Exxon Valdez Oil Spill
Long-Term Herring Research and Monitoring Program Final Report

Herring Research and Monitoring Program

Exxon Valdez Oil Spill Trustee Council Project 16120111
Final Report

Scott Pegau
Mary Anne Bishop, Rob Bochenek, Kevin Boswell, Trevor Branch, Michele Buckhorn Lindsay Butters, Mike Collins, Kristen Gorman, Ron Heintz, Paul Hershberger, Hayley Hoover, Tom Kline, Steve Moffitt, Pete Rand, Fletcher Sewall, Dick Thorne, Johanna Vollenweider, Sharon Wilde, Cordova District Fishermen United

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Study History: This work encompasses the projects within the Herring Research and Monitoring program (16120111A-T), and builds on the work completed in the Prince William Sound Herring Survey program (10100132) and projects within the Sound Ecosystem Assessment program. The program coordinates with the Gulf Watch Alaska Long-Term Monitoring program (16120114) to better understand the conditions affecting survival and condition of Pacific herring. One product of this project is the synthesis submitted to the *Exxon Valdez* Oil Spill Trustee Council titled Pacific herring in Prince William Sound: A synthesis of recent findings. This report draws on the program's annual reports submitted for fiscal years 2012-2015.

Abstract: This report contains a description of the activities that took place in the Herring Research and Monitoring Program. The program was made up of 19 projects designed to address the goal of improving predictive models of Pacific herring (*Clupea pallasii*) stocks through research and monitoring. The program was made up of a mix of monitoring projects designed to provide inputs to the predictive model, and process studies that help understand aspects of the herring life cycle, model parameterization, measurement assumptions, and examining new approaches to monitoring. Most of the work was with fish under one year of age, but there were some studies examining aspects of adult fish. The adult biomass declined significantly during this study, which provided an opportunity to try to understand both a lack of recruitment and collapse of an adult population. Age-0 herring were found to be at minimum energetic and lipid levels in most springs. There was evidence that they foraged through the winter, which makes them more vulnerable to predation. Genetic work showed overlap between the Prince William Sound population with those to the east and west. New techniques in disease detection may allow us to examine the role of disease in the recent collapse.

Key words: *Clupea pallasii*, Pacific herring, Prince William Sound

Project Data: Data generated by individual projects are listed in those reports.

Citation:

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EXECUTIVE SUMMARY

This report contains a description of the activities that took place in the Herring Research and Monitoring Program from 2012 through 2016. The program was made up of 19 projects designed to address the goal of improving predictive models of Pacific herring (*Clupea pallasii*) stocks through research and monitoring. The program was made up of a mix of monitoring projects designed to provide inputs to the predictive model, and process studies that help understand aspects of the herring life cycle, model parameterization, measurement assumptions, and examining new approaches to monitoring. This report highlights some of the program findings, but does not address them in detail. Details regarding methods and results of the individual projects are to be found in the reports from the individual investigators.

The age-structure-analysis (ASA) model used by Alaska Department of Fish and Game (ADF&G) for Prince William Sound (PWS) was rebuilt in a Bayesian framework. That model was then used to examine the value of past datasets to determine which provided the most value to the model. The egg deposition surveys were assumed to be an absolute measure of biomass and therefore a critical past dataset. The disease information was also critical for explaining the large decline in the population in the 1990s. The decline in PWS was compared to other declines around the world and found to be both longer in duration and deeper in extent than almost all other herring collapses.

Data collected as inputs to the existing ASA model included disease prevalence and acoustic biomass estimates. The disease prevalence information showed low prevalence of the primary viral diseases and *Ichthyophonus* prevalence that is similar to other populations. The acoustic biomass estimates showed a rapid decline in the spawning biomass over the past five years to the lowest values seen since the inception of the surveys in 1993.

Other monitoring efforts included acoustic surveys of age-0 herring, aerial surveys of age-1 herring, and condition measurements of age-0 herring. The age-0 and age-1 surveys both indicated that the 2012 year class was larger than normal and the 2013 year class was small. The condition monitoring effort showed that the 2012 year class went into the fall with a high energetic content and came out of the winter with an unusually high energetic content. This was the only year that the age-0 herring reached March without being at the minimum energetic and lipid content expected to be needed to survive. The 2012 year class also had an unusual isotopic composition that suggested the main food source was from the Gulf of Alaska that year.

Combining the lipid and growth information showed that there is a change in allocation of food from growth to lipid storage that occurs around 80 mm in length. Analysis of growth from historic scales also showed a similar length scale as the minimum for surviving to reach the spawning population.

We examined techniques to determine the age at first maturity and found histology to be a good approach to determining the maturity, but also that scale growth may be used to estimate the proportion of an age class that spawned in any given year. We did not reach the point of being able to estimate the maturity function and that work will need to occur in the future.

We tested to determine if multiple herring stocks exist in PWS using genetics. We found that the tests we applied indicated the fish in PWS and to the east as far as Yakutat were genetically similar and that the similarity was stable through time. There is a genetic difference between PWS herring and those in Shelikof Strait with Cook Inlet herring being a mix of those lineages. Using the ADF&G scale library we were able to image scales and measure scale growth back to the 1980s. This allowed us to examine growth in the first year as a function of environmental conditions using long-term temperature records and biological records from the Continuous Plankton Recorder project over a ten-year span. The strongest correlation between first-year growth was with diatom abundance, followed by summer water temperatures, and finally zooplankton abundance. The relationship to diatom abundance suggests that food quality is highly important to growth.

Several projects were undertaken to determine if assumptions in our measurements were valid. In examining the condition of herring through the winter we found the peak value occurred in November and the minimum near March, which was consistent with the sampling efforts in our condition monitoring program. The decline in energetic content after November was nearly exponential rather than the linear model that we were using requiring us to rethink the energetic loss equation for overwintering age-0 herring.

Analysis of fatty acids showed that they are a conservative tracer of the fish diet, but that feeding was occurring over winter which prevented fatty acids to be used to detect movement of fish through the winter. It was possible to determine that, within a season, age-0 fish were not likely to move more than a few kilometers using their fatty acid profile.

Repeated acoustic surveys designed to estimate age-0 herring biomass showed that there were large fluctuations in the estimated population over a two-week time span. Some fluctuations could be explained by the presence of ice reducing the extent of the survey area, but other fluctuations could not be explained. Without having fairly precise estimates of herring biomass it is not possible to determine overwinter survival. Changes in survey methods will be required to achieve enough consistency between surveys to make the approach viable for estimating age-0 herring populations. When the acoustic survey data was combined with direct capture information it was possible to determine that the age-0 herring were primarily near the heads of bays in areas close to eel grass beds and sources of freshwater. It was also clear that age-0 herring use ice cover as a habitat.

Studies focused on *Ichthyophonus* showed that the disease prevalence increases with the age of fish and that needed to be accounted for when estimating mortality from samples. There was also an unusually high prevalence of *Ichthyophonus* in age-0 fish in the Cordova Harbor. This led to finding that the disease can be spread through consumption of infected offal.

We successfully tagged adult herring with acoustic tags and were able to detect them for several months using receiver arrays in PWS. Most fish were observed leaving the spawning grounds to aggregate near the southern entrance of Montague Strait. The detections stopped in July and began again in September. The area at the mouth of Montague Strait appears to be an important foraging area. Some fish were also observed to stay near the spawning grounds for at least a couple months after the spawn ended.

Non-lethal sampling of herring was achieved through the use of imaging sonar and cameras mounted on a Remotely Operated Vehicle. It was possible to identify and measure the length of age-0 herring using this technique. The approach was used to confirm that age-0 herring would shelter under ice shelves in the nursery grounds.

