

Strait of Georgia Juvenile Pacific Herring Survey, September 2019

Matthew Thompson, Jennifer L. Boldt, Hilari Dennis-Bohm, Matthew H. Grinnell

Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
Nanaimo, BC
V9T 6N7

2022

**Canadian Manuscript Report of
Fisheries and Aquatic Sciences 3202**



Fisheries and Oceans
Canada

Pêches et Océans
Canada

Canada

Canadian Manuscript Report of Fisheries and Aquatic Sciences

Manuscript reports contain scientific and technical information that contributes to existing knowledge but which deals with national or regional problems. Distribution is restricted to institutions or individuals located in particular regions of Canada. However, no restriction is placed on subject matter, and the series reflects the broad interests and policies of Fisheries and Oceans Canada, namely, fisheries and aquatic sciences.

Manuscript reports may be cited as full publications. The correct citation appears above the abstract of each report. Each report is abstracted in the data base *Aquatic Sciences and Fisheries Abstracts*.

Manuscript reports are produced regionally but are numbered nationally. Requests for individual reports will be filled by the issuing establishment listed on the front cover and title page.

Numbers 1-900 in this series were issued as Manuscript Reports (Biological Series) of the Biological Board of Canada, and subsequent to 1937 when the name of the Board was changed by Act of Parliament, as Manuscript Reports (Biological Series) of the Fisheries Research Board of Canada. Numbers 1426 - 1550 were issued as Department of Fisheries and Environment, Fisheries and Marine Service Manuscript Reports. The current series name was changed with report number 1551.

Rapport manuscrit canadien des sciences halieutiques et aquatiques

Les rapports manuscrits contiennent des renseignements scientifiques et techniques qui constituent une contribution aux connaissances actuelles, mais qui traitent de problèmes nationaux ou régionaux. La distribution en est limitée aux organismes et aux personnes de régions particulières du Canada. Il n'y a aucune restriction quant au sujet; de fait, la série reflète la vaste gamme des intérêts et des politiques de Pêches et Océans Canada, c'est-à-dire les sciences halieutiques et aquatiques.

Les rapports manuscrits peuvent être cités comme des publications à part entière. Le titre exact figure au-dessus du résumé de chaque rapport. Les rapports manuscrits sont résumés dans la base de données *Résumés des sciences aquatiques et halieutiques*.

Les rapports manuscrits sont produits à l'échelon régional, mais numérotés à l'échelon national. Les demandes de rapports seront satisfaites par l'établissement auteur dont le nom figure sur la couverture et la page du titre.

Les numéros 1 à 900 de cette série ont été publiés à titre de Manuscrits (série biologique) de l'Office de biologie du Canada, et après le changement de la désignation de cet organisme par décret du Parlement, en 1937, ont été classés comme Manuscrits (série biologique) de l'Office des recherches sur les pêcheries du Canada. Les numéros 901 à 1425 ont été publiés à titre de Rapports manuscrits de l'Office des recherches sur les pêcheries du Canada. Les numéros 1426 à 1550 sont parus à titre de Rapports manuscrits du Service des pêches et de la mer, ministère des Pêches et de l'Environnement. Le nom actuel de la série a été établi lors de la parution du numéro 1551.

Canadian Manuscript Report of
Fisheries and Aquatic Sciences 3202

2022

STRAIT OF GEORGIA JUVENILE PACIFIC HERRING SURVEY,
SEPTEMBER 2019

by

Matthew Thompson, Jennifer L. Boldt, Hilari Dennis-Bohm and Matthew H.
Grinnell

Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
Nanaimo, British Columbia
V9T 6N7

© Her Majesty the Queen in Right of Canada, 2022

Cat. No. Fs 97-4/3202E-PDF ISBN 978-0-660-35591-7 ISSN 1488-5387

Correct citation for this publication:

Thompson, M., Boldt, J.L., Dennis-Bohm, H., and Grinnell, M. H. 2022. Strait of Georgia juvenile Pacific Herring survey, September 2019. Can. Manuscr. Rep. Fish. Aquat. Sci. 3202: vi + 44 p.

TABLE OF CONTENTS

LIST OF FIGURES.....	iii
LIST OF TABLES	iii
APPENDIX 1 LIST OF FIGURES AND TABLES	iv
APPENDIX 2 LIST OF FIGURES AND TABLES	v
ABSTRACT	vi
RÉSUMÉ.....	vi
INTRODUCTION.....	1
METHODS.....	1
RESULTS.....	4
CONCLUSIONS.....	5
ACKNOWLEDGMENTS.....	5
REFERENCES.....	5
APPENDIX 1	32
APPENDIX 2	37

LIST OF FIGURES

Figure 1. The five major British Columbia Pacific Herring stock assessment areas	7
Figure 2. Purse seine set locations for the 2019 Strait of Georgia juvenile Pacific Herring survey.....	8
Figure 3. Plankton and CTD stations for 2019 Strait of Georgia juvenile Pacific Herring survey	9
Figure 4. Length-frequency distribution for all Pacific Herring sampled during the 2019 Strait of Georgia juvenile Pacific Herring survey.....	10
Figure 5. Length-frequency histograms of juvenile Pacific Herring by transect location for the 2019 Strait of Georgia juvenile Pacific Herring survey.....	11
Figure 6. Non-transformed (A) and double log-transformed (B) length-weight relationships for all Pacific Herring sampled during the 2019 Strait of Georgia juvenile Pacific Herring survey.....	12
Figure 7. Average proportion zooplankton densities in oblique and vertical bongo tows from the 2019 Strait of Georgia juvenile Pacific Herring survey (only major zooplankton taxonomic groups are shown in the legend; see Tables 5 and 6 for acronym definitions).....	13

LIST OF TABLES

Table 1. Summary of the purse seine set locations from the 2019 Strait of Georgia

juvenile Pacific Herring survey	14
Table 2. Summary of the number and weight by species, transect, and station for 2019 Strait of Georgia juvenile Pacific Herring survey	15
Table 3. Percent occurrence by species in purse seine sets for the Strait of Georgia juvenile Pacific Herring survey in 2019	19
Table 4. Summary of the number of fish sampled, range of length, mean length, range of weight, mean weight, and standard deviations for three Pacific Herring age classes. Total catch in numbers (N) and weight (Wt) of all Pacific Herring by transect for 2019.....	20
Table 5. Grouping of organisms, by phylum with abbreviations from the 2019 plankton tows from the Strait of Georgia juvenile Pacific Herring survey	22
Table 6. Abbreviations for calanoid and cyclopoid copepods identified in the 2019 zooplankton samples from the Strait of Georgia juvenile Pacific Herring survey....	23
Table 7. Volume of water filtered and number of zooplankton per m ³ of water in oblique tow samples collected during the 2019 Strait of Georgia juvenile Pacific Herring survey. Species codes as shown in Tables 5 and 6.	24
Table 8. Volume of water filtered and number of zooplankton per m ³ of water in vertical tow samples collected during the 2019 Strait of Georgia juvenile Pacific Herring survey. Species codes as shown in Tables 5 and 6.	28

APPENDIX 1 LIST OF FIGURES AND TABLES

Figure 1.1. Estimates of catch weight (kg), catch weight-per-unit-effort (weight CPUE; g/m ²), abundance, and abundance CPUE (number/m ²) of age-0 Pacific Herring caught in the Strait of Georgia juvenile Pacific Herring survey at core transects and stations during 1992-2019 (no survey in 1995). Estimates were calculated using a two-stage method (see Boldt et al. 2015). Estimates of CPUE were calculated by dividing catch weight (or abundance) by the area fished by the net (assuming the net length changed in 2002 from 220 m to 183 m; see Boldt et al. 2015 for details). Standard error bars (using the Thompson 1992 variance estimator) are shown..	33
Figure 1.2. Box plots of age-0 Pacific Herring standard lengths (mm; top panel) and weights (g; middle panel), and bar plot of condition (residuals from a double-log-transformed length weight regression; bottom panel), as measured in the laboratory during 1992-2019 (no survey in 1995). Standard error bars are shown.	34
Table 1.1. Mean catch weight (g), catch weight per unit effort (CPUE; g/m ²), abundance, abundance CPUE (number/m ²), standard error (SE), and coefficient of variation	

(CV) of age-0 Pacific Herring caught in the Strait of Georgia juvenile Pacific Herring survey at core transects and stations during 1992-2019 (no survey in 1995). Two-stage sampling formulae (Thompson 1992) were used to calculate the mean and variance.....35

APPENDIX 2 LIST OF FIGURES AND TABLES

Table 2.1. Number of Strait of Georgia age-0 Pacific Herring energy density samples processed per year, 2012-2019. Generally, where possible, 10 individual fish per transect were sampled.	39
Figure 2.1. Average standard length (mm), wet weight (g), dry weight (g), and percent dry weight of age-0 Pacific Herring from the Strait of Georgia collected for energy density analysis, 2012- 2019. Standard error bars are shown.....	40
Figure 2.2. Average energy density and average energy density weighted by catch per unit effort (CPUE) for age-0 Pacific Herring in Strait of Georgia, 2012-2019. Standard error bars are shown.....	41
Figure 2.3. Energy density as a function of standard length (mm), wet weight (g), dry weight (g), percent dry weight, and condition of age-0 Pacific Herring samples collected in the Strait of Georgia for calorimetry analysis. Linear regression lines (solid lines) are shown and grey shaded areas represent the standard errors.	42
Figure 2.4. Estimate of age-2 Pacific Herring recruit abundance estimates (2014-2020) (stock assessment maximum posterior density values; DFO 2021) lagged by two years plotted as a function of average age-0 Pacific Herring energy density (top panel) and age-0 Pacific Herring energy density weighted by catch per unit effort (bottom panel) (2012-2018), in the Strait of Georgia. Labels show years of age-0 Pacific Herring energy density samples and year of recruitment two years later.	43

ABSTRACT

Thompson, M., Boldt, J.L., Dennis-Bohm, H., and Grinnell, M. H. 2022. Strait of Georgia juvenile Pacific Herring survey, September 2019. Can. Manuscr. Rep. Fish. Aquat. Sci. 3202: vi + 44 p.

A fall juvenile Pacific Herring survey of the Strait of Georgia took place September 9th to 24th, 2019. This survey addresses several questions on early Pacific Herring survival, abundance, recruitment and trophodynamics. Thirty-four core stations were sampled throughout the Strait of Georgia on the ten core transects that have been sampled since 1990. The survey area extends from Trincomali Channel in the south to Smelt Bay in the north. Zooplankton and physical environmental data were also collected in the study area.

RÉSUMÉ

Thompson, M., Boldt, J.L., Dennis-Bohm, H., and Grinnell, M. H. 2021. Strait of Georgia juvenile Pacific Herring survey, September 2019. Can. Manuscr. Rep. Fish. Aquat. Sci. 3202: vi + 44 p.

Un relevé automnal du Hareng du Pacifique juvénile dans le détroit de Georgie a été réalisé entre le 9 et le 24 septembre 2019. Ce relevé visait à répondre à plusieurs questions sur la survie, l'abondance, le recrutement et la trophodynamique du Hareng du Pacifique durant les premiers stades de son développement. Les 34 stations situées dans le détroit de Georgie ont été échantillonnées en à les 10 transects principaux qui font l'objet d'un échantillonnage depuis 1990. La zone du relevé s'étend du chenal Trincomali au sud jusqu'à Smelt Bay au nord. Des données sur le zooplancton et l'environnement physique ont également été recueillies dans la zone d'étude.

INTRODUCTION

Pacific Herring (*Clupea pallasii*) are an important commercial fish and a vital forage species for many marine mammals, birds, and fish in British Columbia's coastal waters. Pacific Herring (hereafter referred to as herring) spawn principally on marine vegetation in the subtidal and upper intertidal zone between February and June, with peak spawning between March and April (Humphreys and Hourston 1978). Larvae hatch after two to three weeks, and disperse with surface currents, metamorphosing into juvenile or young-of-the-year herring at a length of ~25mm (Hourston and Haegele 1980). Herring are considered juveniles or immature until they are about three years of age, when they mature sexually and join the adult spawning population (Hay and McCarter 1999). During daylight hours, juvenile herring congregate in schools, occasionally forming mixed aggregates with other pelagic species, close to shore near the bottom (Haegele 1997). At dusk, these fish migrate into surface waters to feed on plankton. During this time they are vulnerable to purse seine gear.

Purse seine surveys have been conducted annually since 1990, except for 1995, to estimate the relative abundance of juvenile herring in the Strait of Georgia (SOG) (Figure 1). Goals of the present report were to update the time series index (and associated variance) of the relative biomass and abundance, as well as mean lengths, weights, and condition of age-0 herring in the SOG using methods identified in Boldt et al. (2015; see Appendix 1 and Appendix 2). Survey data provide a potential leading indicator of recruitment to the adult herring population and may provide an indicator of prey availability and quality to predators in the SOG, such as Coho (*Oncorhynchus kisutch*) and Chinook Salmon (*O. tshawytscha*).

METHODS

The annual survey of juvenile herring in the Strait of Georgia (Figure 2) was conducted at ten core sampling transects (1 – 6, 8 – 11; no transect 7); with 3 to 5 stations per transect, for a total of 48 sampling stations. These stations have been sampled consistently since 1990 (except 1995). Data from these ten core transects have been used to predict juvenile herring recruitment (Hay et al. 2003, Schweigert et al. 2009, Boldt et al. 2018).

The sampling transects were originally chosen based on known historical herring spawning sites and were roughly placed equal distances apart around the Strait of Georgia. Placement also represents both nearshore and open water habitats (Haegele et al. 2005). In 2019, sampling was conducted from September 9th to 24th (Table 1). Thirty-four of the forty eight core stations were sampled. Smelt Bay (transect 8), Henry Bay (transect 4), French Creek (transect 5, station 5) and Clarke Rock (transect 1, station 1-2) were not sampled due to bad weather. Bowser (transect 3, station 3-5) was not sampled due to gear damage.

Fish Sampling

In 2019, the 12 m, aluminum-hulled Fisheries Research Vessel *Walker Rock* was used for all fishing events. A 183 m long and 27 m deep purse seine net of knotless web, with an area fished of ~2665 m², was used for all fishing events. The body of the net had 46 m of 48 mm mesh at the tow end (note: this was misreported as 22.2 mm in previous reports for surveys in 2002-2018) followed by 91 m of 19.0 mm mesh, and the bunt end was 46 m of 9.5 mm mesh. The net fished to a depth of 10 m, and was able to retain fish greater than 20 mm in length. All sets were made after dusk when herring were near the surface. All sets were made at the pre-determined sampling stations. Five sets were completed per night, depending on location, length of travel between transects and the marine weather forecast. For most sets, it was possible to land the entire catch for biological sampling.

