An Index of Relative Biomass, Abundance, and Condition of Juvenile Pacific Herring (*Clupea pallasi*) in the Strait of Georgia, British Columbia

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AN INDEX OF RELATIVE BIOMASS, ABUNDANCE, AND CONDITION OF JUVENILE PACIFIC HERRING (*Clupea pallasi*) IN THE STRAIT OF GEORGIA, BRITISH COLUMBIA

by

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ABSTRACT

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 pallasi*) in the Strait of Georgia, British Columbia. Can. Manuscr. Rep. Fish. Aquat. Sci. 3081: x + 80 p.

Small pelagic fish, such as Pacific Herring (*Clupea pallasi*), are an important prey species for a variety of predators and, in the case of herring, are also culturally and commercially important. The Strait of Georgia juvenile herring and nearshore pelagic ecosystem survey provides time-series information that can be used to estimate the relative abundance of age-0 herring, potentially forecast recruitment to the adult spawning population, and represents trends in prey availability to predators. The main objective of this report was to update the time series and identify a standard set of data and methods for estimating age-0 herring biomass (abundance). The standard set of data was identified as those collected on ten core transects sampled consistently in September-October since 1992. To calculate unbiased estimates of the relative biomass (abundance) of age-0 herring, we applied two methods (two-stage and two-stage stratified) to a variety of data types for three scenarios (based on assumptions about nets used). Since stratification did not always reduce estimates of variance, we recommend using the two-stage approach without stratification. Two alternative estimates of variance were compared; less conservative estimates of variance were still relatively high, with an average CV of ~46%. Estimates of age-0 herring biomass (abundance) were correlated with abundance estimates of age-3 recruits (of the same yearclass) from the stock assessment model, supporting the notion that survey catches of age-0 herring may be indicative of the number of recruits joining the population 2.5 years later. In addition, annual variation in herring lengths, weights, and fish condition (length-weight residuals) were explored and summarized. Mean age-0 herring lengths and weights varied annually with no overall trend during the time series. Length-weight regression coefficients and residuals have changed over time with a shift to positive or neutral residuals in 2002 indicating improved fish condition. This may have implications for the survival of herring as well as the quality of herring available to herring predators.

RÉSUMÉ

Boldt, J.L., Thompson, M., Fort, C., Rooper, C.N., Schweigert, J., Quinn II, T.J., Hay, D. et Therriault, T. W. 2015. Un indice de la biomasse, de l’abondance et de la condition relatives du hareng juvénile du Pacifique (*Clupea pallasi*) dans le détroit de Georgie, en Colombie-Britannique. Rapp. manus. can. sci. halieut. aquat. 3081: x + 80 p.

Les petites espèces pélagiques, comme le hareng du Pacifique (*Clupea pallasi*), constituent des proies importantes pour divers prédateurs et, dans le cas du hareng, sont également importantes sur les plans commercial et culturel. L’étude sur le hareng juvénile du détroit de Georgie et l’écosystème pélagique environnant fournit des séries chronologiques de données qui peuvent être utilisées pour estimer l’abondance relative des harengs d’âge 0, prévoir le recrutement potentiel dans la population reproductrice adulte et évaluer les tendances en ce qui a trait à la disponibilité des proies pour les prédateurs. Ce rapport visait principalement à mettre à jour les séries chronologiques ainsi qu’à définir un ensemble standard de données et de méthodes pour estimer la biomasse de hareng d’âge 0 (abondance). On a établi que l’ensemble de données standard correspondrait à celles recueillies sur 10 principaux transects où des échantillons ont été systématiquement prélevés pendant les mois de septembre et octobre depuis 1992. Afin de produire des estimations non biaisées de la biomasse relative (abondance) de harengs juvéniles d’âge 0, nous avons appliqué deux méthodes (échantillonnage à deux degrés et échantillonnage stratifié à deux degrés) à divers types de données dans trois scénarios (selon les hypothèses sur les filets utilisés). Puisque la stratification n’a pas toujours permis de réduire les estimations de la variance, nous recommandons d’utiliser l’approche à deux degrés, sans stratification. Deux autres estimations de la variance ont été comparées; l’estimation moins conservatrice était encore relativement élevée, avec un coefficient de variation moyen d’environ 46 %. Les estimations de la biomasse de harengs d’âge 0 (abondance) étaient en corrélation avec celles de l’abondance des recrues de 3 ans (de la même classe d’âge) selon le modèle d’évaluation des stocks, ce qui appuie l’hypothèse selon laquelle les captures de harengs d’âge 0 des relevés de recherche pourraient être révélatrices du nombre de recrues qui se joindront à la population de 2,5 ans par la suite. En outre, la variation annuelle de la taille, du poids et de la condition du hareng (variance résiduelle taille-poids) a été examinée et synthétisée. La taille et le poids moyens des harengs d’âge 0 variaient d’une année à l’autre, sans suivre de tendance générale dans le cadre des séries chronologiques. Les coefficients de régression taille-poids et la variance résiduelle ont changé au fil du temps. La variance résiduelle est devenue positive ou neutre en 2002, ce qui signifie que la condition du hareng s’est améliorée. Ces changements pourraient avoir des répercussions sur la survie du hareng ainsi que sur la qualité du hareng disponible pour ses prédateurs.

INTRODUCTION

Small pelagic fish provide important forage for predatory fish, marine mammals, and seabirds. Some species, such as Pacific Herring (*Clupea pallasi*; hereafter referred to as herring) not only provide forage for recreationally and commercially important predatory fish (Schweigert et al. 2010), but are themselves important cultural and commercial species in British Columbia's (BC) coastal waters. Changes in the abundance of small pelagic fish can have both direct and indirect impacts on the trophodynamics of an ecosystem, affecting both First Nations and commercial fisheries as well as prey availability to other predatory fish, such as Coho and Chinook Salmon, that consume herring. Trends in abundance of small pelagic fish species can be affected by a variety of factors including environmental and biological variables.

Evidence indicates that early life history is important for determining fish survival and recruitment (Cushing 1969, Parrish et al. 1981, Lasker 1975). In late winter and spring, Strait of Georgia (SOG) herring (one of five main fished stocks of BC) migrate from summer feeding areas in coastal shelf waters off the west coast of Vancouver Island to the SOG to spawn (Taylor 1964). Eggs are predominately deposited on shallow macrophytes, such as grasses, rockweed, kelps and algae (Humphreys and Hourston 1978, Haegele et al. 1981). Hatching time is temperature dependent and can range from 10 to 28 days (Outram 1955, Alderdice and Velsen 1971, Alderdice and Hourston 1985). Once hatched most herring spend their first summer in nearshore areas; close to the sea floor during daytime hours and dispersed in the upper portion of the water column during nighttime hours. In late fall, the juvenile herring migrate offshore to summer feeding grounds. Most herring are sexually mature and recruit to the adult population at age 3 (Hourston and Haegele 1980, Hay and McCarter 1999).

Herring abundance can be affected by the carrying capacity of the ecosystem, and by a variety of factors affecting survival and recruitment to the adult population. Adult herring productivity may be regulated by bottom-up control of production (Perry and Schweigert 2008). Herring recruitment may be linked to a variety of environmental or biological variables during the egg to recruit period, such as, water temperatures, river discharge, salinity, sea level, Ekman transport, upwelling, timing of primary production, predators or competitors, and/or disease (Tester 1948, Ware 1991, Dreyfus-Leon and Schweigert 2008, Zebdi and Collie 1995, Stocker and Noakes 1988, Schweigert and Noakes 1990, Williams and Quinn 2000, Schweigert et al. 2013, Schweigert et al. 2010, Marty et al. 2003). To understand which of these factors are influencing herring first requires a time series of the relative abundance of herring. Age-structured stock assessment models are used to produce estimates of herring biomass and recruitment in BC; however, annual variability in recruitment to the population is high and unpredictable. Information that provides a prediction of recruitment may help improve forecasts of herring biomass (Schweigert et al. 2009).

The SOG juvenile herring and nearshore pelagic ecosystem survey collects time-series information that can be used to estimate the relative abundance of age-0 herring and perhaps provide a forecast of recruitment to the adult spawning population. This information may also represent trends in potential prey availability to Coho and Chinook Salmon and other predators in the SOG. Previous analyses of the age-0 herring time-series have included all available data and assumed a two-stage or simple random sampling design (Hay et al. 2003, Schweigert et al. 2009). The main objective of this report was to update the time series and identify suitable data and statistical methods for estimating an index (and associated variance) of the relative biomass or abundance of age-0 herring in the SOG from the survey data collected to date. To determine if survey estimates of age-0 herring biomass (abundance) were indicative of recruitment, they were related to age-3 herring abundance from the stock assessment model. In addition, annual variation in herring lengths, weights, and fish condition (length-weight residuals) were explored and summarized.

METHODS

FIELD SAMPLING

Samples of nearshore pelagic fish in the SOG were collected as a part of the annual juvenile herring survey conducted during September-October, 1992-2014 (except 1995; Tables 1-3). Survey methodology and transect locations are described in Thompson et al. (2003). There were ten core transects, each with 3 to 5 core stations, distributed at approximately equal intervals around the perimeter of the SOG that have been consistently sampled since 1992 (except 1995; Figure 1). In some early years, there were additional surveys conducted at different times of the year or additional samples collected in the fall that were designed to address other research questions and they were not included in the analyses for this report (see Appendices 1-3). In order to produce a standardized time series of juvenile herring biomass (abundance), we limited analyses to include data from only the 10 core transects. Some exceptions in sampling occurred; for example, during 1997-1999, only 2 or 3 stations were sampled along core transects, or in some cases the presence of large abundances of jellyfish inhibited the ability to acquire representative fish samples (e.g., 2004 Transect 4), or in some cases inclement weather prevented sampling (e.g., 2005 Transect 10, Stations 2 and 4; Table 2). Over the 22 year time series, 10 core transects, and 48 core stations, there was a total possible sample size of 1,056. The realized sample size was 963 because 93 stations were not sampled.

Core transects were perpendicular to the shoreline in open water (Transects 1, 3, 5, 9, 11) and channel-type habitats (Transects 2, 4, 6, 9, 10). On channel transects, a station was located in the middle of the channel and other stations were placed on both sides of it at a spacing of approximately 1 or 2 km, with outer stations at approximately 360-400 m from the mean high water, located in 10 or 15 m depth (e.g., Haegele and Armstrong 1997, Haegele and Armstrong 1998). On open water transects, the initial station location was approximately 400 m from high water in about 15 m depth and other stations were spaced in a line at 1 km intervals from the first station. There were 5 stations on all transects except Transect 8 that had 3 stations. The bottom depth at stations ranged from 2 to 400 m depth and station depths were recorded as depth intervals (2-5 m, 5-10 m, 10-20 m, 30-50 m, 50-100 m, 100-200 m 300-400 m). Sampling was conducted in September-

October to minimize the bycatch of small salmonids, while maximizing capture of young of the year (YOY) herring. Sampling was conducted after dusk when herring were near the surface and, generally one transect was sampled per night over the course of a 4-7 hour period. The stations were sampled with “blind” or undirected purse seine sets (sets were made at predetermined stations).

The 38 foot (11.6 m) long fishing vessel *Keta* was used during 1992-1994 and the 12 m, aluminum-hulled Fisheries Research Vessel *Walker Rock* was used during 1996-2014. A purse seine was used for all fishing events and techniques used (e.g., pursing speed and drumming of net) were kept as uniform as possible among years. During 2002-2014, the net was 183 m by 27 m, resulting in an area fished of ~2,660 m^2 (based on the geometric formula for the area of a circle). The net had 46 m of 22.2 mm mesh at the tow end, 91 m of 19.0 mm mesh, and, in the bunt of the net, 46 m of 9.5 mm mesh. During 1992-2002, there were inconsistencies in the reported net length used (see Appendix 4); however, the old net used during 1996-2001 was re-measured and confirmed to be 183 m long (although it is currently in two pieces). During the periods of 1992-1995, the net was likely 220 m long, resulting in an area fished of 3,852 m^2. Three possible scenarios were examined in this report (Table 4): 1) during 1992-2014, the net was 183 m long, the unit of effort was the same for all sets, or 2) during1996-2014, the net was 183 m long, and prior to that the net length was either 220 m long or unknown, or 3) during 1992-2001, the net was 220 m long and during 2002-2014, the net was 183 m long. The consensus belief is that Scenario 2 is the most likely scenario.

For most purse seine 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. Subsampling techniques varied slightly during the time series. During 1992-2004, one or two 40 kg totes were filled with randomly selected fish and retained for biological sampling; during 1992-2001, annual reports to the Herring Conservation and Research Society (HCRS) state that two totes were retained and, during 2002-2004, one tote was retained (Haegele 1993, Haegele and Armstrong 1997, 1998, 1999, 2000, 2001, 2002, Haegele et al. 2005). During 2005-2014, several dipnet samples were taken from various parts of the net (catch) to make up a random sub-sample (Thompson et al. in press). The remainder of the set was released over the corkline, its size estimated as the number of totes released. All fish (or a subsample of fish) were retained for sampling in the laboratory, with the exception of large predator species (e.g. adult salmon and flatfish), which were individually measured in the field. During 1992-2013, all fish were preserved in a 3.7% formaldehyde and seawater solution; whereas, in 2014, fish were frozen.

LABORATORY SAMPLING

All retained fish were sampled later in the laboratory at the Pacific Biological Station. In the laboratory, fish from each station were sorted to species and up to 100 individual fish of each species were identified, weighed, and measured. Herring were measured to standard length, salmon to fork length, groundfish to total length, and all other fish species were measured to standard length (nearest millimeter). The number of herring (and other species) caught at each station was determined by dividing the total catch weight (kg) by the mean individual weight of herring (or species-specific weights) weighed in the lab. During 1992-2004, herring were assigned to age classes in the field by visual inspection, resulting in overlapping length distributions between age-classes. During 2005-2014, herring were assigned to age-class by examining the length frequency of measured herring; the length distributions of age-0 herring were distinctly different than those of other age-classes (e.g., Thompson et al. 2013).

DATA ANALYSES

Relative biomass and abundance of age-0 herring

The relative biomass and abundance of age-0 herring was estimated using two different methods. The first method used was a two-stage design in which the primary units were transects, assumed to be selected quasi-randomly without replacement and spaced roughly equidistant around the perimeter of the SOG. Secondary units, stations, were systematically selected without replacement so that they were evenly spaced along transects. The second method used the above-described two-stage design but also incorporated stratification by classifying transects into open water or channel strata. These methods were applied using catch weights and abundance for scenarios 1 and 2 and using catch-per-unit-effort (CPUE) for scenario 3. CPUE was calculated as catch weight (g) or catch abundance (numbers) divided by the area fished by the net.

Two-stage sampling formulae (Thompson 1992) were used to calculate the mean and variance of juvenile herring catch weight, CPUE, and abundance (Appendix 5). We assumed, as stated in Szarzi et al. (1995), for our analyses: 1.) "sample sizes at each stage were assumed to be small compared to the total number of possible samples therefore finite population correction factors were ignored; 2.) to simplify calculations of means and variances, it was assumed that the total numbers of possible samples at each stage were equal; and 3.) it was assumed that the systematic random sampling at the second stage could be treated as simple random sampling for the calculation of variances." Variance estimates were also derived using Szarzi et al. (1995) formulae (Appendix 6). Variance estimates were compared and the coefficient of variation (CV) was examined as a function of sample size (Thompson 2012). To achieve a target CV of 0.3, the factor by which to increase the sample size (10 transects) was estimated as (mean CV/target CV)^2. Anomalies of age-0 herring catch indices were compared. Anomalies were calculated by subtracting the overall mean of annual estimates (over all years) from each annual estimate and dividing by the standard error (over all years). Analyses were performed using R version 3.1.0 (2014 The R Foundation for Statistical Computing).

To test if the indices of herring biomass (abundance) were indicative of recruitment to the population, we examined a linear regression of the log-transformed abundance of age-3 recruits as a function of log-transformed age-0 herring biomass (abundance and CPUE) indices from the same yearclass. The numbers of age-3 recruits were obtained from the age-structured stock assessment model (Cleary and Taylor, in press) and lagged by three years to correspond to the age-0 yearclass sampled in the survey.

Lengths and weights

Age-0 herring were identified each year by examining fish lengths – either visually in the field (during 1992-2004) or using length-frequency histograms of lab-measured fish (during 2005-2014). Given that techniques for identifying the upper size limit of age-0 herring changed slightly in 2005, length frequency histograms of all herring were re-examined to compare previously reported upper size ranges to expected values. If there was a difference, then it would be expected to affect the estimates of age-0 catch weights, CPUE, catch abundance, and mean fish lengths and weights prior to 2005.

Mean annual age-0 herring lengths and weights were calculated by averaging all measurements in each year. Herring weights were log-transformed and regressed against log-transformed standard lengths. Mean residuals from the log-transformed length-weight regression were calculated as an index of fish condition (hereafter referred to as length-weight residuals): positive residuals would indicate that fish were heavier for a given length and, hence, in better condition. An analysis of covariance (ANCOVA) was used to compare log-transformed length–weight regression coefficients among years. The dependent variable was the logarithm of weight (g), the factor used was years, and the covariate was the logarithm of standard length (mm). The length-year interaction term was included to test for homogeneity of slopes. Normal probability plots were used to test for normality and histograms and box plots to test for normality, outliers, and homoscedasticity. No corrections to fish lengths were made to account for any potential differences in shrinkage due to preservation methods used (formaldehyde during 1992-2013 vs. freezing in 2014).

RESULTS

RELATIVE BIOMASS AND ABUNDANCE OF AGE-0 HERRING

Of the 963 seine net samples collected during 1992-2014 (Tables 1 and 2), 760 samples contained age-0 herring, 203 samples did not contain any age-0 herring (Appendices 7 and 8). There were three years with high proportions of samples that contained no age-0 herring: in 1993, 0.46 (22 of the 48 samples); in 2005, 0.74 (34 of the 46 samples); and in 2007, 0.87 (40 of the 46 samples) (Appendices 7 and 8). Together the zero-catches in these three years comprise almost half of all zero-catches in the time series. Over all years, catch weights varied among transects with no apparent pattern and the range of catch weight values decreased with increasing depth bins (Appendices 9 and 10).

Mean catch weights (g) and abundance of age-0 herring varied interannually with no significant overall trend during 1992-2014 (scenario 1) or during 1996-2014 (scenario 2) (Figures 2 and 3, Tables 5-8). Mean catch weights ranged from approximately 7 g to 31,400 g. CPUE estimates of age-0 herring (scenario 3) also varied interannually with no overall significant trend in the time series (Figures 2 and 3). Point estimates determined by the two methods (two-stage, two-stage stratified) were virtually indistinguishable for each individual data type (i.e., catch weights, CPUE, abundance).

Mean catch weight, weight CPUE, abundance, and abundance CPUE estimates showed similar interannual patterns, during 1992-2014 (Figures 2 and 3). One of the biggest discrepancies was between weight-based and abundance based indices in 1998 (Figures 2-4). Weight-based estimates (catch weight and weight CPUE) were highest in 1998, whereas, abundance-based estimates in 1998 were relatively high, but not the highest in the time series (Figure 4). In 1997 and 2006, number-based estimates were higher than weight-based estimates (Figure 4).

Estimates of the coefficient of variance (CV) were compared between methods (two-stage and two-stage stratified) for both the Thompson (1992) and the Szarzi et al. (1995) variance formulae (Figure 5 and Tables 5-8). The CVs of CPUE-based indices were the same as weight or abundance based-indices (Tables 5-8), so are not shown in Figure 5. CVs ranged from 23% to 81% with an average of about 46% (Tables 5-8). In all cases, the Szarzi et al. (1995) CVs were more conservative than the Thompson (1992) CVs (Figure 5 and Tables 5-8). Stratification by transect type (open or channel transects) did not necessarily result in lower variance estimates than non-stratified methods (Figure 5 and Tables 5-8). Stratification reduced CV estimates in 11 or 13 of the 22 years (50% or 59%) for catch weight or abundance, respectively. To acquire an average CV of ~30%, the number of transects required would be 24 (Figure 6).

Age-0 herring survey indices were significantly correlated with the abundance of age-3 recruits estimated by the age-structured stock assessment model (Cleary and Taylor in press; Figure 7). Higher numbers of age-3 recruits were correlated with higher estimates of age-0 survey catch weights (g; R^2= 0.67, $p<0.001$), weight catch-per-unit-effort (CPUE; R^2= 0.67, $p<0.001$), abundance (R^2= 0.70, $p<0.001$), and abundance CPUE (R^2= 0.70, $p<0.001$). The linear regressions were somewhat dependent on data points for two years, 2005 and 2007, that had low age-3 recruit abundances and age-0 survey indices.

LENGTHS AND WEIGHTS

Previously reported upper size ranges of age-0 herring (in historic reports) were compared to those identified in length frequency histograms (Figure 8, Table 9, and Appendix 11). Prior to 2005, there were some cases where fish with the same length measurement were assigned to different age classes, because they were visually classified in the field. For example, in 1992, there were five fish that were 112 mm long: three were classified as age-0 and two were classified as age-1. Beginning in 2005, a distinct length delimiter was used to identify age-0 fish, making it easier to classify age-0 fish. If this method was used on data collected during 1992-2004, there would have been very small differences (-1 to +2% change) in the sample size of age-0 fish, with the biggest difference in 1998 (Table 9). Given these small differences, age classifications of fish prior to 2005 were not altered from the historical values when comparing age-0 herring lengths and weights among years in this report. The small differences in age-class designation among years would have negligible impacts on estimates of age-0 herring catch weights and abundance.

Overall, during 1992-2014, standard lengths of age-0 herring sampled at core stations and transects ranged between 54 mm and 125 mm (Figure 8, Table 10, and Appendix 11). Mean annual individual lengths ranged from a low of 75.19 mm in 2006 to 99.23 mm in 2007 (although only 22 fish were measured in 2007, due to low catches of herring).

Mean individual weights of age-0 herring ranged from 5.25 g in 2006 to 12.86 g in 2007 (Table 10). In three years (1997, 2006, and 2011), age-0 herring were shorter and lighter than other years (Figures 9 and 10). Over all years, age-0 herring tended to be smaller (shorter and lighter) at transects 2 and 6 and tended to be larger at stations with deeper depths (Figure 9 and 10). The number of age-0 herring measured ranged from 22 and 30 in 2007 and 2005, respectively, to 6,695 in 2006 (Table 10).

The log-transformed length-weight regression of age-0 herring was significant (R^2= 0.93, p<0.001, slope = 2.964, intercept = -11.152; Figure 11). ANCOVA results indicated that there were significant differences in age-0 herring weights among years (Table 11), but there were also significant interactions between year and length, indicating a change in the slope of the length-weight regression among years, as seen in the length-weight regression (Figure 11 and Table 11). Mean annual residuals from this linear regression shifted from negative to positive or neutral in 2002 and 2003 and were positive after 2004 (except 2006). This indicates that age-0 herring were heavier for a given length during most years after 2004 compared to earlier years (Figure 12). Given that techniques for categorizing herring as age-0 changed slightly in 2005, length-weight regressions and residuals were also calculated for all herring regardless of age-classification (and for age-1 and age-2 herring) to see if age-categorization contributed to the observed pattern in residuals (Appendices 12-14). Length-weight residuals for all herring became positive in 2005 (Appendix 13), and, for age-1 and age-2 herring, also shifted to positive or neutral residuals in 2005 (Appendix 14).

DISCUSSION

A goal of the work presented in this report was to update indices of age-0 herring in the Strait of Georgia by reviewing historical data collections, identifying those data to include in index calculations, and applying a variety of statistical approaches to calculate indices and estimates of variance. The most appropriate data for an abundance index were those collected from core stations along ten core transects sampled consistently in September-October since 1992. To calculate unbiased estimates of the relative biomass (abundance) of age-0 herring with unbiased estimates of variance, we applied two methods (two-stage and two-stage stratified) to four types of data (catch weight, weight CPUE, abundance, and abundance CPUE) that incorporated three scenarios (1. same net used during 1992-2014, 2. considering data from only 1996-2014, 3. change of net in 2002). In addition we examined two methods for estimating variance (Thompson 1992, Szarzi et al. 1995).

Catch-per-unit-effort (CPUE) estimates were calculated to account for a change in net length that may or may not have occurred in 2002 (scenario 3). Correcting for net length did not have a large effect on the herring index trends. There were some minor annual differences between the weight and abundance based indices (e.g., in 1998). Given that scenario 2 is most likely (same net used during 1996-2014, other net used during 1992-1994), we recommend calculating indices of catch weights and abundance for the 1996-2014 time period. If data prior to 1996 are used, it is recommended that CPUE is used (assuming a 220 m long net during 1992-1994 and a 183 m net during 1996-2014). Alternatively, the index could be presented as an anomaly, with the anomaly computed for the two groups of years treated separately. For future surveys, a net with the same dimensions, mesh sizes, materials, etc. should be used. If for some reason a different size of net is used, there should be side-by-side field trial comparisons of the old and new nets.

