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Capelin (*Mallotus villosus*) recruitment indices in NAFO Division 3KL

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

Trends in larvae emerging from Bellevue Beach, newly-emerged larvae in the Bellevue area, 0-group larvae in Trinity Bay, and ages 1 and 2 capelin offshore in Div. 3L were examined for the 2003-12 year classes. The sampling, development, and utility of each index are described. There is variation among the indices for each year class with some having higher variation such as 2003, 2005, and 2012 and others lower such as 2004 and 2007. However, the overall pattern of the indices was reasonably coherent and may be useful in projecting recruitment to the spawning population. These standardized indices were first examined during the 2010 regional capelin assessment process and more recently during the 2013 capelin assessment process.

Indices de recrutement pour le capelan (*Mallotus villosus*) dans la division 3KL de l'OPANO

RÉSUMÉ

Les tendances concernant les larves émergeant de la plage de Bellevue, les larves ayant émergé récemment dans la zone de Bellevue, les larves de la classe d'âge 0 dans la baie de la Trinité et le capelan d'âge 1 et 2 au large de la division 3L ont été examinées pour les classes d'âge 2003-2012. L'échantillonnage, l'élaboration et l'utilité de chaque index sont décrits. Il y a une variation entre les indices pour chaque classe d'âge. Certaines ont une variation plus élevée, comme 2003, 2005 et 2012, alors que d'autres ont une variation plus faible, comme 2004 et 2007. Cependant, la tendance générale des indices était raisonnablement cohérente et peut être utile pour prévoir le recrutement dans la population de géniteurs. Ces indices normalisés ont d'abord été examinés durant le processus d'évaluation régional du capelan de 2010 et, plus récemment, durant le processus d'évaluation du capelan de 2013.

BACKGROUND

Pre-recruit surveys are generally undertaken to map distributions and to compare trends in distribution and abundance over time. The latter approach is especially pertinent to capelin (Mallotus villosus) where previous research has shown that variation in year-class strength is determined early in the life history and largely regulated by environmental conditions (e.g., Frank and Leggett 1981; Leggett et al. 1984; Carscadden et. al. 2000). Leggett et al. (1984) observed a significant correlation between year class strength of capelin and the frequency of onshore winds following egg hatching in the intertidal zone and water temperatures encountered during larval drift. Re-running the model with more recent environment and recruitment data, Carscadden et al. (2000) found that the frequency of onshore winds remained a significant predictor but water temperature did not.

Capelin larval surveys have been conducted at various times in offshore areas and in Trinity Bay. The first larval and juvenile capelin survey in the northwest Atlantic occurred in September, 1978 (Poletayev 1978). In the mid-1980s ichthyoplankton surveys were conducted in the winter by the Union of Soviet Socialist Republics (USSR) in the Northwest Atlantic Fisheries Organization (NAFO) Div. 3KLNO (e.g., Bakanev and Oganin 1988). From 1992 to 1999, juvenile surveys were conducted by Canada in Div. 2J3KLNO in August–September (Anderson et al. 2002). Inshore larval surveys were conducted monthly from July to October in Trinity Bay from 1982 to1986 (Dalley et al. 2002). A monthly larval survey in Trinity Bay was reintroduced in 2002 covering August, September, and October with fewer sampling stations and other modifications to the sampling design.

For the 1997 assessment, a composite index of recruitment to the spawning population using a multiplicative model was developed from 5 recruitment indices: 1) pre-emergent larvae from 15 capelin beaches in Conception Bay, 2) pre-emergent larvae from 6 capelin beaches in Div. 3KL, 3) emerging larvae from 6 beaches in Div. 3KL, 4) 0-group offshore in Div. 3KL, and 5) age 1 offshore in Div. 3KL (Nakashima and Winters 1997). In later assessments, these recruitment indices were integrated with the indices derived from mature ages in a weighted multiplicative analysis (Evans and Nakashima 2002). The multiplicative approach ended when a majority of the surveys supporting the various indices, including all of the recruitment indices, used in the model were abandoned (DFO 2000).

Several recruitment data series were being collected in the 1990s and 2000s: emergent larvae at Bellevue Beach since 1990; the larvae in surface tows off Bellevue Beach since 2003; the 0-group from Trinity Bay since 2002; and ages 1 and 2 capelin from acoustic surveys since 1999. At the 2010 capelin assessment meeting (DFO 2011), the potential for developing a recruitment index using trends in emergent larvae, surface tow larvae, the 0-group, and age 2 capelin was first considered. At the recent capelin assessment in January 2013 (DFO 2013), age 1 capelin along with the other 4 recruitment indices were examined.

This report describes 5 recent recruitment indices and examines trends in capelin recruitment for the 2003-12 year classes.

RECRUITMENT DATA SOURCES

BELLEVUE BEACH LARVAL PRODUCTION MONITORING

In 1990 spawning times, egg deposition and development, larval emergence and various environmental variables (e.g., sunlight hours, wind direction, air temperature, water temperature, precipitation, beach sediment temperatures, beach disturbance) began to be monitored on two capelin spawning beaches located at Arnold's Cove, Placentia Bay in Div. 3Ps and at Bellevue Beach, Trinity Bay in Div. 3L. The number of sites was expanded in 1991 to include five additional beaches at Chapels Cove, Eastport, Cape Freels, Twillingate, and Hampden in Div. 3KL (Nakashima and Winters 1997). In 1995, Chapels Cove and Bellevue Beach were sampled. Since 1996 Bellevue Beach remains the only capelin spawning beach monitored on an annual basis (Fig. 1).

Fertilized eggs in the intertidal zone of the beach generally hatch between 12 and 20 days depending on the ambient incubation temperatures. Yolk-sac larvae can survive in the gravel sediment up to 5 days and generally emerge when environmental conditions are conducive to survival (Frank and Leggett 1981). Larvae emerging from the beach were collected during each high tide, generally twice a day by towing a 165 μm mesh plankton net parallel to the beach over the intertidal zone for 40 m (Fig. 2) while viable eggs were present in the intertidal area.

Capelin larvae were preserved in 5% formalin and saltwater solution buffered with sodium borate and enumerated later by counting all capelin larvae when less than 500 or sub-sampling using a beaker sub-sampling technique (van Guelpen et al. 1982).

The daily average density of emergent larvae was assumed to be the mean of the two high tide estimates. Annual production of larvae per m^3 (N) was estimated using the trapezoidal integration method:

$$N = \sum (t_n - t_{n-1}) \tfrac{1}{2} [X(t_n) + X(t_{n-1})]$$

where t is the day of the year, n is the number of sampling days, and X(t) is the number of larvae per m3 on day t. If a sample was missed due to adverse sea conditions or for any other reason, the average of the estimates on the same tide from adjacent days was substituted. If sampling was missed for 2 or more days then the missing values were set to 0.

The larval emergence series is the longest 0-group series. Larval emergence has been monitored from 1990 to 2012 except for 1997 (Fig. 3). Since the last assessment in 2010 (DFO 2011), the series has been updated to include estimates for 2010, 2011, and 2012. The 2010 estimate is larger than 2008 and 2009 and will be present as age 3 in 2013. The 2011 estimate is one of the largest in the series and suggests a potential for high abundance of age 2 fish in 2013, especially if a majority of age 2's mature early as they have been doing in recent years (DFO 2011; Mowbray 2014). The amount of emerging larvae in 2012 was lower than 2011 and comparable to 2010. The 2012 value is underestimated because sampling for emerging larvae from the beach terminated on August 13 before all the larvae had emerged. Some capelin spawning occurred the night of August 8 in the study site and on August 10 elsewhere on Bellevue Beach. Given the water temperatures (12-17 °C) at the time, these eggs would not have hatched until 12 to 14 days later. Given the low level of spawning and eggs from this late spawning we assume the amount of larvae produced would have been small. Consequently, the underestimation is likely to be minor.

In the cove adjacent to Bellevue Beach there are two demersal capelin spawning beds (Nakashima and Wheeler 2002) and several small capelin spawning beaches along the western shore. Larvae coming from these sites likely mix with larvae from Bellevue Beach itself. To examine trends in overall larval production from this area we conducted 4 surface tows and 11 vertical tows in 2000 using a 333 μm mesh plankton net, the same mesh size used in the 1980s in Trinity Bay (Dalley at al. 2002). In 2001, 7 stations were monitored using surface tows. The research vessel (22' Topaz) used in 2000 and 2001, was replaced in 2002 with one (27' Narry Face) specifically designed for this project. In response to capelin larvae escaping through the mesh of the plankton net used for surface tows in 2002, several smaller mesh sizes were tested with the 270 μm mesh size proving to be the most effective. Since 2003, the 270 μm mesh size net on a 0.75 m diameter ring has been used consistently for surface tows. Larvae within the cove were collected every 48 hr in surface tows of 10 min duration at 2.1 knots at 5 stations (Fig. 2). Volume filtered was measured with a General Oceanics 2030 Series mechanical flow meter positioned in the opening of the net. Capelin larvae were preserved and enumerated as described above for larvae emerging from the beach.

The daily trends in larval emergence from the beach are compared with daily trends from the surface tows to ensure that the pulses of larvae coming off the beach are being adequately represented. The sampling frequency of surface tows has been adapted to the dynamic processes encountered at the study site. Sampling has been on alternate days or more frequent depending on whether a pulse of larvae has recently exited the beach or the demersal spawning beds. Surface tows commenced when larvae began emerging from the beach and stopped when eggs from nearby demersal spawning sites were predominantly dead (Nakashima and Wheeler 2002). In 2005 larval traps were deployed on Grebes Nest and Gull Rock (Fig. 2) to monitor larvae emerging from the two demersal sites. Traps were emptied every 48 hr, the contents preserved in buffered 5% formalin, and larvae enumerated later. Since 2005, surface tows are terminated when larvae are absent from the traps, eggs remaining at the demersal sites are predominantly dead, and few yolk sac larvae (< 100) are collected in the surface tows for at least a week.

Surface tows were conducted to estimate the presence of newly-emerged larvae. At times, especially in August older capelin larvae were present in the study area. From each set, total length (mm) of 25 larvae was measured and the presence/absence of a yolk sac was determined. The number of larvae per set was adjusted to enumerate only those that had recently emerged from nearby spawning sites. The daily average density of newly-emerged larvae collected off Bellevue Beach was the mean of the 5 surface tows. If any of the 5 stations were not sampled on a given day, that day was assumed to be not sampled. Annual production of larvae per m^3 was estimated using the trapezoidal integration method above. The average of the estimates from the day before and the day after was used to adjust for a missing sample date. If more than 2 days lapsed between collections, then the missing days starting with the second day were set to zero.

