West coast of Newfoundland capelin (*Mallotus villosus* M.) and Atlantic herring (*Clupea harengus harengus* L.) larval survey, part 10: Abundance estimates and marine community analyses of the data collected in partnership with the industry (Barry Group) in July 2009 and comparison with previous surveys

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WEST COAST OF NEWFOUNDLAND CAPELIN (*Mallotus villosus* M.) AND ATLANTIC HERRING (*Clupea harengus harengus* L.) LARVAL SURVEY, PART 10: ABUNDANCE ESTIMATES AND MARINE COMMUNITY ANALYSES OF THE DATA COLLECTED IN PARTNERSHIP WITH THE INDUSTRY (BARRY GROUP) IN JULY 2009 AND COMPARISON WITH PREVIOUS SURVEYS

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ABSTRACT

Grégoire, F., Barry, W., Barry, J.-J., Barry, J., Beaulieu, J.-L., and Gendron, M.-H. 2013. West coast of Newfoundland capelin (*Mallotus villosus* M.) and Atlantic herring (*Clupea harengus harengus* L.) larval survey, part 10: Abundance estimates and marine community analyses of the data collected in partnership with the industry (Barry Group) in July 2009 and comparison with previous surveys. Can. Tech. Rep. Fish. Aquat. Sci. 3062: x + 58 pp.

In partnership with the Barry Group in Corner Brook, four larval surveys were conducted on the west coast of Newfoundland between 2004 and 2008. A last survey was conducted in July 2009 to, once again, measure and describe the spatial distribution of the eggs and larvae of the main fish species sampled. During the survey, eggs were most abundant in the CYT group (cunner [*Tautogolabrus adspersus*] and yellowtail flounder [*Limanda ferruginea*]), followed by the CHW group (Atlantic Cod [*Gadus morhua*], haddock [*Melanogrammus aeglefinus*], and witch flounder [*Glyptocephalus cynoglossus*]), Atlantic mackerel (*Scomber scombrus*) eggs, and eggs from the H4B group (hake [*Urophycis* spp.], fourbeard rockling [*Enchelyopus cimbrius*], and American butterfish [*Peprilus triacanthus*]). Among the larvae collected, the most abundant species were cunner, capelin (*Mallotus villosus*), yellowtail flounder, witch flounder, Atlantic mackerel, and Atlantic herring (*Clupea harengus*). Generalized additive models (GAM) have shown that the abundance of eggs and larvae of the main species sampled could be described using smoothing functions based on water temperature, the interaction between longitude and latitude, and—for the larvae of some species—their egg abundance. From abundance data of the larvae sampled, cluster and ordination analyses revealed the presence of a spatial structure within the larval community. In 2009, this community was mainly characterized by the presence and abundance of cunner and yellowtail flounder.

RÉSUMÉ

Grégoire, F., Barry, W., Barry, J.-J., Barry, J., Beaulieu, J.-L., et Gendron, M.-H. 2013. West coast of Newfoundland capelin (*Mallotus villosus* M.) and Atlantic herring (*Clupea harengus harengus* L.) larval survey, part 10: Abundance estimates and marine community analyses of the data collected in partnership with the industry (Barry Group) in July 2009 and comparison with previous surveys. Can. Tech. Rep. Fish. Aquat. Sci. 3062: x + 58 pp.

En partenariat avec le Groupe Barry de Corner Brook, quatre relevés larvaires ont été réalisés sur la côte ouest de Terre-Neuve entre 2004 et 2008. Un dernier relevé a été réalisé en juillet 2009 pour, une fois de plus, mesurer l'abondance et décrire la distribution spatiale des œufs et des larves des principales espèces de poissons échantillonnées. Lors du relevé, les œufs les plus abondants ont été ceux du groupe CYT (tanche-tautogue [*Tautogolabrus adspersus*] et limande à queue jaune [*Limanda ferruginea*]) suivi du groupe CHW (morue franche [*Gadus morhua*], aiglefin [*Melanogrammus aeglefinus*] et plie grise [*Glyptocephalus cynoglossus*]), des œufs de maquereau bleu (*Scomber scombrus*) et du groupe H4B (merluches [*Urophycis* spp.], motelle à quatre barbillons [*Enchelyopus cimbrius*] et stromatée à fossette [*Peprilus triacanthus*]). Parmi les larves récoltées, les espèces les plus abondantes ont été la tanche-tautogue, le capelan (*Mallotus villosus*), la limande à queue jaune, la plie grise, le maquereau bleu et le hareng de l'Atlantique (*Clupea harengus harengus*). Des modèles additifs généralisés (GAM) ont démontré que l'abondance des œufs et des larves des principales espèces échantillonnées pouvait être décrite à l'aide de fonctions de lissage basées sur la température de l'eau, l'interaction entre la longitude et la latitude et pour certaines espèces de larves, de l'abondance de leurs œufs. À partir des données d'abondance de toutes les larves échantillonnées, des analyses de groupement et d'ordination ont démontré la présence d'une structure spatiale au sein de la communauté larvaire. En 2009, cette dernière était principalement caractérisée par la présence et l'abondance de la tanche-tautogue et de la limande à queue jaune.

1. INTRODUCTION

In the absence of an acoustic survey for capelin (*Mallotus villosus*) and following the end of the west coast of Newfoundland herring (*Clupea harengus harengus*) survey in 2003, a series of larval surveys was initiated in 2004 to study the larval distribution and abundance of these two commercially important species (Grégoire *et al*. 2005). Despite their economic value, very little is known about the ecology and the role of these two species in the ecosystem. In fact, some of the bays surveyed in 2004 were sampled for the first time. The larval survey was also conducted in 2005, 2007, and 2008; in each case, eggs and larvae of several species were sampled (Grégoire *et al*. 2006a, 2008, 2011a). Considering these results, it was decided to apply the initial objective to all these species. From the data of these species, biodiversity was also investigated. Results showed that the larval community structure at the time of the surveys was characterized by a large number of scarce species and by more abundant commercial species concentrated in specific locations (Grégoire *et al*. 2006b, 2009, 2011b, 2011c). Compared to the 2007 survey, and omitting St. George's Bay, the 2008 survey was characterized by a larger number of Atlantic mackerel (*Scomber scombrus* L.) eggs and capelin and Atlantic herring larvae and by a decrease in cod (*Gadus morhua*) and righteye flounder (Pleuronectidae) larvae.

A fifth and final larval survey was conducted on the west coast of Newfoundland in July 2009 (Grégoire *et al*. 2012). As in 2007 and 2008, this survey's study area extended to St. George's Bay. The two most abundant egg groups were CYT (cunner [*Tautogolabrus adspersus*] and yellowtail flounder [*Limanda ferruginea*]) and CHW (cod, haddock [*Melanogrammus aeglefinus*], and witch flounder [*Glyptocephalus cynoglossus*]). In addition, Atlantic mackerel eggs were collected at all stations. Of the 17 larva species identified, the most abundant were cunner and capelin, followed by yellowtail flounder, witch flounder, Atlantic mackerel, and Atlantic herring.

The spatial distribution and abundance of the eggs and larvae sampled in 2009 as well as biodiversity measurements are presented in this document. These results are also compared with those from the previous surveys.

2. MATERIAL AND METHODS

2.1 Study area and sampling procedures

The survey was conducted between 15 and 18 July 2009 aboard the *Ocean Leader*. The study area, located near the coast, extended from south of Bonne Bay to St. George's Bay (Figure 1). Despite poor weather condition, 39 of the 46 stations initially selected were sampled with two bongo nets (Posgay and Marak 1980) with a diameter of 61 cm and a mesh size of 333 microns. Two General Oceanics flowmeters were fixed near the net openings to measure the volume of water filtered. The tows followed a saw-tooth pattern (Hempel 1973) between the surface and a maximum depth of 50 m, or within 5 m of the bottom for shallower stations. A CTD probe (Sea-Bird Electronics Inc., model SBE-19) was used to obtain temperature and salinity profiles. Samples from one of the nets were preserved in a formaldehyde solution (4–5%) (Hunter 1985) while the other was preserved in an ethanol solution (95%).

2.2 Laboratory analyses

The criteria used for identifying fish eggs or egg groups of species with similar characteristics of identification were taken from Fritzsche (1978), Elliott and Jimenez (1981) and Fahay (2007a, 2007b); Girard (2000) was consulted for the description of the development stages of Atlantic mackerel eggs. Egg and larva counts presented in Grégoire *et al*. (2012) were updated and standardized for volumes of 1,000 m^3 of water. Mean egg and larva abundances were estimated and compared with the results of the previous surveys.

2.3 Geostatistical abundance

Mean egg and larva abundances (n/1,000 m^3) were also estimated by ordinary kriging (Isaaks and Srivastava 1989). The geostatistical software GS^+ (version 5.3.2, Gamma Design Software, Plainwell, Michigan, USA) was used to choose the variogram, calculate the semivariance, and create the kriging maps (Robertson 1998). The choice of the final variogram model was based on the coefficient of determination and the residual sum of squares (Robertson 1998). The geostatistical software EVA II (version 2.0, Office de la recherche scientifique et technique outre-mer, Paris, France) was used to calculate the kriging means and variances (Petitgas and Lafont 1997). A correction was applied to these calculations when extreme abundance data were excluded during the variogram development. However, these data were included in the abundance estimations and kriging maps.

2.4 Temperature and abundance

The egg and larva abundance data (n/1,000 m^3) were analyzed according to water temperature (°C) (average of upper 10 m) based on an approach similar to that proposed by Perry and Smith (1994) to visually test the association between fish distribution and habitat conditions. This approach was used to describe the thermal preferences of the main species sampled.

2.5 Generalized additive models (GAM)

Different generalized additive models (GAM) (Hastie and Tibshirani 1990) were used to investigate and describe potential relationships between egg and larva abundances of the main species sampled and the following independent variables: (1) longitude (decimal degrees, expressed as negative values), (2) latitude (decimal degrees), (3) longitude and latitude interaction, (4) abundance of a species' larvae if the eggs of the same species were also sampled, and (5) average water temperature (°C) in the first 10 m.

For a given model, the choice of variables and smoothing functions to be used was based on the values of the *p* statistic compared to the 5% significance level. The *mgcv* library (Wood 2006, 2008) was chosen to test different GAMs models. This library uses the generalized cross-validation (GCV) method as amended by Wood (2006) to automatically determine the degree of smoothing applied to each independent variable. GCV and the Akaike information criterion (AIC) were used to compare the different models. Model quality was determined according to the corresponding values of the coefficient of determination (r^2) and the deviance (%). The latter is defined as the percentage of the sum of squares that is explained by the model (Zuur *et al*. 2007).

In R language (version 2.8.1) (R Development Core Team 2009), the first model studied had the following form:

Model_1 = gam (log(Abundance)) ~ s(Longitude, bs="ts") + s(Latitude, bs="ts") + s(Temperature, bs="ts"), family=gaussian())

where:

s means that the smoothing choice was based on "*spline*," bs="ts" represents the type of smoothing used (*thin plate regression spline smoothers*), and family=gaussian because the chosen function used to describe the distribution of the dependent variable is of normal type.

2.6 Accumulation (ACCUM) and dominance (DOMINANCE) plots

The ACCUM procedure from the Primer software (version 6.1.6, PRIMER-E, Roborough, Plymouth, UK) (Clarke and Gorley 2006) was used to determine whether a sufficient number of stations were sampled during the survey. This procedure was applied on larva abundance data to predict, with the use of three types of permutations (bootstrap, UGE, and MM) (Colwell and Coddington 1994), the total number of species observed if a very large number of stations had been sampled in the study area. The results from this approach were compared to the actual number of species observed.

The abundance and dominance of the larval species were examined using the DOMINANCE procedure (Clarke and Gorley 2006). For each station, the larvae were listed in decreasing order of abundance. Their cumulative relative abundance (i.e., the percentage of total abundance at a sampled station) was transferred to a graph based on the rank (x axis) expressed on a logarithmic scale. Lower curves (stations) show lower dominance and a greater diversity of species.

2.7 Biodiversity measures (DIVERSE, DRAFTSMAN, PCA, and MDS)

The structure of the larval community was described based on the total number of species (S) and larvae (N) and the following diversity indices: (1) Shannon (Legendre and Legendre 1998), (2) Brillouin (Brillouin 1956), (3) Fisher (Fisher *et al*. 1943), and (4) Margalef (Margalef 1951). These indices help measure different attributes of the larval community (Clarke and Warwick 2001). They were calculated and compared by pairings using the DIVERSE and DRAFTSMAN procedures (Clarke and Gorley 2006).

The relative distances between the diversity indices were measured using non-metric multidimensional scaling (MDS procedure; Clarke and Gorley 2006) applied to the correlation matrix (absolute values x 100). The relative significance of each index was calculated using a principal component analysis (PCA procedure; Clarke and Gorley 2006) applied to the standardized values to account for the scaling differences.

2.8 Marine community analyses

2.8.1 Similarity coefficient (RESEMBLANCE)

The Bray-Curtis (S_{jk}) similarity index was calculated for all possible station pairings using the

RESEMBLANCE procedure (Clarke and Gorley 2006). This index is defined as follows:

$$S_{jk} = 100\left\{1 - \frac{\sum_{i=1}^{p}\left|y_{ij} - y_{ik}\right|}{\sum_{i=1}^{p}(y_{ij} + y_{ik})}\right\}$$

where:

y_{ij} represents the abundance (n/1,000 m^3) of species *i* at station *j* (*i*=1,2,…, p; *j*=1,2,…, n) and y_{ik} is the abundance of species *i* at station *k*. As suggested by Clarke and Gorley (2006), the y_{ij} values were first standardized by dividing the abundance of a species at a given station by the sum of abundances of all species at that same station.

2.8.2 Hierarchical clustering (SIMPROF and CLUSTER)

The occurrence of a structure within the larval community (larval assemblage) was tested using permutations (SIMPROF procedure; Clarke and Gorley 2006). Groups of stations were defined using the Bray-Curtis similarity matrix through hierarchical cluster analyses (CLUSTER procedure) (Clarke and Gorley 2006) according to average association (UPGMA) (Legendre and Legendre 1998). The significance of these groups considered *a priori* as non-structured was tested using SIMPROF.

