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

Non-lethal sampling: In situ estimation of juvenile herring sizes

Exxon Valdez Oil Spill Trustee Council Project 15120111-D
Final Report

Kevin M. Boswell
Aubree M. Zenone

Florida International University
Marine Ecology and Acoustics Laboratory
3000 NE 151st ST
North Miami, FL 33181

W. Scott Pegau

Prince William Sound Science Center
300 Breakwater Ave
Cordova, AK 99574

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Study History:

This study examined non-lethal alternatives to direct capture, such as those used in project 16120111-A to provide information needed for acoustic surveys described in 16120111-E and F. It also provides a means to expand the survey effort into areas that cannot be reached by traditional sampling, such as under ice shelves.

Abstract:

This project examined the use of a remotely operated vehicle to collect species and size information of forage fish. A Seamor Marine remotely operated vehicle with a 300 m fiber optic tether, with an integrated imaging sonar and a live-feed camera with recording capabilities, was used to collect data for this project. Fish species identification was based on the camera images. The imaging sonar was then used to provide information about the forage fish schools, such as the size distribution. The remotely operated vehicle was deployed from the *R/V Auklet* during a series of cruises between the fall of 2013 and spring 2015. The remotely operated vehicle was deployed under ice shelves to examine if juvenile herring were using them as a habitat area. Fish under ice were smaller than those in open water. Fish lengths inferred by the sonar measurements were significantly less than those based on trawls, but the inferred lengths were within the range observed for that age of herring. We were able to distinguish characteristics between schools and bays. We did not observe length stratification within age-0 schools.

Key words: Acoustic, *Clupea pallasii*, DIDSON, hydroacoustic, Pacific herring, Prince William Sound, ROV,

Project Data: *Description of data*: Length measurements of Pacific herring (*Clupea pallasii*) in millimeters from DIDSON imaging sonar is provided as an Excel file.

Data archive and custodians:

Carol Janzen
AOOS, 1007 W. 3rd Ave. #100,
Anchorage, AK 99501
907-644-6703
janzen@aoos.org
https://portal.aoos.org/old/gulf-of-alaska#metadata/36e773dc-39c9-47f7-861f-b9e4f7dcbbb3/project

Scott Pegau
Prince William Sound Science Center, P.O. Box 705
Cordova, AK 99574
wspegau@pwssc.org

There are no limitations on the use of the data, however, it is requested that the authors be cited for any subsequent publications that reference this dataset. It is strongly recommended that careful attention be paid to the contents of the metadata file associated with these data to evaluate data set limitations or intended use.

Citation:

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EXECUTIVE SUMMARY

This project examined the use of a remotely operated vehicle to collect species and size information of forage fish. A Seamor Marine remotely operated vehicle (ROV) with a 300 m fiber optic tether, with an integrated imaging sonar and a live-feed camera with recording capabilities, was used to collect data for this project. Fish species identification was based on the camera images. The imaging sonar was then used to provide information about the forage fish schools, such as the size distribution. The ROV was deployed from the *R/V Auklet* during a series of cruises between the fall of 2013 and spring 2015. The ROV was deployed under ice shelves to examine if juvenile herring were using them as a habitat area. Observations were made concurrent to trawl efforts to examine differences in length. We looked to determine if there was a size stratification within a school. We examined if there were differences in school density were different through a day, among schools, and among bays.

Juvenile herring were found using habitat below the ice. The fish under ice were smaller than those in open water. Fish lengths inferred by the sonar measurements were significantly less than those based on trawls, but the inferred lengths were within the range observed for that age of herring. This may also be a result of the trawls being conducted in more open water, where we observed an increase in size of herring compared to those closer to the edge of the bay or closer to ice. We observed changes in herring characteristics between schools and bays but did not observe length stratification within age-0 schools.

