Strait of Georgia Juvenile Pacific Herring Survey, September 2021

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

Fisheries and Oceans Canada
Science Branch, Pacific Region
Pacific Biological Station
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STRAIT OF GEORGIA JUVENILE PACIFIC HERRING SURVEY, SEPTEMBER 2021

by

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A fall juvenile herring survey of the Strait of Georgia took place September 7th to 23rd, 2021. This survey serves to address several questions of early herring survival, abundance, recruitment and trophodynamics. Forty-five core stations were sampled throughout the Strait of Georgia following 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. 2024. Strait of Georgia juvenile Pacific herring survey, September 2021. Can. Manuscr. Rep. Fish. Aquat. Sci. 3249: vi + 53 p.

Un relevé automnal du hareng juvénile dans le détroit de Georgie a été réalisé entre le 7 et le 23 septembre 2021. Ce relevé visait à répondre à plusieurs questions sur la survie, l'abondance, le recrutement et la trophodynamique du hareng durant les premiers stades de son développement. Les 45 stations situées dans le détroit de Georgie ont été échantillonnées en suivant 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 and have joined the sexually mature 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.

To determine the distribution and abundance of juvenile herring in the Strait of Georgia (SOG) purse seine surveys have been conducted annually since 1990, except for 1995 and 2020 (Figure 1). The main objective of the survey was to estimate the relative abundance of juvenile herring in the SOG. Also, a goal of this report was to update the time series index (and associated variance) of the relative biomass and abundance, as well as mean lengths and weights of age-0 herring in the SOG using methods identified in Boldt et al. (2015; see Appendix 1). 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 and Chinook Salmon.

METHODS

The annual survey of juvenile herring in the Strait of Georgia (Figure 2) followed ten core sampling transects (1 – 6, 8 – 11; no transect 7); with three to five stations per transect, for a total of 48 sampling stations. These stations have been sampled consistently since 1990 (except 1995 and 2020). 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). Originally, the sampling transects were 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 2021, sampling was conducted from September 7th to 23rd (Table 1). Two additional transects were added this year at Cowichan Head (transect 38) with five sampling stations and Plumper Sound (transect 12) with three sampling stations. Forty-five of the fifty-six stations were sampled. Bowser (transect 3), Cape Cockburn (transect 10 stations 3, 4 and 5) and Plumper Sound (transect 12) were not sampled due to high winds.

Fish Sampling

In 2021, 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, resulting in an area fished of ~2665 m^2, 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) 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. Up to five sets were completed per night, depending on location, distance 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. 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 millimetre. 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).

In 2021 scientific echosounder data were collected along 1 to 3 track lines along core transects, prior to net sampling. The acoustic data will be used to provide a secondary estimate of age 0+ herring abundance, as part of a DFO Competitive Science Research Fund-funded project (21-FS-11-03). A scientific transducer (with 2 frequencies, 38 and 200 kHz) was attached to a mounting platform on the bottom of an aluminum pole, so that it was at ~1 m depth; the pole was fixed to the starboard side of the vessel. The transducer was connected (via cable) to a SIMRAD EK80 portable transceiver, which recorded the data, and was powered by a marine battery.

Zooplankton Sampling

Twenty 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 twenty vertical zooplankton tows were also performed again this year for comparative sampling between the two methods. No oblique or vertical samples were performed at Bowser (transect 3) or Plumper Sound (transect 12). 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):

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

where:

V = volume of water filtered through the plankton net (m^3)
A = area of net opening (0.02835 m^2)
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 $V = (\pi * \text{net radius}^2 * \text{depth of tow})$. In 2021, the tow depth for all zooplankton samples was 20 m.

An RBR Solo3 depth logger was attached to the zooplankton sampling bongo net to record pressure (dbar) and depth (m), which was used to validate the depth of the tow. The RBR was continuously logging data for the duration of the survey, after which the data were downloaded from the instrument for analysis.

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 where 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 was 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/m^3.

CTD Sampling

A Conductivity Temperature Depth recorder (CTD) was used to record temperature (ºC), salinity (ppt), dissolved oxygen (%) and depth (m). Vertical casts were conducted using a SBE 19plus V2 at stations where zooplankton samples were also collected (Figure 3). 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. The descent rate of the CTD was approximately 1 m/sec. Data from the CTD casts were subsequently downloaded to a laptop. After the survey, the CTD data were sent to DFO's Institute of Ocean Science (IOS) for processing. The approximate depth of the thermocline was identified using the RLakeAnalyzer package and thermo.depth() function within the statistical program R (R Core Team, 2022). This function analyzes the temperature profile in relation to water depth data collected at each location to identify the depth where a significant temperature gradient occurs, thermally separating the upper and lower sections of the water column.

RESULTS

Herring

Forty-five stations were sampled from transects 1, 2, 4, 5, 6, 8, 9, 10, 11 and 38. A total of 1894 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. The following age class designations were used:

0+ = herring less than or equal to 105 mm standard length
1+ = herring between 106 mm and 154 mm standard length
2+ and older = herring greater than or equal to 155 mm standard length

Catches at twenty-six of the forty-five sampled stations (57.8%) contained age-0+ herring (Tables 2 and 3). The mean length and weight of age-0+ herring was 77 mm and 6.38 g, respectively (n = 1333). A total weight of 108.75 kg and an estimated 17441 individual age-0+ herring were caught (Table 4).

Catches at nineteen of the forty-five stations (42.2%) sampled contained age-1+ herring (Tables 2 and 3). The mean length and weight of age-1+ herring was 133 mm and 35.71 g, respectively (n = 540). A total weight of 53.79 kg and an estimated 1503 individual age-1+ herring were caught (Table 4).

Catches at five of the forty-five stations (11.1%) sampled contained age-2+ herring (Tables 2 and 3). The mean length and weight of age-2+ herring was 167 mm and 70.25 g, respectively (n = 21). A total weight of 2.61 kg and 36 individual 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 in Henry Bay (transect 4),Yellow Point (transect 2), and Trincomali Channel (transect 6), representing 90% of the total estimated age-0+ survey 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=0.98; Figure 6).

Zooplankton

Due to a battery issue, RBR data were useable from only ten stations, sampled during September 19-23. The depth of the vertical tows ranged from 20.6 to 21.3 m, the depth of the steeped oblique tows ranged from 11.9 to 16.9 m. The duration of the vertical tows ranged from 1.6 to 2.7 minutes, whereas the steeped oblique casts ranged from 5.8 to 6.6 minutes (Figure 7).

In obliquely-towed zooplankton samples, there were 23 categories of organisms identified in 20 zooplankton samples (Tables 5, 6 and 7). An average of 8.82 m^3 (± 3.11 m^3 SD) of water was filtered per zooplankton tow. *Calanus sp*. copepods, and larvaceans(*Oikopleura sp.* and *Fritillaria sp.*) occurred in all 20 samples. More than 80 % of all zooplankton abundance comprised siphonophores, larvaceans (*Oikopleura sp.* and *Fritillaria sp.*), gastropods, barnacles, and *Pseudocalanus sp*. copepods.

In vertical-towed zooplankton samples, there were 21 categories of organisms identified in 20 zooplankton samples (Tables 5, 6 and 8). An average of 0.57 m^3 of water was filtered per zooplankton tow. *Calanus sp*. copepods, gastropods and siphonophores were the most common groups occurring in all 20 samples. More than 60% of sampled abundance comprised larvaceans (*Oikopleura sp.* and *Fritillaria sp.*), siphonophores and barnacles. There were some station by station differences in zooplankton densities between oblique and vertical tows (not shown), but on average (across all tows) the proportion of zooplankton densities were generally similar between the two methods (Figure 8).

CTD

Twenty CTD casts were completed: two casts on each transect sampled, except for Bowser (transect 3); however, due to a CTD battery issue, there were only twelve usable casts from the survey. The following casts from the latter half of the survey were not useable, due to the battery issues: two at Trincomali Channel (transect 6), two at Yellow Point (transect 2), two at French Creek (transect 5), one cast at Clarke Rock (transect 1), and one at Cowichan Head (transect 38). No casts were conducted at Bowser (transect 3) due to high winds. The depths of the CTD casts ranged from 10-81 m with Clarke Rock having the shallowest depth and Smelt Bay (transect 8) the deepest (Figure 9).

Surface temperatures varied between 9.06 ºC and 18.24 ºC, with the warmest surface temperatures recorded on the eastern side of the SOG at Atrevida Reef (transect 9, station 3) (Table 9). Temperatures at the deepest depths sampled (80 m) ranged from 9.08 ºC at Smelt Bay (station 1) to 9.48 ºC at Secret Cove (transect 11, station 2), however the coldest temperature recorded was 9.06 ºC at Cape Cockburn (transect 10, station 3) at a depth of 75 m (Table 9). Surface salinities were 23.34 PSS-78 to 30.2 PSS-78 at Atrevida Reef(station 3) and Cowichan Head (station 1) and salinities at depth ranged from 30.19 PSS-78 to 30.4 PSS-78 at Smelt Bay (station 1) and Secret Cove (station 2). Thermocline depths were approximately 1.50 m to 22.50 m, with the shallowest thermocline at Clarke Rock (station 1) and the deepest at Atrevida Reef (station 1) (Table 9).

CONCLUSIONS

Forty-five stations were sampled resulting in 18 different fish species recorded from purse seine sets. A total of 1894 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.*), siphonophores, barnacles, and gastropods being the predominant organisms in both tow types.

ACKNOWLEDGMENTS

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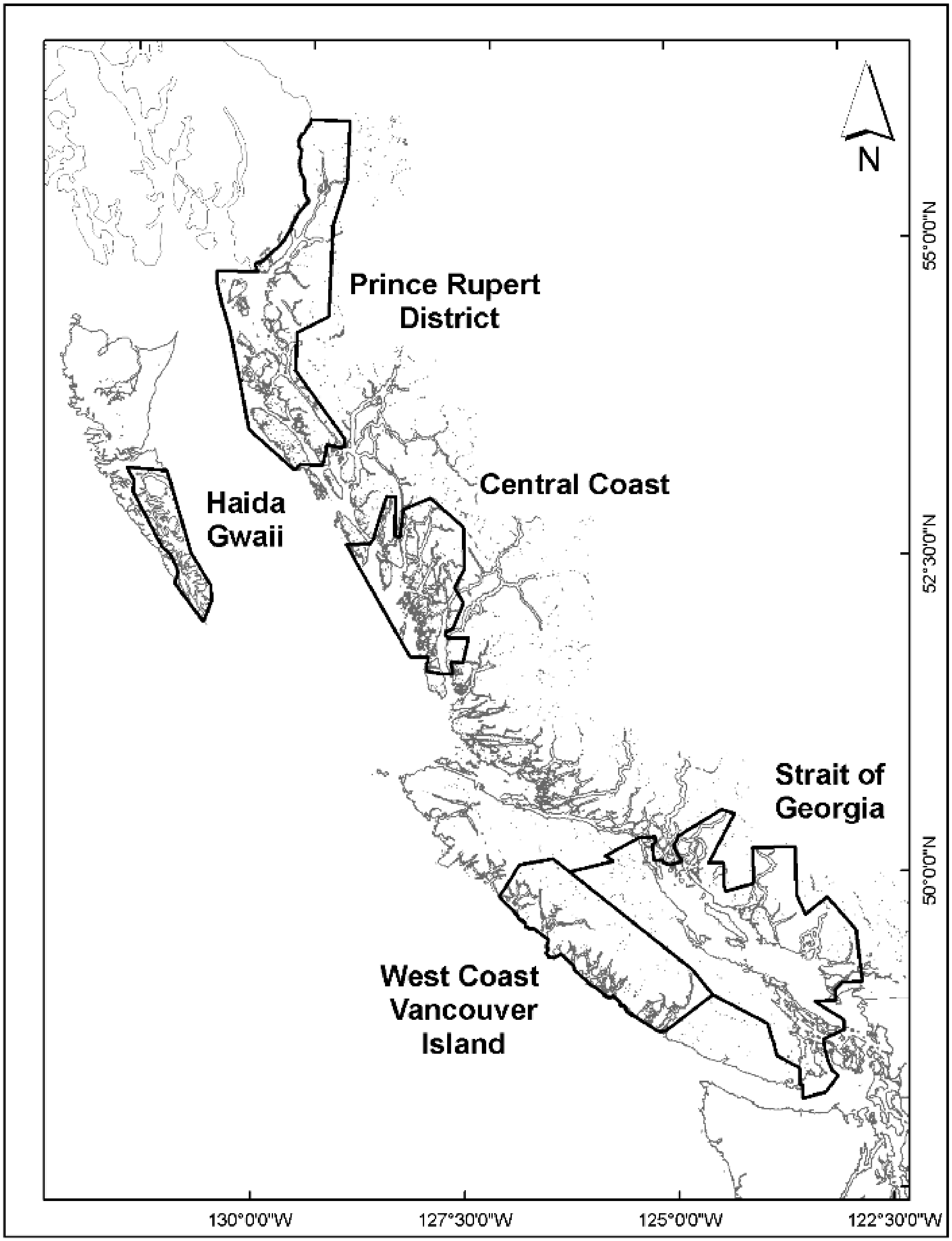


Figure 1. The five major British Columbia herring stock assessment areas.

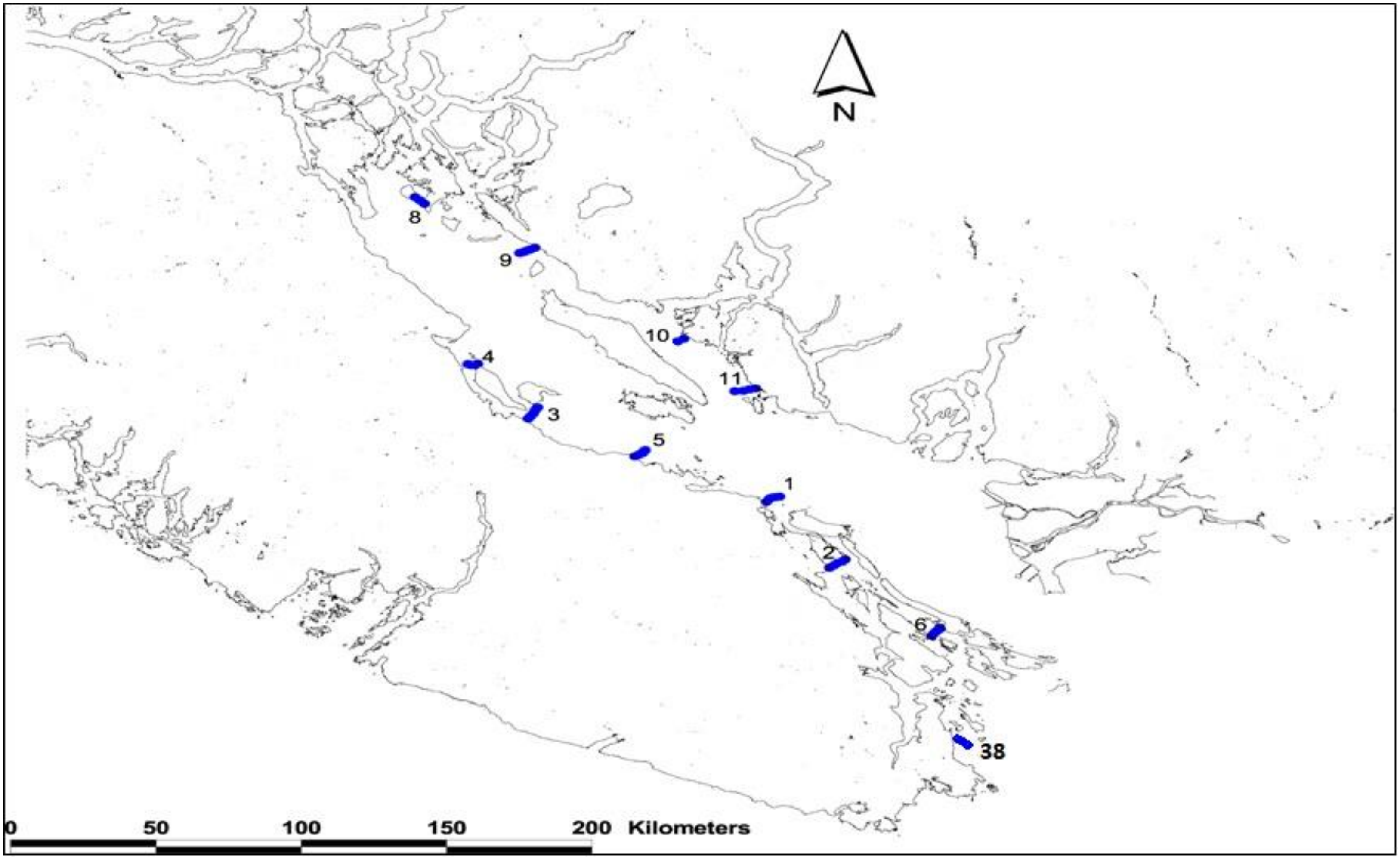


Figure 2. Purse seine set locations for the 2021 Strait of Georgia juvenile herring survey.

