FY16 PROJECT PROPOSAL SUMMARY PAGE

New Project

Project Title: PWS Herring Research & Monitoring: Annual Herring Migration Cycle - Expanding Acoustic Array Infrastructure

Project Period: February 1, 2016 – January 31, 2017

Primary Investigator(s): Mary Anne Bishop, Ph.D., Prince William Sound Science Center, Cordova
mbishop@pwssc.org

Project Website: http://pwssc.org/research/fish/pacific-herring/

Abstract: One of the important knowledge gaps for the Pacific herring (*Clupea pallasii*) population in Prince William Sound (PWS) is understanding adult herring annual migration movements between spawning, summer feeding, and overwintering areas. In 2013 we documented post-spawn migration of herring from Port Gravina to the PWS entrances by acoustic tagging adult herring and collecting data from the Ocean Tracking Network acoustic arrays. The 2013 study, however, could not verify if herring were migrating out into the Gulf of Alaska and then returning to PWS because of the layout of the Ocean Tracking Network arrays.

The goal of this herring study is to clarify the annual migration cycle of PWS adult herring. The objectives of this FY16 proposed project are to 1) purchase and deploy additional acoustic receivers at the Ocean Tracking Network arrays so that the direction of herring movements (into or out of PWS) can be determined; and 2) purchase acoustic tags. Achieving these objectives in FY16 will then allow us in FY17 to begin to address objectives aimed at 1) documenting adult herring migration movements out from and into PWS; and 2) understanding factors that influence migration patterns including age, condition, spawning location, and residency in PWS.

Because it takes several months from the start of funding to get tags and equipment purchased, prepared, and deployed, completing these activities during FY16 will allow us to initiate acoustic tracking studies in 2017 when herring are aggregated on their spring spawning grounds. With the batteries of the Hinchinbrook Entrance and Montague Strait acoustic arrays expiring around March 2020, a tagging program starting in 2017 provides a larger time window (three seasons, FY17, 18, 19) for collecting high quality data and increases the feasibility of monitoring herring aggregations in the three major spawning areas: Port Fidalgo, Port Gravina, and Montague Island. In addition, by using acoustic tag programmed at low power only, battery life on acoustic tags would be increased to of ~400 days. This would allow us to monitor acoustic-tagged herring from one spawning season to the next.

Estimated Budget: EVOSTC Funding Requested* (*must include 9% GA)*:

FY15	FY16	FY17	FY18	FY19	TOTAL
	$272.6				

Non-EVOSTC Funds to be used:

FY15	FY16	FY17	FY18	FY19	TOTAL
	$415k in-kind				

**If the amount requested here does not match the amount on the budget form, the request on the budget form will considered to be correct.*

Date:
August 31, 2015

EXECUTIVE SUMMARY

Justification

One of the important knowledge gaps for the Pacific herring (*Clupea pallasii*) population in Prince William Sound (PWS) is understanding adult herring annual migration movements between spawning, summer feeding, and overwintering areas. In 2013 we documented post-spawn migration of herring from Port Gravina to the Prince William Sound entrances by acoustic tagging adult herring and collecting data from the Ocean Tracking Network acoustic arrays. The 2013 study, however, could not verify if herring were migrating out into the Gulf of Alaska (GOA) and then returning to Prince William Sound because of the single-line layout of the Ocean Tracking Network arrays.

The goal of this herring study is to clarify the annual migration cycle of PWS adult herring. The objectives of this proposed project are to 1) purchase and deploy additional acoustic receivers at the Ocean Tracking Network arrays so that the direction of herring movements (into or out of PWS) can be determined; and 2) purchase acoustic tags. Achieving these objectives in FY16 will then allow us in FY17 to begin to address objectives aimed at 1) documenting adult herring migration movements out from and into PWS; and 2) understanding factors that influence migration patterns including age, condition, spawning location, and residency in PWS.

Because it takes several months from the start of funding to get tags and equipment purchased, prepared, and deployed, completing these activities during FY16 will allow us to initiate acoustic tracking studies in FY17 when herring are aggregated on their spring spawning grounds. With the batteries of the Hinchinbrook Entrance and Montague Strait acoustic arrays expiring around March 2020, a tagging program starting in FY17 provides a larger time window (three seasons: FY17, 18, 19) for collecting high quality data and increases the feasibility of monitoring herring aggregations in the three major spawning areas: Port Fidalgo, Port Gravina, and Montague Island.

Background

Conservation concerns about the recovering Pacific herring population in PWS make it increasingly important to document migration patterns to inform our understanding of PWS adult herring survival. Little is understood about adult Pacific herring annual migration movements between spawning, summer feeding, and overwintering areas within and between PWS and the GOA

Elsewhere, it is common for large herring populations to migrate from nearshore spawning areas to coastal shelf areas for summer feeding habitat (Hay and McCarter 1997, Hay et al. 2008). Corten (2002) suggested that observed herring migration patterns are not innate, but are a learned behavior that initially occurs when the recruiting year class follows older herring. In his review of migration in Atlantic herring (*C. harengus*) Corten observed that herring migration patterns tend to be stable over years, despite environmental variation. In PWS, Brown et al. (2002) compiled local and traditional knowledge on adult herring movements. In that study, some fishers reported herring moving into PWS through Montague Strait prior to the fall bait fishery while others reported herring moving into PWS in spring through Hinchinbrook Entrance, Montague Strait and the southwest passages of Erlington and LaTouche. These observations suggest that PWS herring are regularly migrating out of PWS and onto the shelf.

During winter, adult Pacific herring along the eastern Pacific Ocean often return to coastal areas and remain close to spawning areas and in nearshore channels (Hay and McCarter 1997). This behavior has also been observed in PWS herring populations, where historically large schools both overwintered and spawned around northern Montague and Green Islands. More recently however, the major biomass of adult herring during winter has shifted to the northeast and southwest areas of PWS. Currently the largest concentration of adult herring overwinters and spawns around Port Gravina and Port Fidalgo (ADFG herring portal http://data.aoos.org/maps/pwsherring/***).***

Previous studies of Pacific herring movements in the eastern Pacific have utilized fisheries-dependent tag recovery and CPUE data (*e.g.* Hay and McKinnell 2002, Tojo et al. 2007). Unfortunately, making inferences about herring movement from fisheries-dependent data is problematic because fishing effort may not be consistent in all locations or across seasons, and recapture rates are typically low (< 10 %). Furthermore, tag recovery and CPUE methods typically provide poor temporal and spatial resolution on the rate and timing of large scale migrations.

We propose to utilize acoustic telemetry to investigate seasonal movement patterns of Pacific herring. Post-spawn feeding, winter, and subsequent spawning migrations will be examined by tagging herring on PWS spawning grounds during spring and monitoring their movement patterns with moored acoustic arrays. The use of acoustic telemetry will allow us to look at movement patterns on a variety of temporal and spatial scales, filling in significant gaps in our current knowledge of herring migration.