What is most likely the most important breakthrough of the program was the development of plaque neutralization tests that enabled the detection of viral hemorrhagic septicemia virus antibodies in herring. These tests allows us to examine if an outbreak has occurred between prevalence monitoring samples, and allows us to understand the potential for a large scale epizootic occurring.

A data management project organized and archived data collected through the program. A coordination effort was in place to maximize the overlap between efforts both within the Herring Research and Monitoring program and with the Gulf Watch Alaska long-term monitoring effort. An outreach effort focused on the website and development of short radio descriptions of the work within the program that were then aired on the local public radio station.

Results from this program were combined with previous work to generate a synthesis document that was submitted to the *Exxon Valdez* Oil Spill Trustee Council in 2014 as a product of this program.

INTRODUCTION

Pacific herring (*Clupea pallasii*), hereafter ‘herring’, are an ecologically important forage fish and historically have been an economically and socially important fishery in Prince William Sound (PWS). The Pacific herring population in PWS declined from a peak population of approximately 133 thousand metric tons in 1988 to 30 thousand metric tons by 1993. The recovery of the herring population has been the focus of many projects and programs funded by the *Exxon Valdez* Oil Spill Trustee Council (EVOSTC). This has led to several syntheses of information about Pacific herring in PWS (Norcross et al. 2001; Spies 2007; Rice and Carls 2007; Pegau 2013), many contributions to herring related symposia (e.g. Funk et al. 2001), as well as many research publications.

The PWS herring population remained high for a few years after the 1989 *Exxon Valdez* oil spill, but collapsed by 1993 (Fig. 1). Except for two seasons in the late 1990s, the commercial herring fishery has been closed since 1993. Fluctuations in the herring population are expected with or without a herring fishery. What is not expected is the prolonged state of depressed herring stocks in the absence of an active fishery (Branch 2017). Other factors are thought to be playing a role in keeping the stock depressed including changes in oceanic conditions, predation, salmon hatcheries, and disease (Deriso et al. 2008, Pearson et al. 2012).

The failure of PWS herring to recover is defined by factors that suppress spawning stock biomass and other factors that prevent recruitment events. The factors that prevent an increase in biomass can be different than those that prevent recruitment. For example, predation by whales may reduce herring biomass, but may not be as important in limiting recruitment. Historically, reduced herring stocks associated with earlier fisheries recovered as the result of large recruitment events. However, it is clear that in PWS there has not been a large recruitment event in the last twenty years (Fig. 2). The low recruitment levels have led to a series of studies that examine the early life stage of the Pacific herring. Ward et al. (2017) found a correlation between recruitment and freshwater discharge, but the spawner-recruit relationship remains fairly high so environmental conditions have not limited recruitment since the 1990s.

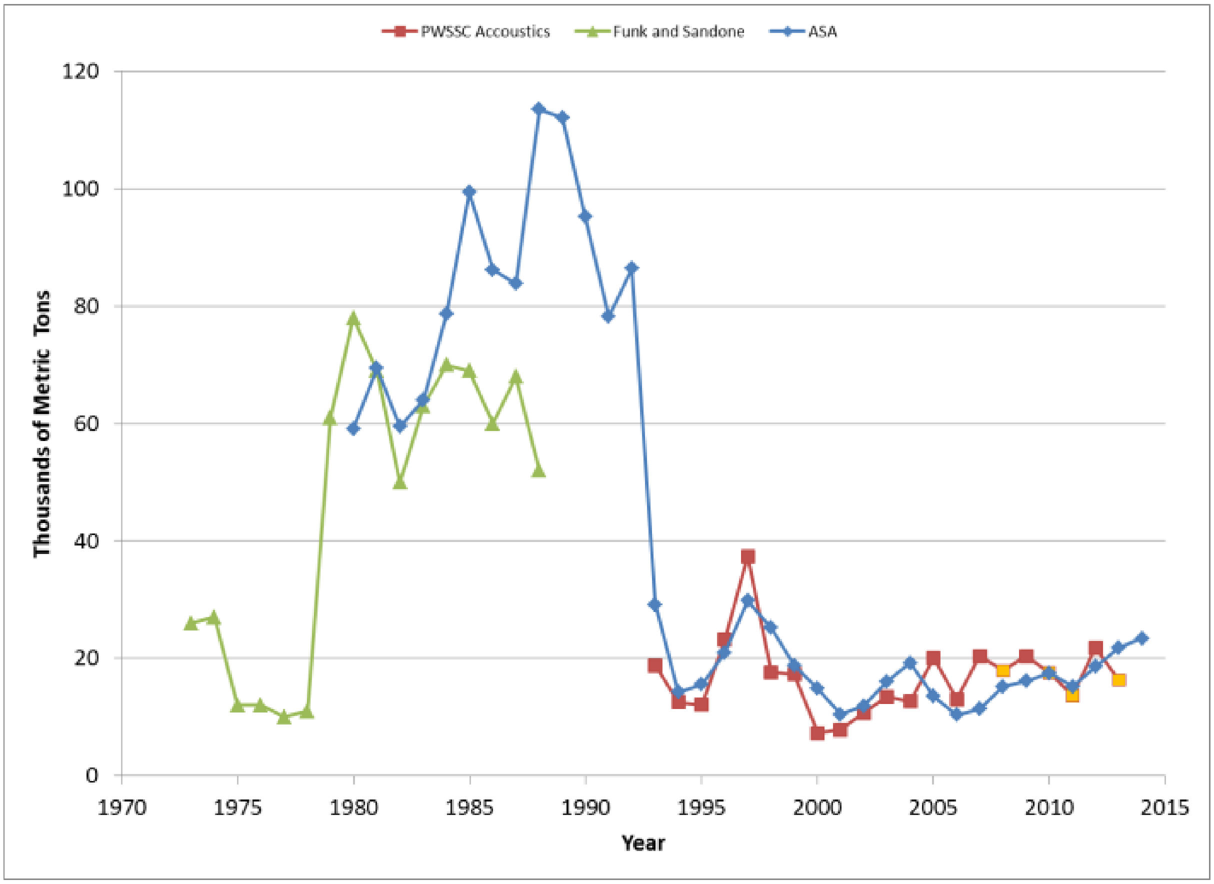

Figure 1. *PWS estimated prefishery run biomass from ASA models (green triangles and blue diamonds) and hydroacoustic surveys (red squares). The squares marked in yellow are years that the hydroacoustic estimate is believed to be biased low due to survey conditions. Funk and Sandone (1990) provide estimates of historic herring biomass based on an early version of the Age-Structure-Analysis (ASA) model. It is important to note that the aerial surveys during the early years did not reach all spawning locations in the Sound. The ASA data is from the 2013 run of the model used by ADF&G.*

