ATTACHMENT B. Annual Project Report Form (Revised 11.21.19)

1. Program Number:

19160111-B

2. Project Title:

PWS Herring Research & Monitoring: Annual Herring Migration Cycle

3. Principal Investigator(s) Names:

Mary Anne Bishop, Ph.D., Prince William Sound Science Center

Report Preparation Assistance: Jordan Bernard, Prince William Sound Science Center

4. Time Period Covered by the Report:

February 1, 2019 – January 31, 2020

5. Date of Report:

March 2020

6. Project Website (if applicable):

http://pwssc.org/tracking-seasonal-movements-of-adult-pacific-herring/

7. Summary of Work Performed:

The acoustic tagging component of this study began in FY17. Objectives of this study are to:

1) Document location, timing, and direction of Pacific herring seasonal migrations between Prince William Sound (PWS) and the Gulf of Alaska (GOA).
2) Relate large-scale movements to year class and body condition of tagged individuals.
3) Determine seasonal residency time within PWS, at the entrances to PWS, and in the Gulf of Alaska.

2019 Field Work and Preliminary Analyses

For this FY19 report, we provide preliminary data analyses from the first two years of acoustic receiver data from April 2017 through March 2019. We also summarize the April 2019 tagging work. Because acoustic receiver arrays at the interface between the GOA and PWS are uploaded every year in February, most transmitter detection data from 2019 tagged fish in PWS were not available before the end of FY19.

2019 Tagged Herring

Alaska Department of Fish and Game (ADF&G) flights (HRM Project 19160111-F) documented the presence of herring spawn along the southwest coast of Port Gravina between 31 March /-5 April, and near Tatilek on 5 April. The next documented PWS spawning event did not occur until 18 April at Port Fidalgo, after our field work was completed. The final 2019 documented spawning event occurred on 4 May at Bligh Island.

In 2019, we jigged 1082 herring and acoustically tagged 165 (63 females, 92 males, 10 unknown sex) at various locations between 2 and 10 April. Tagging occurred around Port Gravina (Knowles Bay), Hawkins Island (Canoe Pass), Hinchinbrook Island (Double Bay), and Montague Island (Rocky Bay). Over the 9-d period, herring were released in 19 cohorts with each cohort consisting of tagged fish and control fish (not sedated nor tagged).

We targeted fish <200 mm and <100 g for the smaller, V8 tags (battery life = 9 months). The V9 tags have an estimated battery life of 25 months. Measurements for tagged fish included standard length and weight (Table 1). We took a scale sample from each tagged fish and were able to estimate the age of 144 of the 165 fish. Mean age was 3.6 $\pm$ 0.9 y (range = 3-6 y) for V8 tagged fish and 4.6 $\pm$ 1.2 y (range = 3-9 y) for V9 tagged fish.

Table 1. Standard length (mm) and weight (g) of herring tagged in April 2019 by tag type and sex.

Tag/Sex	N	Standard Length (mm) x $\pm$ sd	Weight (g) x $\pm$ sd
V9			
F	52	213.7 (9.5)	119.1 (19.1)
M	65	213.4 (11.1)	118.7 (21.6)
Unknown	8	212.9 (7.6)	106.3 (7.8)
V8			
F	11	200.1 (6.6)	93.0 (5.0)
M	27	198.7 (4.8)	90.5 (5.8)
Unknown	2	199.5 (2.1)	87.0 (4.2)

Preliminary movement analyses for 2017 and 2018 tagged fish

We tagged herring during April 2017 (n = 124) and 2018 (n = 202) in and around the spawning grounds at Port Gravina (2017 and 2018) and Hawkins Island (2018). For these analyses, we used detections from all receiver arrays (Fig. 1) and defined two seasons for each 12-month period: spring/summer (1 April – 31 August; 5 months) and fall/winter (1 September – 31 March; 7 months).