Our proposed project builds on an EVOS Herring Research & Management (HRM) pilot project of the Principal Investigator M. Bishop and collaborator J. Eiler (NOAA). Our pilot project developed handling and tagging methods designed to minimize physical injuries and stress to wild herring (Eiler and Bishop *in review*). In April 2012, we successfully tagged 25 wild herring on their spawning grounds with acoustic transmitters. Post-release, 23 (92%) of the 25 tagged individuals were detected by a VR2W acoustic receiver multiple times on one or more days post release. Subsequently, the February 2013 installation of the Ocean Tracking Network's (OTN) six acoustic receiver arrays across the entrances to the GOA provided the first opportunity to detect movements from the spawning grounds to the entrances. In April 2013 we tagged 69 adult Pacific herring on the spawning grounds at Port Gravina. Tags had an expected life of 263 d. Post-release we detected 93% of the tagged herring (64 of 69) either at Port Gravina and/or the OTN arrays (Eiler and Bishop *in review*).

Based on detections at the OTN arrays, we were able to document that many of the tagged herring remained in and around the entrances to PWS from mid April through early June. By July, most tagged herring had departed from Hinchinbrook Entrance and Montague Strait areas, with fish at Montague Strait often shifting west and into to the Southwest Passages. Herring schools appeared to be actively moving throughout fall in and around Montague Strait and the Southwest Passages, although no equivalent movements were detected at Hinchinbrook Entrance. Arrays detected herring at the Montague Strait array and the Southwest Passages arrays right up to when tags expired in early January 2014, indicating that not all herring winter in northeast PWS, and that some herring are highly mobile and may be moving back and forth into the GOA even during winter months (Bishop and Eiler, *in prep*.).

The results of our EVOS pilot study demonstrate the exceptional opportunity to document migration patterns by PWS herring, and specifically the connectivity between the Gulf of Alaska and Prince William Sound. However, we are unable to determine the directionality of tagged fish movements based on data from the Ocean Tracking Network arrays as they are currently configured because each array consists of one, east to west line of receivers. With a relatively small investment, our inability to determine the direction of herring movements could be remedied.

Our 2013 study found that at both the Hinchinbrook Entrance array (n = 16 receivers) and the Montague Strait array (n = 11 receivers) that most acoustic-tagged herring detections occurred at the outermost receivers (Hinchinbrook n = 96% of all detections at 4 receivers; Montague n = 80% at 4 receivers). When we examined final detections of tagged fish, we determined that >85% of the final detections occurred at these outermost receivers (Bishop and Eiler, *in prep.*). Therefore deploying additional receivers just below these outermost receivers would allow for determination of the movement direction for a large proportion of the herring detections. In addition, by using acoustic tags programmed at low power only, battery life would be increased to ~400 days. This would allow us to monitor acoustic-tagged herring from one spawning season to the next.

Key hypotheses and overall goals

The overall goal of our long-term (FY16-20) study is to clarify the annual migration cycle of PWS adult herring. For FY16 we are requesting EVOS funding in order to:

1) purchase and deploy additional acoustic receivers at the Ocean Tracking Network arrays so that the direction of herring movements (into or out of PWS) can be determined; and,

2) purchase acoustic tags.

Achieving these objectives in FY16 will then allow us in FY17 to begin to address objectives aimed at 1) documenting adult herring migration movements out from and into PWS; and 2) understanding factors that influence migration patterns including age, condition, spawning location, and residency in PWS. The FY17-20 portion of the study will be part of the EVOS Herring Research and Monitoring Program and will test the following hypotheses:

H_1: Pacific herring populations in PWS make seasonal, post-spawn feeding migrations through major entrances and passages to the Gulf of Alaska.

a) Fish with poor body condition are less likely to migrate.
b) New recruits to the spawning population are less likely to migrate than older herring.

H_2: The Prince William Sound herring population is comprised of migrant and resident individuals.

a) Resident individuals remain within the confines of Prince William Sound.
b) Resident herring are associated with specific spawning grounds.
c) Migrant individuals exit Prince William Sound by mid-June and return to the Sound in either fall or spring.

H_3 Survival is related to age and body condition.

For FY16 we are requesting a total of **$272.6K** ($250.1K project costs + 22.5K general admin costs) for the purchase of equipment and tags needed to test the above hypotheses about herring movements. We need to purchase equipment in FY16 because:

- It will take several months from the start of funding to get tags and equipment purchased, prepared, and deployed.
- A February start date for FY17 funding means that equipment and acoustic tag purchases cannot be completed by the beginning of April, when herring aggregate to spawn. Capture efficiency is highest during spawning events. Spawning events are also associated with initiation of migration.
- The batteries of the Ocean Tracking Network array VR4 receivers are expected to expire around March 2020. This infrastructure (comprised of 34 acoustic receivers) is essential for collecting high quality data on herring movement and survival. Initiating studies that take advantage of existing OTN infrastructure before it expires allows for major leveraging of funds to complete EVOSTC objectives.

- If we are unable to begin tagging until 2018 we will only have two opportunities to observe annual migration patterns. A tagging program starting in 2017 provides a larger time window for collecting high quality data and increases the feasibility of monitoring herring aggregations in the three major spawning areas: Port Fidalgo, Port Gravina, and Montague Island.

II. COORDINATION AND COLLABORATION

1. Within the Program

Our study, PWS Herring Annual Migration Cycle, will be a component of the larger, EVOS-sponsored Herring Research and Monitoring (HRM) program. While the FY17-21 HRM projects are not yet finalized, we anticipate that we will coordinate with at least two other HRM projects.

EVOS Herring Research & Monitoring	
Herring disease	USGS
Hydroacoustic surveys	PWSSC

Our project will also provide information that will complement data collected by three existing projects in the EVOS Gulf Watch Alaska pelagic component:

EVOS GulfWatch	
Forage fish distribution, abundance, & body condition in PWS	USGS
Humpback whale predation	NOAA/UAS
Fall and winter seabird abundance & distribution	PWSSC

Understanding movements by adult herring throughout the annual cycle will provide valuable information on trophic interactions between herring and piscivorous waterbirds (in particular loons and common murre the major avian consumers of adult herring), humpback whales, and other forage fish competitors.

2. With Other Council-funded Projects

Except for the EVOS Herring Research & Monitoring Program and the EVOS Gulf Watch Alaska program, there are no other EVOS-funded collaborations.

3. With Trustee or Management Agencies

Our project relies on information from Alaska Department of Fish and Game to help locate adult herring schools in spring for acoustic surveys and our sampling. To that extent, we work closely with Steve Moffitt at the Cordova office of ADF&G. Information learned about herring migrations will be shared with ADF&G.

Collaborations with other organizations

This project will synergize with efforts of the Ocean Tracking Network (OTN; Fred Whoriskey, PhD Executive Director, Dalhousie University). In March 2013, OTN installed two, large-scale arrays including one across the mouth of Hinchinbrook Entrance and one across Montague Strait, and four small arrays at the southwest PWS passages of Erlington, LaTouche, Bainbridge and Prince of Whales. Equipment was assembled and configured by PWS Science Center personnel in Cordova. Currently PWSSC maintains the array for OTN on an annual basis. OTN maintains a database with detections from their worldwide network. Our data is archived in the OTN databases, as per their guidelines.

III. PROJECT DESIGN
A. Objectives

Project Objectives FY16

1) Purchase and deploy additional receivers around the Ocean Tracking Network arrays.
2) Purchase acoustic tags

Because it takes several months from the start of funding to get tags and equipment purchased, prepared, and deployed, completing these activities during FY16 will allow us to initiate acoustic tracking studies in 2017 when herring are aggregated on their spring spawning grounds.

