1. Project Number:

19120111-A

2. Project Title:

Herring Program – Program Coordination

3. Principal Investigator(s) Names:

W. Scott Pegau, Prince William Sound Science Center

Maya Groner, 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):

https://pwssc.org/herring/

7. Summary of Work Performed:

The work described here outlines the work of the Coordination project of the Herring Research and Monitoring (HRM) program. The Coordination project includes efforts on coordination, outreach efforts, a postdoctoral researcher to analyze the relationships between herring diseases and physical and biological oceanographic conditions, works with principal investigators (PIs) to examine new means of collecting information, and works with PIs to synthesize existing information. The goal of the project is to provide coordination within the HRM program and with the Gulf Watch Alaska (GWA) and Data Management (DM) programs. The objectives of the project are:

1. *Coordinate efforts among the HRM projects to achieve the program objectives, maximize shared resources, ensure timely reporting, and coordinate logistics.*
2. *Provide outreach and community involvement for the program.*
3. *Oversee a postdoctoral researcher.*

A synthesis describing the current state of knowledge on several aspects of the HRM program was a deliverable this past year.

Coordination is primarily through e-mail and teleconference. We hold one PI meeting each year to provide more intensive interactions between the investigators. The focus of the HRM PI meeting is in sharing findings and spending time coordinating between projects. To coordinate with the other programs, the management team of GWA and the lead of DM are included in the emails to HRM principal investigators (PIs) to ensure they are aware of our activities. We also have joint PI meetings and community involvement activities with the other programs.

Coordination effort

Reports and proposals have been submitted to the National Oceanic and Atmospheric Administration (NOAA) and the *Exxon Valdez* Oil Spill Trustee Council (EVOSTC) on time. Reports and proposals are being requested from the PIs earlier than they have in the past to allow the HRM Science Oversight Group additional time to comment on them before submission and to provide additional internal review of the grammar and formatting of the materials being submitted. We now also include Dr. Whitehead's EVOSTC lingering oil research project in the HRM program.

The annual PI meeting was held in Homer in October in conjunction with the GWA PI meeting. PIs, including the post-doc in this project and the one in the modeling project presented on the progress of their projects. We had the DM program present and work with the PIs. During this meeting we finalized the synthesis contributions and discussed what we felt were important unknowns that should be explored. The following day the HRM PIs joined the GWA PIs to provide coordination among projects from the two programs.

Synthesis

Dr. Pegau worked with the PIs to coordinate the submission of contributions to the synthesis that was submitted in December 2019. He also contributed to two of the chapters. The synthesis examines five aspects of the HRM program research. They include the survey designs used within the HRM program, research on maturity, spawn timing, adult herring movement, and disease.

The survey design chapter describes the methods used for aerial milt surveys and methods we have tested to supplement those surveys, acoustic surveys, age-sex-size sampling, and aerial forage fish surveys. The age-sex-size samples and age-structure-analysis models are used to examine what the maturity of the fish in the pre-spawn aggregations and if fish are missing from the pre-spawn aggregations. We also examine if differential growth can be detected using herring scales. We examine how the spawn timing and location has changed over the past four decades and what factors may have influenced the changes. Changes in spawning location appear to be related to large recruit classes. We examine movement of herring after spawn and find that larger fish are more likely to move to the Gulf of Alaska. Finally, we describe the principles governing the epizootiology of viral hemorrhagic septicemia (VHS) virus and provide an overview of *Ichthyophonous* surveillance results.

Outreach effort

Outreach efforts are focused on providing up-to-date information on the projects and their findings. Keeping the HRM section of the Prince William Sound Science Center (PWSSC) website up to date has been a key objective. During the last year we continued to update the HRM program website with new findings from ongoing projects. All completed projects are now up to date with a results section titled “What we learned” (as opposed to a “What we are learning”). Formatting between project pages has been refined and is consistent throughout. Additionally, two new episodes of Field Notes were created in a story format instead of the traditional interview format. The story format allows the information to be condensed, meaning the same information gathered from a lengthy interview can be delivered in a shorter amount of time in an attempt to make the show more fit for radio programming. Field Notes is a podcast/radio program describing the work of the HRM program. We also contributed six articles to the Delta Sound Connections publication in an HRM spread. updating the spill-affected communities on the year’s findings. Delta Sound Connections is a newspaper produced annually by the PWSSC and distributed widely throughout Prince William Sound and the Copper River Delta (e.g., state ferries, Ted Stevens Anchorage International airport, Mudhole Smith airport in Cordova, Begich Boggs Visitor Center at Portage Glacier, and a variety of sites in Girdwood, Glenallen, Copper Center, and Valdez).

Research effort

The postdoctoral researcher (Maya Groner) has transitioned to an independent research ecologist. The change in title does not affect the deliverables that the person was hired to deliver. The researcher has been able to attract additional funding to conduct additional research that complements their efforts in this project.