Seasonal migration between PWS and the Gulf of Alaska

We developed an Arnason-Schwarz (AS) multistate model (Schwarz and Arnason 1993), a generalization of the Cormack-Jolly-Seber mark-recapture model, to estimate the probability at which PWS herring move between geographic locations while accounting for uncertainty of fish locations and mortality rates in the PWS and GOA (Fig. 2). We implemented a Bayesian version of the AS model where fish direction information recorded at the entrance arrays was incorporated into the model by using informative priors on the movement probabilities at the entrance arrays. The computation was carried out using R (R Core Team 2013) and JAGS (Plummer 2003).

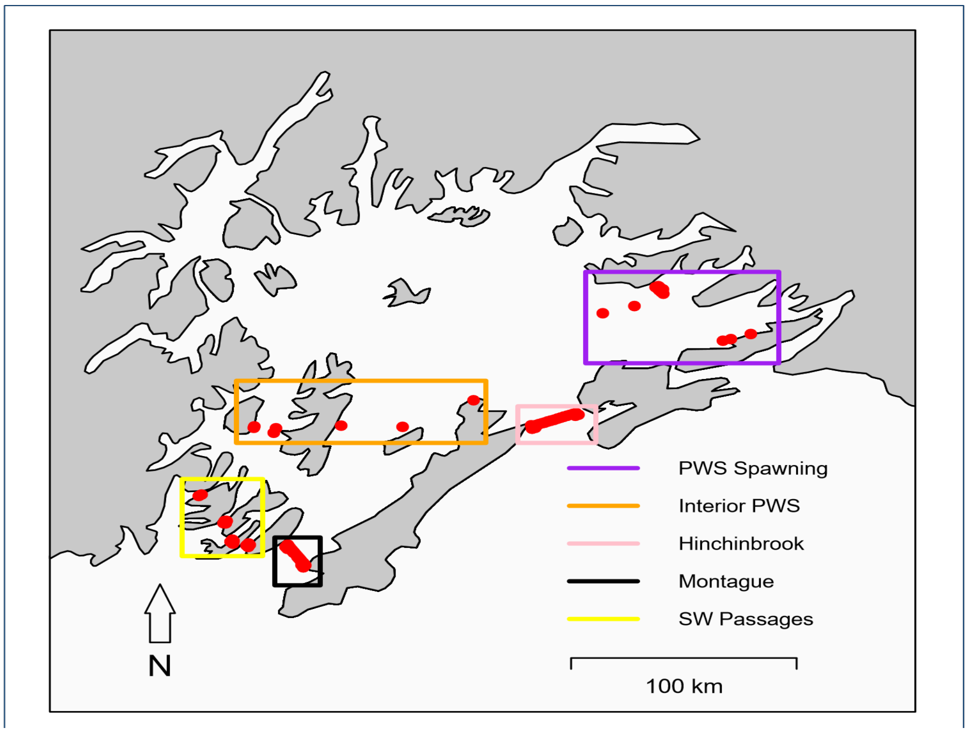

Figure 1. Location of receiver arrays in Prince William Sound. Red circles denote acoustic receiver arrays locations. Colored boxes correspond to the five geographic regions used to partition the receiver arrays.