2.8.3 Species contribution (SIMPER)

The significance of each larval species present in the groups defined by cluster analysis and by SIMPROF was calculated using the SIMPER procedure (Clarke and Gorley 2006). This procedure calculates the contribution of each species in a group to the similarity of the group on the condition that the latter contains at least two samples.

2.8.4 Non-metric multidimensional scaling (MDS)

Clarke and Warwick (2001) suggested that ordination be applied in reduced space to the data that were previously used in a cluster analysis. Ordination in reduced space is also used in the presence of a regular gradient in an ecological community structure (McGarigal *et al*. 2000). According to Everitt (1978), non-parametric multidimensional scaling represents the best ordination technique for describing in a small number of dimensions the complex relationships that may exist between members of an ecological community. Non-parametric multidimensional scaling was applied to the similarity matrix using the MDS procedure (Clarke and Gorley 2006).

The abundance of species that have contributed the most to the similarity of station groupings defined by the CLUSTER and SIMPROF procedures was superimposed on the MDS procedure results.

2.8.5 Similarity analyses between the 2007, 2008, and 2009 assemblages (ANOSIM and SIMPER)

A similarity analysis (the ANOSIM procedure) was used to compare the larval communities described in 2007, 2008, and 2009 (Clarke and Gorley 2006). Where there was a significant difference, the SIMPER procedure was used to identify the species responsible.

3. RESULTS

3.1 Stations and sampling characteristics

In 2009, the first stations to be sampled were the Bay of Islands stations and the stations south of Bonne Bay (Figure 2), followed by those located in Port au Port Bay and St. George's Bay. The last ones were those located between Port au Port Bay and the Bay of Islands. Technical problems with the CTD probe occurred at stations 9, 13, and 20. Nets were damaged at one station (2), and seven stations (6, 10, 23, 35, 40, 45, and 46) were not sampled because of poor weather condition. On the 46 initially selected stations, plankton samples were sorted for 38 stations. Stations were sampled during the day at depths between 9 m and 65 m (Table 1). The volume of water filtered ranged between 127 m^3 and 384 m^3, averaging at 270.1 m^3. The average tow duration was 11:32 minutes.

3.2 Egg distribution and abundance

Atlantic mackerel eggs and eggs from the CHW and CYT groups were found at 38, 36, and 36 of the 38 sampled stations, respectively, compared to 30 stations for the H4B group (hake [*Urophycis* spp.], fourbeard rockling [*Enchelyopus cimbrius*], and American butterfish [*Peprilus triacanthus*]) (Table 2). Windowpane flounder (*Scophthalmus aquosus*) and American plaice (*Hippoglossoides platessoides*) were found at only 18 and 13 stations, respectively.

The CYT group was the most abundant, with an (arithmetic) average of 6,142.4 eggs/1,000 m^3 (Table 3). It was followed by the CHW group, Atlantic mackerel, and the H4B group, with respective averages of 405.0, 376.7, and 146.7 eggs/1,000 m^3. An average of 69.4 eggs/1,000 m^3 was calculated for windowpane flounder and 3.1 eggs/1,000 m^3 for American plaice.

Eggs from the CYT group were found in very large numbers except at the stations located off Bay of Islands (Figure 3). Eggs from the CHW group were abundant at almost all stations compared to eggs from the H4B group, which were abundant only at the stations located between Port au Port Bay and St. George’s Bay. Atlantic mackerel eggs were found in higher abundance in Port au Port Bay and in St. George's Bay. Windowpane flounder eggs were primarily found at the stations located between Port au Port Bay and St. George’s Bay, while American plaice eggs were found mostly at the stations located between Bonne Bay and Bay of Islands.

3.3 Larval distribution and abundance

During the survey, 17 species or groups of species were sampled (Table 4). The most frequently found larvae—at more than 25 stations—were cunner, yellowtail flounder, Atlantic herring, witch flounder, Atlantic mackerel, and capelin, followed by snailfishes (*Liparis* spp.), Atlantic cod, fourbeard rockling, and radiated shanny (*Ulvaria subbifurcata*) (found at 24, 22, 21, and 21 stations). Other species were found at 15 stations or fewer.

The most abundant species were cunner and capelin, with respective averages of 378.6 and 70.2 larvae/1,000 m^3, followed by yellowtail flounder, witch flounder, Atlantic mackerel, and Atlantic herring with 51.1, 42.7, 32.4, and 19.4 larvae/1,000 m^3 (Table 5). Abundances ranging between 0.2 and 9.4 larvae/1,000 m^3 were measured for the other species. For cunner, the highest abundances were measured at some stations located off Bay of Islands, Port au Port Bay, and St. George's Bay, and for capelin, at a few stations located in Bay of Islands and St. George's Bay and off Port au Port Bay (Figure 4). For yellowtail flounder, the highest abundances were measured at a few stations located off Bay of Islands and at two stations in St. George's Bay while witch flounder larvae were most abundant in St. George's Bay. Atlantic mackerel and Atlantic herring larvae were evenly distributed over the sampling area unlike the other species that were found at some stations only.

3.4 Egg and larval abundances in 2004, 2005, 2007, 2008, and 2009

Among the commercial species, only cod larvae showed an increase in abundance between 2008 and 2009 for St. George's Bay (Wilcoxon two-sample test, p=0.009) and the other bays (Wilcoxon two-sample test, p=0.05) (Appendix 1). Abundance values of Atlantic mackerel eggs and capelin larvae peaked in 2008, Atlantic mackerel larvae in 2007, Atlantic herring in 2004, Atlantic cod in 2004 and 2005, and righteye flounder in 2007. Except for St. George's Bay, a decrease in abundance was measured in the other bays between 2008 and 2009 for the CYT group (Wilcoxon two-sample test, p=0.02) compared to an increase for American plaice (Wilcoxon two-sample test, p=0.04) and windowpane flounder eggs (Wilcoxon two-sample test, p=0.02) (Appendix 2). For that last species, an increase was also observed in St. George's Bay (Wilcoxon two-sample test, p=0.02).

An increase in abundance was observed between 2008 and 2009 for the larvae of American plaice (except for St. George's Bay) (Wilcoxon two-sample test, p=0.003), witch flounder (Wilcoxon two-sample test, p=0.004 for St. George's Bay and p=0.01 for the other bays), and yellowtail flounder (Wilcoxon two-sample test, p=0.003 for St. George's Bay and p<0.0001 for the other bays) (Appendix 3). For St. George's Bay, there was a decrease for arctic shanny (*Stichaeus punctatus*) larvae (Wilcoxon two-sample test, p=0.03) between 2008 and 2009. For the other bays, a decrease was also observed for fourbeard rockling (Wilcoxon two-sample test, p=0.003) and radiated shanny (Wilcoxon two-sample test, p=0.0002), and no change for cunner, redfish (*Sebastes* spp.), sandlance (*Ammodytes* spp.), snailfish, windowpane flounder, and winter flounder (*Pseudopleuronectes americanus*).

3.5 Eggs and larval abundances in 2009 derived from geostatistics

The spatial variations of eggs, egg groups, and larval abundances were described using a spherical variogram (Table 6). For all of these models, r^2 ranged between 0.74 and 1, and no anisometry was recorded. It was not possible to define a model for winter flounder larvae, and model results for righteye flounder should be interpreted with caution because this species was found at one station only.

Kriged maps for eggs and egg groups (Figure 5) and for larvae (Figure 6) give a better illustration of the abundance variations presented in Figures 3 and 4. The average abundances calculated by kriging (Table 7) were similar to the arithmetic averages (Tables 3 and 5). However, kriging reduced the variance estimates. Egg abundances of the CYT and CHW groups and Atlantic mackerel were estimated at 4,505.5, 406.5, and 367.5 eggs/1,000 m^3, and for H4B group, windowpane flounder, and American plaice at 219.4, 107.7, and 3.0 eggs/1,000 m^3 (Table 7 and Figure 7A). The abundance of cunner, capelin, yellowtail flounder, witch flounder, Atlantic mackerel, and Atlantic herring were estimated at 262.9, 81.2, 56.1, 44.4, 34.4, and 20.1 larvae/1,000 m^3 compared to abundances of fewer than 10 larvae/1,000 m^3 for the other species (Table 7; Figures 7B and 7C).

3.6 Temperature and abundance

At the time of the survey, thermal preferences of eggs and egg groups showed few interspecific variations except for eggs of American plaice and windowpane flounder, which were associated with colder water (Figure 8A). Larvae of American plaice, arctic shanny, capelin, and snailfish were found in colder water (Figures 8B and 8C). Redfish, windowpane flounder, and witch flounder larvae were associated with warmer water. CTD profiles and mean water temperature by depth interval are presented in Grégoire *et al*. (2012).

3.7 Generalized additive models (GAM)

Significant p statistics (<0.01) were found for the eggs of three species and the larvae of nine species (Table 8). The lowest r^2 and deviance values were calculated for American plaice eggs (0.17 and 21%) and Atlantic cod larvae (0.33 and 38%). The highest values were measured for windowpane flounder eggs (1.00 and 100%), arctic shanny larvae (0.96 and 99%), and Atlantic mackerel eggs (0.93 and 99%). A GAM model was also defined for righteye flounder larvae (0.92 and 98%), even though this species was found at one station only.

The smoothing function for American plaice egg abundance is defined by water temperature and the function for Atlantic mackerel and windowpane flounder egg abundances by the interaction between longitude and latitude (Table 8). In the first case, the smoothing function is characterized by an opposite and almost linear relationship between water temperature and egg abundance (Figure 9A). For Atlantic mackerel and windowpane flounder, the highest abundance values, predicted by the smoothing functions, are found for the longitudes and latitudes associated with the southwestern part of the study area (Figures 9B and 9C). The interaction between longitude and latitude also has an influence on arctic shanny and Atlantic mackerel larva abundances (Table 8). For arctic shanny, the highest larva abundances were found for the longitudes and latitudes associated with the northeastern part of the study area compared to Bay of Islands and St. George’s Bay for Atlantic mackerel larvae (Figures 10A and 10B). The smoothing functions for capelin and Atlantic cod larvae are associated with water temperature and the egg abundance of the CHW group, respectively (Table 8). For capelin, larva abundance increases rapidly between 13.0 and 13.2°C, decreases at the same rate up to 14.0°C, and remains relatively stable thereafter (Figure 10C). However, the first part of the smoothing function is associated with a small number of observed data. The abundance of cod larvae increases with the CHW egg abundance up to 600 eggs/1,000 m^3 and decreases thereafter (Figure 10D). The smoothing function chosen for the cunner larvae is associated with the CYT egg abundance compared to the longitude and latitude interaction functions for fourbeard rockling, redfish, and righteye flounder (Table 8). Cunner larva abundance increases with an increase of the CYT group abundance from 0 to 20,000 eggs/1,000 m^3 and decreases rapidly thereafter (Figure 11A). However, the second part of this function is associated with one station only. The highest fourbeard rockling, redfish, and righteye flounder larva abundances predicted by their corresponding smoothing functions are found respectively for the longitudes and latitudes associated with Port au Port Bay (Figure 11B), Port au Port Bay and St. George’s Bay (Figure 11C), and Bay of Islands (Figure 11D). Finally, the smoothing function for snailfish is also defined by the interaction between longitude and latitude (Table 8). The highest abundances are associated with the three main bays, i.e., Bay of Islands, Port au Port Bay, and St. George’s Bay (Figure 12).

3.8 Accumulation and dominance plots

The total number of species that should be observed in the study area reaches a plateau at around 30 stations (Figure 13A). Reaching such a plateau means that the larval community was properly sampled during the survey. This survey was also characterized by a large number of stations with low dominance and a wide diversity of species (Figure 13B).

3.9 Biodiversity

The total number of species (S) and the total number of larvae (N) varied greatly among stations (Figures 14A and 14B). The four diversity indices also presented similar values and variations among stations (Figure 14C). The maximum number of species was observed at six stations located in and off Bay of Islands, two stations in Port au Port Bay, and four stations in St. George’s Bay (Figure 15). The maximum number of larvae was observed at four stations off Bay of Islands and Port au Port Bay, and at two stations in St. George’s Bay. The highest values from the four diversity indices were primarily observed at the stations in and off Bay of Islands and in St. George's Bay.

There are strong correlations between the Fisher and Margalef indices and the Brillouin and Shannon indices (Figure 16A). These correlations are marked by the close occurrence of these indices in the reduced space defined by non-parametric multidimensional scaling (Figure 16B). This space is also characterized by a linear gradient with limits associated with the total numbers of species (S) and larvae (N).

The strong correlations measured between the four diversity indices are also marked by the matching vectors defined by the principal component analysis (Figure 16C). The first two components (PC1 and PC2) explain 71% and 24%, respectively, of the total variance. With the exception of the total number of larvae, the contributions (eigenvector) from the other indices to the first component were relatively the same (between 37% and 46%). These contributions are positive for the total number of larvae and negative for the other indices. The total number of larvae and the total number of species contributed most to the second component (72% and 52%, respectively).

3.10 Cluster analysis, ordination, and species contribution

The similarity profile presents a larger amount of high values than what was predicted by the hypothesis of a larval community with no internal structure (Figure 17A). The *Pi* statistic significantly differs ($P<0.001$) from a distribution associated with this hypothesis (Figure 17B).

Five groups of stations were determined using cluster analysis and the SIMPROF procedure (Figure 18A). Cunner contributed 91% of the similarity of group *d* (Figure 19). For the other groups, two species contributed more than 60% of the similarity: (1) group *a*, with 46% and 23%

for snailfish and redfish, (2) group *b*, with 31% and 30% for herring and yellowtail flounder, (3) group *c*, with 46% and 23% for yellowtail flounder and witch flounder, and (4) group *e*, with 41% and 20% for cunner and capelin.

Groups of stations that were defined by cluster analysis occupy different positions in the space defined by non-metric multidimensional scaling (Figure 18B). The species that contributed most to their respective group were identified and their abundance was superimposed on the corresponding stations (Figures 20A to 20G).