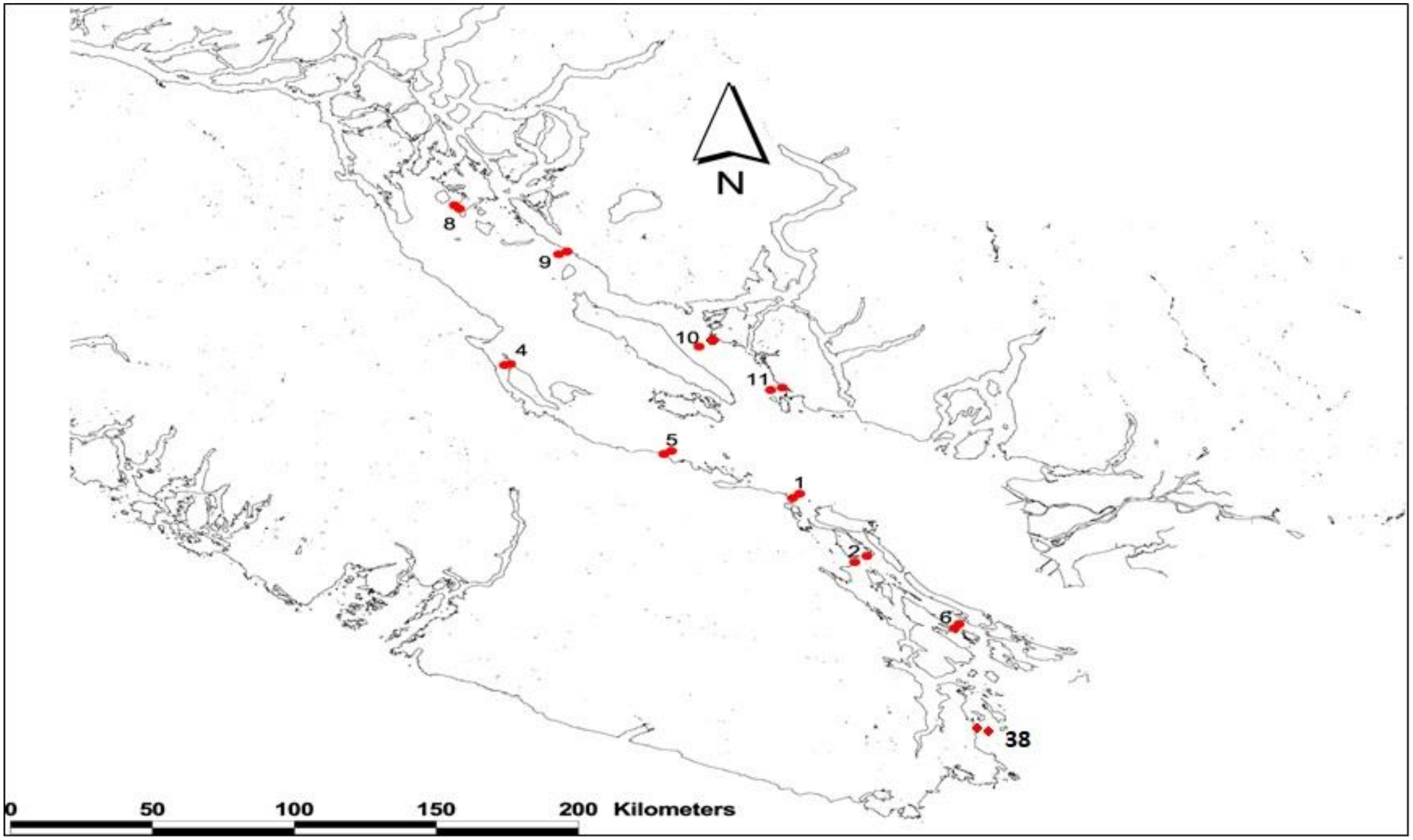


Figure 3. Zooplankton and CTD stations for the 2021 Strait of Georgia juvenile herring survey.

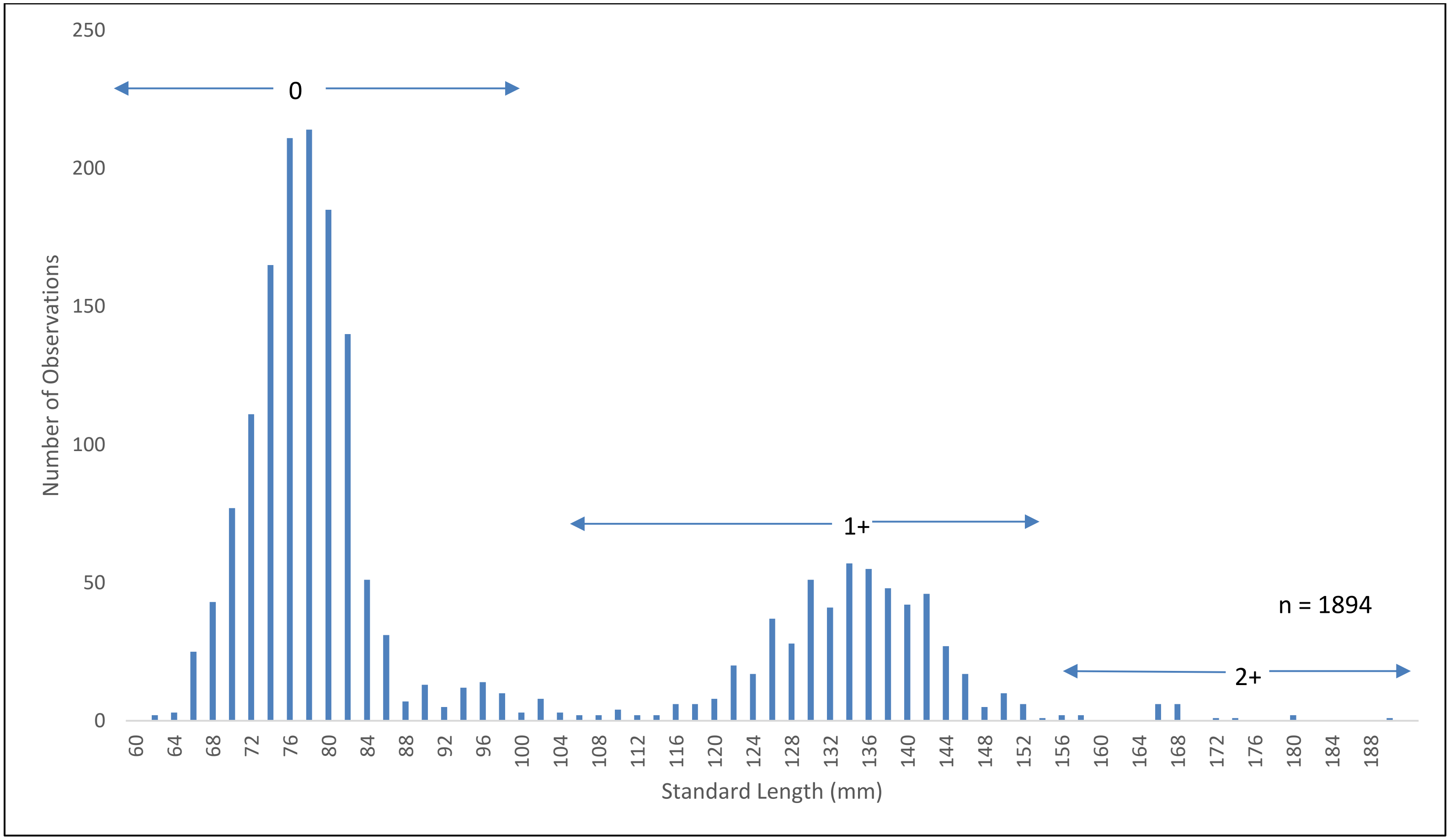
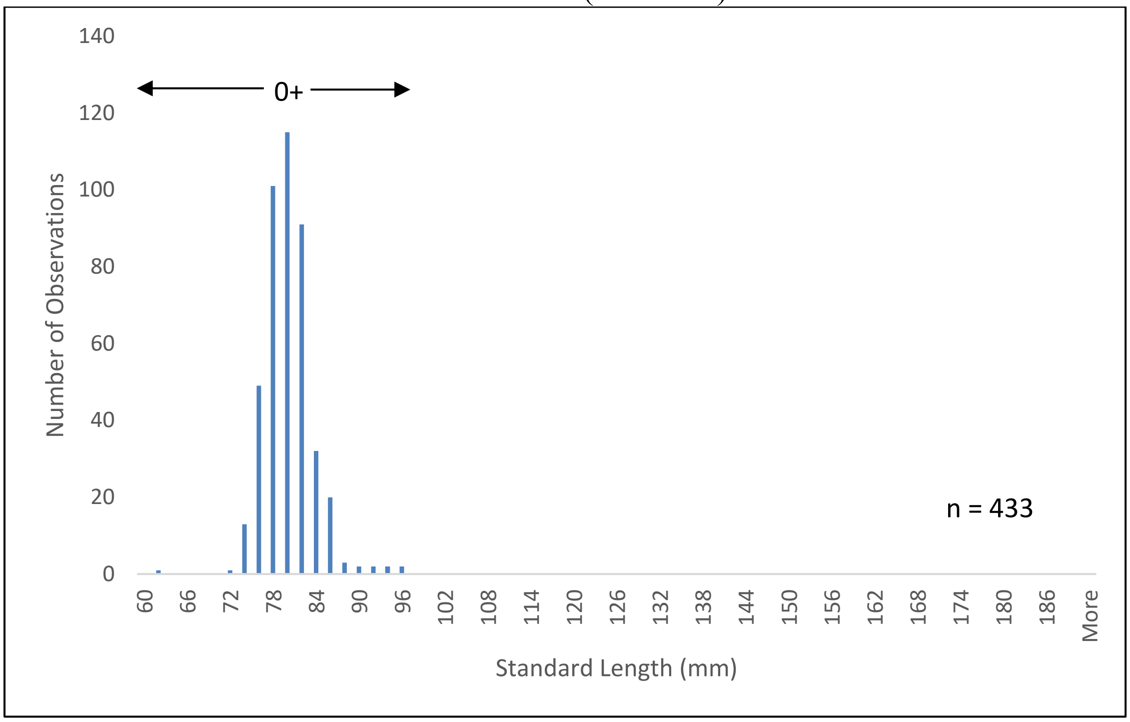


Figure 4. Length-frequency distribution for all herring sampled during the 2021 Strait of Georgia juvenile herring survey.

Yellow Point (transect 2)



Henry Bay (transect 4)

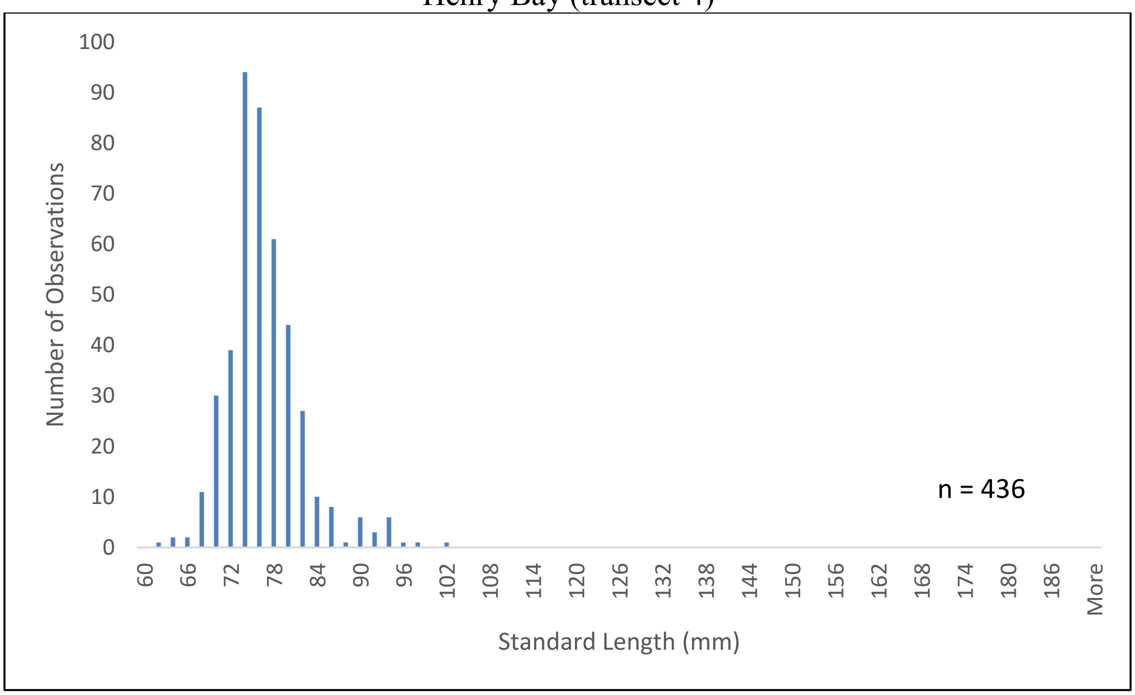
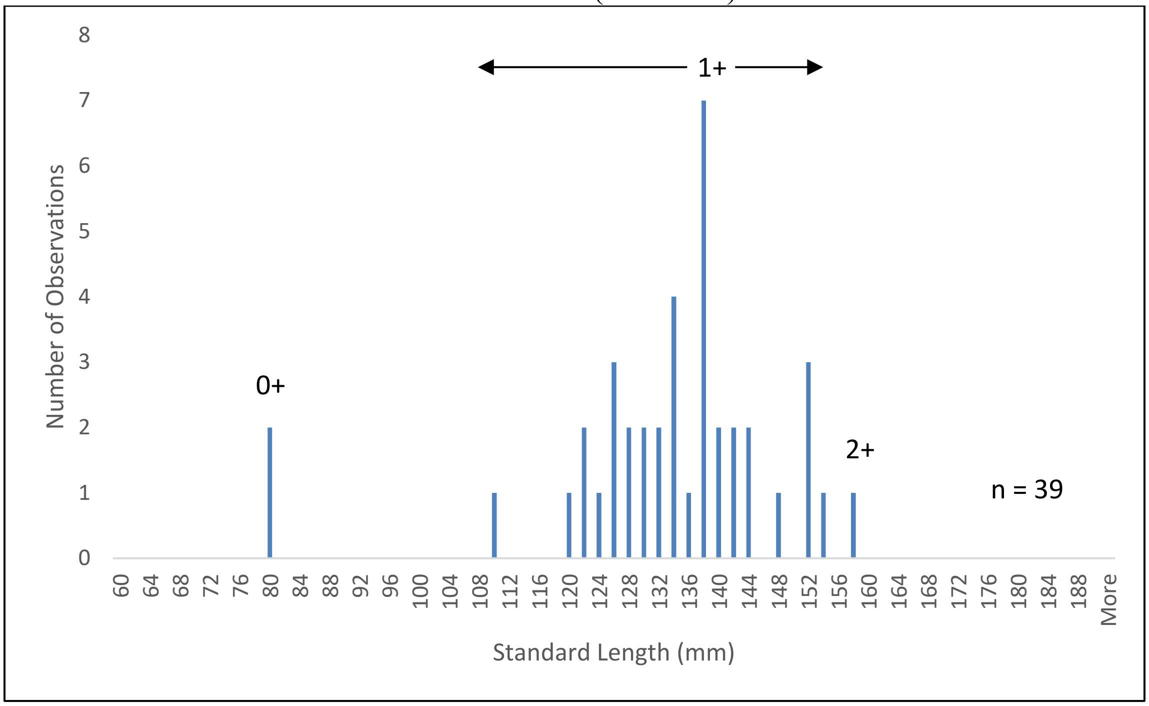