Trends in estimates were similar between the abundance- and weight-based indices, although, there were some annual differences -likely due to differences in estimated mean individual fish weights. For example, in 1997 and 2006, catch abundance anomalies were higher than catch weight anomalies (Figure 4). This was likely because fish were smaller (shorter and lighter) than in other years, so dividing by the relatively large catch weights in those years, resulted in high abundance anomalies. The length-weight residuals for these years were also negative, indicating that fish were lighter for a given length. In 1998, catch abundance anomalies were lower than catch weight anomalies (Figure 4); a relatively high catch weight was divided by the mean individual weight of relatively large fish, resulting in lower estimates of abundance. The high catch abundance anomaly in 1998 was not due to the age-categorization of age-0 herring. In 1998, there were 76 fish classified as age-1 herring that may have been classified as age-0 herring (if we used a length delimiter determined from a length frequency histogram, as is currently done). This, however, does not explain the low abundance estimates in 1998 because including these fish in the mean individual weight calculations would result in a 0.17 g increase in the mean individual fish weight. This difference is minor and would have resulted in higher estimates of abundance. Given the differences (although only minor) between abundance- and weight–based estimates, we recommend calculating both types of indices.

Point estimates of the indices (catch weight, weight CPUE, abundance, abundance CPUE) were virtually indistinguishable among the two methods used (two-stage and two-stage stratified). The choice of method to use, therefore, should be based on the method that produces the lowest estimates of variance. Results indicate that using strata (open or channel transect types) did not always reduce variance estimates and the Szarzi et al. (1995) formula resulted in conservative estimates of variance. We therefore recommend 1.) not utilizing strata when calculating the indices and 2.) using the less conservative variance estimator (Thompson 1992). The less conservative estimates of variance are still relatively high, with an average CV of ~46%. To reduce the CV to ~30%, 24 transects would need to be sampled. Trade-offs between variance, survey costs, staff availability, and survey duration would need to be considered prior to increasing the sample size. During 1997-1999, sampling was reduced at core transects and additional transects were sampled in between core transects to increase coverage and reduce variance. Travel time between transects, however, made it difficult to complete two transects of 3 stations each in a single night. Perhaps, a cost-allocation model could be used to explore the cost and feasibility of sampling additional transects.

The indices of age-0 herring biomass and abundance might be indicative of the number of recruits joining the adult, spawning population at age 3 and of trends in the amount of herring prey available to predators, such as Coho and Chinook Salmon. The question is whether the survey design and resultant indices provide a representation of the true relative abundance of age-0 herring. Factors that may affect survey catches that were not examined in this report include distance from shore, bottom depth, light levels (i.e., phase of the moon and weather), tide, currents, and day of year. Future analyses can address some of these questions and in working towards this goal, it is recommended that more accurate measures of station depths are recorded and used in analyses (currently, the survey data only includes non-continuous depth bin categories for stations).

In the interim, however, indices are correlated with age-3 recruit estimates from the stock assessment model, supporting the notion that age-0 herring indices may be indicative of the relative amount of herring in the SOG and the number of recruits joining the population 2.5 years later (Figure 7). This result is consistent with earlier analyses of a shorter time series (Hay et al. 2003, Schweigert et al. 2009). Schweigert et al. (2009) averaged catch weights from all stations sampled each year during 1991-2007, not just stations along core transects. Estimates of the mean age-0 herring catch weights calculated in this report were significantly (R^2=0.99, p-value <0.001) correlated with those calculated by Schweigert et al. (2009; Figure 13). In 1996 and 2001, the Schweigert et al. (2009) estimates were 2 and 3 kg higher than estimates calculated in this report, respectively. It is recommended, however to use only data from core transects, for a consistent and unbiased estimate of herring biomass (abundance).

Mean age-0 herring lengths and weights varied annually, with no overall trend during the time series. The annual mean size of herring did not vary with annual mean catch weight (CPUE, or abundance) estimates; that is, a higher relative biomass (abundance) of herring did not coincide with larger- or smaller-sized fish; this was also found by Schweigert et al. (2013). Mean fish lengths and weights per seine set, however, tended to have a dome-shaped relationship with catch weights (per seine set) when examined over all years. The length-weight regression coefficients and residuals have changed over time with a shift to positive or neutral length-weight residuals in 2002 (except 2004 and 2006). A shift to positive length-weight residuals may be indicative of improved fish condition: fish are heavier for a given length and may be more energy dense (Paul et al. 1998, Boldt and Rooper 2009). Fish that have a higher energy density have an improved chance at surviving reduced feeding opportunities during winter (Paul et al. 1998, Foy and Paul 1999) and present a more energy-rich prey for predators.

Potential factors that may have caused the observed shift in length-weight residuals include biological, environmental, or methodological. The shift was not likely due to some of the changes in sampling methodology because: 1) the change in subsampling techniques or age-0 classification methods occurred in 2005, and the shift in residuals started in 2002, 2) age-classification methods did not significantly affect results, 3) the same fish-preservation methods were used during 1992-2013, 4) catch weights were not correlated with fish length, fish weight, or length-weight residuals (not shown), and 5) sampling of stations was fairly consistent over the time series and there wasn't a consistent change in stations (or bottom depths) that were sampled. Also, we cannot discount it, but it does not seem likely that the change in length-weight residuals would be due to a change in net length, since mesh sizes of the net were likely the same in all years and not selecting for ‘fatter’ fish. The survey dates changed annually (Table 3) and the survey timing relative to herring egg hatch dates likely affected the size of herring sampled in the survey. Survey dates, however, did not get progressively later when fish might be expected to be bigger and survey dates did not appear to correspond to the shift in length-weight residuals, as might be expected if survey dates were strongly influencing the fish condition observations (Appendix 15).

A combination of biological and environmental factors may have contributed to the observed shift in fish condition. For example, the timing of spawning and subsequent temperatures affect hatch dates of eggs (duration of egg stage; Alderdice and Hourston 1985) and therefore, how much time fish have to grow before they are sampled in the survey. Environmental variables (such as nutrient availability and temperature) can also affect the timing of the herring spawning period and the spring phytoplankton and zooplankton blooms (Li et al. 2013, Schweigert et al. 2013), thereby affecting the prey availability to and growth potential of herring. These factors likely affect the variability in the survey herring indices and could be examined in future analyses. Without a viable way to account for these factors with the survey design, we recommend continuing with the current protocol of sampling the core stations and transects annually in September-early October.

CONCLUSIONS

The SOG juvenile herring survey provides a valuable data set that may be used to estimate the relative biomass (abundance) of age-0 herring. This provides a potential leading indicator of recruitment to the adult population and may provide an indicator of prey availability to predators in the SOG, such as Coho and Chinook Salmon. We recommend that sampling of core stations and transects continue, following consistent and standardized practices and with more accurate measures of depth where samples are collected. To reduce CVs, more transects should be sampled, however, trade-offs between lower CVs and higher costs would need to be considered. We also recommend that multiple indices are calculated (catch weight, CPUE, and abundance) using a two-stage method and the less conservative formulae for estimating variance. Given a consistent approach to sampling and index calculations, the herring indices can be used to explore other research questions that might elucidate factors affecting herring survival and recruitment, as well as the survival of predators.

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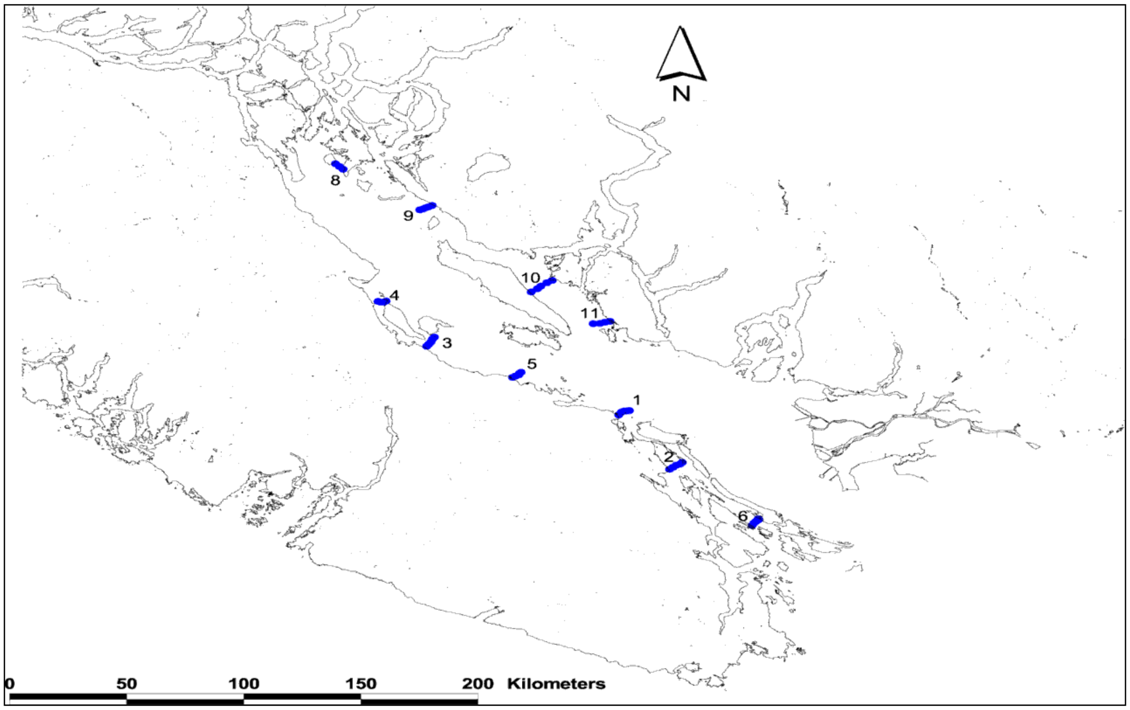


Figure 1. Purse seine set locations along the 10 core transects of the Strait of Georgia juvenile herring survey.

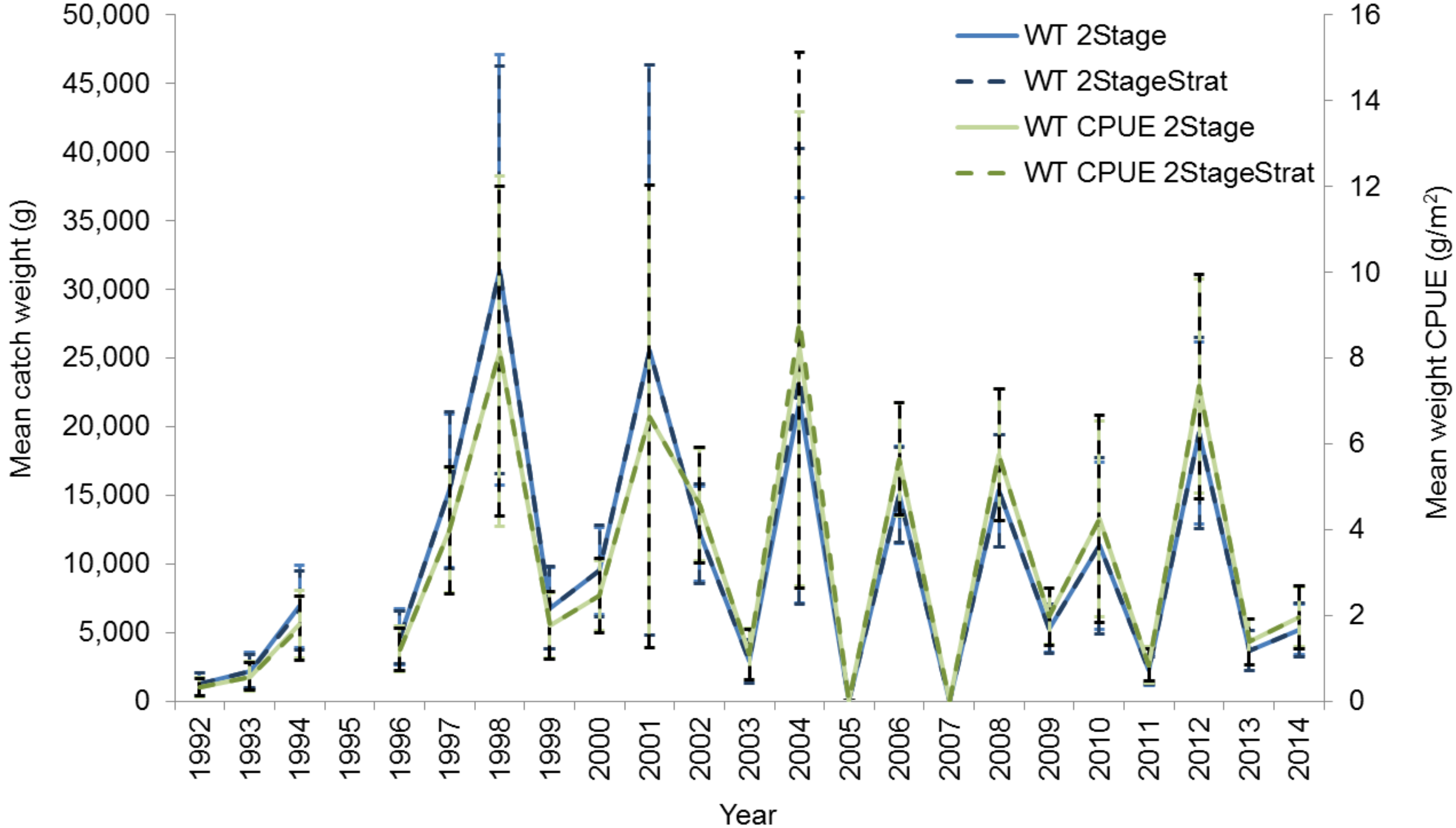


Figure 2. Estimates of catch weight (WT; g) and catch weight-per-unit-effort (WT CPUE; g/m^2) of age-0 herring caught in the Strait of Georgia juvenile herring survey at core transects and stations during 1992-2014 (no survey in 1995). Estimates were calculated using two methods: two-stage (2Stage) and two-stage stratified by transect type (2StageStrat). Estimates of CPUE were calculated by dividing catch weight by the area fished by the net (assuming the net length changed in 2002 from 220 m to 183 m; see text for details). Standard error bars (using the Thompson 1992 variance estimator) are shown.

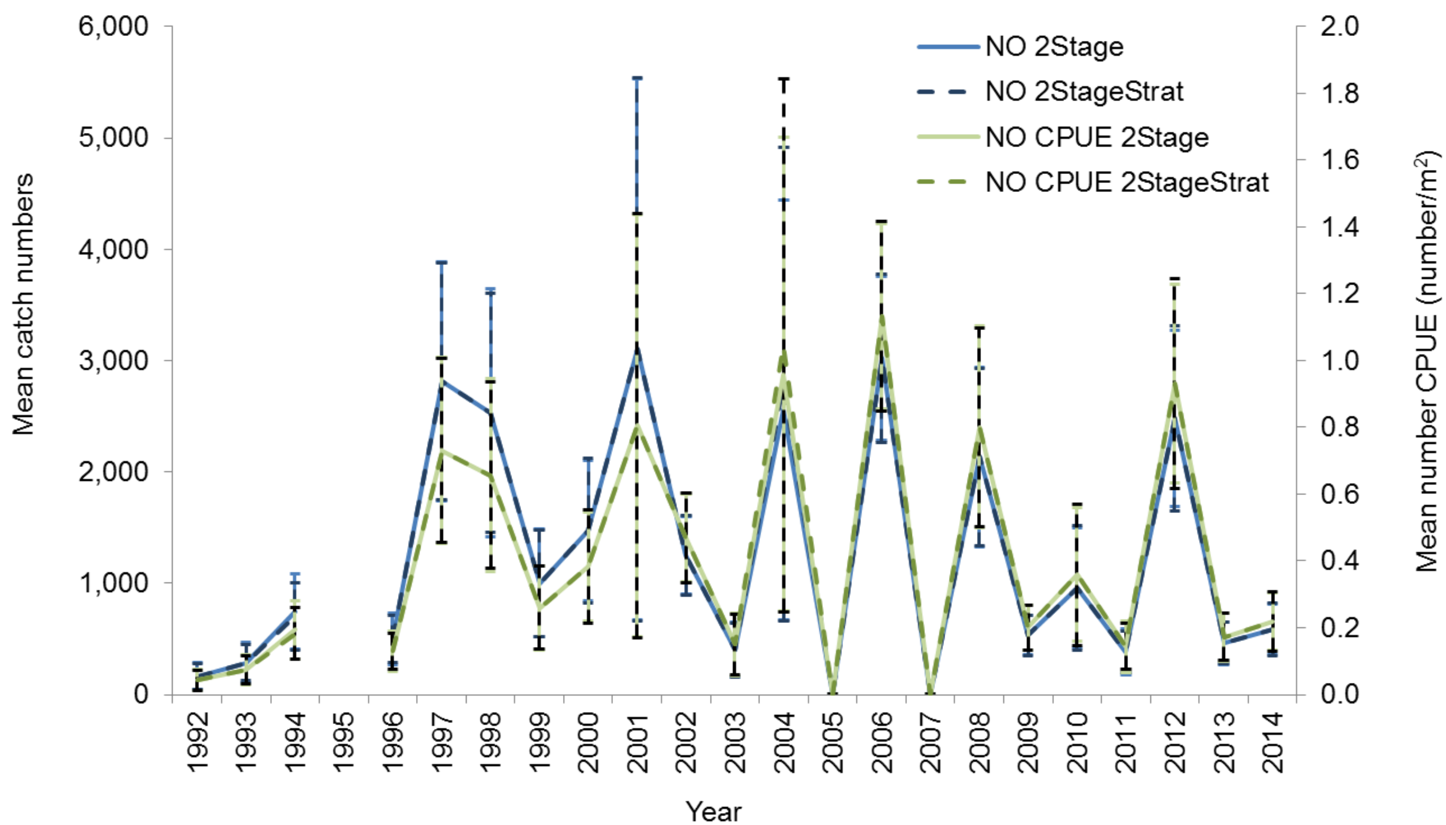


Figure 3. Estimates of catch numbers (NO) and catch numbers-per-unit-effort (NO CPUE; numbers/m^2) of age-0 herring caught in the Strait of Georgia juvenile herring survey at core transects and stations during 1992-2014 (no survey in 1995). Estimates were calculated using two methods: two-stage (2Stage) and two-stage stratified by transect type (2StageStrat). Estimates of NO CPUE were calculated by dividing catch numbers by the area fished by the net (assuming the net length changed in 2002 from 220 m to 183 m; see text for details). Standard error bars (using the Thompson 1992 variance estimator) are shown.

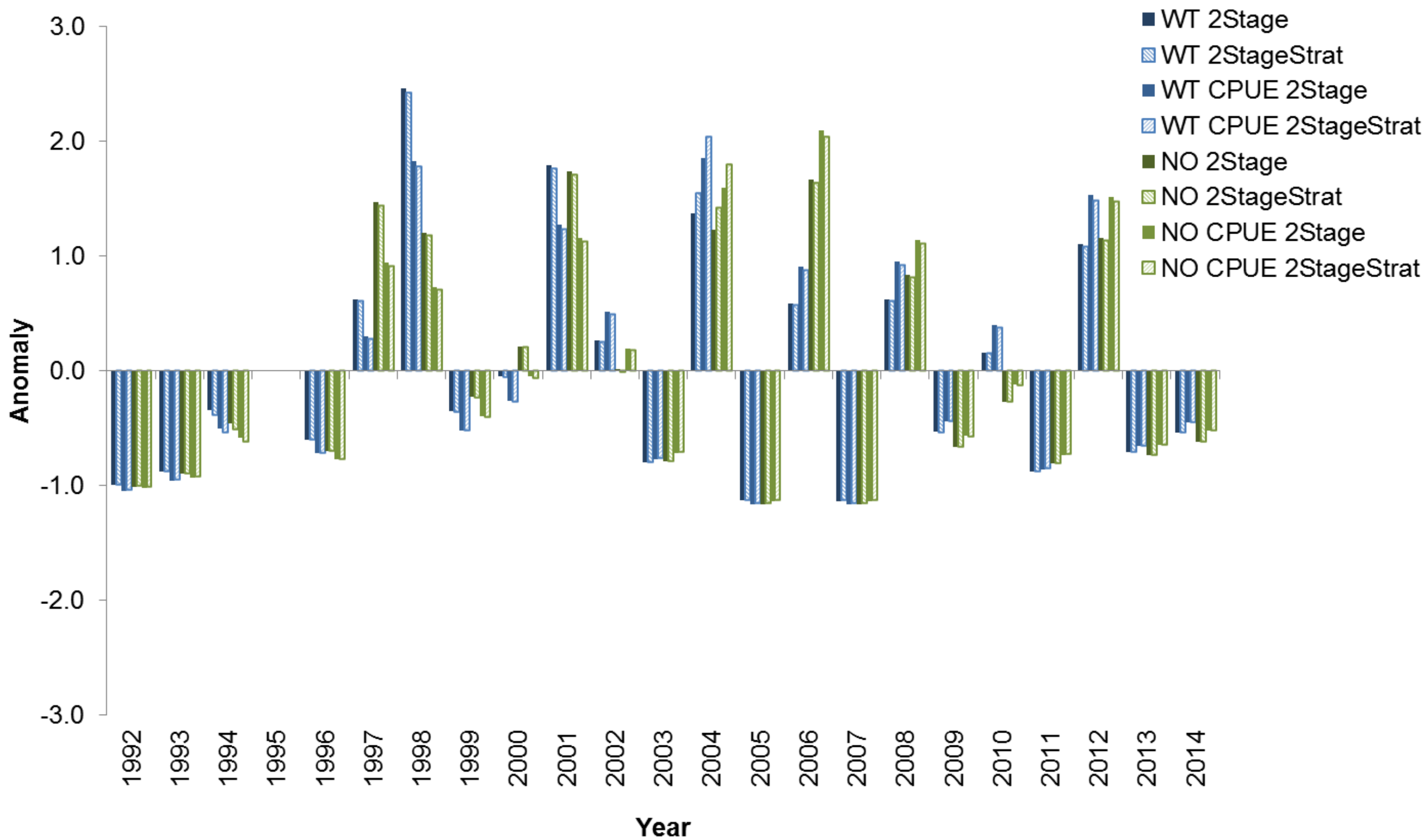


Figure 4. Anomalies of estimated catch weight (WT; g), abundance (NO), and weight and abundance catch-per-unit-effort (CPUE) of age-0 herring caught in the Strait of Georgia juvenile herring survey at core transects and stations during 1992-2014 (no survey in 1995). Values were estimated using the Thompson (1992) estimator for two methods: two-stage (2Stage), two-stage stratified by transect type (2StageStrat).

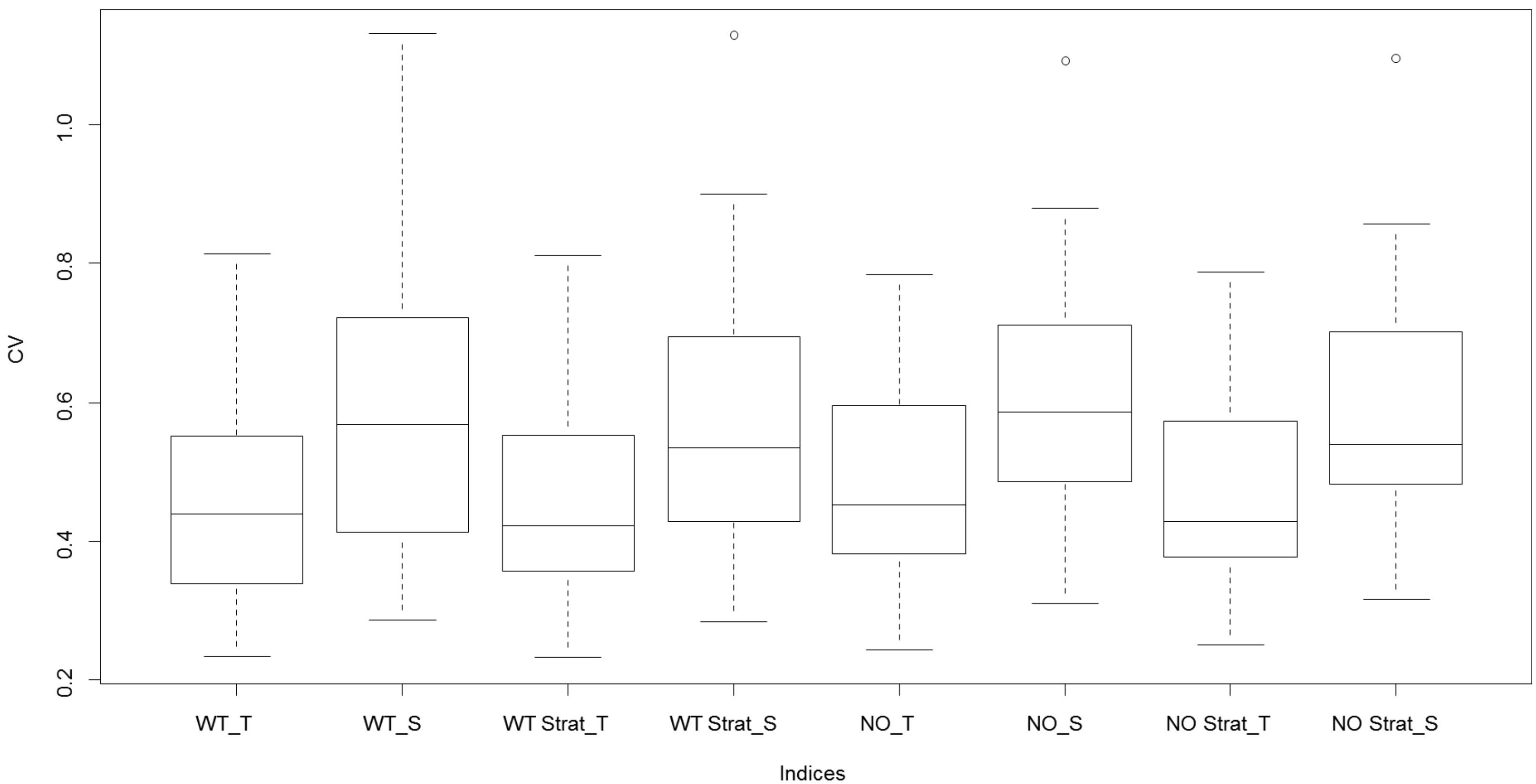


Figure 5. Coefficient of variation (CV) for catch weight (WT; g) and abundance (NO) of age-0 herring caught in the Strait of Georgia juvenile herring survey at core transects and stations during 1992-2014 (no survey in 1995). CVs are shown for two methods: two stage and two-stage stratified (Strat). CVs were calculated using two estimators: Thompson (1992; T) and Szarzi et al. (1995; S).