INTRODUCTION

Historically, Prince William Sound (PWS) supported one of the most productive Pacific herring (*Clupea pallasii*) fisheries in the world. Though important both as a species of fisheries interest and as a critical link between primary producers and higher trophic levels, there is still much unknown about their population dynamics following the *Exxon Valdez* Oil Spill. To meet this need, surveys conducted from the Prince William Sound Science Center have provided data to create models assessing yearly recruitment and stock levels throughout the PWS (Alaska Department of Fish and Game). Biological data to support modeling of Pacific herring in the PWS (e.g., abundance, density, and length distributions) have previously been acquired mainly through the use of nets and trawls. These methods are extractive and may be detrimental to herring populations still in recovery from collapse. To limit the effects of direct sampling and offer additional context to the distribution of important prey resources, we examined the use of hydroacoustic technology to supplement direct biological catch data. Hydroacoustic methods were developed to survey and quantify changes in the herring population in a non-invasive manner at a relatively large scale.

A common source of bias in acoustic surveys is proper partitioning of size classes and species composition, and their respective contribution to biomass estimates. This is particularly evident when considering the probability of encountering multiple size classes (or age classes) within a given survey region, or even within a large school. Several approaches have been successful in estimating *in situ* size distributions, though many require appropriate light fields to determine target sizes (Foote and Traynor 1988; Gauthier and Rose 2001; Kloser and Horne 2003). Recent application of imaging sonars have proven useful for acquiring high-resolution measurements of target-length distribution, without the need for ambient or external light sources, thereby reducing the potential of behaviorally mediated bias in length estimation. Further, automated analysis software has been refined to rapidly provide length estimates and target tracking parameters, even for tightly schooling fishes.

OBJECTIVES

The goal of this project was to develop a method that would acquire *in situ* abundance, density, and length distributions of herring in a non-invasive manner. This method was adopted in favor of minimizing the need for intensive direct capture techniques currently employed in during surveys in PWS.

METHODS

Data for the project were collected using a Seamor Marine ROV with a 300 m fiber optic tether, with an integrated DIDSON imaging sonar and a live-feed camera with recording capabilities (Figure 1). The ROV was deployed from the *R/V Auklet* during a series of cruises in the fall of 2013to Spring 2015, in bays targeted by complementary intensive trawling surveys. In several instances, ROV data were collected immediately after a trawling survey, to ground-truth length estimations in the acoustic methods. Upon school detection, the ROV was stabilized to enhance the quality and accuracy of the coupled video-DIDSON data used to derive density and length distributions. ROV lights were used for initial species verification before being turned off, as lights induced an attraction behavior in the herring. A malfunctioning tether resulted in limited data collection in both the Fall 2014 and Spring 2015 surveys. The DIDSON was effective at providing *in situ* estimates of both herring length distributions and density within the ensonified volume.

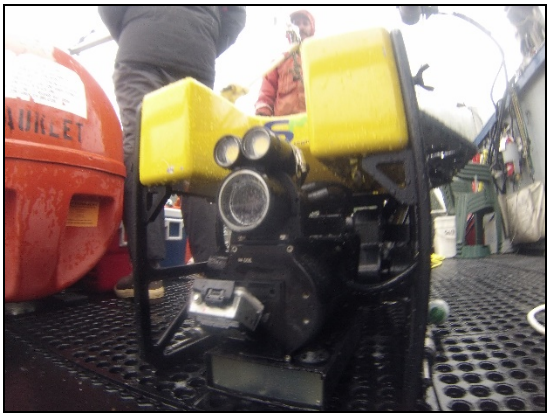

Figure 1. Seamor ROV with DIDSON imaging Sonar, live-feed camera, and Go-Pro.

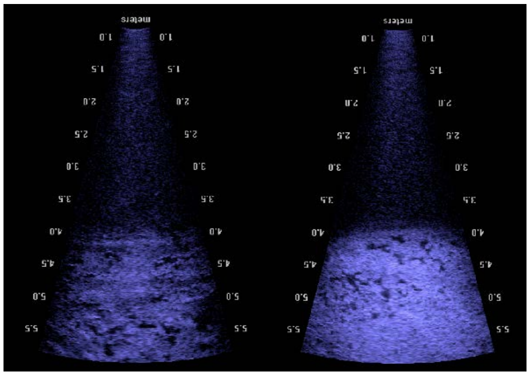

Figure 2. DIDSON images illustrating instances of ocean bottom and ice entering the DIDSON view, precluding accurate volume estimation.