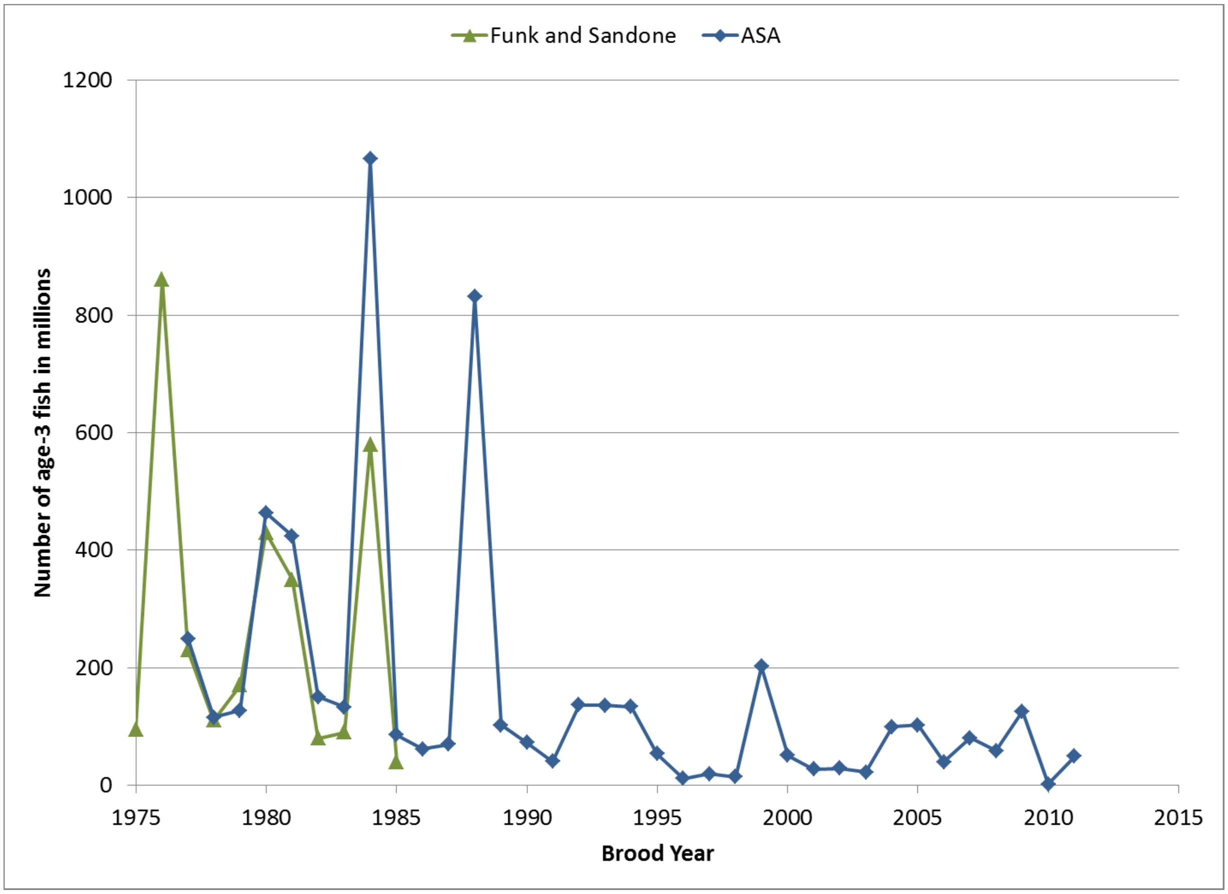

FIGURE 2. *ESTIMATED NUMBER OF AGE-3 FISH RECRUITING TO SPAWNING STOCK BY BROOD YEAR. FUNK AND SANDONE (1990) PROVIDE ESTIMATES OF HISTORIC HERRING BIOMASS BASED ON AN EARLY VERSION OF THE AGE-STRUCTURE-ANALYSIS (ASA) MODEL (GREEN TRIANGLES). THE ASA DATA IS FROM THE 2013 RUN OF THE MODEL USED BY ADF&G (BLUE DIAMONDS).*

The Herring Research and Monitoring (HRM) program began in 2012 and was designed to build upon the earlier work completed in the Prince William Herring Survey and Sound Ecosystem Assessment programs. The work was coordinated with the Gulf Watch Alaska program that monitors ecological conditions in PWS and other *Exxon Valdez* Oil Spill effected waters. The HRM program focused on herring in PWS but uses data from other areas to put the PWS findings in context.

OBJECTIVES

The goal of the HRM program is to improve predictive models of herring stocks through research and monitoring. The program is made up of 19 individual projects that are designed to address four objectives:

1) *Provide information to improve input to the age-structure-analysis (ASA) model, or test assumptions within the ASA model.* ADF&G uses an ASA model to estimate herring biomass (Hulson et al. 2008). Efforts in this program were meant to expand the data available to the ASA model or to examine assumptions in the model. The model was also rebuilt in a Bayesian structure to provide more information on the range of potential biomass.

2) *Inform the required synthesis effort.* A synthesis of the project (HRM 2014) was required midway through the program. Proper completion of a detailed synthesis means being able to access and manipulate different sources of data and information.

3) *Address assumptions in the current measurements.* Many of the existing studies are based on historical or logistical constraints. Research was conducted to put the existing measurements into context, spatially and temporally. Information from these efforts is used to inform the design of future research and monitoring efforts.

4) *Develop new approaches to monitoring.* We examined some of the technological advances to see how they may improve our research and monitoring programs.

A mix of monitoring and process studies were used to address these objectives. Monitoring efforts including adult and juvenile herring acoustic surveys, disease prevalence, age-0 condition, and juvenile herring aerial surveys were selected to contribute to objective 1. Process studies addressing objective 1 included determining age of first spawn, genetic stock structure, and population modeling. Addressing objective 2 required collection and cataloging of historic information. This included a project to image herring scales from historic collections provided information about growth over several decades and a data management effort focused on archiving existing data and making it easier to discover when analyzing and synthesizing information. To address objective 3 there were projects examining juvenile condition on a monthly basis to determine if monitoring was being conducted at the correct time, fatty acid analysis to detect potential migration over winter, additional juvenile acoustic surveys to examine consistency in biomass estimates, capture of herring to apportion the acoustic survey results, and disease studies examining how prevalence data should be integrated into the model. To address objective 4 we used acoustic tags to determine migration patterns, developed a new tool to identify existence of antibodies to allow an understanding of disease exposure, and tested imaging acoustics and cameras for non-lethal sampling of juvenile herring and detection of juvenile herring in areas traditional methods cannot sample, such as under ice shelves.

METHODS

Our approach used an integrated set of studies that included monitoring projects, field-based process studies, and controlled laboratory-based studies. When combined, this approach is intended to inform herring monitoring and modeling efforts by focusing on important population-limiting factors and providing empirical data for the current ASA model. Aspects of the work are informed by projects within the Gulf Watch Alaska program, such as monitoring of basic oceanographic conditions, food availability, and predator populations.

The monitoring efforts were designed to complement the existing ADF&G surveys that determine the spawning biomass, the mile-days of spawn, and the age-sex-weight composition of the spawning stock. The ADF&G surveys are central to our understanding of when the PWS adult herring population is recovering. However, these surveys have limitations that this program addresses.

Monitoring Components:

Monitoring components are designed to address objective 1 by either adding desired information that is not currently being collected by ADF&G or collecting information we believe will allow for advances in the ASA model. Below is a brief description of the methods used by the monitoring projects. Individual project reports provide more information about the methods and results. The project number and principal investigator for each project are provided in the description of their methods.

1. **Disease in the adult population** (16120111-K, Hershberger): Disease prevalence is included in the PWS ASA model; however, it is not part of the ADF&G sponsored surveys. Three or more samples of 60 adult herring were collected during the ADF&G spawning biomass surveys. Two or more samples of 60 juvenile herring were collected as part of the fall juvenile herring surveys. These samples were processed to determine the prevalence of Viral Hemorrhagic Septicemia (VHS), Viral Erythrocytic Necrosis (VEN), and Ichthyophoniasis. Diagnostic techniques for these pathogens will followed standard procedures described in the “Blue Book: Standard procedures for the detection and identification of select fish and shellfish pathogens (American Fisheries Society).”

2. **Enhanced adult biomass surveys** (16120111-E, Rand): Current stock assessment efforts by ADF&G resource managers in PWS focus on the largest spawning aggregations. Additional spawning aggregations exist, but are not regularly surveyed by ADF&G. The Prince William Sound Science Center (PWSSC) conducted acoustic biomass surveys in the region of the main spawning stock and surveyed fish found along Montague Island. The presence of whales and other predators were used to help identify areas with herring and daytime transects were used to confirm the presence of herring schools. Surveys were

then conducted at night when the herring were farther from the bottom. Whenever possible the populations were surveyed multiple times to provide an error bound on the estimated biomass.