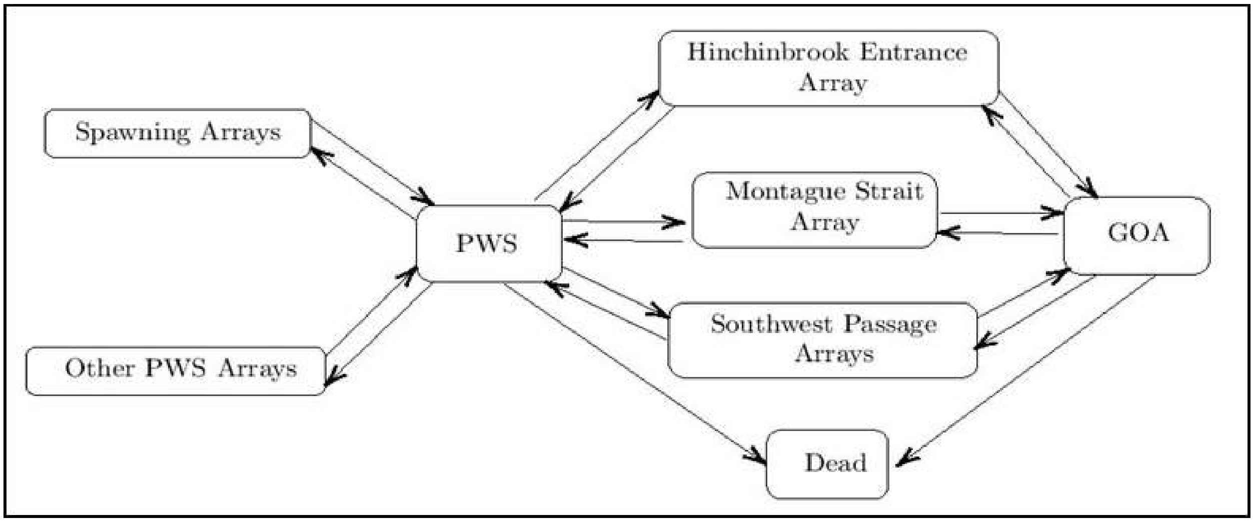

Figure 2. Schematic of multistate model used to describe adult herring movements. Eight model states (shown in rectangles) describe the possible location of a fish and whether or not it is alive. Arrows between geographic locations represent movement probabilities. Arrows pointing to "dead" represent mortality probabilities.

We modeled movement probabilities between PWS and the GOA. At Hinchinbrook Entrance during the spring/summer season the rate at which herring pass into the GOA was higher than the rate at which herring passed into PWS, whereas the opposite trend was reflected during fall/winter months (Fig. 3). However, this pattern was not observed in the movement probabilities at Montague Strait or the southwest passages.

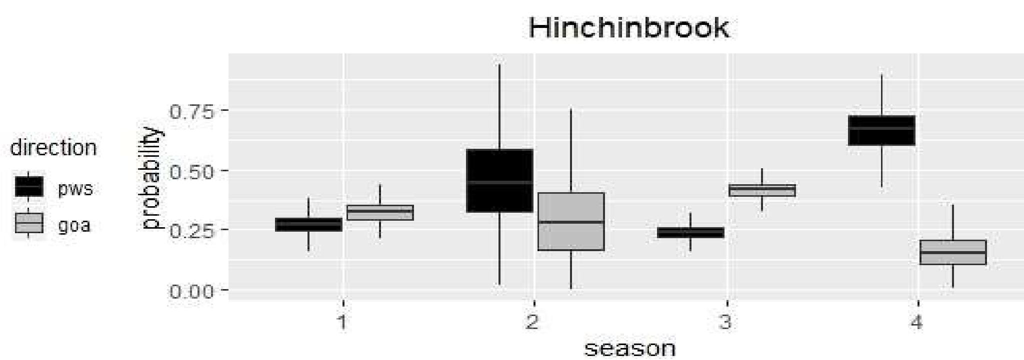

Figure 3. Weekly Pacific herring seasonal movement probabilities between Hinchinbrook Entrance (HE) and Prince William Sound (PWS) and between HE and the Gulf of Alaska (GOA). The HE to PWS and the HE to GOA movement probabilities oscillate by season, with fish more likely to move from PWS to GOA during spring/summer season than from GOA to PWS. During the fall/winter season the trend reverses.

To determine if there was a seasonal difference in the use of entrance arrays, we calculated movement probabilities between PWS and the entrance arrays and between GOA and the entrance arrays. During the spring/summer season herring entered the GOA primarily through Hinchinbrook Entrance whereas, during the fall/winter season herring returned to PWS from the GOA primarily through Montague Strait.

