Form Rev. 8.30.18

1. Program Number:

18170111-D

2. Project Title:

Studies of Reproductive Maturity among Age Cohorts of Pacific Herring (*Clupea pallasii*) in Prince William Sound, Alaska

3. Principal Investigator(s) Names:

Kristen B. Gorman

4. Time Period Covered by the Report:

February 1, 2018-January 31, 2019

5. Date of Report:

April 2019

6. Project Website (if applicable):

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

7. Summary of Work Performed:

OVERVIEW (FY18)

This is the second annual report for this project, *Studies of Reproductive Maturity among Age Cohorts of Pacific Herring (Clupea pallasii) in Prince William Sound, Alaska*, which is a component of the *Exxon Valdez* Oil Spill Trustee Council's (EVOSTC's) Prince William Sound (PWS) Herring Research and Monitoring (HRM) program. The goal of this report is to review the project's development since starting in FY17 and provide a summary of the research accomplished over the last year (FY18).

The FY18 project began in February 2018 following extensive revision of the FY18 renewal proposal during fall 2017 following comments by the EVOSTC Science Panel. These revisions were outlined in the project's 2017 annual report. Feedback from the EVOSTC Science Panel primarily requested that the project 1) focus on direct methods of gonad maturation as the primary test of the Bayesian Age-Structured-Assessment (BASA) model's maturity schedule, as opposed to relying on a scale growth technique, and 2) that the project focus on males, as well as females in FY18. Thus, this report is aimed at describing the work that meets those requests.

Following the FY18 renewal proposal, the main objectives of the study originally proposed in FY17 were fourfold: 1) Assess the seasonal timing (spring, summer, fall, and winter) that allows for accurate determination of both previously spawned and maturing female herring, and maturing male herring, based on direct measures of gonad development (based on gonadosomatic, Hjort, and ovary histopathology criteria) to determine maturation states and the proportion of immature and mature herring per age cohort of interest (ages two through five) in PWS; 2) Assess inter-annual variability in the proportion of immature and mature herring per age cohort of interest in PWS collected at the optimal seasonal time as determined by Objective 1; 3) Couple histology results with annual scale growth information at the individual level, within specific age

cohorts of interest, to understand if scale growth patterns reflect reproductive investment; and 4) Assess annual variation in herring age at maturity schedules before and after 1997 using the Alaska Department of Fish and Game's (ADF&G's) PWS herring scale library. The work conducted in FY18 was focused only on Objective 1, namely the direct measure of reproductive maturation among PWS herring to determine the proportion of immature and mature herring for age cohorts of interest to the BASA model (ages two through five) (BASA, HRM project 18120111-C). Target sample sizes based on the FY18 proposal follow: age 2+ (n = 115 fish per sex, 230 fish per seasonal collection, total 920 per year), age 3+ (n = 115 fish per sex, 230 fish per seasonal collection, total 920 per year), age 4+ (n = 115 per fish per sex, 230 fish per seasonal collection, total 920 per year), and age 5+ (n = 60 per fish per sex, 120 fish per collection, 480 per year) resulting in a total of 3240 fish collected.

METHODS (FY18)

For FY18 field work, the project obtained annual collection and animal care permits through ADF&G (CF-18-032) and Prince William Sound Science Center's (PWSSC's) Institutional Animal Care and Use Committee (PWSSC2018-02). Collection reports for FY18 research were submitted to ADF&G in January 2019 (see Table 5).

Collections of adult female and male Pacific herring in PWS, Alaska, were conducted over the following dates in FY18: 3 March, 13-15 March, 8-11 April, 5-8 July, 11-18 September, and 20 November. The first March collection event occurred over one-day and surveyed areas off Gravina Point. A second March collection event was conducted by John Moran (National Oceanic and Atmospheric Administration) and Jan Straley's (University of Alaska Southeast) Gulf Watch Alaska humpback whale project (EVOSTC project 18120114-O) that surveyed primarily the Montague entrance region of PWS in mid-March over several days. The April collection event was conducted in association with Stormy Haught's (ADF&G) spring spawn herring cruise in PWS as part of the HRM program (project 18160111-F), as well as field collections led by Mary Anne Bishop's (PWSSC) HRM project (18160111-B) as part of her work radio tracking adult herring in PWS. ADF&G and Bishop's group worked primarily off Red Head/Gravina, as well as Cedar and Windy Bays/Hawkins Island. The July collection event surveyed the Montague Strait region of PWS and off Gravina Point. The September collection event was conducted in association with the Gulf Watch Alaska Integrated Predator-Prey cruise led by John Moran and Jan Straley (Project 18120114-O) and Mayumi Arimitsu (U.S. Geological Survey; project 18120114-C) and sampled adult herring from primarily the Montague Strait region of PWS and off Gravina Point. Lastly, the November collection was a one-day event that surveyed for adult herring off Gravina Point. Specific numbers of adult herring collected during 2018 are reported in Table 5.

Once fish were captured, they were either packaged in zip-lock bags, kept cool on ice and shipped to the PWSSC lab for processing (April, July, and November) or immediately processed aboard the vessel (September). A key investment by this project in FY18 was the purchase of a gimballed marine scale ($8000) that allows for weight measurements of herring to be taken accurately onboard vessels. The purchase of this scale has really aided in the logistics for this project such that it is no longer critical to ship herring to Cordova for processing, which allows for working longer at-sea if necessary. All collected herring were processed prior to freezing. Herring were first measured for lengths (mm) and wet weight (g). Gonads from both males and females were dissected from the body and visually examined to determine maturity based on Hjort criteria as outlined by Hay (1985). A gonadosomatic index (GSI) was calculated by weighing the gonad separately where GSI = (ovary weight/whole fish wet weight)*100 (see Hay and Outram, 1981). For female herring, a small mid-section of the ovary was dissected and preserved in formalin for slide mounting and pathology analysis (H. Snyder, President and CEO, and J. Kramer, DVM, Histologistics, Worcester, MA) to

discern maturity states by histopathology following criteria outlined by Brown-Peterson et al. (2011) and Bucholtz et al. (2008). Scales from the lateral side of the body for both males and females were collected and mounted on slides after the initial processing that included length and weight measurements, visual inspection of gonad maturity, as well ovary biopsies for histology. Scales were used to discern the age of fish by counting scale annuli and obtain scale growth measurements for individual annuli for females included in the histology study using imaging software and a fish scale growth measurement macro developed by ADF&G (Juneau).

RESULTS

Age Frequency, GSI, and Hjort Index

March 2018

Field collections in March surveyed areas off Gravina Point in PWS using a fish finder to locate schools of herring. No herring were found during this field trip and the marine predator activity in the region was very slow. A second March survey led by John Moran and Jan Straley's Gulf Watch Alaska humpback whale project collected just under 50 herring. Data shared by J. Moran indicate that captured fish include age-1, along with others in the size range of 5- or 6-year-olds. GSI data suggest an interesting combination of reproductively mature and immature fish in the second March 2018 survey (Fig. 1). Once age data from counts of scale annuli are available for these fish (forthcoming), we will understand the proportion of age-3 and 4 fish that are immature (<5% GSI following Hay and Outram, 1981; Hay, 1985).