Since 2003 surface tows have been conducted following a reasonably consistent manner using the same sampling stations, similar sampling frequency, and the same sampling gear. The surface tow data from 2003 to 2009 were first presented at the 2010 assessment (DFO 2011). This series has been updated and now includes estimates from 2010, 2011, and 2012 (Fig. 4). The 2010 estimate is lower than the previous 5 yrs. However, the first major pulse of larvae emerging from the beach over a weekend in mid-July was missed by the surface tows which sampled on Friday and the following Monday, likely contributing to the underestimate (2010 Fig. 5). In this case, the combination of a strong swell removing the larvae from the beach on Friday and SW winds advecting the larvae away from the beach over the weekend resulted in lower than expected larvae in the tows on Monday. In 2011 due to adverse weather conditions early in August, the surface tows were suspended for 4 days. During this time larvae were emerging from the beach, however the amount emerging was relatively low and the continuous onshore winds during this time probably helped to retain the larvae in the area, thereby increasing the time larvae were available to the surface tows. More consequential was the inability to deploy the larval traps earlier due to the stormy conditions. Once deployed, the traps had high numbers of larvae at the start indicating that larvae had been emerging from the two demersal sites prior to the traps being deployed. The release of larvae from demersal sites appears to have been captured by the surface tows (2011 Fig. 5). Underestimation in 2011 because of the inability to sample during the 4 - day storm event is not considered as significant as missing the first pulse of larvae from the beach in 2010. In 2012 there is a good correspondence between pulses of larvae emerging from the beach and being picked up by the surface tows with a 0 to 2 day lag time (2012 Fig. 5). Very few larvae were recovered in the traps indicating larval production from the two demersal spawning sites was low and confirmed by the low abundance in surface tows after August 11 (2012 Fig. 5). Two days (August 20, 22) of surface tows from 2012 remain to be processed, however these are at the end of the sampling season and are likely to have low estimates of larvae.

TRINITY BAY LARVAL CAPELIN PRODUCTION MONITORING

From 1982 to 1986 investigations into larval capelin production and distribution were carried out in Trinity Bay NL (Dalley et al. 2002). This work consisted of a comprehensive monitoring of capelin production on a monthly basis from July to October, covering the entire main bay. During these surveys 52 randomly chosen stations in 6 strata were repeatedly occupied and fished using a pair of 333 µm mesh nets fitted on a 61 cm diameter bongo frame (Fig. 6). Catches from these surveys indicated that the center portion of the bay contained the highest densities of capelin larvae and that catches in these center strata were correlated with catches in the other strata.

In 2002 a reduced version of this survey was reinstated. Objectives of the survey included tracking larval production at the bay scale and investigating how later spawning times affect larval survival and growth. Coverage during this current period has been reduced to 19 stations in the central strata with sampling occurring from one to three times a year occurring during the months of August, September and October. During years when only one survey could be conducted it was targeted for September. During all surveys in addition to zooplankton sampling vertical CTDs were conducted. CTD locations coincided with bongo stations in the middle of the bay, but were also conducted across the head and mouth of the bay when time and weather conditions permitted (Fig. 7).

In contrast to the former survey series where the initial positions of the fixed sampling stations were randomly generated, the fixed stations sampled from 2002 onward were established along four northwest lines transecting the bay with a 6 nmi spacing. Stations were place at 3 nmi intervals along each line (Fig. 7). All other equipment and methods were the same as in the previous study. Constant descent and ascent rates were maintained at each station by real time monitoring of gear depth using a net-mounted STD. The filtered volume of each net was monitored using mechanical flow meters. Nets were towed at a speed of 2 - 2.5 knots. Target descent rate was 20 m/min and the ascent rate was 10 m/minute. All stations were fished from one to three times each year. Samples were preserved in 2 % buffered formaldehyde. The catch from the net with the highest filtered volume was sorted and contents evaluated. Catches were strained, soaked in fresh water then reconstituted to 1 L volume. Successive 50 ml aliquots of the reconstituted sample were then removed and the content sorted to species. The number of individuals of each species caught was recorded and all capelin, up to a maximum of 50 individuals from each set, were measured for total length. Aliquots continued to be analyzed in this fashion until a minimum of 50 capelin were counted. Capelin density per square meter was then calculated for each station as:

$$\rho_i = C_i * D_i / V_i$$

where ρ is the density of capelin larvae per square meter, i is station, *C* is the number of capelin caught, *D* is the maximum tow depth at station i in meters, and *V* is the filtered volume in m^3. The annual capelin production index used is the mean of the 19 station densities. Length frequencies of capelin measured from each station were scaled to the station density and summed over the survey area.

Since 2002 the bay has been surveyed five times in August (2008-12), eleven times in September (2002-11) and twice in October (2008-09). Distribution and the relative density of capelin among stations and by year are presented in Fig. 8. There is no consistent pattern in distributions among years or months. Overall mean larval density during current surveys ranged from 6-70 larvae/m^2 in August, 7–97 larvae/m^2 in September and 4-11 larvae/m^2 in October. Larval densities in August 2011 were the highest recorded in either 1980s or current surveys (Fig. 9). September 2011 were also the highest in the current series, but can not be compared to those produced in the 1980s as September and October densities from the former study have not been published.

Composite length frequencies for recent bongo surveys (2002-12) are presented in Fig. 10. The largest range of sizes occurred in 2005 and 2010 while length frequencies were most truncated in 2003 and 2008. Catches in 2010 and 2012 contained the highest proportion of recently hatched (4-5 mm) larvae, this finding is unexpected for 2012 as beach and surface tows from this year indicate hatching concluded the earliest of the three years. In many years more than one mode is evident in catches.

Growth rates published for this and other capelin stocks range from 0.1-0.3 mm/day (Jacquaz et al. 1977; Frank and Leggett 1986; Ivarjord et al. 2008). At these rates we would expect 3-9 mm of growth between surveys. Monthly length frequencies from years when multiple surveys were conducted are presented in Fig. 11. In 2008 and 2009 it is possible to track cohorts from one survey to the next although growth appears to be at the low end of previously published rates. Cohorts cannot be tracked through the length frequencies from latter years.

The modal size of capelin during August and September 2012 were the smallest recorded. Over the time series the size composition of August samples was generally more consistent than those of capelin caught in September. The variability in September surveys may be explained by differential rates of advection of different cohorts. Dalley et al. (2002) showed that larval transport in Trinity Bay was positively correlated with the intensity of Ekman transport and a cumulative measure of wind forcing. During two recent surveys (2010 and 2012) a hurricane passed over the Avalon Peninsula between the August and September surveys, potentially impacting the availability of larvae to the September survey. Oceanographic modeling of particle dispersion is underway and may prove helpful in testing this hypothesis.

The mean length of larvae caught during August surveys ranged from 5 to 10 mm (Fig. 12). Larvae in September ranged from 8 to 13 mm with the largest mean size occurring in 2005. October larvae ranged between 11 and 14 mm. These sizes, particularly for September and October are smaller than those recorded for larvae sampled during the same month in the earlier period (Dalley et al. 2002). Overall current lengths are more analogous to those sampled a month earlier in the 1980s (e.g., August in the ‘80s is more similar to September now).

This observation of smaller larvae than historically present is not unexpected since there has been a considerable shift in spawning time between the early 1980s and now, while the timing of the larval surveys has remained constant. Figure 13 shows spawning times and larval sampling times during both the current survey series and those in the 1980s. While Bellevue Beach (Trinity Bay) spawning times are not available for the early 1980s, spawning times are available from an adjacent bay (Bryant’s Cove, Conception Bay). Since 2005 data on date of peak spawning are available from both of these beaches. The timing of peak spawning is well correlated between these locations. Consequently changes in spawning times at Bryant’s Cove are probably a reasonable proxy for changes at Bellevue beach. Since 2002, spawning times in Bryant’s Cove have been on average about 14 days later than during the 1980s. Consequently capelin larvae caught in recent years are relatively younger than those sampled previously.

SPRING ACOUSTIC SURVEY OF PRE-RECRUITS

A May acoustic survey covering NAFO Div. 3L has been conducted most years since 1982. Details and results of these annual spring acoustic surveys for 1982-87 are given in Miller (1991) and for 1988-2012 in Mowbray (2014). This survey was developed to provide an index of incoming year class strength based on the abundance of immature fish. At the time of the survey's inception most capelin matured at age 3, so the age 2 fish monitored by the survey served as a recruitment index for the following year. But since the early 1990s the majority of capelin have been maturing at age 2. Consequently age 2 capelin, which continue to dominate the survey index, do not fully reflect incoming year class strength. The next youngest age (1), although present in the survey area, are not well recruited to the survey, particularly before the implementation of modern scientific echosounders. Small age 1 capelin are difficult to detect acoustically due to their relatively low backscatter cross-section which can be indistinguishable from system noise. Moreover their catchability in the midwater trawl (Diamond IX), used to determine the biological characteristics of the backscatter signal pre 1999, was poor. Since 1999 better echosounders (EK500 and EK60) have permitted identification of age 1 fish at lower densities and the most consistently used trawl (Campelen 1800) retains more age 1 fish, although fish under 10 cm are still very poorly recruited to the gear (Mowbray 2001). For this reason we are now presenting both ages 1 and 2 from this survey as recruiting ages to the mature population. The abundance of these ages in the surveyed population between 1985 and 2012 are shown in Fig. 14. For both ages abundances from 1991 to 2005 were up to an order of magnitude lower than those seen in the 1980s. Since 2007 abundances have increased moderately although still considerably lower than historic levels. Concerns have been raised regarding the availability of maturing capelin to the acoustic survey in 2010, indicating that numbers in this year are underestimated (Mowbray 2014). This is reflected in the current analysis in an anomalously low value for the 2008 cohort, which occurred as age 2 in 2010 acoustic survey. Spring acoustic surveys were not conducted in 1993-95, 1997-98, and 2006.

COMPARISON OF RECRUITMENT INDICES

For a comparison of the 5 indices described above, we start with the 2003 year class and standardize each index to its mean of for the 2004-11 year classes to facilitate comparison of the temporal trends in year class strength (Fig. 15). For the recent year classes, there are no estimates at age 2 for the 2011 year class and at age 1 for the 2012 year class because they are dependent on the spring acoustic survey in May 2013. The 2012 year class only has estimates for the 0 group at this time. The three 0-group indices are collected independently and ages 1 and 2 are estimated from the spring acoustic surveys conducted 1 and 2 years later respectively. Issues related to the annual sampling of each index are provided under the appropriate section. The 5 indices are coherent in terms of trends, with the exception of Trinity Bay (0 group) for the 2003 and 2005 year classes and age 2 for 2008-09 year classes.

Despite the issues in data collection and timing related to individual indices, there is relative coherence amongst the 5 indices. This is not surprising given the success adapting recruitment indices into the multiplicative approach in previous assessments (Nakashima and Winters 1997; Evans and Nakashima 2002) and the biological basis for the relationship between environmental conditions, early life history, and recruitment success (Frank and Leggett 1981; Carscadden et al. 2000).

Trends among the indices are being examined during regional assessments of capelin to provide an indication of the relative size of year classes that are likely to contribute to the incoming spawning population. Should the indices be maintained and the trends among indices remain coherent then the next step is to develop a single recruitment index to predict relative year class strength.

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Table 1. Mean density of capelin larvae during monthly surveys of Trinity Bay, NL.