The stations belonging to the groups defined by cluster analysis were observed at specific locations. This is the case for group *c* and *e*, with most the stations located at the two ends of the sampled area, i.e., off Bay of Islands and in St. George's Bay (Figure 21). Group *d* stations were mainly concentrated in the southern part of the sampled area. Group *a* was characterized by two stations, one in Port au Port Bay and the other in St. George’s Bay. Finally, group *b* was made up three stations, one off Bay of Islands and the other two in Port au Port Bay.

3.11 Similarity analyses

The ANOSIM procedure indicates that the larval assemblages described in 2007, 2008, and 2009 were statistically different (P<0.0001) (Figure 22A). Cunner, righteye flounder, and Atlantic mackerel contributed respectively 45%, 33%, and 8% of the similarity measured in 2007 compared to 59%, 12%, and 12% for capelin, cunner, and Atlantic herring in 2008 (Figure 22B). Finally, 44%, 16%, and 11% of the similarity measured in 2009 were attributed to cunner, yellowtail flounder, and witch flounder.

4. DISCUSSION

Compared to the survey conducted in 2008 (Grégoire *et al*. 2011a, 2011b) and among the commercial species, a reduction of Atlantic herring and capelin larvae and Atlantic mackerel eggs was recorded in 2009 along with an increase in cod larvae. The abundance of the Atlantic mackerel larvae was about the same. Eggs from the H4B and CYT groups were less abundant as were CHW eggs for St. George’s Bay. There was an increase in windowpane flounder eggs for St. George’s Bay while very few American plaice eggs, i.e., less than 4 eggs/1,000 m^3, were found in the whole survey area. For that species, the highest abundance was measured in 2004. For the other larvae, higher abundances were measured in 2009 for American plaice, witch flounder, and yellowtail flounder.

The larval assemblages described in 2009 were mainly characterized by cunner and yellowtail flounder compared to capelin and cunner in 2008 (Grégoire *et al*. 2011c) and cunner and righteye flounder in 2007 (Grégoire *et al*. 2011b). Cunner and capelin also characterized the assemblages described in 2004 and 2005 (Grégoire *et al*. 2006b, 2009). Cunner is by far the most abundant species in these five surveys. For the time being, there is no information on the cunner abundance in the Gulf of St. Lawrence, and few studies have examined the biological characteristics of this species and its potential as a commercial species.

In addition to the abundance and distribution data, multivariate analyses and generalized additive models demonstrated that the larval community of the area covered by the larval surveys was rich and structured spatially, and that the abundance of some larva species would be related to water temperature or to egg abundance of the same species. An analysis of the otolith microstructure of some larvae collected in 2007 and 2009 is under way and will complete this study, which was initiated at the request of the Barry Group of Corner Brook. Subsequently, data from this series of larval surveys will be archived and available for further analyses.

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Table 1. Description of the stations and sampling of the capelin and Atlantic herring larval survey of July 2009 on the west coast of Newfoundland.

STATION NUMBER	DATE (yyyy/mm/dd)	TIME (hh:mm) (NDT)	LONGITUDE °W (degrees minutes)	LATITUDE °N (degrees minutes)	DEPTH Station bottom (m)	Maximum sampled (m)	TOW DURATION (mm:ss)	VOLUME OF WATER FILTERED (m^3)
1	2009-07-15	11:35	58° 12'	49° 09'	180	50	12:08	264
2*	2009-07-15	12:22	58° 12'	49° 12'	183	65	11:35	---
3	2009-07-15	15:22	58° 12'	49° 27'	41	35	11:58	254
4	2009-07-15	16:32	58° 12'	49° 33'	63	50	18:46	286
5	2009-07-16	7:33	58° 18'	49° 06'	60	45	12:02	291
6**	---	---	58° 18'	49° 11'	---	---	---	---
7	2009-07-15	13:23	58° 18'	49° 15'	78	52	11:15	309
8	2009-07-15	14:13	58° 18'	49° 20'	40	35	11:43	297
9***	2009-07-15	17:53	58° 18'	49° 27'	60	50	11:53	305
10**	---	---	58° 24'	49° 11'	---	---	---	---
11	2009-07-15	20:20	58° 24'	49° 15'	39	34	13:07	352
12	2009-07-15	19:14	58° 24'	49° 20'	47	41	11:58	259
13***	2009-07-18	8:15	58° 30'	49° 03'	47	36	12:01	350
14	2009-07-18	9:49	58° 30'	49° 07'	88	55	9:49	266
15	2009-07-15	21:13	58° 30'	49° 12'	64	50	13:34	183
16	2009-07-16	10:58	58° 36'	48° 51'	44	40	10:39	281
17	2009-07-18	6:49	58° 36'	48° 57'	33	20	11:15	319
18	2009-07-18	7:38	58° 36'	49° 03'	47	33	9:45	266
19	2009-07-18	9:10	58° 36'	49° 07'	63	46	12:44	230
20***	2009-07-16	13:00	58° 42'	48° 39'	36	25	10:58	242
21	2009-07-16	12:09	58° 42'	48° 45'	26	22	10:02	287
22	2009-07-16	18:02	58° 42'	48° 51'	19	9	10:36	287
23**	---	---	58° 42'	48° 57'	---	---	---	---
24	2009-07-16	13:57	58° 48'	48° 36'	26	15	8:36	234
25	2009-07-16	14:56	58° 48'	48° 39'	26	15	8:18	219
26	2009-07-16	15:33	58° 48'	48° 42'	17	10	8:19	238
27	2009-07-16	20:22	58° 48'	48° 48'	26	15	9:54	306
28	2009-07-16	20:46	58° 48'	48° 51'	43	35	10:24	284
29	2009-07-16	16:23	58° 54'	48° 39'	14	9	8:47	255
30	2009-07-17	7:26	58° 54'	48° 45'	29	17	9:39	275
31	2009-07-17	8:45	59° 06'	48° 39'	43	35	11:56	313
32	2009-07-17	10:17	59° 18'	48° 30'	58	50	11:32	127
33	2009-07-17	19:46	59° 06'	48° 28'	67	49	13:58	288
34	2009-07-17	17:52	58° 54'	48° 28'	65	51	12:06	257
35**	---	---	58° 42'	48° 30'	---	---	---	---
36	2009-07-17	16:18	58° 36'	48° 30'	45	35	12:34	316
37	2009-07-17	15:44	58° 36'	48° 27'	89	52	11:54	257
38	2009-07-17	11:22	59° 12'	48° 24'	85	51	13:21	295
39	2009-07-17	18:55	59° 00'	48° 24'	91	56	12:02	182
40**	---	---	58° 48'	48° 24'	---	---	---	---
41	2009-07-17	14:58	58° 42'	48° 24'	45	35	13:14	384
42	2009-07-17	12:20	59° 06'	48° 18'	96	50	12:13	248
43	2009-07-17	13:23	58° 54'	48° 18'	105	50	11:59	236
44	2009-07-17	14:02	58° 48'	48° 18'	43	35	11:25	224
45**	---	---	59° 00'	48° 12'	---	---	---	---
46**	---	---	58° 54'	48° 13'	---	---	---	---
Mean					58.2	37.4	11:32	270.1
Std. Dev.					37.1	15.1	1:52	48.7
Minimum					14	9	8:18	127
Maximum					183	65	18:46	384
n					39	39	39	38

* Nets damaged
** Not sampled (poor weather condition)
*** Malfunction of the CTD probe

Table 2. List of egg taxa from the fish egg and larval survey of July 2009 on the west coast of Newfoundland.

	STATION	**American plaice** (*Hippoglossoides platessoides*)	**Atlantic mackerel** (*Scomber scombrus*)	**CHW**[1]	**CYT**[2]	**H4B**[3]	**Windowpane flounder** (*Scophthalmus aquosus*)	**TOTAL**
	1	X	X	X	X	X	X	6
	3	X	X	X	X		X	5
	4	X	X	X	X	X	X	6
	5		X	X	X	X		4
	7		X	X	X	X	X	5
	8	X	X	X	X	X		5
	9	X	X	X	X	X		5
	11	X	X	X	X		X	5
	12		X	X	X	X		4
	13	X	X	X	X	X		5
	14	X	X	X	X	X		5
	15	X	X	X	X			4
	16	X	X	X	X	X		5
	17		X	X	X		X	4
	18	X	X	X	X	X		5
	19		X	X	X	X		4
	20		X	X	X	X	X	5
	21		X	X	X			3
	22		X	X	X	X	X	5
	24		X	X	X	X	X	5
	25		X	X	X	X		4
	26		X	X		X		3
	27		X	X	X	X	X	5
	28		X	X	X	X		4
	29		X	X	X	X		4
	30		X		X	X	X	4
	31		X	X	X	X	X	5
	32		X	X	X	X	X	5
	33		X	X	X	X		4
	34		X	X	X	X	X	5
	36	X	X	X	X	X		5
	37		X	X	X			3
	38	X	X	X	X	X	X	6
	39		X	X	X	X	X	5
	41		X	X	X			3
	42		X			X	X	3
	43		X	X	X			3
	44		X	X	X	X	X	5
TOTAL	38	13	38	36	36	30	18	

[1]CHW = cod, haddock, and witch flounder

[2]CYT = cunner and yellowtail flounder

[3]H4B = hake, fourbeard rockling, and butterfish

Table 3. Abundance of eggs (number/1,000 m^3) from the samples collected during the fish egg and larval survey of July 2009 on the west coast of Newfoundland.

STATION	American plaice	Atlantic mackerel	CHW (cod, haddock, witch flounder)	CYT (cunner, yellowtail flounder)	H4B (hake, fourbeard rockling, butterfish)	Windowpane flounder
1	8	273	68	6 384	15	19
3	14	382	38	5 339	0	14
4	3	480	156	5 159	19	26
5	0	168	502	685	9	0
7	0	335	394	390	12	4
8	3	77	154	38	3	0
9	10	24	461	84	3	0
11	34	131	910	23	0	3
12	0	33	154	33	7	0
13	8	105	225	1 320	4	0
14	4	85	787	139	4	0
15	4	97	116	12	0	0
16	4	30	511	11	8	0
17	0	110	1 231	791	0	5
18	8	201	542	8 838	10	0
19	0	55	340	374	8	0
20	0	825	445	17 076	60	110
21	0	44	137	5	0	0
22	0	2 345	28	119 718	56	14
24	0	636	238	1 603	3	3
25	0	45	105	60	11	0
26	0	13	1 115	0	9	0
27	0	1 072	947	29 186	42	14
28	0	1 600	9	890	1 951	0
29	0	673	12	186	198	0
30	0	709	0	2 304	1 317	110
31	0	118	13	4 344	943	1 515
32	0	425	419	10 466	193	29
33	0	64	759	434	3	0
34	0	1 406	51	6 928	25	76
36	12	171	716	623	4	0
37	0	38	805	278	0	0
38	7	179	675	91	14	11
39	0	588	66	4 238	4	51
41	0	8	881	71	0	0
42	0	20	0	0	628	628
43	0	186	845	582	0	0
44	0	566	537	4 709	10	6
Mean	3.1	376.7	405.0	6 142.4	146.7	69.4
Std. dev.	6.4	506.7	357.9	19 759.0	405.8	262.1
Minimum	0	8	0	0	0	0
Maximum	34	2 345	1 231	119 718	1 951	1 515
n	38	38	38	38	38	38

Table 4. List of larval taxa from the fish egg and larval survey of July 2009 on the west coast of Newfoundland.

			STATION																		
FAMILY	**SPECIES**	**COMMOM NAME**	**1**	**3**	**4**	**5**	**7**	**8**	**9**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**
Ammodytidae	*Ammodytes* spp.	Sandlance							X							X					
Bothidae	*Scophthalmus aquosus*	Windowpane flounder		X									X				X	X			
Clupeidae	*Clupea harengus*	Atlantic herring	X	X	X		X	X	X	X	X	X	X	X	X	X		X	X	X	
Gadidae	*Gadus morhua*	Atlantic cod			X	X	X			X	X	X	X		X	X		X		X	
Labridae	*Tautogolabrus adspersus*	Cunner	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
Liparidae	*Liparis* spp.	Snailfish		X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	
Osmoridae	*Mallotus villosus*	Capelin	X	X	X	X	X	X	X		X	X	X	X	X	X		X	X		X
Phycidae	*Enchelyopus cimbrius*	Fourbeard rockling			X	X	X						X				X	X			X
Pleuronectidae	*Hippoglossoides platessoides*	American plaice	X		X		X	X												X	
Pleuronectidae	Pleuronectidae	Righteye flounder	X																		
Pleuronectidae	*Pseudopleuronectes americanus*	Winter flounder	X		X		X					X	X				X				
Pleuronectidae	*Glyptocephalus cynoglossus*	Witch flounder			X	X	X	X	X	X	X	X	X	X	X	X		X	X		
Pleuronectidae	*Limanda ferruginea*	Yellowtail flounder	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X
Scombridae	*Scomber scombrus*	Atlantic mackerel	X		X	X	X		X	X		X	X	X	X	X	X	X	X		X
Scorpaenidae	*Sebastes* spp.	Redfish				X				X	X		X	X	X		X		X	X	
Stichaeidae	*Stichaeus punctatus*	Arctic shanny	X	X															X		
Stichaeidae	*Ulvaria subbifurcata*	Radiated shanny			X	X	X	X	X		X	X		X			X	X	X	X	
	TOTAL		**9**	**7**	**12**	**10**	**12**	**8**	**9**	**8**	**9**	**10**	**12**	**9**	**9**	**9**	**8**	**11**	**10**	**6**	**5**

			STATION																			**TOTAL**
FAMILY	**SPECIES**	**COMMOM NAME**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**36**	**37**	**38**	**39**	**41**	**42**	**43**	**44**	
Ammodytidae	*Ammodytes* spp.	Sandlance																				**2**
Bothidae	*Scophthalmus aquosus*	Windowpane flounder				X							X	X			X					**8**
Clupeidae	*Clupea harengus*	Atlantic herring		X	X						X	X	X	X	X	X	X	X		X	X	**28**
Gadidae	*Gadus morhua*	Atlantic cod		X	X						X	X		X	X	X	X	X		X	X	**22**
Labridae	*Tautogolabrus adspersus*	Cunner	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	**37**
Liparidae	*Liparis* spp.	Snailfish		X	X							X		X	X	X		X			X	**24**
Osmoridae	*Mallotus villosus*	Capelin	X		X	X	X		X		X	X	X		X		X		X			**27**
Phycidae	*Enchelyopus cimbrius*	Fourbeard rockling	X			X	X	X	X	X		X		X	X	X	X	X		X	X	**21**
Pleuronectidae	*Hippoglossoides platessoides*	American plaice				X									X							**7**
Pleuronectidae	Pleuronectidae	Righteye flounder																				**1**
Pleuronectidae	*Pseudopleuronectes americanus*	Winter flounder				X					X			X	X						X	**11**
Pleuronectidae	*Glyptocephalus cynoglossus*	Witch flounder	X	X	X	X	X			X	X	X	X	X	X	X				X	X	**28**
Pleuronectidae	*Limanda ferruginea*	Yellowtail flounder	X	X	X	X				X	X	X	X	X	X	X	X			X	X	**32**
Scombridae	*Scomber scombrus*	Atlantic mackerel	X		X	X			X		X	X	X	X	X	X	X			X	X	**28**
Scorpaenidae	*Sebastes* spp.	Redfish		X	X							X			X	X		X				**15**
Stichaeidae	*Stichaeus punctatus*	Arctic shanny																				**3**
Stichaeidae	*Ulvaria subbifurcata*	Radiated shanny	X	X		X	X				X	X					X			X	X	**21**
	TOTAL		**7**	**8**	**9**	**10**	**5**	**2**	**4**	**4**	**9**	**11**	**7**	**10**	**12**	**9**	**9**	**6**	**2**	**8**	**10**	

Table 5. Abundance of larvae (number/1,000 m^3) from the samples collected during the fish egg and larval survey of July 2009 on the west coast of Newfoundland.