3. **Juvenile biomass index acoustic surveys** (16120111-F, Rand): Currently there are no observations of herring prior to them joining the spawning biomass. This makes it difficult to predict the number of new recruits to the spawning biomass. The problem is compounded by the fact that the number of new recruits can fluctuate dramatically. Each November acoustic surveys were conducted in eight bays around Prince William Sound focused on determining the amount of age-0 herring present. Surveys were conducted at night following the same transect lines each year. Data from trawls conducted each evening were used to apportion the acoustic signal to the species collected.

4. **Age-0 condition** (16120111-L, Gorman): Overwintering survival of age-0 herring has been considered one area that may be restricting recovery of herring in PWS. The energetic state of juvenile, particularly age-0, herring provides an integrated measure of environmental conditions. Age-0 herring were collected in eight bays each November and nine bays each March. The fish were dried and ground and carbon and nitrogen stable isotopes measured and a relationship between the isotopes and whole body energy used to determine the condition of the fish. A subsample of the fish was also processed using a calorimeter as a direct means of determining whole body energy density.

5. **Juvenile biomass index aerial surveys** (15140111-R, Pegau): An alternate method for providing an index of herring year class strength used aerial surveys. Surveys of forage fish, including age-1 herring were conducted in June each year. Surveys were flown along the coastline of PWS and the number of schools, size of schools and species recorded. Herring were separated into age-1 and age-2+ classes. The number of age-1 schools then provided an index of year class strength.

Process Study Components:

The process studies provide the ability to improve our understanding of the herring population in PWS. Because numerous gaps exist in our understanding of factors controlling the biomass and demographics of herring populations, and some current thinking is based on untested assumptions, the number of potential process studies is very large. In this program we focused on providing the information necessary to ensure the best program moving forward into the future, and also to address issues that can make rapid improvements to the existing modeling efforts. Below each objective is a brief description of proposed projects that address the objective.

Objective 1. Provide information to improve input to the age-structure-analysis (ASA) model, or test assumptions within the ASA model.

The ASA model has a maturity schedule that according to ADF&G fisheries reports has changed over time and is different among regions. However, this maturity schedule has not been confirmed by direct observations; rather it has been allowed to vary in a limited manner to allow the ASA to provide the best fit to the input data. To address this issue we are proposing a study to examine the age at which herring first spawn and determine if there is evidence of some herring skipping potential spawning events.

1. **Age at first maturity** (13120111-J, Vollenweider): A maturity function that describes the portion of each age class expected to be in the spawning population is used to estimate the total herring population from the spawning population measurements. In other locations the determination of age at first spawn has been accomplished via 1) analysis of differential growth increments on scales, and 2) histological analysis of egg development in ovaries. Both approaches were tested to examine the age of maturity of herring in PWS. A laboratory study examined the ability to use postovulatory follicles to determine optimal sampling time for the use of histology to separate fish that had spawned from those that had not. Growth rates determine from the annuli on herring scales was also used to detect when a fish began to spawn. The assumption being that non-spawning fish have greater growth than spawners.

2. **Genetic stock structure** (16120111-P, Wildes): It has been assumed that all the herring in PWS are part of the same stock. Over three years samples from different spawning populations within PWS were examined for differences in 15 microsatellite loci. Microsatellite fragments were amplified by polymerase chain reaction and analyzed on a 16-capillary DNA analyzer. Samples from PWS were also compared to other Pacific herring around Alaska.

3. **Herring population dynamics modeling** (16120111-Q, Branch): Improving our ability to predict the herring population required assessing the current model used for management and determining if alternate models may have greater predictive skill. The age-structure-analysis (ASA) model used by PWS ADF&G was rebuilt in a Bayesian framework. It was then used to examine the value of past survey data by omitting a single dataset at a time. The estimated cost of each survey was then used to determine not only the value, but the cost benefit of each dataset. A meta-analysis of global herring populations was conducted to examine how the PWS population crash compared to other such events in other populations.

Objective 2. Inform the required synthesis effort.

This objective includes efforts to improve access to a wide array of data sources for inclusion in the synthesis efforts. Many of the projects described under Objective 3 will also address this objective.

1. **Herring scale analysis** (13120111-N, Moffit): ADF&G in Cordova have collected scales from herring for age analysis since the 1970s. Those scales are archived on slides and include ancillary data (collection location, date, length, weight, and sex). The total library includes approximately 200,000 herring scales. Scales from 30 males and 30 females of age 4, 5, and 6 were randomly selected from each year's collection from 1982 to 2015. For a total of 180 fish per year. A total of 7,270 scales were digitally imaged and the spacing between annuli measured. Some scales were processed a second time to determine measurement precision.

2. **Data visualization** (16120111-C, Bochenek): Synthesis requires easy access to data and the ability to visualize it along with other sources of data. Several tools were developed or refined to address data storage, access, and visualization. The Ocean Workspace was used for data storage. A metadata generation tool was developed to assist investigators with that aspect of data management. As investigators released data it was made available through the Gulf of Alaska data portal on the Alaska Ocean Observing System website. Tools were developed to allow visualization and integration of different data sets. Finally, long-term archiving of data was made possible by becoming a DataOne node.

Objective 3. Address assumptions in the current measurements.
Many of the existing studies are based on historical or logistical constraints. Several projects were designed to address assumptions in the monitoring and research program.

1. **Herring condition intensive** (14120111-M, Gorman): Herring condition measurements have limited temporal and spatial resolution with only two sampling events per year occur at narrowly defined sampling sites in PWS. This project collected samples at multiple locations within one bay monthly from August to the following June. The fish were processed in the same manner described in the herring condition monitoring project. The analysis looked for within bay variability, the timing of peak and minimum energy content, and how the energy content changes throughout a winter.

2. **Fatty acid analysis** (13120111-I, Heintz): To determine overwintering survival requires population surveys in the fall and spring, but have an inherent assumption that there is no immigration or emigration from the survey area. A laboratory study examined if the fatty acid composition reflected changes in diet and another simulated winter conditions to ensure the assumption that fatty acid composition is conservative in unfed fish. The results from the laboratory experiments were then used to interpret spatial and temporal variability in the fatty acid profiles age-0 herring collected in this program.

3. **Acoustic consistency** (15120111-G, Rand): Determining overwintering survival requires population surveys in the fall and spring, but the precision of juvenile surveys had not been tested. Acoustic surveys of two bays were conducted three nights in a row at eight

times over a winter. Four surveys took place between October and December with three of the surveys spaced two weeks apart in October. Another four surveys were conducted in the spring. The surveys were conducted every two weeks in February and March. The data was analyzed to examine the precision of surveys on consecutive nights and fortnightly. The acoustic signal was apportioned based on the results of trawls conducted each night.

4. **Direct capture** (16120111-A, Bishop): We recognize that a major deficit in our existing program is the lack of an effective means of apportioning the hydroacoustic signal. A light-weight sweeper trawl, castnets, and gillnets were used to collect fish for the acoustics, disease, and condition measurement projects. In November, nightime trawls were used to collect fish in the upper 30 meters of the water column. The location of the trawls was determined by the acoustic measurements. Fish were identified to species, weighed, and indiviuals measured to determine length. In March, commercial fishermen were contracted to collect age-0 herring using variable mesh gillnets.

5. **Disease studies** (16120111-K, Hershberger): Mortality from infectious and parasitic diseases has been identified as a leading hypothesis accounting for the decline and failed recovery of PWS herring; unfortunately, the location and timing of the acute and / or chronic mortalities remain unaddressed because of difficulties inherent to sampling in marine systems. Several laboratory and field studies were conducted to address conditions influencing epizootics. Research topics included, the viability and infectivity of *Ichthyophonus*, the influence of temperature of the efficacy of DNA vaccines against VHS in Pacific herring, and climate change influences on marine infectious diseases.