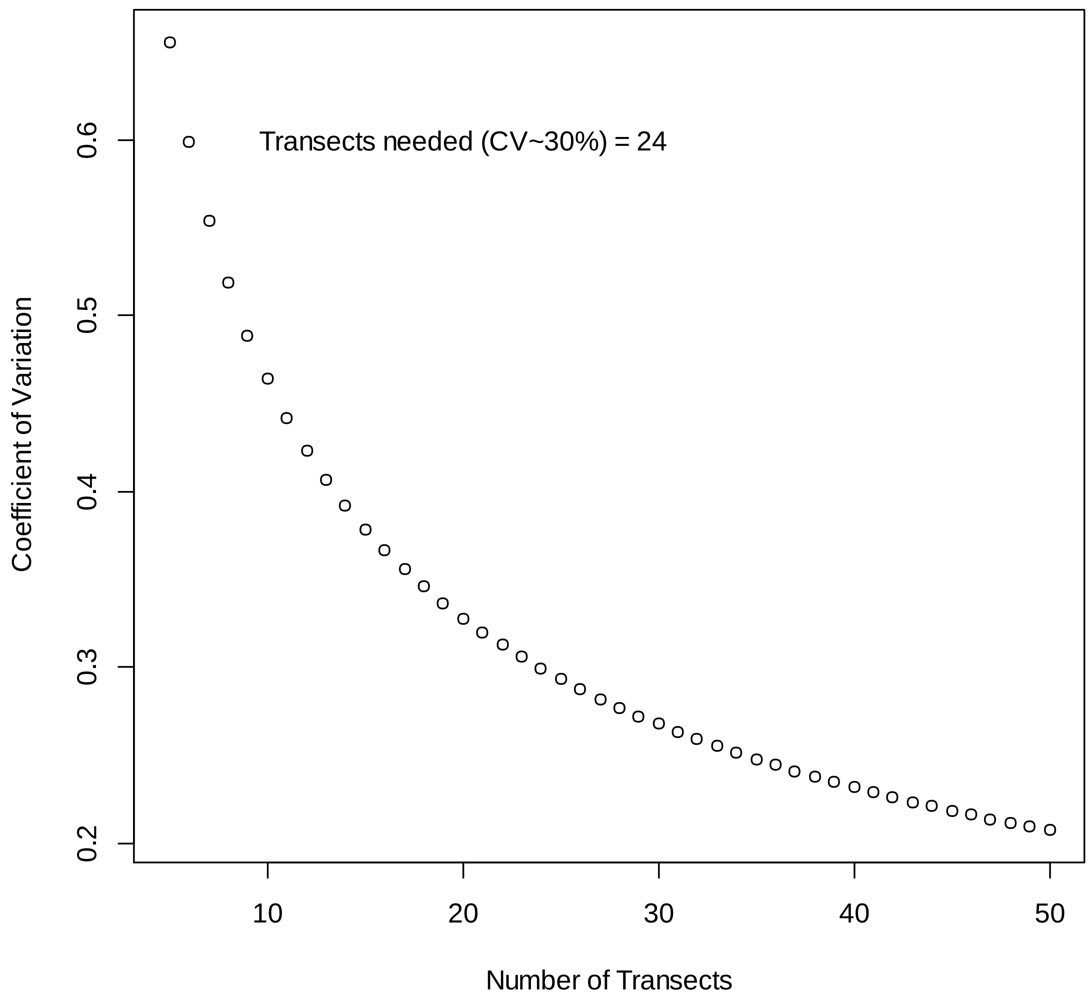


Figure 6. Coefficient of variation (CV) as a function of number of transects, as estimated using herring catch weights (g) in the Strait of Georgia juvenile herring survey and the Thompson (1992) estimator for mean CV. The number of transects needed to get a CV of ~30% is 24.

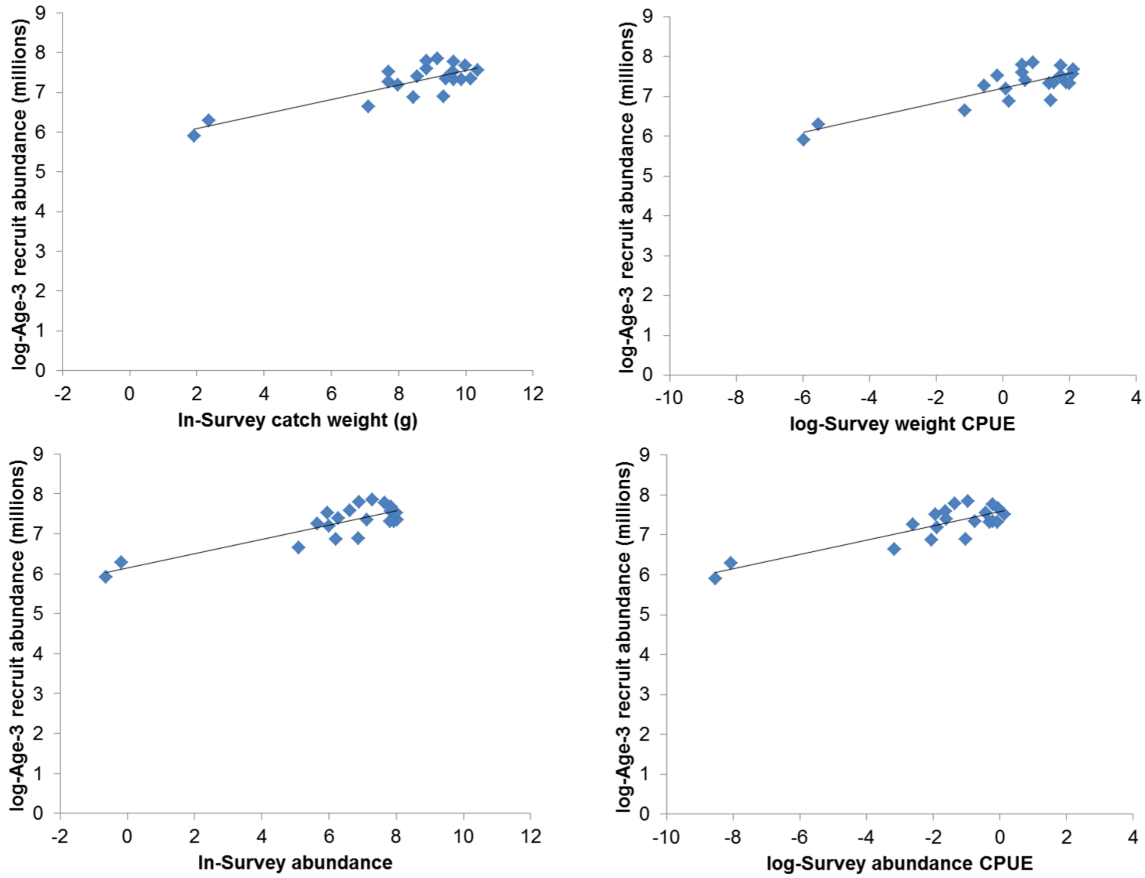


Figure 7. Age-3 herring recruit abundance estimates (log-transformed) from the age-structured stock assessment (1995-2015, except 1998; lagged by three years; Cleary and Taylor *in press*) as a function of two-stage estimates of age-0 herring catch weight (g; R^2= 0.67, p<0.001), weight catch-per-unit-effort (CPUE; R^2= 0.67, p<0.001), abundance (R^2= 0.70, p<0.001), and abundance CPUE (R^2= 0.70, p<0.001) from the Strait of Georgia juvenile herring survey (1992-2012; except 1995) three years prior.

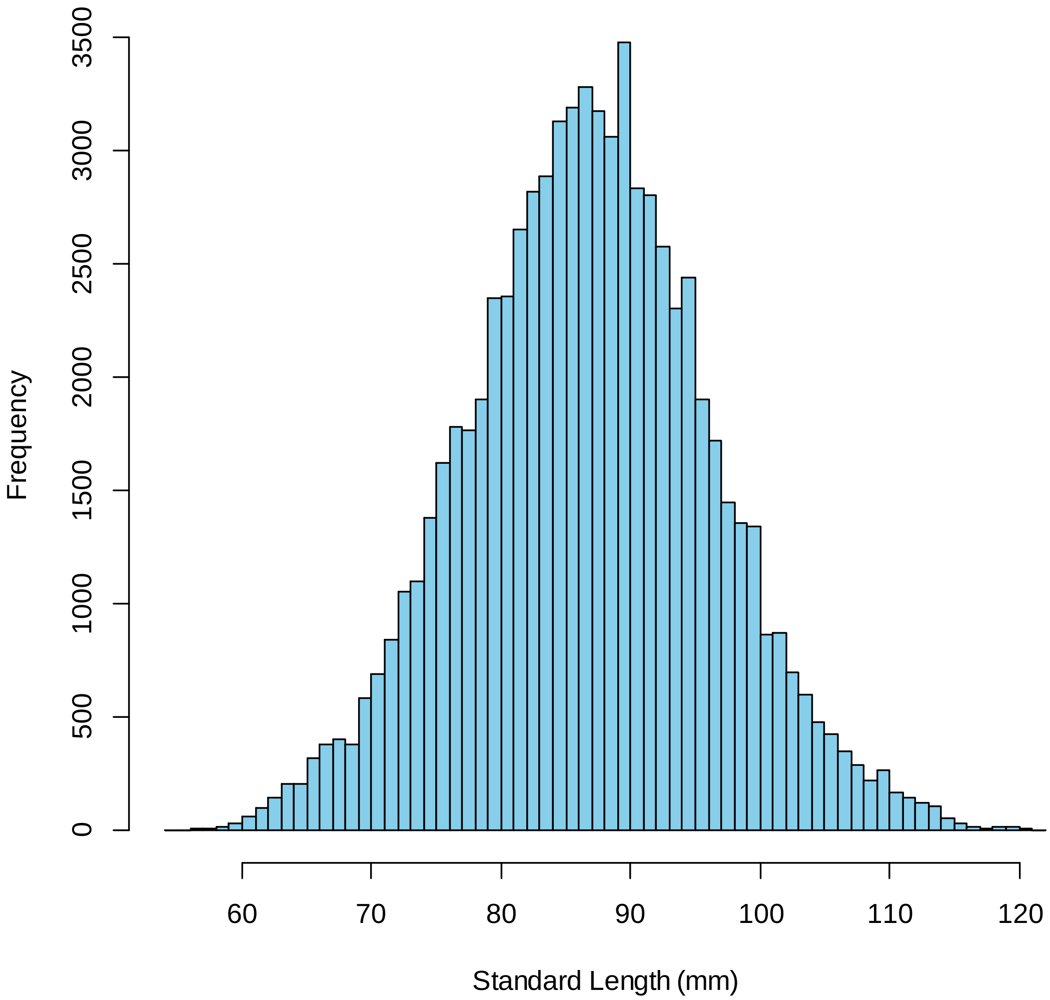


Figure 8. Histogram of standard length (mm) frequencies of age-0 herring sampled at core stations along core transects during 1992-2014 (no survey in 1995).

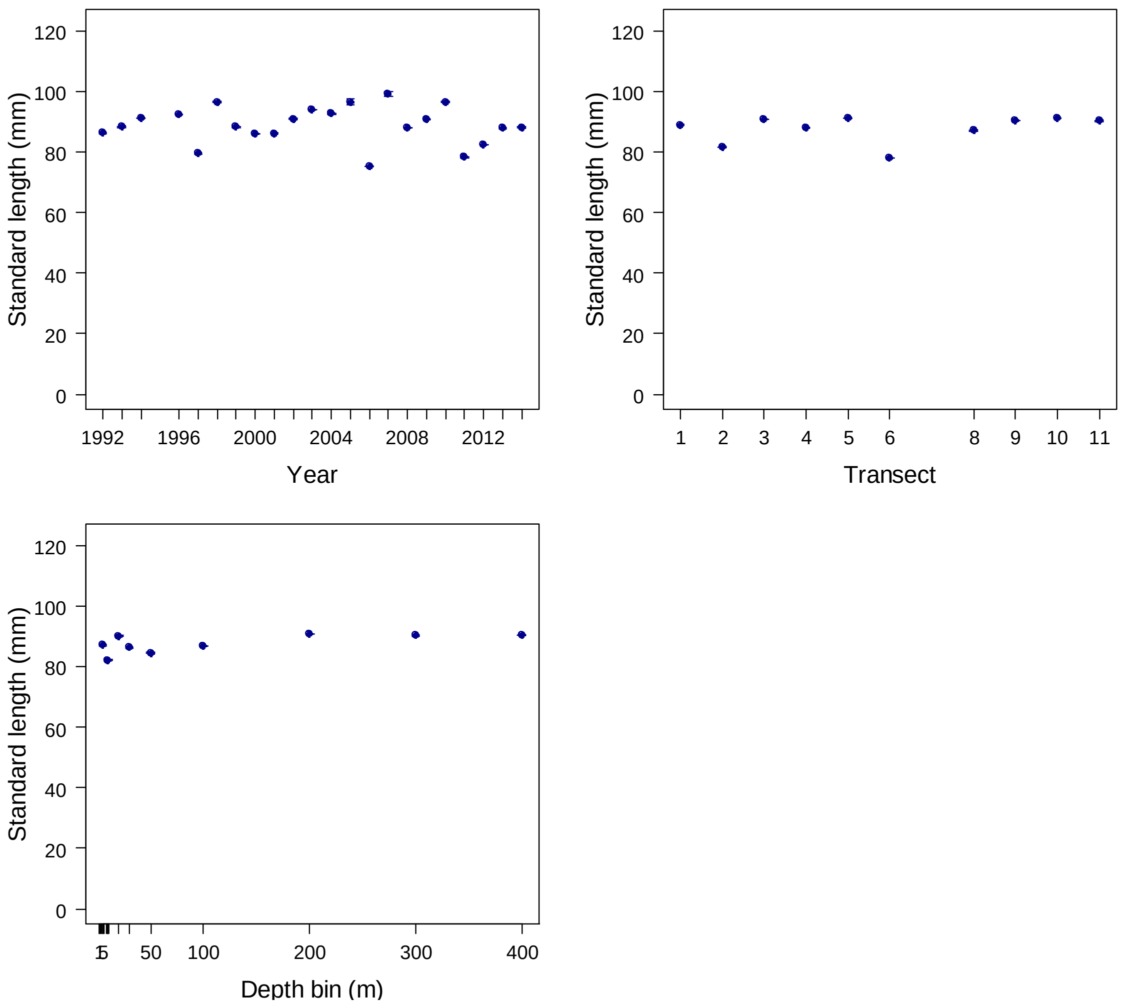


Figure 9. Age-0 herring mean standard lengths (mm) measured in the laboratory as a function of year, transect, and depth bin (m), 1992-2014 (no survey in 1995). Standard error bars are shown.

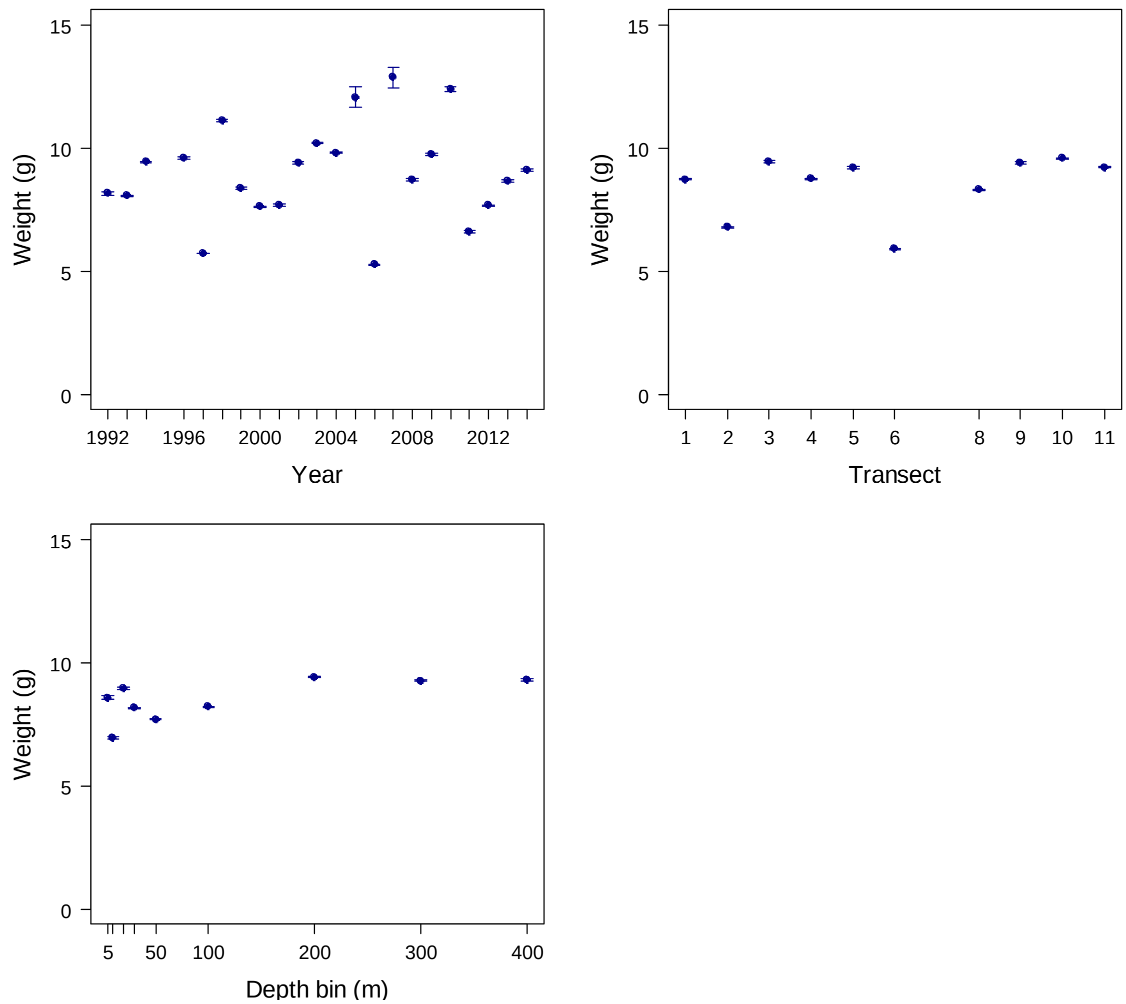


Figure 10. Age-0 herring mean wet weights (g) measured in the laboratory as a function of year, transect, and depth bin (m), 1992-2014 (no survey in 1995). Standard error bars are shown.

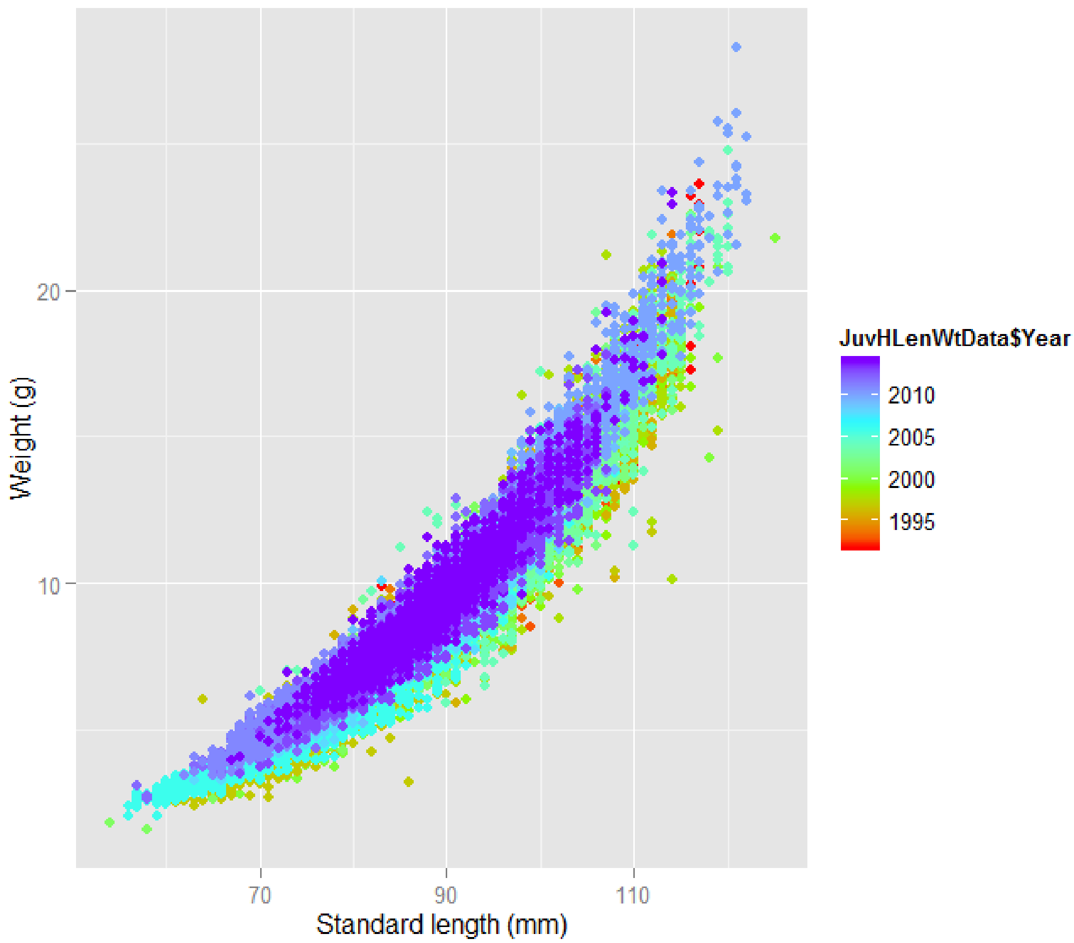


Figure 11a. Standard length-weight relationship for all age-0 herring sampled during the Strait of Georgia juvenile herring survey, 1992-2014 (no survey in 1995).

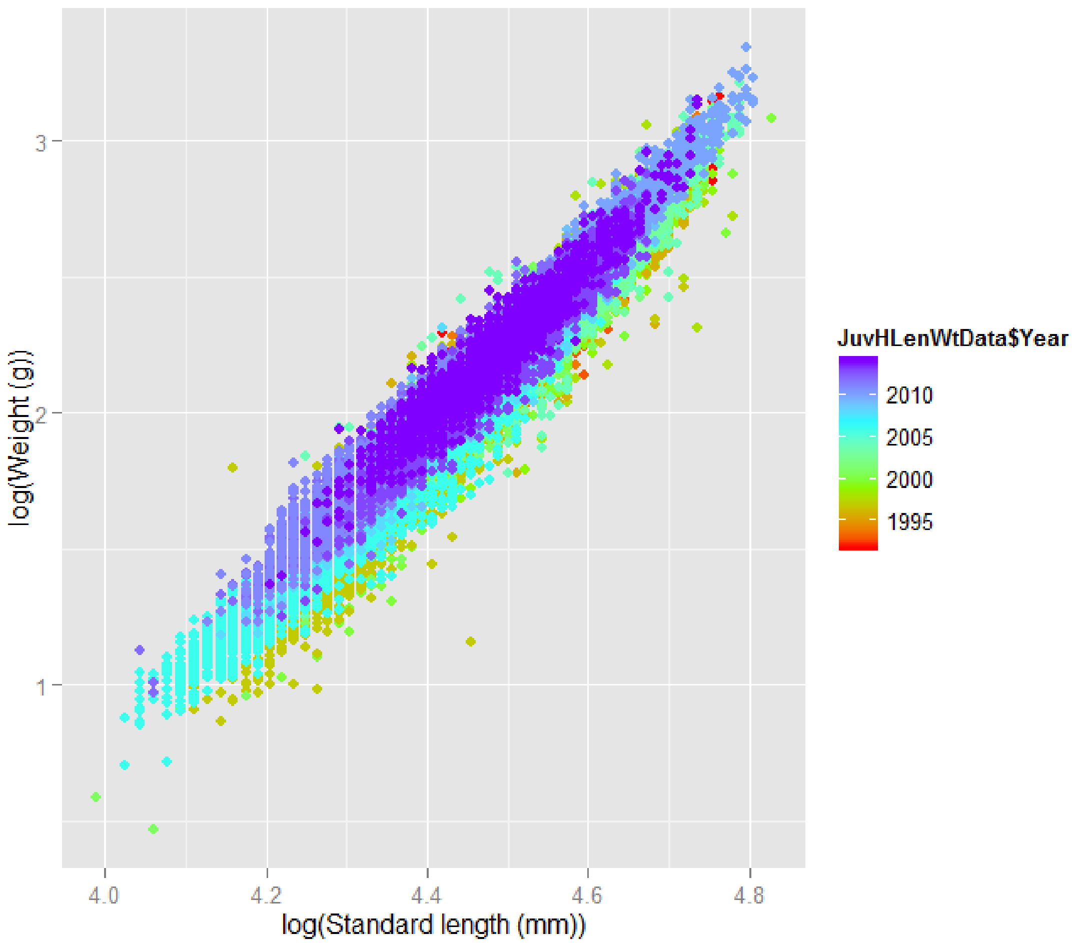


Figure 11b. Standard length-weight (log-transformed) relationship for all age-0 herring sampled during the Strait of Georgia juvenile herring survey, 1992-2014 (no survey in 1995).