	July		August		September		October	
Year	Mean	STD	Mean	STD	Mean	STD	Mean	STD
1982*	31.1		46.5					
1983*	48.8		48.8					
1984*	12.4		41.8					
1985*	6.2		33.2					
1986*	22.6		73.6					
2002					7.31	13.01		
2003					52.88	32.92		
2004					14.86	10.95		
2005					9.92	14.25		
2006					17.27	14.07		
2007					75.50	34.49		
2008			24.67	28.53	48.55	38.89	4.07	4.22
2009			32.02	30.07	12.66	6.36	11.28	
2010			62.98	104.04	26.39	24.80		
2011			70.31	41.45	96.95	98.80		
2012			5.94	12.00	6.73	11.19		

* Dalley et al (2002)

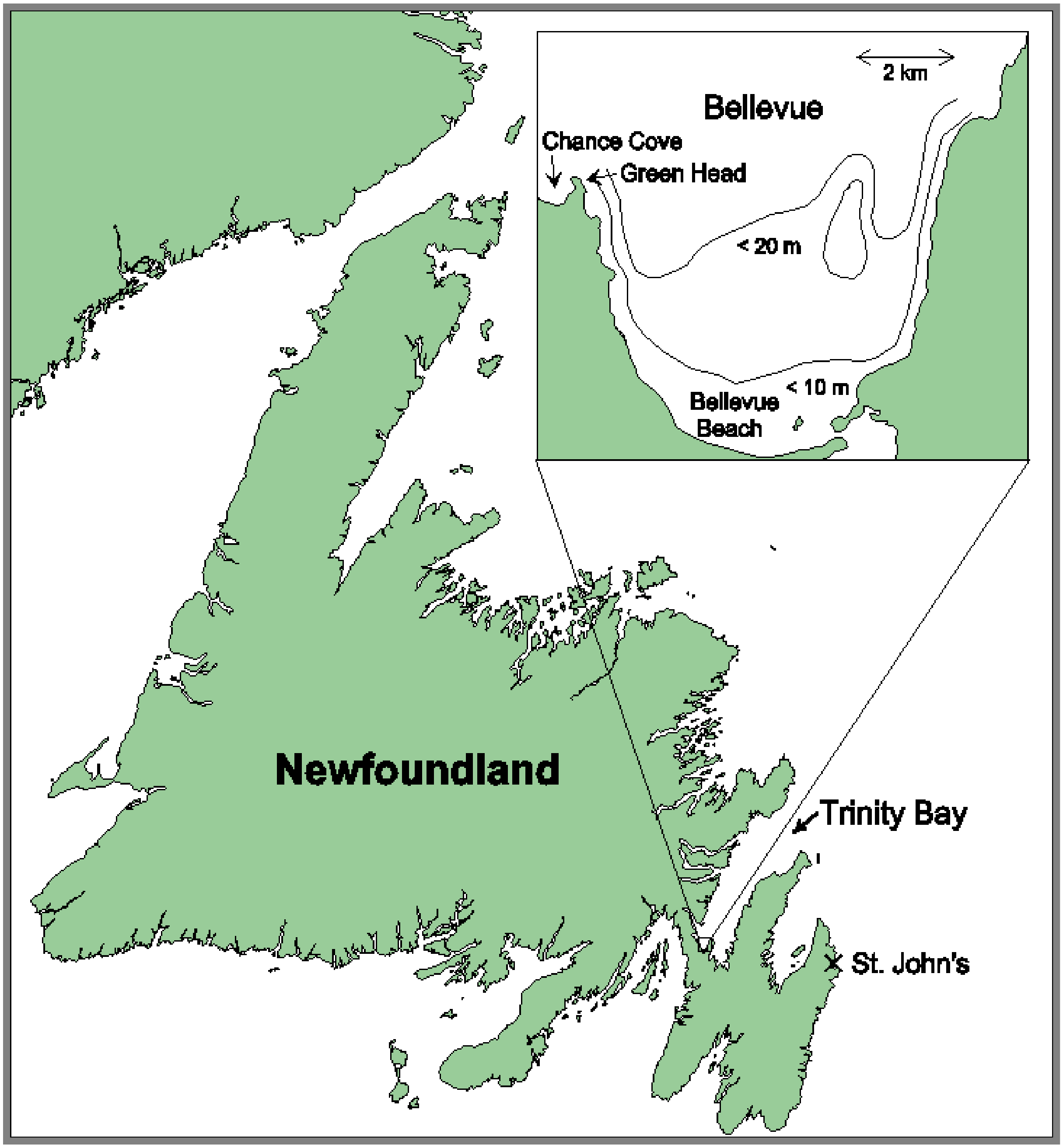


Figure 1. Location of Bellevue Beach study area in Trinity Bay, NL.

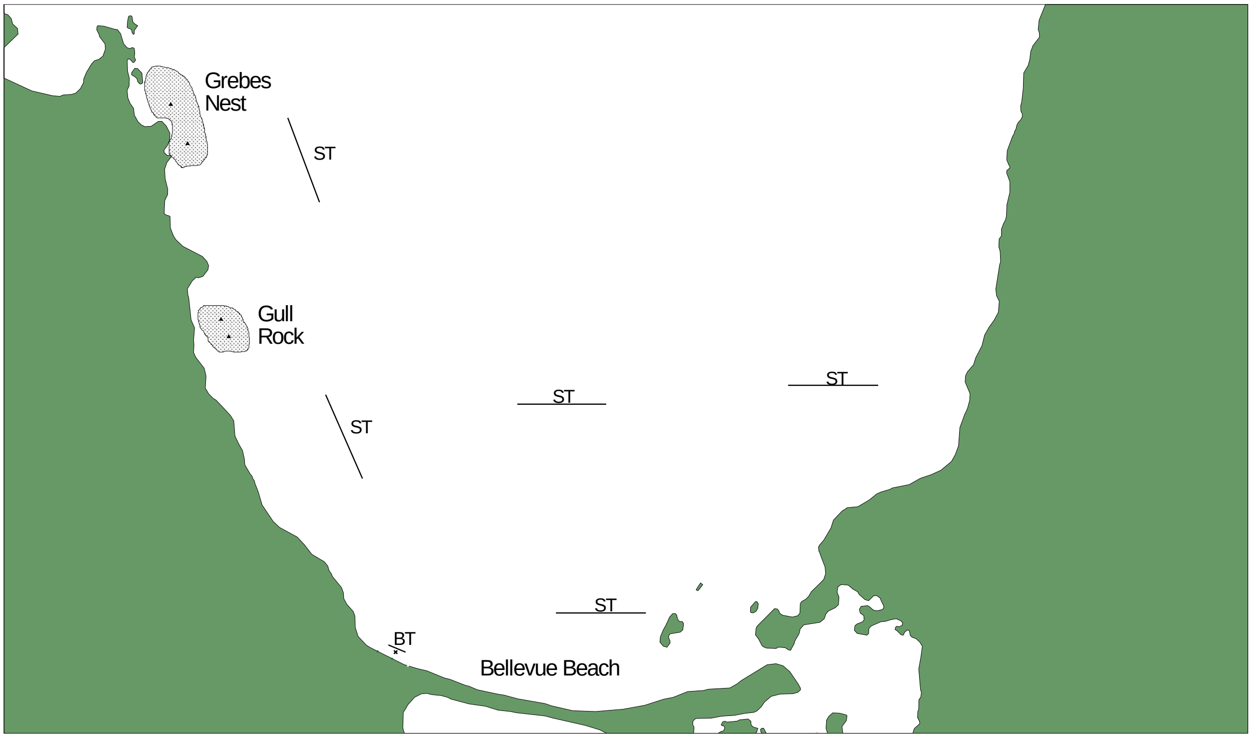


Figure 2. Sampling locations for surface tows (ST), high tide tow (BT) on Bellevue Beach, and larval trap locations (triangles) on demersal spawning beds of Grebes Nest and Gull Rock.

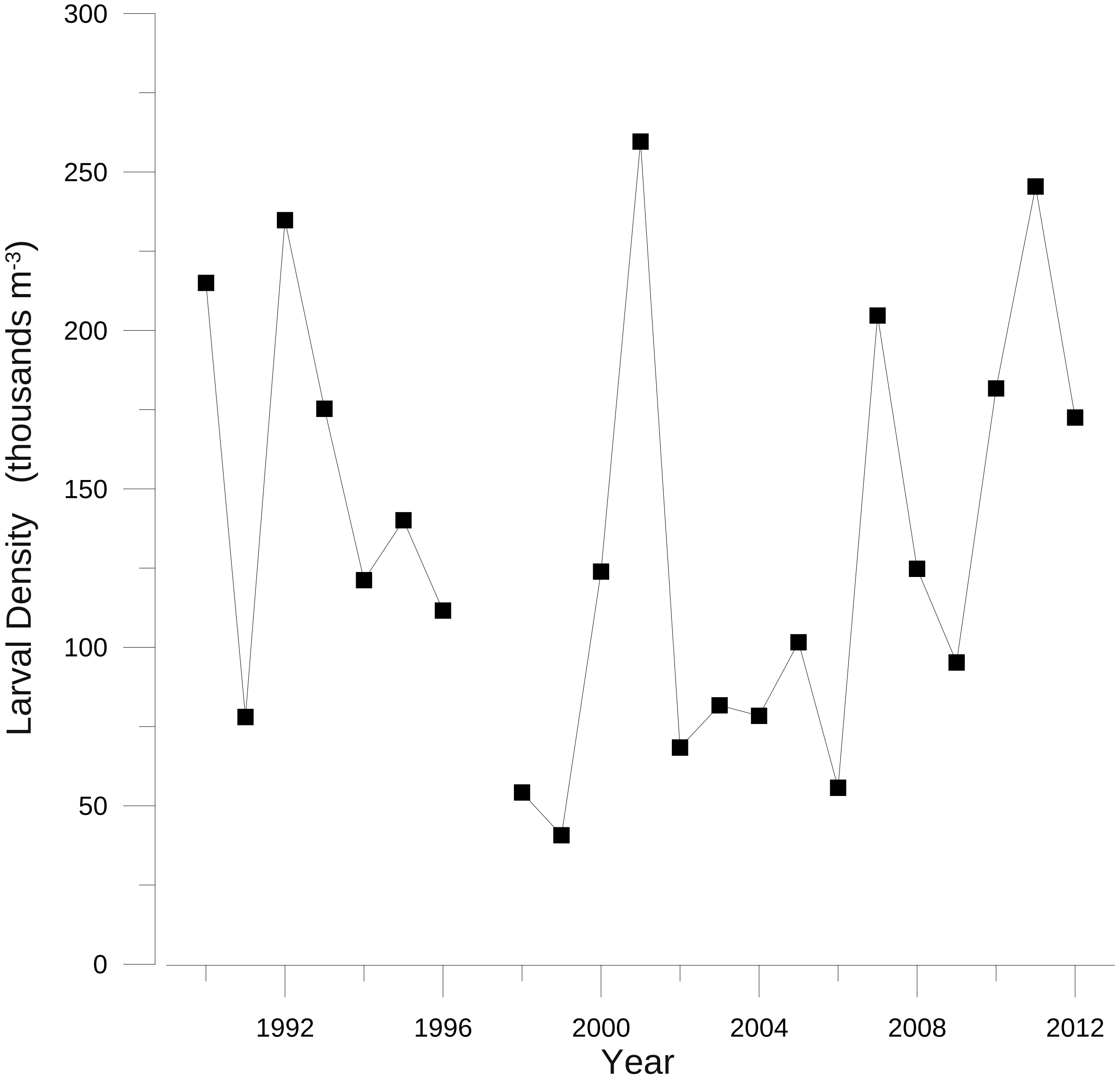


Figure 3. Larval emergence from Bellevue Beach, Trinity Bay in 1990-96, 1998-2012. Larval emergence data were not collected in 1997.