Objective 4. Develop new approaches to monitoring.

The advancement of tools and techniques provides a means to continually improve the research and monitoring efforts. Some projects were conducted to determine if new methods might be appropriate for use in future research.

1. **Herring tagging** (14120111-B and 16160111-T, Bishop): One issue that we have not been able to address is the migration patterns of Pacific herring in Prince William Sound. One technology that was identified for testing was the use of acoustic tags to monitor the passage of fish. Spawning fish were implanted with an acoustic tag. An acoustic receiver array was deployed near the spawning grounds. A second series of receivers was already in place in the various entrances to PWS. Data from the acoustic receivers was analyzed to determine if tagged herring would survive, and if they were traveling to/through the entrances to PWS.

2. **Disease forecasting** (16120111-K, Hershberger): Measures of disease prevalence are not good predictors of disease mortality potential, or necessarily good indicators of mortality over the past year. A better understanding of mortality caused by VHS virus requires being able to detect antibodies indicative of prior exposure to the disease. The use of Blocking Enzyme-Linked Immunosorbent Assay (ELISA) and virus neutralization assay was explored as a detector of antibodies in the blood of herring. Based on that work the use of Plaque Neutralization Tests (PNT) was identified as a better detection approach and work was conducted to optimize the PNT.Work on *Ichthyophonus* included developing techniques for infecting herring in the laboratory, and detection using Chromogenic in-situ hybridization.Two new techniques using conventional and quantitative polymerase chain reaction for detecting viral erythrocytic necrosis (VEN) were developed.

3. **Non-lethal sampling** (15120111-D, Boswell): Interpretation of the acoustic signal, for species or biomass, requires information on the fish distributed within the ensonified volume. We currently rely on direct capture techniques to sample the fish to determine species and size characteristics. We examined the use of a Didson imaging sonar and cameras on a remotely operated vehicle (ROV) to determine if we could identify and measure fish in the upper water column. The ROV was also used to explore under an ice shelf to determine if juvenile herring were present.

Program management

Coordination (16120111-O, Pegau):
The coordination project led the effort to coordinate activities within the program and with the Gulf Watch Alaska program. The project also was responsible for the synthesis, aerial observations of juvenile herring, and program logistics. The primary tools for coordination among projects was through an email list serve. A two-day annual principal investigator (PI) meeting allowed investigators to share results and build connections between projects. In alternating years the PI meeting was held in conjunction with the Gulf Watch Alaska PI meeting to provide for cross-program connections between projects. Coordination was also achieved through scheduling of vessels and aircraft through this project.

An oversight group was set up that consisted of Sherri Dressel with ADF&G, Jeep Rice with the National Oceanic and Atmospheric Administration, and Steve Martell with the International Pacific Halibut Commission. The function of the group was to provide Dr. Pegau with feedback on progress of the research and provide guidance of future research needs.

One deliverable of the program was a synthesis of information related to Pacific herring in PWS. Each project was asked to synthesize the information associated with the field of work their proposal addressed. The individual contributions were then melded together to address topical areas; such as growth, energy, and the environment. The synthesis used contributions both HRM and GWA projects.

Outreach (16120111-H, Hoover):
Outreach of all the projects was conducted using a website, print media, radio programs, community lectures, and education activities. A section of the PWSSC website focused on the HRM projects and their activities. Each project has its own page, and on those pages are links to other outreach materials specific to that project. One-page descriptions of each project were generated for inclusion on the website and provided to the public through PWSSC. These articles made up the materials on the website. Articles describing individual projects and their results targeted at a general audience were published in Delta Sounds Connections. Short radio programs titled, "Field Notes" were generated and submitted to KCHU, the public radio station serving PWS. The Field Notes are aired on a regular basis. PWSSC hosts a community lecture series September to May. Three researchers each year presented results of their work through the lecture series. When PI meetings were held in Cordova they were open to the public to allow further outreach. Education activities included herring centric activities as part of the PWSSC Discovery Room.

RESULTS

Objective 1
Monitoring projects that addressed this objective include measuring disease prevalence, acoustic surveys of adult herring biomass, acoustic surveys of juvenile herring, age-0 herring condition monitoring, and aerial surveys of age-1 herring schools.

Disease in the adult population: The prevalence of VHS, VEN, and *Ichthyophonus* in PWS was similar to that observed in Sitka. *Ichthyophonus* occurred in populations of Pacific herring throughout the NE Pacific. Infection prevalence varied with geographic location, season, and population age structure, with prevalence in adult herring from PWS ranging from 24 - 47% during 2014 – 2016; infection prevalence in juvenile cohorts was typically much lower. One anomaly to the demographic patterns occurred in Cordova Harbor, where infection prevalence was unusually high among juvenile cohorts. During the study period, VHSV was detected at low prevalence and low titer in random samples of adult herring from Sheep Bay (2014). This low prevalence is neither surprising nor uncommon, considering the prevalence of VHSV is generally extremely low during endemic periods (i.e. below the detection threshold of 5% prevalence with 95% confidence provided by a 60 fish sample size). In most cases no VHSV was detected in a sample of 180 fish. Likewise, a low prevalence of VEN was detected in herring populations throughout the NE Pacific, including Cook Inlet (2014), Sitka (2014), and PWS (2016). These were generally low-intensity infections, with the exception of the positive fish from Cook Inlet, which demonstrated a high proportion of circulating erythroblasts and erythrocytes demonstrating VEN inclusions. In all other samples no evidence of VEN was detected.

Enhanced adult biomass surveys: The acoustic surveys of adult herring biomass observed a large decrease in the herring biomass between 2012 and 2016, with 2016 being the lowest levels observed since inception of the surveys in 1993. Acoustic estimates of the spawning biomass were 21,800 mt in 2012 and dropped to 3,453 mt in 2016. We were unable to get a biomass estimate in 2014 because the schools were small and very near shore, which makes them difficult to survey. There was more spawn on Montague Island in 2015 than in other years, but overall the spawning area contracted with the decrease in the population.

Juvenile biomass index acoustic surveys: The mean density of juvenile herring from 2012 through 2015 was highest in Whale Bay, and lowest in Lower Herring Bay. Whale Bay also showed the highest inter-annual variance (113% coefficient of variation across the 4 years). The highest density of juvenile herring during a given night survey was observed in Whale Bay in 2014 (909,465 herring km^{-2}). The lowest densities of juvenile herring were observed in 2013 in Fidalgo (nil, based on a lack of herring in trawl catches), Eaglek (95 herring km^{-2}) and Lower Herring (585 herring km^{-2}). The main effect of bay was not found to be significant, but we did observe a significant effect of year. Results indicate that juvenile herring abundance (fish km^{-2}) was significantly lower in 2013 compared to all the other years of the survey ($p=0.01$). Herring densities observed during 2012 were significantly greater than 2013 ($p=0.01$) and 2013 was found to be lower than 2014 ($p = 0.03$) and 2015 ($p = 0.03$). Most of the age-0 herring were observed in the inner portion of the bay.

Juvenile biomass index aerial surveys: Aerial surveys of age-1 herring found the greatest number of schools in June of 2013 (2118) and 2014 had the least number of schools (170). From 2013 through 2016 the number of age-1 schools was over 1300 in odd years and under 400 in even years. Validation of aerial observation found that most misidentifications were associated with age-0 herring and sandlance that did not normally appear until July.