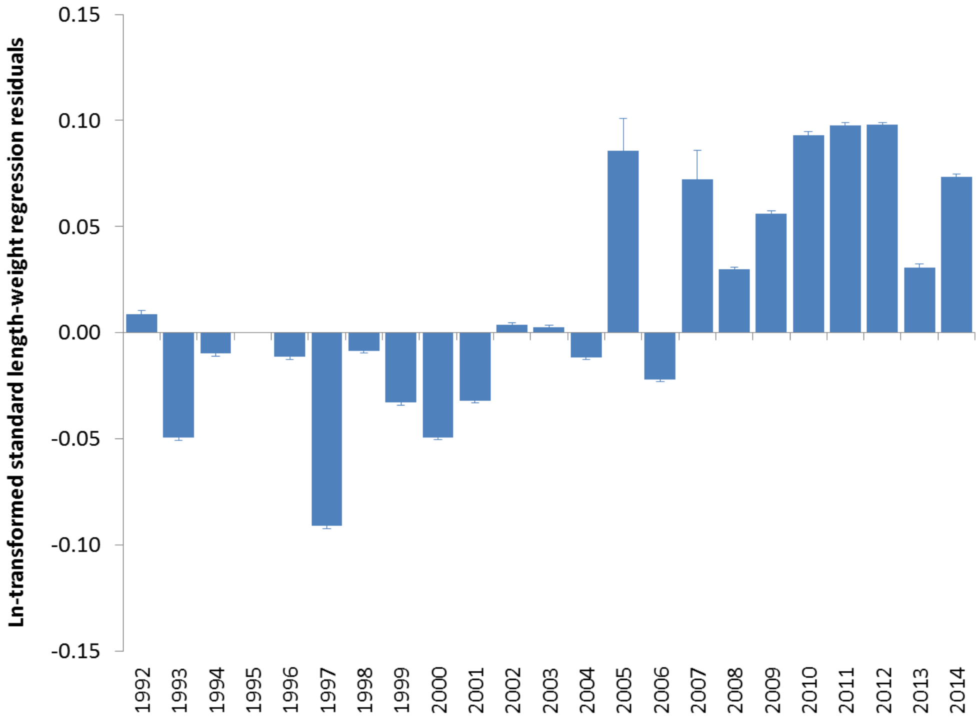


Figure 12. Mean annual residuals (and standard errors) from a log-transformed standard length (mm)-weight (g) regression for age-0 herring sampled at core stations and transects during 1992-2014 (no survey in 1995).

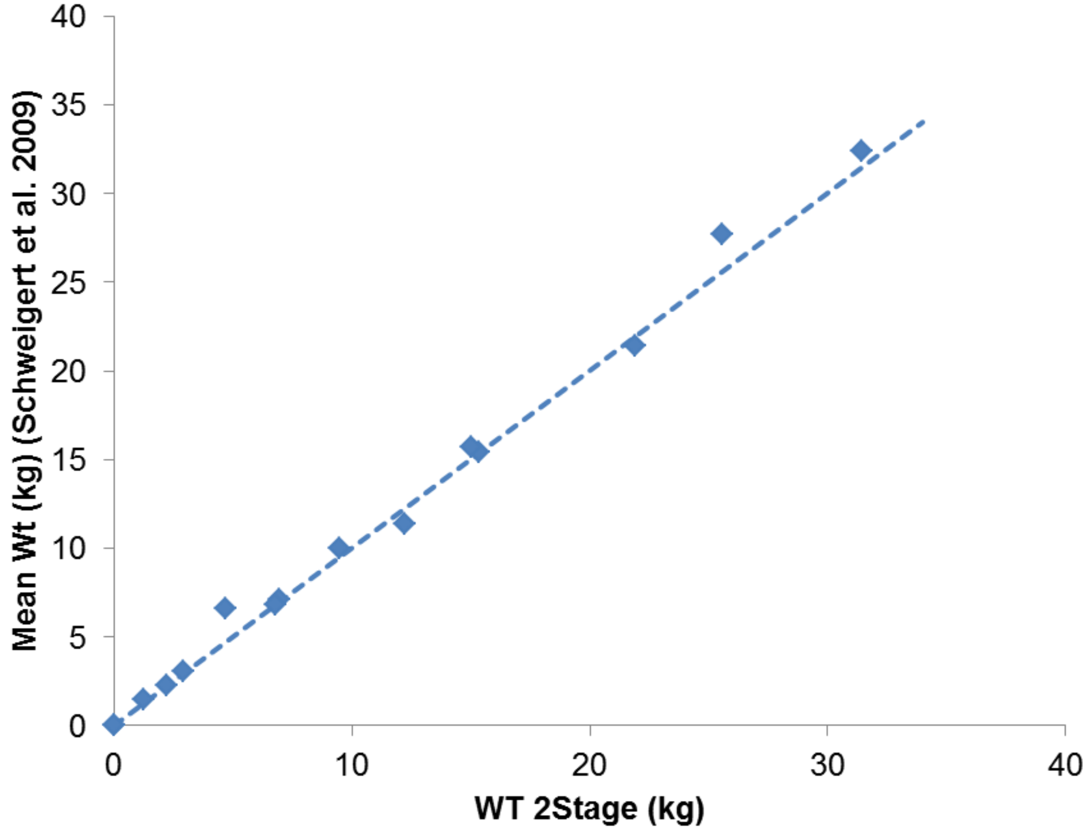


Figure 13. Catch weights (kg) calculated by Schweigert et al. (2009) as a function of catch weights calculated using the two-stage method in this report (WT 2Stage; kg), 1992-2007 (except 1995). The dotted line is the 1:1 line. $R^2 = 0.99$, $p<0.001$.

Table 1. Core station and transect names, locations and depth intervals sampled as part of the SOG juvenile herring survey during 1992-2014 (no survey in 1995).

Transect	Type	Transect name	Station	Latitude	Longitude	Depth interval (m)
1	Open	Clarke Rock	1	49.22	-123.94	10-20
1	Open	Clarke Rock	2	49.23	-123.93	50-100
1	Open	Clarke Rock	3	49.24	-123.92	100-200
1	Open	Clarke Rock	4	49.24	-123.91	100-200
1	Open	Clarke Rock	5	49.24	-123.90	200-300
2	Channel	Yellow Point	1	49.04	-123.75	5-10
2	Channel	Yellow Point	2	49.05	-123.73	50-100
2	Channel	Yellow Point	3	49.06	-123.72	30-50
2	Channel	Yellow Point	4	49.06	-123.71	50-100
2	Channel	Yellow Point	5	49.07	-123.70	30-50
3	Open	Bowser	1	49.45	-124.68	5-10
3	Open	Bowser	2	49.46	-124.67	30-50
3	Open	Bowser	3	49.47	-124.66	50-100
3	Open	Bowser	4	49.48	-124.66	100-200
3	Open	Bowser	5	49.48	-124.65	50-100
4	Channel	Henry Bay	1	49.59	-124.87	20-30
4	Channel	Henry Bay	2	49.60	-124.87	20-30
4	Channel	Henry Bay	3	49.60	-124.86	30-50
4	Channel	Henry Bay	4	49.60	-124.85	30-50
4	Channel	Henry Bay	5	49.60	-124.84	2-5
5	Open	French Creek	1	49.35	-124.35	15-20
5	Open	French Creek	2	49.35	-124.34	50-100
5	Open	French Creek	3	49.36	-124.33	50-100
5	Open	French Creek	4	49.36	-124.32	100-200
5	Open	French Creek	5	49.37	-124.32	200-300
6	Channel	Trincomali Channel	1	48.85	-123.43	20-30
6	Channel	Trincomali Channel	2	48.86	-123.42	30-50
6	Channel	Trincomali Channel	3	48.87	-123.42	30-50
6	Channel	Trincomali Channel	4	48.87	-123.41	30-50
6	Channel	Trincomali Channel	5	48.88	-123.41	50-100
8	Channel	Smelt Bay	1	50.04	-125.00	30-50
8	Channel	Smelt Bay	2	50.05	-125.02	50-100
8	Channel	Smelt Bay	3	50.05	-125.03	15-20
9	Open	Atrevida Reef	1	49.92	-124.66	20-30
9	Open	Atrevida Reef	2	49.91	-124.67	100-200
9	Open	Atrevida Reef	3	49.91	-124.68	100-200
9	Open	Atrevida Reef	4	49.91	-124.69	100-200
9	Open	Atrevida Reef	5	49.90	-124.71	50-100
10	Channel	Cape Cockburn	1	49.67	-124.20	50-100

10	Channel	Cape Cockburn	2	49.66	-124.22	200-300
10	Channel	Cape Cockburn	3	49.65	-124.24	300-400
10	Channel	Cape Cockburn	4	49.64	-124.26	300-400
10	Channel	Cape Cockburn	5	49.63	-124.28	200-300
11	Open	Secret Cove	1	49.53	-123.98	30-50
11	Open	Secret Cove	2	49.53	-124.00	100-200
11	Open	Secret Cove	3	49.53	-124.01	100-200
11	Open	Secret Cove	4	49.53	-124.04	20-30
11	Open	Secret Cove	5	49.52	-124.06	200-300

Table 2. The core station numbers (names) sampled along core transects during September-October, 1992-2014 (no survey in 1995). Data collected at these stations, transects, and years were used in analyses in this report. Odd-numbered transects were in open water; even-numbered transects were in channels.

	Transect									
Year	1	2	3	4	5	6	8	9	10	11
1992	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3	1 2 3 4 5		
1993	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
1994	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3	1 2 3 4 5	1 2 3 4 5	
1996	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
1997	1 2 3	1 3 5	1 2 3	1 3 5	1 2 3	1 3 5	1 2	1 2 3	1 3 5	1 2 3
1998	1 2 3	1 3 5	1 2 3	3 5	1 2 3	1 3 5	1 2 3	1 2 3	1 3 5	1 2 3
1999	1 2 3	1 3 5	1 2 3	1 3 5	1 2 3	1 3 5	1 2 3	1 2 3	1 3 5	1 2 3
2000	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	2 3 5	1 2 3 4 5	1 2 3 4 5	1 2 3	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
2001	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3	1 2 3 4 5	1 2 3 5	1 2 3	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
2002	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4	1 2 3 4 5	1 2 3 4 5	1 2 3	1 2 3 4 5	1 2	1 2 3 4 5
2003	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4	1 2 3 4 5	1 2 3 4 5	2 3	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
2004	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5		1 2 3 4 5	1 2 3 4 5	1 2 3	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
2005	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3	1 2 3 4 5	1 3 5	1 2 3 4 5
2006	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
2007	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3	1 2 3 4 5	1 2 3 4 5	1 2 3 4
2008	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
2009	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
2010	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
2011	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
2012	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
2013	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5
2014	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5	1 2 3	1 2 3 4 5	1 2 3 4 5	1 2 3 4 5

Table 3. Dates of Strait of Georgia juvenile herring survey samples collected at core stations and transects during 1992-2014 (no survey in 1995).

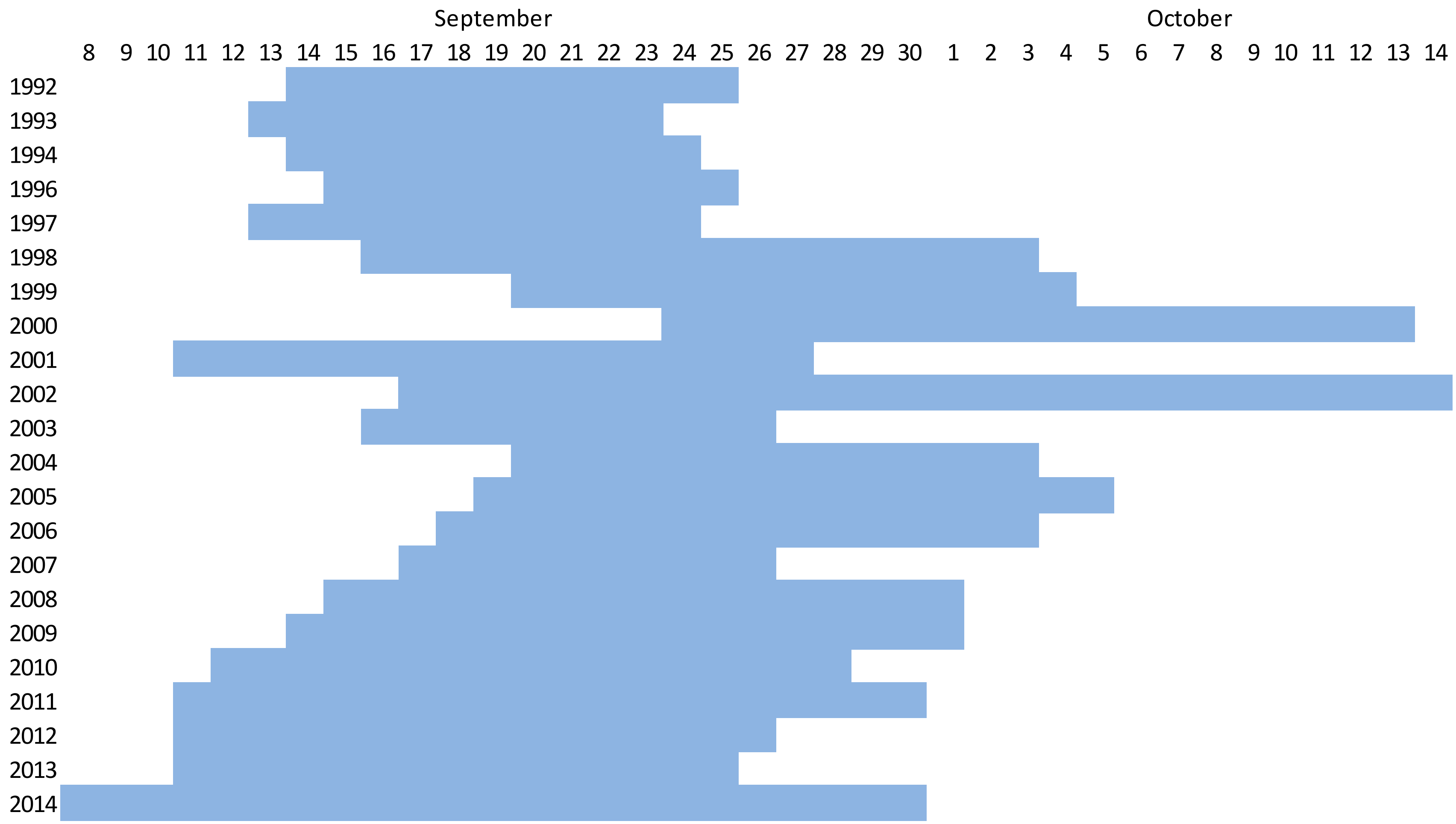


Table 4. Three scenarios used to estimate relative age-0 herring biomass (abundance) from the Strait of Georgia juvenile herring survey. Scenarios encompass assumptions about the length of the purse seine net used during different years. Scenario 2 is the most likely. CPUE = catch-per-unit-effort calculated as catch weight or abundance divided by area fished (m^2).

Scenario	Years	Net length (m)	Area fished (m^2)	Age-0 herring indices
1	1992-2014	183	same throughout time series	catch weights, abundance
2	1996-2014	183	same throughout time series	catch weights, abundance
3	1992-2001, 2002-2014	220, 183	3852, 2660	CPUE

Table 5. Mean catch weight (WT; g) and catch weight per unit effort (WT CPUE; g/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 1992-2014 (no survey in 1995). Values were calculated using the Thompson (1992) estimator and two methods: two-stage (2Stage) and two-stage stratified by transect type (2StageStrat).

	WT 2Stage			WT 2StageStrat			WT CPUE 2Stage			WT CPUE 2StageStrat		
Year	Mean	SE	CV	Mean	SE	CV	Mean	SE	CV	Mean	SE	CV
1992	1226.333	852.076	0.695	1226.333	794.996	0.648	0.318	0.221	0.695	0.318	0.206	0.648
1993	2206.211	1337.446	0.606	2206.211	1220.773	0.553	0.573	0.347	0.606	0.573	0.317	0.553
1994	6930.616	3010.497	0.434	6590.658	2876.680	0.436	1.799	0.782	0.434	1.711	0.747	0.436
1996	4669.740	2065.650	0.442	4669.740	1908.710	0.409	1.212	0.536	0.442	1.212	0.496	0.409
1997	15341.900	5569.885	0.363	15341.900	5728.814	0.373	3.983	1.446	0.363	3.983	1.487	0.373
1998	31418.933	15708.446	0.500	31418.933	14840.044	0.472	8.157	4.078	0.500	8.157	3.853	0.472
1999	6809.267	2963.350	0.435	6809.267	3032.278	0.445	1.768	0.769	0.435	1.768	0.787	0.445
2000	9490.827	3175.900	0.335	9490.827	3349.140	0.353	2.464	0.824	0.335	2.464	0.869	0.353
2001	25568.172	20777.096	0.813	25568.172	20761.205	0.812	6.638	5.394	0.813	6.638	5.390	0.812
2002	12197.863	3497.051	0.287	12197.863	3590.758	0.294	4.577	1.312	0.287	4.577	1.347	0.294
2003	2900.546	1597.512	0.551	2900.546	1569.404	0.541	1.088	0.599	0.551	1.088	0.589	0.541
2004	21901.546	14754.345	0.674	23661.432	16623.793	0.703	8.218	5.536	0.674	8.879	6.238	0.703
2005	10.596	5.108	0.482	10.596	4.331	0.409	0.004	0.002	0.482	0.004	0.002	0.409
2006	15045.055	3526.160	0.234	15045.055	3488.645	0.232	5.645	1.323	0.234	5.645	1.309	0.232
2007	6.804	4.281	0.629	6.804	4.055	0.596	0.003	0.002	0.629	0.003	0.002	0.596
2008	15334.313	4082.787	0.266	15334.313	4096.937	0.267	5.754	1.532	0.266	5.754	1.537	0.267
2009	5261.335	1737.286	0.330	5261.335	1773.664	0.337	1.974	0.652	0.330	1.974	0.666	0.337
2010	11322.919	6089.296	0.538	11322.919	6458.188	0.570	4.249	2.285	0.538	4.249	2.423	0.570
2011	2233.234	1128.388	0.505	2233.234	982.945	0.440	0.838	0.423	0.505	0.838	0.369	0.440
2012	19564.914	6640.157	0.339	19564.914	6977.570	0.357	7.341	2.492	0.339	7.341	2.618	0.357
2013	3688.389	1443.124	0.391	3688.389	1423.933	0.386	1.384	0.542	0.391	1.384	0.534	0.386
2014	5215.187	1856.540	0.356	5215.187	1968.059	0.377	1.957	0.697	0.356	1.957	0.738	0.377

Table 6. Mean catch abundance (NO) and catch abundance per unit effort (NO CPUE; no/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 1992-2014 (no survey in 1995). Values were calculated using the Thompson (1992) estimator and two methods: two-stage (2Stage) and two-stage stratified by transect type (2StageStrat).

	NO 2Stage			NO 2StageStrat			NO CPUE 2Stage			NO CPUE 2StageStrat		
Year	Mean	SE	CV	Mean	SE	CV	Mean	SE	CV	Mean	SE	CV
1992	163.358	122.426	0.749	163.358	115.808	0.709	0.042	0.032	0.749	0.042	0.030	0.709
1993	285.847	178.452	0.624	285.847	163.786	0.573	0.074	0.046	0.624	0.074	0.043	0.573
1994	748.304	334.987	0.448	703.123	301.326	0.429	0.194	0.087	0.448	0.183	0.078	0.429
1996	499.247	228.320	0.457	499.247	209.372	0.419	0.130	0.059	0.457	0.130	0.054	0.419
1997	2813.467	1072.734	0.381	2813.467	1063.508	0.378	0.730	0.278	0.381	0.730	0.276	0.378
1998	2529.717	1111.968	0.440	2529.717	1077.415	0.426	0.657	0.289	0.440	0.657	0.280	0.426
1999	1001.333	485.487	0.485	1001.333	480.673	0.480	0.260	0.126	0.485	0.260	0.125	0.480
2000	1472.513	626.178	0.425	1472.513	653.331	0.444	0.382	0.163	0.425	0.382	0.170	0.444
2001	3100.970	2429.038	0.783	3100.970	2441.904	0.787	0.805	0.631	0.783	0.805	0.634	0.787
2002	1249.845	345.835	0.277	1249.845	357.712	0.286	0.469	0.130	0.277	0.469	0.134	0.286
2003	399.895	247.569	0.619	399.895	241.292	0.603	0.150	0.093	0.619	0.150	0.091	0.603
2004	2556.415	1889.527	0.739	2788.182	2127.501	0.763	0.959	0.709	0.739	1.046	0.798	0.763
2005	0.840	0.396	0.472	0.840	0.334	0.398	0.000	0.000	0.472	0.000	0.000	0.398
2006	3020.660	738.642	0.245	3020.660	756.379	0.250	1.133	0.277	0.245	1.133	0.284	0.250
2007	0.528	0.315	0.596	0.528	0.298	0.564	0.000	0.000	0.596	0.000	0.000	0.564
2008	2132.927	806.846	0.378	2132.927	793.552	0.372	0.800	0.303	0.378	0.800	0.298	0.372
2009	533.687	175.386	0.329	533.687	181.675	0.340	0.200	0.066	0.329	0.200	0.068	0.340
2010	957.535	534.899	0.559	957.535	564.051	0.589	0.359	0.201	0.559	0.359	0.212	0.589
2011	381.820	206.055	0.540	381.820	183.078	0.479	0.143	0.077	0.540	0.143	0.069	0.479
2012	2480.540	791.017	0.319	2480.540	835.641	0.337	0.931	0.297	0.319	0.931	0.314	0.337
2013	460.198	191.919	0.417	460.198	187.482	0.407	0.173	0.072	0.417	0.173	0.070	0.407
2014	581.953	224.927	0.387	581.953	238.191	0.409	0.218	0.084	0.387	0.218	0.089	0.409

Table 7. Mean catch weight (WT; g) and catch weight per unit effort (WT CPUE; g/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 1992-2014 (no survey in 1995). Values were calculated using the Szarzi et al. (1995) estimator and two methods: two-stage (2Stage) and two-stage stratified by transect type (2StageStrat).

	WT 2Stage			WT 2StageStrat			WT CPUE 2Stage			WT CPUE 2StageStrat		
Year	Mean	SE	CV	Mean	SE	CV	Mean	SE	CV	Mean	SE	CV
1992	1226.333	904.606	0.738	1226.333	851.056	0.694	0.318	0.235	0.738	0.318	0.221	0.694
1993	2206.211	1479.466	0.671	2206.211	1374.899	0.623	0.573	0.384	0.671	0.573	0.357	0.623
1994	6930.616	3608.915	0.521	6590.658	3441.909	0.522	1.799	0.937	0.521	1.711	0.894	0.522
1996	4669.740	2936.491	0.629	4669.740	2828.293	0.606	1.212	0.762	0.629	1.212	0.734	0.606
1997	15341.900	7216.747	0.470	15341.900	7340.104	0.478	3.983	1.874	0.470	3.983	1.906	0.478
1998	31418.933	23099.255	0.735	31418.933	22517.710	0.717	8.157	5.997	0.735	8.157	5.846	0.717
1999	6809.267	4119.514	0.605	6809.267	4169.372	0.612	1.768	1.069	0.605	1.768	1.082	0.612
2000	9490.827	3774.691	0.398	9490.827	3921.567	0.413	2.464	0.980	0.398	2.464	1.018	0.413
2001	25568.172	28859.395	1.129	25568.172	28847.957	1.128	6.638	7.492	1.129	6.638	7.489	1.128
2002	12197.863	4646.337	0.381	12197.863	4717.269	0.387	4.577	1.743	0.381	4.577	1.770	0.387
2003	2900.546	1730.668	0.597	2900.546	1704.758	0.588	1.088	0.649	0.597	1.088	0.640	0.588
2004	21901.546	15847.661	0.724	23661.432	17830.815	0.754	8.218	5.947	0.724	8.879	6.691	0.754
2005	10.596	6.391	0.603	10.596	5.790	0.546	0.004	0.002	0.603	0.004	0.002	0.546
2006	15045.055	4314.185	0.287	15045.055	4283.577	0.285	5.645	1.619	0.287	5.645	1.607	0.285
2007	6.804	6.269	0.921	6.804	6.116	0.899	0.003	0.002	0.921	0.003	0.002	0.899
2008	15334.313	6111.022	0.399	15334.313	6120.485	0.399	5.754	2.293	0.399	5.754	2.297	0.399
2009	5261.335	2112.164	0.401	5261.335	2142.185	0.407	1.974	0.793	0.401	1.974	0.804	0.407
2010	11322.919	8180.245	0.722	11322.919	8458.433	0.747	4.249	3.070	0.722	4.249	3.174	0.747
2011	2233.234	1198.531	0.537	2233.234	1062.731	0.476	0.838	0.450	0.537	0.838	0.399	0.476
2012	19564.914	8080.693	0.413	19564.914	8360.167	0.427	7.341	3.032	0.413	7.341	3.137	0.427
2013	3688.389	1844.975	0.500	3688.389	1830.003	0.496	1.384	0.692	0.500	1.384	0.687	0.496
2014	5215.187	2219.273	0.426	5215.187	2313.373	0.444	1.957	0.833	0.426	1.957	0.868	0.444

Table 8. Mean catch abundance (NO) and catch abundance per unit effort (NO CPUE; no/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 1992-2014 (no survey in 1995). Values were calculated using the Szarzi et al. (1995) estimator and two methods: two-stage (2Stage) and two-stage stratified by transect type (2StageStrat).