On occasion, it was not practical to land a large set in its entirety, so sub-sampling was necessary. When sub-sampling was required, a portion of a 40 kg capacity tote was filled with randomly selected fish and retained for biological sampling. Several dipnet samples were taken from various parts of the net (catch) to make up the random sub-sample. The remainder of the set was released over the corkline, its size (volume) estimated as the number of totes released. All fish retained for sampling were bagged and frozen, with the exception of large predator species (e.g., adult salmon and flatfish). These fish were individually measured in the field and released. All retained fish were later sampled in the laboratory at the Pacific Biological Station. From each set, up to 100 herring were individually weighed and measured. Up to 25 individuals for all other species caught were identified, weighed and measured. If the set contained fewer than 100 herring, then all herring were weighed and measured. Consistent with standard practices, herring were measured to standard length, salmon to fork length, groundfish to total length and all to the nearest millimeter. All other fish species were measured to standard length. The number of herring caught in each set was determined by dividing the total catch weight by the mean individual fish weights of the subsampled herring. The number of other species caught was determined in the same manner (Tables 2 and 3). Where scales were present on herring, as a pilot study, a subsample of scales was collected from the preferred region under the pectoral fin for aging (Hamer 1989).

Zooplankton Sampling

Sixteen stepped oblique zooplankton tows were performed (Figure 3). The tows were always completed after dusk and immediately before the fishing events. A nearshore and offshore tow location was sampled on all transects. Dual 19 cm diameter bongo nets with 350 µm mesh were used for sampling, resulting in 'left' and 'right' bongo zooplankton samples (only 'left' samples were processed). The bongos were lowered to 20 m depth (10 m in shallow areas) and raised by an electric winch at a rate of 1 m every 15 sec (or 1 m every 30 sec for shallow areas). The zooplankton tow was performed with the vessel doing a small circle at ~2 knots speed. Each tow took approximately 5 minutes to complete. An additional sixteen vertical zooplankton tows were also performed again this year for comparative sampling between the two methods (vertical zooplankton tows were also collected in 2017 and 2018; Thompson et al. 2020a, Thompson et al. 2020b). No oblique or vertical samples were performed at Smelt Bay (transect 8) and Henry Bay (transect 4). A General Oceanics® 2030R model flowmeter was attached to the left

bongo net to determine the volume of seawater filtered. Volume filtered was calculated for oblique tows using the following equation (McCarter and Hay 2002):

$$V = (A \cdot F \cdot K) / 999,999$$

where:

V = volume of water filtered through the plankton net (m³)

A = area of net opening (0.02835 m²)

F = number of revolutions recorded by the flow meter (m) **K** = standard speed rotor constant for 7 cm rotor (26,873) 999,999 = maximum rotor digit count

Volume filtered was calculated for vertical tows as $V = (\pi * \text{net radius}^2 * \text{depth of tow})$, where the depth was either 10 m (transect 1, station 1; transect 3, station 1; and transect 5, station 1) or 20 m (all other stations).

Upon retrieval, the bongo nets were washed with a high pressure deck hose to rinse zooplankton into the codends, and the samples were preserved in 3.7% seawater formalin.

In the laboratory, a volumetric splitter was used to reduce the sample size to so that organisms could be conveniently counted and identified in a counting tray using a stereo microscope under 30X magnification. Sample splitting continued until a target size of roughly 300 organisms was reached (Thompson et al. 2003).

Zooplankton were identified to the lowest possible taxonomic level. Copepods were identified to species, where possible. Densities for all zooplankton species were determined and expressed as number of animals/m³.

CTD Sampling

A Conductivity Temperature Depth recorder (CTD) was used to characterize oceanographic conditions in the surveyed area. Sixteen casts were conducted using a RBR XR-60 CTD at stations where zooplankton samples were also collected (Figure 3). No casts were conducted at Smelt Bay (transect 8) and Henry Bay (transect 4). One CTD cast was performed at each location before zooplankton sampling. The CTD unit was weighted and lowered over the side of the vessel to within ~2 meters of the bottom to give the largest water profile possible. Descent rate of the CTD was approximately 1 m/sec. Data from the CTD casts were subsequently downloaded to a laptop at the end of the each evening.

RESULTS

Herring

Thirty-four stations were sampled from transects 1, 2, 3, 5, 6, 9 - 11. A total of 949 herring were weighed and measured resulting in a multimodal length frequency distribution (Figure 4). Length designations for juvenile herring age-classes were determined by general spacing of the length frequency histogram. A total of 172 scales were taken for aging to confirm age-classes determined from length frequency categories. The following age class designations were used:

0+ = herring less than or equal to 109 mm standard length
1+ = herring between 110 mm and 156 mm standard length
2+ and older = herring greater than or equal to 157 mm standard length

These age categories were confirmed using the 172 scale samples. Thirteen sampled stations (38%) contained age-0+ herring (Tables 2 and 3). The mean length and weight of age-0+ herring was 92 mm and 10.22 g, respectively (n = 797). A total weight of 119.16 kg and estimated 11,408 age-0+ herring were caught (Table 4).

Catches at ten of the thirty-four stations (29%) sampled contained age-1+ herring (Tables 2 and 3). The mean length and weight of age-1+ herring was 133 mm and 36.82 g, respectively (n = 143). A total weight of 5.73 kg and estimated 165 age-1+ herring were caught (Table 4).

Catches at one of the thirty-four stations (3%) sampled contained age-2+ herring (Tables 2 and 3). The mean length and weight of age-2+ herring was 165 mm and 74.44 g, respectively (n = 9). A total weight of 0.67 kg and 9 age-2+ herring were caught (Table 4).

Length frequency histograms by transect location for all sampled herring are shown in Figure 5. The majority of age 0+ herring were caught at Yellow Point (transect 2), station 2 and this station comprised 77% of the estimated age-0+ catch. The majority of age- 1+ herring were caught on the mainland transects. A length-weight relationship for all sampled herring from the survey showed a significant, positive correlation ($R^2=0.931$; Figure 6).

Zooplankton

In obliquely-towed zooplankton samples, there were 39 categories of organisms identified in 16 zooplankton samples (Figure 7 and Tables 5, 6 and 7). On average, 9.52 m³ (± 2.25 m³) of water was filtered per zooplankton tow. Larvaceans (*Oikopleura sp.* and *Fritillaria sp.*), barnacles, and gastropods occurred in all 16 samples. Calanoid copepods were also prevalent in samples. More than 50% of all zooplankton abundance comprised larvaceans (*Oikopleura sp.* and *Fritillaria sp.*), polychaetes and unidentified copepod nauplii.

In vertically-towed zooplankton samples, there were 39 categories of organisms identified in 16 zooplankton samples (Figure 7 and Tables 5, 6 and 8). On average, 0.51 m³ (± 0.11 m³) of water was filtered during these zooplankton tows. Gastropods, calanoid copepods, and barnacles were the most common taxa, occurring in all 16 samples and larvaceans (*Oikopleura sp.* and *Fritillaria sp.*) occurred in 15 samples. More than 40% of sampled abundance comprised barnacles, larvaceans (*Oikopleura sp.* and *Fritillaria sp.*) and calanoid copepods.

On average (across all tows), zooplankton densities in oblique and vertical tows were generally similar; however, the proportions of larvaceans and calanoid copepods were higher in the vertical tows and the proportions of copepod nauplii and polychaetes were higher in the oblique tows (Figure 7). Also, the average number of animals per volume of water was lower for vertical tows compared to oblique tows.

CTD

Two CTD casts were performed at each transect location before zooplankton sampling. The CTD typically records temperature (°C), salinity (ppt), dissolved oxygen (%) and depth (m). A major failure with the CTD depth sensor occurred during the survey, however, resulting in no usable data.

CONCLUSIONS

Thirty-four stations were sampled resulting in 14 different fish species recorded from purse seine sets. A total of 949 herring were measured and weighed creating a multimodal histogram clearly representing age-0+ and age-1+ juvenile herring. Oblique and vertical plankton tows were performed with Larvaceans (*Oikopleura sp.* and *Fritillaria sp.*), barnacles, gastropods, and calanoid copepods being the predominant organisms in both tow types.

ACKNOWLEDGMENTS

The 2019 Strait of Georgia juvenile herring survey was funded by the Department of Fisheries and Oceans. This survey could not have been possible without the hard work of skipper Phil Dupuis. Zooplankton samples were processed by Zotec services.

REFERENCES

- Boldt, J.L., Thompson, M., Fort, C., Rooper, C.N., Schweigert, J., Quinn II, T.J., Hay, D., and Therriault, T.W. 2015. An index of relative biomass, abundance, and condition of juvenile Pacific Herring (*Clupea pallasii*) in the Strait of Georgia, British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. 3081: x + 80 p.
- Boldt, J.L., Thompson, M., Rooper, C.N., Hay, D.E., Schweigert, J.F., Quinn, T.J. II, Cleary, J.S., Neville, C.M. 2018. Bottom-up and top-down control of small

- pelagic forage fish: factors affecting age-0 herring in the Strait of Georgia, British Columbia. Mar. Ecol. Prog. Ser. <https://doi.org/10.3354/meps12485>.
- Haegle, C.W. 1997. The occurrence, abundance and food of juvenile herring and salmon in the Strait of Georgia, British Columbia in 1990 to 1994. Can. Manuscr. Rep. Fish. Aquat. Sci. 2390: 124 p.
- Haegle, C.W., Hay, D.E., Schweigert, J.F., Armstrong, R.W., Hrabok, C., Thompson, M., and Daniel, K. 2005. Juvenile herring surveys in Johnstone Strait and Georgia Straits – 1996 to 2003. Can. Data Rep. Fish. Aquat. Sci. 1171:xi + 243 p.
- Hamer, L. 1989. Procedures for collecting and processing British Columbia herring samples. Can. MS Rep. Fish. Aquat. Sci. 2030: 27 p.
- Hay, D.E., and McCarter, P.B. 1999. Age of sexual maturation and recruitment in Pacific herring. Can. Sci. Advis. Sec. Res. Doc. 99/175: 42 p.
- Hay, D.E., Schweigert, J.F., Thompson, M., Haegle, C.W., and Midgley, P. 2003. Analyses of juvenile surveys for recruitment prediction in the Strait of Georgia. Can. Sci. Advis. Sec. Res. Doc. 2003/107: 28 p.
- Hourston, A.S., and Haegle, C.W. 1980. Herring on Canada's Pacific coast. Can. Spec. Publ. Fish. Aquat. Sci. 48: 23 p.
- Humphreys, R.D., and Hourston, A.S. 1978. British Columbia herring spawn deposition survey manual. Fish. Mar. Serv. Misc. Spec. Publ. 38: 40 p.
- McCarter, P.B., and Hay, D.E. 2002. Eulachon embryonic egg and larval outdrift sampling manual for ocean and river surveys. Can. Tech. Rep. Fish. Aquat. Sci. 2451: 33 p.
- Schweigert J.F., Hay D.E., Therriault T.W., Thompson M., and Haegle C.W. 2009. Recruitment forecasting using indices of young-of-the year Pacific herring (*Clupea pallasii*) abundance in the Strait of Georgia (BC). ICES J. Mar. Sci. 66: 1681–1687.
- Thompson, M., Hrabok, C., Hay, D.E., Schweigert, J., Haegle, C., and Armstrong, B. 2003. Juvenile herring surveys: methods and data base. Can. Manuscr. Rep. Fish. Aquat. Sci. 2651: 31 p.
- Thompson, M., Boldt, J. and Grinnell, M. H. 2020a. Strait of Georgia juvenile herring survey, September 2017. Can. Manuscr. Rep. Fish. Aquat. Sci. 3200: v + 55 p.
- Thompson, M., Boldt, J.L., Dennis-Bohm, H., and Grinnell, M. H. 2020b. Strait of Georgia juvenile herring survey, September 2018. Can. Manuscr. Rep. Fish. Aquat. Sci. 3201: vi + 53 p.

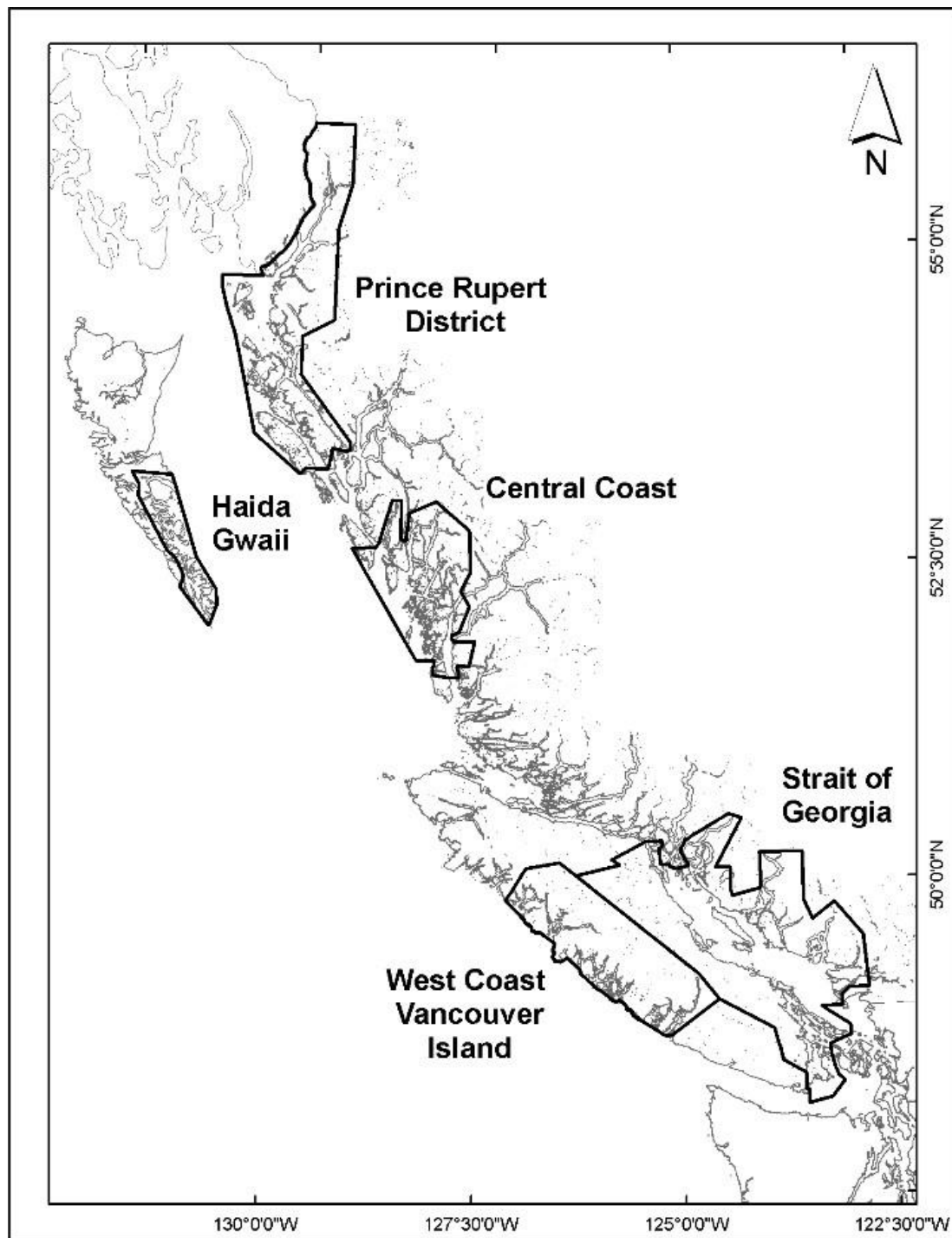


Figure 1. The five major British Columbia Pacific Herring stock assessment areas.