To better describe the phenology of herring migration, we used a kernel density plot to visualize the direction of movements over the two-year period (Fig. 4). The plot shows that most of the PWS-GOA and GOA-PWS detections occurred between April and August. This is because some fish mingle around the entrance arrays, in particular at the Southwest Passages and log both PWS-GOA and GOA-PWS detections.

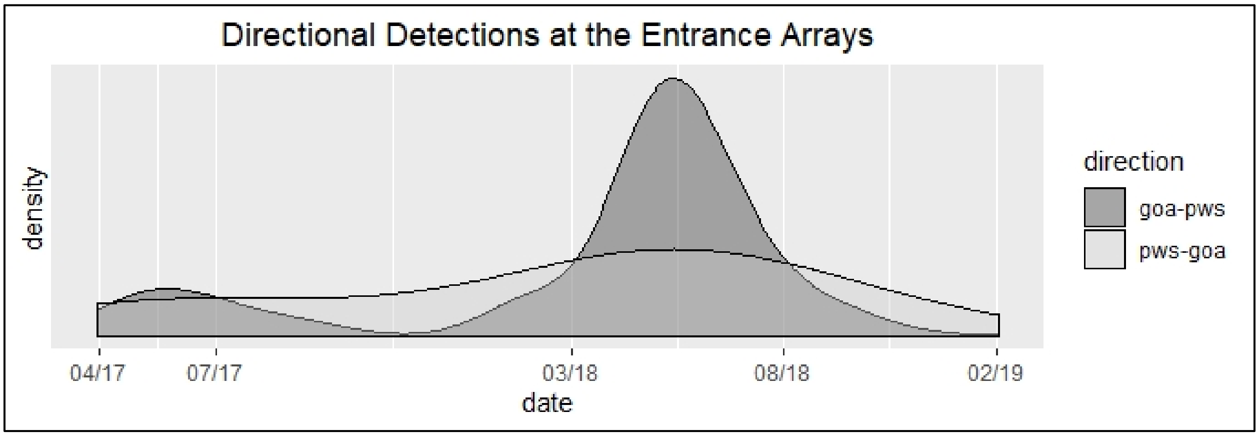

Figure 4. Kernel density estimate of movement direction at Prince William Sound entrance arrays (Hinchinbrook Entrance, Montague Strait, and Southwest Passages), April 2017-February 2019.

Effect of length, weight, and condition on migration

A logit link function was used to model movement probabilities as a function of categorical variables. Variables considered included sex, spawn state at the time of tagging (spawned, not yet spawned), standard length, weight, condition (defined as weight*length-3*1000), and tag burden (tag weight/fish weight). We combined the 2017 and 2018 data and used the median as the break point to separate the variables standard length, weight, condition, and tag-burden into two categories each.

Our analyses indicated that neither sex nor spawning state had a significant effect on movement rates; however, length, weight, and condition did have significant effects. These three variables are deeply correlated, and results were similar across the three variables. By using the median weight for the first two tag years to separate heavy and light fish, we found that during spring/summer season, heavier herring were more likely to move to the entrance arrays (Fig. 5). Likewise, longer, heavier fish in good condition were determined to be the most likely to migrate between PWS and the GOA. Lighter fish, on the other hand, were more likely to return to the PWS spawning areas during the fall/winter season (Fig. 5).

Figure 5. Effect of weight on Prince William Sound (PWS) to entrance array movement probability. Negative β estimates show that heavy fish are more likely to move from PWS to Montague Strait during spring/summer season. Similar trends were found at Hinchinbrook Entrance and the Southwest Passages. Right: Effect of weight on PWS to spawning ground movement probability. Positive β estimates show that during fall/winter season lighter fish are more likely than heavier fish to move from PWS to the spawning grounds.