Research conducted by Groner has been focused on three topics:

1) quantifying mortality in adult herring from Prince William Sound (PWS) and Sitka Sound due to Ichthyophoniasis,

2) characterizing gene expression in both host and virus during incubation, viral proliferation and viral shedding stages of an experimental challenge of herring with viral erythrocytic necrosis (VEN), and

3) developing a mathematical model for VHS in wild herring.

The first topic is being addressed with both a lab experiment and a field study. The goal of the lab study was to quantify the relationship between *Ichthyophonus* sp. pathogen load and mortality of herring. To do this we infected specific pathogen-free herring at the U.S. Geological Survey (USGS) Marrowstone Laboratory. Replicate tanks (3) of age-4 herring were exposed to *Ichthyophonus* via intraperitoneal injection. Mortality, infection status, size, and cardiac tissue samples were collected from all tanks over the course of the experiment. Infection load was quantified by sectioning, staining, and counting all pathogen (schizonts) in ventricle tissue of herring that were sampled during and at the end of the experiment (165 days) (Fig. 1).

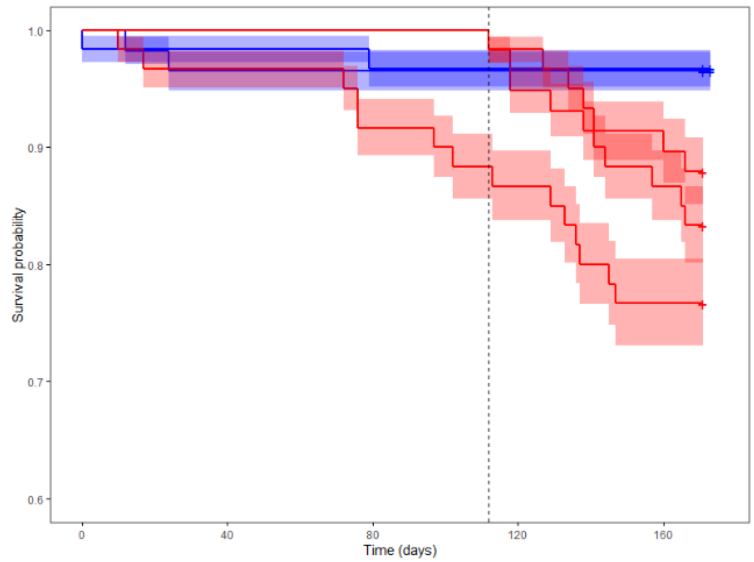

Figure 1. Survival curves for control (blue) and infected (red) herring. Infected herring were exposed to Ichthyophonus sp. via intraperitoneal injection.

Pathogen load was quantified in moribund, dead, and subsamples of live fish using quantitative image analysis of histologically sectioned and stained cardiac tissue (specifically ventricle tissue). A manuscript describing this work has been drafted and will be used to estimate the probability of mortality as a function of infection intensity. Initial results show that mortalities had higher infection loads than survivors and that 0.003 schizonts/ mm^2 of ventricle tissue may be the maximum infection load that these fish can tolerate (Fig. 2). These data are in the process of being written up for publication and will inform estimates of mortality due to Ichthyophoniasis in both Sitka Sound and PWS between 2009 and 2019 (described below).

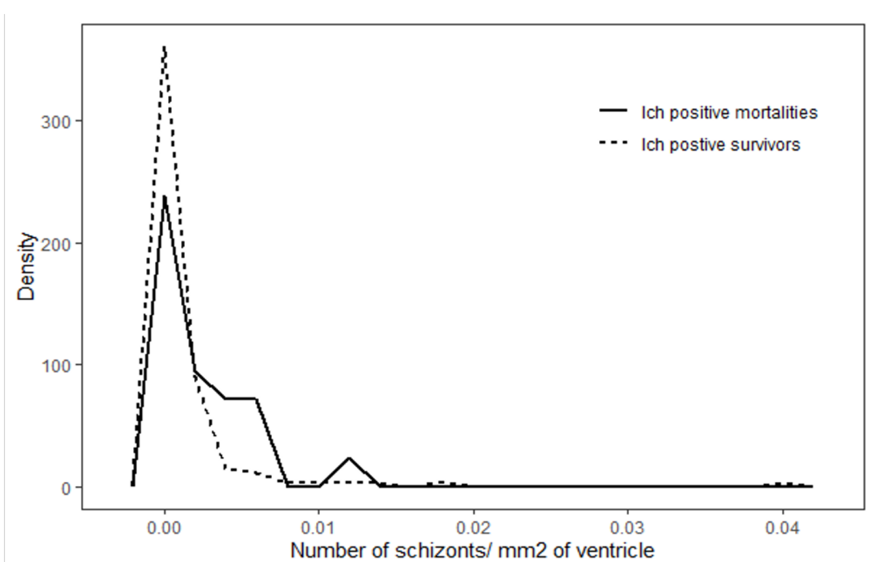

Figure 2. Infection loads of Pacific herring exposed to Ichthyophonus that survived (dotted line) the course of the experiment or died (dark line) during the 165-day experiment.