Post-processing of acoustic data were completed in the acoustic analysis software Echoview (Version 6; Myriax Ltd). School densities were derived from the estimated nominal beam volume approximated as a 14°x 28° rectangular prism, and the number of single target detections per ping. The Multibeam Target Detection Algorithm was tuned to link target clusters, with a seed threshold of 5 cm^2, satellite threshold of 3 cm^2, and link distance of 1 cm. For length estimations, fish track detection algorithms were tuned to accept only the highest quality target tracks, such that a minimum number of 6 single target detections, across a minimum 6 pings, with a maximum gap of 3 pings between single targets. Given that fish length estimated with the DIDSON is dependent upon the orientation of a target to the sonar, the data were first manually filtered following an alpha-beta track detection algorithm tuned to only accept targets that were orthogonal to the transducer face to be measured for length (Figure 3). Fish density estimates were also derived with the alpha-beta track detection algorithm, however the criteria were less restrictive to ensure all detected targets could be enumerated. Here the algorithm was tuned to accept a minimum number of 3 single targets in a track, 3 pings in a track, with a maximum gap of 5 pings between single targets. Schools encountered with either ice or bottom present in the sonar data were excluded, as the volume of the beam occupied with these features could both be determined (Figure 2). School densities were calculated using a constant total beam volume of the DIDSON (A 14°x 28° rectangular prism), and average densities were found by initializing fish counts when a total of five fish were detected at once, and ending 5 seconds after zero fish were detected in the DIDSON. Using this method, frames containing few to no fish were included in the average

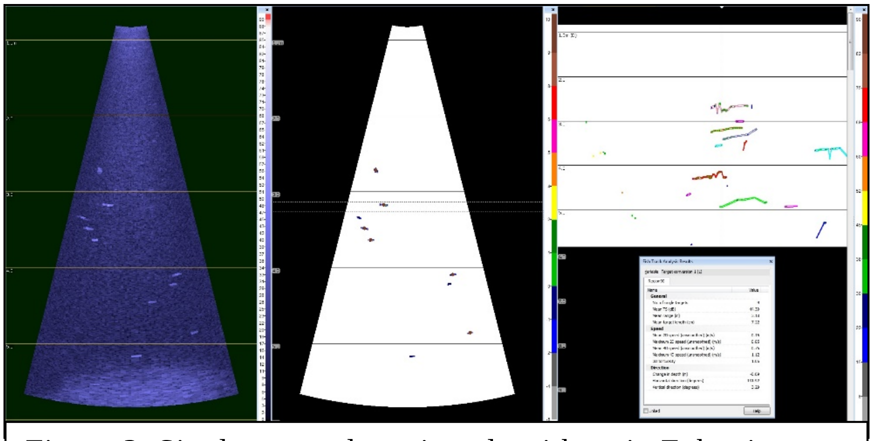

Figure 3. Single target detection algorithms in Echoview software allow for automated isolation of herring from DIDSON data (left). Length estimations are then derived from single target detections (right).

Direct comparisons of length were then made between DIDSON detected fishes, and those captured by trawling efforts. To test for differences, a rank-sum test was used on both methods of length estimation. All statistical analyses were conducted in the statistical programming environment R (CRAN project, 2015).

The ROV was used to examine the potential vertical stratification of varying length classes within individual schools. Upon detection of a herring school, the ROV was slowly descended vertically through the school, while the DIDSON view collected data horizontally through the school to quantify fish size. During the post-processing stage, minimum, median, and maximum school depths were chosen, and 30 random, high quality single targets from each depth were selected for manual measurement in Echoview. Differences among within-school single targets as a function of depth were evaluated using a one-way ANOVA ($\alpha = 0.05$).