Figure 5. Length-frequency histograms of juvenile herring by transect location for the 2021 Strait of Georgia juvenile herring survey. Transects 1 and 11 are not shown because only 4 and 13 herring were caught, respectively.

French Creek (transect 5)



Trincomali Channel (transect 6)

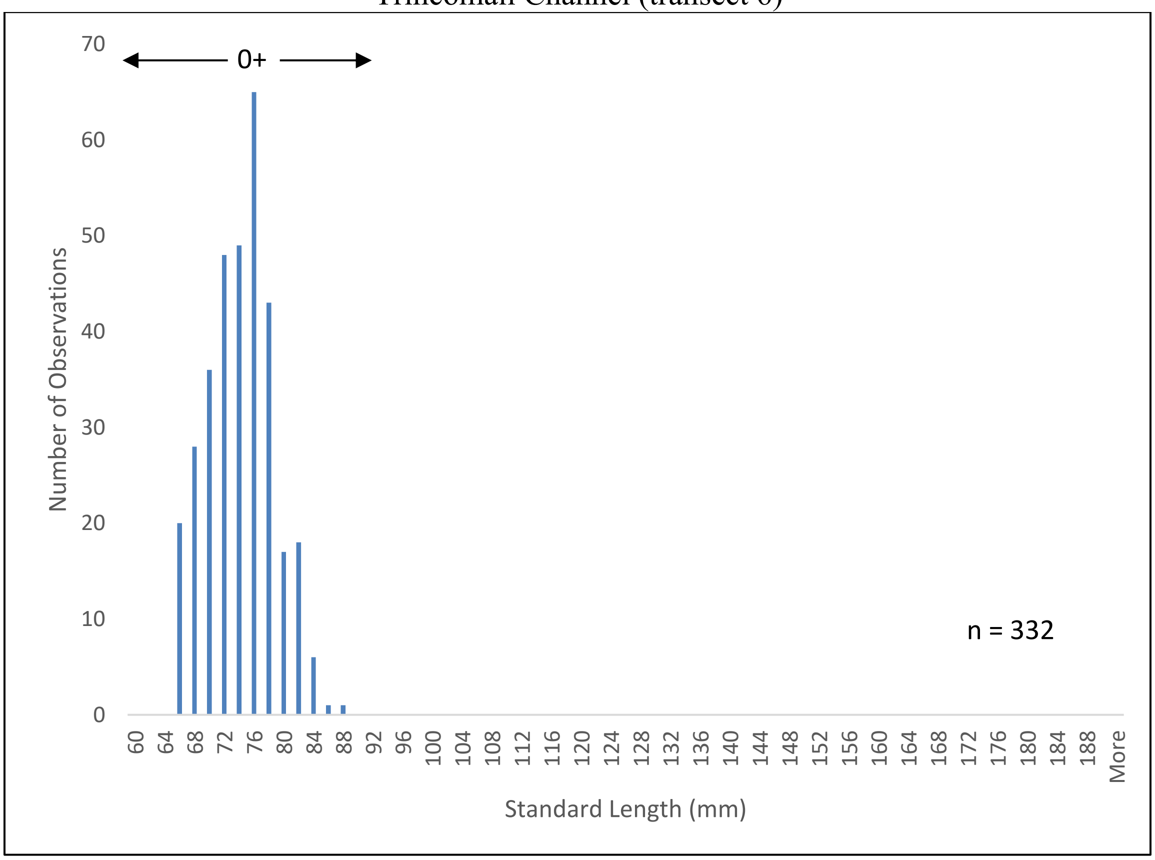
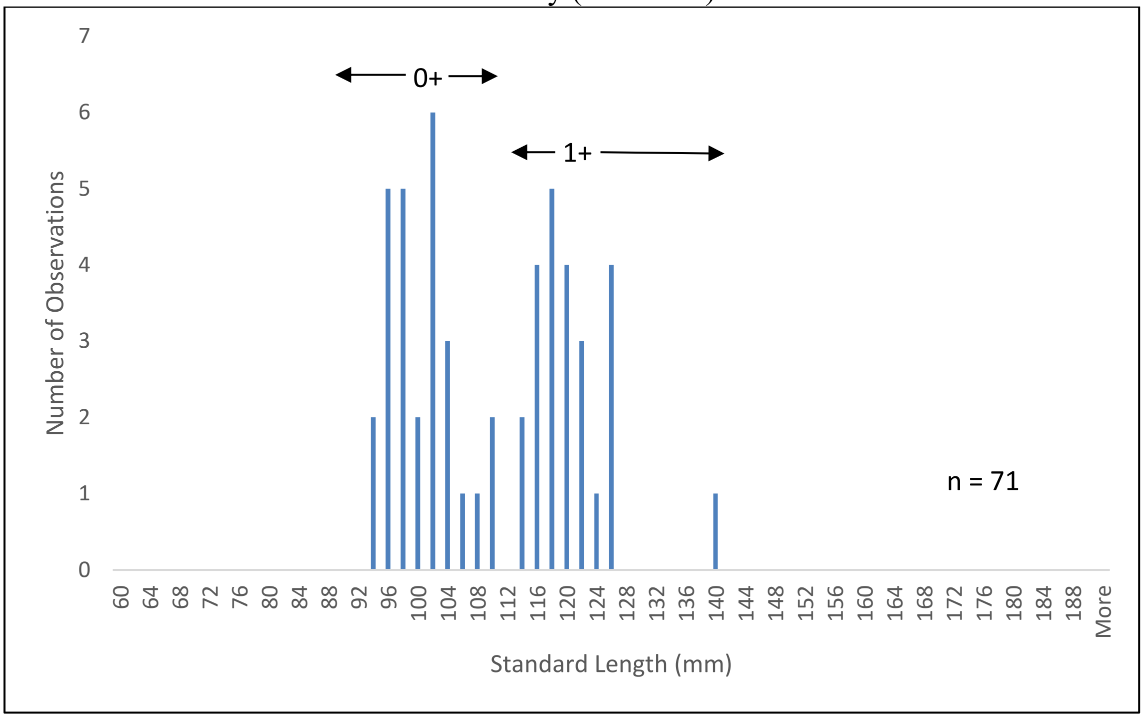


Figure 5 continued.

Smelt Bay (transect 8)



Atrevida Reef (transect 9)

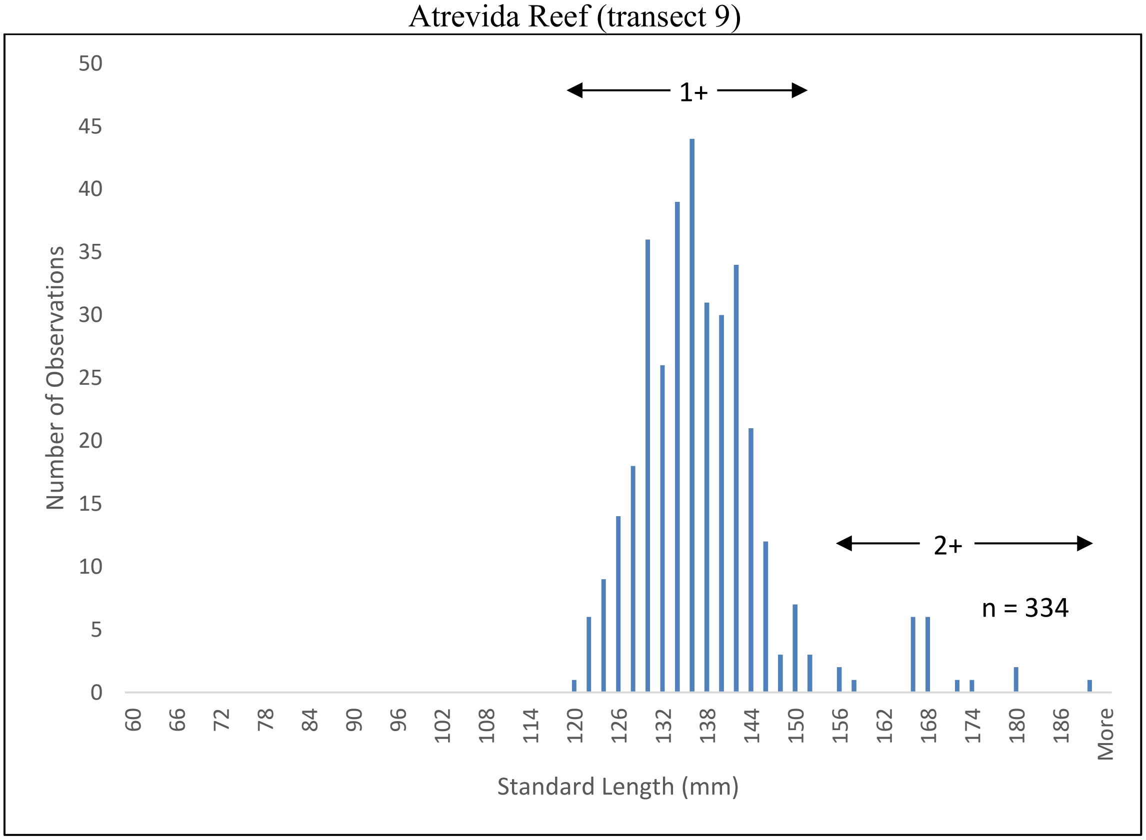
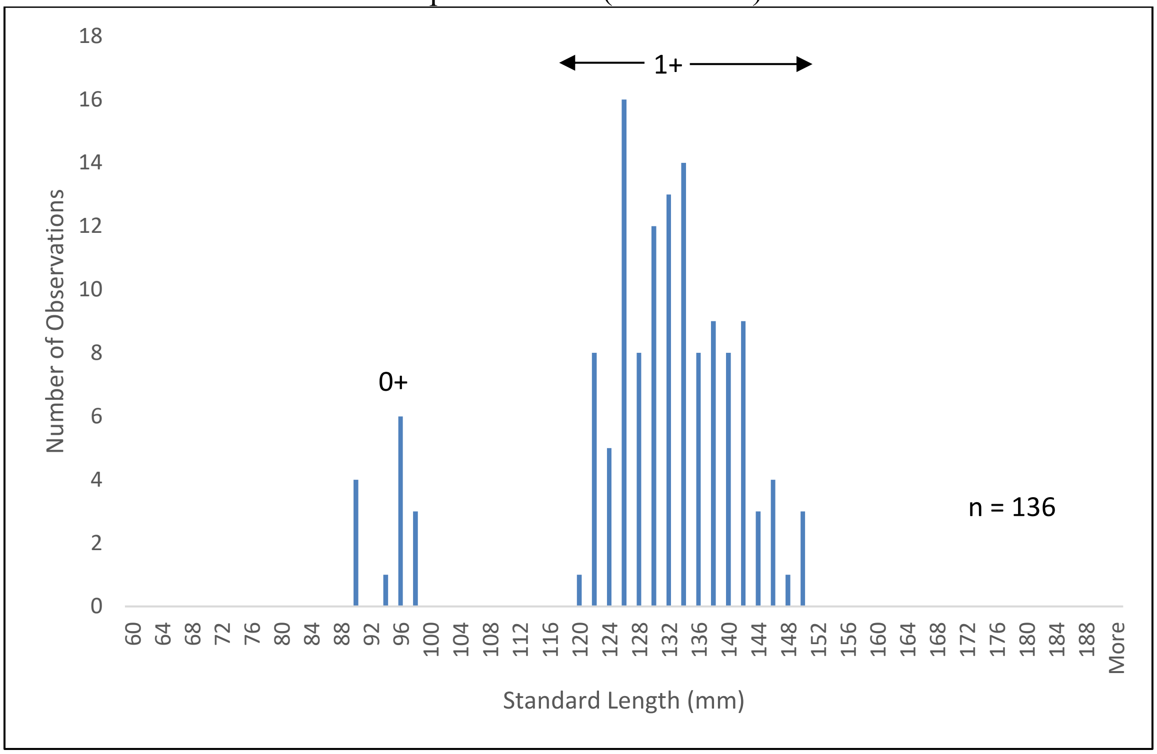


Figure 5 continued.