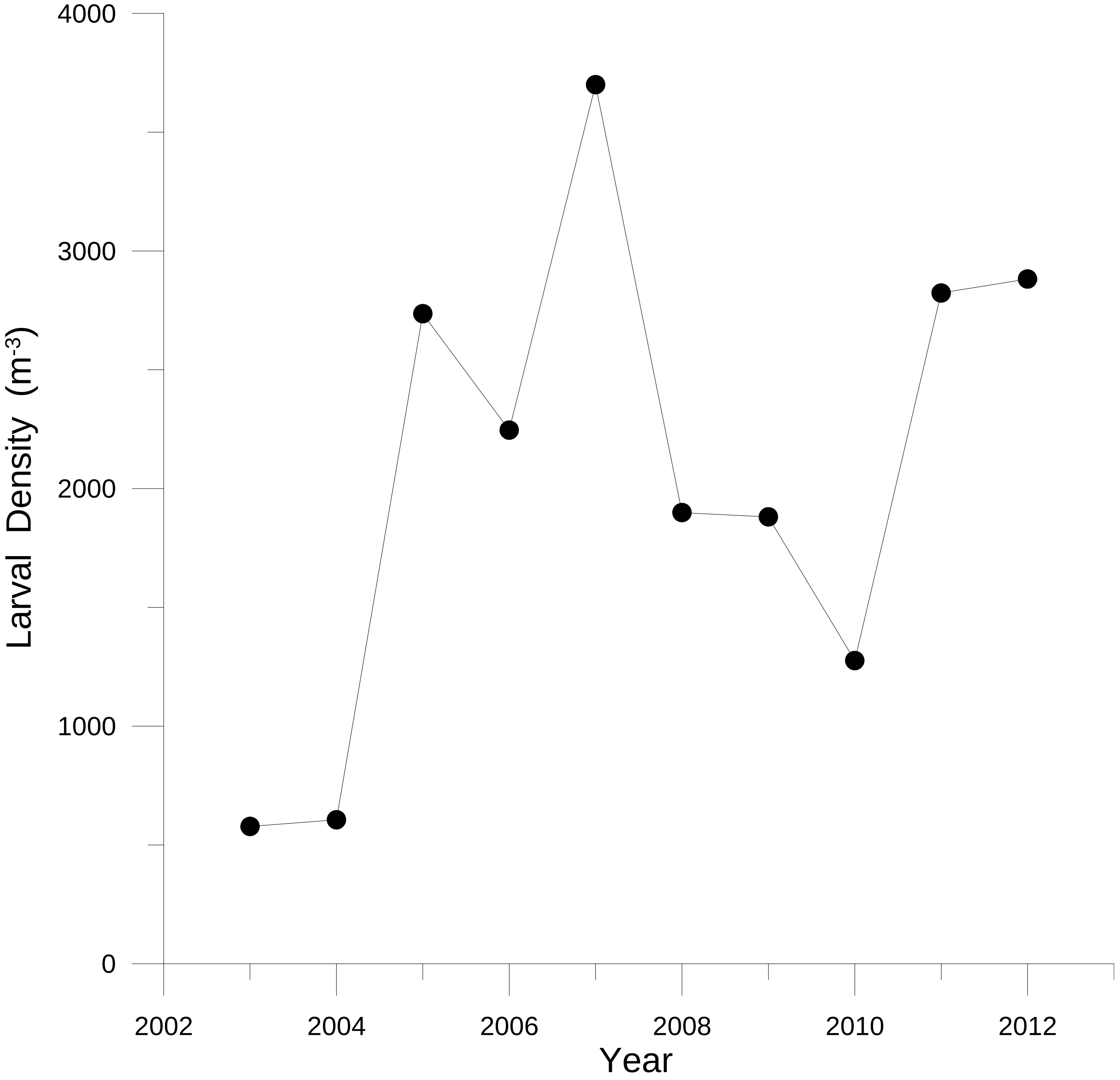


Figure 4. Larval production based on surface tows near Bellevue Beach, Trinity Bay in 2003-12.

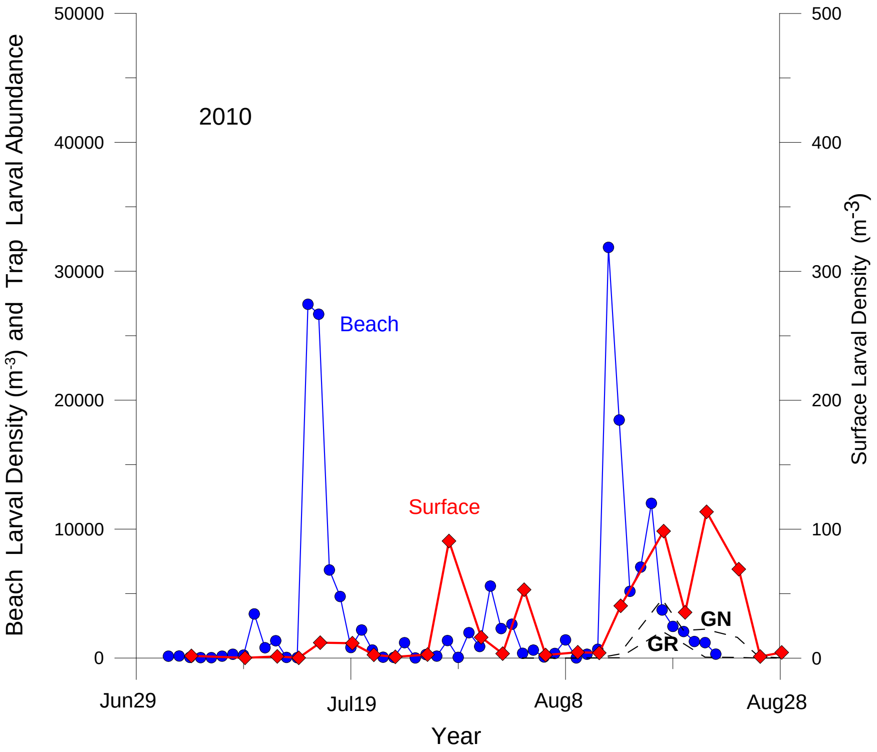


Figure 5a. Comparison of patterns in larvae emerging from the beach (circles), larvae in surface tows (diamonds), and larvae in traps (dashes) emerging from Grebes Nest (GN) and Gull Rock (GR) for 2010.

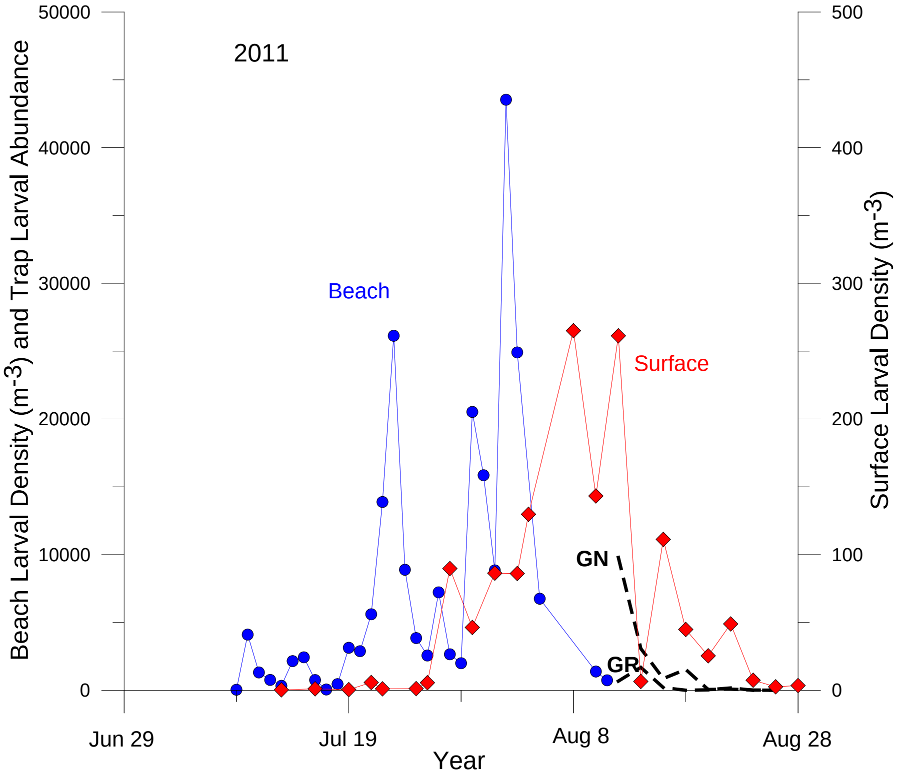


Figure 5b. Comparison of patterns in larvae emerging from the beach (circles), larvae in surface tows (diamonds), and larvae in traps (dashes) emerging from Grebes Nest (GN) and Gull Rock (GR) for 2011.

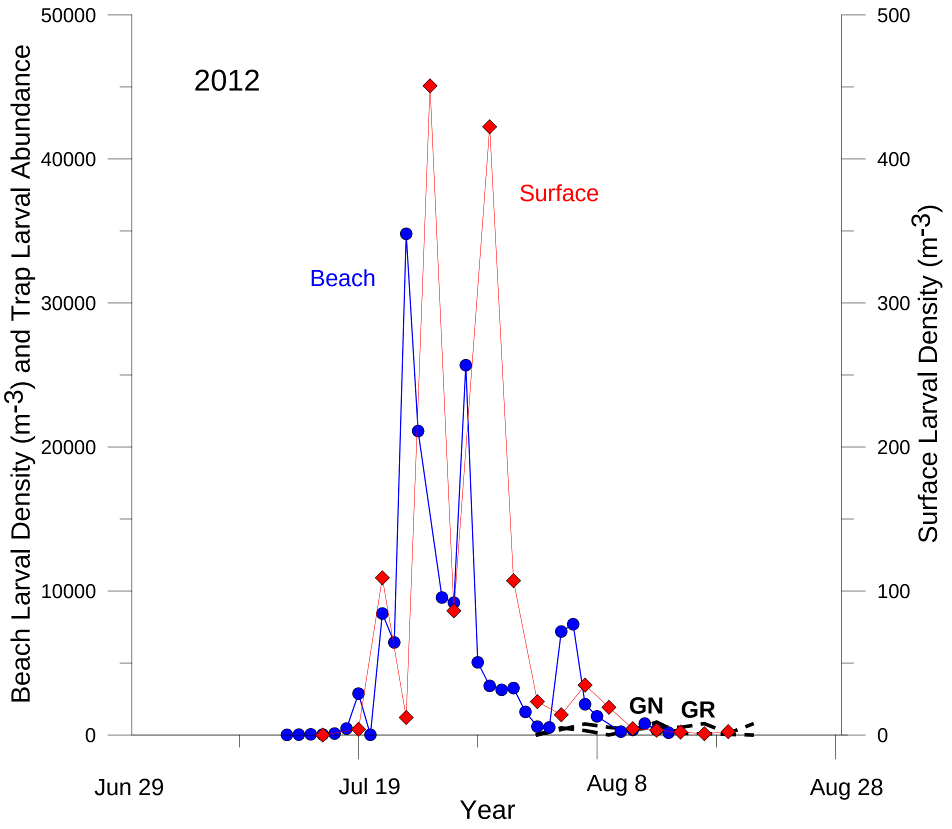


Figure 5c. Comparison of patterns in larvae emerging from the beach (circles), larvae in surface tows (diamonds), and larvae in traps (dashes) emerging from Grebes Nest (GN) and Gull Rock (GR) for 2012.