Data were collected throughout several targeted bays to examine variation in herring school densities, lengths, and school abundance during the Spring 2014 survey period. Beartrap Bay was surveyed in the afternoon, at night, and in the morning surrounding the crepuscular periods. Simpson Bay was surveyed at night upon arrival, and in the morning before departure. Average lengths were measured across all school events in each survey. Schooling events were considered to begin when five individuals or more were encountered simultaneously in the sonar record. The event was noted to end following five seconds after no fish detection. Finally, data were collected in both trawl and DIDSON efforts prior to and after an ice break-up event (Figure 4). Anecdotal data (Pegau, 2013) suggest that age-0 herring may utilize ice cover as protection from predators. Length estimates were used as an indicator of age class to determine if fishes were spatially redistributing after the loss of ice cover and were tested for differences using a Kruskal-Wallis one-way ANOVA on ranks (α = 0.05).

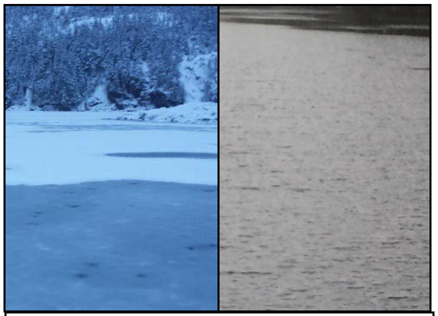

Figure 4. Cruise coincided with an ice breakup event, allowing for an immediate survey of herring that may have been utilizing ice as cover.

RESULTS

Trawling efforts during surveys in which DIDSON surveys occurred were available captured a total of 329 herring, while DIDSON data collected in close proximity to trawling efforts detected a total of 1,270 unique herring. For the most accurate comparison of length estimations, a subset of the data containing only young of the year (YOY) individuals were used. Trawl caught herring had a significantly higher average length of 7.6 ± 0.1 cm when compared to DIDSON detected herring that had an average length of 6.7 ± 0.1 cm (Figure 5; $P < 0.001$). Herring lengths were not corrected based on range bias (Burwen et al., 2010).

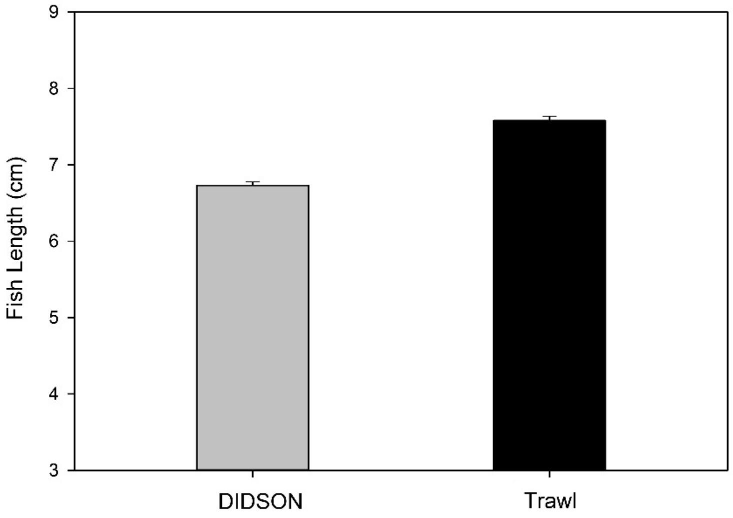

Figure 5. Average lengths measured by trawling efforts and estimated by DIDSON detections during 2014 surveys. Error bars represent +1 standard error.

Average herring length in Beartrap Bay surveyed in the afternoon was 11.4 ± 2.3 cm, 10.4 ± 1.5 cm at night, and 11.5 ± 1.8 in the morning. Herring within-school densities ranged from 1.2 fish/m^3 in the afternoon, dropping to 0.4 fish/m^3 at night, and 0.4 fish/m^3 in the morning. Within-school densities in the afternoon at Beartrap were higher than subsequent survey times on station, however they were excluded from further analysis as there was no comparative analog in Simpson Bay. Simpson Bay herring lengths were measured at 12.2 ± 1.5 cm during the night survey, and 12.3 ± 1.9 during the morning survey. Within-school densities in the bay were higher than those in Beartrap Bay, ranging from 2.6 fish/m^3 in the night survey, to 3.5 fish/m^3 in the morning survey (Table 1).