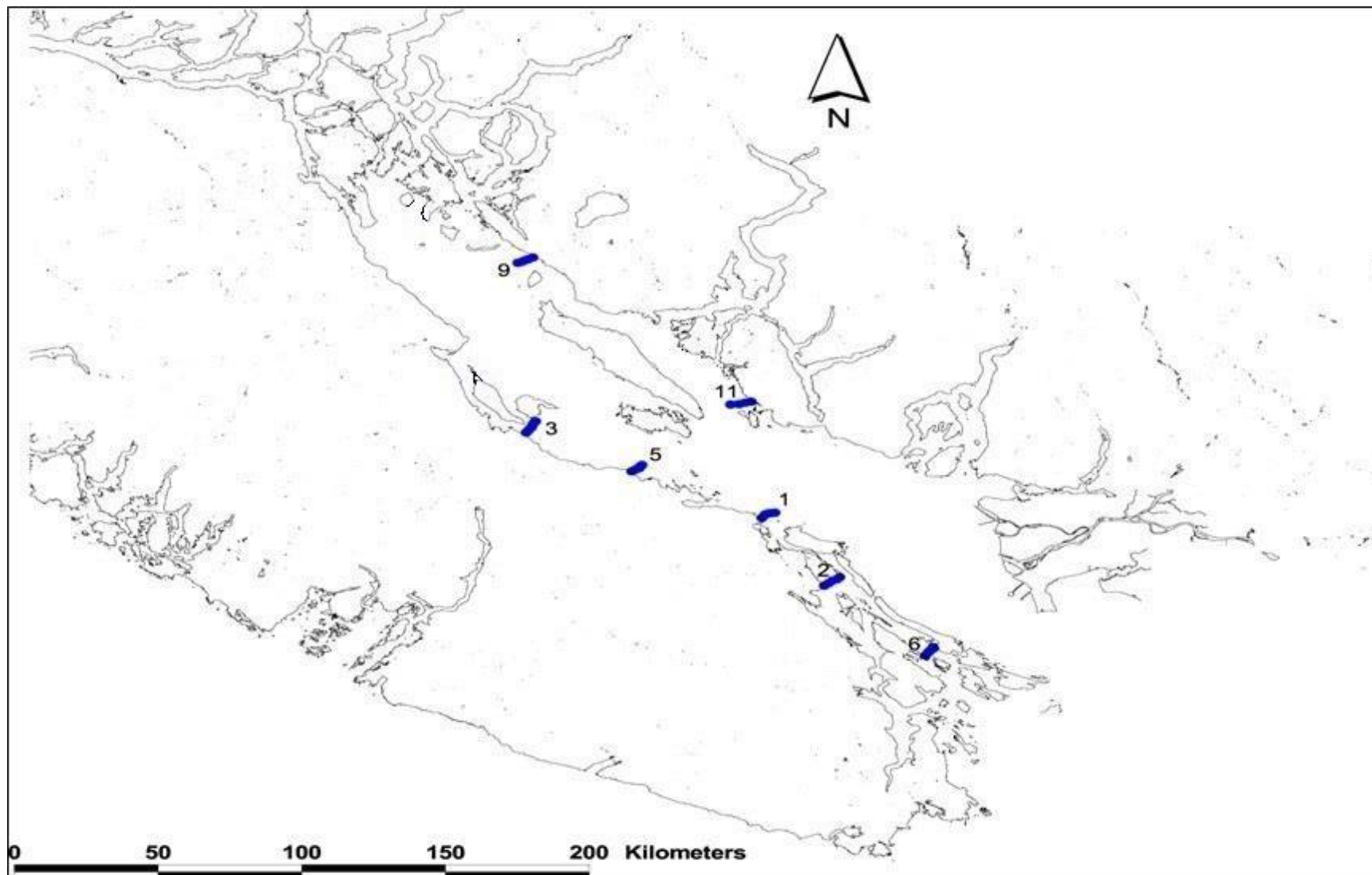


Figure 2. Purse seine set locations for the 2019 Strait of Georgia juvenile Pacific Herring survey.

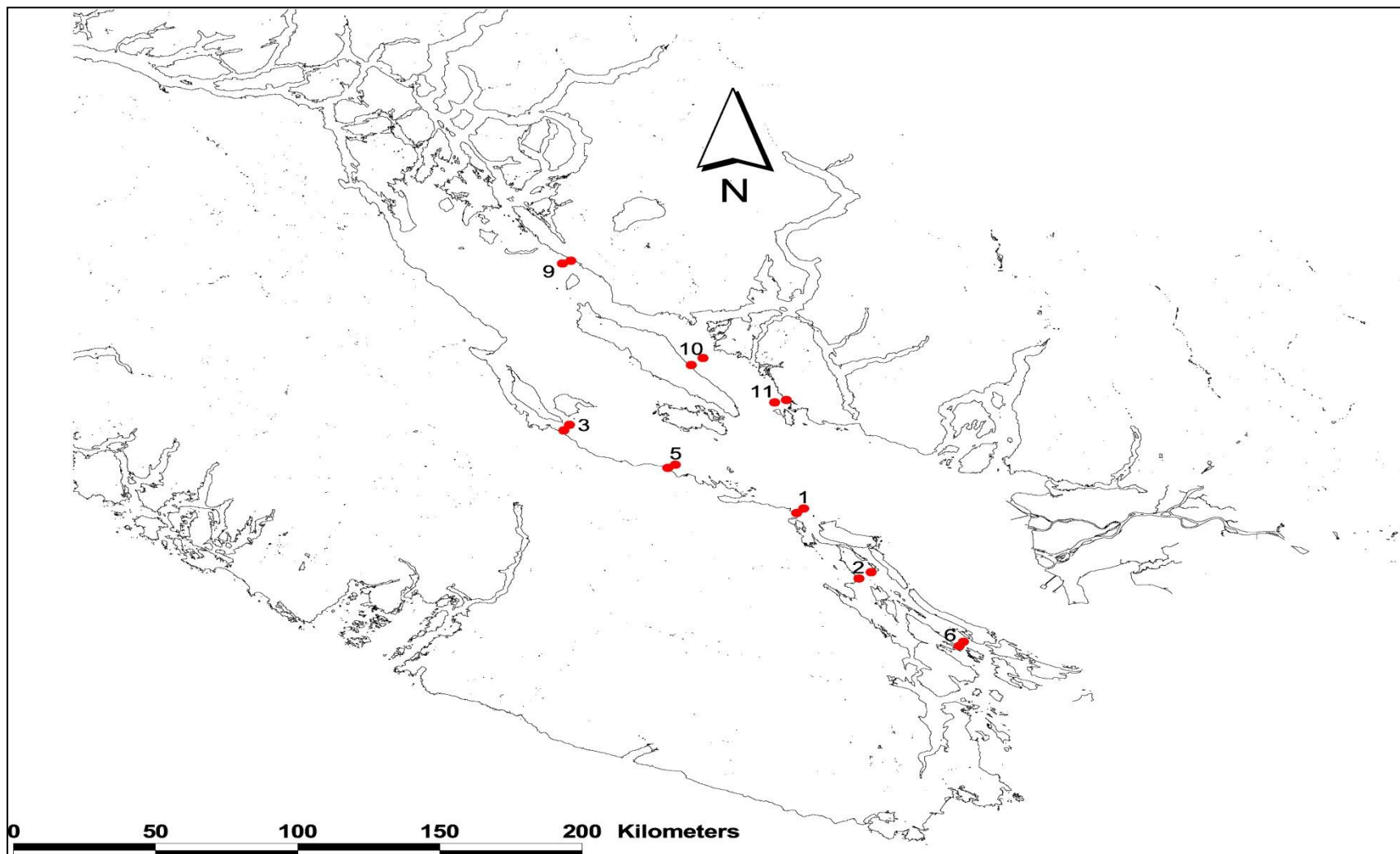


Figure 3. Zooplankton and CTD stations for 2019 Strait of Georgia juvenile Pacific Herring survey.

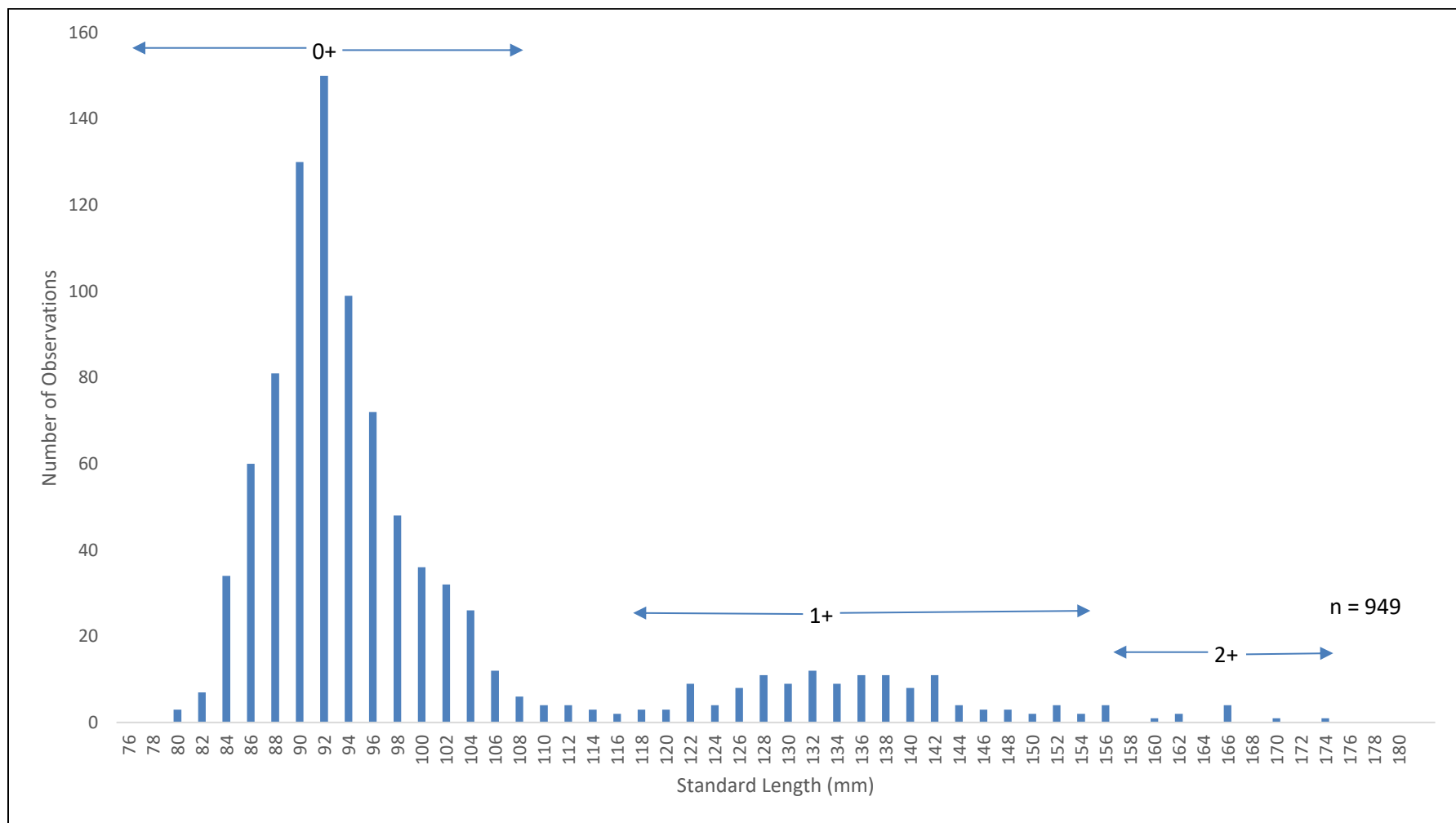


Figure 4. Length-frequency distribution for all Pacific Herring sampled during the 2019 Strait of Georgia juvenile Pacific Herring survey.

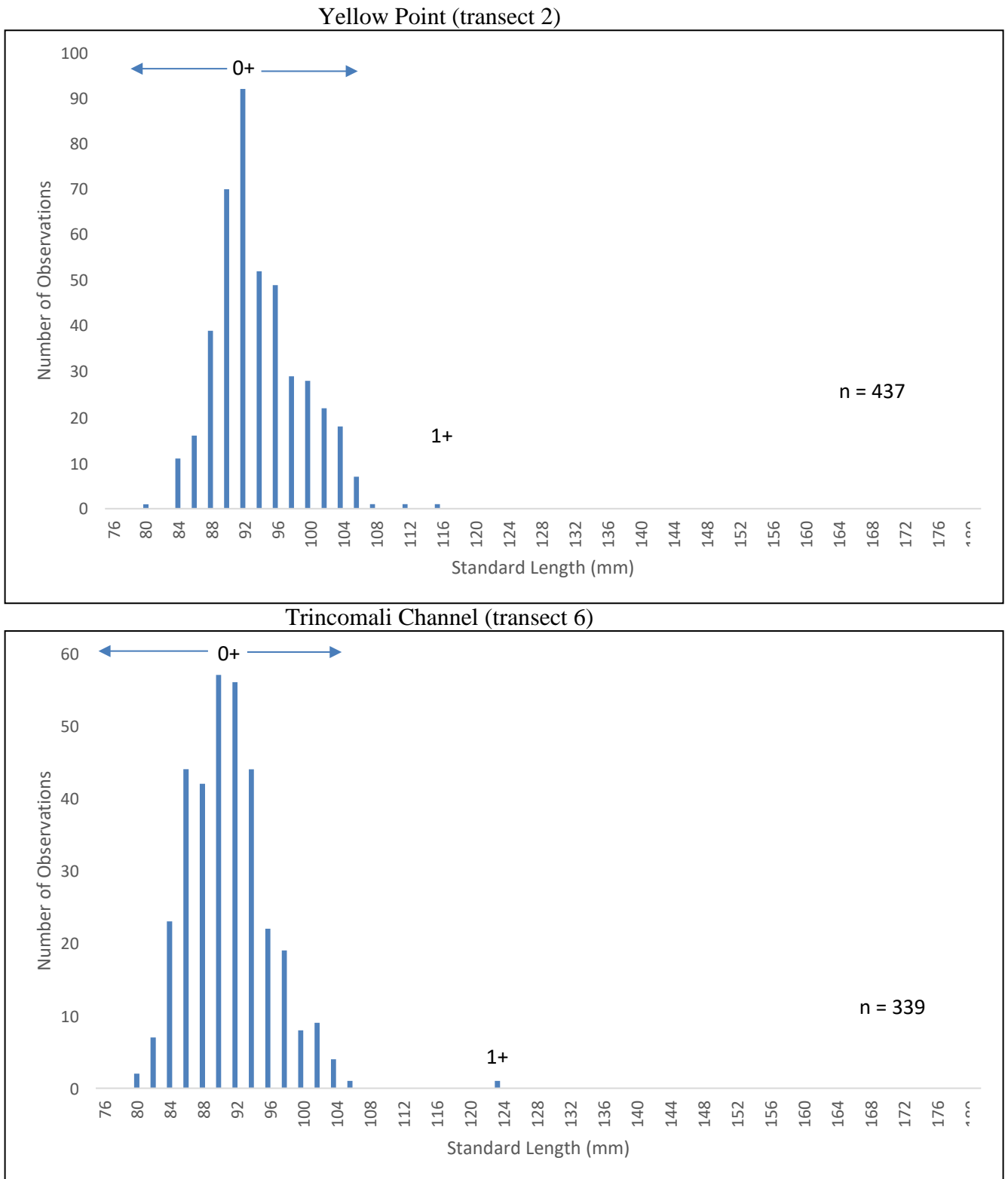


Figure 5. Length-frequency histograms of juvenile Pacific Herring by transect location for the 2019 Strait of Georgia juvenile Pacific Herring survey.