Project Objectives for FY17-20, the second phase of this project, include:

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

The hypotheses we will test as part of the larger study include:

H_1: Pacific herring populations in PWS make seasonal, post-spawn feeding migrations through major entrances and passages to the Gulf of Alaska.

a) Fish with poor body condition are less likely to migrate.
b) New recruits to the spawning population are less likely to migrate than older herring.

H_2: **The** Prince William Sound herring population is comprised of migrant and resident individuals.

a) Resident individuals remain within the confines of Prince William Sound.
b) Resident herring are associated with specific spawning grounds.
c) Migrant individuals exit Prince William Sound by mid-June and return to the Sound in either fall or spring.

H_3: Survival is related to age and body condition.

H_4: Fine-scale spatial use patterns are associated with individual biological characteristics and vary seasonally.

B. Procedural and Scientific Methods

Acoustic receivers will be secured via a combination of static subsurface moorings and subsurface moorings with acoustic releases (depending on the individual receiver location, depth and potential interaction with commercial fishing operations; Eiler and Bishop, *in review*).

Acoustic tag data collected via fixed acoustic arrays provide presence-absence data of individual herring with very high temporal resolution; however, the spatial resolution depends upon detection range and the size and configuration of the acoustic array. The acoustic arrays currently deployed in the entrances and major passages into Prince William Sound (PWS) are configured as a 'gate' (Heupel et al. 2006) and are designed to detect fish moving through these corridors. Detection probability of this gate is likely high based on the spacing of the receivers (mean distance between receivers= 724 m; max= 835 m) and detection range data collected in 2013 using moored range tags (Fig. 1). At 400 m, 93% of the

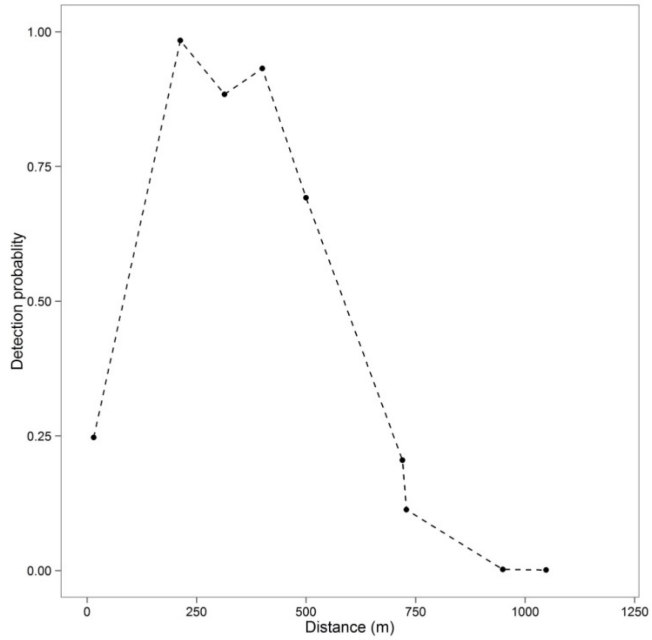

Figure 1. Proportion of reference transmitter signals detected by acoustic receivers near Hinchinbrook Entrance in Prince William Sound.

transmitted signals were recorded and 69% were recorded at 500 m; thus, all fish moving through this acoustic gate will have a high probability of being detected by at least one receiver.

However, as currently configured, the directionality of movement (north into PWS or south towards the Gulf of Alaska) after detection at any of the arrays cannot be determined. To address the objectives of this study, the detection capabilities of these acoustic arrays will be increased by deploying 16 receivers in January 2017. These additional receivers will be configured as a second gate at each array and will provide the data needed to determine directionality of movement away from the array (Fig. 2; Fig. 3). At Montague Strait and Hinchinbrook Entrance, deploying complete second lines of 11 and 16 receivers, respectively, is currently cost prohibitive. Therefore, receivers will be deployed along the east and west coastlines of these two corridors (Figs. 2, 3). These receiver configurations are based on data from the 2013 tagging study that indicate herring use nearshore habitat much more frequently than mid-channel habitat at both these sites. Specifically, 86.8% of the 26,371 detections from Montague Strait and Hinchinbrook Entrance were recorded on the outermost (nearshore) receivers (Bishop and Eiler, *in prep*.). Thus, a second gate at both Montague Strait and Hinchinbrook Entrance, though incomplete, will each have a high probability of detecting tagged herring using these corridors. Further, the detection probability of the second gate can be estimated in our data analysis and used to reduce the bias in our movement rate estimates caused by incomplete detection at the second gate.

In addition to the installation of a second gate at the major entrances and the southwest passages, an array of nine VR2W receivers located near tagging sites in northeast Prince William Sound will be deployed in order to monitor post-tagging movements and the timing of outmigration and subsequent migrations back to the area. These receivers are currently being used by PWSSC in a Pacific cod movement project that is scheduled to end shortly before the 2017 field season. The intent of our array configuration will be to maximize the detection probability of tagged fish on the spawning grounds. Data from this array will allow researcher to address questions relating spawning site fidelity, monitor post-tagging survival, increase the resolution of movement patterns within PWS, and provide data needed for robust survival estimation. These receivers will be deployed with acoustic releases and upon

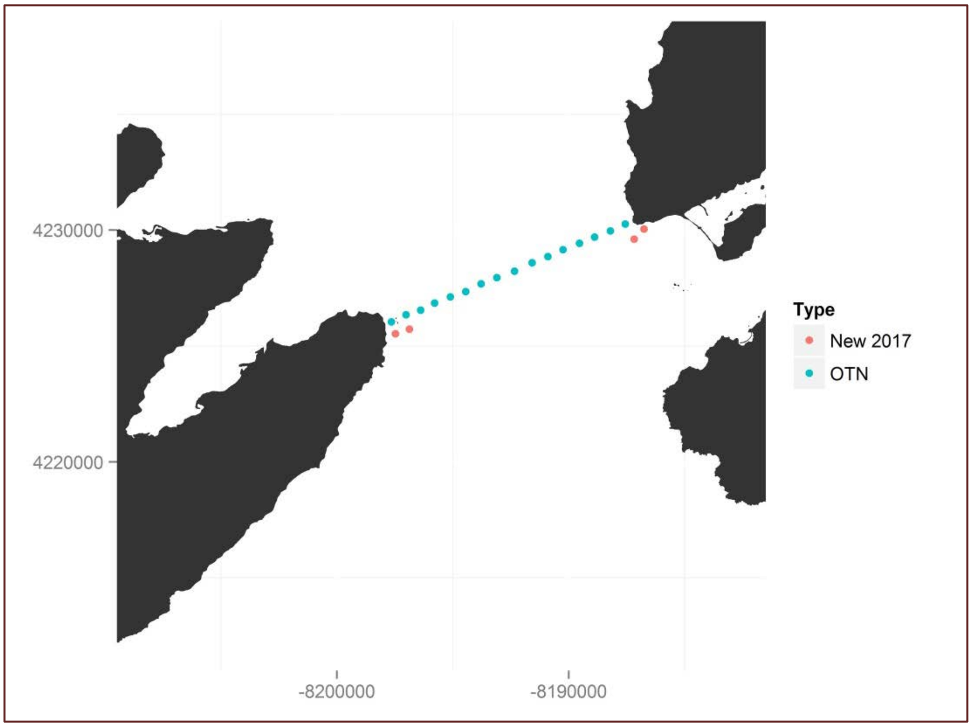

Figure 2. Location of the OTN acoustic array in Hinchinbrook Entrance and proposed locations for receivers to be deployed in January 2017.