Age-0 condition: The condition of the age-0 herring was such that in most years the fish were at minimum whole body energy density (WBED) (3.3 kJ/g) and lipid levels (1.5% of wet tissue mass) to survive by March. March 2013 was an exception to this pattern with WBED > 4 kJ/g and elevated lipid levels observed. November WBED varied more than March levels, and were not a good predictor of March WBED. There was no consistent difference in the herring condition among the bays. Eaglek and Simpson bays tended to have lower condition, while Whale and Zaikof tended to have above average condition, but every location had above and below average years. Based on the RNA/DNA ratio there was a shift from growth to lipid storage that began at approximately 74 mm fork length and the minimum RNA/DNA ratio reached once the herring reached 85 mm. This shift led to larger fish being more energy dense because of increasing lipid stores. There was evidence of winter feeding, but not enough to impact the energy density. Fish with the lowest lipid levels were more likely to have greater stomach content. The energy density of prey was highest in fall of 2011; however, it did not result in high lipid levels or growth.

Process studies addressing objective 1 included efforts to determine the age at first maturity, genetic stock structure, and rebuilding the age-structure-analysis model.

Age at first maturity: Laboratory testing of herring showed that histology could identify postovulatory follicles for three months after spawning. Histological analysis of female herring, ages 3-11, collected in July found that most had previously spawned (58%), 6% were spawning capable, 23% were regenerating from earlier spawning, and 7% were primiparous. The primiparous fish include three age-3, two age-4, and one age-6. Another 7% of the fish had never spawned and not developing their ovaries and they were all age-3 fish. Herring scales showed bimodal growth patterns indicative of a mix of spawners and non spawners from ages 3-6. Scale growth was unimodal during age-1 and age-2. The probability of skip spawning for ages 3-6 fish ranged from 13 to 50%, with age-3 and age-6 with the highest rates of skip spawning. The scales that were imaged did not include fish older than six.

Genetic stock structure: The genetics work showed genetic similarities among the fish spawning in PWS and to the east as far as Yakutat. Samples collected in PWS from several years showed genetic similarity showing the genetic results were temporally stable. Additionally, herring of different ages were genetically similar both within and among collections. There is a large change in the genetic structure of fish west of PWS. When examining genotypes from individual herring, we found that some Cook Inlet herring are similar to PWS herring, and some are completely divergent.

Herring population dynamics modeling: The model was rebuilt in Bayesian framework in AD Model Builder that is faster to run and allows for consistent statistical weighting of different data sources and allows uncertainty to be automatically calculated. The Bayesian model provides good fits to the time series of data. In the most recent Bayesian assessment (2015), the estimated biomass in early 2014 was 17,000 metric tonnes, just below the threshold for opening the fishery (19,958 mt). There was a wide 95% posterior probability interval (10,300-41,700 mt), with an 80% probability that spawning biomass was below the management threshold. The last year of medium recruitment was in 2002, but since then recruitment has been poor, ranging from 9 to 103 million fish compared to 117-1234 million fish in every year from 1980 to 1988. The trade-off between survey cost vs. measures of precision and bias revealed that the disease survey (low cost for benefit) and the egg-deposition diver survey (expensive but assumed an absolute index of abundance) were the most valuable sampling programs in the past. Meta-analysis of world-wide herring populations shows that the depth and length of the crash of herring in PWS is unusual. The meta-analysis also demonstrated that post-collapse PWS herring have the lowest recruits per spawner of all herring populations worldwide.

Objective 2

Herring scale analysis: The imaging of herring scales collected since the 1980s were used to examine the age at first maturity and first-year growth relationship to oceanographic conditions. Imaging of the scales allowed for examining changes in growth patterns over time. Examination of the scale measurements found that there were not differences in growth based on gender. There was correlation of growth within a brood year sampled at different ages. First-year growth was found to be strongly correlated to diatom abundance anomaly and more weakly correlated to summer water temperatures and zooplankton abundance anomaly.

Data visualization: The data management project provided a single location for storing data from all projects through the Ocean Workspace. From there it could be connected to the Alaska Ocean Observing System website for visualization and DataOne for long-term archiving. Through these efforts, we built a data management system that includes 32,000 data files (1.4 TB) among nearly 50 users in the EVOSTC Herring Program Workspace group. Twenty nine of the datasets are available publically through the Gulf of Alaska Data Portal. These datasets are discoverable among 300 additional GIS, environmental, numerical modeling and remote sensing data resources for the Gulf of Alaska. Ultimately, the HRM projects datasets are replicated in the DataONE archive for long-term preservation and discovery by over 60,000 annual users.

Objective 3.

Herring condition intensive: Monthly sampling of herring condition showed a peak in WBED and lipid levels in November with a rapid decline through January to a minimum level. The WBED and lipids remained at that minimum through March and then began to increase in the spring. Samples collected at multiple sites within a bay had similar condition. There was some difference in condition and growth variables between larger and smaller fish. Since gill nets selectively caught larger fish than cast nets the sampling method had to be accounted for in the analysis. There was an increase in the size of the fish caught through the winter; however, the RNA/DNA data did not support growth through the winter.

Fatty acid analysis: The laboratory testing of fatty acids showed the fatty acid composition was dependent on diet and remained the same if the diet was reduced or the fish were starved. The fatty acid composition changed if the diet was altered. Fish collected in November from various bays around PWS were found to have different fatty acid composition, consistent with regional differences in diet. There were large changes in fatty acid composition in the bays between fall and the following spring. Only a few, generally larger, fish conserved their fatty acid profile through the winter.

Acoustic consistency: During the acoustic survey intensive juvenile Pacific herring were the dominant species caught in the near surface waters (median proportion 0.86). The precision of the survey (variation over three consecutive nights) varied considerably over the study period.

The coefficient of variation of densities ranged from 2-106%, with a median of 53.2%. Variation between cruises spaced two weeks apart showed up to ten-fold differences in estimated juvenile herring. The maximum density was observed in October, declined by December and then increased into the April. Ice growth through the winter caused variations in the survey area. The general pattern observed was that there were higher densities in the inner bay, and that was the portion in which ice formed.

Direct capture: Direct capture efforts found that through the five-year study 85.3% of all fish caught were Pacific herring with walleye pollock (11.6%) and capelin (2.3%) making up much of the remainder of the fish catch. We hypothesized that age-0 Pacific herring density would be associated with trawl tow depth, thermohaline conditions, and geospatial factors (distance from shore, bottom depth, and distance from eelgrass habitat). Using generalized linear mixed models, results indicated that the distribution of age-0 Pacific herring in the pelagic environment was influenced by shoreline habitat, salinity, and water depth. Age-0 Pacific herring catch rate was negatively associated with distance from eelgrass beds and tow depth, with herring favoring shallower water across the range of depths sampled (7.2–35.4 m). In addition, herring distribution was positively associated with fresher water within the sampled salinity gradient (24.1–32.3 psu). Age-0 herring tended to be found in the inner bay throughout the winter, whereas age-1 herring shifted from the inner to outer bays by spring. The catch rate of age-0 herring was higher in areas that had recently been covered by ice.

Disease studies: We investigated the appearance of external ichthyophoniasis signs on the flank of juvenile herring. The characteristic open ulcers can be quite persistent on infected cohorts, but the appearance of these signs does not necessarily precede host mortality. A very small stage of *Ichthyophonus* was detected in the blood of infected fish. This parasitic life stage is most certainly involved in dissemination throughout the host tissues, and it may represent the infectious stage. We also determined that *Ichthyophonus* life stages remain viable and infectious in a dead host for extended periods; this ability of the parasite to survive both saprophytically and facultatively likely provides the parasite with a persistence strategy in the wild. We confirmed tissue explant culture is the most sensitive diagnostic technique for detecting low-intensity Ichthyophonus infections; more sensitive than PCR. Laboratory studies indicated that cooler water temperatures were more conducive to VHS epizootics, resulting in greater mortality, higher viral tissue titers, and longer viral persistence in the host tissues. This inverse relationship between temperature and VHS was likely mediated by an enhanced immune response at warmer temperatures, where a robust type I interferon response was indicated by rapid and significant upregulation of the herring Mx gene.