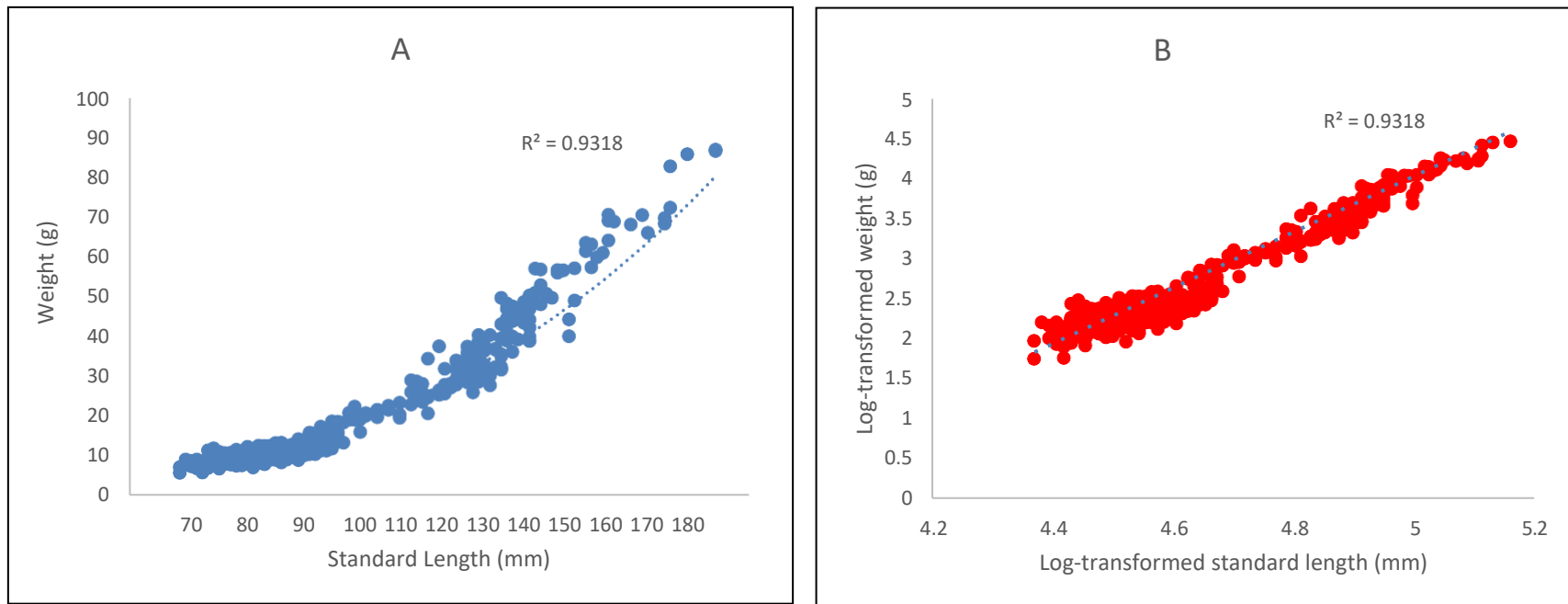


Figure 6. Non-transformed (A) and double log-transformed (B) length-weight relationships for all Pacific Herring sampled during the 2019 Strait of Georgia juvenile Pacific Herring survey.

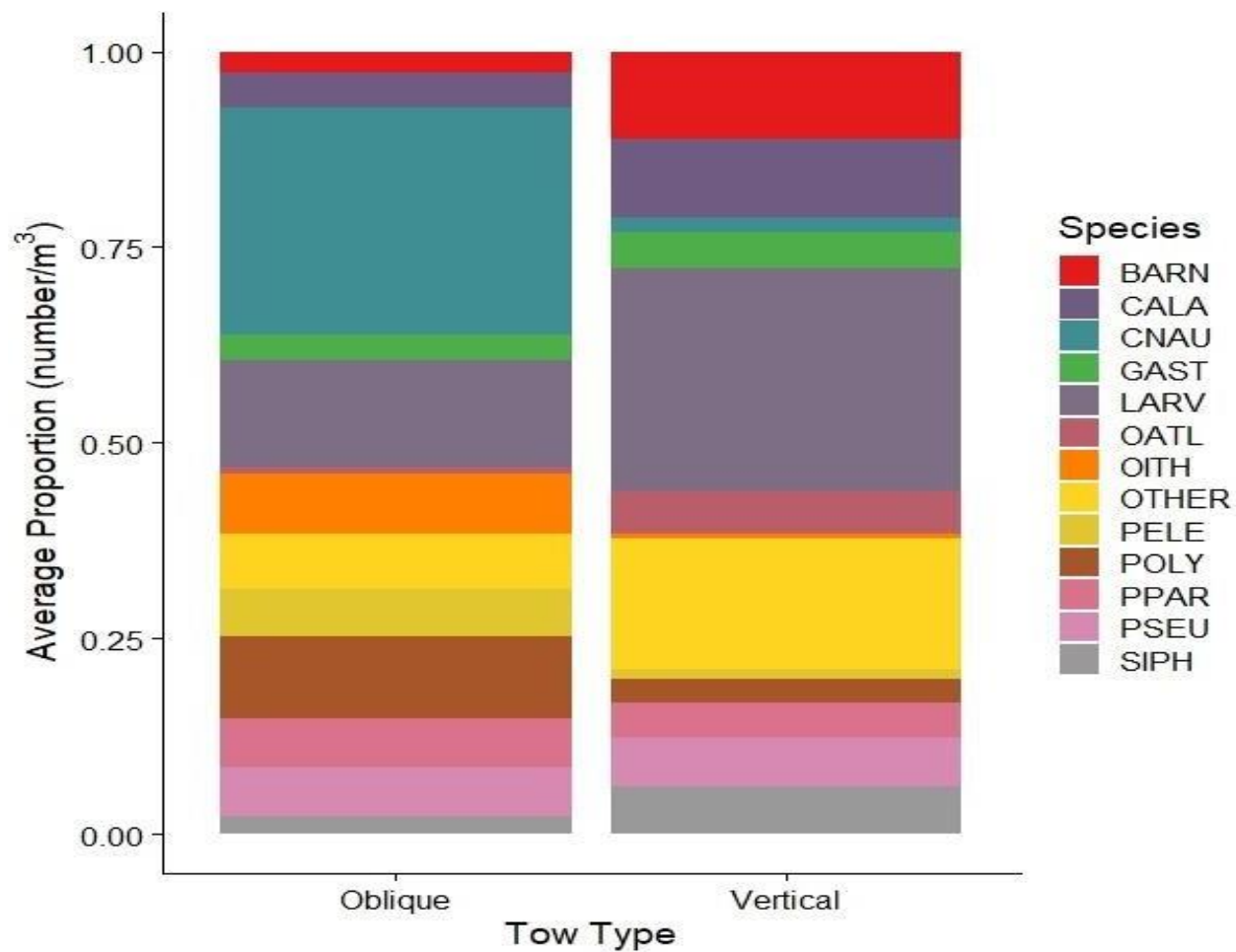


Figure 7. Average proportion zooplankton densities in oblique and vertical bongo tows from the 2019 Strait of Georgia juvenile Pacific Herring survey (only major zooplankton taxonomic groups are shown in the legend; see Tables 5 and 6 for acronym definitions).

Table 1. Summary of the purse seine set locations from the 2019 Strait of Georgia juvenile Pacific Herring survey. DD = decimal degrees.

Year	Month	Day	Transect	Station	Seine Set Time	Location Name	DD Lat (N)	DD Long (W)
2019	9	9	11	1	20:25	Secret Cove	49.535	-123.977
2019	9	9	11	2	21:00	Secret Cove	49.532	-123.995
2019	9	9	11	3	21:35	Secret Cove	49.528	-124.014
2019	9	9	11	4	22:15	Secret Cove	49.527	-124.040
2019	9	9	11	5	22:50	Secret Cove	49.523	-124.060
2019	9	10	10	1	20:35	Cape Cockburn	49.670	-124.198
2019	9	10	10	2	21:10	Cape Cockburn	49.662	-124.218
2019	9	10	10	3	21:45	Cape Cockburn	49.651	-124.242
2019	9	10	10	4	22:15	Cape Cockburn	49.642	-124.255
2019	9	10	10	5	22:50	Cape Cockburn	49.632	-124.278
2019	9	11	9	1	20:10	Atrevida Reef	49.916	-124.659
2019	9	11	9	2	20:35	Atrevida Reef	49.911	-124.673
2019	9	11	9	3	21:00	Atrevida Reef	49.909	-124.684
2019	9	11	9	4	21:30	Atrevida Reef	49.906	-124.694
2019	9	11	9	5	21:55	Atrevida Reef	49.902	-124.707
2019	9	13	3	1	20:05	Bowser	49.459	-124.672
2019	9	13	3	2	20:30	Bowser	49.452	-124.680
2019	9	16	5	1	20:10	French Creek	49.348	-124.350
2019	9	16	5	2	20:35	French Creek	49.353	-124.338
2019	9	16	5	3	21:00	French Creek	49.358	-124.327
2019	9	16	5	4	21:30	French Creek	49.353	-124.338
2019	9	18	6	1	20:10	Trincomali Channel	48.855	-123.430
2019	9	18	6	2	20:45	Trincomali Channel	48.862	-123.423
2019	9	18	6	3	21:15	Trincomali Channel	48.867	-123.417
2019	9	18	6	4	21:45	Trincomali Channel	48.873	-123.407
2019	9	18	6	5	22:15	Trincomali Channel	48.877	-123.407
2019	9	19	2	1	20:05	Yellow Point	49.066	-123.698
2019	9	19	2	2	20:40	Yellow Point	49.060	-123.708
2019	9	19	2	3	21:20	Yellow Point	49.056	-123.722
2019	9	19	2	4	21:55	Yellow Point	49.050	-123.733
2019	9	19	2	5	22:40	Yellow Point	49.042	-123.747
2019	9	24	1	5	20:15	Clarke Rock	49.238	-123.902
2019	9	24	1	4	20:45	Clarke Rock	49.237	-123.912
2019	9	24	1	3	21:15	Clarke Rock	49.236	-123.921

Table 2. Summary of the number and weight by species, transect, and station for the 2019 Strait of Georgia juvenile Pacific Herring survey.

Transect	Station	Location Name	Species	Number	Weight (kg)*
1	3	Clarke Rock	Chum salmon	6	0.76
			Coho salmon	1	0.30
1	4	Clarke Rock	Chinook salmon	1	0.27
			Chum salmon	2	0.21
			Coho salmon	2	0.57
1	5	Clarke Rock	Chinook salmon	2	0.41
			Chum salmon	2	0.26
			Coho salmon	1	0.34
			Squid	1	0.31
2	1	Yellow Point	Pacific Herring age-0+	234	2.40
			Squid	99	0.32
			Chinook salmon	3	0.23
2	2	Yellow Point	Pacific Herring age-0+	8967	94.75
			Pacific Herring age-1+	21	0.45
			Squid	399	1.47
			Northern anchovy	21	0.15
			Chinook salmon	21	1.42
2	3	Yellow Point	Pacific Herring age-0+	860	8.95
			Pacific Herring age-1+	2	0.03
			Squid	104	0.24
			Chinook salmon	4	0.26
			Plainfin midshipman	2	0.03
2	4	Yellow Point	Pacific Herring age-0+	158	1.62
			Squid	229	0.40
			Northern anchovy	3	0.05
			Chinook salmon	3	0.20
			Plainfin midshipman	1	0.01
2	5	Yellow Point	Pacific Herring age-0+	58	0.59
			Squid	760	2.26
			Pacific sand lance	2	0.01
			Three-spine stickleback	1	trace

* weights <0.01kg referred to as trace

Transect	Station	Location Name	Species	Number	Weight (kg)*
3	1	Bowser	Chinook salmon	1	0.05
3	2	Bowser	Chum salmon	4	0.34
			Chinook salmon	2	0.28
			Squid	2	0.03
5	1	French Creek	NO CATCH		
5	2	French Creek	NO CATCH		
5	3	French Creek	Squid	17	0.18
			Coho salmon	2	0.55
			Chinook salmon	1	0.09
5	4	French Creek	Coho salmon	3	0.97
6	1	Trincomali Channel	Pacific Herring age-0+	870	8.23
			Squid	186	1.11
6	2	Trincomali Channel	Pacific Herring age-0+	91	0.87
			Pacific Herring age-1+	1	0.02
			Squid	18	0.05
			Chum salmon	1	0.08
			Snake pricklyback	1	0.01
			Pacific sand lance	1	trace
6	3	Trincomali Channel	Pacific Herring age-0+	56	0.54
			Squid	28	0.15
			Three-spine stickleback	6	0.01
6	4	Trincomali Channel	Pacific Herring age-0+	42	0.40
			Squid	43	0.17
			Chum salmon	2	0.12
			Northern anchovy	1	trace
			Pacific sand lance	1	trace
6	5	Trincomali Channel	Pacific Herring age-0+	49	0.46
			Squid	6	0.04
			Chum salmon	2	0.14
9	1	Atrevida Reef	NO CATCH		

Transect	Station	Location Name	Species	Number	Weight (kg)*
9	2	Atrevida Reef	Pacific Herring age-1+	63	2.98
			Pacific Herring age-2+	9	0.67
			Squid	97	0.13
			Plainfin midshipman	11	0.01
			Chinook salmon	1	0.08
			Coho salmon	1	0.17
9	3	Atrevida Reef	NO CATCH		
9	4	Atrevida Reef	Pacific Herring age-0+	3	0.04
			Chum salmon	1	0.12
9	5	Atrevida Reef	Chum salmon	1	0.12
10	1	Cape Cockburn	Pacific Herring age-1+	53	1.57
			Squid	9	0.01
			Walleye pollock, juvenile	1	0.01
10	2	Cape Cockburn	Hake, juvenile	45	0.13
			Chum salmon	7	0.66
			Bay pipefish	1	trace
10	3	Cape Cockburn	Hake, juvenile	106	0.39
			Chum salmon	4	0.40
			Chinook salmon	3	0.24
			Three-spine stickleback	1	0.00
10	4	Cape Cockburn	Hake, juvenile	254	0.47
			Northern anchovy	3	0.02
			Chum salmon	3	0.30
10	5	Cape Cockburn	Pacific Herring age-1+	20	0.56
			Pacific Herring age-0+	1	0.02
			Squid	172	0.42
			Plainfin midshipman	37	0.02
			Hake, juvenile	21	0.04
			Chinook salmon	2	0.27
			Chum salmon	2	0.27
			Northern anchovy	1	0.01
			Bay pipefish	1	trace

Transect	Station	Location Name	Species	Number	Weight (kg)*
11	1	Secret Cove	Pacific Herring age-0+	19	0.27
			Pacific Herring age-1+	2	0.04
			Three-spine stickleback	129	0.30
			Squid	33	0.04
			Walleye pollock, juvenile	3	0.02
			Northern anchovy	1	trace
			Chinook salmon	1	0.05
11	2	Secret Cove	Pacific Herring age-1+	1	0.04
			Chum salmon	3	0.25
			Hake, juvenile	1	trace
			Three-spine stickleback	1	trace
11	3	Secret Cove	Pacific Herring age-1+	1	0.02
			Chum salmon	2	0.25
			Hake, juvenile	2	0.09
			Pink salmon	1	2.50
11	4	Secret Cove	Pacific Herring age-1+	1	0.02
			Northern anchovy	1	trace
			Chinook salmon	1	0.10
			Chum salmon	1	0.10
11	5	Secret Cove	Chinook salmon	1	0.17

Table 3. Percent occurrence by species in purse seine sets for the Strait of Georgia juvenile Pacific Herring survey in 2019.