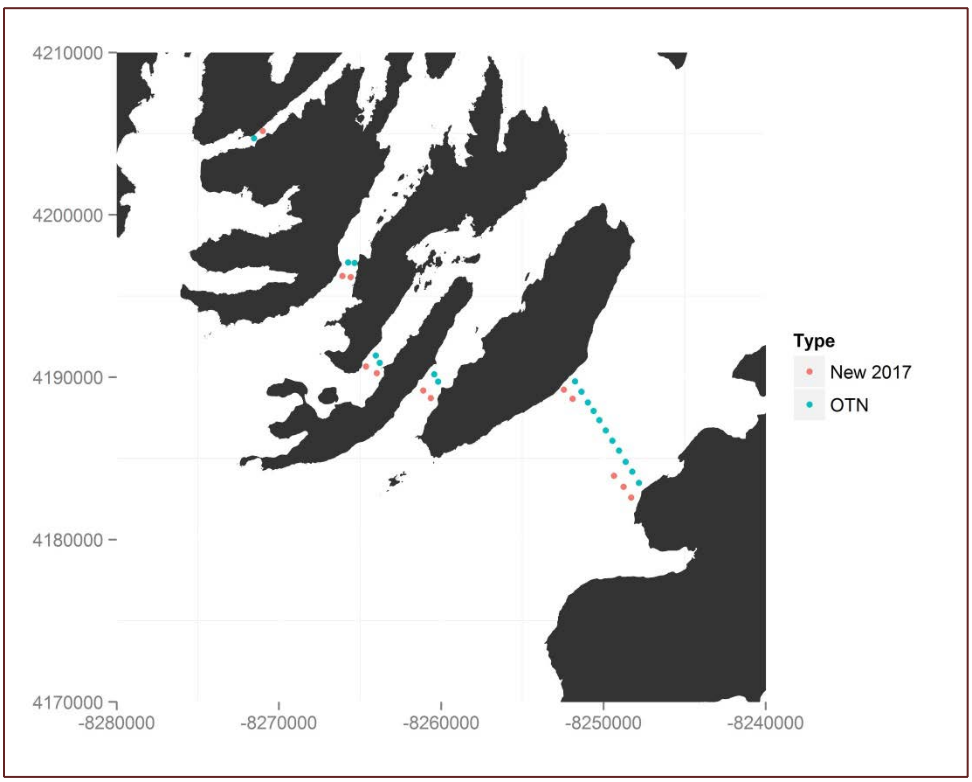

Figure 3. Location of the OTN acoustic array in Montague Strait and the four southwest passages and proposed locations for receivers to be deployed in January 2017.

retrieval at the end of the first year of data collection (May 2018) they can be redeployed at the 2018 tagging site to monitor the 2018 tagging cohort. The feasibility of monitoring multiple spawning sites per year with the available number receivers will be assessed after the first year of data collection.

Because it takes several months from the start of funding to get tags purchased, ordering tags during FY16 will allow us to initiate acoustic tracking studies in 2017 when herring are aggregated on their spring spawning grounds. Herring will be tagged with acoustic transmitters (Model V9-2L, 69 kHz) programmed to transmit at 146 dB every 90-150 seconds with a battery life of approximately 400 days. Each transmitter emits a unique series of pings that can be decoded and recorded if the tagged herring is within the detection range of a receiver. Codes from successfully decoded transmissions are recorded and stored in the receiver memory along with the date and time they were received. Once the receiver is in hand (VR2W receivers) or connection is made with a Teledyne Benthos surface modem (VR4 receivers) a file containing the complete detection records for the duration of deployment can be uploaded.

During spring 2017 (FY17) herring will be captured and tagged in Port Gravina following the methods of Eiler and Bishop (*in review*). Using these methods, 91.4% of tagged fish (N= 94) were subsequently detected in PWS, indicating that measures taken to reduce tagging and handling related stress were successful and post-tagging survival was high (Eiler and Bishop *in review*). Based on the minimum standard length of herring tagged by Eiler and Bishop, the minimum standard length of herring considered for tagging in this study will be 190 mm (age ~3-4 yrs). To address hypotheses related to the relationship between individual biological characteristics and movement and survival, we will ensure that the length distribution of our tagged fish sample is approximately uniform over a wide size range. Specifically, 10-mm length bins ranging from 190 mm to 250 mm (the largest length bin contains fish > 250 mm) will be implemented and each length bin will constitute approximately 14% of the total tagged sample. In addition to standard length, the sex of each tagged herring will be determined and weight (g) data will be collected. Finally, a condition index ($k = weight \cdot length^{-3}$; Slotte, 1999; Kvamme et al., 2003) will be calculated for each tagged herring from individual length and weight data.

C. Data Analysis and Statistical Methods

Hypotheses $\mathbf{H_1}$, $\mathbf{H_2}$, and $\mathbf{H_3}$ pertain to herring survival rates and large scale movement rates and how these rates change seasonally or in relation to individual biological characteristics. Estimates of survival are needed to generate unbiased estimate movement rates; therefore, our ability to estimate survival will affect the quality of our movement rate estimates. Our analytical approach for addressing these hypotheses has two major components: estimating survival using discrete-time multistate Markov models (Lebreton and Pradel 2002) and estimating herring movement with continuous-time multistate Markov models (Miller and Andersen 2008). Survival will be estimated by binning detection data into discrete intervals (Barbour et al. 2013) and analyzing these data using discrete-time multistate Markov models developed using the RMark package (Laake 2013). Binning continuous-time detection data into relatively large discrete time steps is necessary for estimating survival using the well-established methods developed for convention mark-recapture experiments; however, this diminishes the quality of the data collected by fixed acoustic arrays. To efficiently utilize the high-quality data collected by the acoustic arrays, we will use continuous-time Markov models to estimate herring movement rates and fix the survival rate at the value estimated from the discrete time model. In addition to movement rates, we will use the continuous-time model to calculate seasonal mean residency time in the GOA and PWS.

As permanent emigration from the study area cannot be distinguished from mortality, the discrete-time model actually estimates apparent survival; however, apparent survival is equal to the true survival rate if tagged herring do not permanently emigrate from the study area. Herring emigration out of PWS is likely temporary, and based on the spatial coverage of our acoustic array and the extended battery life of our acoustic tags (400 days), we expect the bias in our survival estimates due to permanent emigration from the study area to be low.

Finally, our hypothesis (**H_4**) addressing fine-scale spatial use patterns will be investigated using Brownian bridge movement models (Horne et al. 2007; Pages et al. 2013) and by calculating simple summary statistics for each acoustic receiver.

Survival estimation and power analyses

To address our hypothesis relating to the relationship between individual biological characteristics and survival, we will develop discrete-time multistate Markov models with covariates for size, weight, and condition. A suite of estimation models will be developed and the most parsimonious models will be selected using Akaike's information criterion (AIC) corrected for small sample size bias (AIC*c*) (Burnham and Anderson 2002).

To further support our analytical approach and to determine the sample size needed to generate estimates of herring survival rates, we simulated datasets and conducted a power analysis using our proposed methods to estimate survival. Datasets were generated from a transition intensity matrix with instantaneous transition rates based on estimates from the 2013 pilot project. The instantaneous transition rates describe the movement of herring between states defined by the acoustic arrays. The states that tagged herring could inhabit were: present at an array, undetected in PWS, undetected in the GOA (outside of the entrance arrays), or mortality (Fig. 4). Of these seven states, there are three observable states (one for each array: northeast PWS spawning grounds, inner PWS gate, outer PWS gate), four unobservable states (three undetected states and the mortality state), and 10 instantaneous transition rates based on the spatial configuration of the arrays (Fig. 4).

