. We are in discussion with Hershberger on how best to proceed, but it looks like we may only be able to estimate annual disease prevalence rather than prevalence by both year and age

Different factors affect herring at different stages which is being incorporated into the ASA model. We find this valid and useful and are excited to see this published. In the FY18 work plan, the Science Panel suggested the PI to consider the development of a similar model for Sitka herring, which would be valuable as a contrast. We still believe this is an important exercise and it likely will be informative for PWS herring and valuable globally. As Sitka Sound is outside of the spill area, we encourage the PI to seek funding to accomplish this. Collaboration with ADFG in Southeast Alaska would be ideal.

A Bayesian model was developed in AD Model Builder for Sitka by Steve Martell (Sea State, Inc.) and is under further refinement by Jane Sullivan (ADF&G), although this has substantial differences in the data used, model assumptions, and functional forms of the individual components. At the present time we are not able to develop a new model for Sitka, but will continue collaborating with ADF&G about how best to coordinate efforts.

11. Budget:

EXXON VALDEZ OIL SPILL TRUSTEE COUNCIL
PROGRAM PROJECT BUDGET PROPOSAL AND REPORTING FORM

Budget Category:	Proposed FY 17	Proposed FY 18	Proposed FY 19	Proposed FY 20	Proposed FY 21	TOTAL PROPOSED	ACTUAL CUMULATIVE
Personnel	$48.7	$138.2	$144.3	$152.4	$64.8	$548.4	$ 180.9
Travel	$6.4	$13.7	$12.1	$9.3	$6.9	$48.4	$ 6.3
Contractual	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	
Commodities	$25.1	$25.7	$26.1	$25.0	$24.2	$126.1	$ 41.9
Equipment	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	
Indirect Costs (*will vary by proposer*)	$33.8	$86.9	$90.0	$91.6	$40.7	$343.0	$ 106.0
SUBTOTAL	$114.0	$264.5	$272.5	$278.3	$136.6	$1,065.9	$335.1
General Administration (9% of subtotal)	$10.3	$23.8	$24.5	$25.0	$12.3	$95.9	N/A
PROJECT TOTAL	$124.3	$288.3	$297.0	$303.3	$148.9	$1,161.9	
Other Resources (Cost Share Funds)	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	