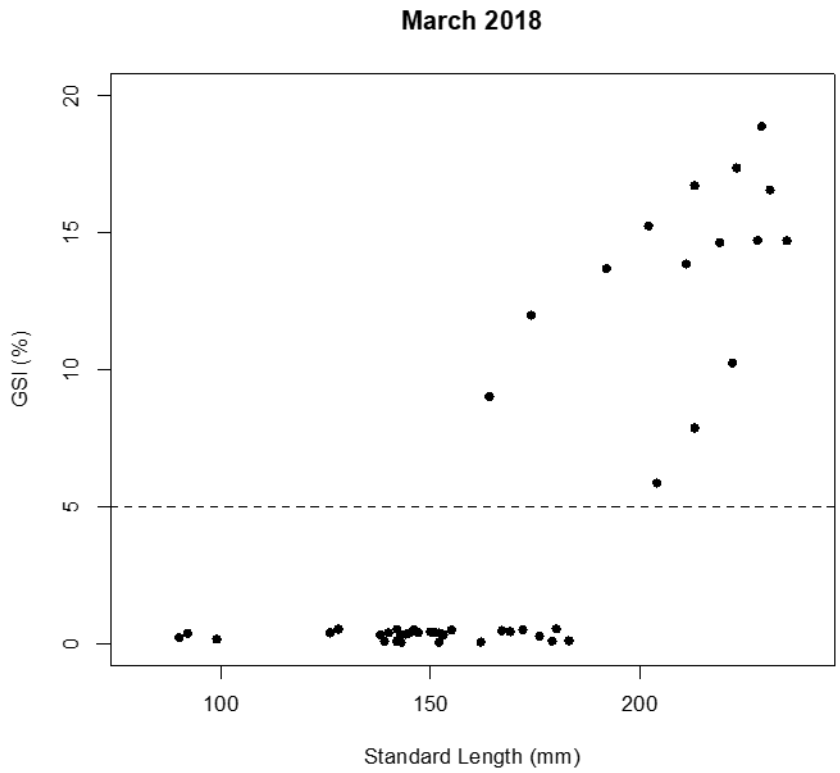

Figure 1. Body length and GSI for female and male Pacific herring caught during March 2018 from the Montague Entrance region of Prince William Sound, Alaska. Dashed line indicates the GSI threshold between reproductive immaturity (<5%) and maturity (>5%).

April 2018

The April collections relied upon ADF&G's purse seine (HRM project 18160111-F), as well as using a fish finder and jig gear from the PWSSC contracted vessel to collect herring. Over 750 adult herring were processed from April 2018 collections for age-at-maturity studies. Based on the samples collected for this project, the spawning population appeared to be dominated by age-3 and 4 fish in 2018 (Fig. 2). The presence of age-2 fish, however, is certainly of interest to the BASA model (Trevor Branch, University of Washington, HRM project 18120111-C), as this age class is currently not considered in the maturity schedule. Interestingly, the jigging effort in April resulted in the project sampling fish outside of the spawning aggregation and resulted in collections of some of the smallest fish of the collection event. Some of the low GSI values apparent in Fig. 3 and noted in Table 1, below, are likely driven by the fact that ADF&G collections occurred after the main spawning event, which means that some of these fish are post-spawn fish with lower GSI values and not necessarily immature fish. Of note is the higher Hjort Index values for all age cohorts, which suggests that some proportion of fish were recovering from spawning (Fig. 4).

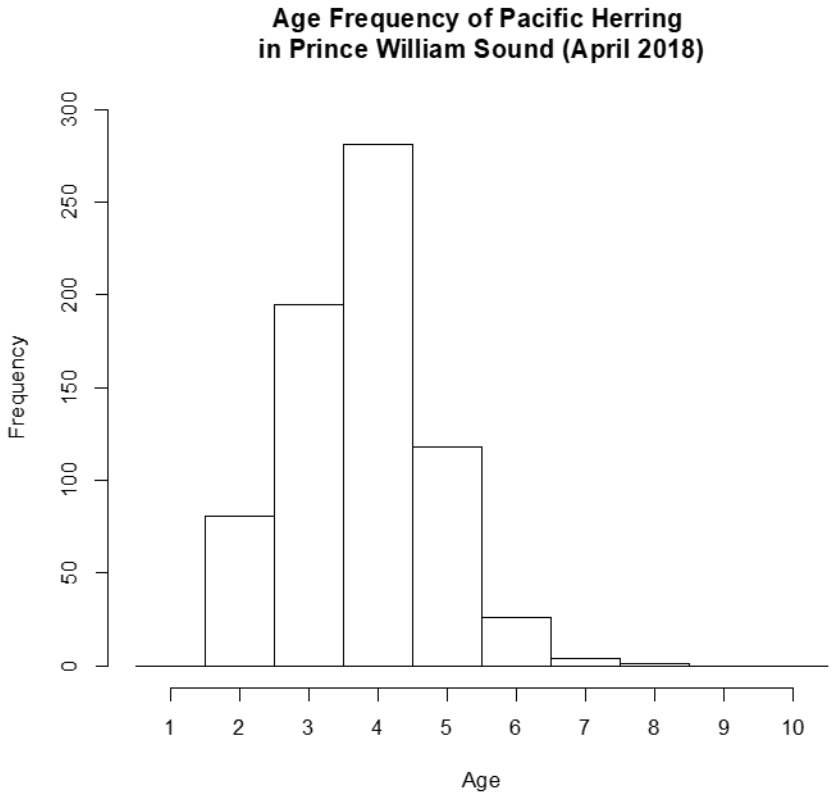

Figure 2. Age frequency distribution of adult herring caught in April 2018.