Survey	Average length (cm)	Average density (fish/m^3)	School Events
Beartrap Bay Afternoon	11.4 ± 2.3	1.2	2
Beartrap Bay Night	10.4 ± 1.5	0.4	20
Beartrap Bay Morning	11.5 ± 1.8	0.4	23
Simpson Bay Night	12.2 ± 1.5	2.6	3
Simpson Bay Morning	12.3 ± 1.9	3.5	10

Table 1. Average herring length (mean ±1 SE) and density estimated from detected schools encountered in the spring 2014 survey.

Herring school density during the morning and night periods at each bay were compared to examine possible differences in habitat utilization. Histograms of each survey density were plotted against each other to visualize potential differences detected by the DIDSON (Figure 6).

The analysis indicated that there may be differences in density estimates between each bay, and perhaps also between survey times. Each bay was individually examined for the role of survey time on the density estimates of individual schools. Beartrap Bay exhibited significant differences in density estimates based on time of day, with individual schooling events having higher densities in the morning than their night time counterparts (*P* = 0.0006; Figure 7). Time was excluded as a factor when examining school densities in Simpson Bay as a result of too few observations.

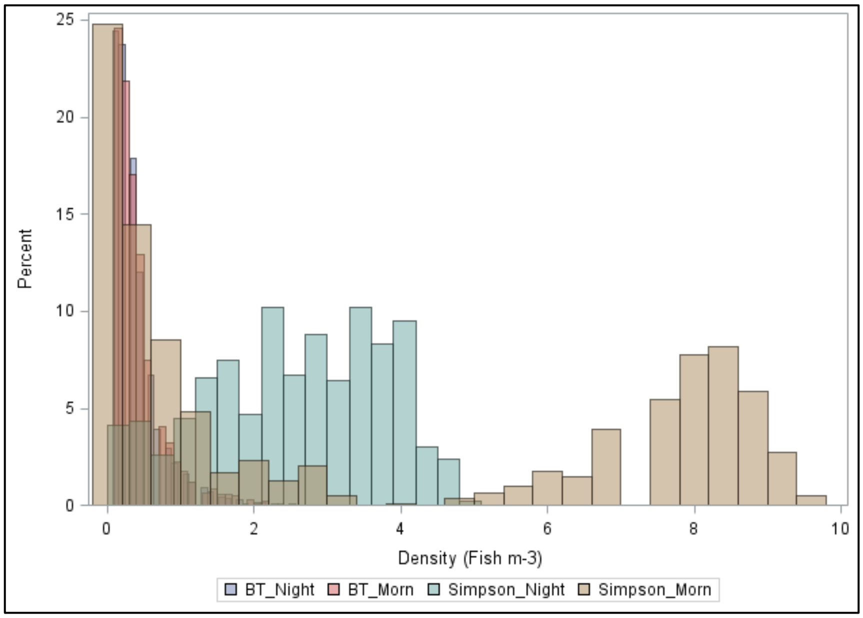

Figure 6. Histogram of within-school herring density. estimates between bays and times of day.

Randomly chosen schools of herring encountered in the November 2014 surveys were used to detect within-school length differences. Randomly selected herring targets were averaged, similar lengths were found at the minimum depth of the school (7.8 ± 1.3 cm), the middle of the school (7.7 ± 1.0), and the maximum depth of the school (8.1 ± 1.3 cm). Results of a one-way ANOVA show that there is no particular layer within a school containing either larger or smaller herring than another layer (Figure 8; n = 90, *P* = 0.512).