Survival was assumed to be constant over the duration of the study, while movement rates changed seasonally to describe a herring population that moved towards the entrances after spawning, had a long

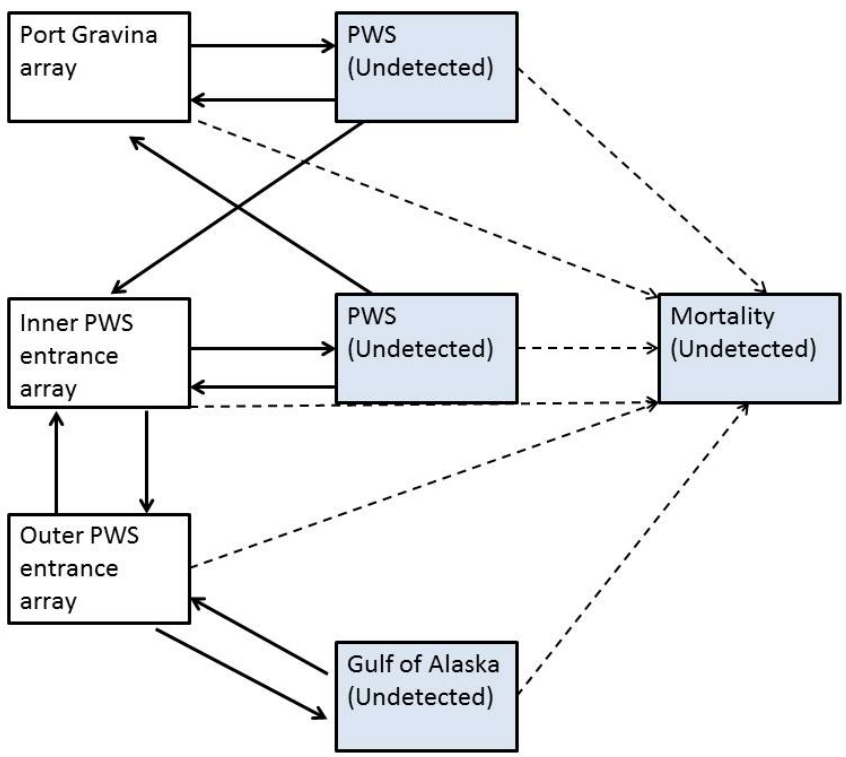

Figure 4. Schematic of the multistate model used to describe herring movements between acoustic arrays (solid line= movement; broken line= mortality).

average residency time in the GOA in the summer, and returned to the spawning area the following spring with high fidelity. Incomplete detection of herring moving through the outer entrance array (detection probability=0.85) was simulated by including an indicator variable for detection at the outer entrance array. The detection indicator variable was populated by a random binomial with a success probability of 0.85. Residency periods at the outer array with a 1 were observed, while residency periods with a 0 were undetected and removed from the dataset.

Additionally, the simulated population had different annual survival rates (S) based on group membership (two groups). Group membership was assumed to be related to length, weight, or body condition and, therefore, would be known to researchers. Two effect sizes, a moderate (S=0.85; S=0.71) or large (S=0.88; S=0.68) difference in annual survival between the two groups, and five sample sizes (60, 80, 100, 120, and 140 herring released with 50% in each group) were considered. During each simulation the data were fit to two models, the full model with two survival rates based on group (the true model) and a reduced model with a single survival rate, and AIC*c* was calculated for each model. For each simulation scenario, 350 datasets were generated and statistics relating to model convergence, model selection, and parameter estimation were recorded. Model section statistics (ΔAIC*c*= AIC*c* full – AIC*c* reduced; percent correct= the percent of simulations where AIC*c* full < AIC*c* reduced) indicate the effect size detected and the probability of selecting the true model. Parameter estimation statistics (percent bias, percent root-mean-square error, 95% CI coverage, and 95% confidence interval half-width) assess the accuracy and precision of the survival estimates (Miller 2015).

The formulas for percent bias and percent RMSE are

1) Percent bias $= 100 * \left(\frac{S_{est} - S_{true}}{S_{true}}\right)$,

2) Percent RMSE $= 100 * \sqrt{\left(\frac{S_{est} - S_{true}}{S_{true}}\right)^2}$,

where S_{est} is the estimated annual survival rate and S_{true} is the true annual survival rate of the simulated population. Finally, percent bias, percent RMSE, and 95% CI half-width values from the 350 simulations were calculated for each simulation (N = 350) and the mean value was reported. This analysis was conducted using R (R Core Team 2014) and the RMark package (Laake 2013).

Model convergence in all simulation scenarios was high (0.95–1.00) and the probability of selecting the correct model using AIC*c* increased as sample size or effect size were increased (Table 1). Using the correct model for inferences, estimates on average tended to minimally underestimate the true survival rate (percent bias ranging from 0.4% to -1.8%), while the accuracy of estimates (measured by percent root-mean-square error) improved as sample size was increased. The coverage of the 95% CI for survival (i.e. the percentage of 95% confidence intervals that contained the true survival rate) was near the expected 95% for all simulation scenarios (91-95%), though the precision of the survival estimate (measured by the 95% CI half-width) increased as sample size was increased (Table 1).

Based on these results, a minimum of 120 herring will be tagged each year. This sample size will likely provide researchers enough statistical power to detect large differences in survival in herring based on measured biological covariates. Additionally, with this sample size we expect survival estimates to be both accurate (percent RMSE<11) and precise (95% CI half-width <0.13).

Our power analysis provides an example of the statistical methodology we propose to use to estimate apparent survival and the feasibility of applying these techniques to PWS Pacific herring stocks. Apparent survival of other species with large home ranges have been estimated from fixed acoustic

Table 1. Power analysis results for survival estimation and model selection using Multistate Markov models. For each simulation scenario consisting of an effect size (moderate or large) and sample size (N=60, 80, 100, 120, or 140), model selection and survival estimation summary statistics were calculated from 350 datasets generated from a simulated herring population.

	Moderate (S_1= 0.85; S_2= 0.71)					Large (S_1= 0.88; S_2= 0.68)				
Sample size	60	80	100	120	140	60	80	100	120	140
Model convergence	94.9	97.4	99.4	99.4	99.7	94.9	97.4	99.4	99.4	99.7
Model selection										
Median ΔAICc	-1.58	-0.47	-0.01	0.73	1.46	-0.14	1.86	2.82	4.73	5.68
Percent correct	29.4	43.8	49.6	58.5	64.9	49.3	69.3	76.0	85.7	89.4
Survival estimation										
Percent bias (S_1)	-0.9	-0.3	-0.6	-0.2	-0.3	-0.5	-0.1	-0.5	-0.2	-0.1
Percent bias (S_2)	-0.6	-0.8	-1.0	-0.7	-1.3	0.4	-1.1	-1.1	-1.8	-1.6
Percent RMSE (S_1)	7.9	7.7	6.6	6.1	5.5	6.7	6.3	5.9	5.1	4.7
Percent RMSE (S_2)	12.2	10.6	9.9	8.3	8.3	13.2	11.3	10.6	10.5	9.1
95%CI coverage (S_1)	94.1	91.1	94.6	92.6	93.1	91.9	92.9	92.2	93.4	93.7
95%CI coverage (S_2)	93.5	95.4	92.6	95.7	94.9	93.4	95.0	93.1	93.4	92.6
95%CI halfwidth (S_1)	0.135	0.117	0.107	0.098	0.091	0.12	0.105	0.097	0.089	0.083
95%CI halfwidth (S_2)	0.171	0.149	0.134	0.122	0.113	0.174	0.153	0.137	0.125	0.116

receiver arrays using discreet-time multistate Markov models, including Gulf sturgeon (*Acipenser oxyrinchus desotoi*; Rudd et al. 2014) and broadnose seven gilled shark (*Notorynchus cepedianus;* Dudgeon et al. 2015); thus, this methodology has also been successfully applied to real ecological datasets.