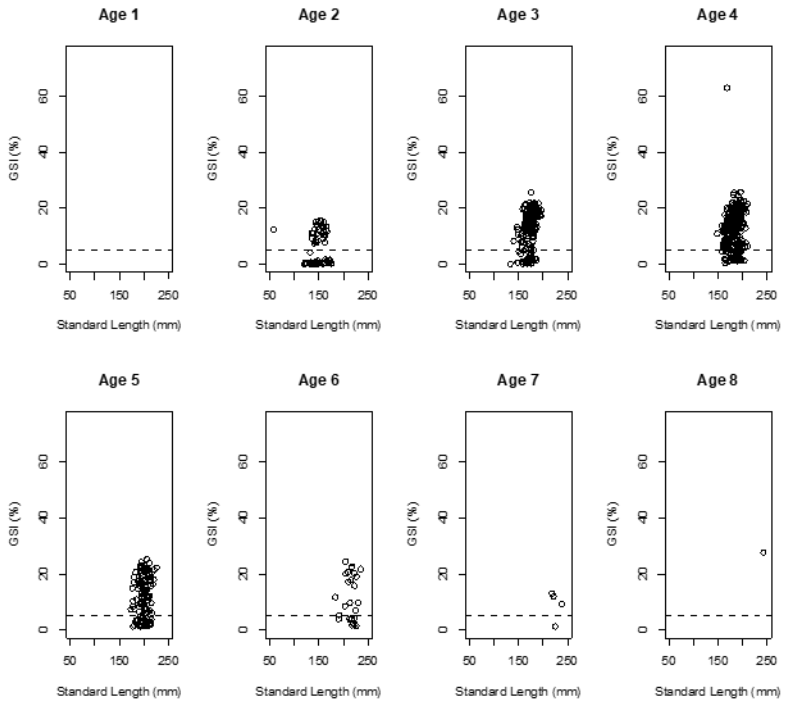

Figure 3. Size and GSI for age cohorts of adult pacific herring caught in April 2018. Dashed line indicates the GSI threshold between reproductive immaturity (<5%) and maturity (>5%).

Table 1. Proportion of immature and mature female Pacific herring caught from the spawning population during April 2018.

Age	No. Immature GSI<5%	No. Mature GSI>5%	% Immature	% Mature	Range of GSI (%)
2	50	31	62	38	0.02-15.71
3	48	145	25	75	0.02-25.66
4	52	229	18	82	0.36-62.94
5	33	85	28	72	1.16-25.33
6	9	17	35	65	1.36-24.47
7	1	3	25	75	1.24-12.98
8	0	1	0	100	27.68-27.68

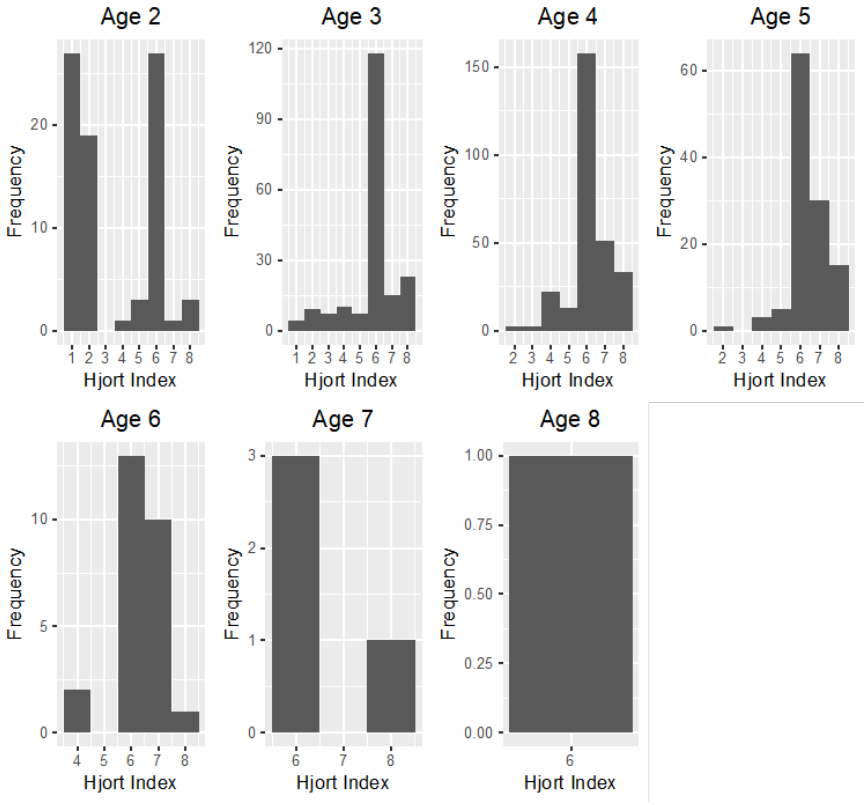

Figure 4. Hjort Index frequency for age classes of Pacific herring caught in April 2018. Hjort values follow: 1: undeveloped, 2: starting, 3: developing, 4: maturing, 5: mature, 6: ripe, 7: spent, 8: recovering.

The July collections fortuitously included adult herring that were caught as by-catch in commercial salmon purse seine sets during the time period when crew for this project were surveying areas around Montague Strait. This project's crew also caught over 130 adult herring by using a fish finder, observations of marine predators, and jig gear in July 2018. Overwhelmingly, a large proportion of the fish captured were age-2 fish, with only a small portion made up by older age classes (Fig. 4). None of the fish processed from July 2018 had a GSI index over 5% (Fig. 6, Table 2). Not surprisingly, nearly all fish had low values for the Hjort Index (Fig. 7).

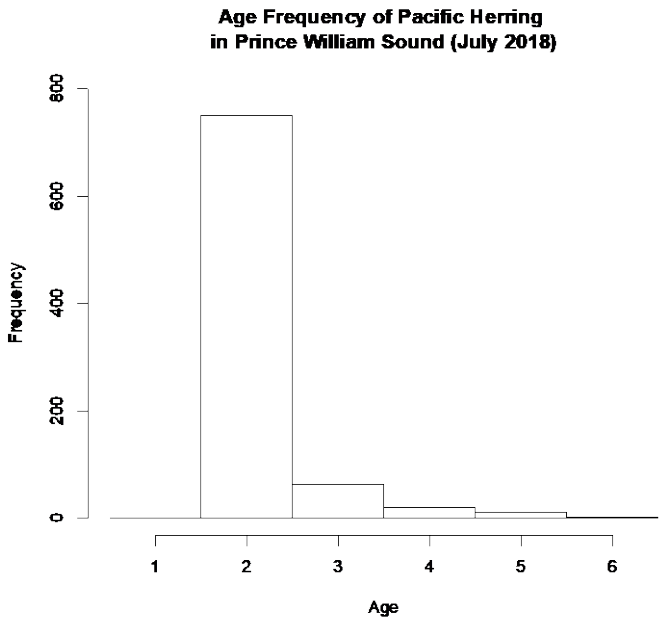

Figure 5. Age frequency distribution of adult herring caught in July 2018.