Common Name	Scientific Name	Number of sets	Percent Occurrence
Pacific Herring age-0+	<i>Clupea pallasii</i> in year of birth	13	38.2
Pacific Herring age-1+	<i>Clupea pallasii</i> in first year	10	29.4
Pacific Herring age-2+	<i>Clupea pallasii</i> in second or more years	1	2.9
Bay pipefish	<i>Syngnathus griseolineatus</i>	2	5.9
Chinook salmon	<i>Oncorhynchus tshawytscha</i>	15	44.1
Chum salmon	<i>Oncorhynchus keta</i>	16	47.1
Coho salmon	<i>Oncorhynchus kisutch</i>	6	17.6
Hake, juvenile	<i>Merluccius productus</i>	6	17.6
Northern anchovy	<i>Engraulis mordax mordax</i>	7	20.6
Northern sand lance	<i>Ammodytes hexapterus</i>	3	8.8
Pink salmon	<i>Oncorhynchus gorbuscha</i>	1	2.9
Plainfin midhsipman	<i>Porichthys notatus</i>	4	11.8
Snake prickpleback	<i>Lumpenus sagitta</i>	1	2.9
Squid	<i>Loligo opalescens</i> , or <i>Gonatus fabricii</i>	17	50.0
Three-spine stickleback	<i>Gasterosteus aculeatus</i>	5	14.7
Walleye pollock, juvenile	<i>Gadus chalcogrammus</i>	2	5.9

* Jellyfish occurrence is not included due to the large quantities usually encountered and the inability to correctly quantify.

Table 4. Summary of the number of Pacific Herring sampled, range of standard lengths (mm), mean lengths, range of weights (g), mean weights, and standard deviations for three age classes sampled during the 2019 Strait of Georgia juvenile Pacific Herring survey. Total catch in numbers (N) and weight (Wt) of all Pacific Herring are shown for each transect.

Age-0+ Pacific Herring

Location Name	Transect	Number Sampled	Length (mm)			Weight (g)			N	Wt (Kg)
			Range	Mean	SD	Range	Mean	SD		
Clarke Rock	1	-	-	-	-	-	-	-	-	-
Yellow Point	2	435	80-107	93	5.06	6.66-15.54	10.52	1.03	10277	108.3
Bowser	3	-	-	-	-	-	-	-	-	-
Henry Bay	4	-	-	-	-	-	-	-	-	-
French Creek	5	-	-	-	-	-	-	-	-	-
Trincomali	6	338	79-105	91	4.87	5.74-17.29	9.54	1.29	1108	10.51
Smelt Bay	8	-	-	-	-	-	-	-	-	-
Atrevida Reef	9	3	103-108	106	2.52	12.69-13.34	13.12	0.37	3	0.04
Cape Cockburn	10	2	107-109	108	1.41	18.26-20.81	19.54	1.80	1	0.02
Secret Cove	11	19	90-108	99	6.92	9.73-18.63	14.21	3.06	19	0.27
All Locations		797	79-109	92	5.41	5.74-20.81	10.22	1.54	11408	119.16

Age-1+ Pacific Herring

Location Name	Transect	Number Sampled	Length (mm)			Weight (g)			N	Wt (Kg)
			Range	Mean	SD	Range	Mean	SD		
Clarke Rock	1	-	-	-	-	-	-	-	-	-
Yellow Point	2	2	111-116	114	3.54	16.01-21.57	18.79	3.93	23	0.48
Bowser	3	-	-	-	-	-	-	-	-	-
Henry Bay	4	-	-	-	-	-	-	-	-	-
French Creek	5	-	-	-	-	-	-	-	-	-
Trincomali	6	1	123	123	-	20.66	20.66	-	1	0.02
Smelt Bay	8	-	-	-	-	-	-	-	-	-
Atrevida Reef	9	63	120-156	140	8.33	28.98-70.46	47.25	10.04	63	2.98
Cape Cockburn	10	72	110-148	128	8.07	19.01-44.25	29.28	5.57	73	2.13
Secret Cove	11	5	110-148	122	15.13	19.57-40.01	24.27	8.83	5	0.12
All Locations		143	110-156	133	10.74	16.07-61.88	36.82	12.28	165	5.73

Table 4 continued.

Age-2+ Pacific Herring										
Location Name	Transect	Number Sampled	Length (mm)			Weight (g)			N	Wt (Kg)
			Range	Mean	SD	Range	Mean	SD		
Clarke Rock	1	-	-	-	-	-	-	-	-	-
Yellow Point	2	-	-	-	-	-	-	-	-	-
Bowser	3	-	-	-	-	-	-	-	-	-
Henry Bay	4	-	-	-	-	-	-	-	-	-
French Creek	5	-	-	-	-	-	-	-	-	-
Trincomali	6	-	-	-	-	-	-	-	-	-
Smelt Bay	8	-	-	-	-	-	-	-	-	-
Atrevida Reef	9	9	159-174	165	4.47	65.99-86.85	74.44	8.23	9	0.67
Cape Cockburn	10	-	-	-	-	-	-	-	-	-
Secret Cove	11	-	-	-	-	-	-	-	-	-
All Locations		9	159-174	165	4.47	65.99-86.85	74.44	8.23	9	0.67

Table 5. Organisms by phylum, and with abbreviations, observed in zooplankton samples collected during the 2019 Strait of Georgia juvenile Pacific Herring survey.

<u>Coelenterata</u>	
COEL	Medusae - <i>Aequorea victoria</i>
SIPH	Siphonophores
<u>Ctenophora</u>	
CTEN	Ctenophores
<u>Annelida</u>	
POLY	Polychaetes
<u>Mollusca</u>	
GAST	Prosobranch gastropods
PELE	Pelecypods
<u>Arthropoda</u>	
AMPH	Amphipods
BARN	Barnacle, unknown stage
CLAD	Cladocerans; <i>Podon sp.</i> and <i>Evadne sp.</i>
CNAU	Unidentified copepod nauplii
COPE	Copepods (see Table 6 for list of species)
CRAM	Crab megalopea, including porcellinadea
CRAZ	Crab zoea, including porcellinadea
CUMA	<i>Cumacea sp.</i>
EUPA	Adult euphausiids; mainly <i>Euphausia pacifica</i>
EUPL	Larval euphausiids; mainly <i>Euphausia pacifica</i>
ISOP	Isopods
SHRI	Shrimp zoea
<u>Chaetognatha</u>	
CHAE	Chaetognaths; mainly <i>Sagitta sp.</i>
<u>Chordata</u>	
LARV	Larvaceans; mainly <i>Oikopleura sp.</i> and some <i>Fritillaria sp.</i>
TELA	Teleosts (fish larvae)
<u>Echinoderm</u>	
ECHI	Echinoderms
<u>Ectoproct</u>	
ECTO	Ectoprocts
<u>Miscellaneous</u>	
EGGS	Unidentified eggs; either euphausiid or teleost

Table 6. Abbreviations for calanoid and cyclopoid copepods identified in the 2019 zooplankton samples from the Strait of Georgia juvenile Pacific Herring survey.

Calanoid copepods

ACLA	<i>Acartia clausi</i>
ADIV	<i>Aetideus divergens</i>
ALON	<i>Acartia longiremis</i>
CABD	<i>Centropages abdominatus</i>
CALA	<i>Calanus sp.</i>
CPAC	<i>Calanus pacificus</i>
EBUN	<i>Eucalanus bungii</i>
ELON	<i>Epilabidocera longipedata</i>
MPAC	<i>Metridia pacifica</i>
PPAR	<i>Paracalanus parvus</i>
PSEU	<i>Pseudocalanus sp.</i>
SMIN	<i>Scolecithricella minor</i>
TDIS	<i>Tortanus discaudatus</i>
UCAL	Unidentified calanoid copepod

Cyclopoid copepods

CANG	<i>Corycaeus anglicus</i>
OATL	<i>Oithona atlantica</i>
OITH	<i>Oithona sp.</i>
OSIM	<i>Oithona similis</i>
UCYC	Unidentified cyclopoid copepod

Harpacticoid copepods

UHAR	Unidentified harpacticoid copepod
-------------	-----------------------------------

Table 7. Volume of water filtered and number of zooplankton per m³ of water in oblique tow samples collected during the 2019 Strait of Georgia juvenile Pacific Herring survey. Species codes as shown in Tables 5 and 6.

Location	Tran	Stn	Volume (m ³)	ADIV	ALON	AMPH	BARN	CABD	CALA	CANG	CHAE	CLAD
Clarke Rock	1	1	9.541	1.68	-	-	23.48	-	8.38	1.68	0.42	4.19
		3	8.033	-	1.00	0.50	1.37	-	6.97	-	-	0.37
Yellow Point	2	1	3.896	-	-	-	131.41	-	459.95	65.71	-	32.85
		4	4.982	-	-	-	205.55	-	513.88	205.55	-	-
Bowser	3	1	10.213	-	-	1.57	17.23	-	43.86	-	-	100.26
		3	10.594	-	12.08	1.51	14.35	-	205.39	-	-	28.69
French Creek	5	1	9.720	-	3.29	-	3.91	0.82	2.47	-	-	17.90
		3	10.368	-	3.09	0.96	1.35	3.09	9.26	-	0.19	2.51
Trincomali Ch	6	1	9.870	-	35.66	-	486.33	-	19.45	19.45	-	149.14
		4	9.753	-	65.62	19.69	91.87	-	170.61	65.62	6.56	78.74
Atrevida Reef	9	1	10.738	-	1.49	0.65	1.12	1.49	22.35	-	0.09	0.09
		3	11.166	-	8.60	1.88	0.27	-	134.69	-	0.09	-
Cape Cockburn	10	1	12.580	-	1.27	3.02	10.33	-	26.71	1.27	0.32	2.07
		3	11.789	-	2.71	16.63	0.34	-	65.15	8.14	1.02	-
Secret Cove	11	1	9.469	-	5.07	-	70.97	-	-	-	-	20.28
		3	9.674	-	13.23	5.79	6.62	-	119.08	-	1.65	4.13

Table 7 continued.

Location	Tran	Stn	CNAU	COEL	CPAC	CRAM	CRAZ	CUMA	EBUN	ECHI	ECTO	EGGS	EUPA
Clarke Rock	1	1	-	0.42	-	0.84	-	0.42	-	-	0.42	-	0.42
		3	1.99	0.25	1.00	-	0.25	-	-	0.37	-	-	0.50
Yellow Point	2	1	4468.05	98.56	-	-	-	-	-	32.85	131.41	-	-
		4	6988.72	205.55	-	-	102.78	-	-	-	205.55	51.39	-
Bowser	3	1	-	-	-	-	9.40	-	-	98.69	4.70	-	-
		3	-	1.51	-	0.76	-	-	-	77.02	-	-	-
French Creek	5	1	-	-	-	-	0.21	-	-	-	-	-	-
		3	-	0.19	-	-	1.74	-	-	-	-	-	-
Trincomali Ch	6	1	22.70	-	-	-	-	-	-	6.48	-	-	-
		4	78.74	6.56	13.12	-	-	-	-	39.37	6.56	6.56	-
Atrevida Reef	9	1	4.47	0.37	-	-	-	-	-	2.14	-	-	-
		3	-	0.27	-	0.09	-	-	-	2.51	-	-	-
Cape Cockburn	10	1	3.82	2.70	-	-	0.48	-	-	0.16	0.16	-	-
		3	-	0.34	8.14	-	-	-	2.71	0.34	-	-	-
Secret Cove	11	1	-	3.38	-	-	1.69	-	-	-	-	-	-
		3	-	-	6.62	-	-	-	-	0.83	-	4.96	-

Table 7 continued.

Location	Tran	Stn	EUPL	GAST	LARV	MPAC	OATL	OITH	OSIM	PELE	POLY	PPAR
Clarke Rock	1	1	-	29.76	8.80	15.09	67.08	-	-	-	0.42	3.35
		3	-	8.34	1.37	8.96	33.86	-	1.99	-	-	-
Yellow Point	2	1	65.71	459.95	1544.11	-	65.71	1182.72	197.12	1314.13	3383.89	854.19
		4	-	205.55	1336.08	-	-	1901.34	-	1027.75	770.82	1387.47
Bowser	3	1	1.57	281.98	130.03	25.07	62.66	-	-	-	1.57	12.53
		3	-	18.12	114.78	24.16	48.33	-	48.33	-	-	36.25
French Creek	5	1	-	43.01	2.26	-	14.82	-	4.12	-	-	5.76
		3	-	35.30	1.54	18.52	24.69	3.09	-	-	0.19	15.43
Trincomali Ch	6	1	-	45.39	920.79	-	-	-	3.24	-	12.97	45.39
		4	-	85.31	826.80	13.12	-	-	13.12	32.81	32.81	52.50
Atrevida Reef	9	1	0.09	2.98	0.84	-	-	8.94	-	-	-	10.43
		3	-	2.24	0.27	-	-	-	14.33	-	-	-
Cape Cockburn	10	1	1.27	5.56	16.69	-	-	-	5.09	-	-	12.72
		3	1.02	56.32	8.82	13.57	2.71	-	2.71	-	0.34	2.71
Secret Cove	11	1	-	23.66	366.67	-	3.38	-	3.38	1.69	3.38	8.45
		3	0.83	6.62	181.93	-	13.23	-	13.23	-	-	52.93

Table 7 continued.