Estimates of adult herring mortality in Sitka Sound and PWS that are due to infection with *Ichthyophonus* sp. are in the process of being calculated. These calculations are dependent upon infection loads calculated from herring hearts collected in Sitka Sound and PWS during the spawning seasons between 2009 and 2019 (180 hearts/ site/ year). Previously pathogen presence/absence has been measured on these samples, further examination of infection intensity (# parasites/ area tissue) will allow us to determine if there has been an increase in mortality associated with higher intensity *Ichthyophonus* infections. This work is motivated by shifting patterns in disease prevalence across age (as a proxy for size) and an increase in gross observations of severely diseased herring particularly in Sitka Sound after 2013. Quantitative estimates of survival as a function of infection intensity can be made using the likelihood method outlined in Wilber et al. (2016). Briefly, the probability of survival for a host with x number of parasites or pathogens can be determined using standard rules of conditional probability:

$$P(x|survival) = \frac{h(survival;x,\theta)*g(x,\varphi)}{\sum_{x=0}^{\infty} h(survival;x,\theta)*g(x,\varphi)} \qquad \text{(eq. 1)}$$

In this equation (eq. 1), $h(survival; x, \theta)$ is the probability of having x parasites, conditional on host survival, and $g(x, \varphi)$ is the pre-mortality distribution of parasites among hosts. The pre-mortality distribution is typically assumed to be a negative binomial, but other distributions are possible. This distribution can be determined empirically from our data (though we suspect it will take a negative binomial distribution). Using the probability distribution in equation 1, the parameters θ and φ that maximize the likelihood of the data can be determined. Code for fitting estimating θ and φ from empirical data is available at: (https://github.com/mqwilber/parasite_mortality). Comparisons will be made to determine how if probabilities calculated with this method agree with those determined experimentally using *Ichthyophonus* challenge experiments (described above). Ultimately, these probabilities will feed into population models for Sitka Sound and PWS. Disease prevalence for different age classes will be calculated using an age-length key and empirically sampled values from our collections. Mortality due to disease from our calculations will be applied to these age classes in yearly time steps to determine if the mortality can account for changes in disease prevalence and cohort size over time and across cohorts.

Progress on this project has been steady. We have finished processing, sectioning, staining, imaging, and quantifying infection loads in all hearts collected from 2009 through 2019 (Fig. 3). This work has been further facilitated by a North Pacific Research Board (NPRB) grant awarded to Groner and Hershberger that allowed us to hire a technician (through the USGS Western Fisheries Research Center) in summer 2018 and 2019.