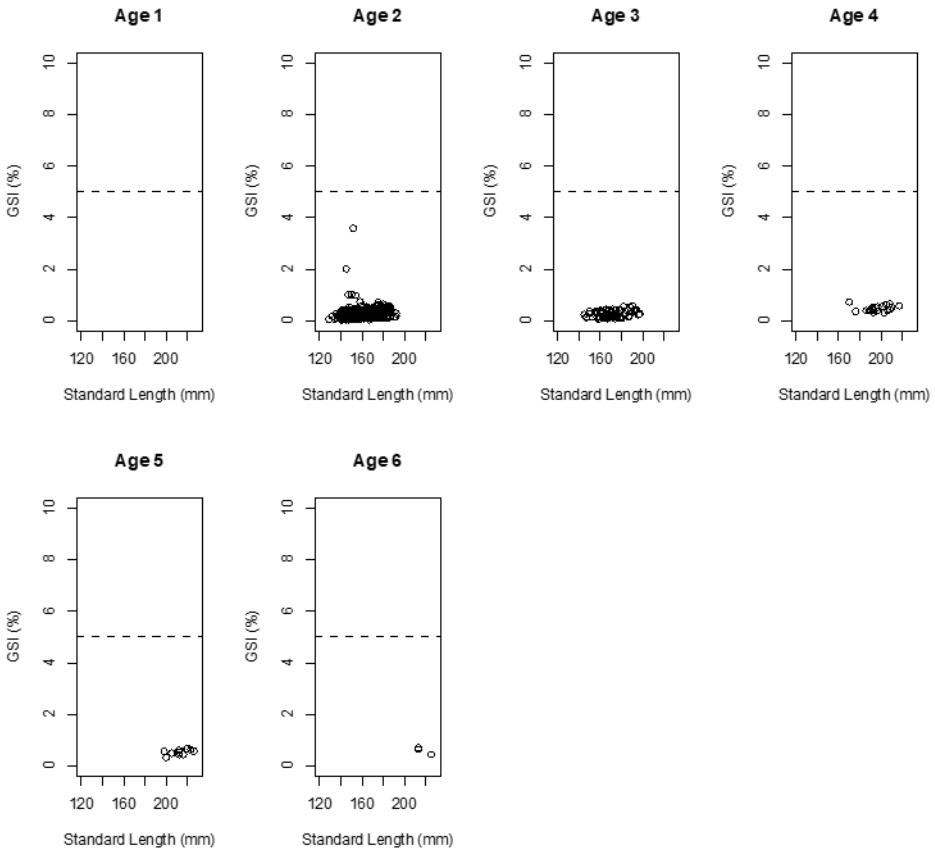

Figure 6. Size and GSI for age cohorts of adult Pacific herring caught in July 2018. Dashed line indicates the GSI threshold between reproductive immaturity (<5%) and maturity (>5%).

Table 2. Proportion of immature and mature female Pacific herring caught from the spawning population during July 2018.

Age	No. Immature GSI<5%	No. Mature GSI>5%	% Immature	% Mature	Range of GSI (%)
2	742	0	100	0	0.03-3.59
3	64	0	100	0	0.07-0.59
4	20	0	100	0	0.32-0.74
5	11	0	100	0	0.34-0.68
6	3	0	100	0	0.45-0.71

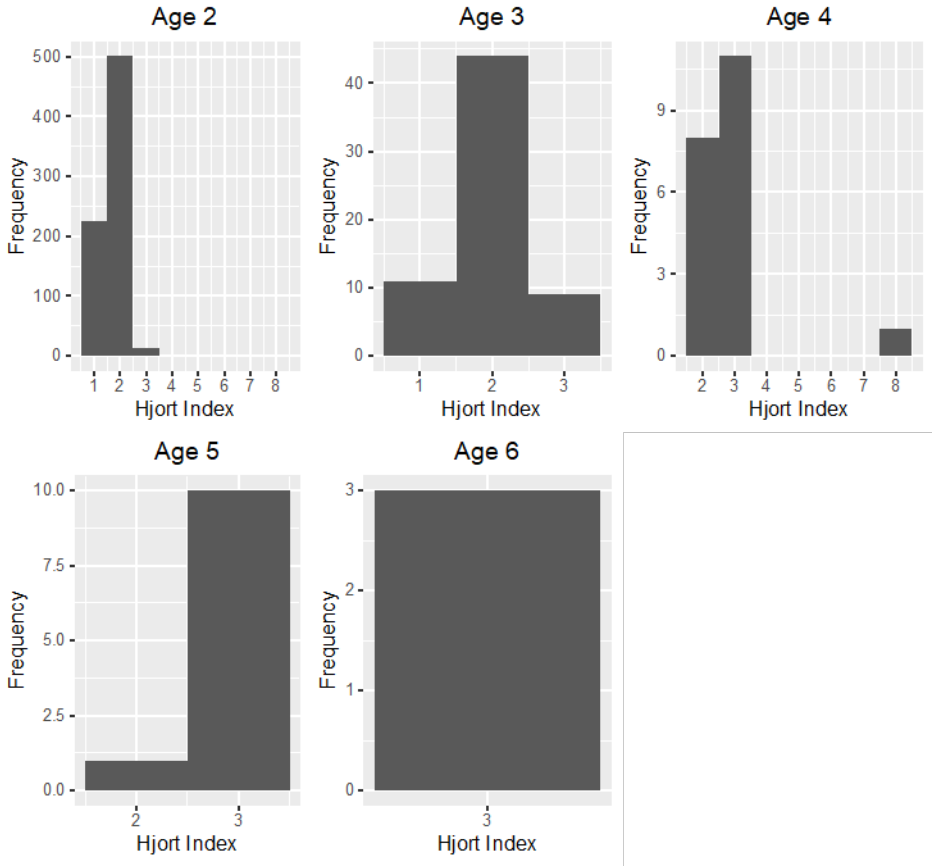

Figure 7. Hjort Index frequency for age classes of Pacific herring caught in July 2018. Hjort values follow: 1: undeveloped, 2: starting, 3: developing, 4: maturing, 5: mature, 6: ripe, 7: spent, 8: recovering.

The September collections relied only on acoustic surveys and observations of marine mammals to locate herring schools that were subsequently sampled using jig gear as part of the Gulf Watch Alaska Integrated Predator-Prey cruise. Similar to the July 2018 collections, the September collections had a large proportion of age 2 fish (Fig. 8). All fish captured in September had GSI values below levels of maturity (<5%) (Fig. 9, Table 3). Not surprisingly, fish caught in September had low Hjort Index values (Fig. 10).

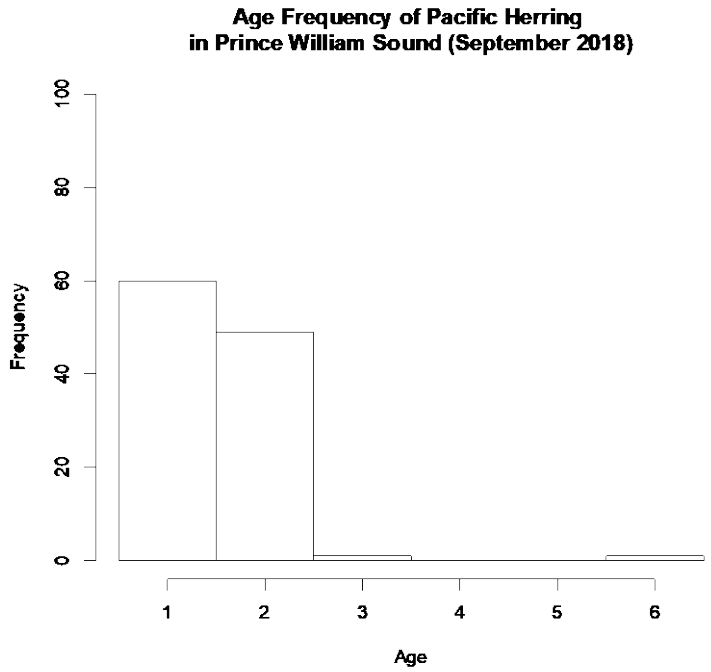

Figure 8. Age frequency distribution of adult herring caught in September 2018.