Cape Cockburn (transect 10)



Cowichan Head (transect 38)

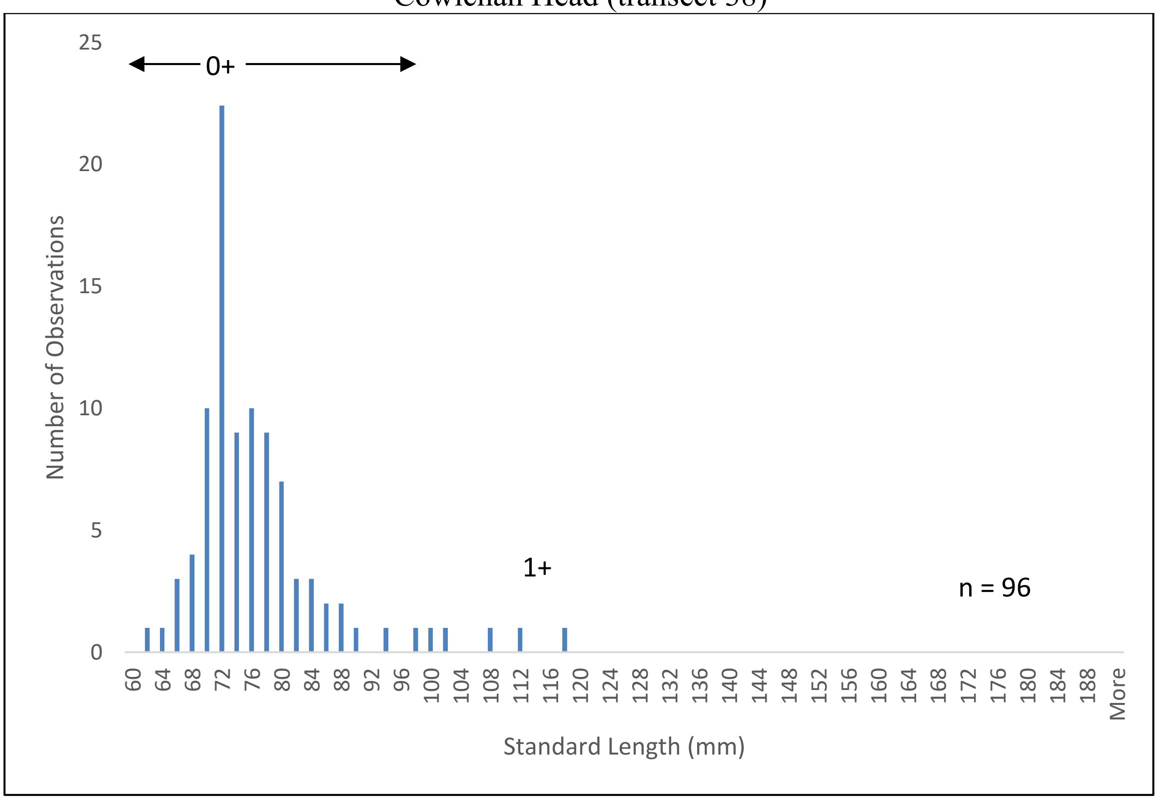


Figure 5 continued.

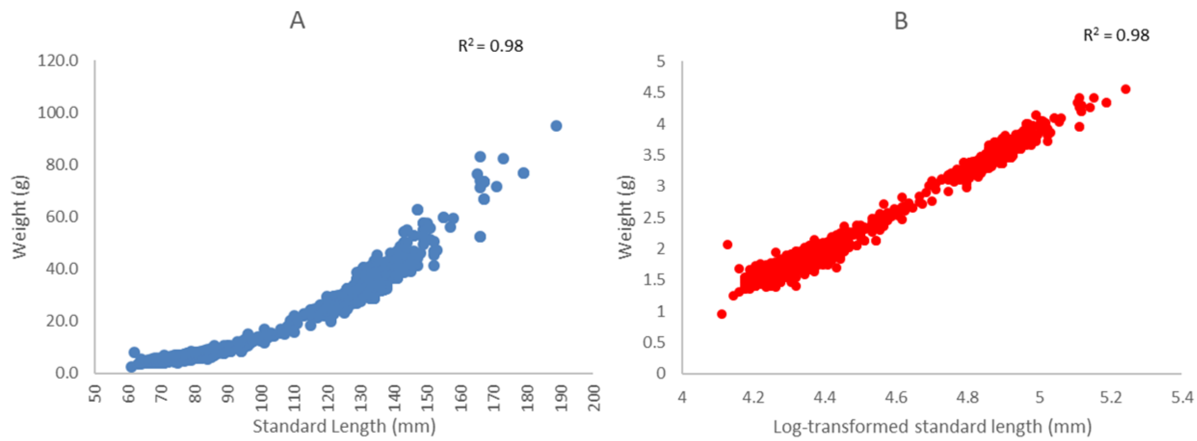


Figure 6. Non-transformed (A) and double log-transformed (B) length-weight relationships for all herring sampled during the 2021 Strait of Georgia juvenile herring survey.

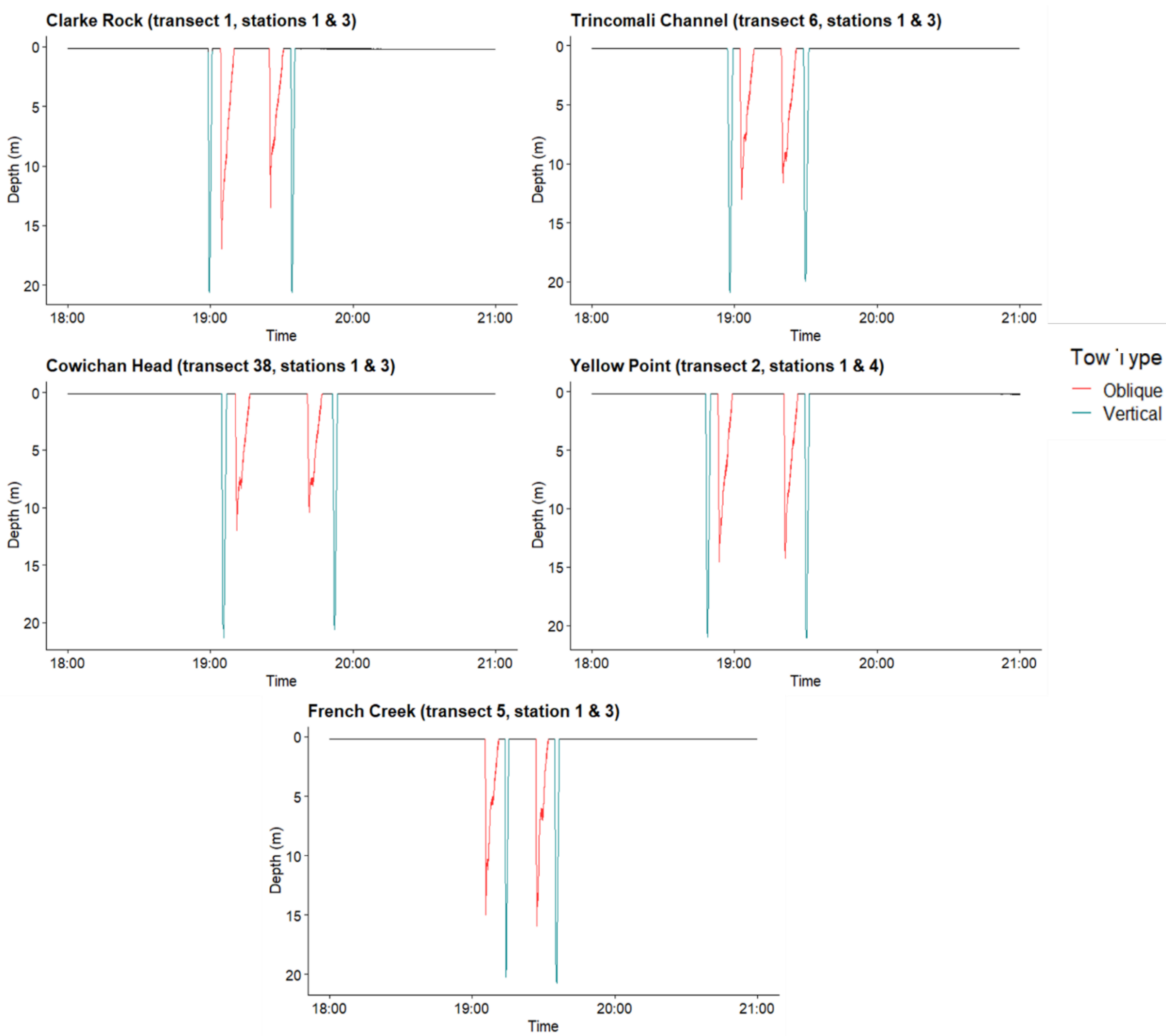


Figure 7. Daily RBR casts showing oblique and vertical bongo tows for the 2021 Strait of Georgia juvenile herring survey.

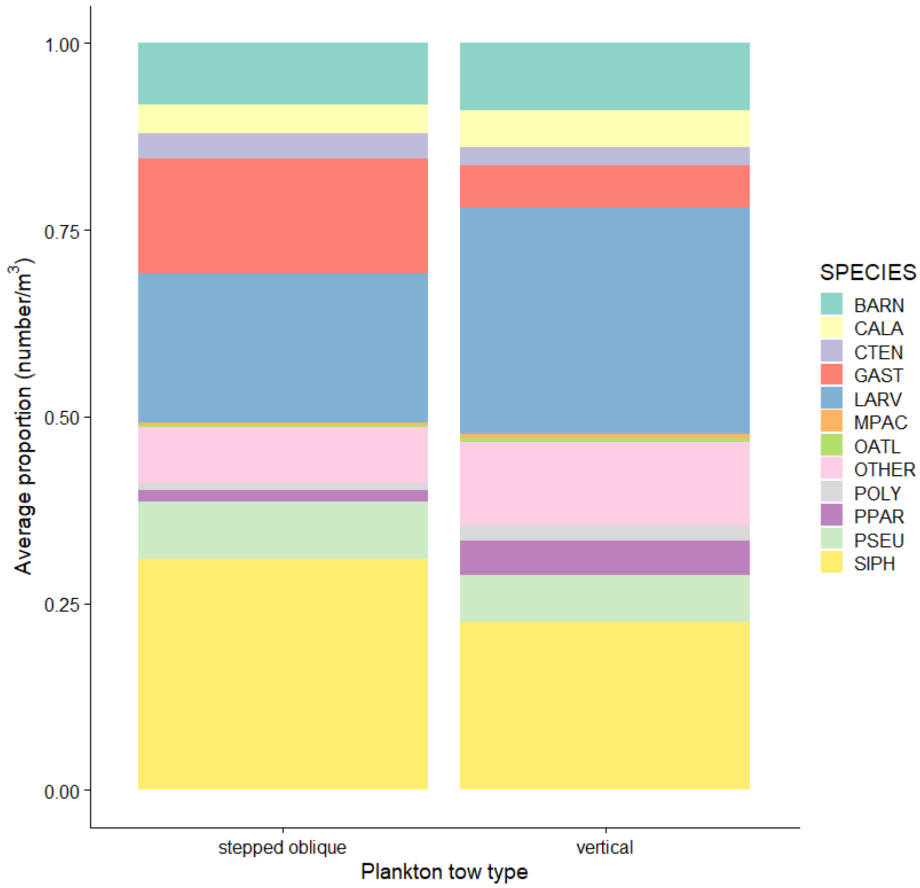


Figure 8. Average proportion zooplankton densities in oblique and vertical bongo tows from the 2021 Strait of Georgia juvenile herring survey (only major zooplankton taxonomic groups are shown in the legend; see Tables 5 and 6 for acronym definitions).

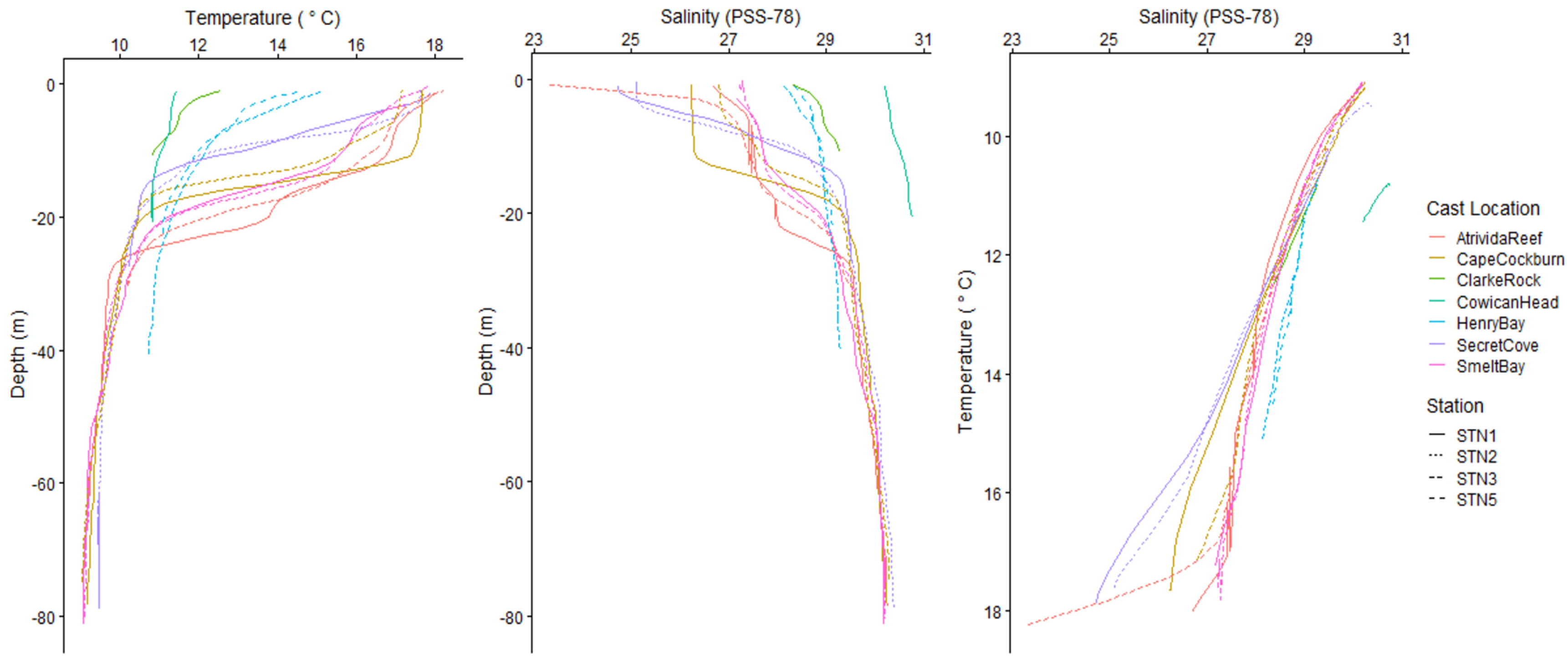


Figure 9. CTD cast locations (transect and station) from the 2021 Strait of Georgia juvenile herring survey. Shown are the relationships between temperature (ºC) and depth (m) (left panel), between salinity (PSS-78 or ppt) and depth (m) (middle panel), and between salinity (PSS-78 or ppt) and temperature (ºC) (right panel).

Table 1. Summary of the purse seine set locations from the 2021 Strait of Georgia juvenile herring survey. DD = decimal degrees.