	NO 2Stage			NO 2StageStrat			NO CPUE 2Stage			NO CPUE 2StageStrat		
Year	Mean	SE	CV	Mean	SE	CV	Mean	SE	CV	Mean	SE	CV
1992	163.358	129.918	0.795	163.358	123.701	0.757	0.042	0.034	0.795	0.042	0.032	0.757
1993	285.847	195.839	0.685	285.847	182.575	0.639	0.074	0.051	0.685	0.074	0.047	0.639
1994	748.304	402.126	0.537	703.123	364.539	0.518	0.194	0.104	0.537	0.183	0.095	0.518
1996	499.247	323.433	0.648	499.247	310.347	0.622	0.130	0.084	0.648	0.130	0.081	0.622
1997	2813.467	1364.784	0.485	2813.467	1357.544	0.483	0.730	0.354	0.485	0.730	0.352	0.483
1998	2529.717	1632.432	0.645	2529.717	1609.094	0.636	0.657	0.424	0.645	0.657	0.418	0.636
1999	1001.333	655.256	0.654	1001.333	651.697	0.651	0.260	0.170	0.654	0.260	0.169	0.651
2000	1472.513	730.680	0.496	1472.513	754.079	0.512	0.382	0.190	0.496	0.382	0.196	0.512
2001	3100.970	3382.533	1.091	3100.970	3391.783	1.094	0.805	0.878	1.091	0.805	0.881	1.094
2002	1249.845	454.994	0.364	1249.845	464.086	0.371	0.469	0.171	0.364	0.469	0.174	0.371
2003	399.895	285.830	0.715	399.895	280.411	0.701	0.150	0.107	0.715	0.150	0.105	0.701
2004	2556.415	2013.171	0.787	2788.182	2265.303	0.812	0.959	0.755	0.787	1.046	0.850	0.812
2005	0.840	0.504	0.600	0.840	0.457	0.544	0.000	0.000	0.600	0.000	0.000	0.544
2006	3020.660	940.643	0.311	3020.660	954.634	0.316	1.133	0.353	0.311	1.133	0.358	0.316
2007	0.528	0.464	0.879	0.528	0.453	0.857	0.000	0.000	0.879	0.000	0.000	0.857
2008	2132.927	1153.763	0.541	2132.927	1144.506	0.537	0.800	0.433	0.541	0.800	0.429	0.537
2009	533.687	214.253	0.401	533.687	219.432	0.411	0.200	0.080	0.401	0.200	0.082	0.411
2010	957.535	680.410	0.711	957.535	703.559	0.735	0.359	0.255	0.711	0.359	0.264	0.735
2011	381.820	218.728	0.573	381.820	197.233	0.517	0.143	0.082	0.573	0.143	0.074	0.517
2012	2480.540	962.530	0.388	2480.540	999.526	0.403	0.931	0.361	0.388	0.931	0.375	0.403
2013	460.198	245.216	0.533	460.198	241.759	0.525	0.173	0.092	0.533	0.173	0.091	0.525
2014	581.953	265.477	0.456	581.953	276.806	0.476	0.218	0.100	0.456	0.218	0.104	0.476

Table 9. Standard lengths (mm) used to define age-0 herring, during 1992-2014 (no survey in 1995). Prior to 2005, age classes had overlapping distributions; after 2005, one length delimiter, as determined from a length-frequency histogram, was used to identify age classes. To compare pre- and post-2005 methods, an age-0 length delimiter was estimated for this report (and shown in parentheses) from length frequency histograms for years prior to 2005 (Appendix 11). If a delimiter was used to identify age-0 herring during 1992-2004, there would be small differences in age-classifications and sample sizes, as shown. Sources of information are shown.

Year	Cutoff or range of overlap between age0 and age-1 (mm)	Length frequency cutoff used or (estimated for this report) (mm)	Number of fish that would change from age-1 to age-0	Number of fish that would change from age-0 to age-1	Age-0 sample size	Source
1992	112-117	(≤112)	2	13	1,463	Haegele 1997
1993	≤112	(≤112)	0	0	2,919	Haegele 1997
1994	≤114 (*120)	(≤120)	16	0	3,583	Haegele 1997
1996	≤114	(≤114)	0	0	3,808	Haegele et al. 2005
1997	110-112	(≤106)	0	2	4,221	Haegele et al. 2005
1998	115-119	(≤120)	76	0	3,728	Haegele et al. 2005
1999	≤117	(≤115)	0	3	2,768	Haegele et al. 2005
2000	110-125	(≤113)	3	14	5,921	Haegele et al. 2005
2001	107-116	(≤107)	0	1	5,375	Haegele et al. 2005
2002	110-114	(≤114)	11	0	5,184	Haegele et al. 2005
2003	115-116	(≤113)	0	2	2,819	Haegele et al. 2005
2004	≤120	(≤118)	0	13	5,171	Thompson and Hrabok 2007
2005		≤100			30	Thompson and Schweigert 2007
2006		≤108			6,695	Thompson and Schweigert 2007
2007		≤105			22	Thompson and Schweigert 2009
2008		≤103			3,885	Thompson et al. 2009
2009		≤110			2,473	Thompson et al. 2010
2010		≤122			1,899	Thompson et al. 2011
2011		≤97			2,306	Thompson et al. 2013
2012		≤109			4,279	Thompson et al. 2013

2013	≤107	2,553	Thompson et al. *In press*
2014	≤114	2,749	Thompson et al. *In draft*

* in the report a slightly different length is reported (and shown in parentheses here). In this table, only data from core stations were examined, which resulted in a slightly different realized length cutoff.

Table 10. Mean individual standard lengths (mm) and wet weights (g) of age-0 herring measured in the laboratory, 1992-2014 (no survey in 1995). Sample sizes (Count), standard deviations (SD), and standard errors (SE) are shown.

Year	Count	Mean individual length (mm)	Length SD	Length SE	Mean individual weight (g)	Weight SD	Weight SE
1992	1,463	86.20	8.25	0.22	8.14	2.65	0.07
1993	2,919	88.19	6.30	0.12	8.06	1.66	0.03
1994	3,583	91.18	8.15	0.14	9.42	2.80	0.05
1996	3,808	92.29	6.10	0.10	9.59	2.02	0.03
1997	4,221	79.42	5.86	0.09	5.71	1.37	0.02
1998	3,728	96.39	9.06	0.15	11.11	3.27	0.05
1999	2,768	88.25	9.59	0.18	8.36	2.63	0.05
2000	5,921	86.02	7.83	0.10	7.62	2.26	0.03
2001	5,375	86.07	6.99	0.10	7.68	1.83	0.02
2002	5,184	90.87	8.00	0.11	9.39	2.49	0.03
2003	2,819	93.86	5.85	0.11	10.20	1.88	0.04
2004	5,171	92.60	7.79	0.11	9.80	2.79	0.04
2005	30	96.40	5.68	1.04	12.05	2.34	0.43
2006	6,695	75.19	7.76	0.09	5.25	1.63	0.02
2007	22	99.23	4.08	0.87	12.86	1.95	0.42
2008	3,885	87.97	7.39	0.12	8.71	1.96	0.03
2009	2,473	90.72	6.47	0.13	9.75	1.94	0.04
2010	1,899	96.39	10.13	0.23	12.38	3.95	0.09
2011	2,306	78.30	6.15	0.13	6.60	1.56	0.03
2012	4,279	82.35	6.41	0.10	7.66	1.73	0.03
2013	2,553	87.87	6.22	0.12	8.67	1.94	0.04
2014	2,749	88.11	6.09	0.12	9.10	1.96	0.04

Table 11. Results of an analysis of covariance (ANCOVA) used to compare log-transformed length–weight regression coefficients among years. The dependent variable was the logarithm of weight (g), the factor used was years, and the covariate was the logarithm of standard length (mm).

	Degrees of freedom	Sum of squares	Mean squared error	F-value	p-value
log(Standard length (mm))	1	7,791	7,791	1,573,000.000	<0.001
Year	21	180	9	1,734.000	<0.001
Interaction term log(length)*Year	21	9	0	83.850	<0.001
Residuals	73,806	366	0		

Appendix 1. The number of stations sampled along transects during May-August, 1990-2014 (no samples were collected in these months during 1995, 1998, and 2004-2014); these samples were not included in analyses in this report. All transects sampled are shown (transect numbers represent transect 'names' and are not necessarily consecutive). Transects 1-6 and 8-11 are considered core transects.

Transect	1990	1991	1992	1993	1994	1996	1997	1999	2000	2001	2002	2003
1	15	15	5	5	5	5	3		4	5		
2	15	10	5	5	5	5	3		5	5		
3	15	15	5	5	5	5	3		4	5		
4	15	15	5	5	5	5	3					
5	13	10	5	5	5	5	3		5	5		
6		15	5	5	5	5	3					
7		10										
8		12	4	4	4	4	3		3	3		
9		15	5	5	5	5	3		5	5		
10		15	5	5	5	5	3		3	5		
11		15		3	5	5	3		5	5	1	
12							3					
13							3					
14							3					
15							3					
16							3					
17							3					
18							3					
19							3					
20							3					
21							3					
22							3					
23							2					
24							3					
37										2		
99									1		6	6
136											1	1
137											1	
138											1	
139											1	
140											2	2
141											1	
142											1	
143											1	
201								1				
205								1				

207	1	
208	1	
210	1	
213	1	
214	1	
215		1

Appendix 2. The number of stations sampled along transects during September-October, 1990-2014 (no samples were collected in these months during 1995). All transects sampled are shown (transect numbers represent transect 'names' and are not necessarily consecutive). Transects 1-6 and 8-11 are considered core transects and only core stations sampled along these core transects were included in analyses in this report (in some years additional stations were sampled). In 2002, there were two surveys, and only data from one of these surveys was included in analyses in this report (see Appendix 3).

Transect	1990	1991	1992	1993	1994	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
1		5	5	5	5	5	3	3	7	9	9	6	5	5	5	5	5	5	5	5	5	5	5	5
2	6	10	5	5	5	5	3	3	3	5	5	10	5	5	5	5	5	5	5	5	5	5	5	5
3	2		5	5	5	5	3	3	7	9	9	9	5	5	5	5	5	5	5	5	5	5	5	5
4	2	5	5	5	5	5	3	2	3	4	3	8	5	3	5	5	4	5	5	5	5	5	5	5
5	3		5	5	5	5	3	3	6	8	8	10	5	5	5	5	5	5	5	5	5	5	5	5
6	3		5	5	5	5	3	3	3	5	5	10	5	5	5	5	5	5	5	5	5	5	5	5
8		4	4	4	4	4	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
9			5	5	5	5	3	3	3	5	5	10	5	5	5	5	5	5	5	5	5	5	5	5
10				5	5	5	3	3	3	5	5	5	5	5	3	5	5	5	5	5	5	5	5	5
11		5		5	5	5	3	3	3	5	5	10	5	5	5	5	4	5	5	5	5	5	5	5
12							3	3	2	3	3													
13							3	3		3	3													
14							3	2		3	3													
15							3	1		3	3													
16							3	1		3	3													
17							3																	
18							3																	
19							3	2		3	3													
20							3	2		3	3													
21							3	3	3	3	2													
22							3	3		3	3													
23							3																	

24	6			
25	4	1	4	4
26	1			
27	1			
28	1			
29	1			
30	1			
31	1			
32	1			
33	1			
34	1			
35	2			
36		4	4	4
37				5
101	1	1		
102	1	1		
103	1	1		
104	1	1		
105	1			
106	1	1		
107	1	1		
108	1	1		
109	1	1		
110	1			
111	1			
112	1			
113	1			
114	1	1		

115		1	1
116		1	1
117		1	1
118		1	1
119		1	1
120		1	1
121		1	1
122		1	1
123		1	1
124		1	1
125		1	1
126		1	1
127		1	1
128		1	1
129		1	1
130		1	
131		1	1
132		1	1
133		1	
134		1	1
135		1	1
999	2		

Appendix 3. Sampling coverage (the number of times core stations were sampled) along the core transects during the two surveys conducted during September-October, 2002. Only the first survey trial was included in analyses in this report because it collected more samples from the core stations and transects.

		Core Station				
Survey Trial	Core Transect	1	2	3	4	5
1	1	1	1	1	1	1
1	2	1	1	1	1	1
1	3	1	1	1	1	1
1	4	1	1	1	1	
1	5	1	1	1	1	1
1	6	1	1	1	1	1
1	8	1	1	1		
1	9	1	1	1	1	1
1	10	1	1	1	1	1
1	11	1	1	1	1	1
2	1					1
2	2	1	1	1	1	1
2	3		1	1	1	1
2	4	1	1	1	1	
2	5	1	1	1	1	1
2	6	1	1	1	1	1
2	9	1	1	1	1	1
2	11	1	1	1	1	1

Appendix 4. Net lengths used in the Strait of Georgia juvenile herring survey, 1992-2014.

There were inconsistencies in the reported net length used during 1992-2014. One report on survey methods (Thompson et al. 2003) states that during 1991-2001, the same net was used for all years (220 m long by 27 m deep). Haegele (1997) stated that during 1990-1994, the net was 220 m long by 27 m deep with marquisette webbing, resulting in an area fished of ~3,852 m^2. During 1992-2001, informal but detailed annual reports prepared for the Herring Conservation Research Society (HCRS), who provided funding for earlier surveys, stated the net was 220 m long (Haegele unknown report and date, Haegele and Armstrong 1997, 1998, 1999, 2000, 2001, 2002) and, in 2002, was 183 m long (Haegele and Armstrong 2003). Another report (Haegele et al. 2005) stated that during 1996-2003, the net was 183 m long by 27 m deep, resulting in an area fished of ~2,660 m^2. In addition, in June 2002, an order was placed for a replacement net stating it was "imperative the new net duplicates the original"; the size specifications given for the net were 183 m by 27 m (100 fathoms by 14.74 fathoms; see below). Since 2002, one person has been coordinating the survey and confirmed that the net used during 2002-2014 was 183 m by 27 m. The 183 m long net had 46 m of 22.2 mm mesh at the tow end, 92 m of 19.0 mm mesh, and, in the bunt of the net, 46 m of 9.5 mm mesh. The 220 m long net was assumed to have the same mesh sizes in the same proportions.

Below is a request for net replacement in June 2002 indicating that it was imperative that the new net duplicates the old net and the request is for a 100 fathom long net (183 m), implying the net used prior to 2002 was also 183 m long.

REPLACEMENT STANDARD JUVINILE HERRING PURSE SEINE NET

(June / 02)

REDDEN NET COMPANY LTD.
1638 WEST 3RD AVE. VANCOUVER, B.C.
CANADA V6J 1K2
PHONE (604)-736-5636 FAX (604) 736-9161
Toll Free 1-800-667-9455

It is imperative the new net duplicates the original so the potential catch equals the possible catch of the old net as much as possible. Therefore, the fishing depth, hanging ratio, length of leadline to corkline and mesh size must be the same. The catch is used to provide data to predict future herring run size based on the catch of up to 150 seine sets in the Strait of Georgia per year. Any change in the net efficiency could effect the catch and the subsequent prediction.
To insure the net is duplicated as much as possible the old net is available as a guide.

Specifications for a replacement juvenile herring purse seine net:

- Overall Size ------------ 100fms X 14.75fms
- Bunt --------------------- 25fma 3/8" knotless green mesh / 210/10
- Body -------------------- 50fms 3/4" knotless green mesh / 210/10
- Tow end-------------------- *25fms 17/8" knotless green or black mesh / 210/42
- Corkline ------------- 9/16 diameter braided commercial seine corkline
- Floats -------------------- BL-6 @ 12" centers
- Leadline ----------------- 4lbs/fm braided leadcore

- Rings -------------------- 5” dia SS, four bridles/ 10fm stretch, Gable rings 4” SS
- Purseline ---------------- 5/8” diameter double braided (full purse line)

- Hanging ratio: the same as the old net – or as appropriate for this type and size of net

- Leadline length: the same as the old net – or as appropriate for this type and size of net

- Gable end or Brest: with a large ring at the bottom (5 or 6”) for wt. – the other rings can be 4 inch brass or stainless.

***Note from RWA - Green may not be available in time but black is OK**

The finished seine net is to be completely ready for use including release shackle and swivels. It is not intended that these specifications should cover all details, therefore, any discrepancies or omissions of material, which would interfere with the delivery of a complete net, ready for use, must be supplied by the builder without additional cost. In addition, the builder will provide a detailed net plan as part of the contract.

The bidder must have experience in building small nets using netting as small as 3/8”.
Please provide a statement of experience in building small seines.

The net must be ready for use [this sentence was left unfinished or cut off].

Appendix 5. Formulae used to estimate the mean and variance using a two-stage design (Thompson 1992).

The second stage sampling units (stations), y_{ij} , are the catch weights (or CPUE or abundance) of age 0+ herring from the jth station on the ith transect. The mean catch on each transect was calculated as:

$\bar{y}_i = \frac{\sum_{j=1}^{ni} y_{ij}}{n_i}$, where n_i is the number of stations sampled on the ith transect.

The estimated variance is:

$$s_i^2 = \frac{\sum_{j=1}^{n_i}\left(y_{ij}-\bar{y}_i\right)^2}{n_i(n_i-1)}.$$

The mean catch weight (or CPUE or abundance) of age 0+ herring each year is the mean of transect means:

$$\bar{y} = \frac{\sum_{i=1}^{n} \bar{y}_i}{n},$$

where n is the number of transects sampled in a year.

The estimated variance at this stage is:

$$s^2 = \frac{\sum_{i=1}^{n}(\bar{y}_i-\bar{y})^2}{n(n-1)}.$$

If N>>n and Ni>>ni, an estimator of total variance of the overall mean simplifies to:
$\widehat{var}(\bar{y}) \approx \frac{s^2}{n}$.

To calculate a stratified estimate of herring catch weights (or CPUE or abundance), the two stage formulae from above were also used. The strata (h) were the designations of transects as either open water or channel. The two stage sampling formulae were used to calculate a stratum mean for each stratum. The overall mean was calculated assuming equal stratum weighting as:

$$y_s = \frac{\sum_{i=1}^{h} y_h}{h},$$

with variance:

$$s_s^2 = \frac{1}{h^2}\sum_{i=1}^{h} s_h^2.$$

Appendix 6. Formulae (Szarzi et al. 2005) used to estimate the mean and variance using a two-stage design. The second stage sampling units (stations), y_{ij} , are the catch weights (or CPUE or abundance) of age 0+ herring from the jth station on the ith transect. The mean catch on each transect was calculated as:

$$\bar{y}_i = \frac{\sum_{j=1}^{ni} y_{ij}}{n_i},$$

where n_i is the number of stations sampled on the ith transect.

The estimated variance is:

$$s_i^2 = \frac{\sum_{j=1}^{n_i} \left(y_{ij} - \bar{y}_i\right)^2}{n_i(n_i - 1)}.$$

The mean catch weight (or CPUE or abundance) of age 0+ herring each year is the mean of transect means:

$$\bar{y} = \frac{\sum_{i=1}^{n} \bar{y}_i}{n},$$

where n is the number of transects sampled in a year.

The estimated variance at this stage is:

$$s^2 = \frac{\sum_{i=1}^{n} (\bar{y}_i - \bar{y})^2}{n(n-1)}.$$

An estimator of total variance of the overall mean is the combination of variances at all stages:

$$s_T^2 = s^2 + \frac{1}{n^2} \sum_{i=1}^{n} s_i^2.$$

To calculate a stratified estimate of herring catch weights (or CPUE or abundance), the two stage formulae from above were also used. The strata were the designations of transects as either open water or channel. The two stage sampling formulae were used to calculate a stratum mean for each stratum. The overall mean was calculated assuming equal stratum weighting as:

$$y_s = \frac{\sum_{i=1}^{h} y_h}{h},$$

with variance:

$$s_s^2 = \frac{1}{h^2} \sum_{i=1}^{h} s_h^2.$$

Appendix 7. Catch weights (g) of age-0 herring at core stations sampled along core transects during 1992-2014 (no survey in 1995). Blank cells indicate either no station existed (e.g., Transect 8 had only stations 1-3) or that no sample could be collected.

		Station				
Year	Transect	1	2	3	4	5
1992	1	0	0	0	0	0
1992	2	132.8	4500	8000	11781.6	10500
1992	3	1008	39.3	13.1	0	105.7
1992	4	0	0	58.6	3853.6	5524.8
1992	5	495	13	4.9	0	0
1992	6	69.2	1.3	12.7	7.3	64.7
1992	8	484.4	495.5	662.2		
1992	9	115.4	5.1	10.4	0	0
1993	1	29.5	56.7	359.8	2260.8	0
1993	2	1059.6	16359.7	7233.5	5351.6	1230.6
1993	3	93	0	0	0	0
1993	4	11046.5	7814	6000	35000	5000
1993	5	1263.9	0	0	0	0
1993	6	992	0	0	22.4	113.6
1993	8	871.2	2597.4	448.1		
1993	9	0	0	0	0	0
1993	10	1260.9	1225.8	0	0	8.8
1993	11	0	0	0	0	0
1994	1	8.8	6.9	0	0	0
1994	2	17000	9080.7	5992.7	3669.2	583.6
1994	3	0	1237.5	16234.9	43727.2	7500
1994	4	0	8000	35560.2	70000	154.5
1994	5	138.2	0	0	0	0
1994	6	223.8	75.7	72.8	179	157.6
1994	8	5.2	116.8	25.5		
1994	9	83.9	33.8	55.8	558.3	1035.4
1994	10	49411.9	16800	12334.4	8315.1	3400
1996	1	31966	23	84	0	0
1996	2	97100	1219	13	0	4800
1996	3	0	0	103	270	351
1996	4	25111	6440	16500	2846	69
1996	5	2144	0	0	0	0
1996	6	61	0	36	42	8
1996	8	2602	7300	2884		
1996	9	0	0	5	0	0
1996	10	1600	10100	5449	13	89

1996	11	4293	471	717	240	14
1997	1	66	13600	11400		
1997	2	105700		19500		25200
1997	3	531	78	1257		
1997	4	0		285		71800
1997	5	188	374	682		
1997	6	14900		24400		18100
1997	8	102	1426			
1997	9	7600	19000	91600		
1997	10	373		4600		4200
1997	11	20288	1040	1203		
1998	1	4409	56600	78200		
1998	2	14500		66800		23769
1998	3	30	18976	39752		
1998	4			92		3096
1998	5	499433	0	0		
1998	6	8844		9000		3149
1998	8	594	54	316		
1998	9	10600	10242	33200		
1998	10	17083		399		636
1998	11	11800	12800	16600		
1999	1	699	0	0		
1999	2	70000		1400		4100
1999	3	0	46600	407		
1999	4	4000		55		0
1999	5	1841	212	16		
1999	6	27000		2500		26700
1999	8	114	246	171		
1999	9	918	1520	1392		
1999	10	723		109		120
1999	11	10300	1435	1700		
2000	1	40700	194	38	0	0
2000	2	17700	7200	80400	3100	49700
2000	3	573	3300	19000	4800	1471
2000	4		3000	5300		10000
2000	5	1180	788	1485	259	77
2000	6	133	228	201	134	58
2000	8	793	673	2508		
2000	9	38200	6000	10506	17100	34100
2000	10	23000	42500	521	470	336
2000	11	966	4100	11100	12900	2900
2001	1	1011000	29500	8300	4000	6900
2001	2	56000	1552	22900	1405	1481