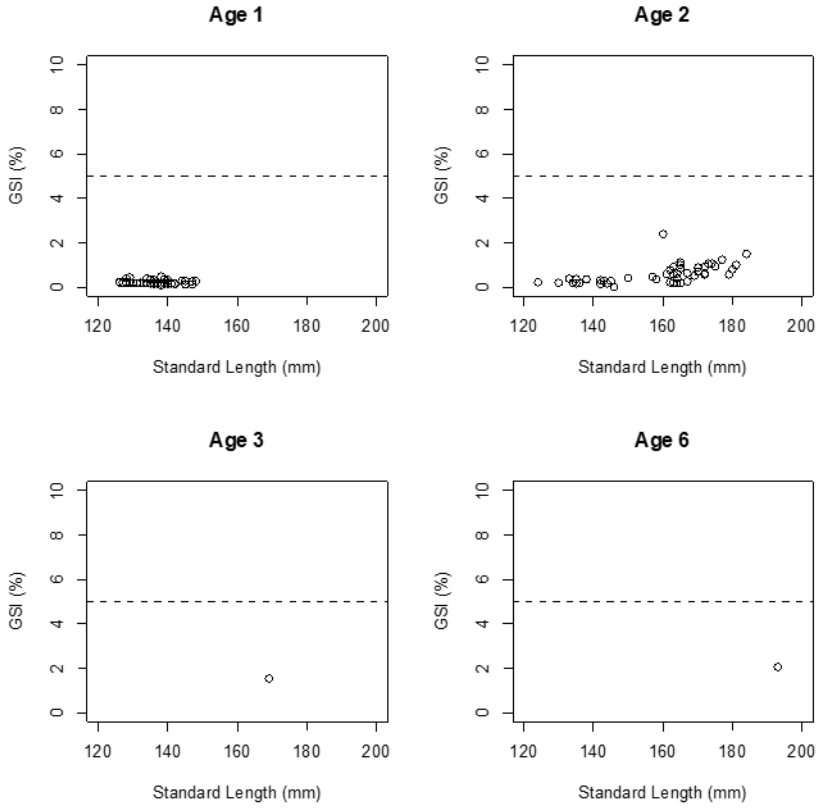

Figure 9. Size and GSI for age cohorts of adult pacific herring caught in September 2018. Dashed line indicates the GSI threshold between reproductive immaturity (<5%) and maturity (>5%).

Table 3. Proportion of immature and mature female Pacific herring caught from the spawning population during September 2018.

Age	No. Immature GSI<5%	No. Mature GSI>5%	% Immature	% Mature	Range of GSI (%)
1	60	0	100	0	0.08-0.49
2	48	0	100	0	0.01-2.39
3	1	0	100	0	1.54
6	1	0	100	0	2.06

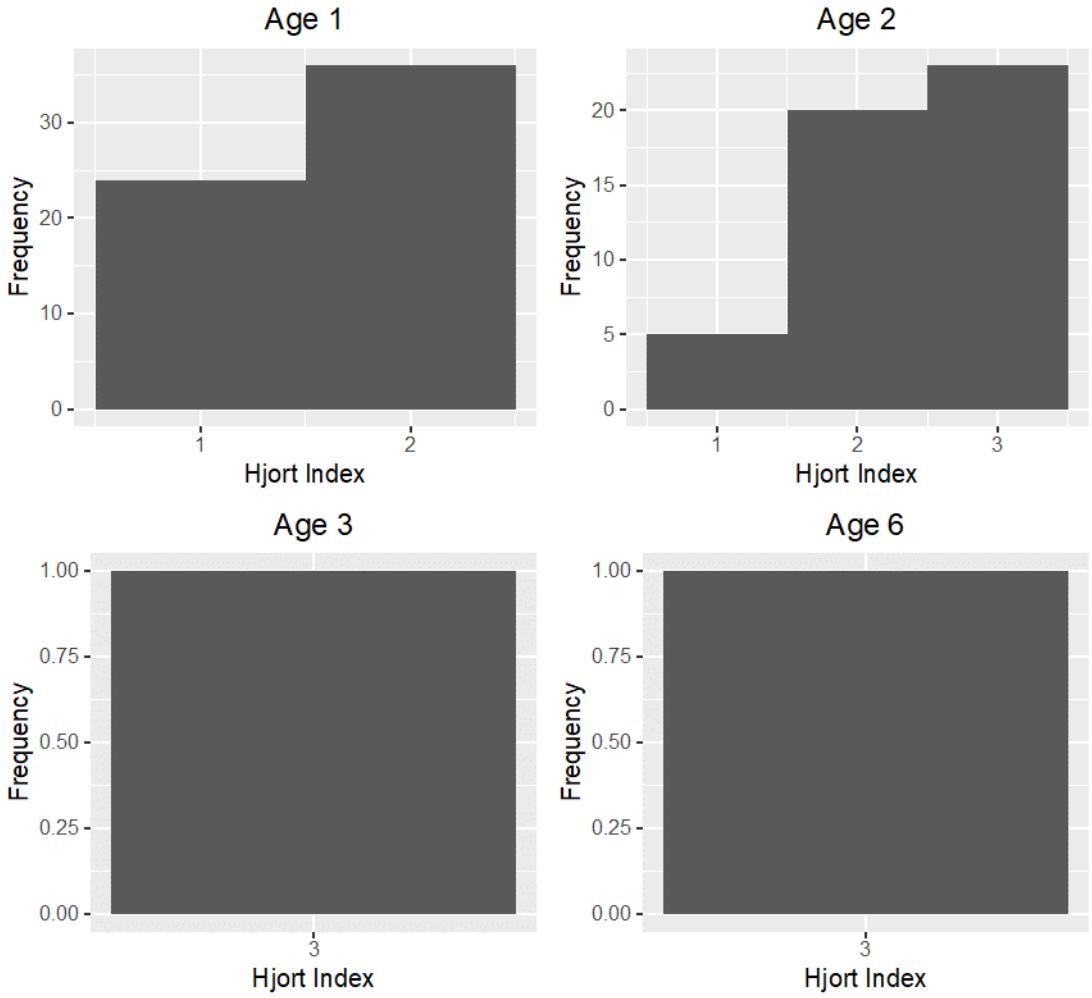

Figure 10. Hjort Index frequency for age classes of Pacific herring caught in September 2018. Hjort values follow: 1: undeveloped, 2: starting, 3: developing, 4: maturing, 5: mature, 6: ripe, 7: spent, 8: recovering.