Mortality rates

To estimate seasonal mortality in PWS and the GOA we used an unconstrained version of the multi-state AS model. Because permanent immigration into the GOA cannot be distinguished from mortality, and because we would expect permanent immigration to be relatively low, we refer to our estimate as the GOA mortality rate.

Seasonal mortality rates in PWS and the GOA were not found to differ significantly from each other. In PWS, mortality was significantly higher during the spring/summer than the fall/winter. In the GOA, the median point estimates reflect the same seasonal trend as in PWS: the mortality rates were higher during the spring/summer than the fall/winter. Given the lifespan of PWS Pacific herring (8-13 years; ADF&G unpubl. data), mortality rates were higher than expected during the spring/summer season. For instance, during spring/summer 2017 the weekly death rate in PWS was estimated to be 0.15. These trends would appear if mortality was higher for newly tagged fish. We suggest that the higher mortality rate observed during the first one-half of the spring/summer season may be due to two factors: a) negative effects of tagging; and b) higher predation rate by marine mammals as a result of converging herring schools on the spawning grounds.

Residency times at PWS arrays

Within PWS, the longest residency times at the entrance arrays occurred during the spring/summer season. Longest residencies were recorded during spring/summer 2017 at Prince of Wales and Elrington, two adjacent Southwest Passages, when estimated mean residency was 59.2 hours and 34.8 hours, respectively (Table 2). On the spawning grounds during winter, average residency time was 3.2 hours (n = 4 fish) the first winter (September 2017 – March 2018) when there were only receivers at Gravina array; average residency time was 15.0 h (n = 33 fish) the second winter (September 2018 – March 2019) when there were additional arrays at Redhead and Hawkins Island.

Table 2. Estimated mean residency time (h) at entrance to Gulf of Alaska receiver arrays by season, April 2017 – March 2019. Number of individual fish denoted in parentheses. Fish were considered having departed from an array if no detections occurred for 24h.

Array	**Apr-Aug 2017**	**Sep 2017-Mar 2018**	**Apr-Aug 2018**	**Sep 2018-Mar 2019**
Hinchinbrook	11.0 (47)	0.2 (2)	7.7 (115)	1.0 (29)
Montague	13.4 (30)	5.9 (15)	16.8 (63)	12.3 (46)
Southwest Passages				
LaTouche	1.7 (4)	-	5.5 (19)	-
Elrington	34.8 (14)	22.1 (10)	25.0 (33)	17.4 (2)
Prince of Wales	59.2 (5)	42.0 (1)	44.3 (22)	28.4 (1)
Bainbridge	-	-	5.1 (4)	-

Residency in GOA and effect of sex and weight

Residency time in the GOA was estimated at 39.7 d for fish exiting from Hinchinbrook Entrance, 47.7 d for fish exiting through Montague Strait, and 31.2 d for fish exiting through the Southwest Passages. Fish exiting through Hinchinbrook Entrance and returning to PWS via Montague Strait had the longest GOA residency times (64.9 d, n = 6; Fig. 6). One-third (n = 42) of the GOA 126 residency events involved fish exiting from and returning along the western shoreline of Montague Strait. Of the 126 occurrences where we could estimate residency time, 17 (14%) were in the GOA for >3 months (max = 295 d) and 10 of the 17 fish (59%) returned during either January of February.

We used linear regression to understand the factors influencing residency time in the GOA. Variables examined included exit array, as well as fish length, weight, condition, sex, and spawning state. At the $\alpha = 0.10$, only weight ($p = 0.04$) was significant. Fish weight had a positive linear effect on residency time. An increase in 1.0 g weight was associated with a 0.34 d increase in residency (90% CI = 0.06 - 0.62).