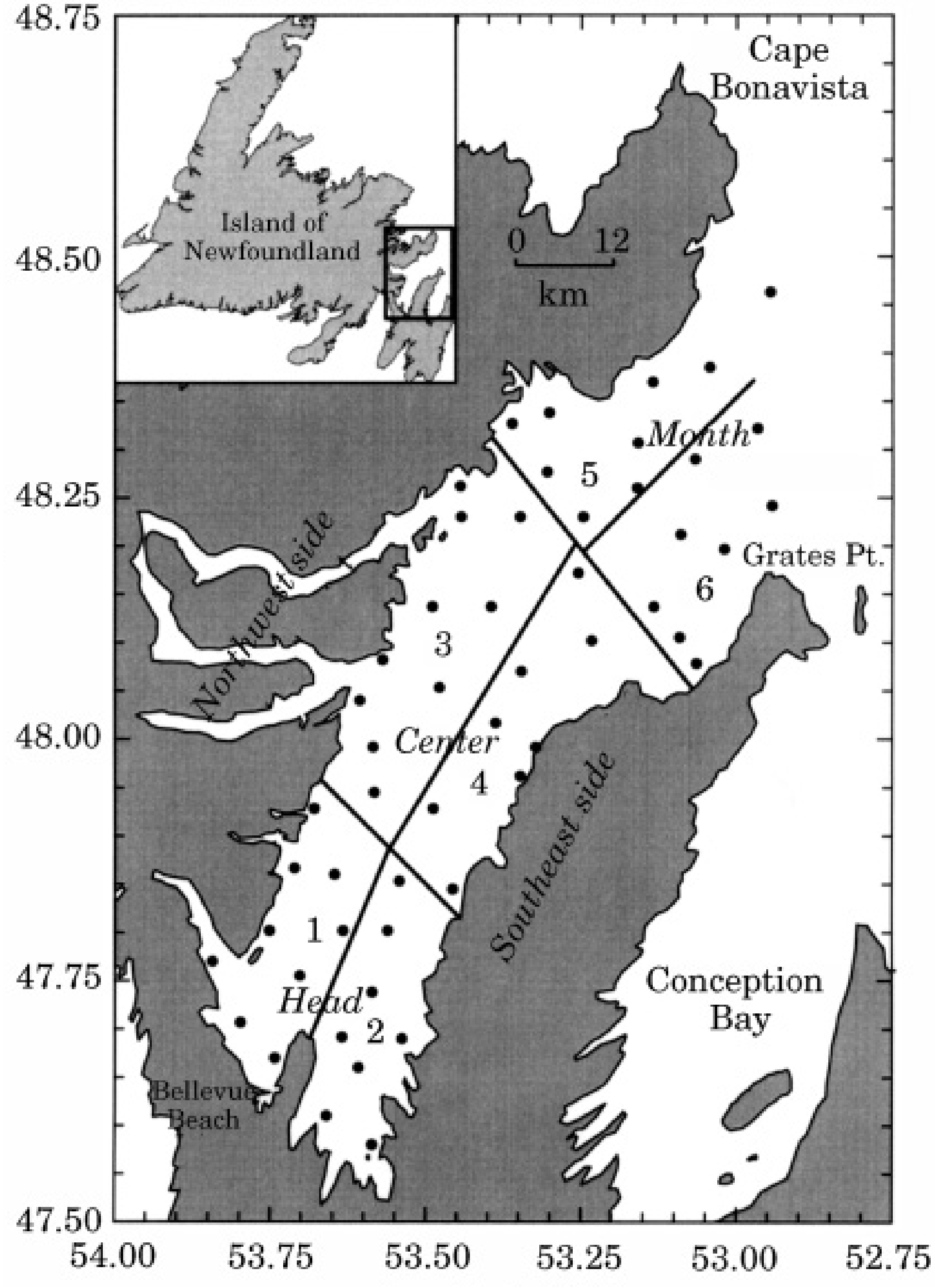


Figure 6. Sampling stations occupied during larval capelin surveys occurring in Trinity Bay, NL from 1982 to 1986. Figure reproduced from Dalley et al. (2002).

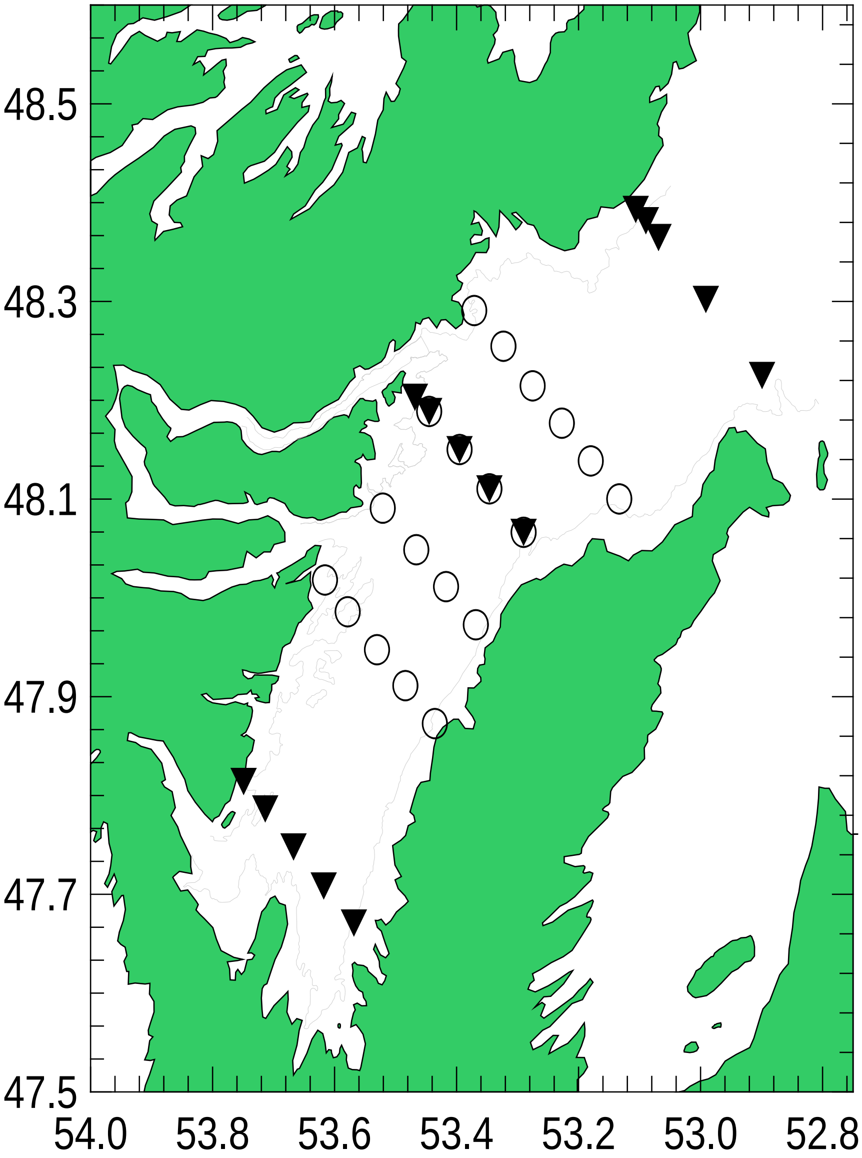


Figure 7. Map of Trinity Bay indicating locations of larval tows and CTD profiles occupied during surveys conducted between 2002 and 2012. Circles indicate stations where bongo nets were fished. Triangles give locations of CTD profiles. Axis labels are in decimal degrees.

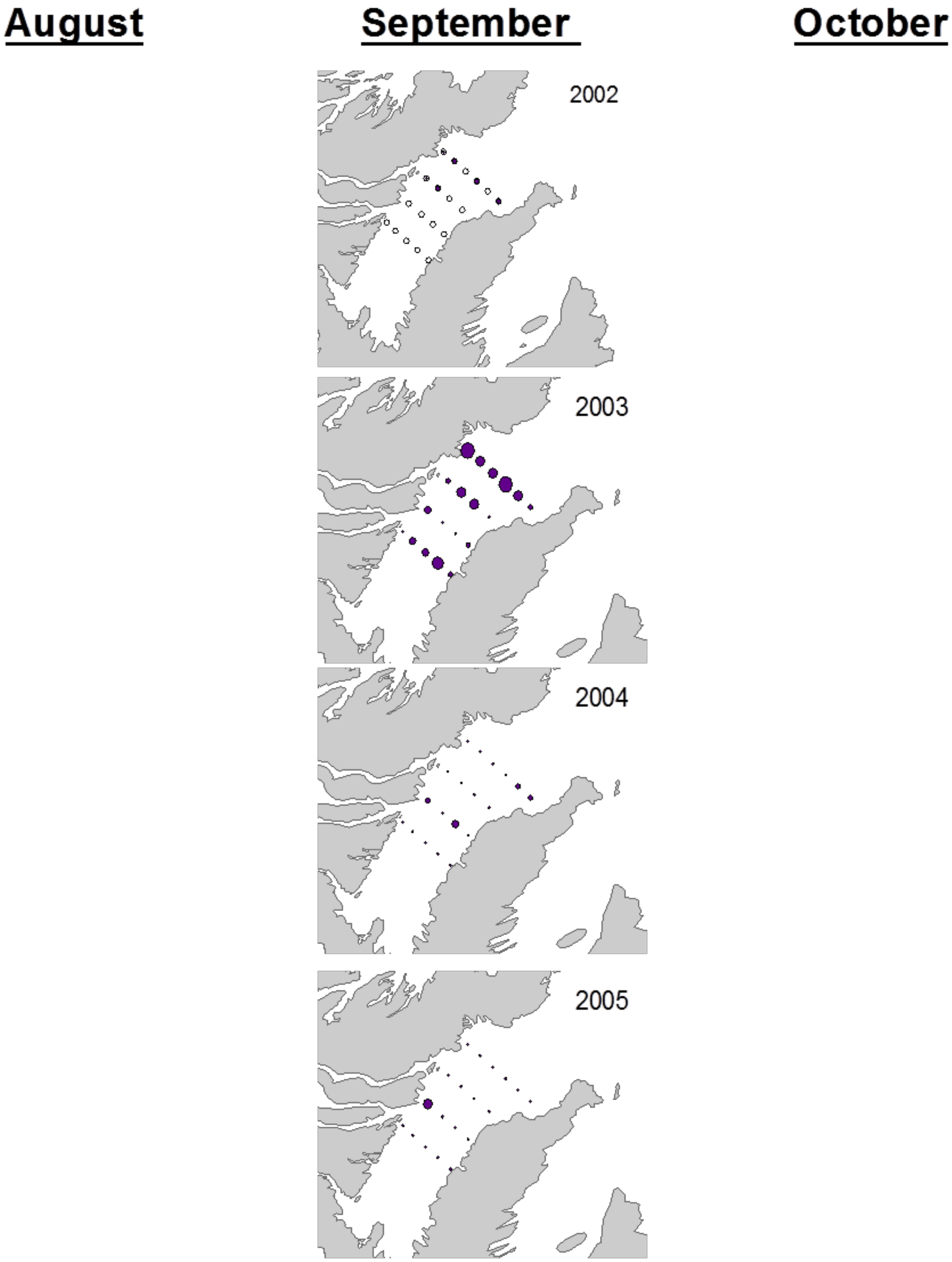


Figure 8. Distribution and density of larval capelin during surveys from 2003 to 2012. Size of solid purple circle is proportional to the density of capelin at the sampling station. Empty circles indicate no capelin larvae caught.