Location	Tran	Stn	PSEU	SHRI	SIPH	SMIN	TDIS	TELA	UCAL	UCYC	UHAR
Clarke Rock	1	1	13.42	2.52	9.22	1.68	1.68	-	-	-	-
		3	1.00	0.37	3.98	1.00	1.00	-	-	-	-
Yellow Point	2	1	722.77	32.85	164.27	-	-	-	-	-	-
		4	1284.69	-	668.04	-	-	-	-	-	-
Bowser	3	1	18.80	9.40	1.57	-	18.80	-	-	-	-
		3	96.66	-	3.78	-	-	-	-	-	-
French Creek	5	1	0.82	2.47	-	-	7.41	-	-	-	0.82
		3	55.56	-	0.19	-	-	-	-	-	-
Trincomali Ch	6	1	32.42	6.48	25.94	-	-	12.97	-	-	-
		4	144.36	13.12	13.12	-	-	-	-	-	-
Atrevida Reef	9	1	20.86	0.65	0.09	-	-	-	-	-	-
		3	37.25	0.63	0.09	-	-	0.09	-	-	-
Cape Cockburn	10	1	6.36	8.90	-	-	-	-	-	-	-
		3	62.43	0.34	0.68	-	-	-	-	-	-
Secret Cove	11	1	-	5.07	-	-	-	-	6.76	1.69	-
		3	33.08	3.31	-	-	-	-	-	-	-

Table 8. Volume of water filtered and number of zooplankton per m³ of water in vertical tow samples collected during the 2019 Strait of Georgia juvenile Pacific Herring survey. Species codes as shown in Tables 5 and 6.

Location	Tran	Stn	Volume	ACLA	ADIV	ALON	AMPH	BARN	CABD	CALA	CANG	CHAE
Clarke Rock	1	1	0.284	-	-	-	-	21.13	-	10.56	3.52	-
		3	0.567	-	-	1.76	-	5.29	-	5.29	-	-
Yellow Point	2	1	0.567	-	-	-	-	268.08	-	507.94	169.31	-
		4	0.567	-	-	-	14.11	437.39	-	592.59	620.81	-
Bowser	3	1	0.284	-	-	-	3.52	49.30	-	422.54	-	-
		3	0.567	-	-	7.05	3.53	7.05	-	275.13	-	-
French Creek	5	1	0.284	7.04	-	70.42	-	52.82	-	-	-	-
		3	0.567	-	-	-	1.76	12.35	-	42.33	-	1.76
Trincomali Ch	6	1	0.567	-	-	14.11	21.16	1114.64	-	28.22	49.38	7.05
		4	0.567	-	-	42.33	14.11	670.19	-	155.20	28.22	-
Atrevida Reef	9	1	0.567	-	-	35.27	7.05	7.05	7.05	70.55	7.05	1.76
		3	0.567	-	-	14.11	1.76	3.53	-	261.02	21.16	1.76
Cape Cockburn	10	1	0.567	-	-	-	5.29	79.37	-	204.59	7.05	-
		3	0.567	-	5.29	1.76	15.87	10.58	-	28.22	-	-
Secret Cove	11	1	0.567	-	-	28.22	-	211.64	-	14.11	14.11	-
		3	0.567	-	-	5.29	3.53	5.29	-	33.51	7.05	5.29

Table 8 continued.

Location	Tran	Stn	CLAD	CNAU	COEL	CPAC	CRAM	CRAZ	CTEN	EBUN	ECHI	ECTO
Clarke Rock	1	1	3.52	3.52	-	-	-	-	-	-	-	3.52
		3	3.53	-	-	-	-	1.76	-	-	-	-
Yellow Point	2	1	14.11	-	3.53	-	-	28.22	-	-	28.22	28.22
		4	84.66	310.41	1.76	-	-	14.11	-	-	14.11	28.22
Bowser	3	1	95.07	-	-	28.17	-	-	-	-	-	-
		3	10.58	-	1.76	7.05	-	-	-	-	8.82	1.76
French Creek	5	1	144.37	7.04	-	-	-	10.56	-	-	-	-
		3	10.58	-	-	-	1.76	1.76	-	-	1.76	-
Trincomali Ch	6	1	112.87	21.16	21.16	-	-	28.22	-	-	21.16	7.05
		4	14.11	-	35.27	-	-	7.05	42.33	-	42.33	7.05
Atrevida Reef	9	1	1.76	21.16	3.53	-	-	-	-	-	5.29	-
		3	-	-	-	-	-	-	-	7.05	15.87	-
Cape Cockburn	10	1	7.05	-	-	-	-	1.76	-	-	3.53	-
		3	-	-	1.76	-	-	-	-	1.76	3.53	-
Secret Cove	11	1	63.49	112.87	7.05	-	-	7.05	7.05	-	-	-
		3	-	3.53	1.76	1.76	-	-	-	-	-	-

Table 8 continued.

Location	Tran	Stn	EGGS	ELON	EUPL	GAST	ISOP	LARV	MPAC	OATL	OITH	OSIM
Clarke Rock	1	1	-	-	-	21.13	-	105.63	28.17	105.63	-	3.52
		3	-	-	-	22.93	-	1.76	10.58	65.26	-	-
Yellow Point	2	1	183.42	-	112.87	183.42	-	1481.48	-	14.11	84.66	84.66
		4	126.98	-	84.66	56.44	-	2370.37	-	56.44	-	28.22
Bowser	3	1	-	-	10.56	193.66	3.52	390.85	140.85	323.94	14.08	-
		3	-	-	3.53	35.27	-	119.93	56.44	63.49	-	-
French Creek	5	1	-	-	-	285.21	-	24.65	14.08	288.73	-	-
		3	-	-	-	70.55	-	10.58	338.62	126.98	-	-
Trincomali Ch	6	1	-	-	-	77.60	-	818.34	-	-	-	-
		4	-	-	14.11	112.87	-	790.12	-	28.22	-	14.11
Atrevida Reef	9	1	-	-	-	19.40	-	49.38	14.11	42.33	35.27	-
		3	-	-	-	15.87	-	3.53	-	-	7.05	-
Cape Cockburn	10	1	5.29	-	1.76	44.09	-	97.00	21.16	49.38	-	-
		3	-	-	-	15.87	-	-	112.87	24.69	-	-
Secret Cove	11	1	21.16	14.11	-	63.49	-	1008.82	-	225.75	56.44	42.33
		3	31.75	-	1.76	14.11	-	227.51	-	19.40	-	-

Table 8 continued.

Location	Tran	Stn	PELE	POLY	PPAR	PSEU	SHRI	SIPH	SMIN	TDIS	UCAL	UHAR
Clarke Rock	1	1	-	3.52	7.04	3.52	-	7.04	3.52	3.52	3.52	-
		3	-	-	-	3.53	-	26.46	5.29	1.76	-	-
Yellow Point	2	1	268.08	380.95	211.64	183.42	56.44	776.01	-	-	-	-
		4	14.11	352.73	225.75	84.66	-	634.92	-	28.22	-	28.22
Bowser	3	1	3.52	10.56	28.17	98.59	14.08	45.77	-	42.25	-	14.08
		3	-	-	21.16	91.71	-	12.35	-	-	-	-
French Creek	5	1	-	7.04	42.25	35.21	59.86	3.52	-	56.34	-	-
		3	-	1.76	56.44	522.05	-	1.76	28.22	14.11	-	-
Trincomali Ch	6	1	14.11	28.22	63.49	119.93	42.33	35.27	-	28.22	-	-
		4	14.11	28.22	211.64	169.31	35.27	42.33	-	-	-	-
Atrevida Reef	9	1	1.76	1.76	98.77	35.27	-	1.76	-	-	-	-
		3	-	1.76	-	190.48	3.53	1.76	-	-	-	-
Cape Cockburn	10	1	1.76	-	49.38	28.22	14.11	1.76	-	7.05	-	-
		3	-	-	3.53	24.69	-	8.82	-	-	-	-
Secret Cove	11	1	-	-	126.98	42.33	21.16	-	-	-	-	-
		3	-	-	10.58	35.27	1.76	3.53	-	-	1.76	-

APPENDIX 1

An index of relative biomass and abundance of juvenile Pacific Herring in the Strait of Georgia

The Strait of Georgia (SOG) juvenile Pacific Herring (hereafter referred to as herring) survey collects time-series information that can be used to estimate the relative abundance of age-0 herring and perhaps provide a forecast of low recruitment to the adult spawning population. Survey information may also represent trends in prey availability and quality to Coho and Chinook Salmon and other predators in the SOG. The index (and associated variance) of the relative biomass or abundance of age-0 herring in the SOG was updated with the 2019 survey data using methods identified in Boldt et al. (2015). In addition, annual variation in herring lengths, weights, and condition were examined.

Estimates of mean catch weights (g), abundance, and CPUE (weight and abundance) of age-0 herring varied interannually with no significant overall linear trend during 1992-2019 (Figures 1.1 and Table 1.1). In 2019, the index of the relative biomass of age-0 herring was of the same general magnitude observed since 2013; it was higher than in 2018, but with higher variance. The interannual variability in mean estimates has been low compared to observations prior to 2013, when there was a pattern of alternating high (with high associated variance estimates) and low indices every two or three years. (Figure 1.1 and Table 1.1). Estimates of CVs ranged from 23% to 81% with an average of 48% (Figure 1.1 and Table 1.1). In 2019, age-0 herring lengths and weights were similar to those measured in 2018; their condition (residuals from a double-log-transformed length-weight regression) was slightly lower than measured in 2018 but still above average (Figure 1.2). During the time series, there was no significant linear trend in mean lengths or weights of age-0 herring (Figure 1.2).

Literature cited:

Boldt, J.L., Thompson, M., Fort, C., Rooper, C.N., Schweigert, J., Quinn II, T.J., Hay, D., and Therriault, T.W. An index of relative biomass, abundance, and condition of juvenile Pacific Herring (*Clupea pallasii*) in the Strait of Georgia, British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. 3081: x + 80 p.

Thompson, S.K. 1992. Sampling. John Wiley and Sons, Inc. New York. 343 p.

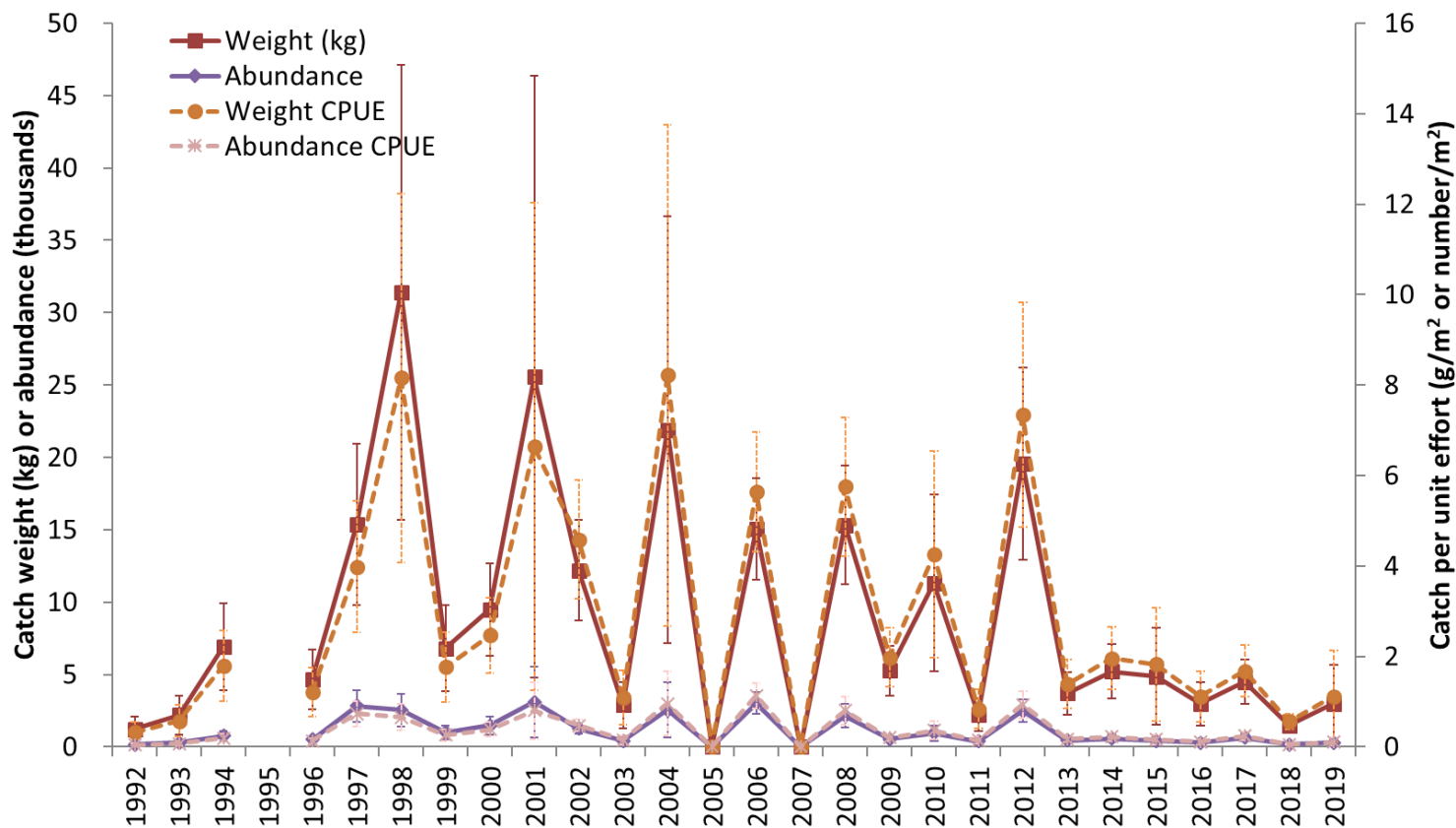


Figure 1.1. Estimates of catch weight (kg), catch weight-per-unit-effort (weight CPUE; g/m^2), abundance, and abundance CPUE (number/ m^2) of age-0 Pacific Herring caught in the Strait of Georgia juvenile Pacific Herring survey at core transects and stations during 1992-2019 (no survey in 1995). Estimates were calculated using a two-stage method (see Boldt et al. 2015). Estimates of CPUE were calculated by dividing catch weight (or abundance) by the area fished by the net (assuming the net length changed in 2002 from 220 m to 183 m; see Boldt et al. 2015 for details). Standard error bars (using the Thompson 1992 variance estimator) are shown.