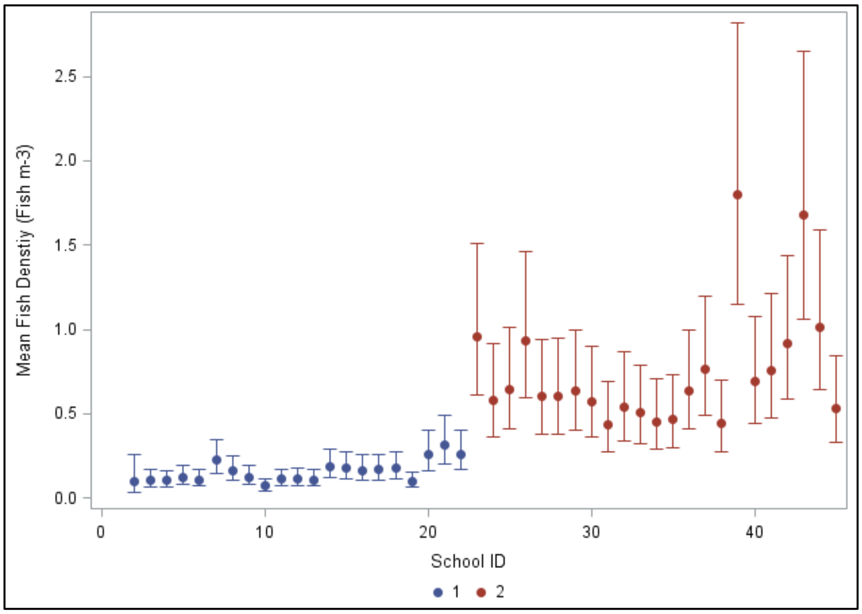

Figure 7. Each schooling event was measured for density and examined for difference is estimates as a function of time. Bars represent ±1 SE. Blue = night, Red=morning.

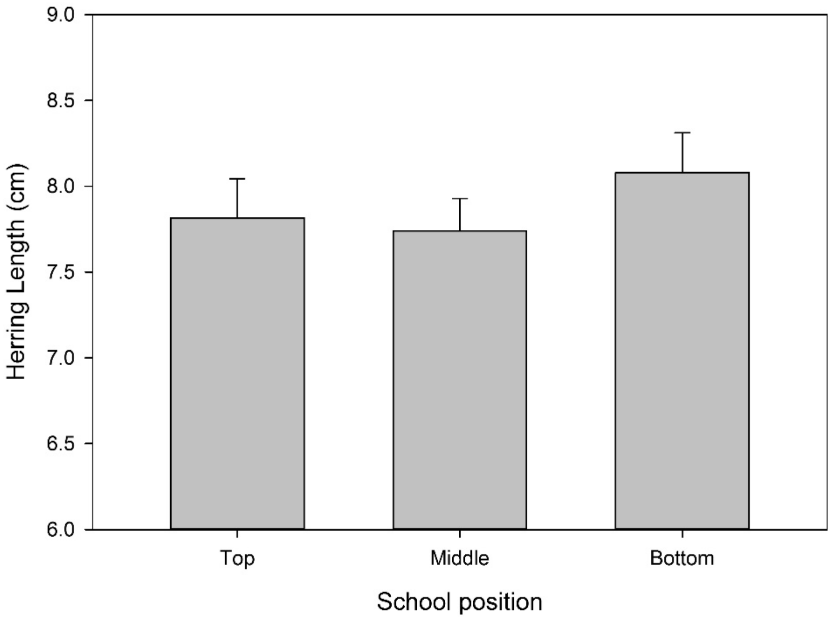

Figure 8. Average lengths of herring within a single school in Simpson Bay detected by DIDSON ROV surveys. Error bars indicate +1 SE.

Trawl data in Simpson bay were collected both prior to (14.1 ± 1.5 cm), and after (13.2 ± 2.0 cm) an ice breakup event. DIDSON data were similarly collected on the same transect both before (12.3 ± 12.3 cm), and after loss of ice cover (11.7 ± 1.2 cm; Figure 9). Length estimates were significantly different from each other (*P* < 0.001), though within the average lengths of a single age class according to historic trawl data (14.4 ± 2.1 cm; PWSSC Intensive Trawl data, 2014).