STATION	American plaice	Arctic shanny	Atlantic herring	Atlantic mackerel	Capelin	Cod	Cunner	Fourbeard rockling	Radiated shanny	Redfish	Righteye flounder
1	8	8	38	15	49	0	72	0	0	0	8
3	0	3	52	0	45	0	103	0	0	0	0
4	13	0	6	16	62	3	84	3	23	0	0
5	0	0	0	3	274	6	194	11	9	3	0
7	8	0	20	16	910	8	221	12	43	0	0
8	3	0	28	0	14	0	14	0	3	0	0
9	0	0	10	7	91	0	74	0	17	0	0
11	0	0	6	3	0	14	3	0	0	3	0
12	0	0	46	0	7	7	33	0	10	3	0
13	0	0	8	16	16	16	85	0	4	0	0
14	0	0	31	241	22	40	1431	4	0	4	0
15	0	0	19	4	12	0	35	0	4	4	0
16	0	0	26	4	4	11	23	0	0	11	0
17	0	0	44	38	49	5	27	0	0	0	0
18	0	0	0	39	0	0	688	3	3	3	0
19	0	0	8	72	8	25	85	4	4	0	0
20	0	4	7	14	21	0	302	0	4	4	0
21	5	0	82	0	0	11	0	0	5	11	0
22	0	0	0	14	209	0	600	14	0	0	0
24	0	0	0	22	44	0	338	3	41	0	0
25	0	0	26	0	0	19	128	0	4	4	0
26	0	0	74	4	4	4	13	0	0	13	0
27	14	0	0	70	21	0	3676	14	56	0	0
28	0	0	0	0	9	0	145	17	9	0	0
29	0	0	0	0	0	0	29	12	0	0	0
30	0	0	0	18	105	0	1353	59	0	0	0
31	0	0	0	0	0	0	51	8	0	0	0
32	0	0	3	13	3	16	2931	0	20	0	0
33	0	0	17	10	3	20	17	3	3	3	0
34	0	0	13	253	545	0	190	0	0	0	0
36	0	0	74	62	0	4	125	4	0	0	0
37	3	0	10	28	17	35	118	7	0	14	0
38	0	0	11	7	0	42	21	4	0	4	0
39	0	0	51	179	117	4	374	4	4	0	0
41	0	0	8	0	0	8	8	8	0	86	0
42	0	0	0	0	4	0	8	0	0	0	0
43	0	0	4	18	0	15	612	7	25	0	0
44	0	0	16	45	0	45	179	6	6	0	0
Mean	1.4	0.4	19.4	32.4	70.2	9.4	378.6	5.5	7.8	4.5	0.2
Std. dev.	3.5	1.4	22.9	60.9	172.8	12.9	777.3	10.2	13.4	14.2	1.2
Minimum	0	0	0	0	0	0	0	0	0	0	0
Maximum	14	8	82	253	910	45	3 676	59	56	86	8
n	38	38	38	38	38	38	38	38	38	38	38

Table 5. (Continued).

STATION	Sand-lance	Snailfish	Windowpane flounder	Winter flounder	Witch flounder	Yellowtail flounder
1	0	0	0	4	0	4
3	0	10	3	0	0	7
4	0	6	0	3	3	16
5	0	11	0	0	40	26
7	0	16	0	8	59	67
8	0	10	0	0	7	21
9	10	20	0	0	54	84
11	0	11	0	0	6	28
12	0	3	0	0	43	128
13	0	4	0	4	24	32
14	0	9	18	4	45	45
15	0	15	0	0	42	108
16	0	8	0	0	19	30
17	5	11	0	0	27	11
18	0	0	8	16	0	13
19	0	4	4	0	68	81
20	0	11	0	0	57	53
21	0	22	0	0	0	0
22	0	0	0	0	0	14
24	0	0	0	0	75	75
25	0	8	0	0	98	26
26	0	9	0	0	9	44
27	0	0	14	7	7	77
28	0	0	0	0	17	0
29	0	0	0	0	0	0
30	0	0	0	0	0	0
31	0	0	0	0	25	4
32	0	0	0	10	10	29
33	0	7	0	0	108	91
34	0	0	25	0	152	291
36	0	4	16	4	23	58
37	0	3	0	7	389	236
38	0	4	0	0	56	70
39	0	0	4	0	0	47
41	0	24	0	0	0	0
42	0	0	0	0	0	0
43	0	0	0	0	87	47
44	0	54	0	3	70	77
Mean	0.4	7.5	2.4	1.8	42.7	51.1
Std. dev.	1.8	10.3	5.9	3.5	68.3	61.3
Minimum	0	0	0	0	0	0
Maximum	10	54	25	16	389	291
n	38	38	38	38	38	38

Table 6. Parameters of the isotropic variograms used to calculate the abundance estimates of eggs and larvae from the samples collected during the fish egg and larval survey of July 2009 on the west coast of Newfoundland (Note: it was not possible to build a variogram and apply kriging on larval winter flounder data; see text).

SPECIES	MODEL*	Nugget (C_0)	Sill ($C_0 + C$)	Range (A_0)	r^2	RSS: Residual Sum of Square
EGGS						
American plaice	Spherical	0.10	48	16.6	0.94	5.91E+01
Atlantic mackerel	Spherical	100	280000	17.5	0.85	6.59E+09
CHW	Spherical	15800	142000	12.6	0.59	6.50E+08
CYT	Spherical	10000	15730000	16.3	0.77	2.88E+13
H4B	Spherical	100	79590	22.4	0.82	1.18E+09
Windowpane flounder	Spherical	100	94310	33.1	0.89	6.99E+08
LARVAE						
American plaice	Spherical	0.01	6	15.8	0.83	5.89E-01
Arctic shanny	Spherical	0.29	2	26.0	0.82	2.19E-01
Atlantic herring	Spherical	1	677	12.7	0.80	2.07E+04
Atlantic mackerel	Spherical	1	2634	14.6	0.74	1.02E+06
Capelin	Spherical	100	40370	19.9	0.82	4.31E+08
Atlantic cod	Spherical	96	198	62.4	0.90	6.88E+02
Cunner	Spherical	500	247000	14.3	0.82	6.70E+08
Fourbeard rockling	Spherical	0.1	33	20.4	0.88	1.20E+02
Radiated shanny	Spherical	0.1	86	18.9	0.79	1.69E+03
Redfish	Spherical	0.1	228	28.0	0.92	1.94E+03
Righteye flounder	Spherical	0.0	2	33.1	1.00	3.08E-03
Sandlance	Spherical	0.0	1	26.4	0.78	2.12E-01
Snailfish	Spherical	0.1	96	21.3	0.84	1.31E+03
Windowpane flounder	Spherical	0.1	54	24.8	0.77	6.91E+02
Witch flounder	Spherical	1	1617	22.5	0.84	2.73E+05
Yellowtail flounder	Spherical	10	5149	27.7	0.87	1.51E+06

* Spherical model $\gamma(h) = C_0 + C\left[1.5\left(\frac{h}{A_0}\right) - 0.5\left(\frac{h}{A_0}\right)^3\right]$ if $h \le A_0$, and $C_0 + C$ otherwise

Table 7. Abundance estimates (number/1,000 m^3) of eggs and larvae calculated by kriging from the samples collected during the fish egg and larval survey of July 2009 on the west coast of Newfoundland (Note: it was not possible to build a variogram and apply kriging on larval winter flounder data; see text).

	KRIGING			95% CONFIDENCE INTERVAL	
	Average	SE	CV	Lower Limit	Upper Limit
EGGS					
American plaice	3.0	0.80	0.27	1.4	4.5
Atlantic mackerel	367.5	60.71	0.17	248.5	486.5
CHW	406.5	49.41	0.12	309.7	503.4
CYT	4505.5	88.55	0.02	4331.9	4679.0
H4B	219.4	20.34	0.09	179.5	259.3
Windowpane flounder	107.7	28.32	0.26	52.2	163.2
LARVAE					
American plaice	1.0	0.23	0.24	0.5	1.4
Arctic shanny	0.5	0.16	0.34	0.2	0.8
Atlantic herring	20.1	3.27	0.16	13.7	26.5
Atlantic mackerel	34.4	5.00	0.15	24.6	44.2
Capelin	81.2	22.12	0.27	37.9	124.6
Atlantic cod	8.2	1.78	0.22	4.7	11.7
Cunner	262.9	43.31	0.16	178.0	347.8
Fourbeard rockling	6.6	0.31	0.05	6.0	7.2
Radiated shanny	6.3	0.72	0.12	4.9	7.7
Redfish	4.4	1.48	0.34	1.5	7.3
Righteye flounder	0.4	0.12	0.32	0.1	0.6
Sandlance	0.5	0.05	0.09	0.4	0.6
Snailfish	7.3	1.06	0.14	5.2	9.4
Windowpane flounder	2.6	0.75	0.28	1.2	4.1
Witch flounder	44.4	2.31	0.05	39.9	48.9
Yellowtail flounder	56.1	7.07	0.13	42.2	70.0

Table 8. Results of the ANOVA analyses on different generalized additive models applied on the abundance estimates (number/1,000 m^3) of some eggs and larvae collected during the fish egg and larval survey of July 2009 on the west coast of Newfoundland.

SPECIES	MODEL FAMILY	VARIABLE SMOOTHING FUNCTION	d.f.	F	p-value	r^2 (adjusted)	DEVIANCE EXPLAINED (%)
EGGS							
American plaice	Gaussian	s(Temp)	1.32	0.89	0.009	0.17	21
Atlantic mackerel	Gaussian	s(Long, Lat)	27.69	15.63	0.001	0.93	99
Windowpane flounder	Gaussian	s(Long, Lat)	28.79	345.80	0.000	1.00	100
LARVAE							
Arctic shanny	Gaussian	s(Long, Lat)	27.46	29.05	0.000	0.96	99
Atlantic mackerel	Gaussian	s(Long, Lat)	24.58	3.77	0.009	0.74	93
Capelin	Gaussian	s(Temp)	8.49	6.30	0.000	0.60	70
Atlantic cod	Gaussian	s(CHW)	2.40	1.93	0.001	0.33	38
Cunner	Gaussian	s(CYT)	7.36	21.91	0.000	0.85	88
Fourbeard rockling	Gaussian	s(Long, Lat)	26.55	7.78	0.000	0.86	97
Redfish	Gaussian	s(Long, Lat)	26.58	7.59	0.000	0.86	97
Righteye flounder	Gaussian	s(Long, Lat)	25.92	13.08	0.000	0.92	98
Snailfish	Gaussian	s(Long, Lat)	26.51	8.76	0.000	0.88	97