Movement rate estimation

The rate of herring movement between PWS and the GOA will be modeled using continuous-time multistate Markov models developed with the *msm* package (Jackson 2011) in R. Continuous time Markov models are commonly used in survival analysis in the medical field (Duffy et al. 1995) and have been used in a fisheries context to model Atlantic bluefin tuna (*Thunnus orientalis)* regional migration (Miller and Andersen 2008). Our approach will be to use the multistate model depicted in Figure 4 and estimate the transition rates (solid lines) and fix the survival rate (broken lines) at the estimated rate from the discrete model output. All of the possible transitions between states form a transition intensity matrix Q, such that:

$$Q = \begin{pmatrix} \varphi_{1,1} & \varphi_{1,2} & 0 & 0 & 0 & 0 & \varphi_{1,7} \\ \varphi_{2,1} & \varphi_{2,2} & 0 & \varphi_{2,4} & 0 & 0 & \varphi_{1,7} \\ \varphi_{3,1} & 0 & \varphi_{3,3} & \varphi_{3,4} & 0 & 0 & \varphi_{3,7} \\ 0 & 0 & \varphi_{4,3} & \varphi_{4,4} & \varphi_{4,5} & \varphi_{4,6} & \varphi_{4,7} \\ 0 & 0 & 0 & \varphi_{5,4} & \varphi_{5,5} & \varphi_{5,6} & \varphi_{5,7} \\ 0 & 0 & 0 & \varphi_{6,4} & \varphi_{6,5} & \varphi_{6,6} & \varphi_{6,7} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

where $\varphi_{i,j}$ is the instantaneous transition rate from state *i* to state *j*. The $\varphi_{4,6}$ and $\varphi_{6,4}$ transitions are included to allow for incomplete detection at the outer entrance array (state 5). All rows sum to zero and the probability of remaining in each state (transitions with state *i* = state *j*) is solved by subtraction. All transitions to the mortality state are set to a fixed rate and the remaining 12 transition parameters are estimated via maximum likelihood using the *msm* package (Jackson 2011). Due to incomplete detection at the outer entrance array, censored states need to be included in the analyses. Herring last detected at the inner array either migrated back into PWS (state 3) or moved through the outer array undetected and migrated into the GOA (state 6); thus, these herring are considered to be in a censored state that includes states 3 and 6. Similar to our approach for modeling herring survival, our hypotheses regarding herring movement can be addressed by developing models with covariates relating to time and individual biological characteristics and conducting model selection using AIC*c*.

Seasonal residency time

The estimated mean residency time at a given state can be estimated as -1/*q*, where *q* is one of the diagonal entries in *Q* (i.e. a φ value with state *i* equal to state *j*) (Duffy et al. 1995). If transition rates change seasonally, the corresponding seasonal mean residency times can be calculated. Additionally, we will calculate a residency index for each tagged individual as the proportion of calendar days detected at an array during a season and use this index to describe seasonal habitat usage (Cagua et al. 2015).

Spatial analyses

The multistate Markov model we used to estimate herring movement rates contained the minimum number of spatial states needed to describe large-scale herring movements because these models are “data-hungry” and become unwieldy as the number of states is increased. Therefore, spatially explicit Brownian bridge movement models (BBMM) will be used to investigate fine-scale herring movement patterns. These models are commonly used in wildlife ecology (Horne et al. 2007) and have recently been applied to datasets obtained from fixed acoustic telemetry arrays (Pages et al. 2013). In brief, BBMM estimate the probability of a tagged individual occupying an area over a given time period based on known locations collected at an intervals during that time period. From this output, home range size (km^2) can be estimated and the seasonality of spatial use patterns (e.g., preferentially using Montague Strait over Hinchinbrook Entrance post-spawning) can be examined.

Finally, statistics for individual receivers will be calculated to investigate spatial use patterns. The intensity of habitat use will be measured by calculating total number of detections and total number of individual herring for each receiver. Areas primarily used as corridors will be identified by calculating the ratio between non-consecutive detections (first detection after being detected by another receiver) and total detections (Pages et al. 2013). A non-consecutive detection will be defined as the first detection of an individual at a receiver after previously being detected at a different receiver. A high proportion of non-consecutive detections will indicate the area is primarily used as a corridor. Trends in these receiver-based statistics over time will be examined to investigate seasonal and diurnal trends in spatial usage patterns.