2001	3	17	2250	15200	26400	6800
2001	4	0	0	4700		
2001	5	34400	6900	153	132	10
2001	6	2500	244	289		1332
2001	8	398	114	157		
2001	9	577	2800	2700	410	2100
2001	10	13692	4000	1157	18	0
2001	11	307	739	139	65	0
2002	1	3398	18900	6618	16500	9600
2002	2	25930	29700	6700	2600	1313
2002	3	0	164	25373	66361	27561
2002	4	26	11448	7385	4099	
2002	5	0	214	47	0	0
2002	6	392	449	56	717	45
2002	8	23	38	0		
2002	9	1350	11878	23771	42192	55500
2002	10	53100	3900			
2002	11	9368	15000	3297	33600	0
2003	1	26600	25700	11500	12700	0
2003	2	315.67	298.86	671.72	555.28	1212.13
2003	3	50.56	226.15	63.61	64.24	47.95
2003	4	13.88	8.42	243.66	1538.45	
2003	5	1147.45	0	0	0	0
2003	6	68.17	76.25	58.35	116.91	646.44
2003	8		145.7	0		
2003	9	175.37	37.33	17.94	14.6	0
2003	10	1966.52	18500	89.74	104.73	45.67
2003	11	6500	14500	12386	5800	149.91
2004	1	186.1	280.8	2545.9	2851.7	22000
2004	2	1364.4	312400	102900	112000	157200
2004	3	0	0	36.8	38.3	857.3
2004	5	31.5	40.1	0	209	356.5
2004	6	525.4	309.2	161.7	283.4	244.6
2004	8	0	11	0		
2004	9	0	2367.5	55500	35000	36318.8
2004	10	25354.7	10500	25200	22300	19246.5
2004	11	10109.22	11703.04	7901.36	2609	4618.4
2005	1	0	0	0	0	0
2005	2	26.4	0	0	14.8	0
2005	3	0	0	0	13.8	0
2005	4	0	45.9	0	23.6	149
2005	5	0	0	0	0	0
2005	6	0	11.5	0	12.6	0

2005	8	0	85.12	28.1		
2005	9	0	0	0	0	0
2005	10	13.5		0		0
2005	11	0	0	0	21	0
2006	1	0	30526.8	18745.68	45357.96	36045.55
2006	2	3538.62	13765.98	3932.44	14367.6	16625.95
2006	3	18.87	1023.86	22365.55	21562.76	1713.12
2006	4	10246.98	10534.65	38553.15	26030.48	100.12
2006	5	226.78	290.73	141.47	4.95	20.89
2006	6	1498.85	1117.43	1880.9	1972.14	81090.11
2006	8	0	327.68	71.18		
2006	9	44.54	7842.46	30607.15	35149.31	45191.97
2006	10	34913.75	7227.04	1306.48	5187.48	6246.08
2006	11	32922.65	25884.1	27911.85	75441.74	12411
2007	1	0	0	0	0	0
2007	2	0	0	0	0	0
2007	3	0	0	0	0	0
2007	4		0	0	0	176.63
2007	5	0	0	0	0	0
2007	6	10.91	0	14.38	0	0
2007	8	11.86	0	0		
2007	9	0	0	0	0	0
2007	10	0	0	0	0	48.77
2007	11	20.47	0	0	0	
2008	1	86907.45	67.82	97.94	47.13	0
2008	2	399.32	22777.62	30273.6	44807.07	38646.08
2008	3	0	1415.42	21172.9	11265.12	70.49
2008	4	2509.66	626.18	2877.37	16832.05	0
2008	5	6553.8	452.52	920.8	6084.92	10412.85
2008	6	3098.82	9058.48	4240.2	2360.85	203783.2
2008	8	25856.04	23280.6	5872.7		
2008	9	60.17	5981.18	20626.1	26430.24	22033.75
2008	10	3582.4	1890.9	616.23	1491.95	997.77
2008	11	16185.55	18938.2	1231.38	1661.28	25546.64
2009	1	2015.53	3572.14	251.96	26.66	0
2009	2	1830.66	8713.04	4599.6	23695.1	339.22
2009	3	0	21.95	120.23	26923.59	162.4
2009	4	2511.86	4010.12	3884.68	26040.48	13265.28
2009	5	291.88	0	0	0	0
2009	6	253.6	361.47	96.41	69.38	2534.36
2009	8	9.6	487.09	15.46		
2009	9	0	11550.06	15375.3	18981	20406.66
2009	10	774.45	62.94	11.61	124.56	2177.5

2009	11	43542.45	10841.28	12661.56	112.21	0
2010	1	0	0	0	0	0
2010	2	5810.2	76676.14	102248.8	16184.48	268.66
2010	3	3863.74	17.71	0	0	0
2010	4		209.42	28.48	3103.1	11.53
2010	5	109.8	807.8	614.65	378.15	554.32
2010	6	400.05	118.21	69.2	117.43	2580.48
2010	8	25609.5	6630.58	296.42		
2010	9	0	868.65	327.48	1151.08	1695.63
2010	10	24109.92	1109.23	103.84	204.91	254.57
2010	11	6478.74	5484.06	252369.4	2648.63	101.82
2011	1	68.79	265.43	108.31	150.78	95.41
2011	2	2828.02	5149.08	9257.45	15938.64	20089.62
2011	3	358.76	0	0	17.27	0
2011	4	688.42	43.92	2368.34	161.65	0
2011	5	995.67	84.07	59.05	7.93	0
2011	6	1315.68	2229.08	11736.1	9268.75	9145.7
2011	8	629.29	2555.1	49.18		
2011	9	143.72	46	23.36	55.42	33.9
2011	10	443.24	1455.56	2736.46	3164.1	704.02
2011	11	3189.27	112.24	223.28	216.28	1293.63
2012	1	180351.2	32216.47	26499.88	26694.47	5744.78
2012	2	33145.45	21041.02	49831.95	22876.74	2906.8
2012	3	2262.28	4060.74	18616.59	25461.9	30939.93
2012	4	6136.72	13266.56	3793.34	76778.1	154614.6
2012	5	1957.44	12444.65	2377.64	1908.39	2930.46
2012	6	1067.71	2597.75	2610.04	2110.04	10392.3
2012	8	1345.04	1386.05	7556.19		
2012	9	80725.47	37605.88	15046.55	32555.07	12319.92
2012	10	836.07	75.89	0	0	196.21
2012	11	929.35	1150.3	1275.48	376.88	371.21
2013	1	3136.8	12785.04	5471.2	702.9	18.72
2013	2	496.6	1564.3	1191.02	2253.84	542.16
2013	3	3833.34	378.49	9518.9	11099.13	2613.32
2013	4		24545.79	24837.39	2852.04	1478.56
2013	5	568.24	548.29	1109.24	197.52	0
2013	6	1121.48	265.99	302.93	603.61	44897.84
2013	8	205.95	236.86	2762.67		
2013	9	0	0	26.66	0	12.21
2013	10	4687.9	296.74	730.13	360.07	118.45
2013	11	153.09	196.47	11.59	120.56	0
2014	1	39858.21	3234.86	8457.64	4731.02	5835.42
2014	2	19619.53	606.52	685.1	525.87	1582.33

2014	3	11987.42	35816.3	2525.82	1837.22	5123.2
2014	4	21191.06	8734.8	12627.9	37847.92	110.79
2014	5	32.21	40.4	9.5	0	0
2014	6	9.48	9.14	0	0	27.83
2014	8	3637.74	1156.26	2524.58		
2014	9	1228.39	1262.12	701.17	209.84	290.74
2014	10	1168.62	8724.68	0	10.78	50.22
2014	11	1943.76	5413.56	4235.28	245.84	9.24

Appendix 8. Catch abundance of age-0 herring at core stations sampled along core transects during 1992-2014 (no survey in 1995). Blank cells indicate either no station existed (e.g., Transect 8 had only stations 1-3) or that no sample could be collected.

		Station				
Year	Transect	1	2	3	4	5
1992	1	0	0	0	0	0
1992	2	20	503	1169	1665	1670
1992	3	77	3	1	0	10
1992	4	0	0	7	334	591
1992	5	34	1	1	0	0
1992	6	9	1	2	1	9
1992	8	76	80	92		
1992	9	11	1	1	0	0
1993	1	3	6	38	250	0
1993	2	157	1962	1024	731	169
1993	3	8	0	0	0	0
1993	4	1535	1021	768	4586	749
1993	5	133	0	0	0	0
1993	6	150	0	0	3	18
1993	8	95	304	53		
1993	9	0	0	0	0	0
1993	10	115	112	0	0	1
1993	11	0	0	0	0	0
1994	1	1	1	0	0	0
1994	2	2514	1254	761	532	87
1994	3	0	107	1331	3310	1022
1994	4	0	950	4155	8916	22
1994	5	14	0	0	0	0
1994	6	32	13	11	27	20
1994	8	1	12	3		
1994	9	7	3	5	43	86
1994	10	4590	1540	1152	825	316
1996	1	3016	3	12	0	0
1996	2	10789	107	1	0	480
1996	3	0	0	9	23	33
1996	4	2854	716	1793	304	9
1996	5	212	0	0	0	0
1996	6	7	0	4	5	1
1996	8	294	830	324		
1996	9	0	0	1	0	0
1996	10	179	953	462	1	8
1996	11	443	41	62	20	1
1997	1	15	2443	2005		

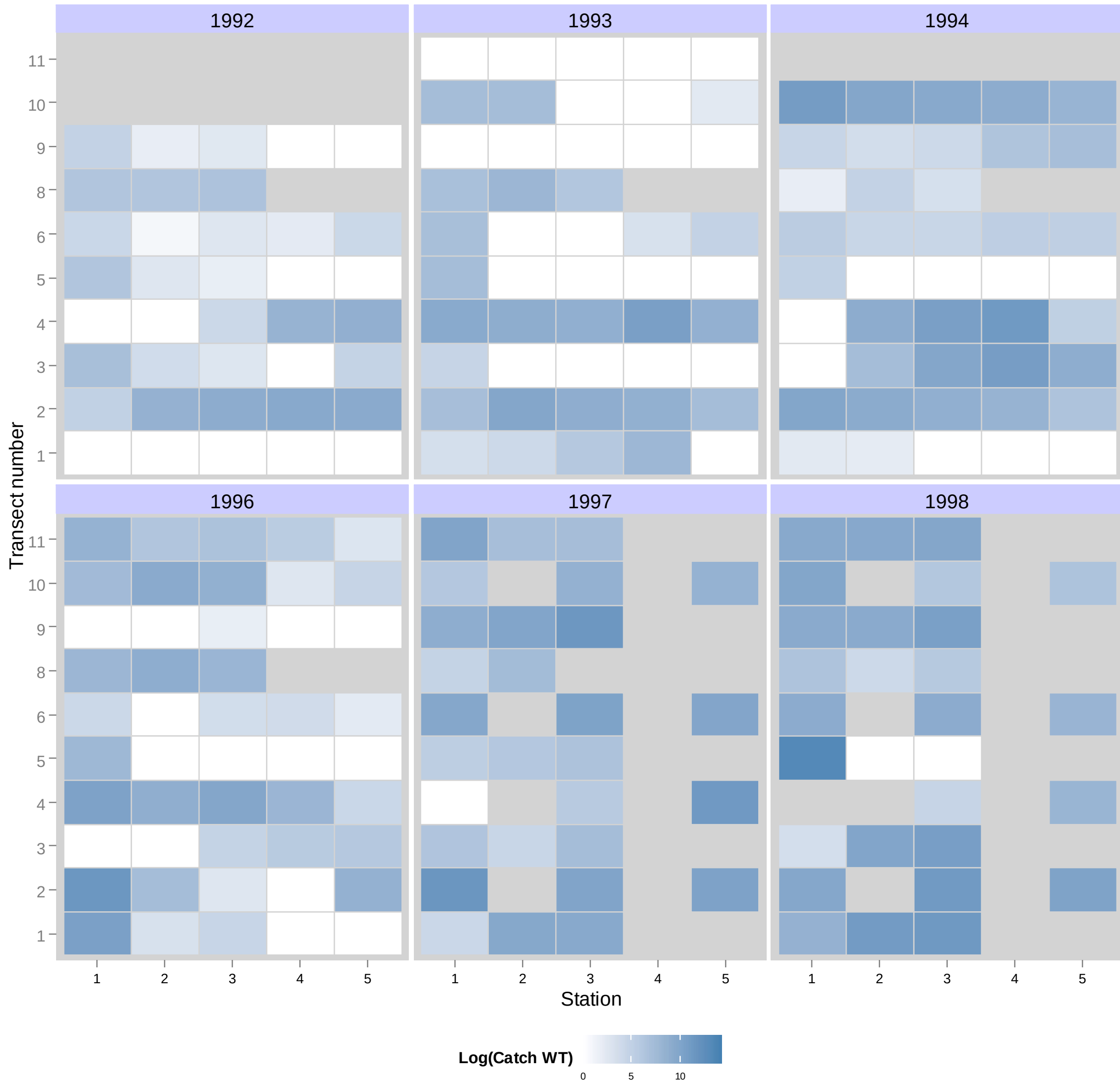
1997	2	22815		3979		5072
1997	3	95	15	232		
1997	4	0		47		13296
1997	5	32	64	114		
1997	6	3371		4471		4435
1997	8	16	248			
1997	9	1074	2768	12390		
1997	10	62		721		695
1997	11	3436	166	195		
1998	1	374	4944	6865		
1998	2	1951		8150		2870
1998	3	2	1325	2807		
1998	4			7		252
1998	5	34755	0	0		
1998	6	1161		1081		396
1998	8	70	6	39		
1998	9	926	783	2343		
1998	10	1398		30		49
1998	11	1077	947	1154		
1999	1	94	0	0		
1999	2	11771		218		681
1999	3	0	5278	45		
1999	4	516		7		0
1999	5	184	21	2		
1999	6	4417		392		4697
1999	8	12	31	23		
1999	9	81	139	128		
1999	10	70		10		11
1999	11	930	128	154		
2000	1	7397	28	5	0	0
2000	2	3563	1200	17264	626	10389
2000	3	67	319	2035	447	141
2000	4		320	594		1162
2000	5	151	107	200	34	11
2000	6	25	41	37	26	11
2000	8	96	81	307		
2000	9	5241	924	1385	2012	3763
2000	10	2830	4820	60	56	45
2000	11	121	545	1415	1630	388
2001	1	118523	3371	904	454	819
2001	2	10566	246	3706	241	235
2001	3	2	281	1624	2770	768
2001	4	0	0	639		

2001	5	3972	783	17	14	1
2001	6	450	35	41		200
2001	8	65	25	30		
2001	9	87	377	366	56	274
2001	10	1646	476	145	2	0
2001	11	40	85	16	9	0
2002	1	426	1831	598	1525	868
2002	2	3868	4394	986	389	197
2002	3	0	15	2297	7420	3282
2002	4	3	1109	722	325	
2002	5	0	17	4	0	0
2002	6	54	67	10	95	8
2002	8	4	5	0		
2002	9	144	1174	2217	4095	5030
2002	10	4742	347			
2002	11	1023	1596	329	3097	0
2003	1	2546	7471	1057	1185	0
2003	2	36	32	78	62	133
2003	3	5	24	7	8	6
2003	4	1	1	27	176	
2003	5	106	0	0	0	0
2003	6	8	9	7	14	77
2003	8		21	0		
2003	9	24	5	3	2	0
2003	10	200	1685	8	10	5
2003	11	651	2608	1055	503	56
2004	1	25	33	281	319	2537
2004	2	185	38005	13075	14993	21330
2004	3	0	0	4	4	77
2004	5	4	3	0	20	31
2004	6	78	49	25	44	41
2004	8	0	1	0		
2004	9	0	197	4136	2946	3052
2004	10	2622	934	2389	2072	1638
2004	11	1122	1312	698	254	502
2005	1	0	0	0	0	0
2005	2	3	0	0	1	0
2005	3	0	0	0	1	0
2005	4	0	3	0	2	13
2005	5	0	0	0	0	0
2005	6	0	1	0	1	0
2005	8	0	6	2		
2005	9	0	0	0	0	0

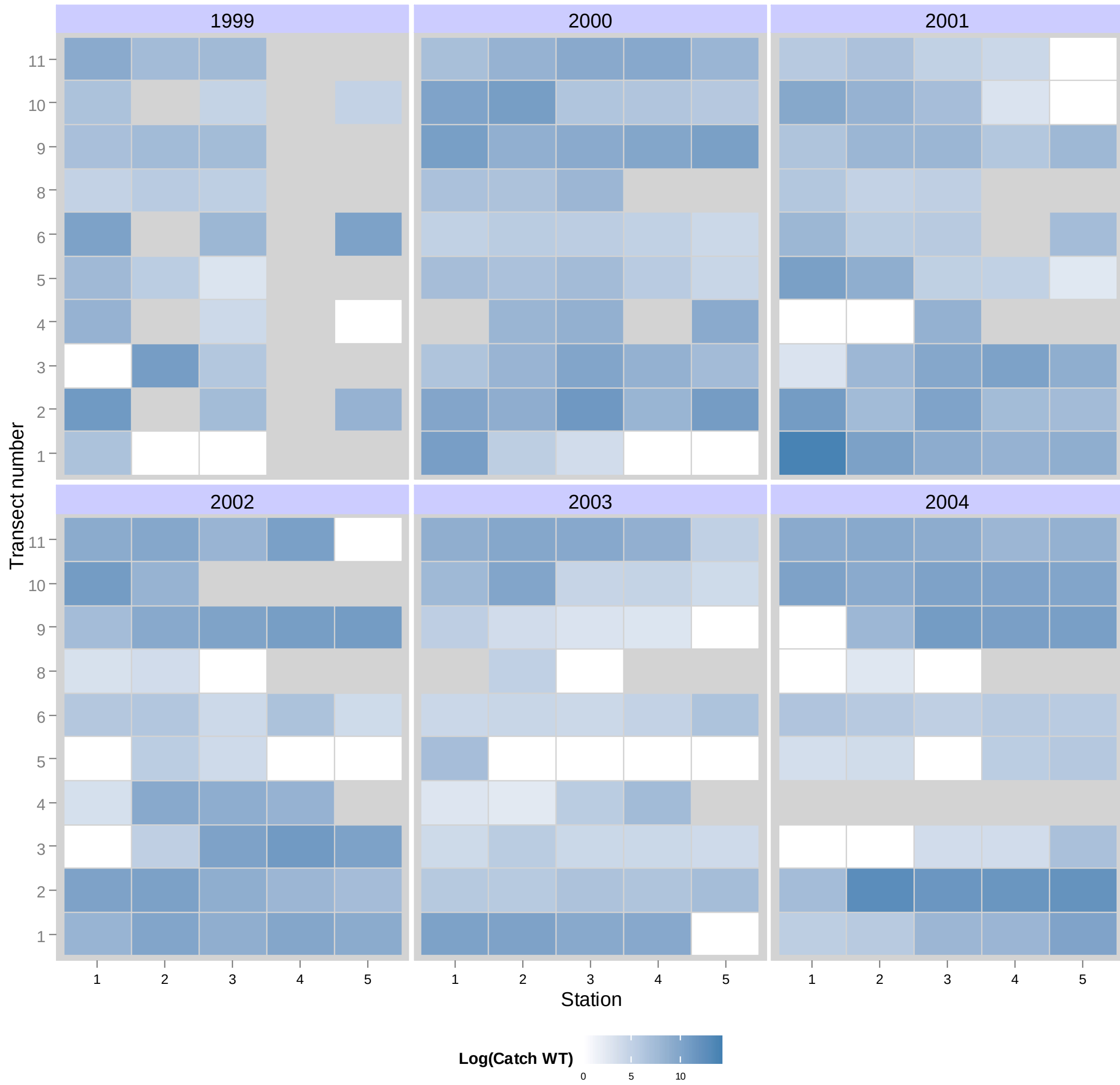
2005	10	1		0		0
2005	11	0	0	0	2	0
2006	1	0	5590	3939	9528	7695
2006	2	959	3668	1012	3860	4655
2006	3	3	142	3220	3140	251
2006	4	1446	1356	5340	3296	12
2006	5	32	44	22	1	3
2006	6	409	276	448	540	23915
2006	8	0	50	13		
2006	9	10	1670	5215	6573	8451
2006	10	6135	1346	252	966	1084
2006	11	7335	5295	5550	13794	2450
2007	1	0	0	0	0	0
2007	2	0	0	0	0	0
2007	3	0	0	0	0	0
2007	4		0	0	0	13
2007	5	0	0	0	0	0
2007	6	1	0	1	0	0
2007	8	1	0	0		
2007	9	0	0	0	0	0
2007	10	0	0	0	0	4
2007	11	2	0	0	0	
2008	1	10416	7	11	5	0
2008	2	65	3069	4102	6644	5929
2008	3	0	145	2075	1152	7
2008	4	243	62	278	1620	0
2008	5	744	52	100	604	1017
2008	6	568	1650	776	430	39925
2008	8	2653	2535	652		
2008	9	8	654	2085	2766	2265
2008	10	365	192	63	160	104
2008	11	1775	2020	124	165	2471
2009	1	220	362	27	3	0
2009	2	249	1029	595	3198	46
2009	3	0	2	10	2250	14
2009	4	216	364	354	2384	1218
2009	5	32	0	0	0	0
2009	6	39	49	13	10	362
2009	8	1	56	2		
2009	9	0	1212	1506	1872	2070
2009	10	76	6	1	10	197
2009	11	4473	992	1116	9	0
2010	1	0	0	0	0	0

2010	2	670	8157	11593	1859	36
2010	3	262	1	0	0	0
2010	4		16	2	232	1
2010	5	6	66	44	31	45
2010	6	51	17	9	15	354
2010	8	1673	444	22		
2010	9	0	45	17	60	90
2010	10	1512	65	6	17	16
2010	11	663	394	17685	204	8
2011	1	12	47	18	24	15
2011	2	518	921	1670	2916	3681
2011	3	42	0	0	2	0
2011	4	102	6	322	23	0
2011	5	126	11	7	1	0
2011	6	208	369	2175	1765	1410
2011	8	97	408	8		
2011	9	17	7	4	8	5
2011	10	61	190	322	382	90
2011	11	540	14	26	26	153
2012	1	20448	3887	3355	3146	662
2012	2	5239	3445	7329	3384	432
2012	3	281	524	2250	3204	4122
2012	4	778	1480	440	9177	18495
2012	5	281	1485	265	207	308
2012	6	202	472	462	366	2085
2012	8	222	213	1245		
2012	9	10815	4680	1820	3699	1420
2012	10	92	9	0	0	23
2012	11	107	132	139	40	40
2013	1	326	1302	750	67	2
2013	2	62	187	150	277	71
2013	3	460	45	1065	1267	324
2013	4		3179	3258	356	200
2013	5	59	54	115	19	0
2013	6	163	40	44	84	6162
2013	8	21	26	338		
2013	9	0	0	2	0	1
2013	10	370	23	58	28	10
2013	11	14	17	1	8	0
2014	1	4464	378	956	516	558
2014	2	1953	61	70	54	161
2014	3	604	3549	269	178	490
2014	4	2607	1122	1716	5280	16

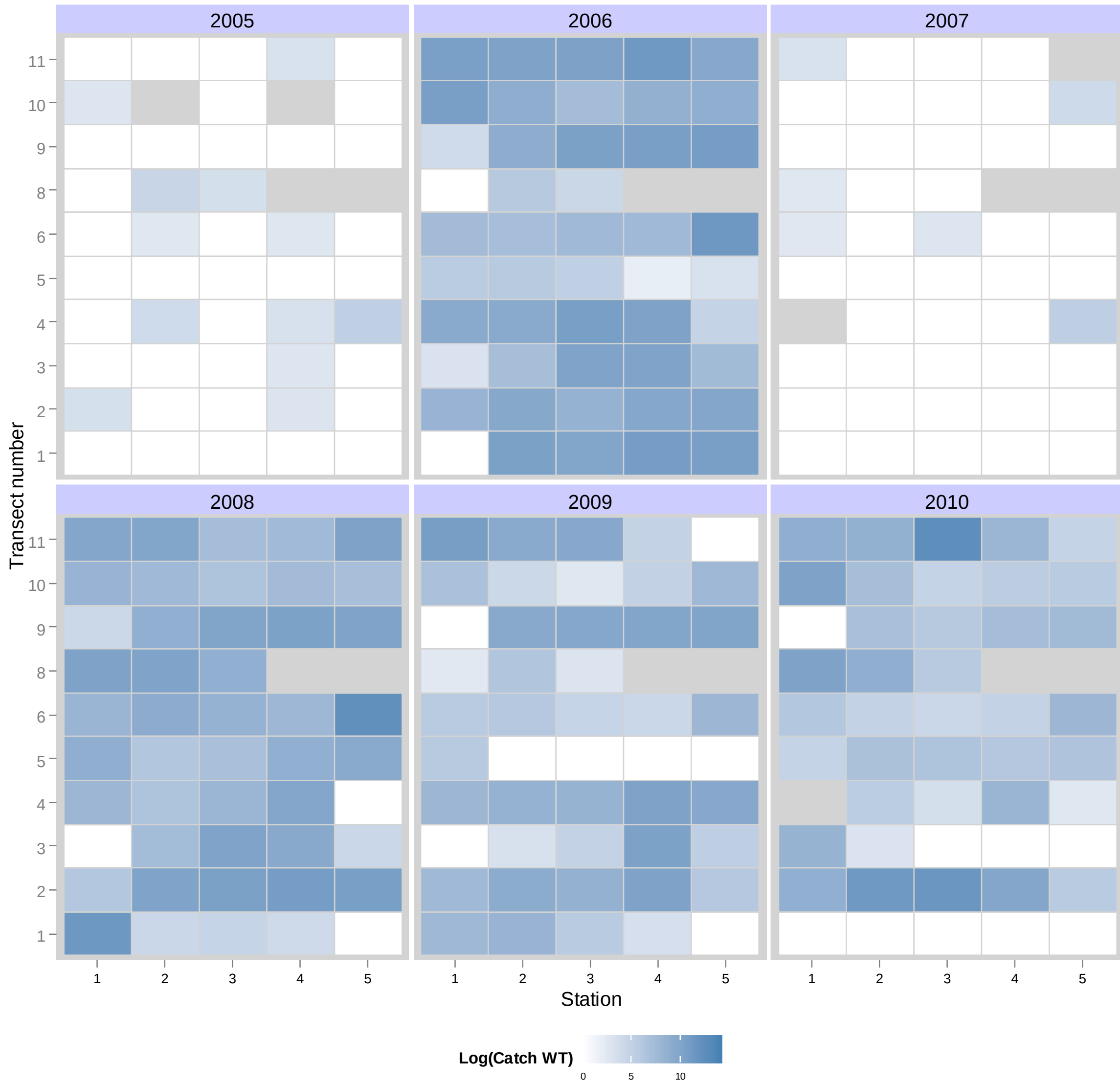
2014	5	3	3	1	0	0
2014	6	1	1	0	0	3
2014	8	434	138	314		
2014	9	165	152	83	26	36
2014	10	124	848	0	1	5
2014	11	192	544	406	24	1