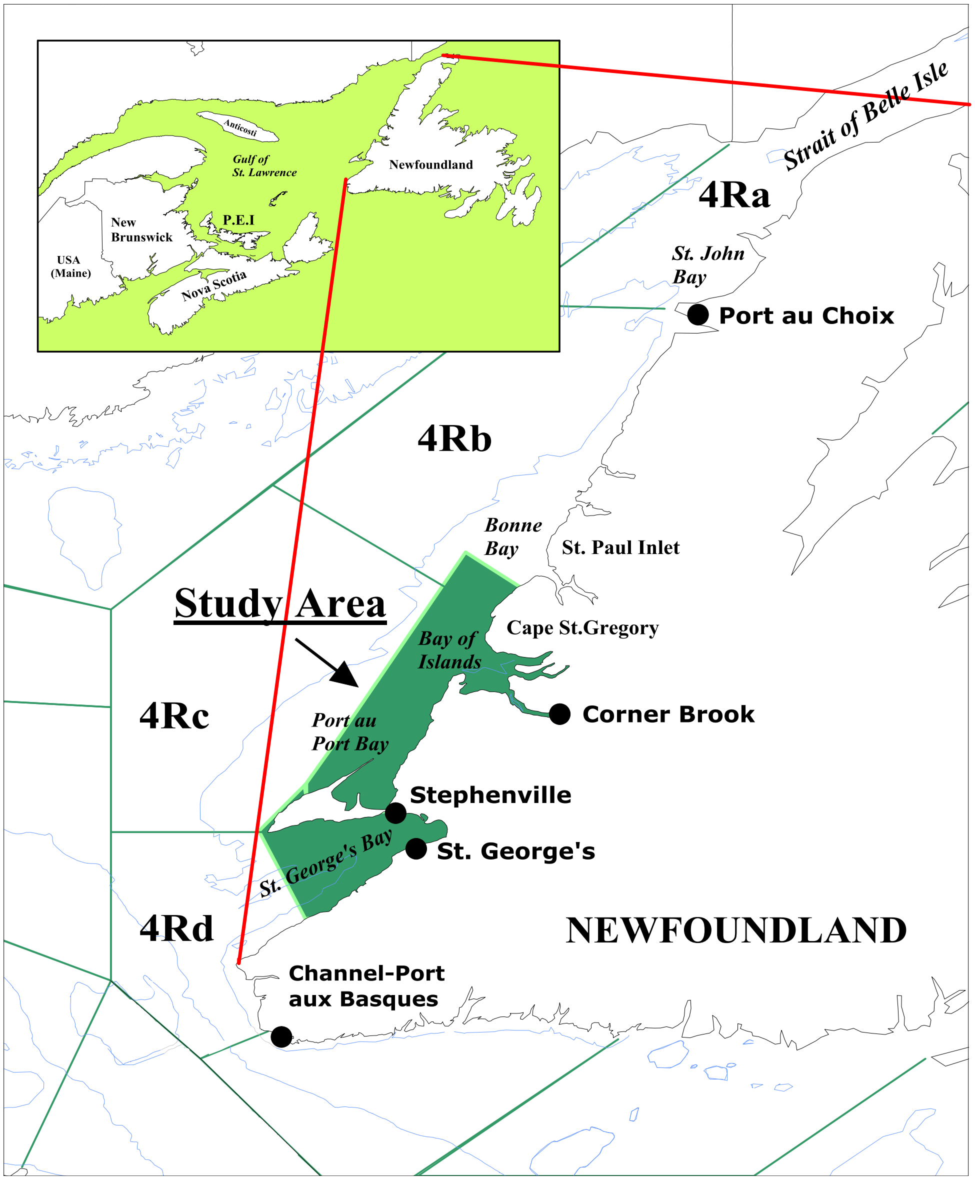


Figure 1. Map of the west coast of Newfoundland showing the study area and the other locations mentioned in the document.

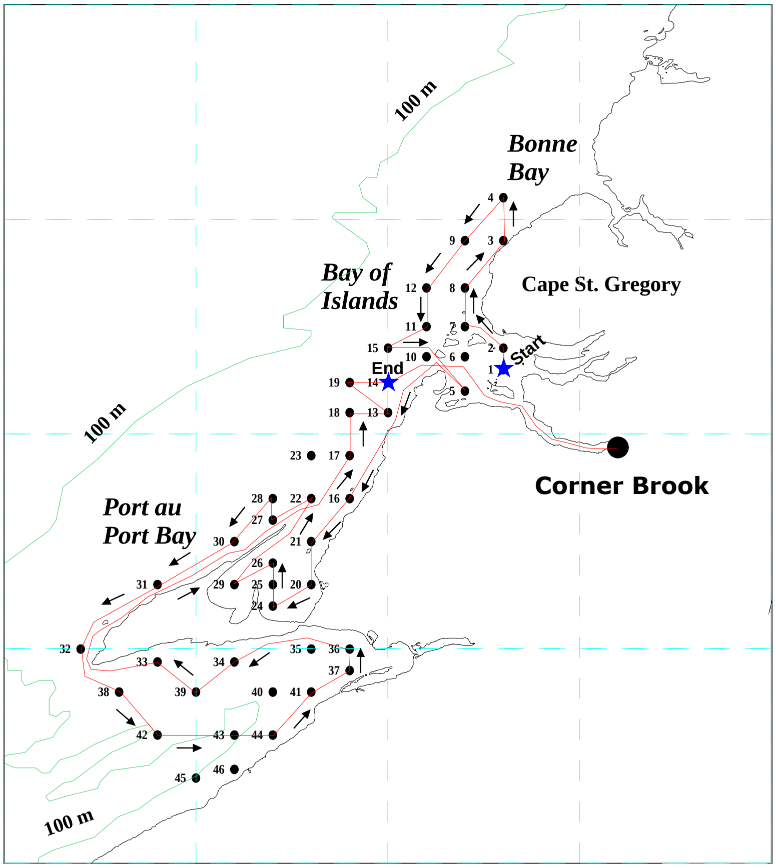


Figure 2. Map of the 39-station sampling grid of the capelin and Atlantic herring larval survey of July 2009 on the west coast of Newfoundland.

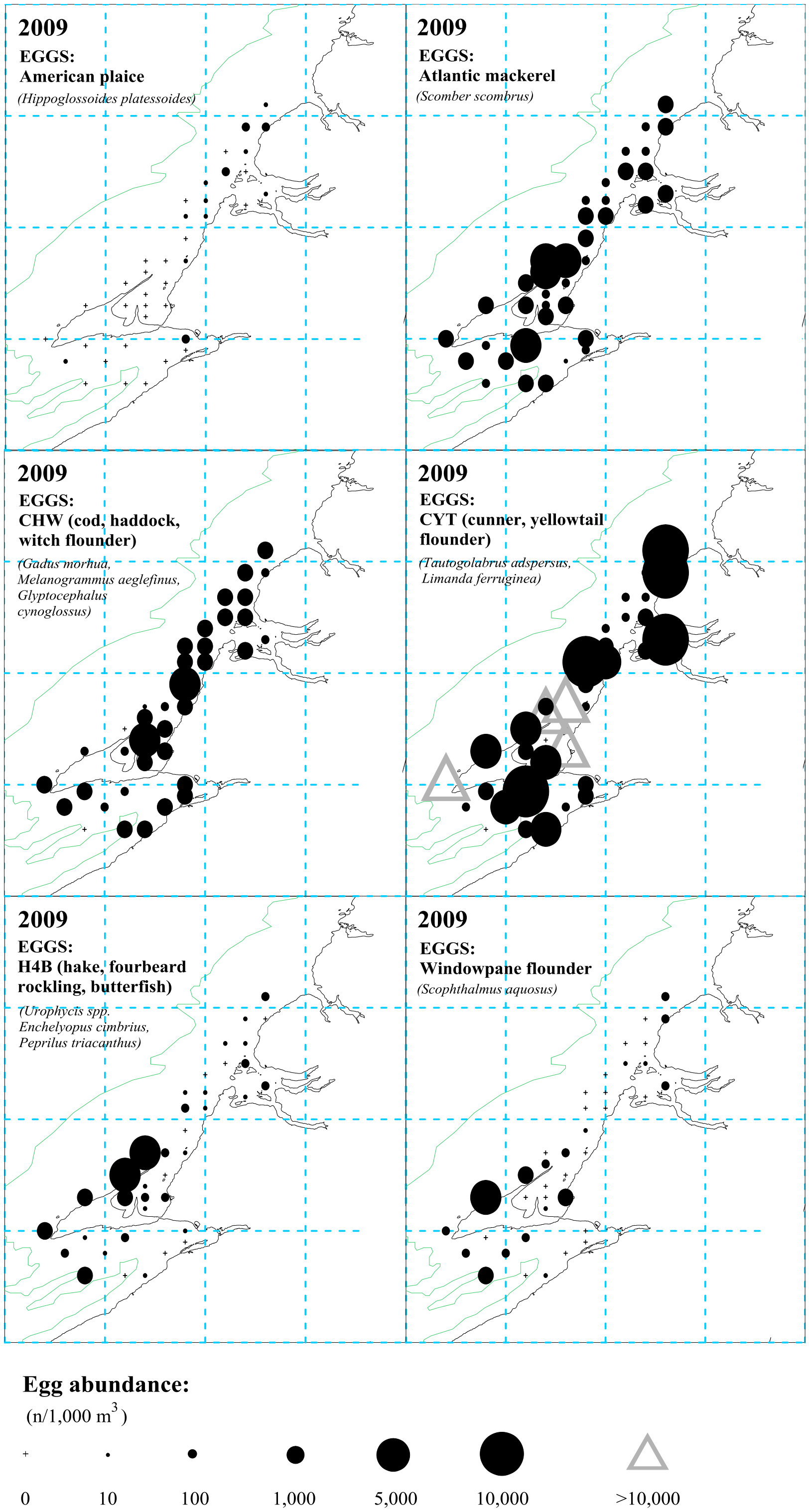


Figure 3. Maps of egg abundance (number/1,000 m^3) distributions from the capelin and Atlantic herring larval survey of July 2009 on the west coast of Newfoundland.

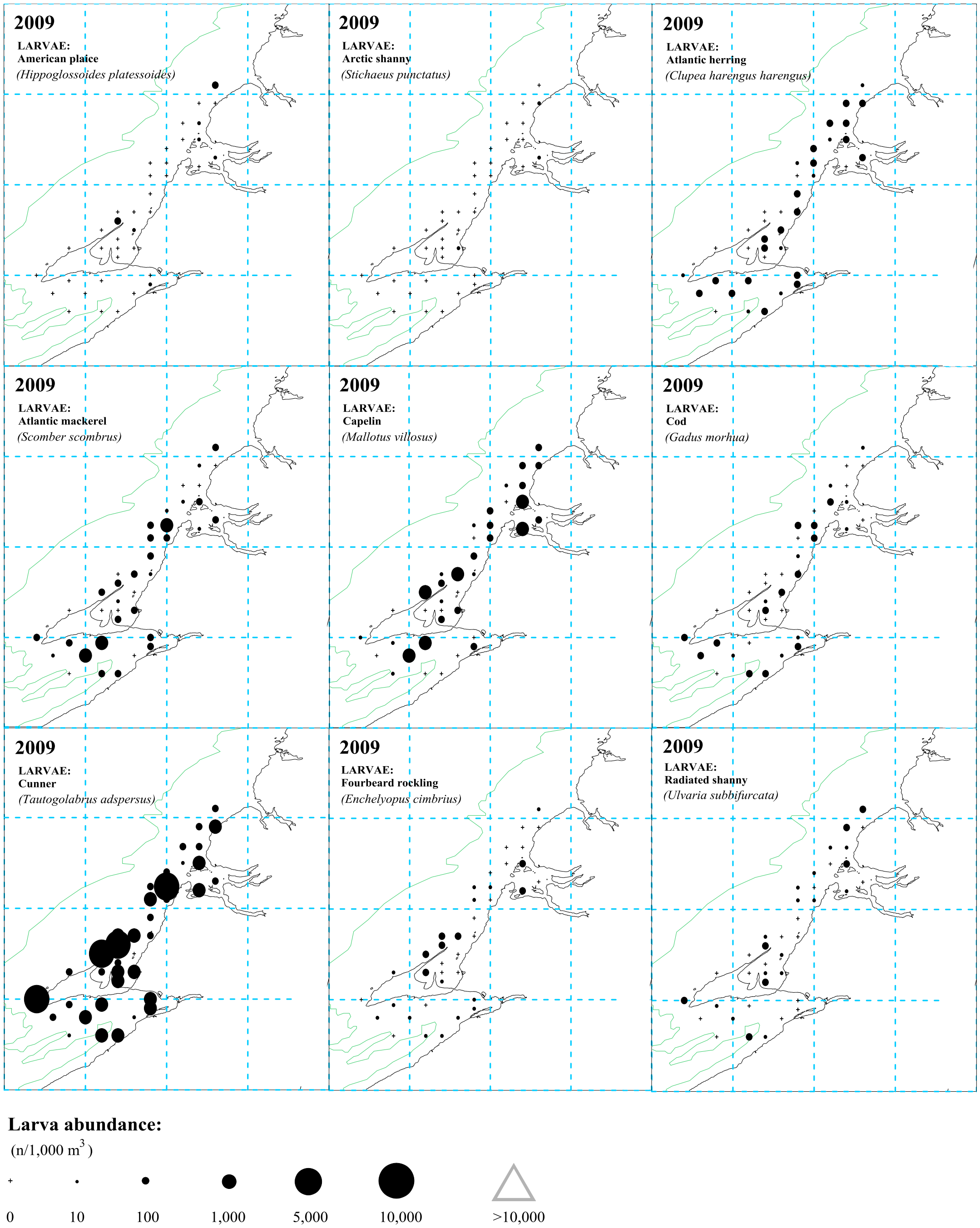


Figure 4. Maps of larval abundance (number/1,000 m^3) distributions from the capelin and Atlantic herring larval survey of July 2009 on the west coast of Newfoundland.