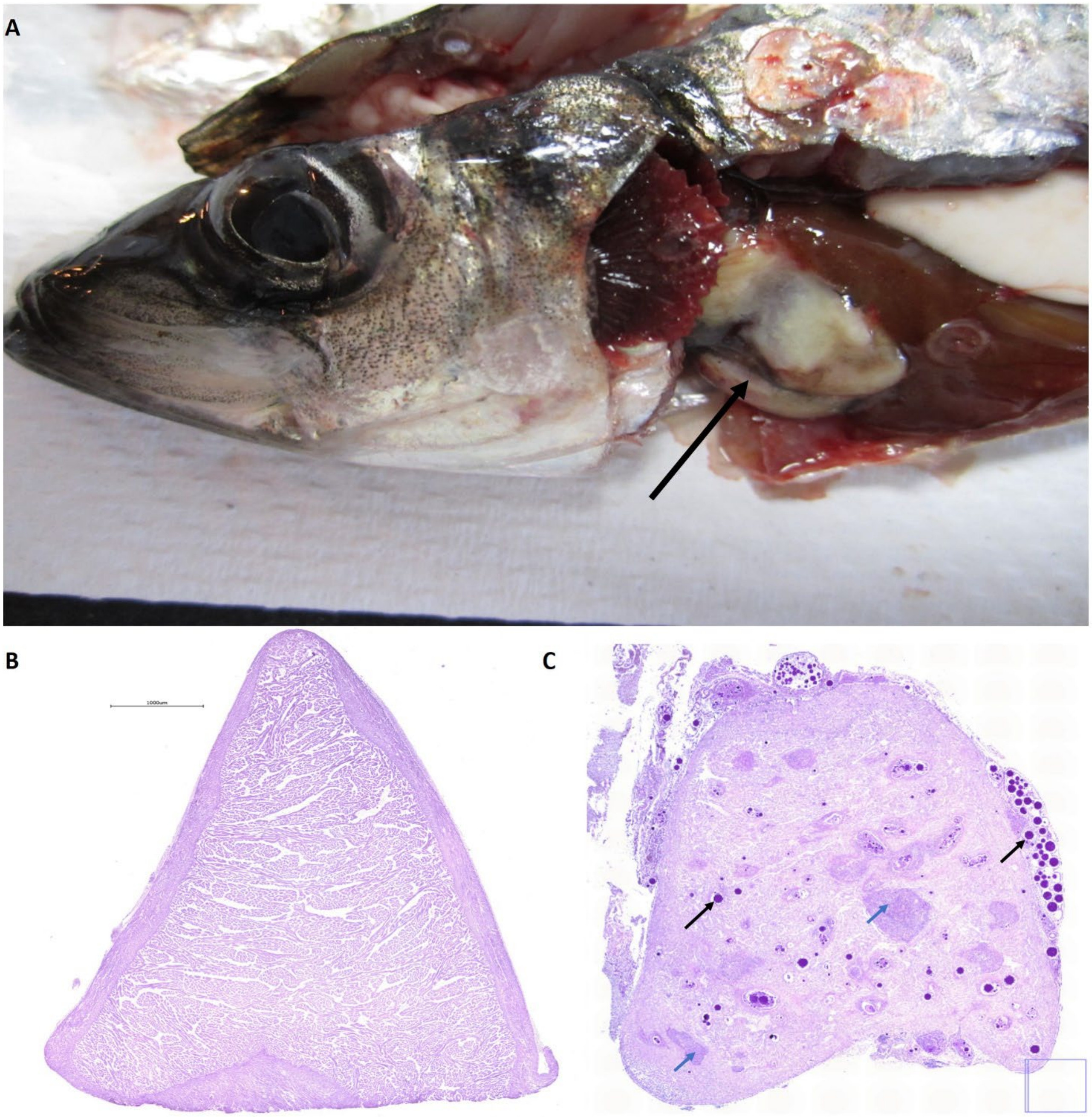

Figure 3. Hearts heavily infected with Ichthyophonus *sp. can appear white instead of dark red (arrow) (A). Histological sections of a healthy herring ventricle (B) next to an infected ventricle (C). On the infected ventricle, the dark purple circles (black arrows) indicate* Ichthyophonus *sp. schizonts. Granulomas of darker staining tissue surround some of the schizonts (blue arrows).*

The second ongoing project is an experiment investigating gene expression in herring and virions through key stages during an epizootic of VEN (Fig. 4). Replicate tanks (3) of age-1 herring were exposed to erythrocytic necrosis virus (ENV) or a control (phosphate buffered saline). At regular timepoints (initially every other day and then weekly) fish are subsampled from these tanks to quantify viral loads and gene expression. Head kidney (the suspected site of viral incubation) is being sampled for subsequent analysis of infection load and gene expression. Blood films are being collected to quantify infection in erythrocytes (via the presence of inclusion bodies) and hematocrits are being collected to quantify anemia. A study of VEN was conducted by our team in 2018 with mixed success due to the presence of VEN in one control tank (due to suspected vertical transmission of VEN) and the use of a low virulence strain. To rectify these problems, we have screened our Specific Pathogen Free (SPF) fish for VEN prior to the experiment and are using a previously tested virulent strain of ENV.

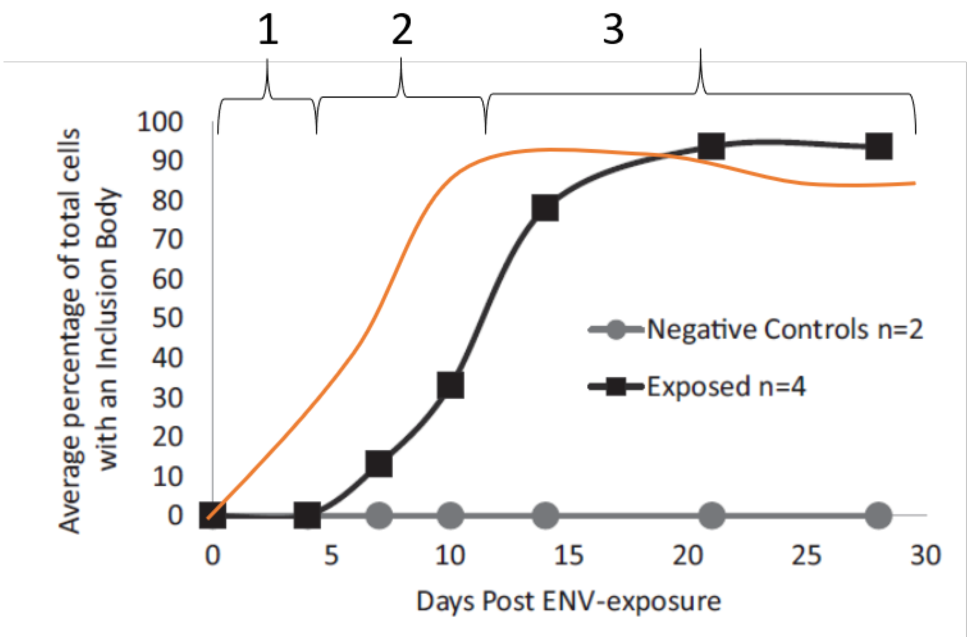

Figure 4. Typical time course of viral erythrocytic necrosis disease. The black curve represents the time course that inclusion bodies become visible in erythrocytes after exposure on day 0 (from Glenn et al. 2012), while the orange curve represents typical qPCR curve in kidneys for erythrocytic necrosis virus (based on Purcell et al. 2016). Sampling is designed to quantify host and pathogen examined during (1) viral incubation, (2) viral proliferation, and (3) viral shedding stages.