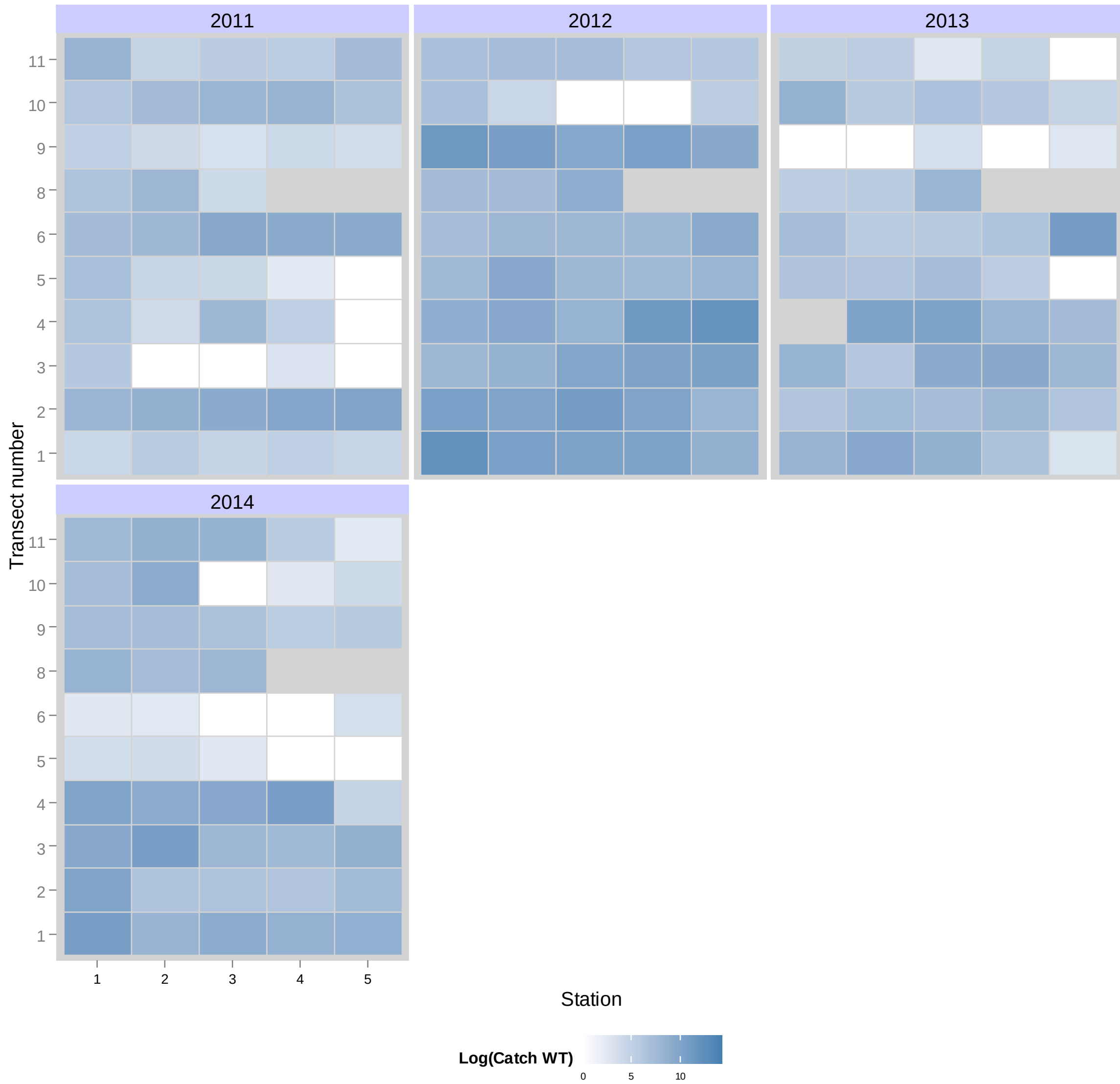
Appendix 9. Catch weight (g; log-transformed) of age-0 herring caught at core stations and transects during 1992-1998 (no survey in 1995). Colour gradient indicates zero catch (white) to highest catch (shades of blue; dark blue indicates the highest catch weight). Grey colour indicates no set was made or no core-station exists.



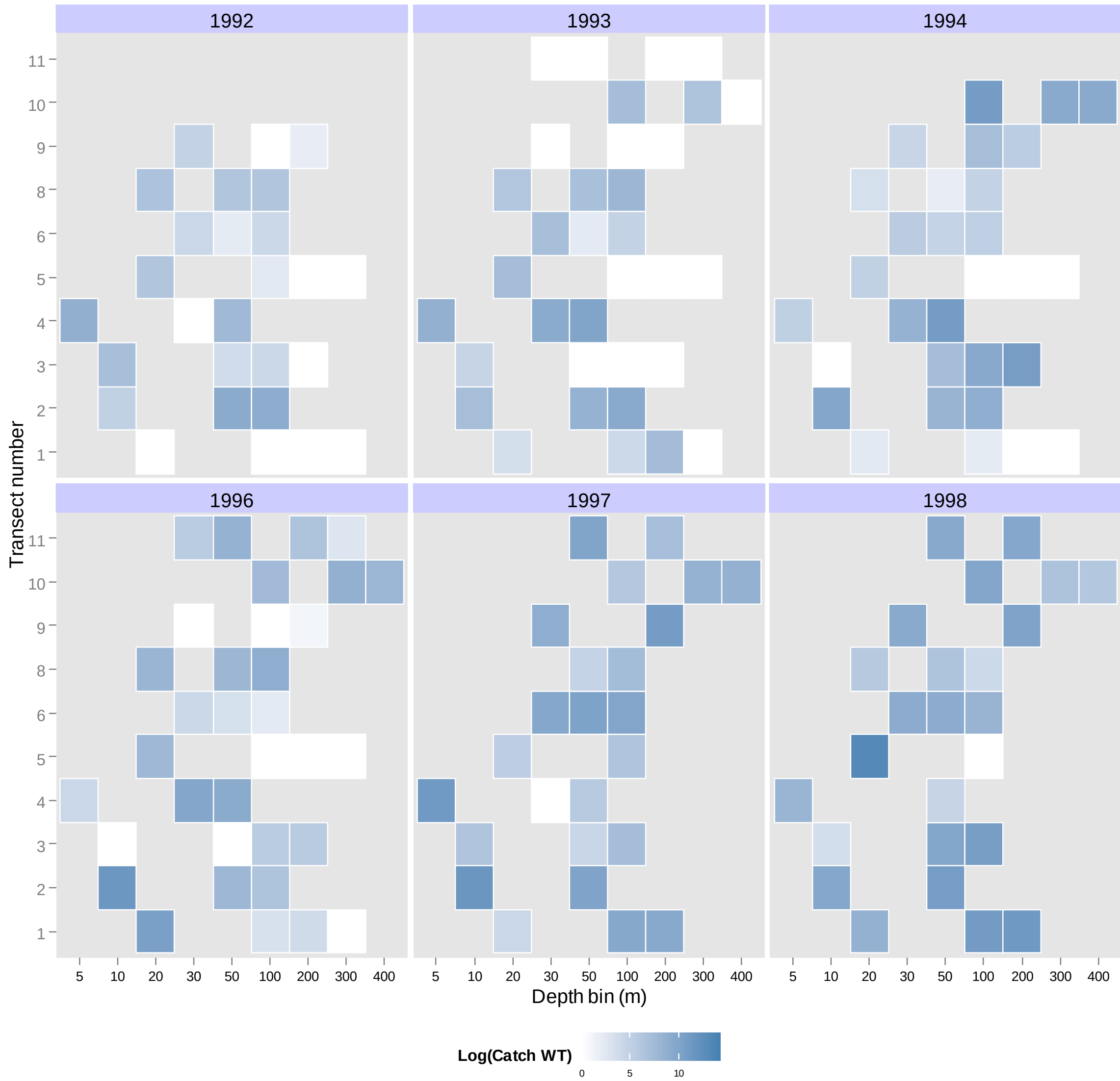
Appendix 9 continued. Catch weight (g; log-transformed) of age-0 herring caught at core stations and transects during 1999-2004. Colour gradient indicates zero catch (white) to highest catch (shades of blue; dark blue indicates the highest catch weight). Grey colour indicates no set was made or no core-station exists.



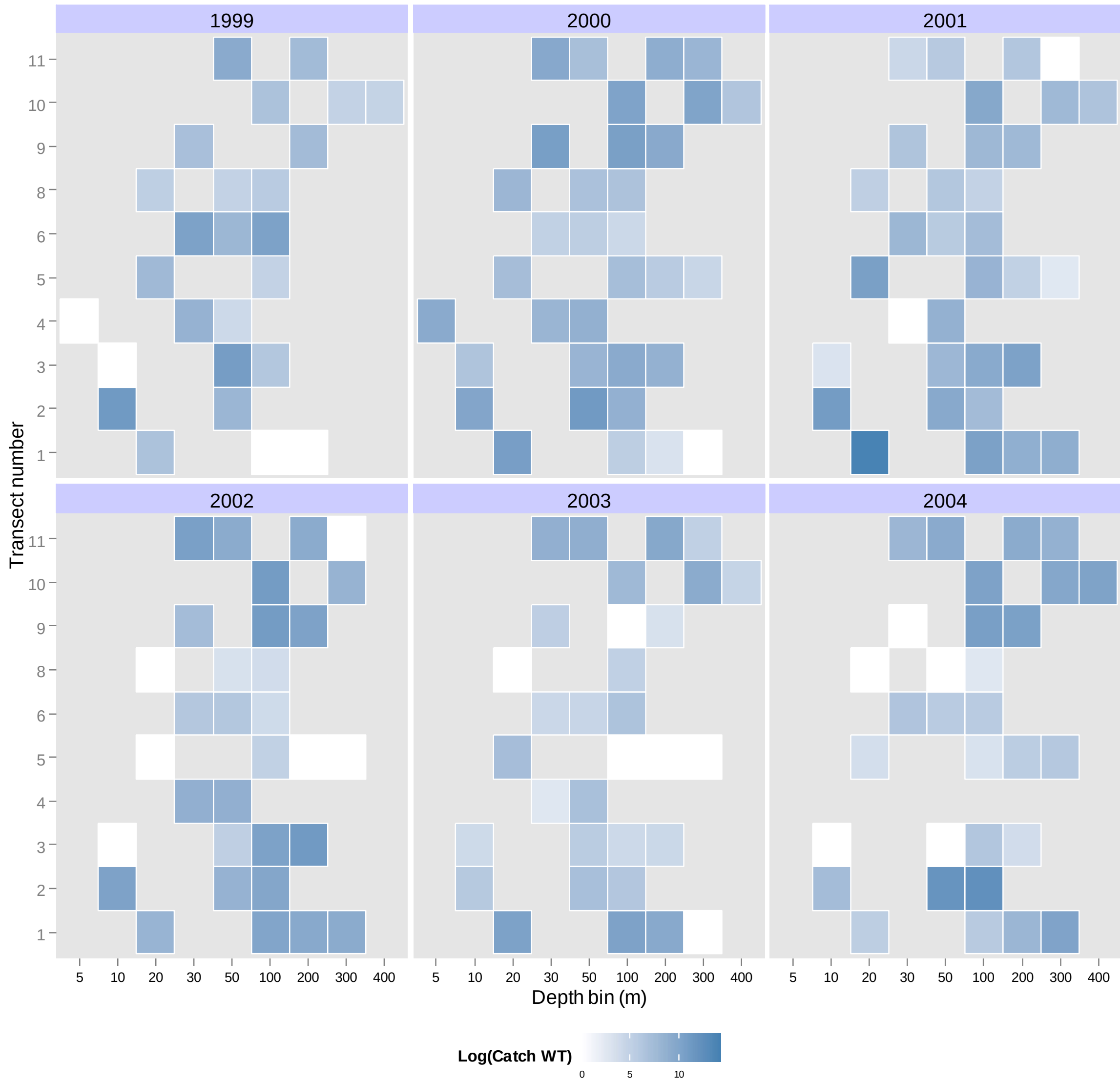
Appendix 9 continued. Catch weight (g; log-transformed) of age-0 herring caught at core stations and transects during 2005-2010. Colour gradient indicates zero catch (white) to highest catch (shades of blue; dark blue indicates the highest catch weight). Grey colour indicates no set was made or no core-station exists.



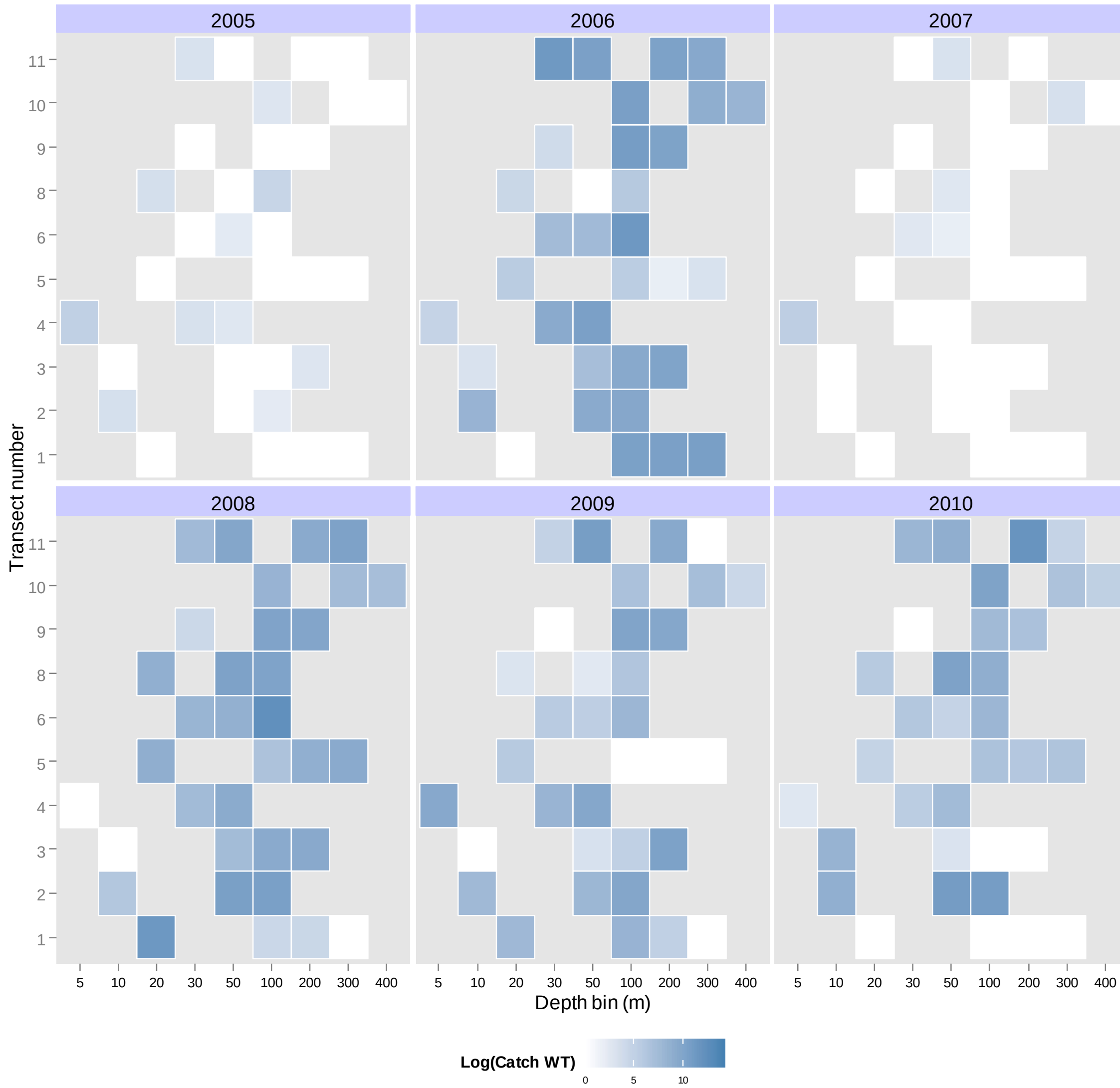
Appendix 9 continued. Catch weight (g; log-transformed) of age-0 herring caught at core stations and transects during 2011-2014. Colour gradient indicates zero catch (white) to highest catch (shades of blue; dark blue indicates the highest catch weight). Grey colour indicates no set was made or no core-station exists.



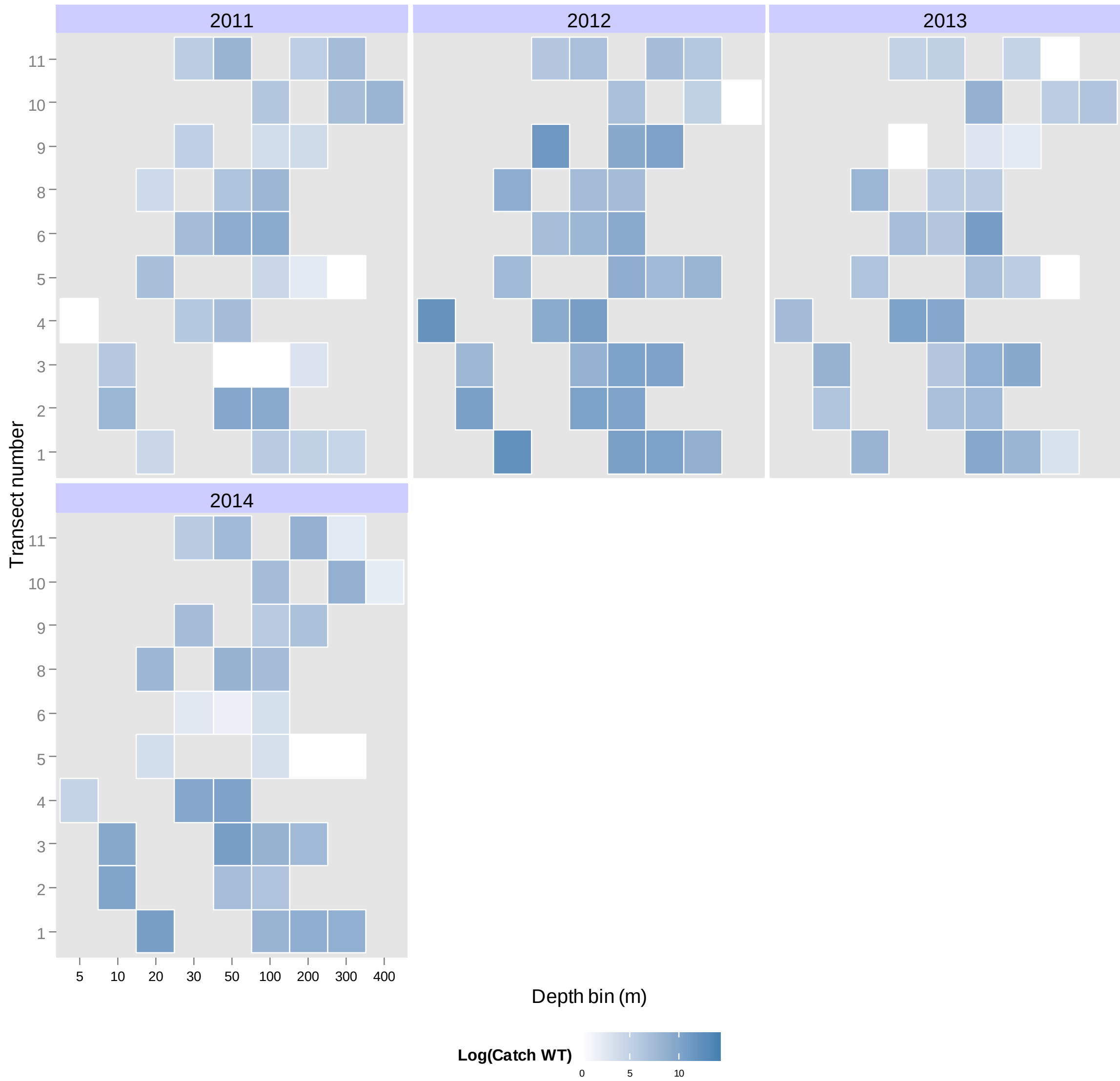
Appendix 10. Catch weight (g; log-transformed) of age-0 herring caught at depth intervals along core transects during 1992-1998 (no survey in 1995). Depth bins are categorical (not continuous), so the x-axis categories do not represent equal depth intervals. Where stations had the same depth interval, catch weights were averaged. Colour gradient indicates zero catch (white) to highest catch (shades of blue; dark blue indicates the highest catch weight). Grey colour indicates no set was made or no core-station exists.



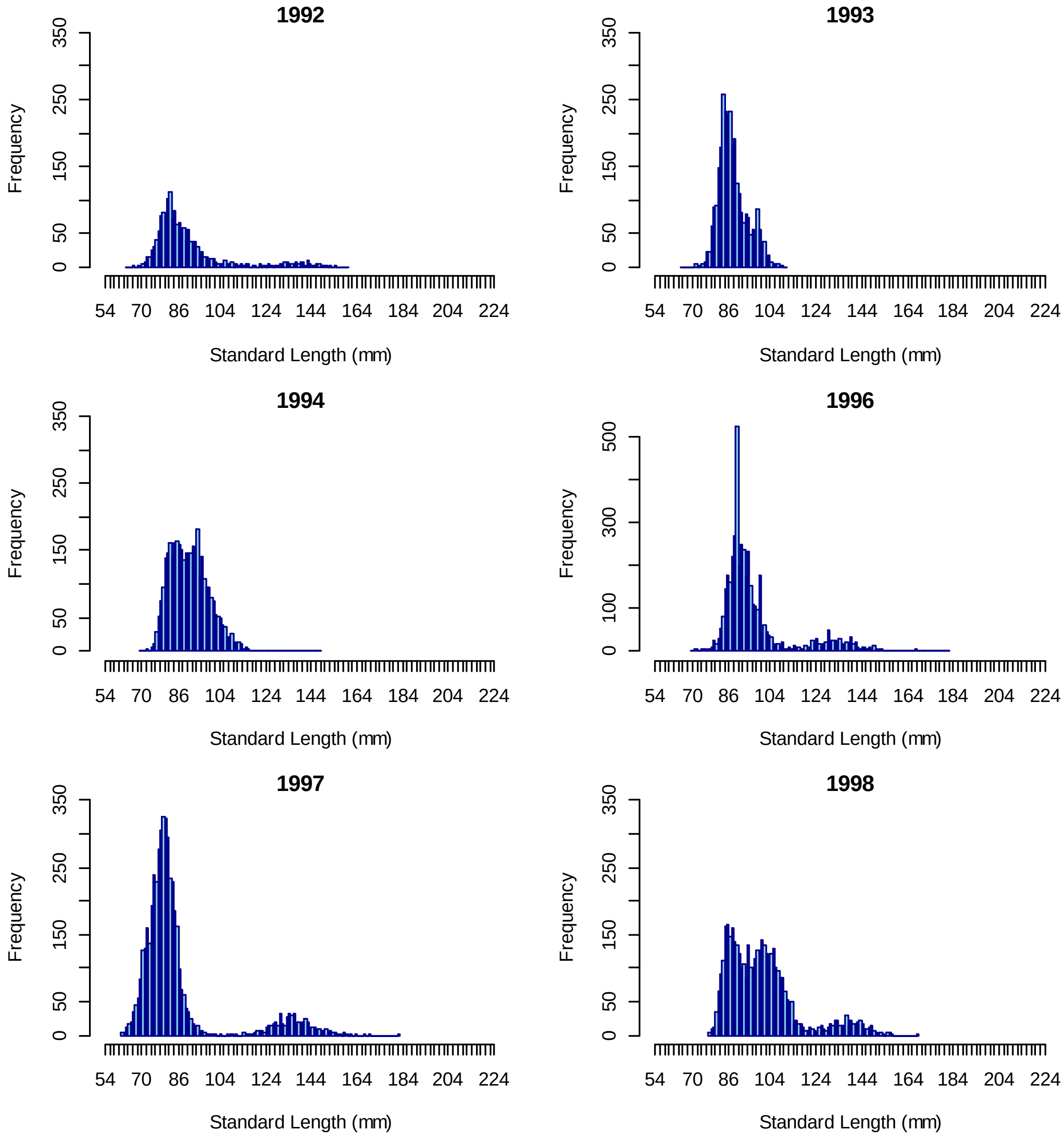
Appendix 10 continued. Catch weight (g; log-transformed) of age-0 herring caught at depth intervals along core transects during 1999-2004. Depth bins are categorical (not continuous), so the x-axis categories do not represent equal depth intervals. Where stations had the same depth interval, catch weights were averaged. Colour gradient indicates zero catch (white) to highest catch (shades of blue; dark blue indicates the highest catch weight). Grey colour indicates no set was made or no core-station exists.