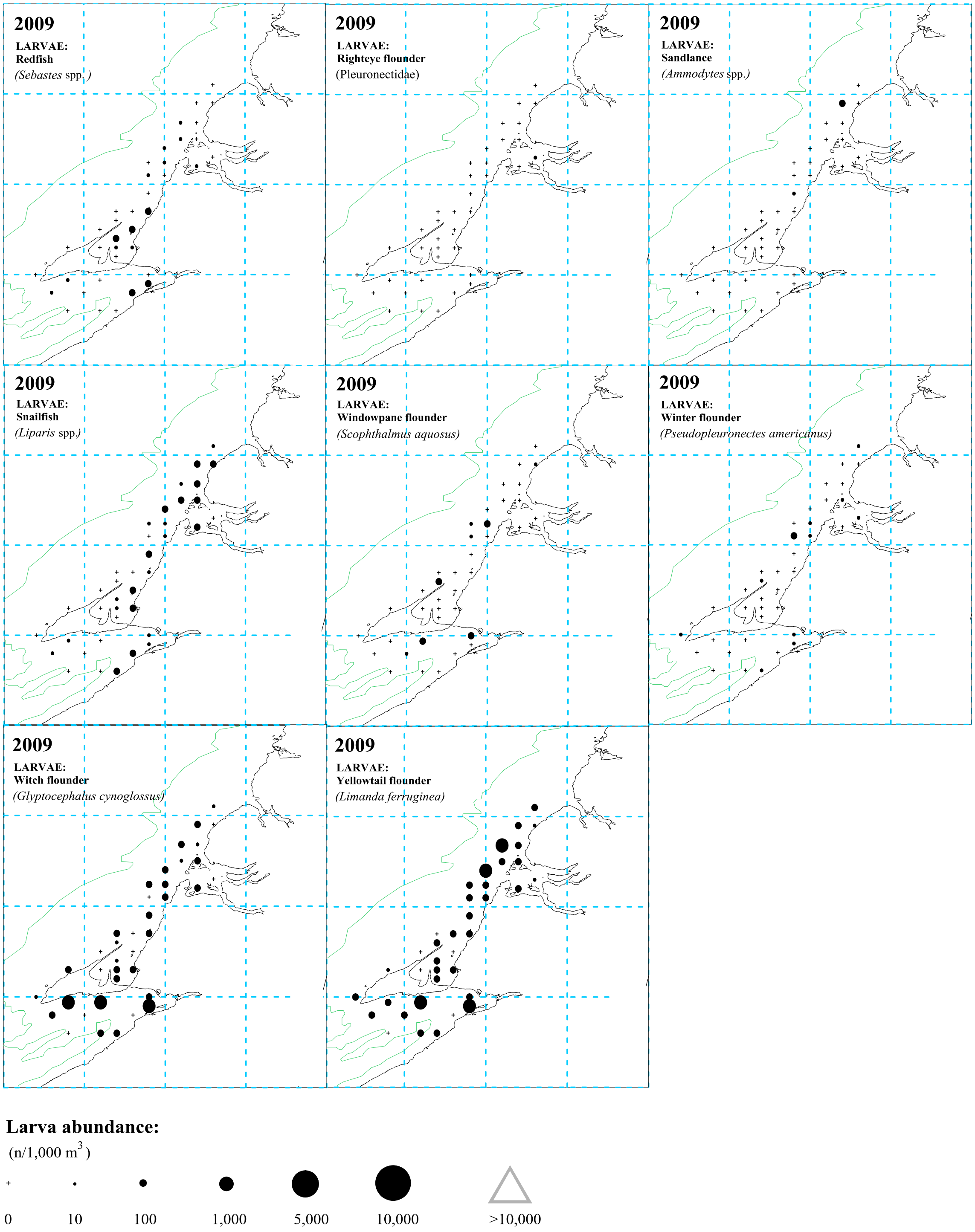


Figure 4. (Continued).

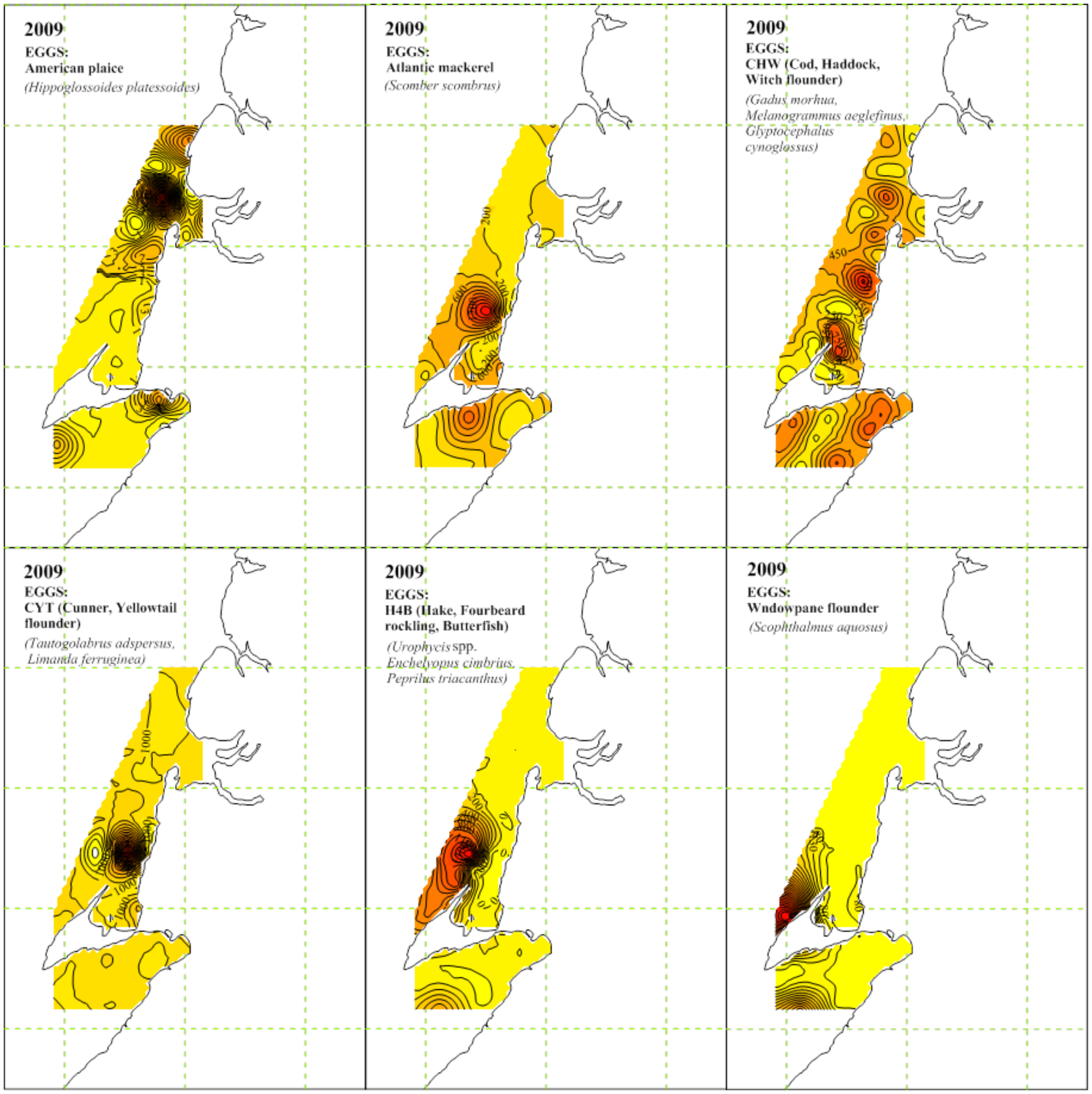


Figure 5. Abundance distribution maps (number/1,000 m^3) as derived by kriging of the eggs of some species sampled during the capelin and Atlantic herring larval survey of July 2009 on the west coast of Newfoundland.

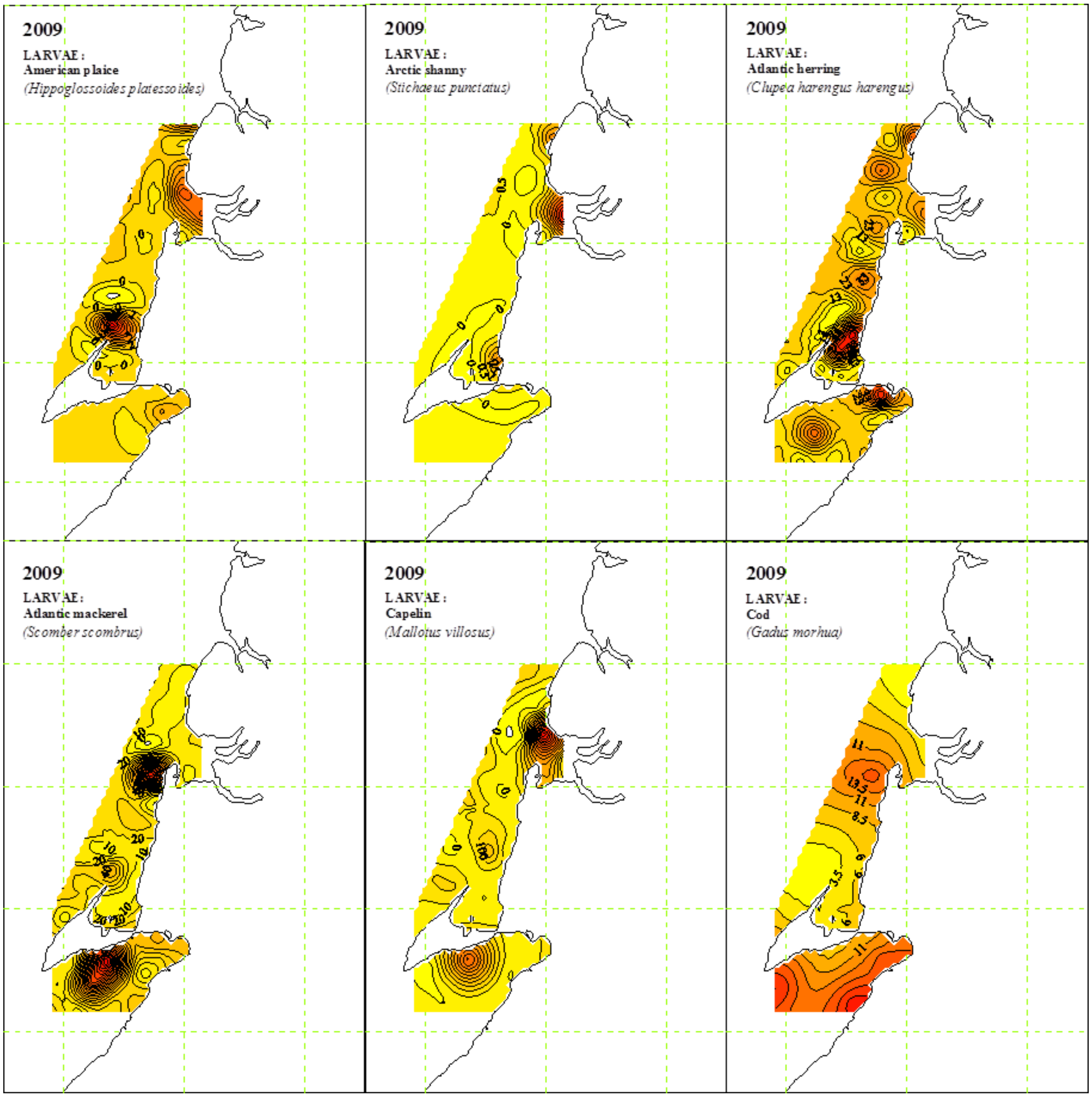


Figure 6. Abundance distribution maps (number/1,000 m^3) as derived by kriging of the larvae of some species sampled during the capelin and Atlantic herring larval survey of July 2009 on the west coast of Newfoundland (Note: it was not possible to build a variogram and apply kriging on winter flounder larva data).

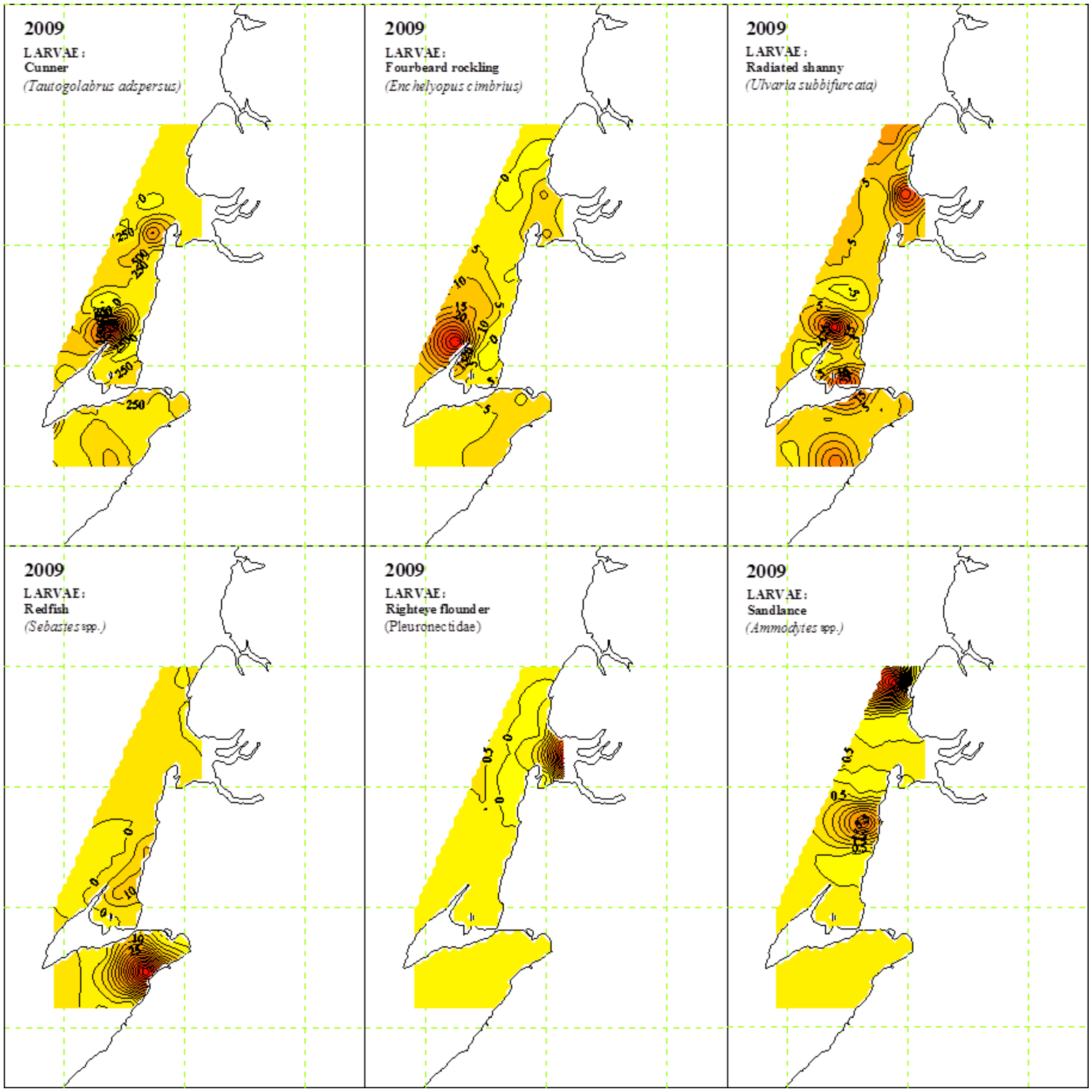


Figure 6. (Continued).