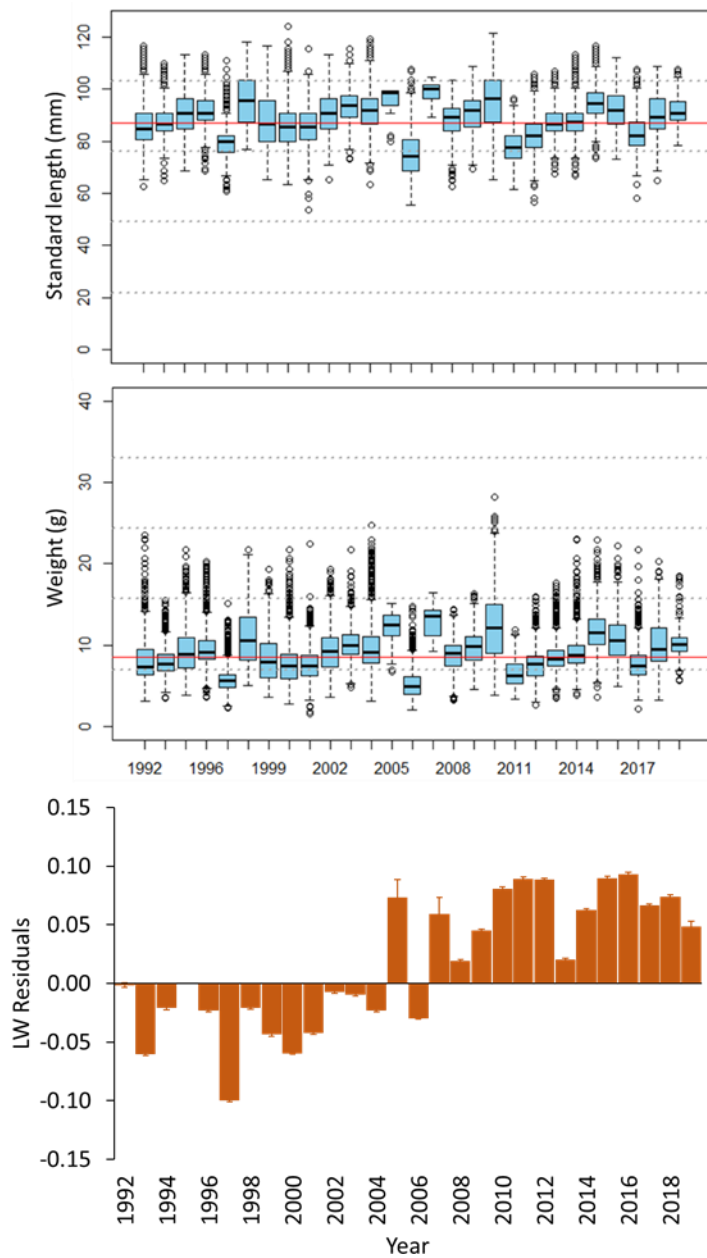


Figure 1.2. Box plots of age-0 Pacific Herring standard lengths (mm; top panel) and weights (g; middle panel), and bar plot of condition (residuals from a double-log-transformed length weight regression; bottom panel), as measured in the laboratory during 1992-2019 (no survey in 1995). Standard error bars are shown.

Table 1.1. Mean catch weight (g), catch weight per unit effort (CPUE; g/m²), abundance, abundance CPUE (number/m²), standard error (SE), and coefficient of variation (CV) of age-0 Pacific Herring caught in the Strait of Georgia juvenile Pacific Herring survey at core transects and stations during 1992-2019 (no survey in 1995). Two-stage sampling formulae (Thompson 1992) were used to calculate the mean and variance.

Year	Weight (g)	SE	CV	Weight CPUE (g/m ²)	SE	CV	Abundance	SE	CV	Abundance CPUE (number/m ²)	SE	CV
1992	1226.333	852.076	0.695	0.318	0.221	0.695	163.358	122.426	0.749	0.042	0.032	0.749
1993	2206.211	1337.446	0.606	0.573	0.347	0.606	285.847	178.452	0.624	0.074	0.046	0.624
1994	6930.616	3010.497	0.434	1.799	0.782	0.434	748.304	334.987	0.448	0.194	0.087	0.448
1995												
1996	4669.740	2065.650	0.442	1.212	0.536	0.442	499.247	228.320	0.457	0.130	0.059	0.457
1997	15341.900	5569.885	0.363	3.983	1.446	0.363	2813.467	1072.734	0.381	0.730	0.278	0.381
1998	31418.933	15708.446	0.500	8.157	4.078	0.500	2529.717	1111.968	0.440	0.657	0.289	0.440
1999	6809.267	2963.350	0.435	1.768	0.769	0.435	1001.333	485.487	0.485	0.260	0.126	0.485
2000	9490.827	3175.900	0.335	2.464	0.824	0.335	1472.513	626.178	0.425	0.382	0.163	0.425
2001	25568.172	20777.096	0.813	6.638	5.394	0.813	3100.970	2429.038	0.783	0.805	0.631	0.783
2002	12197.863	3497.051	0.287	4.577	1.312	0.287	1249.845	345.835	0.277	0.469	0.130	0.277
2003	2900.546	1597.512	0.551	1.088	0.599	0.551	399.895	247.569	0.619	0.150	0.093	0.619
2004	21901.546	14754.345	0.674	8.218	5.536	0.674	2556.415	1889.527	0.739	0.959	0.709	0.739
2005	10.596	5.108	0.482	0.004	0.002	0.482	0.840	0.396	0.472	0.000	0.000	0.472
2006	15045.055	3526.160	0.234	5.645	1.323	0.234	3020.660	738.642	0.245	1.133	0.277	0.245
2007	6.804	4.281	0.629	0.003	0.002	0.629	0.528	0.315	0.596	0.000	0.000	0.596
2008	15334.313	4082.787	0.266	5.754	1.532	0.266	2132.927	806.846	0.378	0.800	0.303	0.378
2009	5261.335	1737.286	0.330	1.974	0.652	0.330	533.687	175.386	0.329	0.200	0.066	0.329
2010	11322.919	6089.296	0.538	4.249	2.285	0.538	957.535	534.899	0.559	0.359	0.201	0.559
2011	2233.234	1128.388	0.505	0.838	0.423	0.505	381.820	206.055	0.540	0.143	0.077	0.540
2012	19564.914	6640.157	0.339	7.341	2.492	0.339	2480.540	791.017	0.319	0.931	0.297	0.319

2013	3688.389	1443.124	0.391	1.384	0.542	0.391	460.198	191.919	0.417	0.173	0.072	0.417
2014	5215.187	1856.540	0.356	1.957	0.697	0.356	581.953	224.927	0.387	0.218	0.084	0.387
2015	4855.123	3343.553	0.689	1.822	1.255	0.689	428.560	301.774	0.704	0.161	0.113	0.704
2016	2976.148	1499.108	0.504	1.117	0.563	0.504	289.093	157.325	0.544	0.108	0.059	0.544
2017	4472.289	1536.429	0.344	1.678	0.577	0.344	640.950	237.764	0.371	0.241	0.089	0.371
2018	1492.813	468.729	0.314	0.560	0.176	0.314	150.458	45.529	0.303	0.056	0.017	0.303
2019	2978.465	2681.382	0.900	1.118	1.006	0.900	285.200	254.358	0.892	0.107	0.095	0.892

APPENDIX 2

INTRODUCTION

In British Columbia, a key forage fish species is Pacific Herring (*Clupea pallasii*) (hereafter called herring). Juveniles need to store enough energy before the fall to survive their first winter when food is scarce (Haegele 1997, Paul et al. 1998, Foy and Paul 1999). Energy density is an indicator of fish physiological status, nutritional status, and overall condition (Johnson et al. 2017). Calorimetry is a method of measuring the heat energy of a reaction from combusting a tissue sample to determine caloric content (Hartman and Brant 1985, Paul 1997). The objectives of this study were to measure whole body energy density of age-0 herring, where sufficient samples were collected, in an effort to improve the understanding of herring survival by examining the size and condition of juveniles prior to their first winter. These measures can then be related to estimates of future recruitment. Age-0 herring for energy density analysis were collected as part of the annual Strait of Georgia (SOG) juvenile herring survey.

METHODS

Energy Density Sampling

Where sufficient numbers existed, a sample of twenty juvenile herring per station (not exceeding three stations per transect) were frozen and brought back to the laboratory. In 2019, three samples were collected from stations at three transects (Table 2.1). Individual lengths (standard to the nearest mm) and weights (nearest 0.01 g) were measured, otoliths and stomach contents were removed, then fish were oven-dried at 60°C until reaching a consistent weight (+/- 5%). Of the juvenile herring samples collected at each station, morphometrics were collected for all fish but only 10 age-0 herring were randomly selected to be processed for energy density. A Parr Instrument 6765 Combination Calorimeter was used to determine caloric content (interchangeable with the term energy density) of the sample. Individual dried fish were homogenized thoroughly with an electric grinder. A subsample of each ground fish was pressed into a pellet of about 0.150 g using a pellet press (Parr 2817). Pellets were weighed immediately after being pressed and stored in a desiccator to maintain sample integrity. Methods used for calorimetry process were as stated in the Parr manual (Parr Instrument Co. 1994). Sulfuric and nitric acid formations were disregarded in energy calculations because they are considered minimal (Parr Instrument Co. 1994, Boldt and Haldorson 2004). The number of fish processed ranged from 30-80 individuals per year from 2012 to 2019 (Table 2.1).

Linear regression was used to model the relationship of energy density as a function of various parameters including standard length (mm), wet weight (g), dry weight (g), percent dry weight, and condition. Condition values were obtained from calculating the residuals from a double log-transformed length-weight regression (Appendix 1; Boldt et al. 2020). One-way analysis of variance (ANOVA) was used to compare energy density, wet weights, and lengths among years. If a difference was found then a Tukey's or Games-Howell post-hoc test was conducted to determine which years were different.

RESULTS

Fish length, weight, and energy density values varied among years, with 2012 and 2015 representing the minimum and maximum for most parameters examined. Average fish standard lengths ranged from 81.8 mm to 96.7 mm and wet weight ranged from 7.1 g to 11.3 g in 2012 and 2015, respectively (Figure 2.1). Average dry weight ranged from 1.6 g (2012) to 2.7 g (2015) and the percent dry weight ranged from 23% in 2012 and 2017 to 26% in 2019 (Figure 2.1). Average energy density values ranged from 4,854 cal/g in 2012 to 5,317 cal/g in 2015 (Figure 2.2). Weighting the energy density estimates by catch-per-unit-effort (CPUE) had minimal effect on values, except in 2019, where majority of the catch was represented by one transect which, had the lowest energy density values that year (Figure 2.2).

There was evidence of an effect of year on the fish length, weight (wet, dry, and percent dry), energy density, and body condition (length-weight residuals) (Figure 2.3). Fish sampled in 2012 were significantly shorter and lighter than fish sampled in other years and they had the lowest energy density values ($p < 0.001$). Fish sampled in 2016, 2018, and 2019 were significantly longer ($p < 0.001$) and, along with fish sampled in 2015, had significantly higher average wet weights and energy density values compared to other years ($p < 0.001$).

Preliminary results indicated there may be a positive relationship between age-0 herring energy density and age-2 recruit abundance (DFO 2021), lagged by two years; however, the relationship is not significant ($p = 0.95$) (Figure 2.4). Samples from 2012 were stored in the freezer for several years and appeared to be freezer-burned which may have contributed to the low energy density values. Removing values from 2012 did not change the relationship between age-2 recruit abundance and age-0 energy density; however, there are currently only six years of data. This data along with estimates of juvenile herring abundance data will be further explored towards improving estimates of age-2 recruit abundance, which can be highly variable and comprise over 50% of the adult spawning biomass. Continued monitoring of age-0 herring could improve stock assessment model projections of spawning stock biomass.

Table 2.1. Number of Strait of Georgia age-0 Pacific Herring energy density samples processed per year, 2012-2019. Generally, where possible, 10 individual fish per transect were sampled.

Year	Number of fish processed for energy density	Transects from which samples were collected
2012	80	1-6, 8, 9
2013	60	1-4, 6, 8
2014	75	1-4, 8, 9, 11
2015	50	1-4, 10
2016	50	1, 2, 4-6
2017	80	1-6, 8 9
2018	60	2-4, 8-10
2019	30	2, 6, 11

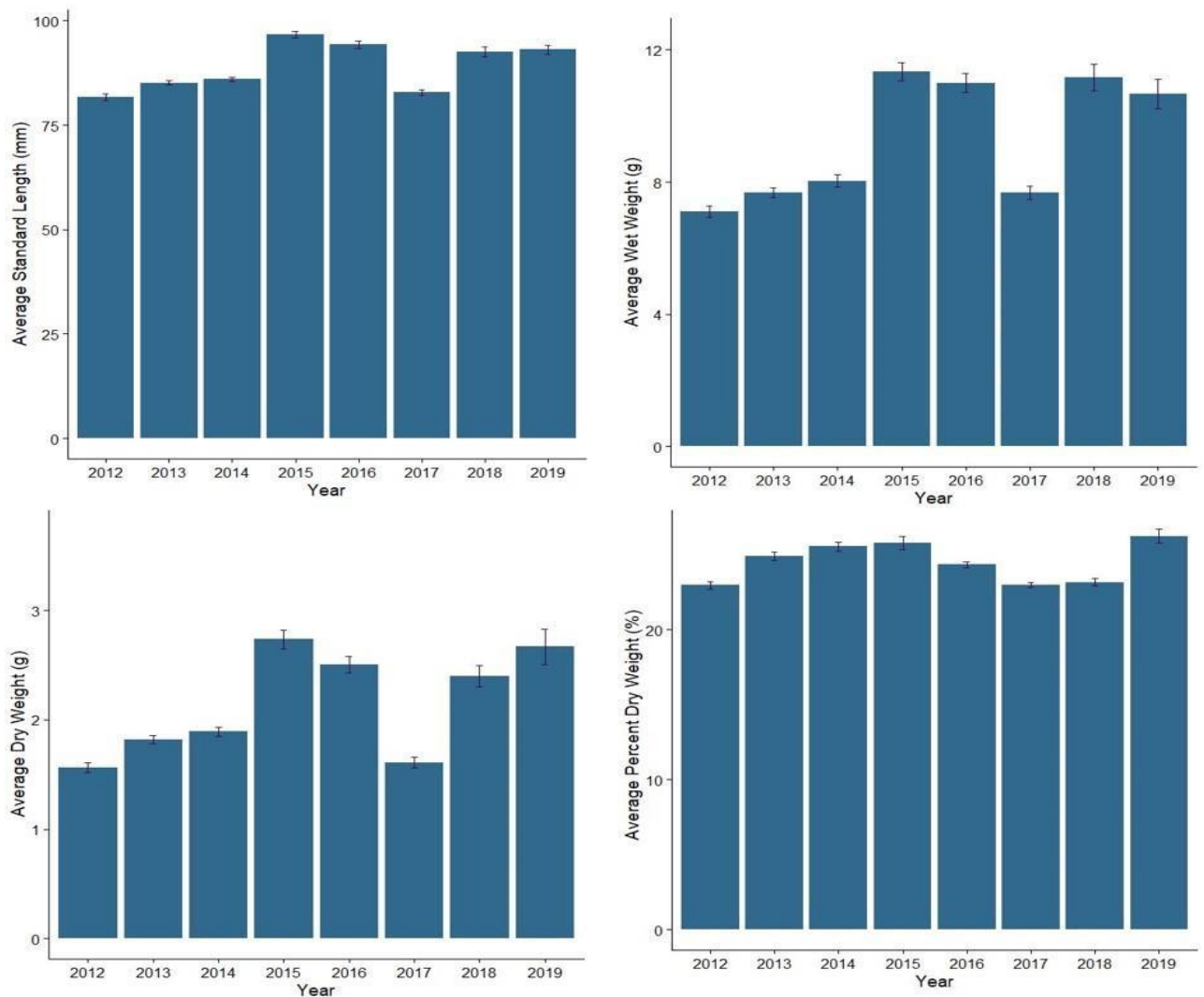


Figure 2.1. Average standard length (mm), wet weight (g), dry weight (g), and percent dry weight of age-0 Pacific Herring from the Strait of Georgia collected for energy density analysis, 2012- 2019. Standard error bars are shown.