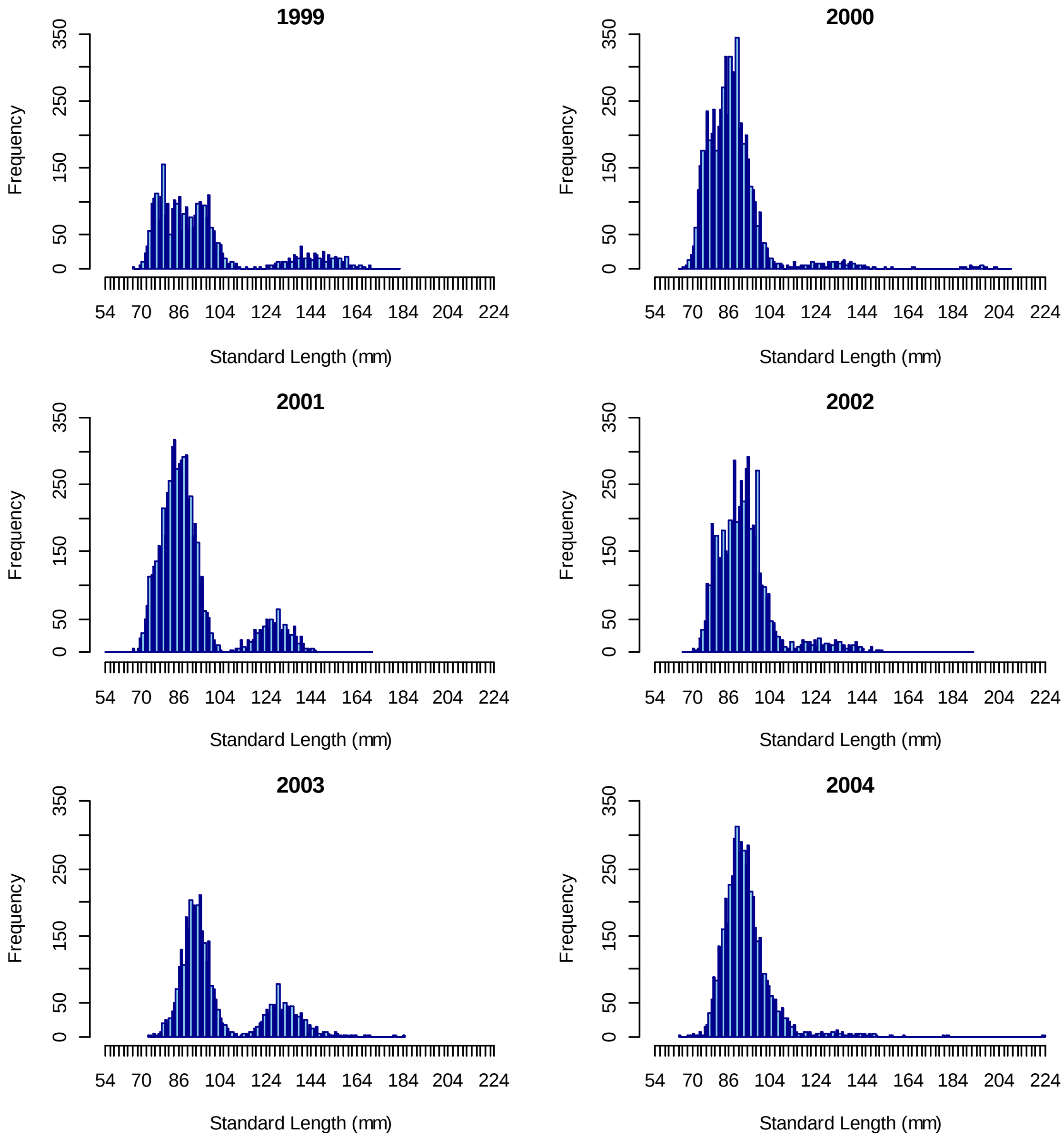
Appendix 10 continued. Catch weight (g; log-transformed) of age-0 herring caught at depth intervals along core transects during 2005-2010. Depth bins are categorical (not continuous), so the x-axis categories do not represent equal depth intervals. Where stations had the same depth interval, catch weights were averaged. Colour gradient indicates zero catch (white) to highest catch (shades of blue; dark blue indicates the highest catch weight). Grey colour indicates no set was made or no core-station exists.



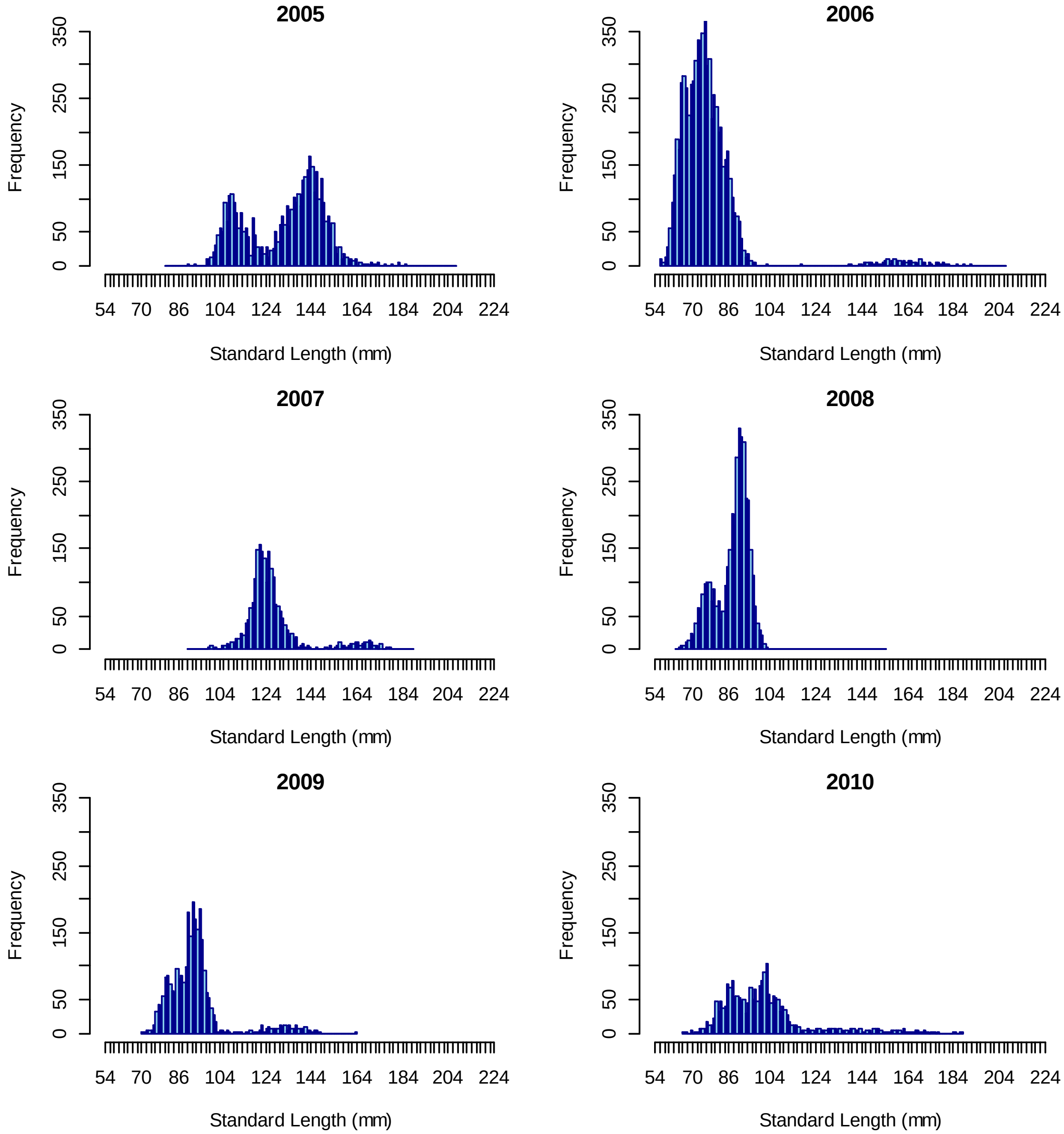
Appendix 10 continued. Catch weight (g; log-transformed) of age-0 herring caught at depth intervals along core transects during 2011-2014. Depth bins are categorical (not continuous), so the x-axis categories do not represent equal depth intervals. Where stations had the same depth interval, catch weights were averaged. Colour gradient indicates zero catch (white) to highest catch (shades of blue; dark blue indicates the highest catch weight). Grey colour indicates no set was made or no core-station exists.



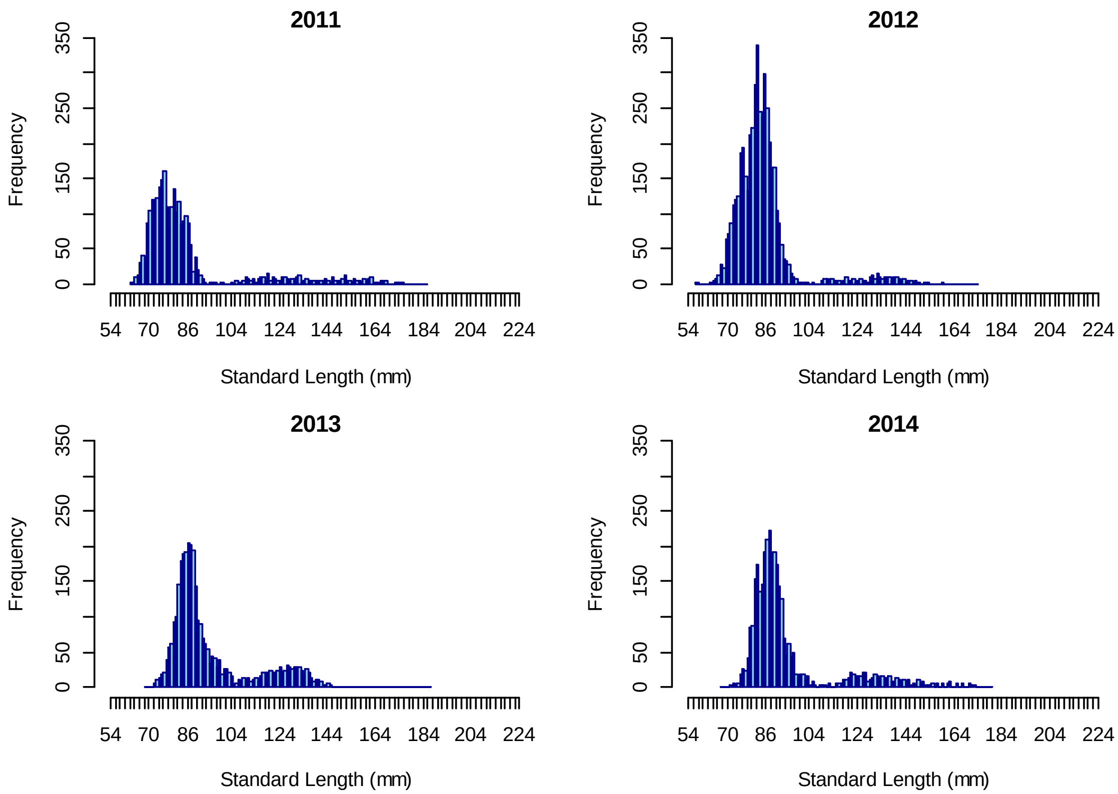
Appendix 11. Histograms of standard length (mm) frequencies of herring sampled at core stations along core transects in the Strait of Georgia juvenile herring survey, during 1992-2014 (no survey in 1995).



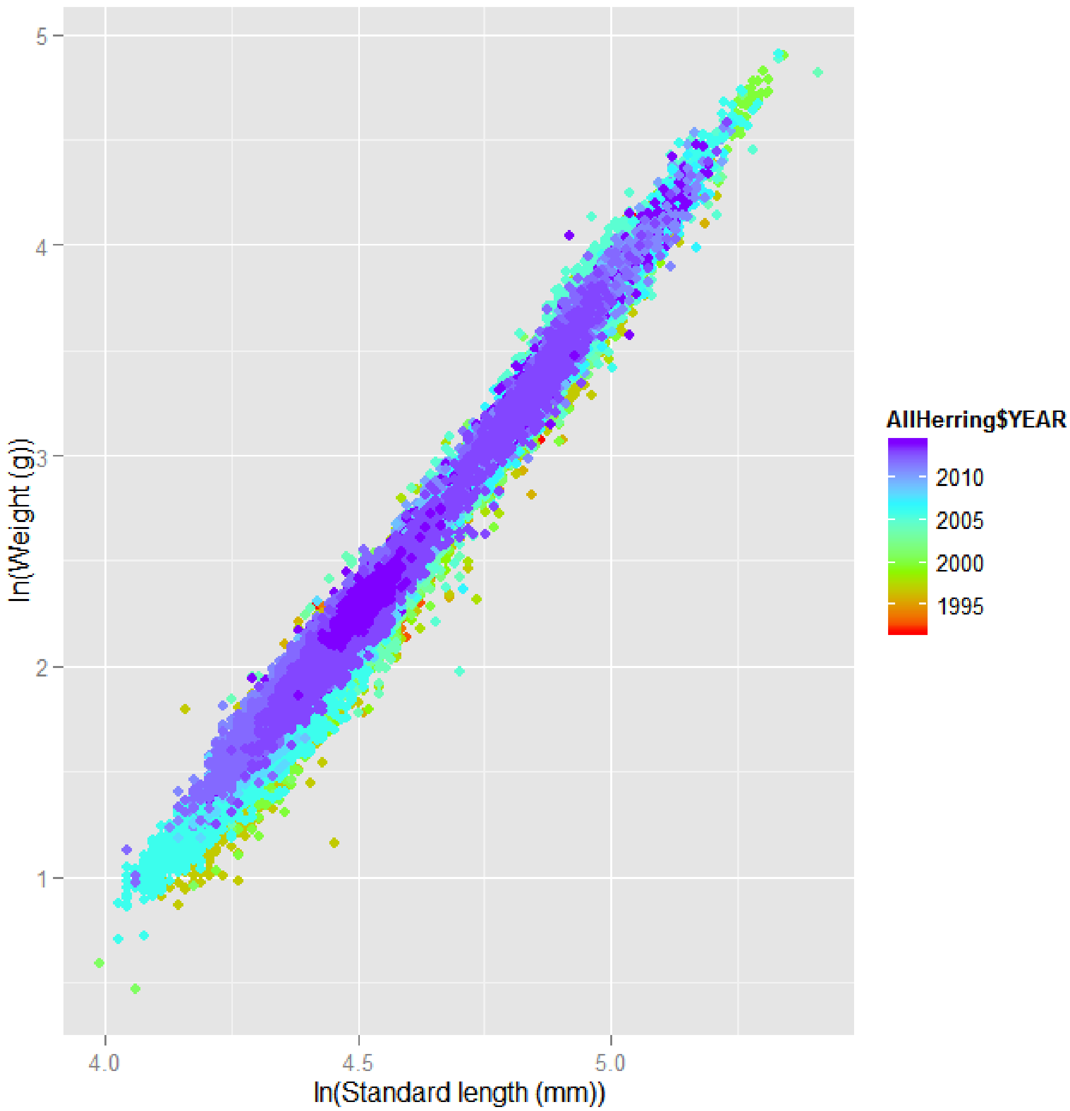
Appendix 11 continued. Histograms of standard length (mm) frequencies of herring sampled at core stations along core transects in the Strait of Georgia juvenile herring survey, during 1992-2014 (no survey in 1995).



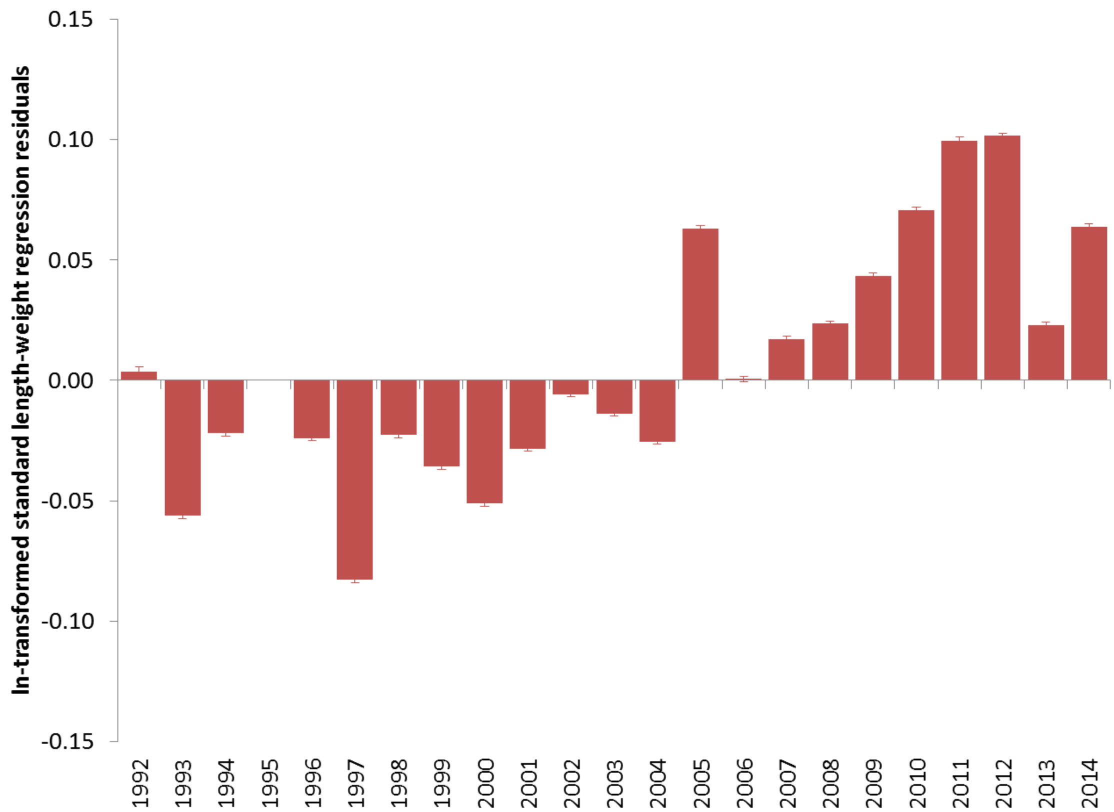
Appendix 11 continued. Histograms of standard length (mm) frequencies of herring sampled at core stations along core transects in the Strait of Georgia juvenile herring survey, during 1992-2014 (no survey in 1995).



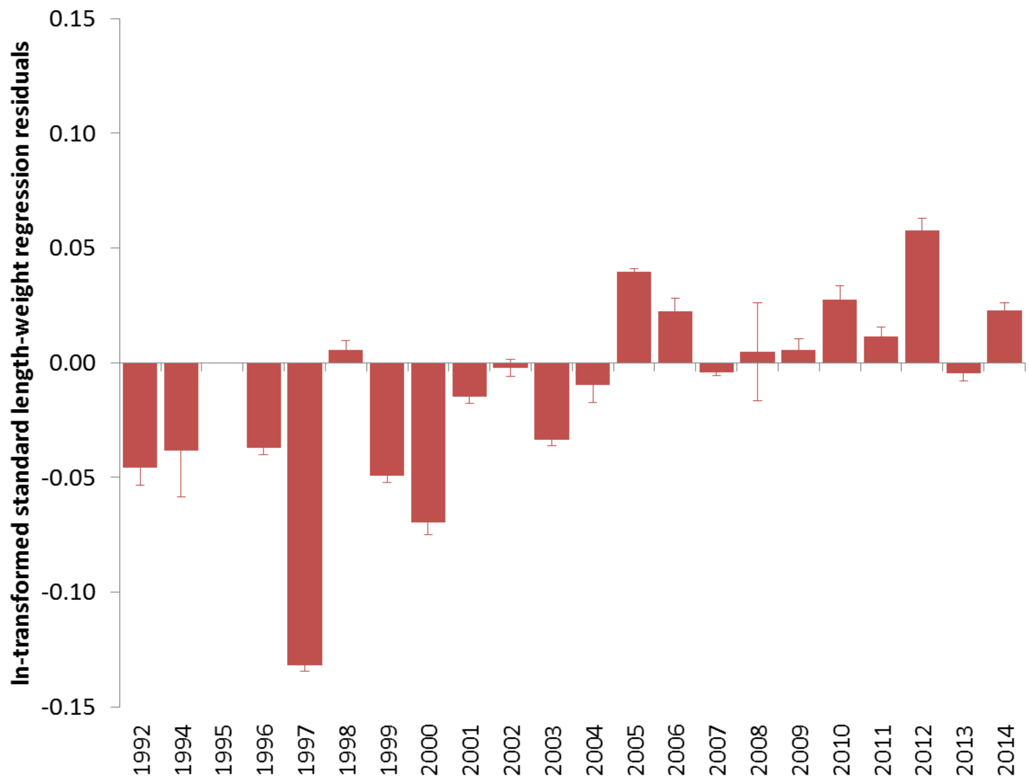
Appendix 11 continued. Histograms of standard length (mm) frequencies of herring sampled at core stations along core transects in the Strait of Georgia juvenile herring survey, during 1992-2014 (no survey in 1995).



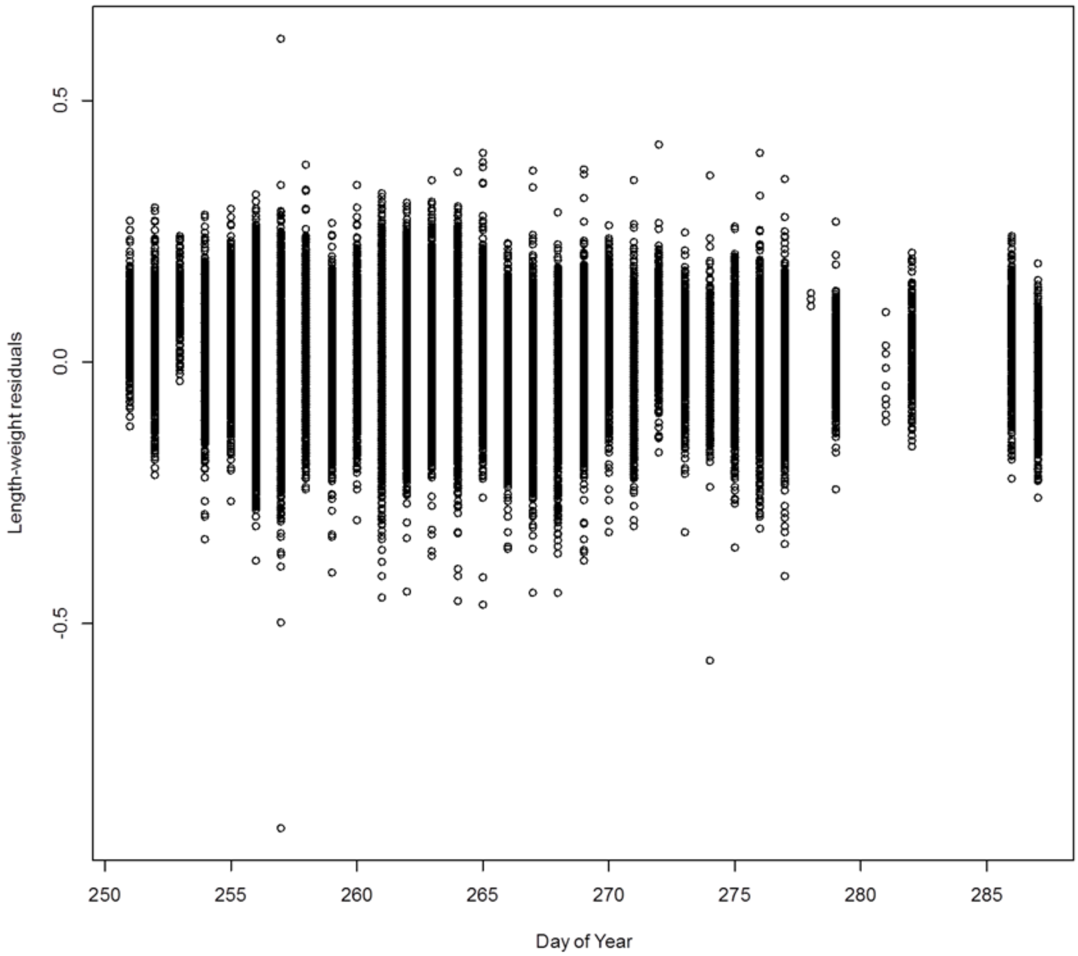
Appendix 12. Standard length-weight (log-transformed) relationship for all ages of herring sampled during the Strait of Georgia juvenile herring survey, 1992-2014 (no survey in 1995).



Appendix 13. Mean annual residuals (and standard errors) from a log-transformed standard length (mm)-weight regression for all ages of herring sampled at core stations and transects during 1992-2014 (no survey in 1995).



Appendix 14. Mean annual residuals (and standard errors) from a log-transformed standard length (mm)-weight regression for age-1 and age-2 herring sampled at core stations and transects during 1992-2014 (no survey in 1995).



Appendix 15. Age-0 herring length-weight residuals (from a log-transformed length-weight regression) as a function of day of year, as sampled as part of the Strait of Georgia juvenile herring survey during 1992-2014 (no survey in 1995).