Objective 4.

Herring tagging: The tagging study showed that herring could survive being implanted with an acoustic tag. In 2012, 23 of 25 fish were detected at an acoustic array in Port Gravina. In 2013, 64 of 69 tagged fish were later observed by the acoustic arrays in Port Gravina or the entrances to PWS. Herring tagged in Port Gravina were able to reach Hinchinbrook Entrance (50 km) in under two days, and the mouth of Montague Strait (115 km) as quickly as three days after release. Most of the fish observed spent time in the southern Montague Strait area after spawning. Fish tagged in April were observed in the Entrances throughout May and into June. By late June observations of tagged fish were sporadic with detections in Montague Strait and the southwest passages increasing again from mid-September through October. Fish were regularly detected in those regions through the end of life of the tags in December. Only one fish was observed at the Hinchinbrook Entrance array during the fall and winter.

Non-lethal sampling: Measurements of age-0 herring lengths were made using a DIDSON sonar mounted on a remotely operated vehicle. It was not possible to overlap sampling but 329 fish were caught by trawl and 1,270 fish measured using the DIDSON at a nearby location. The trawl caught fish had a length of 7.6 cm vs 6.7 cm as found using the DIDSON. Because of the resolution we were able to examine the length as a function of position within a school. We did not find a difference in length between the top, middle, and bottom of the school. We found school densities decreased from day to night. The school density also differed between the two bays sampled. Age-0 herring were observed under ice using the ROV.

Disease forecasting: An important advancement during this funding cycle included the development and optimization of a number of techniques (ELISA, virus neutralization, and PNT) that are capable of measuring VHSV antibodies in surviving fish. Using this approach we found that approximately 15% of the fish sampled in PWS had VHSV antibodies, whereas Sitka had about 1-2% antibody prevalence. Additionally, the methods for two new VEN diagnostic techniques (conventional and quantitative PCR's) were published, thereby enabling confirmation of this condition from standard tissue samples.

Other efforts: Herring spawn was observed in MODIS satellite images. The cloud cover and need for large spawn events limit the utility of the methods. We could not clearly detect spawn using cameras mounted above the shore, although changes in bird behavior were observed during spawn events.

Program management

The coordination effort and the outreach component worked closely together to achieve the program objectives. A product of the coordination project was the development of a synthesis midway through the five-year effort. The coordinator also served as a guest editor for the special issue of *Deep Sea Research II* that includes results from this program. The coordination effort was responsible for the timely submittal of reports. The outreach effort developed webpages for all of the projects and transitioned them over three websites in the five years. Print version of the web materials were created for distribution at various events. They further developed short audio programs for transmission on the local public radio station that are also included with the other materials on the HRM website.

DISCUSSION

Objective 1:
The monitoring components were designed to provide inputs to the existing model (disease prevalence and acoustic biomass estimate) while also looking at potentially new streams of data (juvenile condition, juvenile acoustic surveys, aerial age-1 surveys) that provide a means to expand the model to provide more information on age classes not currently in the model.

The disease prevalence data currently used by the model did not detected any unusual disease conditions, but are limited in that for VHS and VEN the ability to detect prior exposure has not been possible. Since a VHS outbreak can have large population effects but not last for long we have been aware that the prevalence measures used might not be a good indicator of mortality from disease. It is through the development of new procedures that can detect the presence of antibodies in herring that we are beginning to see that the prevalence of VHS is very different in PWS compared to Sitka and that we have a more appropriate measure of the disease to use in the model to measure potential mortality by the disease. Similarly, we understand that the prevalence of *Ichthyophonus* increases with age and that needs to be accounted for when being considered in the ASA model. There still are questions about what conditions lead to *Ichthyophonus* causing mortality.

The acoustic surveys did not find significant populations outside of the main spawning areas in most years. What was startling was the decline in the existing herring population down to new record low values. With the low population levels there was a contraction of the spawning grounds being used. Hence, the miles-day-spawn measured declined in a manner similar to that observed in the acoustic estimates of the adult biomass. There were also changes in the behavior of the pres-pawning fish detected in recent years, in that the fish arrived at the spawning grounds in much smaller schools that spent more time in shallow waters.

Two types of surveys were conducted to provide a measure of juvenile herring biomass. Acoustic surveys conducted in November each year were designed to survey age-0 herring within index bays. An aerial survey conducted in June each year focused on an index of age-1 herring. A high acoustic backscatter was observed in 2012, but did not have corresponding trawl data to separate into components, that suggests a strong year class. The acoustic surveys found significantly fewer fish in November 2013 than the other years surveyed, suggesting a poor year class was likely. These results agreed well with the age-1 aerial surveys. The greatest number of age-1 schools were observed in 2013 and the fewest observed in 2014.

Since the trawl data used in the hydroacoustic analysis was limited to the upper 30 m of the water column an analysis was conducted to examine the impact of changing the depth integration on the estimated biomass. Increasing the depth integration to 40 m we found that the biomass index was not affected by the depth integration. It was also observed that the majority of age-0 herring were found in the inner portion of the bays during the November surveys.

In most years the whole body energy density and lipid levels observed in March where at the minimum level expected for a fish to survive. The whole body energy density (WBED) observed in March was typically near 3.3 kj/g, which is similar to the minimum WBED observed by Paul and Paul (1998). This low level was reached independent of the starting energy content with the exception of the winter of 2012-2013. It is not clear what was different that winter that allowed the WBED to remain high. Although differences in the carbon isotope signatures suggested a difference in diet in the summer of 2012 that had more of a Gulf of Alaska carbon signature, rather than one indicative of PWS. It is possible that a difference in food quality led to the fish's ability to better survive the winter.

In most years the fish appear to be starving in the spring and it is not clear what portion of the population was able to survive. We began the project with a linear model of energetic loss. If there was a constant energy loss it would be possible to determine how long the fish had been under starvation conditions from the fall energy content and estimate the overwintering mortality and therefore be able to predict the impact of overwintering on the strength of a year class. However, the condition intensive work showed that the constant loss model was not appropriate and a new model needs to be generated to help understand the energy loss.

The work on age at first maturity demonstrated the value of histology in being able to determine if a fish had spawned in the previous three months. A sample of fish collected in July demonstrated that histology could be used to help identify fish that had spawned and those that hadn't. Analysis of scale growth detected that there were bimodal growth patterns. Assuming that egg production limits the growth the bimodal distribution suggests the possibility of detecting age at maturity and potential for detecting skip spawning at older age classes. The scale growth of age-1 and age-2 fish was unimodal suggesting they did not include spawning fish. From age3-6 the scale analysis suggested that the female fish were more likely to skip spawning and the greatest proportion of fish that skipped spawn were age-3 and age-6. This suggests that a significant proportion of the age-3 fish are not spawning with greater proportions spawning at age-4 and 5. While the work did not provide an age-at-maturity function, it did demonstrate the potential using histology and scale analysis to make observations regarding the proportion of the population likely to spawn each year.

A weak divergence in the genetic structure was observed between eastern and western spawning herring. The genetic structure within PWS was temporally stable. Generally, the genetic structure in PWS was similar to those fish collected at Kayak Island and Yakutat. Principal component analysis showed divergence of genetic structure between PWS herring and those to the west, Cook Inlet and Kodiak Island. Examining the genetic structure of individual fish determined that the fish in Cook Inlet had a mixture of two genetic types, one of which was similar to PWS.