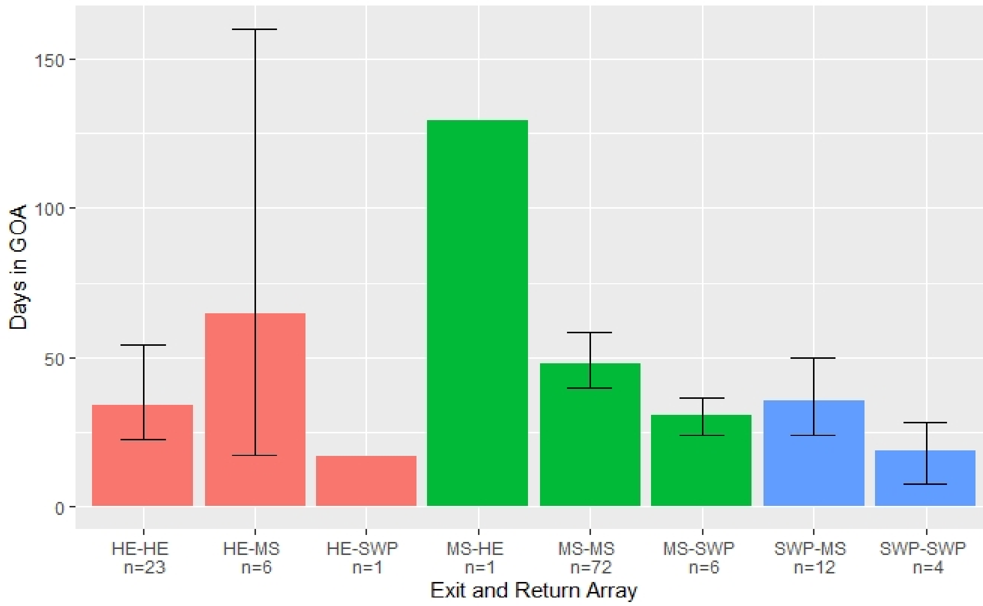

Figure 6. Estimated mean residency time (d) and 90% confidence interval for fish exiting to and remaining in the Gulf of Alaska > 7 d, followed by a return to Prince William Sound. Residency estimate shown by exit and return entrance arrays. Arrays: HE = Hinchinbrook Entrance, MS = Montague Strait, SWP = Southwest Passages. n = total exit/return where residency could be estimated for a total of 69 individual fish.

8. Coordination/Collaboration:

A. Projects Within a Trustee Council-funded program

1. Within the Herring Research & Monitoring (HRM) Program

Herring age, sex, and size collection, Project 19160111-F, ADF&G, principal investigator (PI) Haught: During April 2019, we received critical information on timing and location of herring spawn.

Herring hydroacoustic surveys, Project 19120111-G, PWS Science Center, PI Rand: In April 2019, we received information from PI Rand's project on adult school locations.

Herring age at reproductive maturity, Project 19170111-D, PWS Science Center, PI Gorman: In May 2019, we assisted PI Gorman with field capture of adult herring.

Herring Disease, Project 19120111-E, U.S. Geological Survey, PI Hershberger: In April 2019 we provided water samples from our tagging totes that were analyzed by PI Hershberger for presence of herring viruses.

2. Across Programs

a. Gulf Watch Alaska

PWS Oceanographic conditions, 19120114-G, PWS Science Center, PI Campbell: We have collaborated regularly with PI Campbell's project, both assisting him in the field, and PI Campbell assisting us with data uploads and grappling for missing receivers.

Long-term monitoring of oceanographic conditions in the Alaska coastal current from hydrographic station GAK1, 19120114-I, University of Alaska-Fairbanks, PI Danielson: We are planning to collaborate with PI Danielson during FY20 to use a glider equipped with a Vemco acoustic receiver to search in PWS for tagged herring. The glider study will be funded by the Alaska Ocean Observing System (AOOS) through a grant to University of Alaska-Fairbanks.

b. Data Management

Metadata is on file with Axiom (Research Workspace)