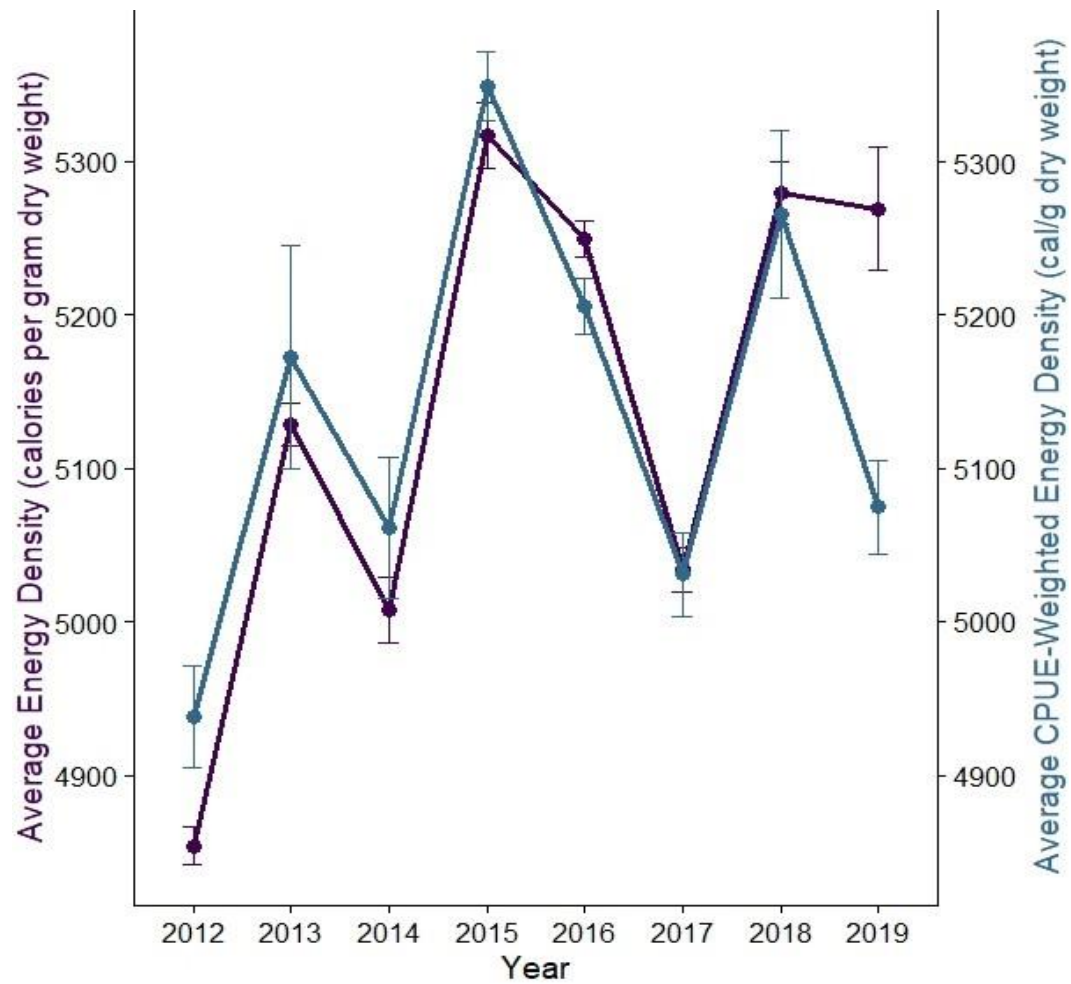


Figure 2.2. Average energy density and average energy density weighted by catch per unit effort (CPUE) for age-0 Pacific Herring in Strait of Georgia, 2012-2019. Standard error bars are shown.

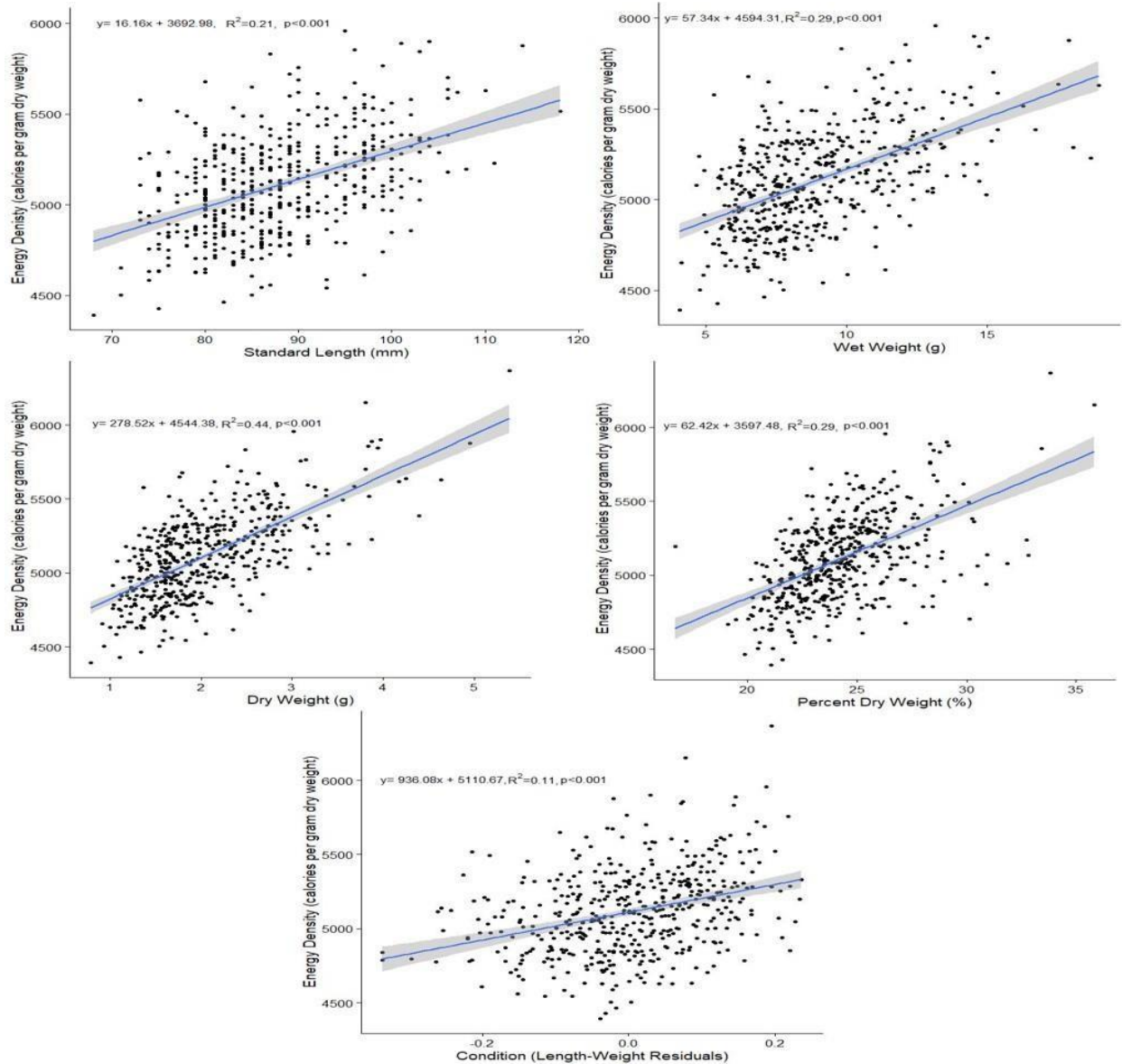


Figure 2.3. Energy density as a function of standard length (mm), wet weight (g), dry weight (g), percent dry weight, and condition of age-0 Pacific Herring samples collected in the Strait of Georgia for calorimetry analysis. Linear regression lines (solid lines) are shown and grey shaded areas represent the standard errors.

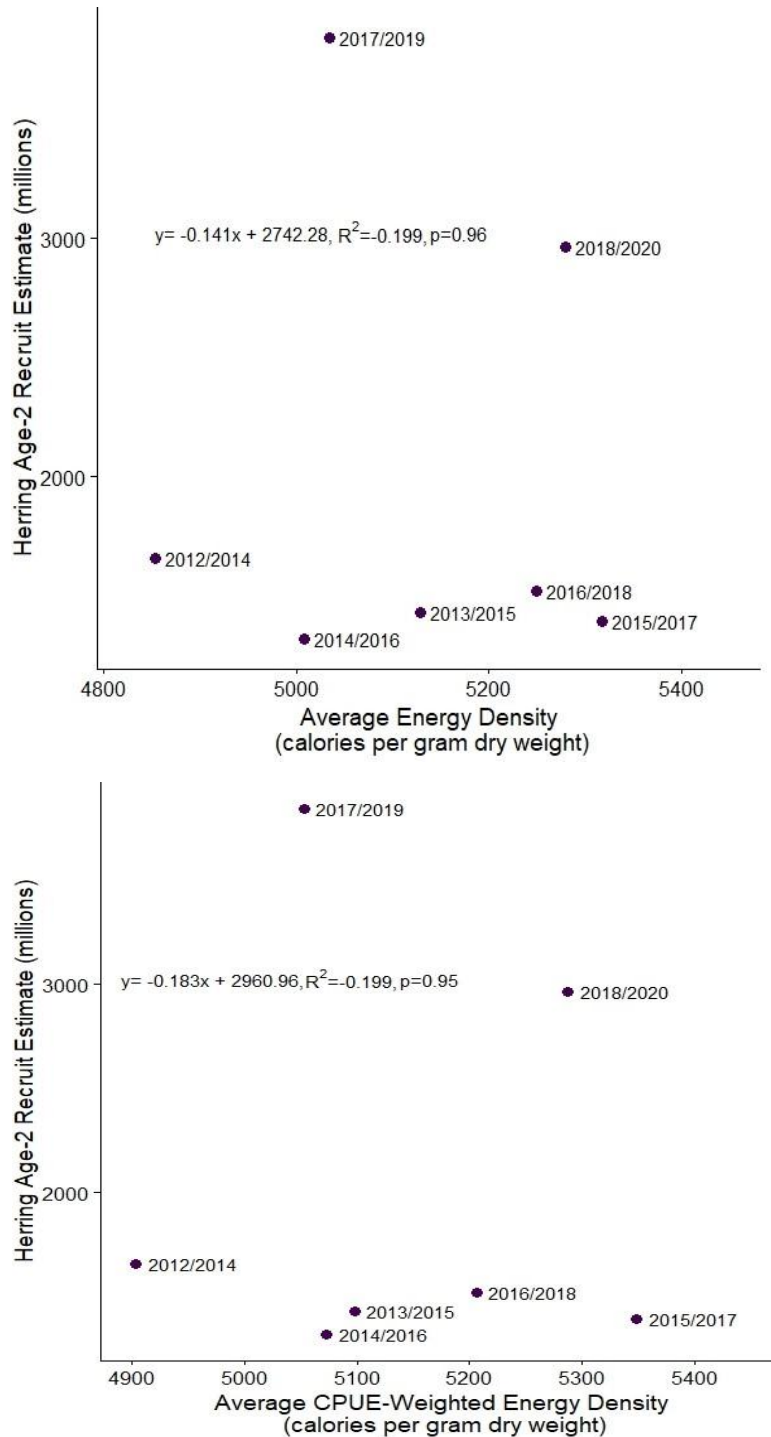


Figure 2.4. Estimate of age-2 Pacific Herring recruit abundance estimates (2014-2020) (stock assessment maximum posterior density values; DFO 2021) lagged by two years plotted as a function of average age-0 Pacific Herring energy density (top panel) and age-0 Pacific Herring energy density weighted by catch per unit effort (bottom panel) (2012-2018), in the Strait of Georgia. Labels show years of age-0 Pacific Herring energy density samples and year of recruitment two years later.

References

- Boldt, J.L., and Haldorson, L.T. 2004. Size and condition of wild and hatchery pink salmon juveniles in Prince William Sound, Alaska. *Trans. Am. Fish. Soc.* 133(1): 173-184.
- Boldt, J.L., Thompson, Dennis-Bohm, H., M., Grinnell, M.H., Cleary, J., Rooper, C., Schweigert, J., and Hay, D. 2020. Strait of Georgia juvenile herring survey. In: Boldt, J.L., Javorski, A., and Chandler, P.C. (Eds.). *State of the physical, biological and selected fishery resources of Pacific Canadian marine ecosystems in 2019*. Can. Tech. Rep. Fish. Aquat. Sci. 3377: x + 288 p.
- DFO. 2021. Stock status update with application of management procedures for Pacific Herring (*Clupea pallasii*) in British Columbia: Status in 2020 and forecast for 2021. DFO Can. Sci. Advis. Sec. Sci. Resp. 2021/001.
- Foy R.J., and Paul A.J. 1999. Winter feeding and changes in somatic energy content of age-0 Pacific herring in Prince William Sound, Alaska. *Trans Am Fish Soc* 128: 1193–1200.
- Haegle, C.W. 1997. The occurrence, abundance and food of juvenile herring and salmon in the Strait of Georgia, British Columbia in 1990 to 1994. *Can. Manusc. Rep. Fish. Aquat. Sci.* 2390: 124 p.
- Hartman, K. J., and Brandt, S.B. 1995. Estimating energy density of fish. *Transactions of the American Fisheries Society* 124: 347–355.
- Johnson, B.M., Pate, W.M., and Hansen, A.G. 2017. Energy density and dry matter content in fish: new observations and an evaluation of some empirical models. *Transactions of the American Fisheries Society*, 146, 1262-1279. <http://doi/abs/10.1080/00028487.2017.1360392>
- Parr Instrument Co. 1994. Parr Instrument Co. manual. Madison, Wisconsin.
- Paul, A. J. 1997. The use of bioenergetic measurements to estimate prey consumption, nutritional status, and thermal habitat requirements for marine organisms reared in the sea. *Bulletin of the National Research Institute of Aquaculture, Supplement 3*: 59–68.
- Paul A.J, Paul J.M., and Brown E.D. 1998. Fall and spring somatic energy content for Alaskan Pacific herring (*Clupea pallasii* Valenciennes 1847) relative to age, size and sex. *J Exp Mar Biol Ecol* 223: 133–142.