Adult herring caught in November also only relied on using a fish finder and jig gear to sample herring. Our crew found herring off Gravina Point and sampled these fish. Similar to September and July, age-3 fish dominated the age classes (Fig. 11). However, we found evidence of older fish given the presence of age-4 and 5 herring (Fig. 11). Notably, fish older than age-1 had some evidence of developing gonads in November (Fig. 12, Table 4). Not surprisingly, herring collected in November all had lower Hjort Index values (Fig. 13).

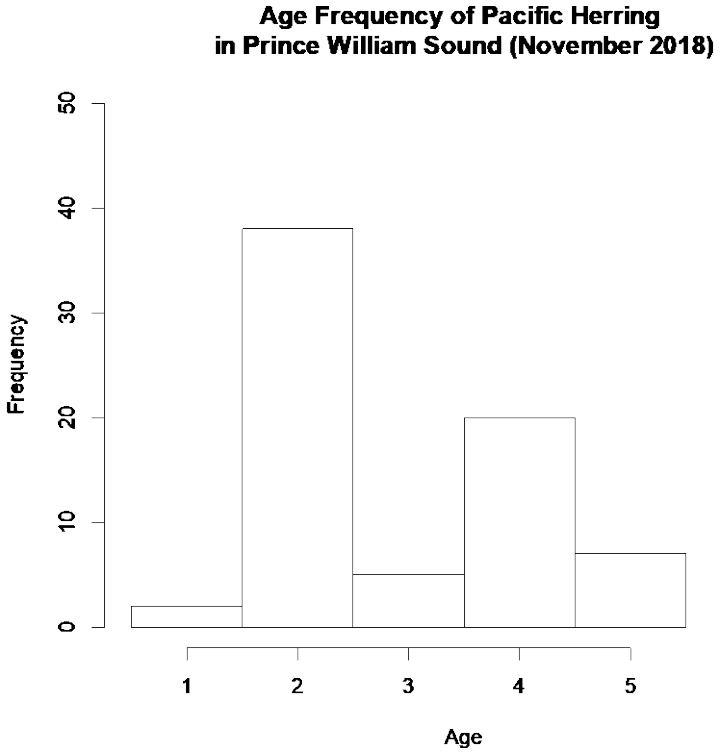

Figure 11. Age frequency distribution of adult herring caught in November 2018.

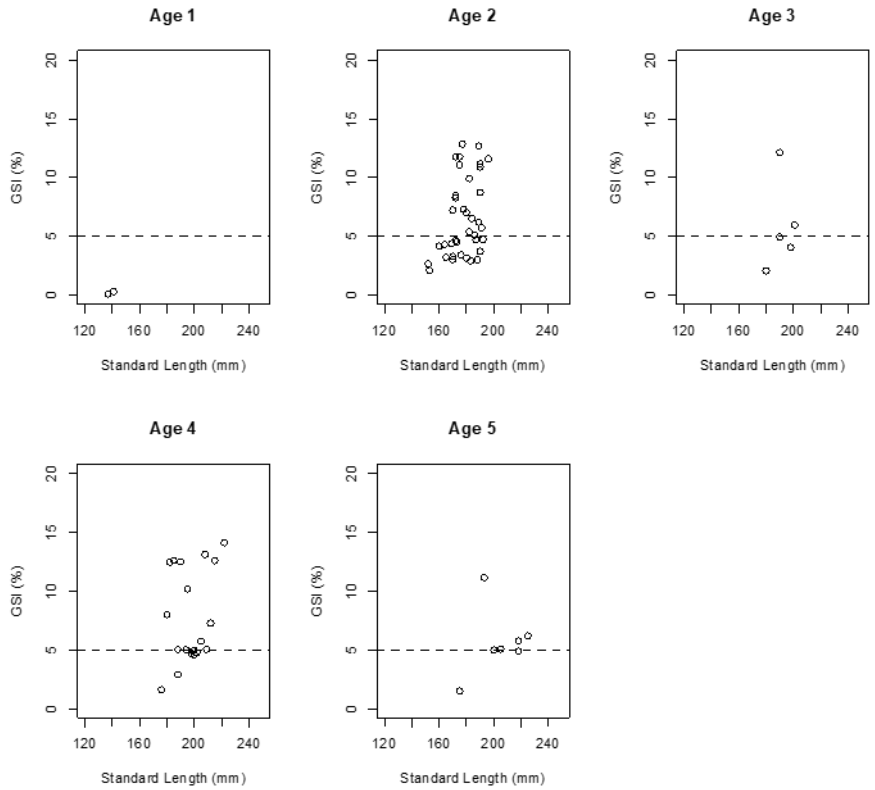

Figure 12. Size and GSI for age cohorts of adult Pacific herring caught in November 2018. Dashed line indicates the GSI threshold between reproductive immaturity (<5%) and maturity (>5%).

Table 4. Proportion of immature and mature female Pacific herring caught from the spawning population during November 2018.

Age	No. Immature GSI<5%	No. Mature GSI>5%	% Immature	% Mature	Range of GSI (%)
1	2	0	100	0	0.09-0.29
2	17	20	46	54	2.09-12.84
3	3	2	60	40	2.07-12.13
4	7	13	35	65	1.61-14.12
5	3	4	43	57	1.50-11.15