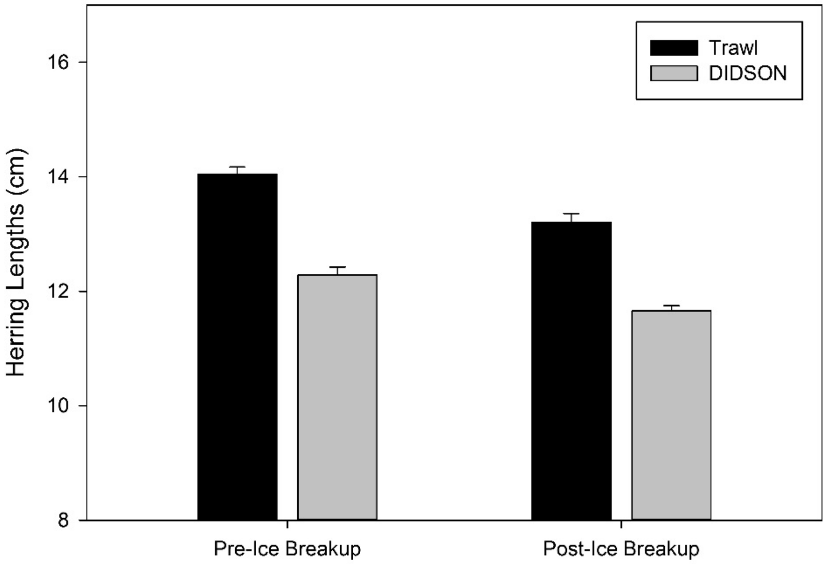

Figure 9. Length estimates by trawl and DIDSON efforts showing similar lengths both pre and post ice cover loss in the head of Simpson Bay. Error bars indicate +1 SE.

DISCUSSION

A primary goal in this project was to examine the potential of utilizing non-invasive survey techniques to acquire in situ abundance, density, and length distributions of herring in the PWS. First, it was necessary to examine the effectiveness of a DIDSON at estimating in-situ herring lengths. We examined the direct comparisons of automated length estimations of herring with trawling data. Our surveys indicate that there is a systemic underestimation of herring length in DIDSON data as compared to trawl data (Burwen et al. 2010). However, these estimated shorter lengths from DIDSON data are still within the confidence intervals of average lengths of specific age-class herring, verified by trawling data. Recent trawl data from the PWS show that YOY herring have a mean length of 8.3 ± 1.6 cm, while DIDSON data estimated them to be 6.7 ± 0.1 cm. Further, trawl data indicate that juvenile herring had a mean length of 14.4 ± 2.1 cm, while the DIDSON data estimated their lengths in a range from 10.4 ± 1.5 cm to 12.3 ± 1.9 cm depending on the bay and school (Table 1; PWSSC Validated Trawl Data, 2014). Further verification lies in previous tests on estimating lengths of targets in a testing pool, where the DIDSON was shown to be effective in differentiating targets with lengths that were different by only several centimeters (Zenone unpbl, 2014). It is likely, then, that length observations from spring and fall surveys were derived from fish of the same cohort, allowing for potential age-class discrimination using non-invasive methodology.

Our surveys were able to describe differences in herring school morphometrics between Beartrap and Simpson Bays. We further identified distinct temporal differences in herring schooling behavior as a function of school density. Data show that herring schools encountered in the morning are significantly denser than their afternoon and evening counterparts. This is indicative of crepuscular and night time foraging behavior exhibited by the herring, resulting in looser aggregations as fish display foraging behavior. Beartrap Bay was the only bay that showed a pattern of decreasing school densities from night to morning. This reversed trend may be explained by a lack of consistent effort among surveys to detect herring schools, as more time was spent in the afternoon in Beartrap searching than later in the evening (Table 1). It should also be noted that these analyses utilized single target detections in each ping to determine an average estimate of density over the entire school. This may result in auto-correlation due to individual fish contributing to density estimates multiple times within each school. To improve upon this, it would be useful to attempt enumeration of each individual in the DIDSON by using fish tracking algorithms that follow a single fish throughout its entire presence in the sonar beam. This is a very tedious and time consuming process, however, particularly for large datasets. Future studies should also incorporate survey methodologies that allow for in depth examination of density differences among herring schools as a function of standardized effort.