D. Description of Study Area

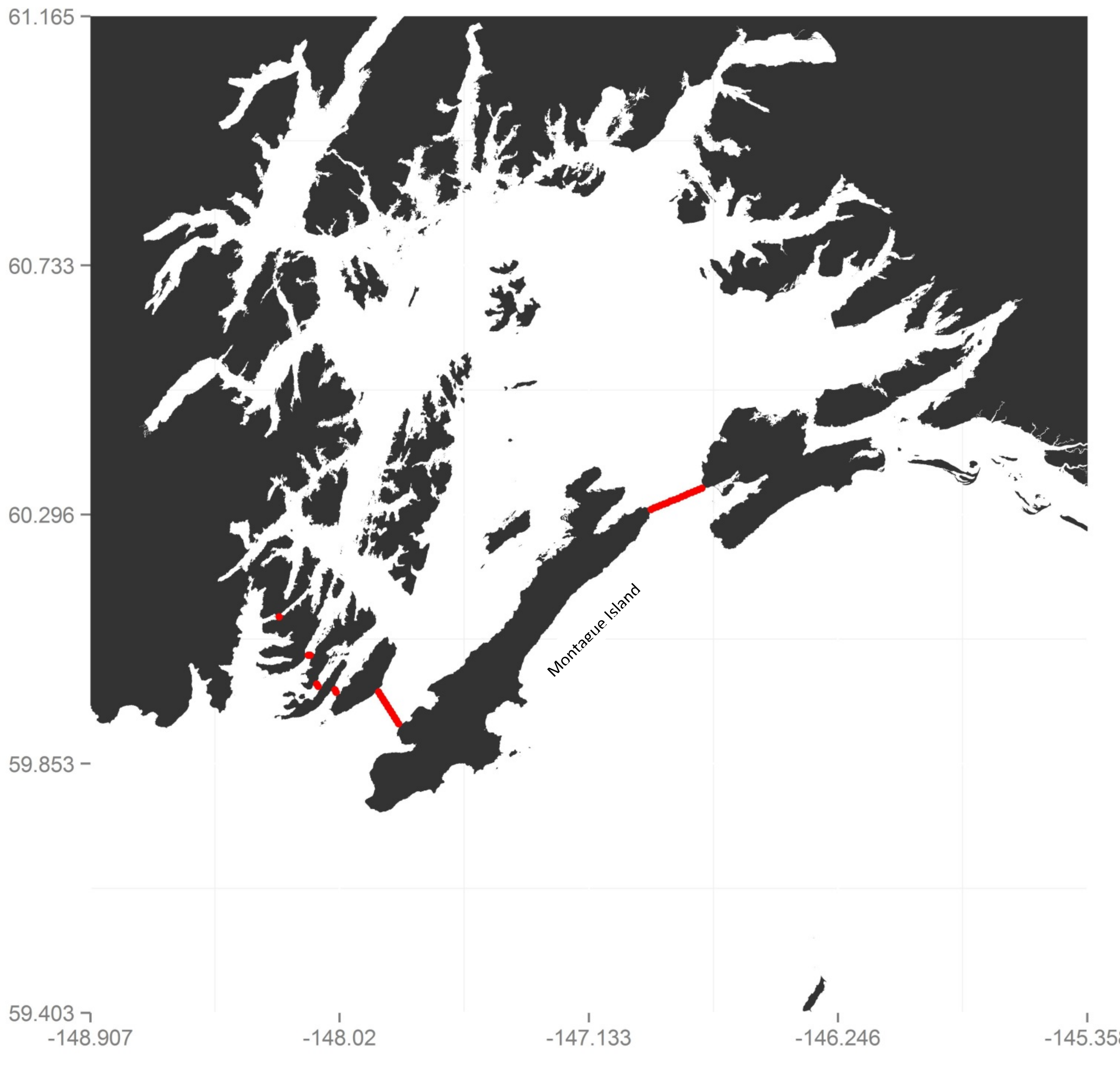

Fig. 5. Prince William Sound, Alaska. Our study will take place around spawning sites in northeast Prince William Sound and northern Montague Island and the Ocean Tracking Network acoustic arrays (noted in red).

IV. SCHEDULE

A. Project Milestones

Objectives 1 and 2 apply to this FY16 project. Objectives 3-5 apply to the next phase of this project (FY17-20).

Objective 1. Purchase and deploy additional receivers around the Ocean Tracking Network arrays.
To be met by January 31, 2017

Objective 2. Purchase acoustic tags.
To be met by January 31, 2017

Objective 3. Document location, timing and direction of Pacific herring seasonal migrations between Prince William Sound and the Gulf of Alaska.
To be met by January 2020

Objective 4. Relate large-scale movements to year class and body condition of tagged individuals.
To be met by January 2020

Objective 5. Determine seasonal residency inside PWS, at the entrances to Prince William Sound, and in the Gulf of Alaska.
To be met by January 2020

B. Measurable Project Tasks for FY 16

Specify, by each quarter of each fiscal year, when critical project tasks (for example, sample collection, data analysis, manuscript submittal, etc.) will be completed. Please format your schedule like the following example:

FY 16, 1st quarter (Feb 1 – Apr 30, 2016)

Apr Purchase acoustic receivers and acoustic release

FY 16, 2nd quarter (May 1-Jul 31, 2016)

Jun-Jul Prepare moorings

FY 16, 3rd quarter (Aug 1- Oct 31, 2016)

Aug Prepare FY17 work plan

FY 16, 4th quarter (Nov 1, 2016 – January 31, 2017)

Nov Order acoustic tags
Jan Deploy receivers at entrances in coordination with Ocean Tracking Network cruise
Jan Alaska Marine Symposium
Jan Submit annual report

V. PROJECT PERSONNEL

Curriculum Vitae

MARY ANNE BISHOP, Ph.D.

Research Ecologist,
Prince William Sound Science Center
300 Breakwater, PO Box 705
Cordova, Alaska 99574
907-424-5800 x 228; mbishop@pwssc.org

EDUCATION

Ph.D. Department of Wildlife and Range Sciences, University of Florida, Gainesville, 1988.
M.S. Wildlife and Fisheries Sciences, Department of Wildlife and Fisheries Sciences, Texas A & M University, College Station, 1984.
B.B.A. School of Business, University of Wisconsin, Madison, 1974.

RECENT PROFESSIONAL EXPERIENCE

Research Ecologist, Prince William Sound Science Center, Cordova, Alaska, Jun 1999-present
Research Wildlife Biologist, Copper River Delta Institute, Pacific Northwest Research Station, U.S. Forest Service, Cordova, Alaska, 1990-1994 and 1997- May1999
Research Wildlife Biologist, Center for Streamside Studies and Dept. Fisheries, University of Washington, assigned to Copper River Delta Institute, Cordova, Alaska, 1994-1997
Acting Manager, Copper River Delta Institute, Pacific Northwest Research Station, U.S. Forest Service, Cordova, Alaska, 1992-1993

SELECTED SCIENTIFIC PUBLICATIONS (10 of 53)

- = publication resulting from either acoustic or radio telemetry study (13 total)

Bishop, M.A., J.T. Watson, K. Kuletz, T. Morgan. 2015. Pacific herring consumption by marine birds during winter in Prince William Sound, Alaska. *Fisheries Oceanography*. 24:1-13.
***Bishop, M.A.**, B.F. Reynolds, S.P. Powers. 2010. An *in situ*, individual-based approach to quantify connectivity of marine fish: ontogenetic movements and residency of lingcod. *PLoS ONE* 5(12): e14267
***Bishop, M.A.**, N. Warnock, and J. Takekawa. 2004. Differential spring migration of male and female Western Sandpipers at interior and coastal stopover sites. *Ardea* 92: 185-196.
Bishop, M.A. and S.P. Green. 2001. Predation on Pacific herring (*Clupea pallasi*) spawn by birds in Prince William Sound, Alaska. *Fisheries Oceanography* 10 (1): 149-158.
***Bishop, M.A.** and N. Warnock. 1998. Migration of Western Sandpipers: links between their Alaskan stopover areas and breeding grounds. *Wilson Bulletin* 110: 457-462.
Dawson, N.M., **M.A. Bishop**, K.J. Kuletz, A.F. Zuur.. 2015. Using ships of opportunity to assess winter habitat associations of seabirds in subarctic coastal Alaska. Northwest Science. 89(2):111-128.
*Eiler, J., and **M.A. Bishop.** Determining the post-spawning movements of Pacific herring, a small pelagic forage fish sensitive to handling, with acoustic telemetry. *Transactions of American Fisheries Society (in review)*
Powers, S.P., **M.A. Bishop**, S. Moffitt, and G.H. Reeves. 2007. Variability in Freshwater, Estuarine and Marine Residence of Sockeye Salmon (*Oncorhynchus nerka*) within the Copper and Bering River Deltas, Alaska. Pages 87-99 in C. A. Woody (ed) *Sockeye salmon evolution, ecology and management*. American Fisheries Society, Symposium 54, Bethesda, MD.
Powers, S.P., **M.A. Bishop**, J.H. Grabowski, and C.H. Peterson. 2002. Intertidal benthic resources of the Copper River Delta, Alaska, USA. *Journal Sea Research* 47: 13-23.
*Reynolds, B.F., S.P. Powers, **M.A. Bishop.** 2010. Application of Acoustic Biotelemetry to Assess Quality of Created Habitats for Rockfish and Lingcod in Prince William Sound, Alaska. *PLoS One* 5(8): e12130.
Zuur, A.F., N. Dawson, **M.A. Bishop**, K. Kuletz, A.A Saveliev and E.N. Ieno. 2012. Two-stage GAMM applied on zero inflated Common Murre density data. Pages 155-188 *in* A.F. Zuur, A.A.Saveliev, E.N. Ieno (eds).