Research Workspace:

https://researchworkspace.com/project/283150/files

Ocean Tracking Network

https://members.oceantrack.org/project?ccode=NEP.PWS

https://members.oceantrack.org/project?ccode=NEP.PWSPH

B. Individual Projects

This project synergizes with efforts of the OTN (Fred Whoriskey, Ph.D. Executive Director, Dalhousie University) and with the Alaska Ocean Observing System (Molly McCammon, Executive Director). In March 2013, OTN installed two, large-scale arrays including one across the mouth of Hinchinbrook Entrance and one across Montague Strait, and four small arrays at the southwest PWS passages of Latouche, Elrington, Prince of Whales, and Bainbridge. With FY16 *Exxon Valdez* Oil Spill Trustee Council funding, in February 2017, PWS Science Center expanded the OTN array. Because biofouling was impacting detections by some of the receivers originally deployed in 2013, in 2018, OTN provided 18 additional VR2AR receivers to maintain the integrity of the array.

Currently, PWS Science Center maintains the array for OTN on an annual basis. OTN maintains a database with detections from their worldwide network. Our data are archived in the OTN databases, as per their guidelines. For 2017-2021 the Alaska Ocean Observing System (AOOS) has provided funding to cover the costs of maintaining the OTN arrays. AOOS is also providing University of Alaska Fairbanks with funding for glider work. The first project will take place in PWS and will include a glider equipped with a Vemco acoustic receiver to search in PWS for tagged herring.

C. With Trustee or Management Agencies

We work closely with Stormy Haught at the Cordova office of ADF&G. Our project relied on information from Haught's program in 2019 to help locate adult herring schools in spring for capture and tagging. We also received age, weight, and length data from ADF&G that has helped us with aging the herring we captured. Information derived from this project about herring migrations will be shared with ADF&G.

9. Information and Data Transfer:

A. Publications Produced During the Reporting Period

1. Peer-reviewed Publications

Bishop, M.A., J.W. Bernard. *In review.* An empirical Bayesian approach to incorporate directional information into the Arnason-Schwartz mark-recapture model. *Movement Ecology*

Gray, B., M.A. Bishop, and S.P. Powers. 2019. Structure of winter groundfish feeding guilds in Pacific herring *Clupea pallasii* and walleye pollock *Gadus chalcogrammus* nursery fjords *Journal of Fish Biology* 95(2):527-539. https://doi.org/10.1111/jfb.13984.

Gray, B., M.A. Bishop, and S.P. Powers. *In prep*. Winter variability in the diets of groundfish predators of Pacific Herring and Walleye Pollock in a subarctic sound. Targeted journal: *Deep-Sea Research Part II.*

2. Reports

Bishop, M.A. and J.W. Bernard. 2020. Annual Herring Migration Cycle. Pages 4-1 to 4-10 in W.S. Pegau and D. R. Aderhold, eds. Herring Research and Monitoring Science Synthesis. Herring Research and Monitoring Synthesis Report, (*Exxon Valdez* Oil Spill Trustee Council Program 20120111). *Exxon Valdez* Oil Spill Trustee Council, Anchorage, Alaska

3. Popular articles

Bishop, M.A. 2019. Time to spawn. Delta Sound Connections. Prince William Sound Science Center (https://pwssc.org/wp-content/uploads/2019/05/DSC-2019_WEB.pdf).

Gray, B. 2019. Ping! Tracking fish using passive acoustic technology. Delta Sound Connections. Prince William Sound Science Center (https://pwssc.org/wp-content/uploads/2019/05/DSC-2019_WEB.pdf).

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

1. Conferences and Workshops

Bishop, M.A. Annual herring migration cycle. Herring Research and Monitoring and Gulf Watch Alaska joint Principal Investigators annual meeting, November 2019. Homer.

2. **Public presentations**

None.

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

None.

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

A tagging log with accompanying age, sex, and length of each herring tagged along with a unique tag ID number. These data were recorded in April 2019 and have been uploaded to the Research Workspace. Detection data through May 2019 were uploaded and includes data from Ocean Tracking Network receiver through February 2019 and spawning ground receivers through May 2019. These files include detections of the unique tag ID numbers at each receiver with the accompanying time and date. Our data will be publicly available on the data portal by February 2021.