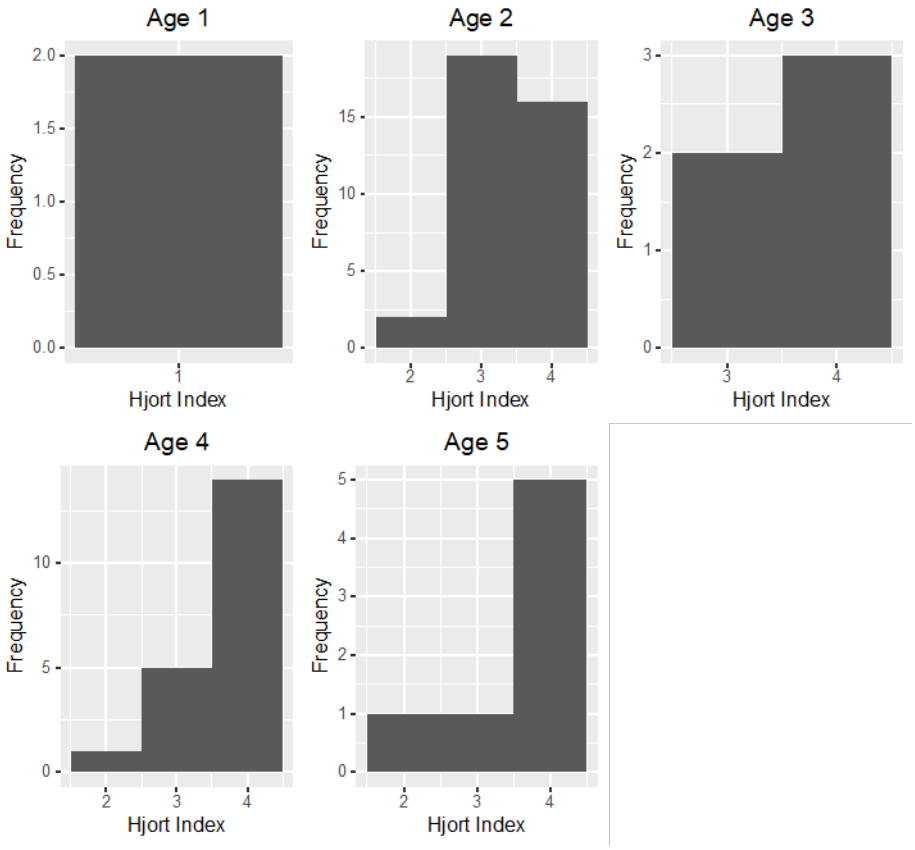

Figure 13. Hjort Index frequency for age classes of Pacific herring caught in November July 2018. Hjort values follow: 1: undeveloped, 2: starting, 3: developing, 4: maturing, 5: mature, 6: ripe, 7: spent, 8: recovering.

Data are beginning to show that there are some interesting sex-specific differences in GSI for Pacific herring, particularly for fish caught in November. Fig. 14 shows that in 2017 and 2018 males had larger GSI values than females, likely suggesting that gonad maturation by females is likely more energetically expensive and it therefore takes females longer to mature. Fig. 15 shows the difference in gonad maturation between herring caught during spawning versus those caught in the summer.

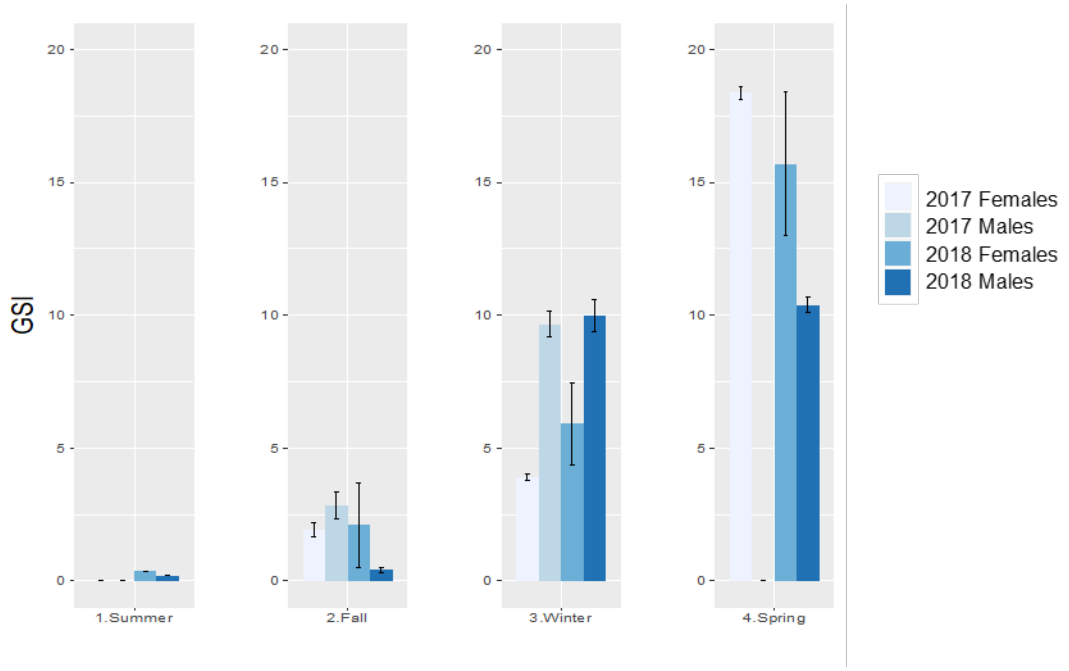

Figure 14. Variability in the gonadsomatic index (%) of Pacific herring caught in Prince William Sound, Alaska during summer (July), fall (September), early winter (November), and spring (April) in 2017 and 2018. Values are means ± standard errors.

Figure 15. Photographs showing a mature adult herring sampled during the spring spawn event and an immature herring sampled in summer.

Collection Effort

Table 5. Collection effort during 2018 for adult Pacific herring in Prince William Sound, Alaska

Date	*Location*	*No. Herring Collected*
4/8/18	Off of Red Head	200
4/8/18	Off of Red Head	35
4/11/18	North of Windy Bay	300
4/12/18	North of Windy Bay	800
7/5/18	Rocky Bay	1
7/6/18	Stockdale	7
7/6/18	Port Chalmers	202
7/6/18	Port Chalmers	555
7/7/18	LaTouche Island/Montague Straight	136
9/13/18	Needles/Montague Straight	59
9/15/18	Outside of Herring Bay	51
9/17/18	Off of Red Head	1
11/20/18	Off Gravina Point	72

Histology and Scale Growth Measurements

To date, the project has received histology results for 2017. The 2018 data are forthcoming, however, samples from July and September were sent to the lab for processing in November 2018. Samples from November 2018 were not sent for histological analysis as there was no evidence of post ovulatory follicles during this time based on the 2017 results. We are very interested in the July 2018 histology results given that we were unable to collect any herring in June 2017. We also wanted to better assess histology for September 2018 samples since so few September 2017 samples were collected (~20). Results from the 2017 samples suggest that for herring caught in September and November, there was no evidence of post-ovulatory follicles at that time of year. The September 2017 herring were all found to be at stage 3, while November fish ranged from stages 2-5 with most being a stage 4. In 2017, we were unable catch herring in June, so there are no histology data for this sampling period. For April 2017, these fish were collected from the spawning population and, not surprisingly, the predominant histology stages were 5-6.

The 2017 and 2018 scale growth measurements have been completed for all fish sent for histological analysis. These measurements began in summer 2018 following the purchase of a new laptop to run the scale growth macro and considerable time spent this spring and early summer getting the ADF&G scale growth macro to work, in addition to sorting out the process to scan the scale images. The growth data analysis is forthcoming. The 2018 data were completed only recently.

Data Submission to Workspace

The 2017 and 2018 data that are available have been submitted to the Research Workspace with the submission of this report. We are working on updating the current Access database for this project to include

the histology and scale growth data. These data are not yet incorporated into the Access database, but copies of the Excel files with these data have been submitted to the workspace.

DISCUSSION

The FY18 project has documented seasonal aspects to the gonad maturity of adult Pacific herring in PWS (Figs 1, 3, 6, 9, 12, 14). Work by Hay (1985) documents a similar seasonality to the reproductive maturity of adult herring in British Columbia, Canada, based on GSI. While I was not surprised to detect a seasonality to PWS herring reproductive maturity, I was surprised that we documented elevated GSI values for age-2 herring in PWS mainly because it is thought that adults of this population mature between ages-3 and 4. It is important to note that the term "immature" in this report refers to adult herring with non-developed gonads. This should not be confused for fish that have not spawned previously.