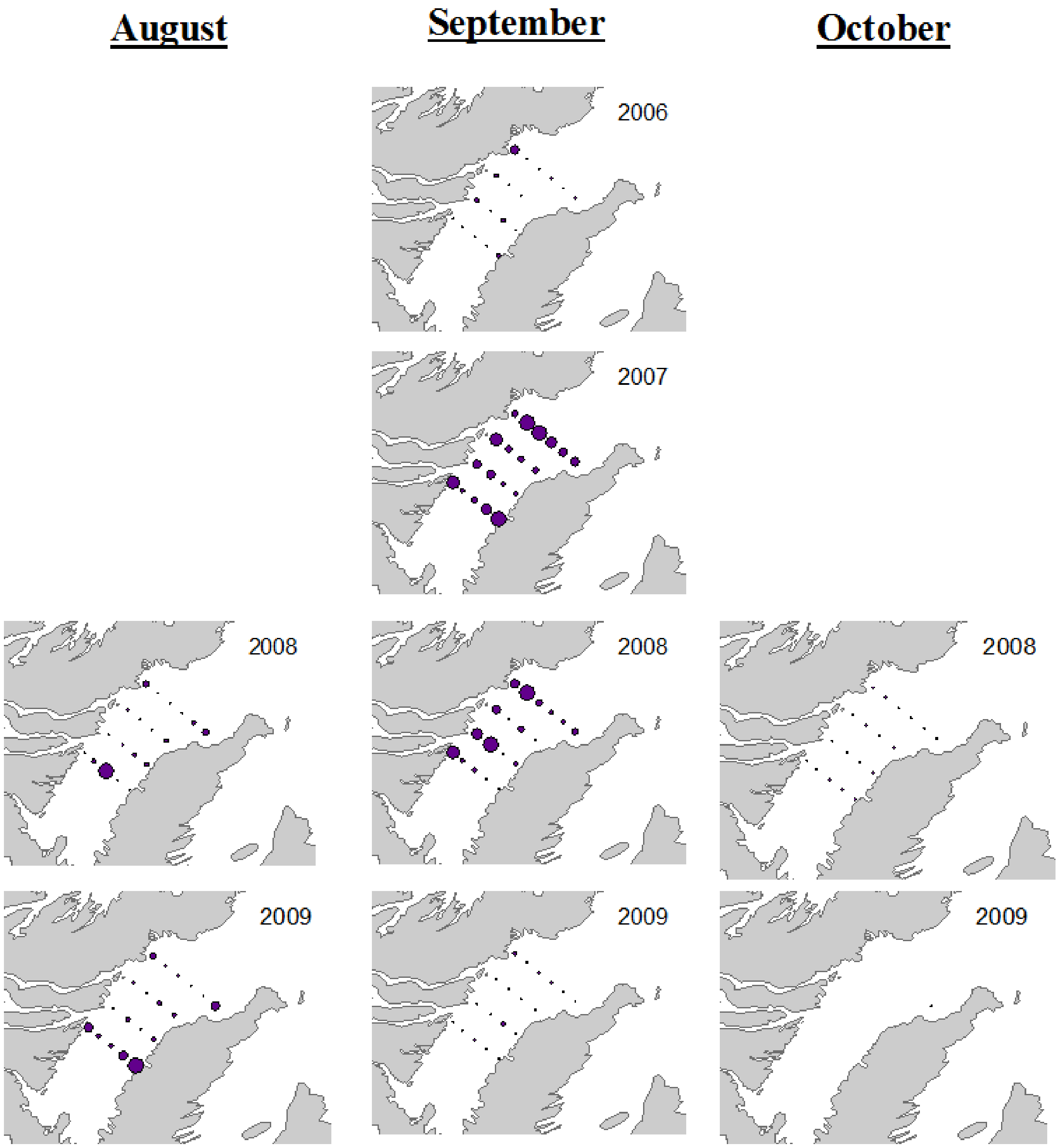


Figure 8 (Cont'd).

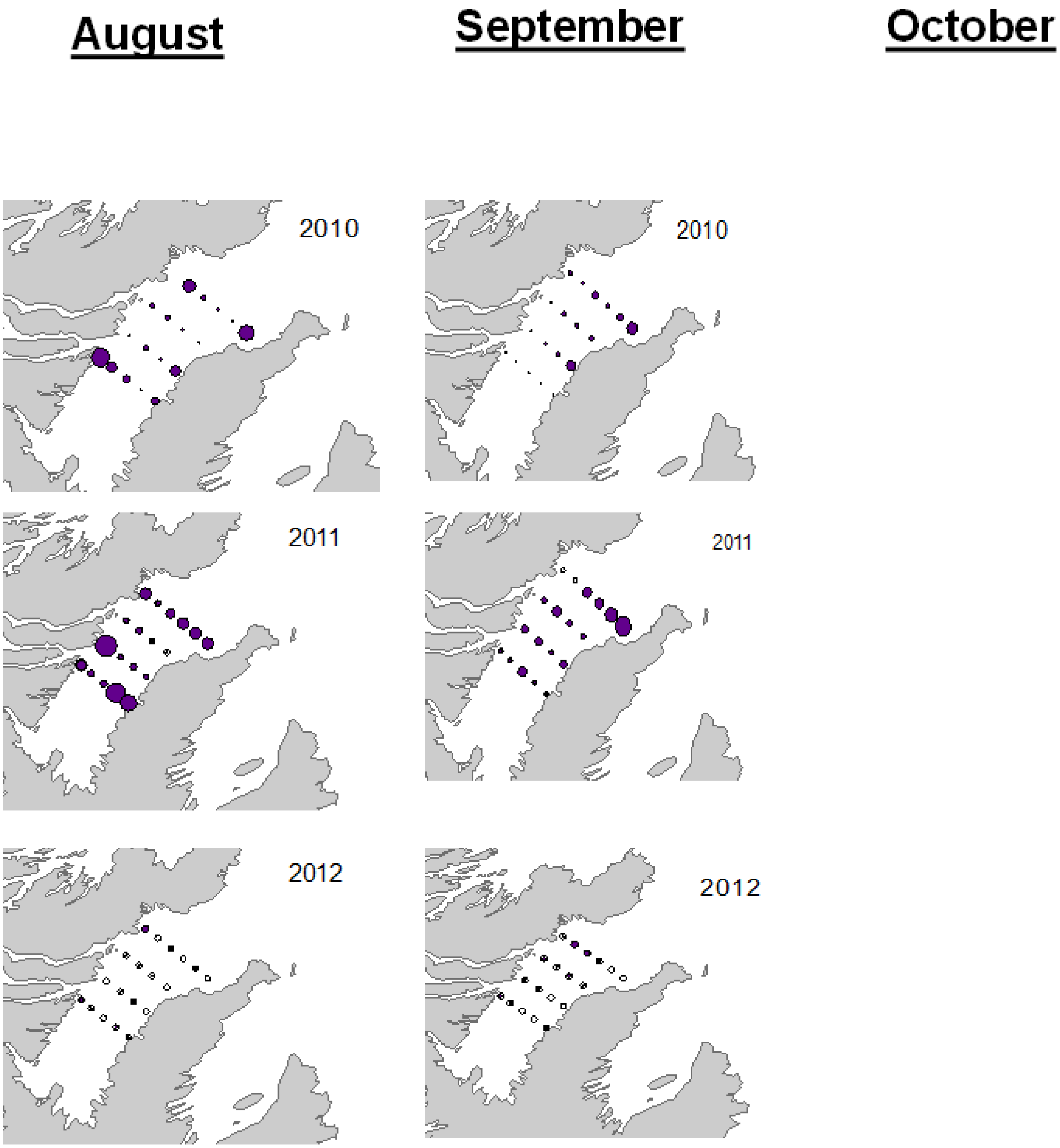
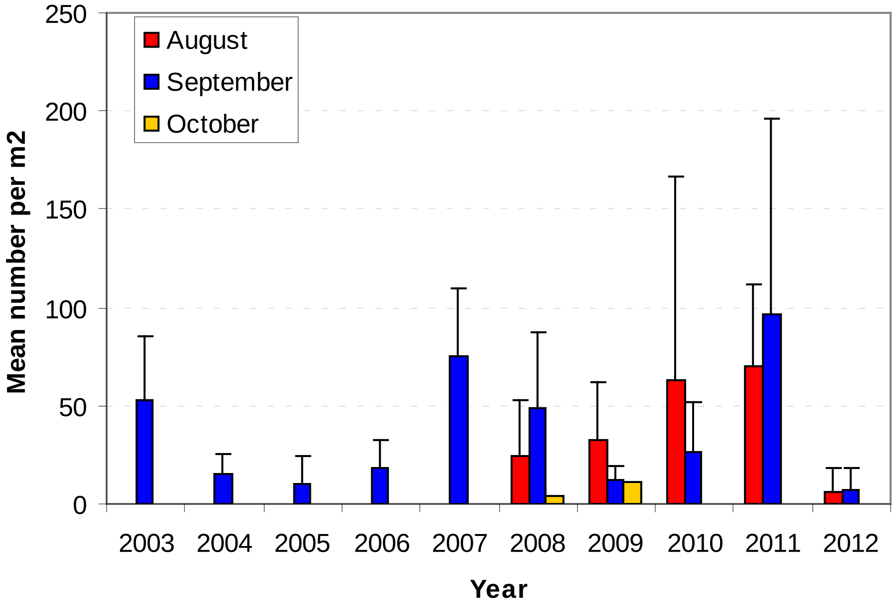


Figure 8 (Cont'd).



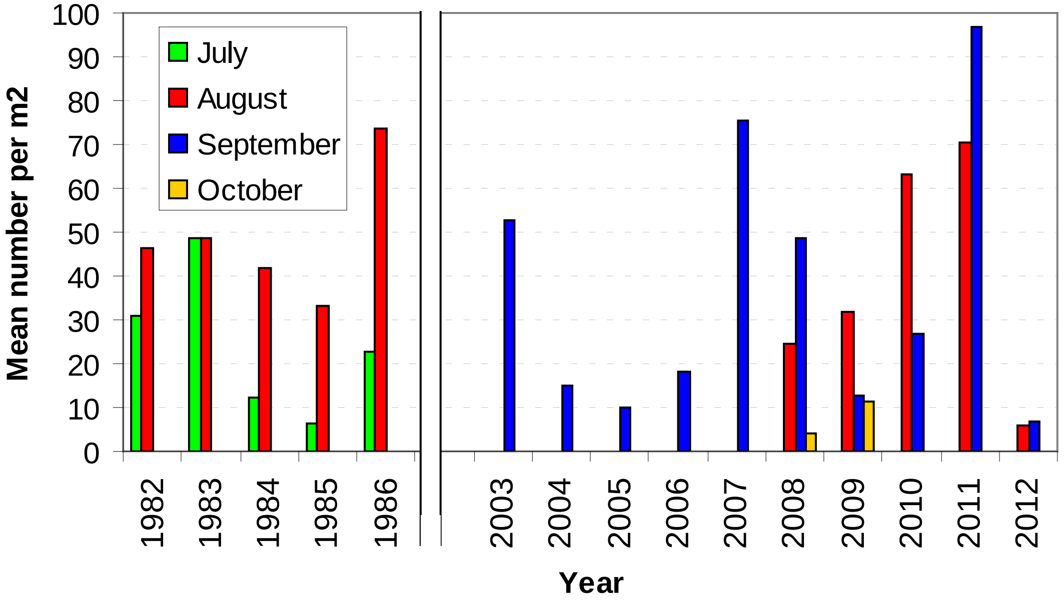


Figure 9. Upper panel. Mean density of capelin during survey of 19 index sites in Trinity Bay between 2002 and 2012. Red bars indicate results from August surveys, Blue bars results from September and Yellow bars results from October. Error bars shown are 95% confidence limits. Lower panel: Larval densities from Dalley (2002) along side Larval densities from current study. Color schema is the same as in the upper panel.