Year	Month	Day	Transect	Station	Seine Set Time	Location Name	DD Lat (N)	DD Long (W)
2021	9	7	11	1	2040	Secret Cove	49.535	-123.977
2021	9	7	11	2	2115	Secret Cove	49.532	-123.995
2021	9	7	11	3	2150	Secret Cove	49.528	-124.014
2021	9	7	11	4	2235	Secret Cove	49.527	-124.040
2021	9	7	11	5	2300	Secret Cove	49.523	-124.060
2021	9	8	10	1	2105	Cape Cockburn	49.670	-124.198
2021	9	8	10	2	2135	Cape Cockburn	49.662	-124.218
2021	9	9	9	1	2035	Atrevida Reef	49.916	-124.659
2021	9	9	9	2	2105	Atrevida Reef	49.912	-124.673
2021	9	9	9	3	2130	Atrevida Reef	49.909	-124.684
2021	9	9	9	4	2200	Atrevida Reef	49.906	-124.694
2021	9	9	9	5	2230	Atrevida Reef	49.902	-124.707
2021	9	10	8	3	2015	Smelt Bay	50.054	-125.030
2021	9	10	8	2	2040	Smelt Bay	50.046	-125.016
2021	9	10	8	1	2110	Smelt Bay	50.036	-125.000
2021	9	13	4	5	2020	Henry Bay	49.602	-124.836
2021	9	13	4	4	2050	Henry Bay	49.598	-124.846
2021	9	13	4	3	2115	Henry Bay	49.598	-124.856
2021	9	13	4	2	2145	Henry Bay	49.601	-124.866
2021	9	13	4	1	2215	Henry Bay	49.593	-124.875
2021	9	19	1	1	2000	Clarke Rock	49.224	-123.943
2021	9	19	1	2	2030	Clarke Rock	49.233	-123.932
2021	9	19	1	3	2055	Clarke Rock	49.237	-123.922
2021	9	19	1	4	2120	Clarke Rock	49.237	-123.912
2021	9	19	1	5	2145	Clarke Rock	49.238	-123.902
2021	9	20	6	1	2005	Trincomali Channel	48.855	-123.430
2021	9	20	6	2	2025	Trincomali Channel	48.862	-123.423
2021	9	20	6	3	2100	Trincomali Channel	48.867	-123.417
2021	9	20	6	4	2125	Trincomali Channel	48.873	-123.407
2021	9	20	6	5	2155	Trincomali Channel	48.877	-123.407
2021	9	21	38	1	2015	Cowichan Head	48.564	-123.354
2021	9	21	38	2	2040	Cowichan Head	48.556	-123.332
2021	9	21	38	3	2115	Cowichan Head	48.548	-123.288
2021	9	21	38	4	2145	Cowichan Head	48.540	-123.288
2021	9	21	38	5	2215	Cowichan Head	48.532	-123.266

Year	Month	Day	Transect	Station	Seine Set Time	Location Name	DD Lat (N)	DD Long (W)
2021	9	22	2	1	2000	Yellow Point	49.042	-123.747
2021	9	22	2	2	2025	Yellow Point	49.050	-123.733
2021	9	22	2	3	2055	Yellow Point	49.056	-123.722
2021	9	22	2	4	2120	Yellow Point	49.060	-123.708
2021	9	22	2	5	2150	Yellow Point	49.066	-123.698
2021	9	23	5	1	2005	French Creek	49.348	-124.350
2021	9	23	5	2	2030	French Creek	49.353	-124.338
2021	9	23	5	3	2100	French Creek	49.358	-124.327
2021	9	23	5	4	2125	French Creek	49.362	-124.323
2021	9	23	5	5	2150	French Creek	49.366	-124.317

Table 2. Summary of the number and weight by species, transect, and station for the 2021 Strait of Georgia juvenile herring survey.

Transect	Station	Location Name	Species	Number	Weight (kg)*
1	1	Clarke Rock	**Pacific herring age-0+**	1	0.01
1	2	Clarke Rock	**Pacific herring age-1+**	2	0.07
			Chum salmon	1	0.15
			Coho salmon	13	3.97
1	3	Clarke Rock	**Pacific herring age-1+**	1	0.05
			Chum salmon	1	0.12
1	4	Clarke Rock	Chinook salmon	1	0.17
			Chum salmon	3	0.35
			Coho salmon	4	1.02
			Bay pipefish	1	trace
1	5	Clarke Rock	Chinook salmon	1	0.19
			Chum salmon	3	0.43
			Coho salmon	24	5.74
2	1	Yellow Point	**Pacific herring age-0+**	434	2.69
			Chum salmon	5	0.47
			Northern anchovy	43	0.07
			Bay pipefish	2	trace
			Shrimp	47	0.05
			Squid	56	0.14
2	2	Yellow Point	**Pacific herring age-0+**	3582	23.11
			Northern anchovy	666	3.11
			Pacific sand lance	9	0.03
			Squid	63	0.23
2	3	Yellow Point	**Pacific herring age-0+**	2653	16.67
			Northern anchovy	553	3.18
			Squid	224	0.52

Table 2 continued.

Transect	Station	Location Name	Species	Number	Weight (kg)*
2	4	Yellow Point	**Pacific herring age-0+**	165	1.05
			Chum salmon	5	0.29
			Northern anchovy	3675	18.94
			Sculpin	5	0.12
			Squid	40	0.06
			Three-spine stickleback	5	trace
2	5	Yellow Point	**Pacific herring age-0+**	369	2.30
			Chum salmon	2	0.18
			Plainfin midshipman	1	0.06
			Northern anchovy	63	0.27
			Pacific sand lance	1	trace
			Squid	93	0.21
			Three-spine stickleback	2	trace
			Tubesnout	1	trace
4	1	Henry Bay	**Pacific herring age-0+**	845	4.52
			Gunnel	26	0.14
			Plainfin midshipman	130	0.15
			Northern anchovy	8671	23.87
			Shiner perch	13	0.08
			Squid	338	1.11
			Three-spine stickleback	13	0.01
4	2	Henry Bay	**Pacific herring age-0+**	910	5.50
			Plainfin midshipman	26	0.03
			Northern anchovy	7722	30.64
			Squid	234	0.43
			Three-spine stickleback	13	0.01
4	3	Henry Bay	**Pacific herring age-0+**	2748	18.67
			Plainfin midshipman	39	0.28
			Northern anchovy	21	0.19
			Sculpin	3	0.11
			Snake prickleback	3	trace
			Squid	45	0.12

Table 2 continued.

Transect	Station	Location Name	Species	Number	Weight (kg)*
4	4	Henry Bay	**Pacific herring age-0+**	490	2.95
			Plainfin midshipman	30	0.07
			Northern anchovy	2	trace
			Squid	18	0.07
4	5	Henry Bay	**Pacific herring age-0+**	1192	7.47
			Plainfin midshipman	22	0.03
			Northern anchovy	8	0.06
			Shiner perch	2	0.01
			Squid	52	0.09
5	1	French Creek	Chinook salmon	2	0.09
			Chum salmon	22	2.57
			Squid	472	11.37
5	2	French Creek	**Pacific herring age-1+**	27	0.93
			Pacific herring age-2+	1	0.06
			Chinook salmon	10	1.02
			Chum salmon	4	0.38
			Coho salmon	1	0.18
			Plainfin midshipman	1	0.04
			Northern anchovy	2	0.01
			Squid	83	0.23
5	3	French Creek	**Pacific herring age-1+**	18	0.60
			Chinook salmon	4	0.51
			Chum salmon	50	7.30
			Coho salmon	14	2.92
			Squid	32	0.05
5	4	French Creek	**Pacific herring age-0+**	2	0.01
			Pacific herring age-1+	1	0.02
			Chinook salmon	1	0.36
			Chum salmon	3	0.41
5	5	French Creek	Coho salmon	3	0.62
6	1	Trincomali Channel	**Pacific herring age-0+**	79	0.44
			Chum salmon	1	0.07
			Northern anchovy	2	0.01
			Squid	7	0.02

Table 2 continued.

Transect	Station	Location Name	Species	Number	Weight (kg)*
6	2	Trincomali Channel	**Pacific herring age-0+**	2826	16.48
			Chinook salmon	9	0.52
			Northern anchovy	153	0.48
			Squid	54	0.14
6	3	Trincomali Channel	**Pacific herring age-0+**	700	3.81
			Chum salmon	21	1.35
			Northern anchovy	168	0.58
			Squid	56	0.10
			Three-spine stickleback	7	0.02
			Walleye pollock, juvenile	14	0.07
6	4	Trincomali Channel	**Pacific herring age-0+**	265	1.60
			Chum salmon	5	0.44
			Northern anchovy	90	0.36
			Pacific sand lance	5	0.01
			Squid	10	0.01
6	5	Trincomali Channel	**Pacific herring age-0+**	20	0.12
			Chum salmon	2	0.15
			Northern anchovy	4	0.01
			Pacific sand lance	1	trace
8	1	Smelt Bay	**Pacific herring age-0+**	4	0.05
			Pacific herring age-1+	3	0.06
			Chinook salmon	2	0.21
			Chum salmon	1	0.11
			Plainfin midshipman	2	0.02
			Bay pipefish	5	trace
			Squid	52	0.14
8	2	Smelt Bay	**Pacific herring age-0+**	10	0.14
			Pacific herring age-1+	9	0.24
8	3	Smelt Bay	**Pacific herring age-0+**	11	0.31
			Pacific herring age-1+	21	0.46
			Chinook salmon	9	0.65
			Squid	4	0.15

Table 2 continued.

Transect	Station	Location Name	Species	Number	Weight (kg)*
9	1	Atrevida Reef	**Pacific herring age-1+**	236	8.84
			Pacific herring age-2+	12	0.85
			Chum salmon	22	2.38
			Northern anchovy	4	0.01
9	2	Atrevida Reef	**Pacific herring age-1+**	468	17.66
			Pacific herring age-2+	15	1.07
			Chum salmon	24	2.74
			Hake, juvenile	3	0.22
9	3	Atrevida Reef	**Pacific herring age-1+**	146	5.43
			Pacific herring age-2+	5	0.40
			Chum salmon	8	0.92
			Plainfin midshipman	5	0.58
9	4	Atrevida Reef	**Pacific herring age-1+**	9	0.33
			Chum salmon	4	0.43
9	5	Atrevida Reef	**Pacific herring age-1+**	28	1.14
			Pacific herring age-2+	3	0.24
			Chum salmon	3	0.31
			Plainfin midshipman	2	0.02
			Sockeye salmon	1	1.96
			Three-spine stickleback	1	trace
10	1	Cape Cockburn	**Pacific herring age-0+**	42	0.47
			Pacific herring age-1+	462	15.65
			Chum salmon	18	2.12
10	2	Cape Cockburn	**Pacific herring age-1+**	44	1.55
			Chum salmon	6	0.58
			Pink salmon	1	1.38
11	1	Secret Cove	**Pacific herring age-1+**	3	0.06
			Chinook salmon	2	0.06
			Chum salmon	5	0.32
			Northern anchovy	2	0.05
			Pink salmon	4	5.69
			Three-spine stickleback	1	trace

Table 2 continued.

Transect	Station	Location Name	Species	Number	Weight (kg)*
11	2	Secret Cove	**Pacific herring age-1+**	20	0.55
			Chum salmon	4	0.20
			Hake, juvenile	4	0.11
			Northern anchovy	684	17.98
11	3	Secret Cove	**Pacific herring age-1+**	5	0.20
			Chum salmon	6	0.60
			Northern anchovy	104	2.89
11	4	Secret Cove	Hake, juvenile	2	0.01
			Northern anchovy	312	8.96
11	5	Secret Cove	Chinook salmon	1	0.04
			Chum salmon	4	0.37
			Coho salmon	1	0.19
			Hake, juvenile	80	0.63
			Northern anchovy	59	1.53
38	1	Cowichan Head	**Pacific herring age-0+**	7	0.04
			Chinook salmon	3	0.22
			Gunnel	1	0.01
			Northern anchovy	2	trace
			Bay pipefish	2	trace
			Snake prickleback	1	trace
			Squid	17	0.03
38	2	Cowichan Head	**Pacific herring age-0+**	13	0.10
			Pacific herring age-1+	3	0.06
			Northern anchovy	2	trace
			Shrimp	5	0.03
			Snake prickleback	3	trace
			Squid	6	0.01
38	3	Cowichan Head	**Pacific herring age-0+**	7	0.05
			Shrimp	871	1.28
			Snake prickleback	1	trace
			Walleye pollock, juvenile	3	0.02

Table 2 continued.

Transect	Station	Location Name	Species	Number	Weight (kg)*
38	4	Cowichan Head	**Pacific herring age-0+**	2	0.01
			Shrimp	485	0.40
			Squid	1	trace
38	5	Cowichan Head	**Pacific herring age-0+**	64	0.35
			Chum salmon	7	0.44
			Shrimp	41	0.04

Table 3. Percent occurrence by species in purse seine sets for the Strait of Georgia juvenile herring survey in 2021.

Common Name	Scientific Name	Number of sets	Percent Occurrence
Pacific herring age-0+	*Clupea pallasii* in year of birth	26	57.8
Pacific herring age-1+	*Clupea pallasii* in first year	19	42.2
Pacific herring age-2+	*Clupea pallasii* in second or more years	5	11.1
Bay pipefish	*Syngnathus griseolineatus*	4	8.9
Chinook salmon	*Oncorhyncus tshawytscha*	12	26.7
Chum salmon	*Oncorhyncus keta*	28	62.2
Coho salmon	*Oncorhyncus kisutch*	7	15.6
Gunnel	*Apodichthys flavidus or Pholis laeta*	2	4.4
Hake, juvenile	*Merluccius productus*	4	8.9
Northern anchovy	*Engraulis mordax mordax*	24	53.3
Pacific sand lance	*Ammodytes hexapterus*	4	8.9
Pink salmon	*Oncorhyncus gorbuscha*	2	4.4
Plainfin midshipman	*Porichthys notatus*	10	22.2
Sculpin	*Leptocottus armatus or Hemilepidotus hemilepidotus*	2	4.4
Shiner perch	*Cymatogaster aggregata*	2	4.4
Shrimp	*Pandalus borealis*	5	11.1
Snake prickleback	*Lumpenus sagitta*	4	8.9
Sockeye salmon	*Oncorhynchus nerka*	1	2.2
Squid	*Loligo opalescens,* or *Gonatus fabricii*	22	48.9
Three-spine stickleback	*Gasterosteus aculeatus*	7	15.6
Tubesnout	*Aulorhynchus flavidus*	1	2.2
Walleye pollock, juvenile	*Gadus chalcogrammus*	2	4.4

* 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 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 2021 Strait of Georgia juvenile herring survey. Total catch in numbers (N) and weight (Wt) of all herring are shown for each transect.