An important improvement to our collections in 2018 included the focused use of fish finders to locate herring and jig gear to sample fish. This technique was used throughout the various seasons, i.e., spring spawn, summer, fall, and early winter, including times when fish are not as densely schooled as they are during spawning. Also, what has impressed me is that we have been able to sample very small schools of herring at depth using jig gear. It is a very effective way of sampling for the type of research conducted by this project. Further, it is apparent that there were more herring available to catch at the times that we sampled in 2018 than 2017, which greatly increased our success. That said, the spawning population in 2018 was at a historically low level and I suspect it will continue to become more difficult to catch fish in the future. After reviewing the age frequency results from this report, it seems that in 2018 during July and September, the older fish appear to leave PWS with age-1 and 2 fish continuing to use PWS. The older fish re-appeared in our catch data by November and the few March samples we have from 2018 indicate the presence of possibly older fish in PWS at that time. Further, the documentation of age-2 fish in the spawning population and with elevated GSI values in November and April suggest that the BASA model should begin considering incorporating this age group into the model.

ACKNOWLEDGEMENTS

Special thanks are extended to Mayumi Arimitsu for her help in understanding the most effective ways to catch Pacific herring for this project. Following our failure to catch herring in June 2017 using the trawl, which was primarily due to the absence of herring in PWS at that time, Yumi suggested we consider using standard fish finders and jigs to catch herring, as this is the most effective way to try to target small schools of fish. This technique has greatly improved our ability to collect fish for this project. Further, sincere thanks are also extended to a number of individuals who helped with field collections and lab processing this year, particularly Kirsti Jurica, Ben Gray, Anne Schaefer, Mary Anne Bishop, Brad Reynolds, Andy Craig, Brent Davis, and Seawan Gehlbach, as well as ADF&G staff that helped with spring spawn collections, and members of the NOAA and USGS teams that helped with September field collections.

LITERATURE CITED

Brown-Peterson, N. J., Wyanski, D. M., Saborido-Rey, F., Macewicz, B. J., and Lowerre-Barbieri, S. K. 2011. A standardized terminology for describing reproductive development in fishes. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, 3: 52-70.

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Hay, D. E. 1985. Reproductive biology of Pacific herring (Clupea harnangus pallasi). Canadian Journal of Fisheries and Aquatic Sciences, 42: 111-126.

Hay, D. E., and Outram, D. N. 1981. Assessing and monitoring maturity and gonad development in Pacific herring. Canadian Technical Report of Fisheries and Aquatic Sciences: i-v, 1-31.

8. Coordination/Collaboration:

A. Projects Within a Trustee Council-funded program

1. Within the Program

This project coordinated with multiple other projects in the HRM program. First, spring samples were collected in conjugation with the ADF&G age, sex, and length cruise (project 18160111-F) and PWSSC's adult herring tagging cruise (project 18160111-B). We will provide the data generated as part of this project to the HRM modeling project (18120111-C) to at least test maturity schedules, or possibly as an input in the model if solid data are available.

2. Across Programs

a. Gulf Watch Alaska

This project coordinated with several Gulf Watch Alaska pelagic component projects. Some March 2018 herring samples were collected by the humpback whale project (18120114-O). The forage fish project (18120114-C) contributed to sampling methods employed in FY18. The September fieldwork was conducted with Gulf Watch Alaska's Integrated Predator-Prey cruise (projects 18120114-C, 18120114-E, and 18120114-O).

b. Data Management

PI Gorman met with data coordinator Stacey Buckelew at the November 2018 PI meeting in Anchorage. Data management is on schedule.

c. Lingering Oil

None.

B. Projects not Within a Trustee Council-funded program

None.

C. With Trustee or Management Agencies

First, spring samples were collected in conjugation with the ADF&G age, sex, and length cruise (project 18160111-F) and PWSSC's adult herring tagging cruise (project 18160111-B). We will provide the data generated as part of this project to the HRM modeling project (18120111-C) to at least test maturity schedules, or possibly as an input in the model if solid data are available.

9. Information and Data Transfer:

A. Publications Produced During the Reporting Period

None

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

November 2018 PI meeting in Anchorage, AK.

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

Prince William Sound Science Center has uploaded a description of this project to the institute's website and can be found here: http://pwssc.org/reproductive-maturity-of-pacific-herring/

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

PWS Pacific herring age at maturity Access database, histology, and scale growth datasets as of February 2019.

10. Response to EVOSTC Review, Recommendations and Comments:

The FY18 project began in February 2018 following extensive revision of the FY18 renewal proposal during fall 2017 following comments by the EVOS Science Panel. These revisions were outlined in the project's 2017 annual report. Feedback regarding the FY18 proposal from the EVOS Science Panel primarily requested that the project 1) focus on direct methods of gonad maturation as the primary test of the Bayesian Age-Structured-Assessment model's maturity schedule, as opposed to relying on a scale growth technique, and 2) that the project focus on males, as well as females in FY18. Thus, this report is aimed at describing the work that meets those requests. See the EVOSTC FY18 work plan for detailed responses with the Science Panel for the FY18 proposal.

11. Budget: *See,* Reporting Policy at III (C) (11).

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	$71.5	$74.3	$79.4	$82.6	$85.2	$393.0	$ 98.3
Travel	$1.1	$1.1	$1.1	$1.1	$1.1	$5.5	$ 2.6
Contractual	$45.0	$44.2	$34.2	$34.2	$34.2	$191.8	$ 49.8
Commodities	$2.4	$1.8	$1.8	$1.8	$1.8	$9.6	$ 4.5
Equipment	$0.0	$0.0	$0.0	$0.0	$2.6	$2.6	$ 8.2
Indirect Costs (*will vary by proposer*)	$36.0	$36.4	$35.0	$35.9	$36.7	$180.0	$ 46.5
SUBTOTAL	$156.0	$157.8	$151.5	$155.6	$161.6	$782.4	$209.9
General Administration (9% of	$14.0	$14.2	$13.6	$14.0	$14.5	$70.4	N/A
PROJECT TOTAL	$170.0	$172.0	$165.1	$169.6	$176.1	$852.8	
Other Resources (Cost Share Funds)	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	

Spending is behind on this project partly because we are waiting on histology results for FY18. Further, this project lost its full-time technician when Julia McMahon started graduate school, about 6 mo of her time was originally budgeted in the initial 5-year proposal. There was a gap in time between the loss of Julia and hiring a part-time technician. The technician duties are being covered by a part-time assistant (Kirsti Jurica) in addition to others helping to process samples (S. Pegau, C. Pegau, M. Bishop, B. Grey, and A. Schaefer).