For the third goal, modeling VHS in Pacific herring, a novel modeling approach has been developed to parameterize factors influencing VHS in Pacific herring. Groner is using existing data from VHS infection trials conducted by Paul Hershberger (and described in his current annual report) to parameterize mathematical models of VHS dynamics in herring populations. The model is a deterministic Susceptible-Exposed-Infected-Carrier (S-E-I-C) model, which will allow investigation of the role of herd immunity and pulsed, variable recruitment in disease outbreaks. Because parameters are derived from lab experiments, these models will be conceptual in nature (as opposed to modeling distinct geographic areas) and will provide the first disease models of VHS in Pacific herring. Sensitivity analyses of model parameters will be used to identify processes that have the most influence on outbreak dynamics. Within schools, VHS outbreaks occur on the order of weeks, with mortality tapering after 3-4 weeks. Impacts of recruitment and herd immunity (i.e., a dampening of a disease epidemic due to a high number of resistant individuals in a population) will impact disease dynamics across years. The model has now been coded in R and iterations are being run to explore the impact of variable recruitment and herd immunity on short-term disease dynamics (Fig. 5).

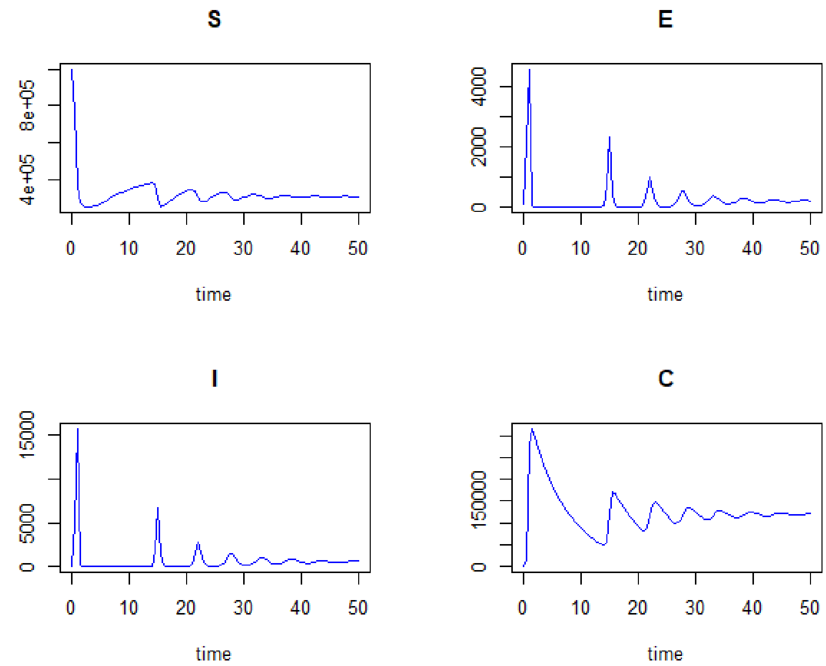

Figure 5. Model output showing dampening oscillations of Susceptible (S), Exposed (E), Infected (I), and Carrier (C) state herring. Model parameters require additional tuning before results will be publishable.

Dr. Groner has participated in several publications that are tangentially related to this project, including (1) a book chapter on marine disease modeling, (2) a manuscript identifying a hotspot for *Ichthyophonus* infection in Pacific herring in Puget Sound (published in 2019 in Diseases of Aquatic Organisms) and (3) a manuscript describing methods for modeling dispersal of marine pathogens using coupled biophysical-hydrodynamic models (published 2-20 in Trends in Parasitology). The book chapter will be published in a textbook on marine diseases (Marine Disease Ecology, Oxford University Press, release date in US is 2-21-20). Dr. Groner's contribution is focused on how to infer epidemiological processes by examining and modeling distributions of parasites within hosts. The theory in this chapter underlies her current work being applied to quantifying and interpreting *Ichthyophonus* intensities in herring hearts.

Dr. Pegau tested the use of satellite information from Planet.com for detecting herring spawn. The satellite data available through that site has ground resolution on the order of a few meters with imagery available almost daily. A limitation is that the imagery is only available on a subscription basis. There is free (or low cost) high-resolution satellite imagery available for the European Sentinel Satellite system. The coverage of that system is very limited. As with all visible wavelength satellites, the satellites are not able to detect spawn through cloud cover. The high-resolution imagery (Fig. 6) allows the detection of much smaller spawn events than the moderate resolution imaging spectroradiometer (MODIS) images that have been used in the past and allow a large area to be searched for spawn activity. There is an archive of images that could be used to search for spawn events that occur outside of the aerial spawn surveys.

Figure 6. A satellite image of herring spawn on March 31, 2019 from Knowles Head to Red Head in Prince William Sound.

An intern working with Dr. Pegau imaged herring scales collected in 2016, 2017, and 2018 to update the earlier herring scale database developed by Steve Moffitt. The intern followed the protocols as were used by Moffitt. The updated database has been uploaded to the Research Workspace and available through the Alaska Ocean Observing System Gulf of Alaska Data Portal.