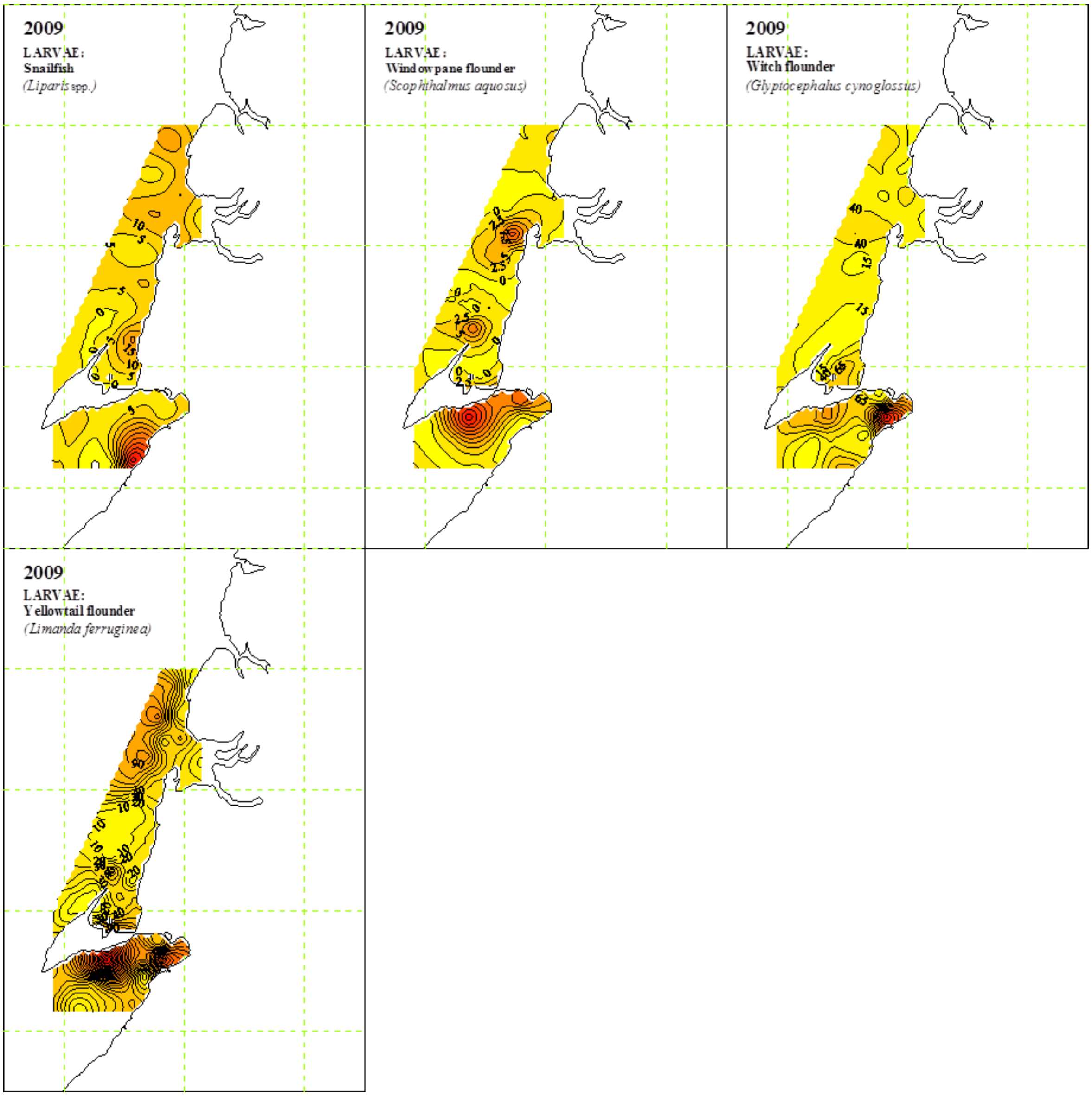


Figure 6. (Continued).

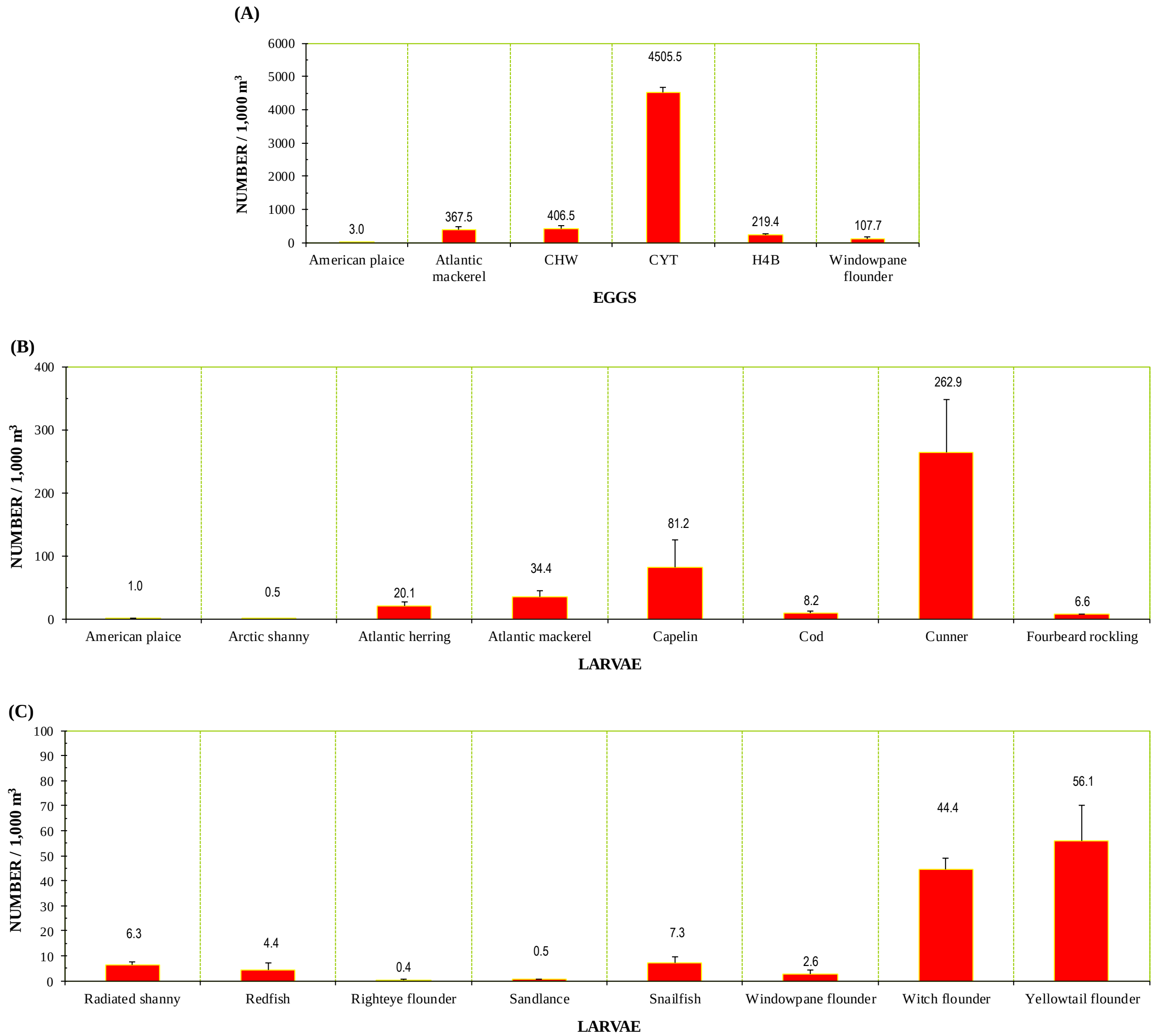


Figure 7. Mean abundance estimates (number/1,000 m^3) (with 95% confidence intervals) calculated by kriging of the eggs (A) and larvae (B and C) of some species sampled during the capelin and Atlantic herring larval survey of July 2009 on the west coast of Newfoundland.

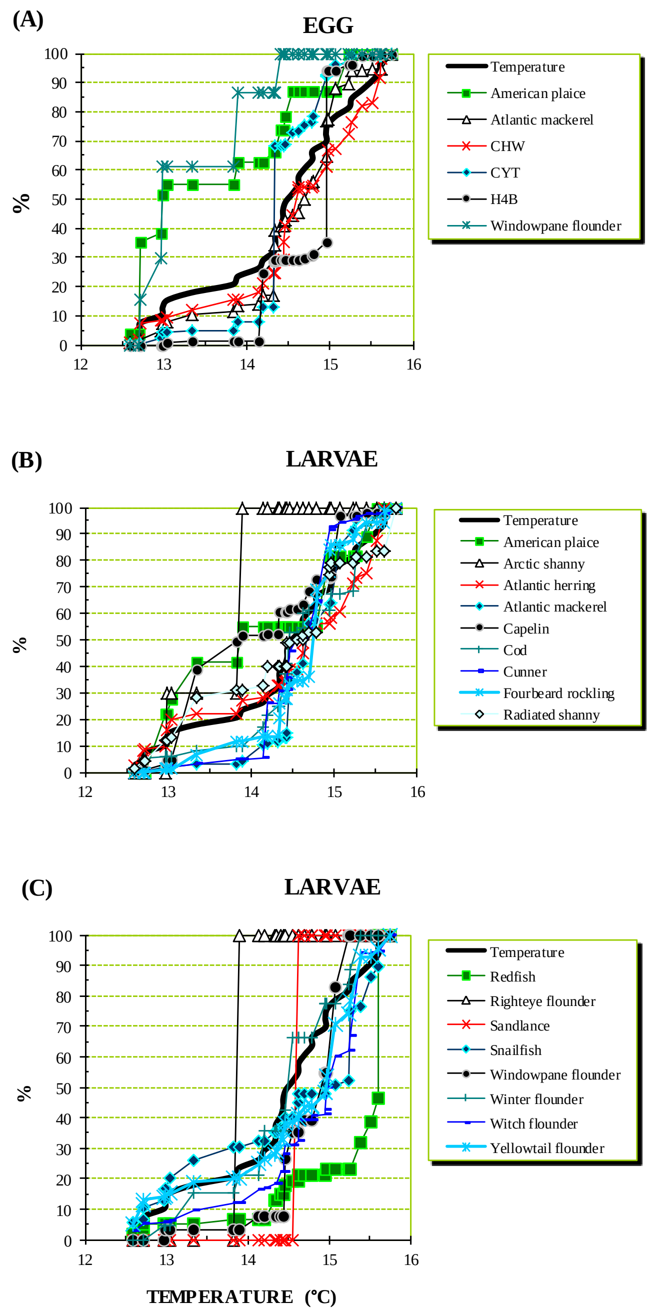


Figure 8. Cumulative curves of the abundance data of some eggs (A) and larvae (B and C) in relation to water temperature for the capelin and Atlantic herring larval survey of July 2009 on the west coast of Newfoundland.

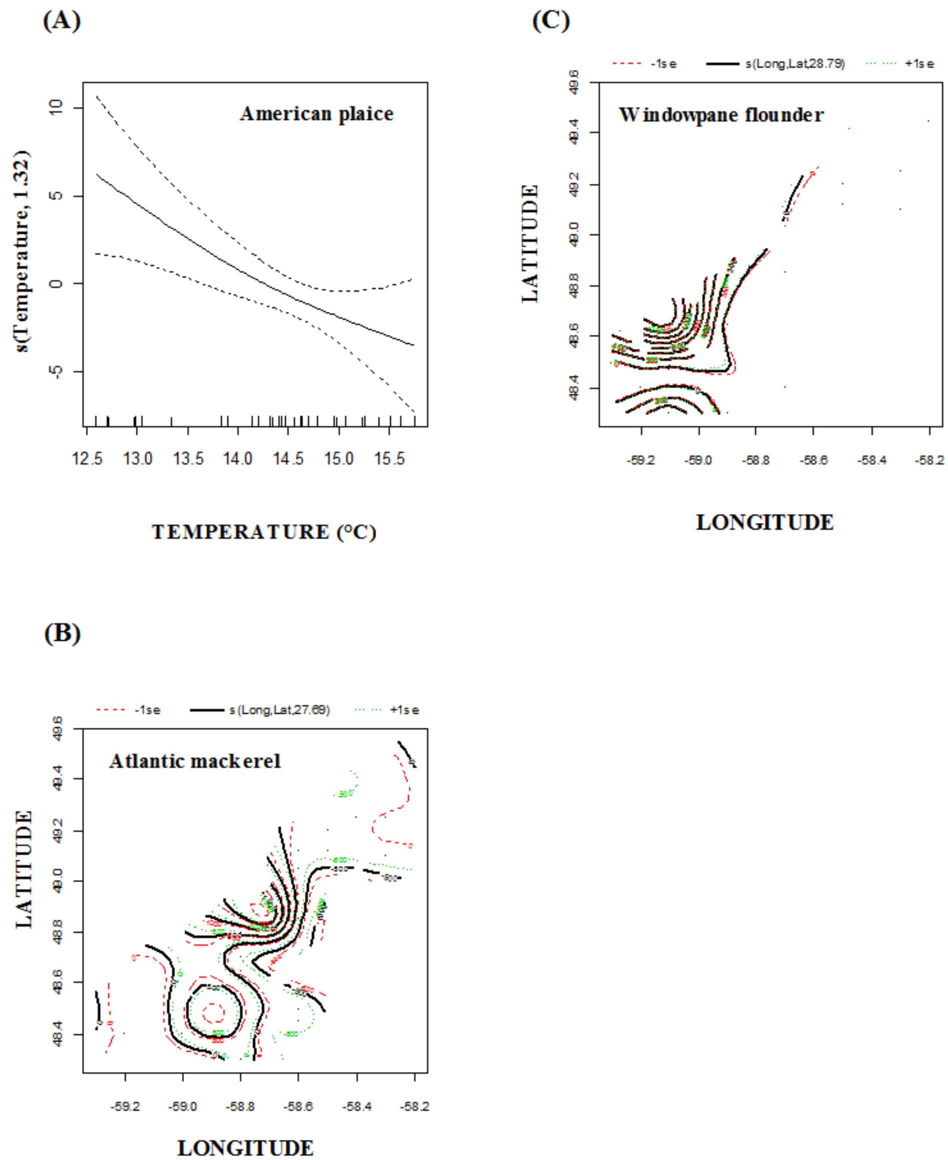


Figure 9. Smoothing functions between temperature (°C) and American plaice egg abundance data (with 95% confidence intervals) (A) and of the interaction between longitude and latitude (with standard error) on Atlantic mackerel (B) and windowpane flounder (C) egg abundance data (number/1,000 m^3). Degrees of freedom were estimated respectively at 1.32, 27.69, and 28.79. Vertical lines on the x-axis (A) represent the observed temperature values.