Although school encounter rates in Simpson Bay were low, herring densities were highest. This is in agreement with recent trawl data that indicate Simpson Bay to be the major contributor to herring biomass in sites targeted by the yearly herring intensive survey. Additional effort placed on examining the potential contributions to increasing density and biomass within this bay would offer important context to the drivers of the disproportionate herring abundance within Simpson Bay. Finally, school densities were calculated using a constant total beam volume of the DIDSON (A 14°x 28° rectangular prism), and average densities were found by initializing fish counts when a total of five fish were detected at once, and ending 5 seconds after zero fish were detected in the DIDSON. Using this method, frames containing few to no fish were included in the average, driving fish densities below 5 fish/m^3. This method resulted in comparable densities between bays but future studies wishing to obtain accurate density counts should exclude beam volume that does not contain fish.

Other trends, though not significant, were observed within the datasets examined. There existed a trend that fish of different size classes were observed to be utilizing disparate microhabitats within each bay. Smaller herring congregated directly under and near the ice edge, while larger size classes were more commonly encountered in deeper waters. To explore these trends, we recommend a survey design that includes an equal effort spent near ice, bottom, and in pelagic areas of a survey site. Future data collection and analysis is necessary to elucidate any potential habitat utilization patterns as a function of age class.

It has previously been noted that herring schools may be vertically stratified within a school based upon length, or age-class. Given that current acoustic survey analyses assume a single age of encountered schools, this assumption may result in the over or underestimation of herring in a school that is stratified. To examine this potential source of error, the DIDSON and ROV were lowered slowly through the entirety of a herring school distributed within the water column. Targeted schools were divided into upper, middle, and lower layers, while targets of high quality for length estimation in each layer were randomly selected and manually measured. Our data indicate that the herring schools encountered during the spring and fall surveys are homogenous, with little variance in average fish length between school layers. Schools encountered ranged from YOY to juveniles, and it has been proposed that adult schools exhibit far greater length variation than younger cohorts. Further work may be necessary to examine our detected lack of length stratification in adult herring schools as opposed to the YOY and juvenile schools surveyed here.

Finally, personal observations led to a hypothesis that younger fish utilize ice shelves in the heads of PWS bays as protection from predation events, while adults tend towards deeper habitats. While surveying under-ice herring, an ice-break event occurred and ice cover was lost. We examined surveys prior to, and after, the ice-break event in the interest of detecting length changes as juvenile herring shift from using ice as cover to potentially different areas. Our data show significantly different lengths in the trawl data and DIDSON data both prior to, and after the ice-break event. However, these lengths are still within the average ranges of a juvenile herring as recorded by trawl data. This would indicate that fish of the juvenile age class are not leaving an area or relocating simply due to loss of ice cover and may perhaps instead depend on other environmental criteria to exhibit dispersal behavior.

Further work to advance the non-lethal sampling of herring in PWS can also aid in the systemic improvement of acoustic data collection during herring intensives. Previous efforts from the PWS Herring Survey Program have attempted to utilize nets and trawls in conjunction with acoustic surveys as a method of ground-truthing data output from acoustic systems, however there have been noted issues with timely net deployment and mesh sizes which exclude a range of size classes. Original plans included using the DIDSON and ROV to attempt to directly observe herring missed by trawling efforts; however, the failure of the ROV on the latest two cruises resulted in the abandonment of this idea. Future work may wish to follow through on this idea and allow for increased confidence in the validity of non-invasive survey methodology.

ACKNOWLEDGEMENTS

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