Age-0+ Herring

			Length (mm)			Weight (g)				
Location Name	**Transect**	**Number Sampled**	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**N**	**Wt (Kg)**
Clarke Rock	1	1	81	-	-	6.5	-	-	1	0.01
Yellow Point	2	433	71-96	80	3.32	4.9-11.6	6.44	0.67	7203	45.81
Henry Bay	4	435	62-102	76	5.30	3.72-14.7	6.36	1.32	6185	39.11
French Creek	5	2	79-80	80	0.71	6.6-8	7.30	0.99	2	0.01
Trincomali	6	332	65-87	74	4.48	3.9-9.6	5.80	1.02	3890	22.45
Smelt Bay	8	23	94-104	99	3.17	10.28-16.97	13.21	1.58	25	0.35
Atrevida Reef	9	-	-	-	-	-	-	-	-	-
Cape Cockburn	10	14	89-97	94	2.94	9.47-13.02	11.19	1.03	42	0.47
Secret Cove	11	-	-	-	-	-	-	-	-	-
Cowichan Head	38	93	61-102	75	7.34	2.6-13.9	5.84	1.97	93	0.54
All Locations		1333	61-104	77	6.19	2.60-16.97	6.38	1.56	17441	108.75

Age-1+ Herring

			Length (mm)			Weight (g)				
Location Name	**Transect**	**Number Sampled**	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**N**	**Wt (Kg)**
Clarke Rock	1	3	124-144	136	10.41	28.00-54.9	41.03	13.47	3	0.12
Yellow Point	2	-	-	-	-	-	-	-	-	-
Henry Bay	4	-	-	-	-	-	-	-	-	-
French Creek	5	37	110-153	135	9.88	21.00-50.7	33.78	7.31	46	1.55
Trincomali	6	-	-	-	-	-	-	-	-	-
Smelt Bay	8	28	106-140	119	6.84	15.2-40.5	25.41	4.90	33	0.79
Atrevida Reef	9	334	119-152	135	6.45	22.3-62.7	37.78	6.58	887	33.39
Cape Cockburn	10	122	120-150	133	7.10	19.8-57.6	33.82	7.14	506	17.19
Secret Cove	11	13	106-146	125	13.31	15.6-46.8	30.54	11.46	28	0.81
Cowichan Head	38	3	108-117	112	4.58	18.2-21.5	19.63	1.69	3	0.06
All Locations		540	106-153	133	8.30	15.20-62.70	35.71	7.62	1503	53.79

Table 4 continued.

Age-2+ Herring

			Length (mm)			Weight (g)				
Location Name	**Transect**	**Number Sampled**	**Range**	**Mean**	**SD**	**Range**	**Mean**	**SD**	**N**	**Wt (Kg)**
Clarke Rock	1	-	-	-	-	-	-	-	-	-
Yellow Point	2	-	-	-	-	-	-	-	-	-
Bowser	3	-	-	-	-	-	-	-	-	-
Henry Bay	4	1	157	-	-	56.1	-	-	1	0.06
French Creek	5	-	-	-	-	-	-	-	-	-
Trincomali	6	-	-	-	-	-	-	-	-	-
Smelt Bay	8	20	155-189	168	7.91	52.3-95.1	70.95	10.52	35	2.56
Atrevida Reef	9	-	-	-	-	-	-	-	-	-
Cape Cockburn	10	-	-	-	-	-	-	-	-	-
Secret Cove	11	-	-	-	-	-	-	-	-	-
All Locations		21	155-189	167	8.06	52.30-95.10	70.25	10.75	36	2.61

Table 5. Organisms by phylum, and with abbreviations, observed in zooplankton samples collected during the 2021 Strait of Georgia juvenile herring survey.

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

Table 6. Abbreviations for calanoid and cyclopoid copepods identified in the 2021 zooplankton samples from the Strait of Georgia juvenile herring survey.

Calanoid copepods	
ACLA	*Acartia clausi*
ALON	*Acartia longiremis*
CABD	*Centropages abdominates*
CALA	*Calanus sp.*
EBUN	*Eucalanus bungii*
ELON	*Epilabidocera longipedata*
MPAC	*Metridia pacifica*
PPAR	*Paracalanus parvus*
PSEU	*Pseudocalanus sp.*
SMIN	*Scolecithricella minor*
TDIS	*Tortanus discaudatus*
UCAL	Unidentified calanoid copepod
Cyclopoid copepods	
CANG	*Corycaeus anglicus*
OATL	*Oithona atlantica*
OBOR	*Oncaea borealis*
OSIM	*Oithona similis*

Table 7. Volume of water filtered and number of zooplankton per m^3 of water in oblique tow samples collected during the 2021 Strait of Georgia juvenile herring survey. Species codes as shown in Tables 5 and 6.

Location	Tran	Stn	Volume (m^3)	ALON	AMPH	BARN	CALA	CANG	CHAE	CLAD	CNAU
Clarke Rock	1	1	12.372	-	2.34	0.73	0.65	0.81	0.16	-	-
		3	9.265	-	0.76	0.11	5.18	0.43	0.43	-	-
Yellow Point	2	1	8.550	-	-	112.28	74.85	9.36	-	-	1.87
		4	8.264	-	3.87	158.76	67.77	19.36	-	-	1.94
Henry Bay	4	3	4.970	-	1.61	140.05	0.20	-	-	22.54	-
		5	2.283	-	-	518.73	7.01	3.50	-	14.02	-
French Creek	5	1	8.239	0.49	2.91	7.77	6.31	0.49	-	3.88	-
		3	9.846	0.81	5.69	8.94	8.13	-	-	-	-
Trincomali Ch	6	1	10.736	-	10.80	317.44	14.90	47.69	1.49	-	1.49
		3	11.076	4.33	2.89	174.80	5.78	70.79	1.44	-	-
Smelt Bay	8	1	5.670	2.82	0.71	22.58	22.58	5.64	-	-	-
		2	3.236	-	19.78	-	8.65	-	-	-	-
Atrevida Reef	9	1	12.474	2.57	4.33	0.32	15.39	-	-	0.64	-
		3	12.356	5.18	11.33	0.16	233.09	-	-	0.16	-
Cape Cockburn	10	1	8.060	0.50	1.49	0.50	8.93	0.50	-	0.62	-
		3	11.211	-	13.65	0.09	239.76	-	0.09	-	-
Secret Cove	11	1	8.609	-	27.88	42.75	6.50	2.79	-	63.19	0.93
		3	5.520	0.36	2.90	3.99	3.62	2.90	-	8.33	0.36
Cowichan Head	38	1	11.873	-	22.91	102.42	47.17	45.82	0.42	-	1.35
		3	11.858	-	7.42	6.75	8.10	67.46	26.31	0.67	5.40

Table 7 continued.

Location	Tran	Stn	COEL	CRAM	CRAZ	CTEN	EBUN	ECHI	ECTO	EGGS	ELON	EUPL	GAST
Clarke Rock	1	1	-	-	-	-	-	-	-	-	-	-	1.54
		3	-	-	-	-	-	-	-	-	-	-	0.54
Yellow Point	2	1	24.09	-	3.74	7.25	-	3.74	3.74	3.74	-	3.74	26.20
		4	28.80	-	-	11.37	-	-	7.74	-	-	3.87	23.23
Henry Bay	4	3	18.11	-	1.61	3.22	-	1.61	-	-	-	-	19.32
		5	199.34	-	-	5.26	-	-	-	-	-	-	168.24
French Creek	5	1	3.88	-	0.49	2.43	-	0.97	0.49	-	-	-	54.38
		3	5.69	-	1.63	2.44	0.81	0.81	-	-	0.81	-	28.44
Trincomali Ch	6	1	4.19	-	1.49	1.49	-	1.49	-	1.49	-	5.96	13.41
		3	1.17	-	3.16	1.44	-	-	1.44	1.44	-	1.44	13.00
Smelt Bay	8	1	19.05	0.71	11.29	180.61	-	62.08	-	-	-	-	1817.38
		2	71.70	2.47	59.34	417.85	-	69.23	-	-	-	9.89	830.76
Atrevida Reef	9	1	2.08	-	0.64	5.29	-	10.58	-	-	-	5.77	14.75
		3	2.35	0.16	1.62	7.85	-	2.91	0.16	-	-	1.62	22.66
Cape Cockburn	10	1	0.12	-	0.50	1.49	-	0.12	-	-	-	0.37	2.48
		3	0.36	-	0.45	1.43	-	0.98	-	-	-	21.76	-
Secret Cove	11	1	3.72	-	1.86	-	-	-	1.86	11.15	-	1.86	5.58
		3	1.81	-	1.09	0.36	-	-	-	9.06	-	1.45	7.25
Cowichan Head	38	1	3.79	-	4.46	-	-	-	-	1.35	-	9.43	9.43
		3	0.08	-	-	-	-	-	0.34	0.67	-	1.35	3.04

Table 7 continued.

Location	Tran	Stn	LARV	MPAC	MYSI	OATL	OBOR	OSIM	OSTR	PELE	POLY	PPAR
Clarke Rock	1	1	1.45	6.47	-	23.44	-	2.10	-	0.08	-	0.32
		3	0.11	44.04	-	34.54	-	3.02	0.11	-	-	-
Yellow Point	2	1	258.24	-	-	1.87	-	3.74	-	-	-	11.23
		4	286.55	-	-	-	-	-	-	-	7.74	15.49
Henry Bay	4	3	123.95	-	-	-	-	-	-	-	3.22	1.41
		5	1373.93	-	-	-	-	35.05	-	-	42.06	31.54
French Creek	5	1	75.26	0.24	-	0.97	0.73	7.53	-	-	8.74	1.70
		3	101.56	11.17	-	2.44	-	8.13	-	-	0.81	13.00
Trincomali Ch	6	1	149.03	-	-	-	4.47	4.47	-	-	14.90	7.45
		3	173.35	-	-	-	2.89	-	-	1.44	8.67	4.33
Smelt Bay	8	1	372.51	-	-	-	-	-	-	-	33.86	39.51
		2	336.26	-	-	-	-	-	-	9.89	59.34	2.47
Atrevida Reef	9	1	22.13	-	-	-	-	25.65	-	-	-	28.22
		3	10.04	-	-	5.18	5.18	-	-	-	0.16	72.52
Cape Cockburn	10	1	45.28	-	-	0.99	-	0.50	-	-	-	9.43
		3	7.31	-	-	-	-	5.71	-	-	-	11.42
Secret Cove	11	1	330.82	0.93	-	4.65	-	15.80	-	1.86	1.86	13.01
		3	118.11	-	-	-	-	2.54	-	-	-	11.23
Cowichan Head	38	1	99.72	1.35	0.17	-	1.35	-	2.70	-	13.48	10.78
		3	50.60	-	-	-	-	-	-	0.34	1.69	2.70

Table 7 continued.

Location	Tran	Stn	PSEU	SHRI	SIPH	SMIN	TDIS	TELA	UCAL
Clarke Rock	1	1	9.38	0.32	1.21	0.65	-	-	0.16
		3	7.77	-	-	6.48	-	-	-
Yellow Point	2	1	-	-	580.10	-	-	-	-
		4	-	-	730.90	-	-	-	-
Henry Bay	4	3	0.80	1.61	435.45	-	0.40	-	-
		5	-	0.44	1631.54	-	-	-	-
French Creek	5	1	14.57	3.88	15.54	-	-	-	-
		3	0.81	0.81	48.75	-	0.81	-	-
Trincomali Ch	6	1	4.47	1.49	79.55	-	-	-	1.49
		3	10.11	1.44	7.22	-	4.33	-	-
Smelt Bay	8	1	110.06	34.57	870.59	-	-	-	-
		2	11.13	255.90	1634.33	-	-	-	-
Atrevida Reef	9	1	156.49	1.04	7.70	-	-	0.08	-
		3	683.73	2.59	3.08	-	-	-	-
Cape Cockburn	10	1	4.47	0.37	1.12	-	-	-	-
		3	371.05	0.09	3.30	-	-	0.27	-
Secret Cove	11	1	3.72	13.01	-	-	-	-	-
		3	6.52	2.90	0.36	0.36	-	-	-
Cowichan Head	38	1	41.78	12.13	61.23	-	8.09	-	-
		3	86.35	2.02	14.84	-	13.49	-	-

Table 8. Volume of water filtered and number of zooplankton per m^3 of water in vertical tow samples collected during the 2021 Strait of Georgia juvenile herring survey. Species codes as shown in Tables 5 and 6.

Location	Tran	Stn	Volume (m^3)	ACLA	ALON	AMPH	BARN	CABD	CALA	CANG	CHAE	CLAD
Clarke Rock	1	1	0.567	-	-	7.05	-	-	-	-	-	1.76
		3	0.567	-	-	3.53	1.76	-	14.11	1.76	1.76	-
Yellow Point	2	1	0.567	-	-	-	239.83	-	345.64	126.97	-	-
		4	0.567	-	-	-	239.83	-	169.30	112.86	-	-
Henry Bay	4	3	0.567	-	-	-	395.02	-	28.22	7.05	-	-
		5	0.567	-	-	-	902.91	-	14.11	-	-	-
French Creek	5	1	0.567	-	-	14.11	17.63	-	22.93	1.76	-	3.53
		3	0.567	-	-	35.27	12.34	-	10.58	10.58	-	-
Trincomali Ch	6	1	0.567	-	-	28.22	1975.11	14.11	169.30	253.94	-	-
		3	0.567	-	-	28.22	81.12	-	42.32	42.32	1.76	-
Smelt Bay	8	1	0.567	1.76	-	-	-	-	98.76	5.29	-	-
		2	0.567	-	-	14.11	14.11	-	211.62	14.11	-	-
Atrevida Reef	9	1	0.567	-	7.05	28.22	14.11	-	112.86	-	-	-
		3	0.567	-	-	24.69	3.53	-	761.83	84.65	-	-
Cape Cockburn	10	1	0.567	--	-	10.58	3.53	-	81.12	1.76	-	-
		3	0.567	-	-	7.05	1.76	-	179.88	3.53	-	-
Secret Cove	11	1	0.567	3.53	-	3.53	81.12	-	24.69	24.69	-	132.26
		3	0.567	-	-	3.53	17.63	-	17.63	21.16	-	17.63
Cowichan Head	38	1	0.567	-	-	28.22	56.43	-	17.63	59.96	14.11	1.76
		3	0.567	-	-	169.30	641.91	-	253.94	225.73	-	-

Table 8 continued.

Location	Tran	Stn	CNAU	COEL	CRAM	CRAZ	CTEN	EBUN	ECHI	ECTO	EGGS	EUPL	GAST
Clarke Rock	1	1	-	-	-	-	-	1.76	-	-	-	-	3.53
		3	-	-	-	-	-	-	-	-	-	1.76	-
Yellow Point	2	1	-	98.76	-	14.11	42.32	-	14.11	-	14.11	14.11	98.76
		4	14.11	70.54	-	28.22	28.22	-	-	28.22	-	-	28.22
Henry Bay	4	3	14.11	366.81	-	-	84.65	-	648.96	56.43	-	-	423.24
		5	7.05	366.81	-	-	112.86	-	112.86	28.22	-	-	225.73
French Creek	5	1	-	3.53	-	-	10.58	-	3.53	-	-	-	98.76
		3	-	8.82	-	3.53	-	-	8.82	-	-	1.76	22.93
Trincomali Ch	6	1	14.11	1.76	-	28.22	-	-	-	-	-	28.22	141.08
		3	1.76	8.82	-	1.76	8.82	-	5.29	-	1.76	1.76	22.93
Smelt Bay	8	1	-	38.80	3.53	12.34	345.64	-	-	-	-	1.76	1.76
		2	-	28.22	8.82	67.01	599.59	-	931.12	-	-	44.09	1622.41
Atrevida Reef	9	1	-	3.53	-	10.58	37.03	-	112.86	-	-	31.74	56.43
		3	3.53	3.53	3.53	7.05	14.11	-	-	-	-	56.43	141.08
Cape Cockburn	10	1	-	5.29	-	5.29	8.82	-	-	-	-	7.05	7.05
		3	-	-	-	1.76	1.76	-	7.05	-	-	33.51	1.76
Secret Cove	11	1	-	-	-	-	10.58	-	-	-	10.58	7.05	35.27
		3	3.53	7.05	-	7.05	-	-	3.53	-	10.58	7.05	3.53
Cowichan Head	38	1	-	5.29	-	-	-	-	-	-	1.76	1.76	7.05
		3	-	14.11	-	35.27	-	-	-	-	7.05	84.65	56.43

Table 8 continued.