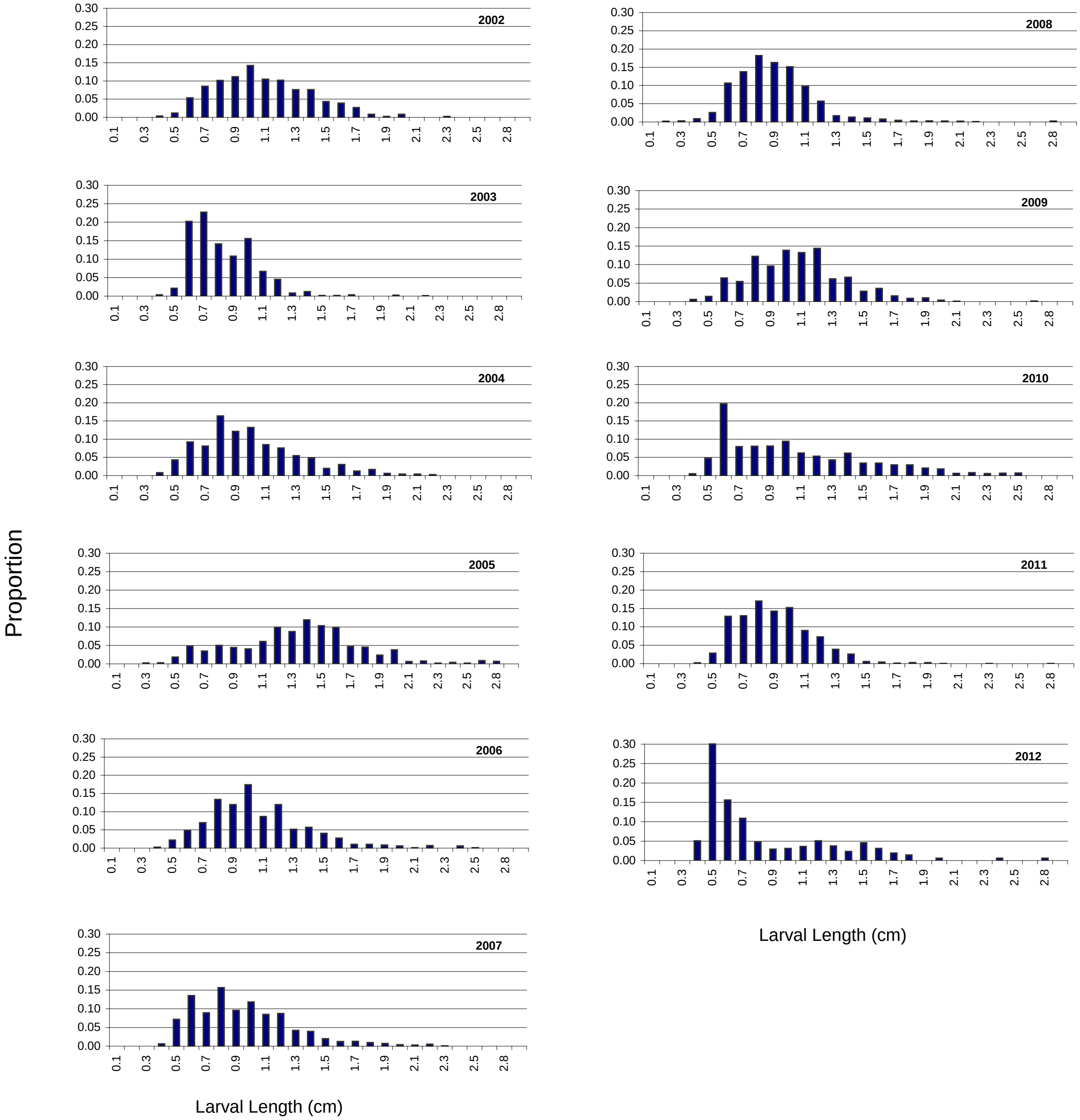


Figure 10. Proportion at length of capelin larvae captured during September surveys (2002-12).

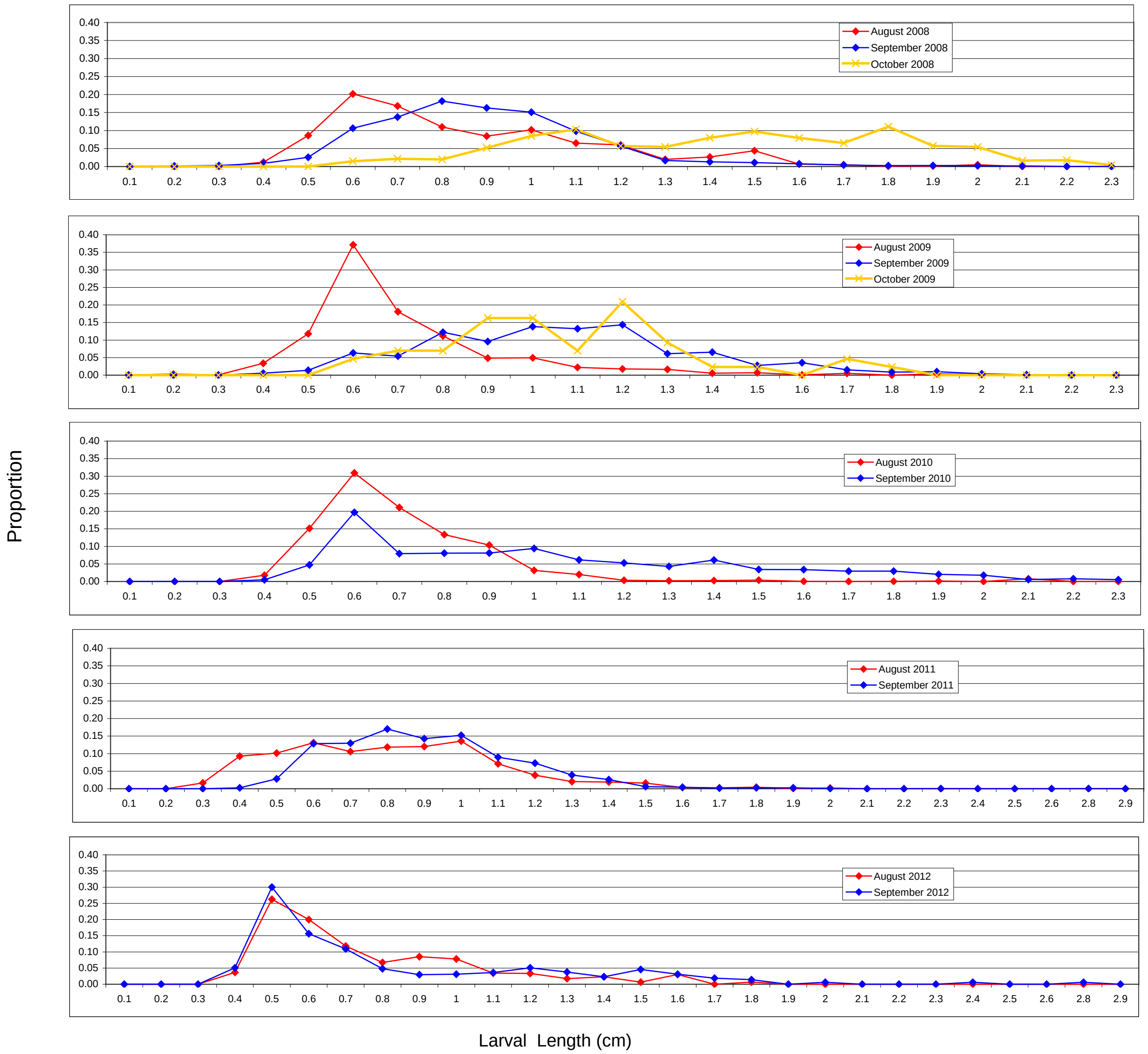


Figure 11. Monthly length frequencies during survey years in which sampling occurred in more than one month (2008-12).

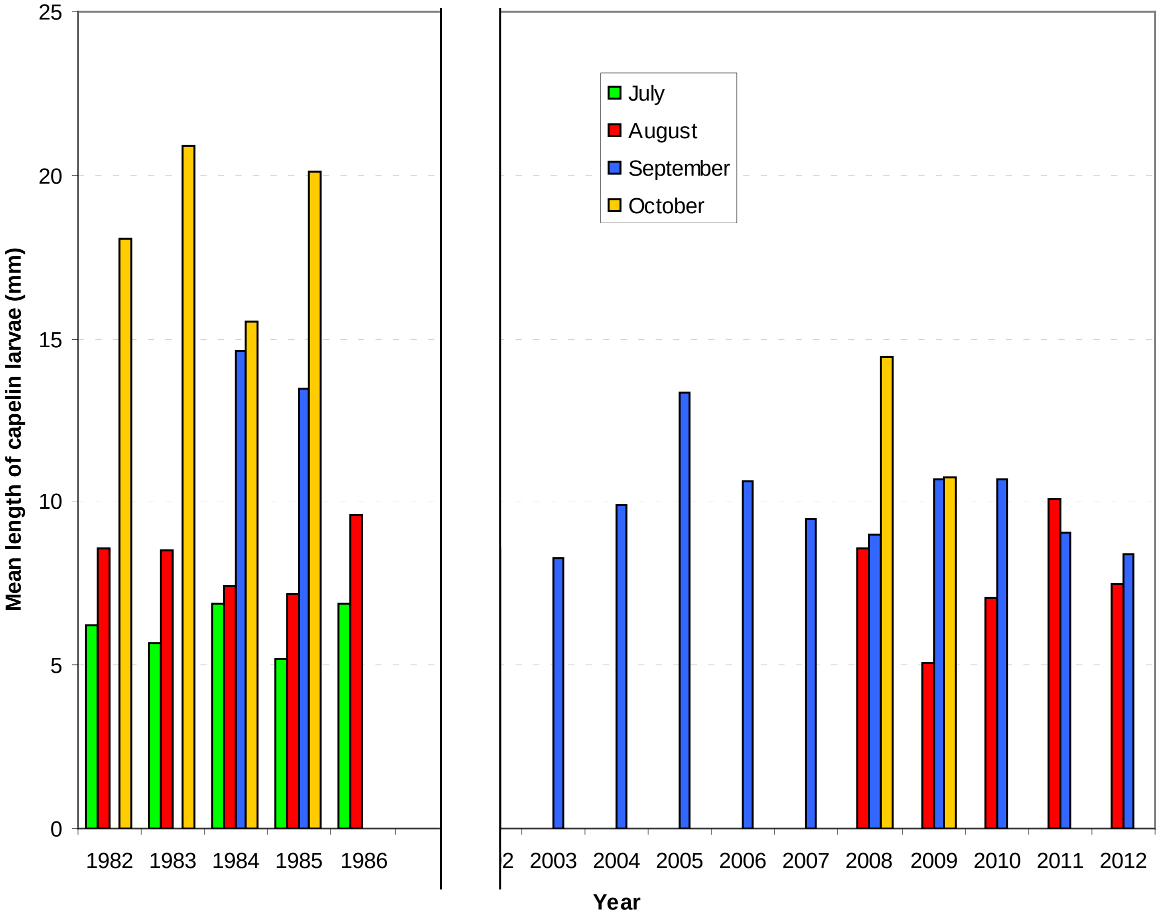


Figure 12. Mean weighted length of larval capelin in each month surveyed. The left panel presents data from Dalley (unpublished) from survey 1982-86. The right panel presents results of the present study.