The model was rebuilt in a Bayesian structure to provide more information on the range of potential biomass. It was used to examine the cost benefit of previous measurements and found that egg depositions surveys (assumed to represent absolute biomass) and disease surveys (explain large decline and low cost) were the most important inputs to the model in the past. The model was also used to examine the impact of environmental variables on herring recruitment. It was found that pink salmon production, freshwater discharge, sea level height, and disease may all play a role in the lack of herring recovery.

A meta-analysis of worldwide herring populations found that the magnitude of the decrease in population and the length of the lack of recovery in PWS are both highly unusual for herring populations. It was also seen that the recruits per spawner in PWS is low compared to other herring populations. No environmental parameter was found to be a good predictor of either collapse or recovery. It is clear from this analysis that the collapse in PWS is unusual in many ways.

Objective 2.
There were two projects that addressed this objective. The data management project addressed the objective by making the data available and discoverable in a manner that made the synthesis effort simpler. The second project used the ADF&G scale library to extend our information on herring back in time. The synthesis was a deliverable of the coordination project. It was completed in 2014 and can be found on the PWSSC website under the herring research and monitoring program page (http://pwssc.org/wp-content/uploads/2014/12/HRM-synthesis.pdf).

The scale imagery was used to examine historical growth in the first year. When combined with information from the Continuous Plankton Recorder project in the GWA program it was seen that first-year growth was strongly correlated to diatom abundance (Batten et al. 2016). It was also correlated to summertime water temperatures and zooplankton abundance. The relationship with diatom abundance was maintained even in years where the correlation to summer temperatures broke down. The relationship with zooplankton was the weakest of the correlations. This suggests that food quality, from essential fatty acids in diatoms, may be more important to growth than food quantity.

Historic first-year growth derived from the scales was combined with the observed fish length to scale growth of age-0 herring. Based on fish captured at ages 4-6 it appears that a herring must reach a length of 8 cm in the first year to survive to spawning age. Interestingly, this is also the length that fish appear to shift from growth to lipid storage as determined by the herring condition project (16120111-L). Some smaller fish were observed to survive the first winter, but may be of such poor condition to be more likely to be predated on, or in so low of abundance to not be seen in the historic scale analysis. When combining results from the fatty acids and herring condition projects it was clear that age-0 herring feed during the winter, but not at a rate that allows for growth. The smaller more lipid poor fish had the most food in their stomachs indicating that they were more likely to be feeding.

Objective 3.
The fatty acid project was designed to detect if there was evidence of movement between bays that would lead to errors in survival estimates from acoustic surveys. While it was shown that the fatty acid signature was determined by diet, conserved during starvation, and varied between bays, there was enough evidence of feeding through the winter that the approach could not be used to detect migration between bays. The larger fish that were less likely to feed in the winter were the most likely to have a fatty acid profile in the spring that was similar to that in the fall. During a season there were differences in the fatty acid profiles of herring collected in different locations within a bay that suggested the herring were foraging in spatial ranges of the order of kilometers.

The estimation of survival through the winter depends on being able to get accurate estimates of age-0 herring at the beginning and end of the winter. We conducted four cruises in the fall and another four cruises the following spring to determine how consistent our estimates would be. Each cruise consisted of three acoustic surveys conducted on consecutive nights. There were significant fluctuations in biomass estimates between cruises in the fall with a four-fold increase through the month of October, a value in December that was lower than that observed in the spring. Spring surveys were hampered by the presence of ice with large concentrations of age-0 herring discovered once the ice moved away. These results show the difficulty of being able to use the acoustic surveys to provide biomass estimates that can be used to estimate overwintering mortality. Either the survey method left areas with high concentrations of age-0 fish (under ice and possibly closer to shore than the survey could reach) or there were significant migrations of fish in a two week period.

While the direct capture project was primarily meant to support other projects by providing fish, the analysis of the trawl catch did show that the age-0 herring were primarily near the heads of the bays where eelgrass beds were near and freshwater input is higher. The age-1 fish would be in the same nursery areas during the winter, but moved out to deeper water early in the spring. This is consistent with the findings of Stokebury et al. (1999).

An interesting anomaly in the demographic pattern of *Ichthyophonus* infections was observed in samples from the Cordova Harbor. While in most instances *Ichthyophonus* is not associated with young fish, in the harbor there were high rates of *Ichthyophonus* prevalence. This led to work that demonstrated that *Ichthyophonus* could be transmitted through the consumption of infected offal. Further work confirmed that *Ichthyophonus* prevelance increases with age and that needs to be accounted for when looking at changes in prevalence over time. We still do not know what leads to lethal *Ichthyophonus* infections, which makes estimating mortality difficult.

Objective 4.
In many ways some of the more significant advances came from this line of research. The tagging project was able to demonstrate that herring could be successfully tagged with acoustic tags and survive. Most of the fish were observed moving to the southern entrance of Montague Strait after spawning where they were observed over a two month period. It is not clear if they went out into the Gulf of Alaska after that point, but they returned to that area again starting in September and were observed in the Southwest passages until the tags failed in December. Some fish remained near the spawning grounds and were observed by a receiver array there until it was removed in June. Based on the results of this project a larger tagging effort and extended array has been proposed to determine if the fish are migrating into the Gulf of Alaska and if smaller fish are more likely to remain in PWS.

A ROV with imaging sonar and camera were able to detect, identify, and size age-0 herring in nearshore waters and under ice where the acoustic survey was unable to make measurements. The technique might be able to help determine the acoustic backscatter signal associated with age-0 herring if the imaging sonar could make concurrent measurements with the acoustic survey gear. This would improve the age-0 biomass estimates.

One of the more important breakthroughs came with the development of the PNT. This test allows for measuring the presence of VHSV antibodies in surviving fish for at least a year after exposure. This is important because a VHS outbreak can occur over a short time span and may not be detected by annual prevalence measurements. Now we are able to detect if an outbreak had occurred and are working on how to use that information in the population models. The information may also be used in disease forecasting by being able to identify populations with a large portion that is immune to the disease versus one that is highly susceptible to large epizootics.

CONCLUSIONS

The metadata analysis showed that the collapse of the herring population in PWS is unusual in its severity and duration. It is clear that there has not been a strong recruitment in the past twenty years and we have not determined the cause for that lack of recruitment. We do think that the observations made by the HRM and GWA programs may be able to address both questions of recruitment and the reason for a further rapid decline in the adult biomass that occurred in the past five years.

The program was able to rebuild the ASA model used by ADF&G in a Bayesian framework. This provides a tool to examine the value of past and present input data to determine the most cost effective sampling that can be used to get good population estimates. It is also a tool to test hypotheses about the lack of recruitment and population fluctuations. Several projects continued to collect data that is either used by the existing ASA model or may allow better estimation of recruitment to the spawning stock.

It is clear that age-0 fish reach the minimum energy state for survival during most winters and that mortality at this stage may be high. We don't have a good means for estimating survival though which hampers the use of the energetic information. The existence of an unusually good year for condition may still allow us to identify the conditions that may lead to good survival and recruitment. We found that we are not able to sufficiently measure the abundance of age-0 herring to make survival estimates. Other approaches must be developed before we can understand survival at the early life stages. Through the analysis of scale growth we have the ability to examine conditions that are favorable to growth and recruitment. The ADF&G scale library is able to extend the time series for this type of analysis back to the 1980s.

The ability to acoustically tag herring and to detect the presence of VHSV antibodies may be two of the greatest advances of the program. The tagging provides an opportunity to learn about the movement of herring without requiring a large recapture program. The detection of VHSV antibodies allows us to detect disease outbreaks that occur between disease prevalence sampling events. It also gives information about how immune the population may be to future epizootics.

While many questions exist about the PWS herring population, the work over the past five years is able to help us focus our future efforts and provide information that can be used to connect changes in the population to environmental conditions.

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PEER-REVIEWED PUBLICATIONS

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