Additionally, Dr. Pegau has been examining the conditions that lead to either very good or poor recruitment. This effort brings in data collected by the HRM and GWA programs along with data associated with herring in Sitka. This work is in a preliminary stage. It hypothesizes that recruitment is limited by the space available in the nursery ground. It assumes there is either competition for resources or predation by older age classes the occurs when a new year class tries to recruit into the nursery areas and that a significant proportion of age classes through age-3 occupy the nursery areas. This hypothesis sets up a four-year cycle in recruitment because after an excellent year class the nursery area is considered fully occupied until year 4 (Fig. 7).

The first environmental hypothesis considered is the match-mismatch hypothesis that states that food must be available when the larvae begin to feed and grow. There is limited data available so we can only consider if there is food available during the first three months after hatching. Examining the Continuous Plankton Recorder data available on the Gulf of Alaska shelf (Fig. 8) shows that since 2000 three of the years with the lowest zooplankton levels are ones with the poorest recruitment in Sitka Sound (2009, 2011, 2013). The exception to poor recruitment in poor zooplankton years is 2004. Years with exceptional recruitment include 2000, 2012, and 2016. 2000 and 2016 both have higher than normal pteropod levels and 2016 also had high small zooplankton numbers. 2012 and

2010 also have higher pteropod levels but nothing in the zooplankton data suggests why 2012 would have a much better recruitment year than 2010.

This work remains in the preliminary stage with a couple more hypotheses that may provide additional information about the conditions that lead to exception recruitment events.

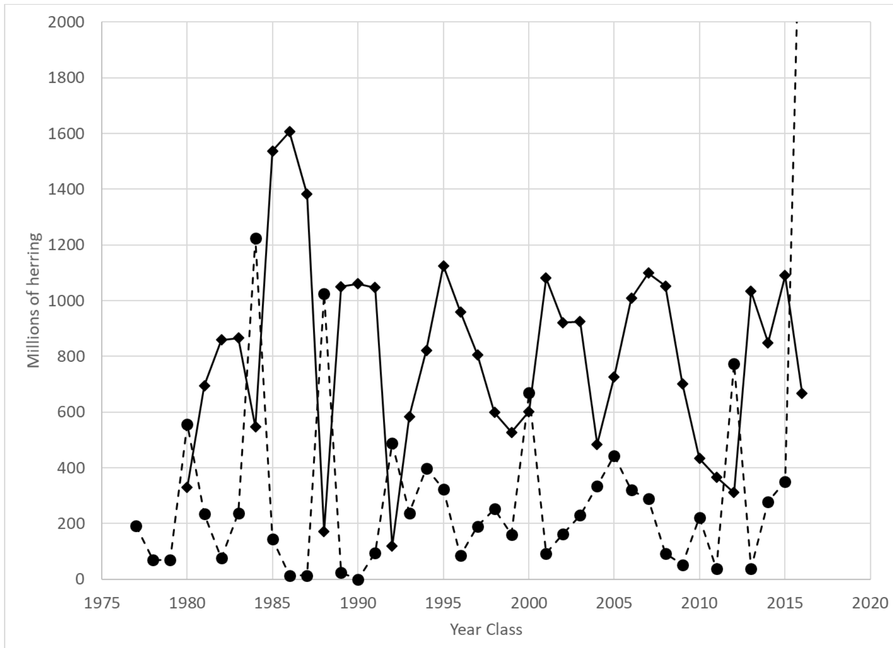

Figure 7. An index of nursery ground fullness is the sum of the previous three years of age-3 herring (solid line) and the number of age-3 herring in each recruit class. Data shown are from Sitka Sound. The initial estimate of the 2016 year class is over 2700 million age-3 herring.