Location	Tran	Stn	LARV	MPAC	OATL	OBOR	OSIM	OSTR	PELE	POLY	PPAR	PSEU
Clarke Rock	1	1	14.11	14.11	74.07	-	-	-	-	1.76	-	17.63
		3	-	139.32	125.21	-	-	-	-	-	1.76	21.16
Yellow Point	2	1	1467.22	-	-	-	56.43	-	-	98.76	134.03	-
		4	987.56	-	-	-	28.22	-	-	84.65	141.08	-
Henry Bay	4	3	3103.74	-	-	14.11	112.86	-	-	423.24	232.78	42.32
		5	2257.27	-	-	7.05	387.97	-	-	253.94	437.35	-
French Creek	5	1	377.39	-	17.63	-	-	-	-	-	47.61	10.58
		3	428.53	7.05	-	-	3.53	-	-	-	-	21.16
Trincomali Ch	6	1	3273.04	-	14.11	28.22	-	-	-	86.41	126.97	56.43
		3	218.67	-	3.53	-	-	-	-	5.29	21.16	15.87
Smelt Bay	8	1	-	-	-	-	1.76	-	-	-	116.39	21.16
		2	620.75	-	-	-	7.05	-	28.22	84.65	137.55	31.74
Atrevida Reef	9	1	698.34	-	-	-	28.22	-	-	-	246.89	275.10
		3	440.87	-	-	-	56.43	7.05	-	-	592.53	1890.46
Cape Cockburn	10	1	105.81	-	-	-	5.29	-	-	-	37.03	26.45
		3	24.69	10.58	-	-	17.63	-	-	-	-	313.90
Secret Cove	11	1	444.40	59.96	52.90	-	7.05	-	-	-	88.17	-
		3	215.15	-	17.63	-	24.69	-	-	-	59.96	38.80
Cowichan Head	38	1	202.80	-	-	-	10.58	-	1.76	1.76	-	222.20
		3	1008.72	-	-	-	28.22	-	-	14.11	-	296.27

Table 8 continued.

Location	Tran	Stn	SHRI	SIPH	SMIN	TDIS	UCAL
Clarke Rock	1	1	-	5.29	3.53	-	-
		3	-	-	5.29	-	-
Yellow Point	2	1	14.11	1537.76	-	-	-
		4	-	1297.93	-	14.11	-
Henry Bay	4	3	-	2539.43	7.05	-	-
		5	28.22	2229.05	-	-	-
French Creek	5	1	7.05	56.43	-	-	-
		3	-	96.99	3.53	3.53	-
Trincomali Ch	6	1	-	366.81	-	-	-
		3	3.53	88.17	-	-	-
Smelt Bay	8	1	15.87	93.47	-	-	-
		2	102.28	2952.08	-	-	-
Atrevida Reef	9	1	7.05	84.65	-	-	-
		3	-	91.70	-	56.43	-
Cape Cockburn	10	1	3.53	1.76	-	-	-
		3	-	7.05	-	-	-
Secret Cove	11	1	17.63	14.11	7.05	-	-
		3	7.05	3.53	-	-	3.53
Cowichan Head	38	1	1.76	28.22	-	14.11	-
		3	162.24	289.21	-	296.27	-

Table 9. Summary of the CTD information for the 2021 Strait of Georgia juvenile herring survey. The thermocline depth for Cowichan Head could not be calculated.

Location	Transect	Station	Date Sampled	Cast Depth (m)	Temperature at Surface (°C)	Temperature at Depth (°C)	Salinity at Surface (PSS-78)	Salinity at Depth (PSS-78)	Thermocline depth (m)
Secret Cove	11	1	09/07	27.6	17.89	10.25	24.72	29.54	3.54
	11	2	09/07	79.0	17.64	9.48	25.10	30.40	8.07
Cape Cockburn	10	1	09/08	78.2	17.68	9.18	26.23	30.24	13.39
	10	3	09/08	75.0	17.16	9.05	26.80	30.28	13.72
Atrevida Reef	9	1	09/09	78.6	18.03	9.07	26.67	30.25	22.50
	9	3	09/09	30.7	18.24	10.22	23.33	29.50	17.66
Smelt Bay	8	1	09/10	81.3	17.26	9.07	27.17	30.19	3.500
	8	3	09/10	80.4	17.82	9.11	27.28	30.20	16.40
Henry Bay	4	3	09/13	40.8	15.12	10.72	28.14	29.28	1.60
	4	5	09/13	22.5	14.52	11.08	28.35	29.12	1.55
Clarke Rock	1	1	09/19	10.9	12.57	10.82	28.31	29.25	1.50
Cowichan Head	38	1	09/21	20.7	11.45	10.84	30.20	30.77	-

APPENDIX A

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

The Strait of Georgia (SOG) juvenile 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 2021 survey data using methods identified in Boldt et al. (2015). In 2021, a transect was added to the survey area; however, to be consistent with past years, only standard transects were utilized here (transect numbers <12). In addition, annual variation in herring lengths and weights 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 1992-2021 (Figures A1 and Table A1). In 2021, the index (excluding the new transect) was similar to that observed in 2019, but still below the time series mean and median. The age-0 herring index tended to peak every two or three years, with the peaks occurring in even years during 2004-2012. During 2013-2021, the index was intermediate-low compared to the peaks in the time series (Figure A1 and Table A1). High estimates of variability were associated with peak estimates; the survey coefficient of variation (CV) was 0.48 (Figure A1 and Table A1). If the added, non-standard transect was included, the index of age-0 herring abundance would decrease slightly (e.g., weight CPUE with added non-standard transect= 0.82 compared to 0.91). In 2021, age-0 herring lengths and weights were below the time-series average; however, age-0 herring condition (residuals from a double-log-transformed length weight regression) was above average (Figure A2). During the time series, there was no significant linear trend in mean lengths or weights of age-0 herring (Figure A2).

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 pallasi*) 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.

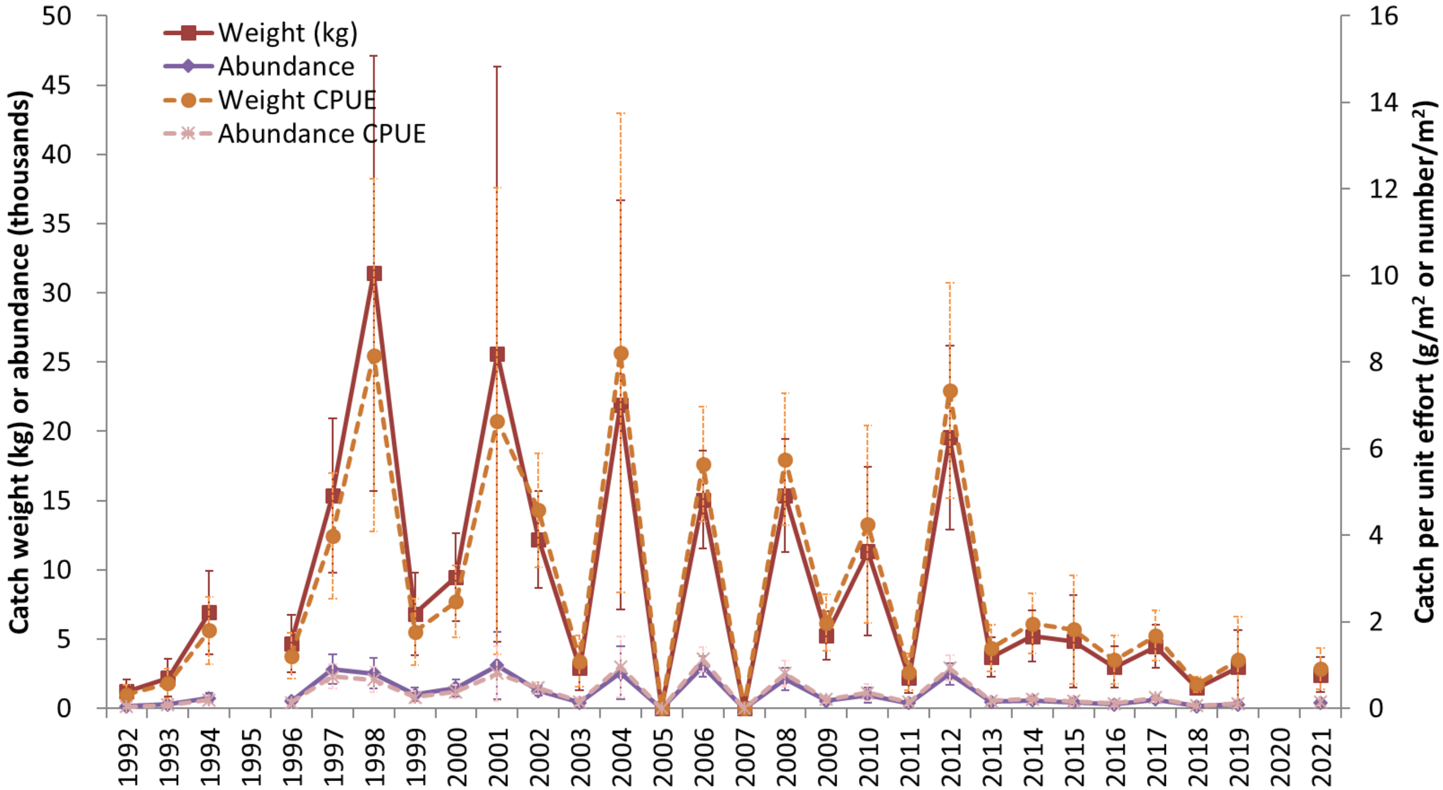


Figure A1. Estimates of catch weight (kg), catch weight-per-unit-effort (weight CPUE; g/m^2), abundance, and abundance CPUE (number/m^2) of age-0 herring caught in the Strait of Georgia juvenile herring survey at core transects and stations during 1992-2021 (no survey in 1995 or 2020). Estimates were 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.

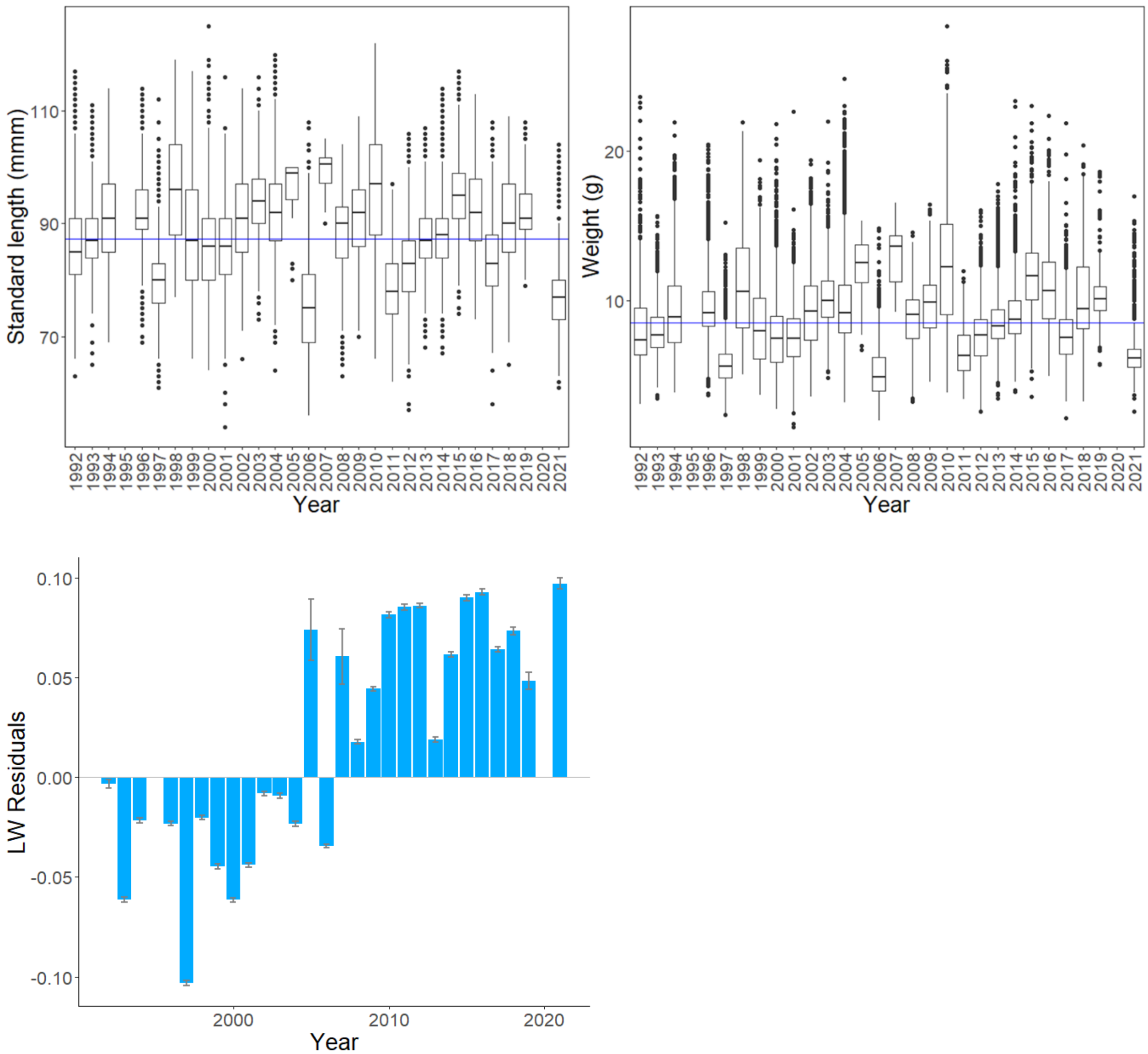


Figure A2. Boxplots of age-0 herring standard lengths (mm; top, left panel) and weights (g; top, right panel), and barplot of condition (residuals from a double-log-transformed length weight regression; bottom panel), as measured in the laboratory during 1992-2021 (no survey in 1995 or 2020). Blue horizontal lines are the time-series mean standard length and weight (top panels). Standard error bars are shown on the bottom panel.

Table A1. 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 herring caught in the Strait of Georgia juvenile herring survey at core transects and stations during 1992-2021 (no survey in 1995 or 2020). 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

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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
2020												
2021	2430.830	1248.220	0.513	0.912	0.468	0.513	387.281	199.353	0.515	0.145	0.075	0.515

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APPENDIX B

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, twenty juvenile herring (not exceeding three samples per transect) were frozen and brought back to the laboratory. In 2021, five samples were collected. 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 2021 (Table 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 81.8mm to 96.7mm and wet weight ranged from 7.1g to 11.3g in 2012 and 2015, respectively (Figure 1). Average dry weight ranged from 1.6g (2012) to 2.7g (2015) and the percent dry weight ranged from 23% in 2012 and 2017 to 26% in 2019 (Figure 1). Average energy density values ranged from 4,854 cal/g in 2012 to 5,317 cal/g in 2015 (Figure 2). Other than in 2019, weighting the energy density estimates by catch-per-unit-effort (CPUE) had minimal effect on values and CPUE estimates for 2021 are the second lowest of the time series (Figure 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 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 ($p<0.001$).