Zero Inflated and Generalized Linear Mixed Models with R. Highland Statistics Ltd, Newburgh, United Kingdom.

PROFESSIONAL COLLABORATIONS

A. Arab (Quanticipate Consulting), J. Buchanan (WDFG), M. Buckhorn (PWSSC), K. Carpenter (CRWP), N. Dawson (PWSSC), J. Eiler (NOAA), R. Heintz (NOAA), N. Hill (MIT), E.N. Ieno (Highland Statistics), J. Johnson (USFWS), K. Kuletz (USFWS), A. Lang (Memorial Univ.), F. Li (Intl. Crane Foundation), B. McCaffrey (USFWS), M. McKinzie (PWSSC), J. Moran (NOAA), T. Morgan (PWSSC), E. Nol (Trent Univ.), W.S. Pegau (OSRI), S. Powers (U. S. Alabama), B. Reynolds (PWSSC), G. Robertson (CA), D. Roby (OSU), J. Runstadler (MIT), A Saveliev (Highland Statistics), S. Senner (Audubon), Y. Suzuki (OSU), A. Taylor (UAA), R. Thorne (PWSSC), D. Tsamchu (Tibet Plateau Institute of Biology, PR China), J. Vollenweider (NOAA), J. Watson (PWSSC), M. Wille (Memorial Univ.), Z. Zuur (Highland Statistics)

VI. BUDGET

A. Budget Spreadsheet (*See Attached*)

B. Sources of Additional Funding

This project uses Dalhousie University's Ocean Tracking Network, a series of acoustic arrays that are in place at Hinchinbrook Entrance, Montague Strait, and 4 smaller southwestern Prince William Sound passages. The value of these Ocean Tracking Network acoustic arrays is estimated at $337,200.
This project also piggy-backs on the annual Ocean Tracking Network maintenance cruise which includes 5d@$3/k day. This EVOS budget only includes an additional 2d ($6k) of charter costs for deploying the new receivers.
For the FY17-20 tagging studies, PWS Science Center will also provide in-kind equipment (9 VR2-W acoustic receivers and 9 acoustic releases and 9 floats) for an array that will be deployed at the tagging site. The value of this equipment is estimated at $63k.

VII. Literature Cited

Barbour, AB, JM Ponciano, & K Lorenzen. 2013. Apparent survival estimation from continuous mark–recapture/resighting data. Methods in Ecology and Evolution 4.9: 846-853.
Bartumeus, F, B Hereu, À López-Sanz, J Romero, & T Alcoverro. 2013. Evaluating a key herbivorous fish as a mobile link: a Brownian bridge approach. Marine Ecology Progress Series 492:199-210.
Brown, ED, J Seitz, BL Norcross, & HP Huntington. 2002. Ecology of herring and other forage fish as recorded by resource users of Prince William Sound and the outer Kenai Peninsula, Alaska. Alaska Fishery Research Bulletin 9(2): 75-101.
Burnham, KP & DR Anderson. 2002. Model selection and multimodel inference: a practical information-theoretic approach. Springer Science & Business Media.
Cagua, EF, JEM Cochran, CA Rohner, CEM Prebble, TH Sinclair-Taylor, SJ Pierce, & ML Berumen. 2015. Acoustic telemetry reveals cryptic residency of whale sharks. Biology letters 11(4): 20150092.
Corten, A. 2002. The role of` ‘conservatism'' in herring migrations. Reviews in Fish Biology and Fisheries 11: 339-361.
Dudgeon, CL, KH Pollock, JM Braccini, JM Semmens, & A Barnett. 2015. Integrating acoustic telemetry into mark–recapture models to improve the precision of apparent survival and abundance estimates. Oecologia 178: 1-12.

Duffy, SW, H-H Chen, L Tabar, & NE Day. 1995. Estimation of mean sojourn time in breast cancer screening using a Markov chain model of both entry to and exit from the preclinical detectable phase. Statistics in medicine 14(14): 1531-1543.

Eiler, J & MA Bishop. Determining the post-spawning movements of Pacific herring, a small pelagic forage fish sensitive to handling, with acoustic telemetry. Transactions of American Fisheries Society (*in review*)

Hay, D & SM McKinnell. 2002. Tagging along: association among individual Pacific herring (Clupea pallasi) revealed by tagging. Canadian Journal of Fisheries and Aquatic Sciences, 59(12), 1960-1968.

Hay, DE & PB McCarter. 1997. Continental shelf area, distribution, abundance and habitat of herring in the North Pacific. Wakefield Fisheries Symposium. Alaska Sea Grant College Program 97-01, pp. 559–572

Hay, DE, KA Rose, J Schweigert, & BA Megrey. 2008. Geographic variation in North Pacific herring populations: Pan-Pacific comparisons and implications for climate change impacts. Progress in Oceanography 77: 233–240.

Heupel, M R, JM Semmens, & AJ Hobday. 2006. Automated acoustic tracking of aquatic animals. Marine and freshwater Research 57:1-13.

Horne, JS, EO Garton, SM Krone, & JS Lewis.2007. Analyzing animal movements using Brownian bridges. Ecology 88(9):2354-2363.

Jackson, CH. 2011. Multi-state models for panel data: the msm package for R. Journal of Statistical Software 38, no. 8 (2011): 1-29.

Kvamme, C, L Nøttestad, A Fernö, OA Misund, A Dommasnes, BE Axelsen, P Dalpadado, & W Melle. 2003. Migration patterns in Norwegian spring-spawning herring: why young fish swim away from the wintering area in late summer. Marine Ecology Progress Series 247:197-210

Laake, JL. 2013. RMark: An R interface for analysis of capture-recapture data with MARK. AFSC Processed Rep 2013-01, 25p. Alaska Fish. Sci. Cent., NOAA, Natl. Mar. Fish. Serv., 7600 Sand Point Way NE, Seattle WA 98115.

Lebreton, J D, & RP Cefe. 2002. Multistate recapture models: modelling incomplete individual histories. Journal of Applied Statistics 29.1-4: 353-369.

Millar, RB. 2015. A better estimator of mortality rate from age-frequency data. Canadian Journal of Fisheries and Aquatic Sciences 72: 364-375.

Miller, TJ, & PK Andersen. 2008. A finite-state continuous-time approach for inferring regional migration and mortality rates from archival tagging and conventional tag-recovery experiments. Biometrics 64.4: 1196-1206.

R Core Team. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL http://www.R-project.org/

Rudd, MB, RNM Ahrens, WE Pine III, & SK. Bolden. 2014. Empirical, spatially explicit natural mortality and movement rate estimates for the threatened Gulf sturgeon (Acipenser oxyrinchus desotoi). Canadian Journal of Fisheries and Aquatic Sciences 71(9): 1407-1417.

Slotte, A. 1999. Effects of fish length and condition on spawning migrations in Norwegian spring spawning herring (Clupea harengus L.). Sarsia 84:111-127.

Tojo, N, GH Kruse, & FC Funk. 2007. Migration dynamics of Pacific herring (Clupea pallasii) and response to spring environmental variability in the southeastern Bering Sea. Deep Sea Research Part II: Topical Studies in Oceanography 54.23: 2832-2848.