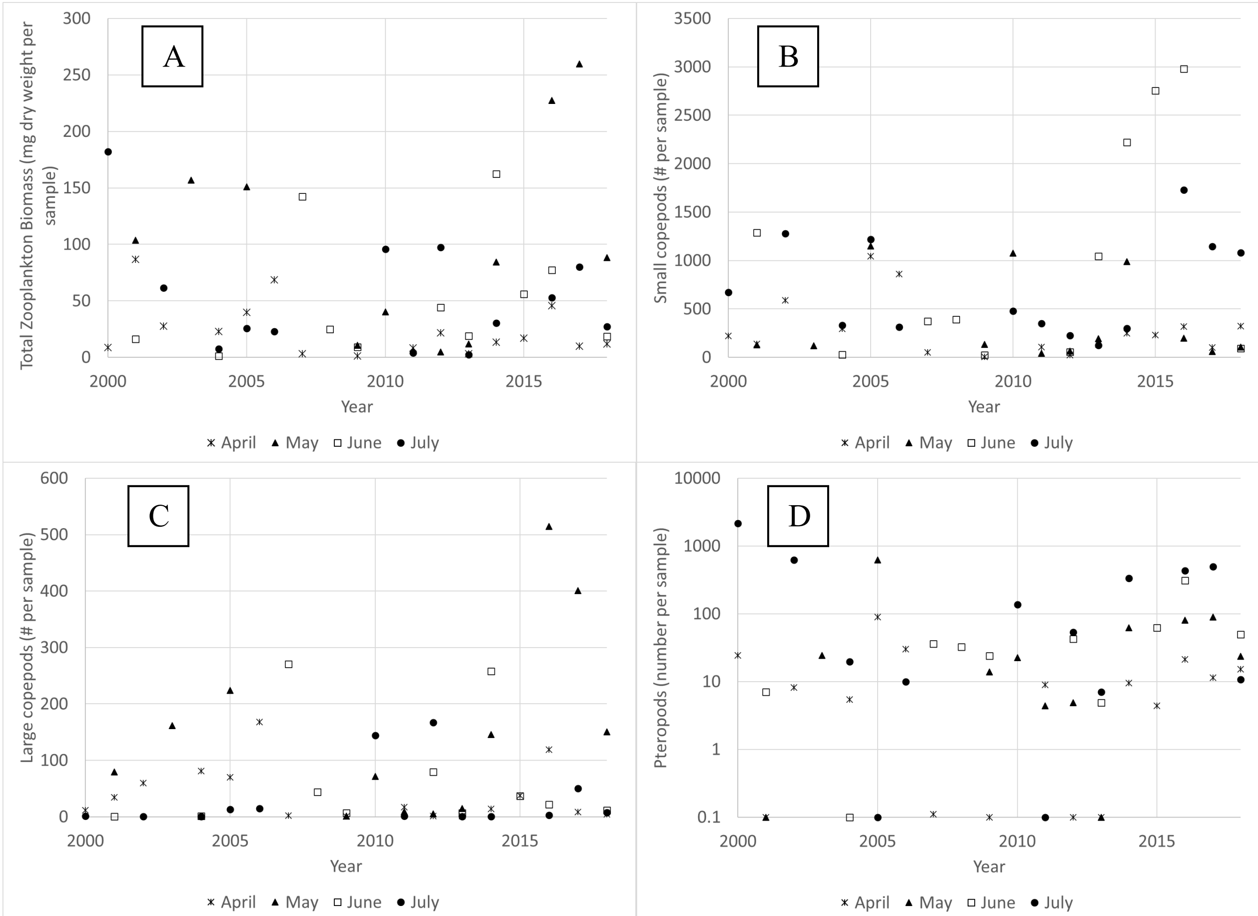

Figure 8. Measures of zooplankton biomass (A), small copepods (B), large copepods (C), and pteropods (D note the log scale) as measured by the Continuous Plankton Recorder on the Gulf of Alaska Shelf.

8. Coordination/Collaboration:

A. Long-term Monitoring and Research Program Projects

1. Within the Program

This project works with all projects within the HRM program. Coordination is primarily through email and the annual PI meeting. Work with projects includes ensuring reporting is completed promptly and assisting the coordination of sampling logistics. Dr. Pegau works with individual projects to coordination of the collection of samples needed and as a source of information about existing data and results.

The research aspects of this project are closely tied to the herring disease research being led by Dr. Hershberger (19120111-E). The examination of new monitoring approaches is coordinated with the sampling effort of Haught (19160111-F).

2. **Across Programs**

   a. **Gulf Watch Alaska**

   Dr. Pegau serves as the primary contact for the HRM program with the GWA and DM programs. Coordination includes having the leads to all the programs on the HRM mailing list, so everyone is aware of any information going out to the HRM Principal Investigators (PIs). He also works with the leads to address specific topics of joint interest, such as reporting. The HRM PI meeting was conducted in conjunction with the GWA PI meeting in October.

   The Prince William Sound Regional Citizens' Advisory Council is funding the continuation of aerial forage fish surveys conducted by Dr. Pegau. This project is completed in coordination with the GWA forage fish project. The aerial survey data is provided to the GWA project and the GWA project provides validation of aerial observations.

   Research examining recruitment is dependent on data provided by members of the GWA team.

   b. **Data Management**

   We work with the Data Management team to ensure PIs are submitting data and metadata in a timely manner. The Data Management team works with PIs to ensure they understand how to best get their data into the Workspace.

B. Individual Projects

We incorporated Dr. Whitehead's lingering oil project into the HRM program.

We supported a graduate research project examining reasons that may explain the high *Ichthyphonus* prevalence in age-0 herring around Cordova. Support included collection of fish and sediment samples. While not an HRM sponsored study, this work is relevant to HRM and Dr. Hershberger is a member on the student's graduate committee.

The Prince William Sound Regional Citizens' Advisory Council is funding the continuation of aerial forage fish surveys.

C. With Trustee or Management Agencies

Sherri Dressel of Alaska Department of Fish and Game (ADF&G) is on the HRM scientific oversight group. Sherri, along with Stormy Haught of the Cordova office of ADF&G, are the primary contact points between the HRM program and the Trustee Agency with oversight of herring in PWS. The monitoring work of the HRM program provides the data necessary for ADF&G to monitor the Pacific herring population in PWS and determine if the population is at a fishable threshold. The exchange of information with ADF&G is important for being able to track similar research efforts ongoing at ADF&G and in the HRM program.