10. Response to EVOSTC Review, Recommendations and Comments:

Sept 2018: Science Panel Comments - FY19 The Science Panel applauds the PIs work and recognizes that it has greatly advanced our understanding of herring migration within and outside of PWS. It would be nice to be able to compute SE to be comfortable with the accuracy of these data and inferences, given the relatively small sample sizes. What would it take to tag 500 fish? Is it feasible? The PI's work has wide applications. For instance, results from this project help interpret historical ADFG data. We note that, in the FY17 annual report, the PI reports that there is the ability to remotely download data but the PI was not able to access data from all of the receivers. The PI also reports that some of the receivers were tilted. Was the tilting an unexpected event? Is the download problem linked to the tilting issue? What steps will be taken to address tilt issues and loss of data from happening in the future?

Bishop response to Science Panel:

Can we tag 500 fish?

We catch fish right before spawning (many are milting when we tag them). Because of the reduced PWS herring population and predominance of younger and smaller age classes, we have had to search long and hard to locate, catch, and tag over 200 fish during the short pre-spawning window.

We would like to suggest adding a 4th year of tagging in 2020 of at least 210 fish (right now spring 2019 is scheduled to be the final year for tagging). An additional year of tagging would boost our sample size of fish that move to the entrances to approximately 500 fish. By

2020, the dominant age class would be larger, and it will be easier to find and tag larger herring.

Was the tilting an unexpected event?

We consulted with various people before putting out the receivers in March 2013 and were advised that biofouling would not be an issue at the depths we were deploying.

It was not until the September 2017 upload, we noted that some receivers in the Ocean Tracking Network arrays had consistent tilts of 80-90 degrees. Looking at the tilts over time, it appears that biofouling is what is causing the tilting. Depending on the tides, sometimes we can upload receivers with 90 degree tilts. However, receiver tilting appears to affect receiver detection efficiency.

How we are addressing tilt issues?

We have put a second receiver nearby the 18 receivers that are tilting 80-90 degrees. We are going out 2x a year instead of just once to upload data at Montague Strait and Hinchinbrook Entrance. This way we can identify and resolve problems faster and mitigate data loss.

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	$121.5	$139.9	$135.6	$153.9	$157.9	$708.8	$ 382.7
Travel	$1.2	$1.2	$1.2	$3.1	$1.6	$8.1	$ 4.9
Contractual	$23.6	$46.3	$52.9	$50.3	$31.1	$204.2	$ 100.8
Commodities	$118.7	$80.5	$5.0	$99.1	$2.0	$305.3	$ 228.1
Equipment	$5.9	$0.0	$0.0	$0.0	$0.0	$5.9	$ 17.2
Indirect Costs (*will vary by proposer*)	$79.5	$80.3	$58.4	$91.9	$57.8	$367.9	$ 215.0
SUBTOTAL	$350.3	$348.1	$253.0	$398.3	$250.3	$1,600.2	$948.7
General Administration (9% of subtotal)	$31.5	$31.3	$22.8	$35.8	$22.5	$144.0	N/A
PROJECT TOTAL	$381.9	$379.5	$275.8	$434.2	$272.8	$1,744.2	
Other Resources (Cost Share Funds)	$15.0	$15.0	$15.0	$15.0		$60.0	

LITERATURE CITED

Schwarz, C.J. and Arnason, A.N., 1996. A general methodology for the analysis of capture-recapture experiments in open populations. Biometrics, pp.860-873.

Plummer, M., 2003, March. JAGS: A program for analysis of Bayesian graphical models using Gibbs sampling. In Proceedings of the 3rd international workshop on distributed statistical computing (Vol. 124, No. 125, p. 10).

R Core Team, 2013. R: A language and environment for statistical computing.