The age-2 recruitment estimate for 2023 has not been published at this time so the following analysis only looks at energy density values from 2012-2019. Preliminary results indicated there may be a positive relationship between age-0 herring energy density and age-2 recruit abundance (DFO 2022), lagged by two years; however, the relationship is not significant ($p=0.69$) (Figure 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 does not change the relationship between age-2 recruit abundance and age-0 energy density; however, there are currently only seven 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.

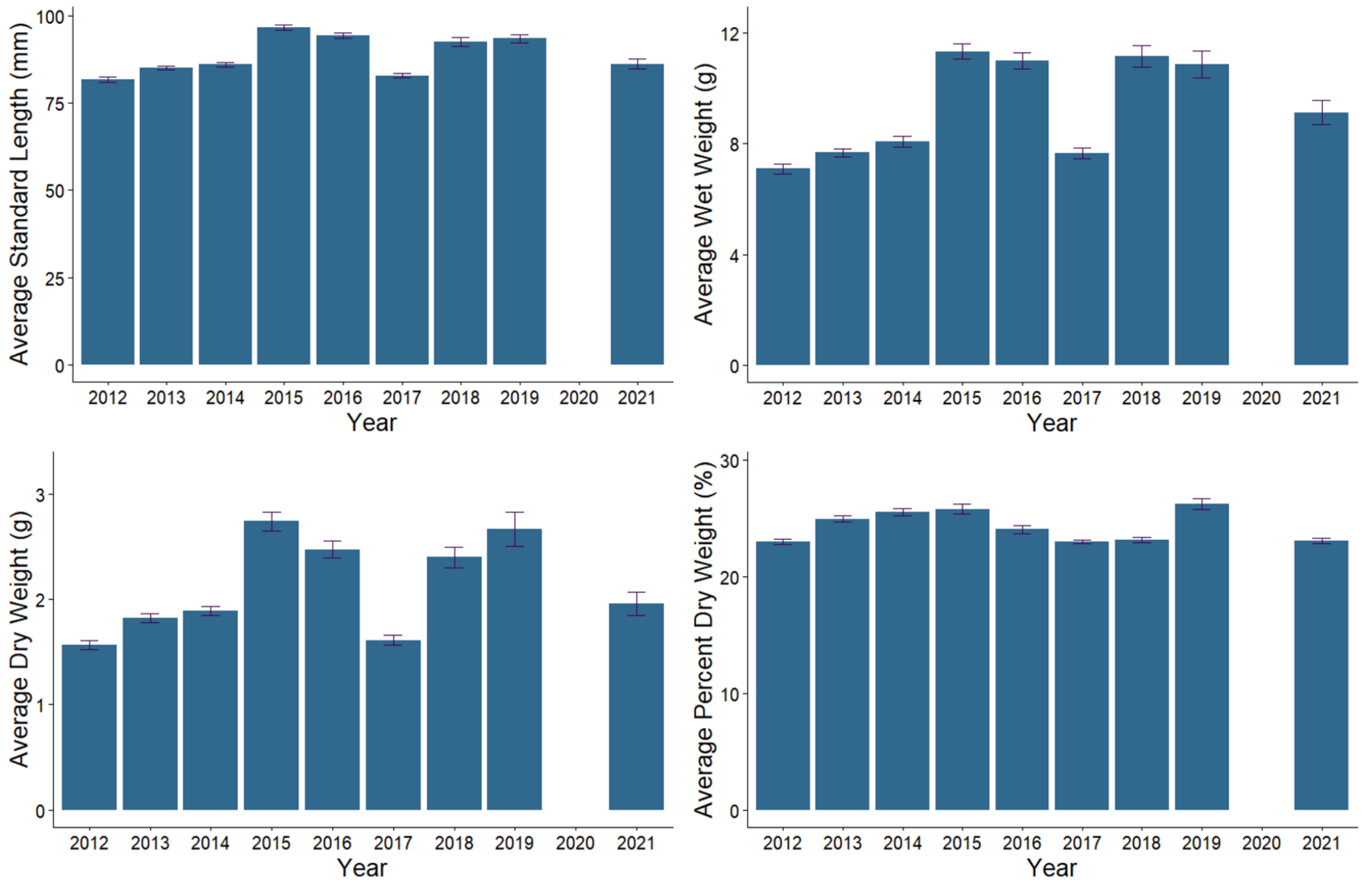

Figure B1. Average standard length (mm), wet weight (g), dry weight (g), and percent dry weight of age-0 Pacific Herring from the Strait of Georgia collected for energy density analysis, 2012-2021. Error bars calculated using standard error.

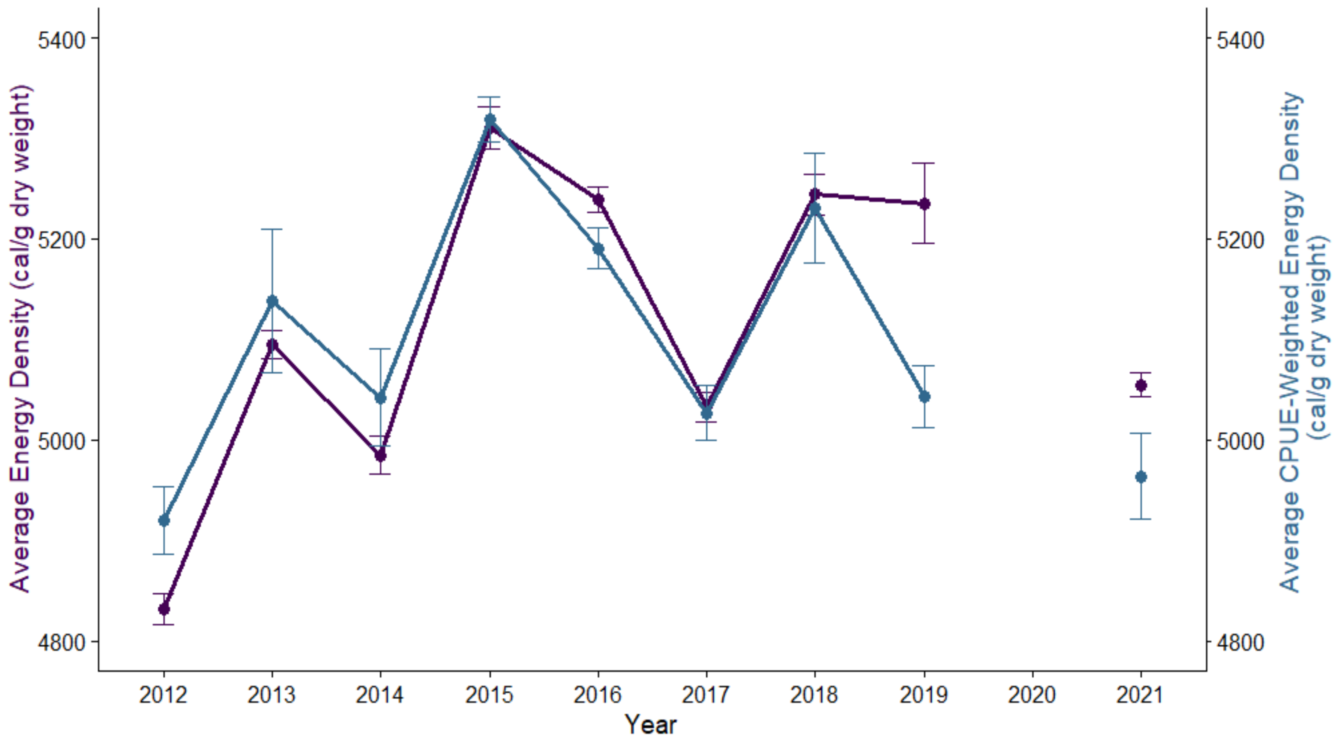

Figure B2. Average energy density and average energy density weighted by catch per unit effort (CPUE) for age-0 Pacific Herring in Strait of Georgia, 2012-2021. Error bars calculated using standard error.

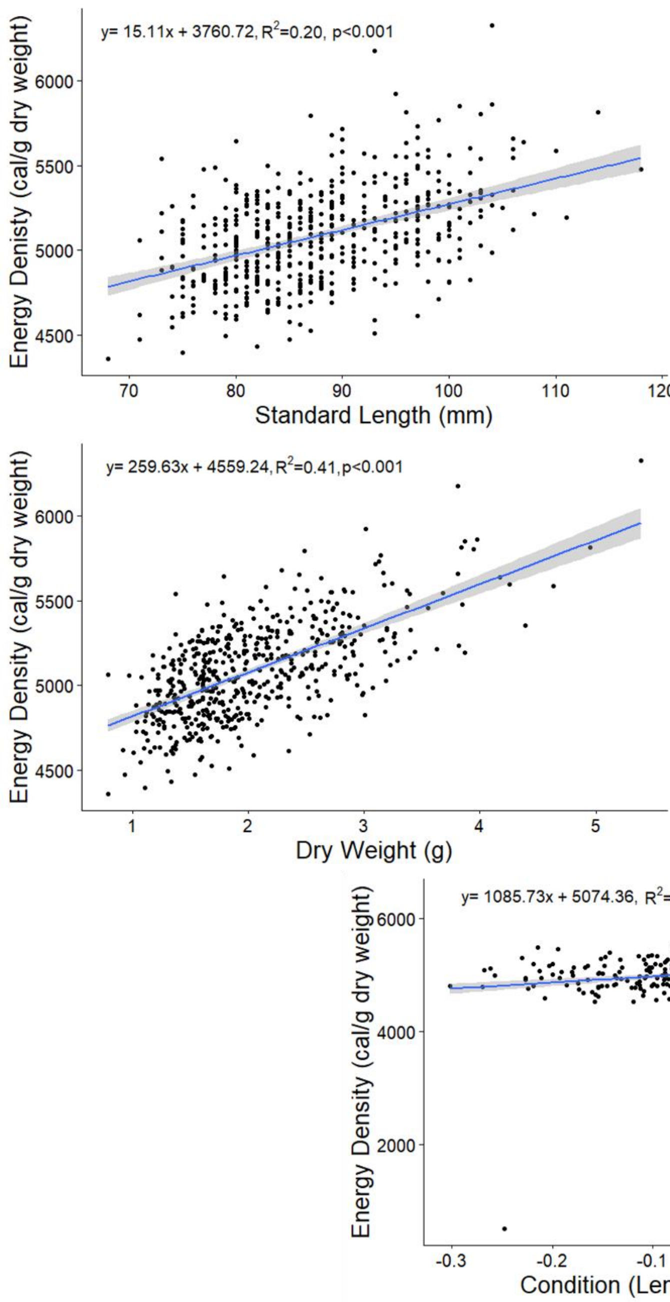

Figure B3. Standard length (mm), wet weight (g), dry weight (g), percent dry weight, and condition as a function of energy density of age-0 Pacific Herring samples collected in the Strait of Georgia for calorimetry analysis from 2012-2021. Linear regression lines (solid lines) are shown and grey shaded areas represent the standard errors.

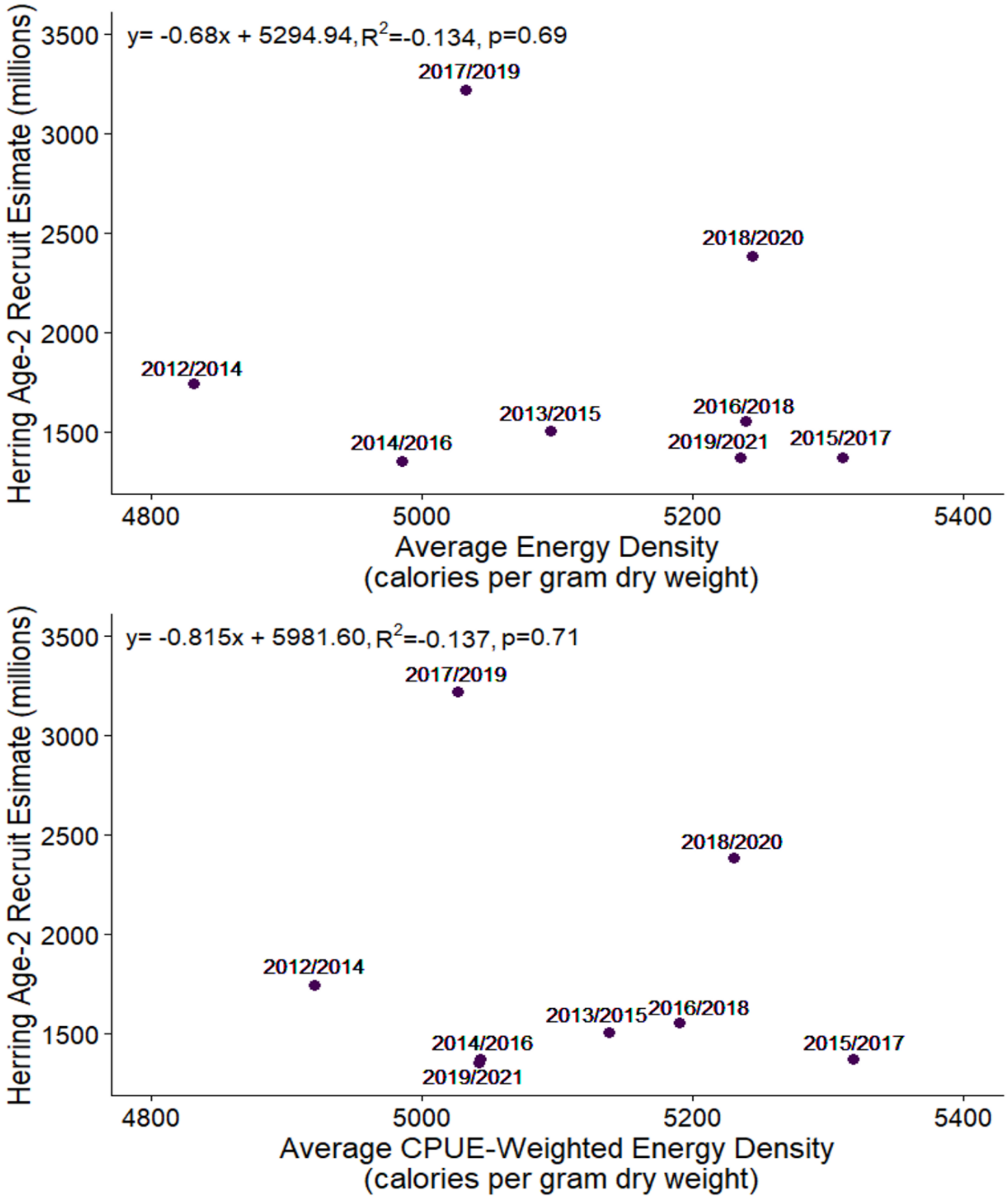

Figure B4. Estimate of age-2 herring recruit abundance estimates (2014-2021) (stock assessment median posterior values (50 percentile); DFO 2022) lagged by two years plotted as a function of average age-0 herring energy density (top panel) and age-0 herring energy density weighted by catch per unit effort (bottom panel) (2012-2019), in the Strait of Georgia. Labels show years of age-0 herring energy density samples and year of recruitment two years later.

Table B1. Number of Strait of Georgia age-0 Pacific Herring energy density samples processed per year, 2012-2021. 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
2020	--	----
2021	50	2, 4, 6, 8, 10

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