Drs. Groner and Hershberger have partnered with ADF&G in Sitka to assess whether temporal changes in the severity of *Ichthyophonus* infections may be responsible for recent declines in the spawning herring biomass and age structure. Data and archived samples from the past 10 years of this EVOSTC-funded project were leveraged to obtain supplemental funding from the NPRB (Project # 1807: *Ichthyophonus* in Pacific Herring).

A status of PWS herring was provided to the National Oceanographic and Atmospheric Administration for incorporation into their Gulf of Alaska ecosystem status report, which is reviewed by the North Pacific Fisheries Management Council (Zador et al. 2019).

9. Information and Data Transfer:

A. Publications Produced During the Reporting Period

1. Peer-reviewed Publications

Ben-Horin, T., M.L. Groner, G. Bidegain, H. McCallum, E. Powell, and E. Hofmann. 2020. Modeling and forecasting disease dynamics in the sea. K. Lafferty, editor. Marine disease ecology. Ed. Lafferty, K

Cantrell, D.L., M.L. Groner, T. Ben-Horin, J. Grant, and C.W. Revie. 2020. Modeling parasite dispersal in marine ecosystems. *Trends in Parasitology*.

Hershberger, P.K., A.H. MacKenzie, J.L. Gregg, A. Lindquist, T. Sandell, M.L. Groner, and D. Lowry. 2019. A Geographic Hot Spot of I*chthyophonus* infection in the Southern Salish Sea, USA. *Diseases of Aquatic Organisms*. **136**(2) 157-162.

2. Reports

Pegau, W.S, and D.R. Aderhold, editors. 2020. 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.

Pegau, W.S., J. Trochta, and S. Haught. 2019. Prince William Sound Herring. In Zador et al. 2019.

3. Popular articles

Hoover, H. 2019. Herring Research and Monitoring. *Delta Sound Connections*. Prince William Sound Science Center (https://pwssc.org/wp-content/uploads/2019/05/DSC-2019_WEB.pdf).

Pegau, S. 2019. Changes in Forage Fish. *Delta Sound Connections*. Prince William Sound Science Center (https://pwssc.org/wp-content/uploads/2019/05/DSC-2019_WEB.pdf).

Groner, M. 2019. 'ICH-Y' Diseases in Pacific Herring. *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

Arimitsu, M., M.A. Bishop, D. Cushing, S. Hatch, R. Kaler, K. Kuletz, C. Matkin, J. Moran, D. Olsen, S. Pegau, J. Piatt, A. Schaefer, and J. Straley. 2020. Changes in Marine Predator and Prey Populations in the Northern Gulf of Alaska: Gulf Watch Alaska Pelagic update 2019. (poster) Alaska Marine Science Symposium, January.

Bishop, M.A., T. Branch, K. Gorman, M. Groner, S. Haught, P. Hershberger, S. Pegau, P. Rand, J. Trochta, and A. Whitehead. 2020. PWS Herring Research and Monitoring. (poster) Alaska Marine Science Symposium, January.

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

None

10. Response to EVOSTC Review, Recommendations and Comments:

EVOSTC Science Panel Comment. We agree with the Science Coordinator that the PI and the HRM program would benefit from additional administrative assistance. We have no other project-specific comments.

Response. A new administrative assistant has been added as requested.

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	$57.0	$153.3	$177.4	$171.9	$51.7	$611.2	$ 313.9
Travel	$6.4	$9.9	$6.4	$6.4	$6.4	$35.5	$ 30.1
Contractual	$24.7	$26.0	$26.2	$11.0	$4.4	$92.3	$ 72.8
Commodities	$3.8	$1.5	$3.5	$1.4	$1.5	$11.7	$ 2.5
Equipment	$0.0	$0.0	$0.0	$0.0	$30.1	$30.1	$ -
Indirect Costs (*will vary by proposer*)	$35.1	$57.20	$64.0	$57.2	$19.2	$232.7	$ 133.3
SUBTOTAL	$127.0	$247.8	$277.5	$247.9	$113.3	$1,013.5	$552.6
General Administration (9% of subtotal)	$11.4	$22.3	$25.0	$22.3	$10.2	$91.2	N/A
PROJECT TOTAL	$138.4	$270.2	$302.5	$270.2	$123.5	$1,104.7	
Other Resources (Cost Share Funds)	$26.0	$26.6	$69.7	$90.5	$28.0	$240.8	

Spending on Personnel remains slightly behind due to the late start of Dr. Groner with the project. We expect to allow the salary to complete the three-year post-doctoral fellowship. We are slightly over in travel costs due to Dr. Groner needing to travel to the USGS Marrowstone facility for experiments.

LITERATURE CITED

Wilbur M.Q., S.B. Weinstein, and C.J. Briggs. 2016. Detecting and quantifying parasite-induced host mortality from intensity daa: method comparisons and limitations. *International Journal for Parasitology*. **46**(1). 59-66.

Zador, S., E. Yasumiishi, and G.A. Whitehouse. 2019. Ecosystem Status Report 2019 Gulf of Alaska. North Pacific Fishery Management Council, Anchorage, AK.