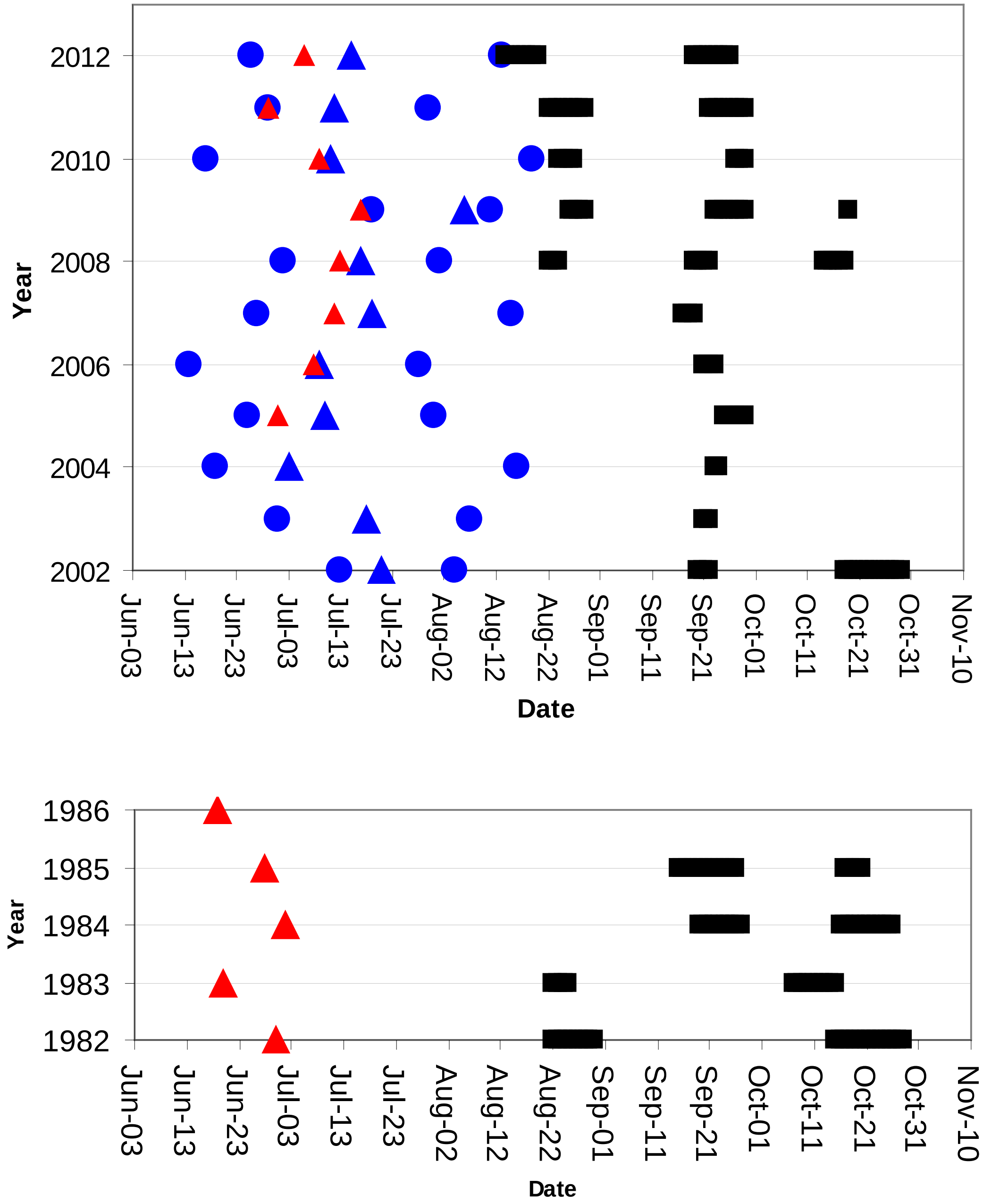


Figure 13. Timing of sampling of larval stations (black squares) in contrast with the time of peak (blue triangles), first and last (blue circles) spawning at Bellevue Beach, Trinity Bay. Also presented are peak spawning times at Bryant's Cove in Conception Bay (red triangles).

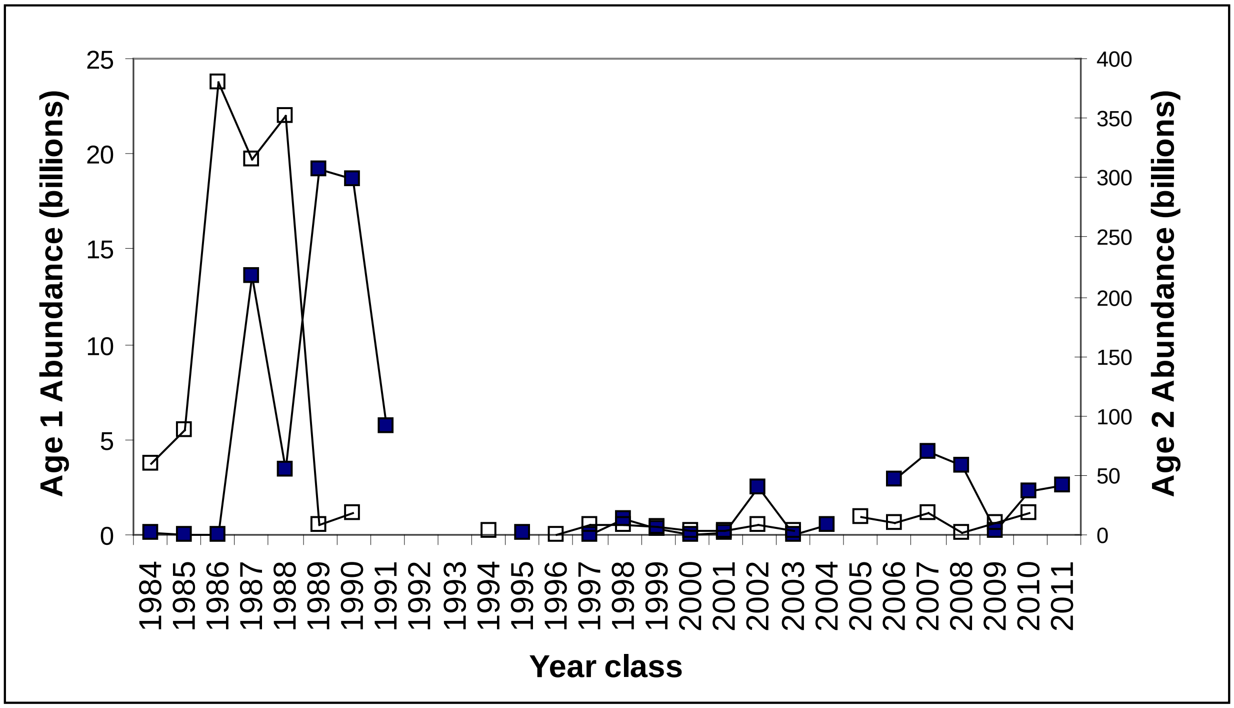


Figure 14. Acoustic index of abundance for age 1 (solid squares) and age 2 capelin (empty squares) recruited to May 3L acoustic surveys conducted between 1985 and 2012.

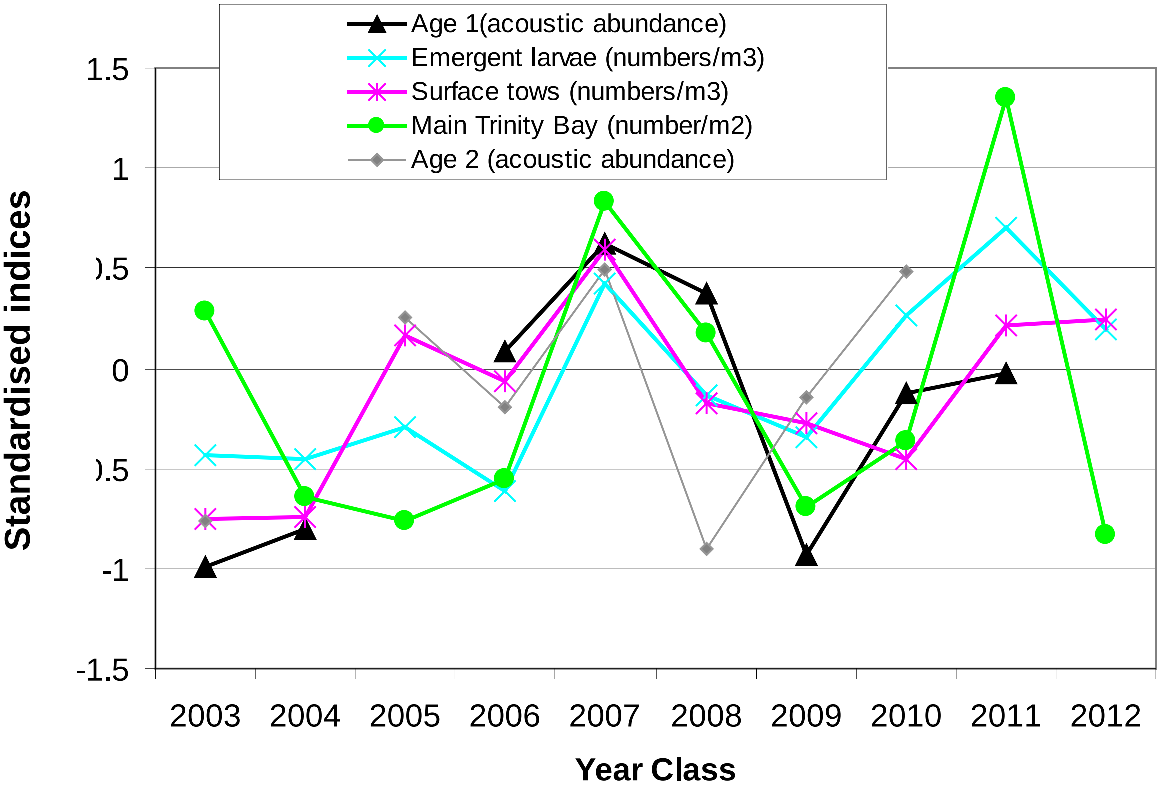


Figure 15. Capelin recruitment indices for emerging larvae from Bellevue Beach, larvae in surface tows off Bellevue Beach, 0-group from Trinity Bay, and spring acoustic abundance estimates for age 1's and age 2's for the 2003-12 year classes. Each index was standardized to the mean of the 2004-11values.