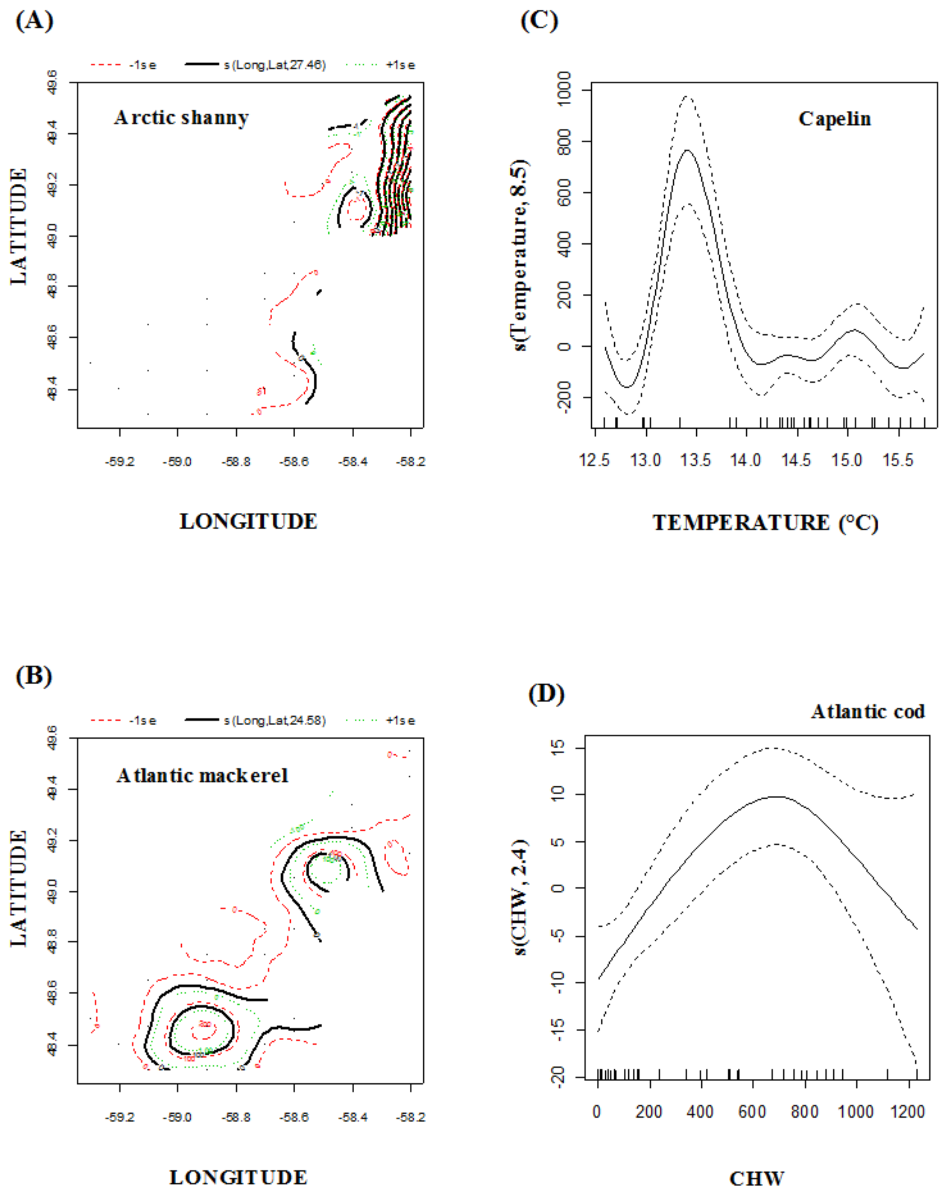


Figure 10. Smoothing functions of the interaction between longitude and latitude (with standard error) for arctic shanny (A) and Atlantic mackerel (B) larva abundance data (number/1,000 m^3) and temperature (°C) and CHW egg abundance data on capelin (C) and Atlantic cod (D) larva abundance data (number/1,000 m^3) (with 95% confidence intervals). Degrees of freedom were estimated at 27.46, 24.58, 8.5, and 2.4, respectively. Vertical lines on the x-axes (C and D) represent the observed temperature and CHW egg values.

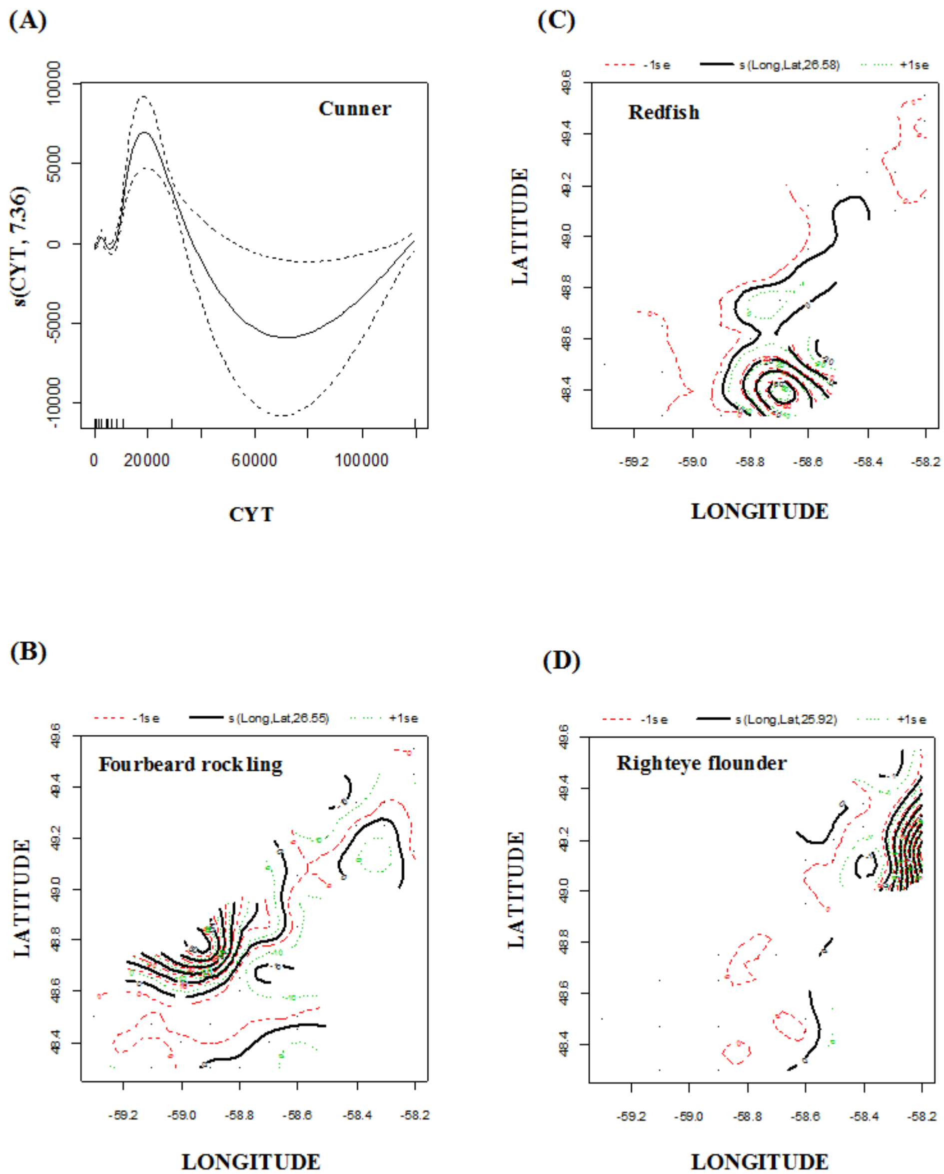


Figure 11. Smoothing functions of CYT egg abundance data (with 95% confidence intervals) on cunner larva abundance data (A) and of the interaction between longitude and latitude (with standard error) on fourbeard rockling (B), redfish (C), and righteye flounder (D) larva abundance data (number/1,000 m^3). Degrees of freedom were estimated respectively at 7.36, 26.55, 26.58, and 25.92. Vertical lines on the x-axis (A) represent the observed CYT egg values.

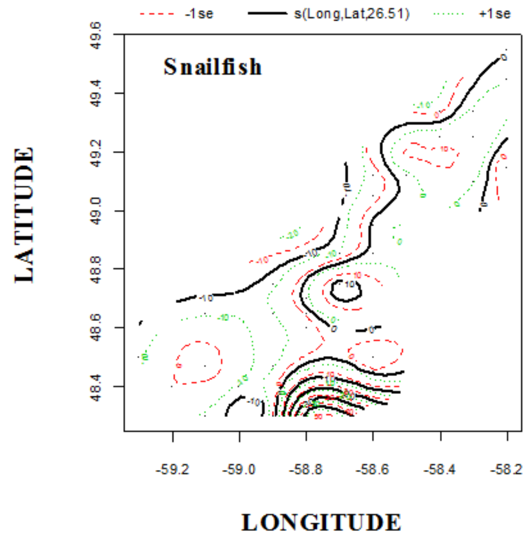
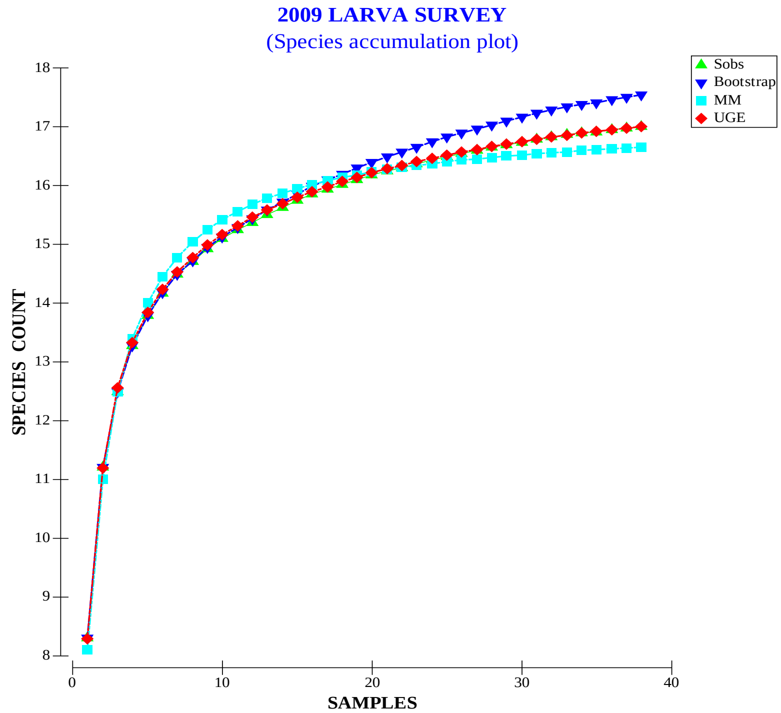


Figure 12. Smoothing function of the interaction between longitude and latitude (with standard error) on the snailfish larva abundance data (number/1,000 m^3). Degree of freedom was estimated at 26.51.

(A)



(B)

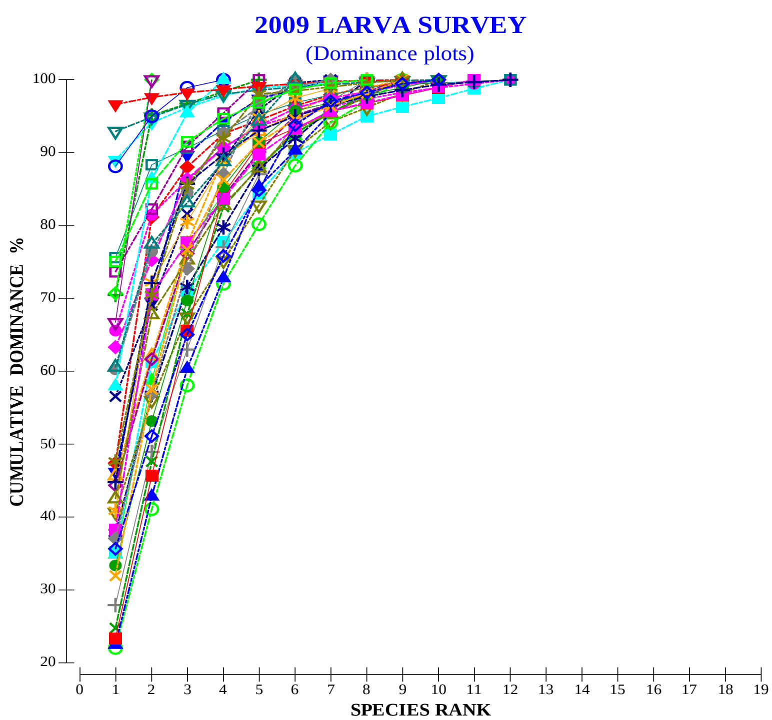


Figure 13. Species accumulation (A) and dominance (B) plots for the fish egg and larval survey of July 2009 on the west coast of Newfoundland. In A, Sobs = observed data; bootstrap, MM, UGE = predicted data; see text for explanation. In B, the lines–symbols represent the cumulative dominance and species rank of each station.

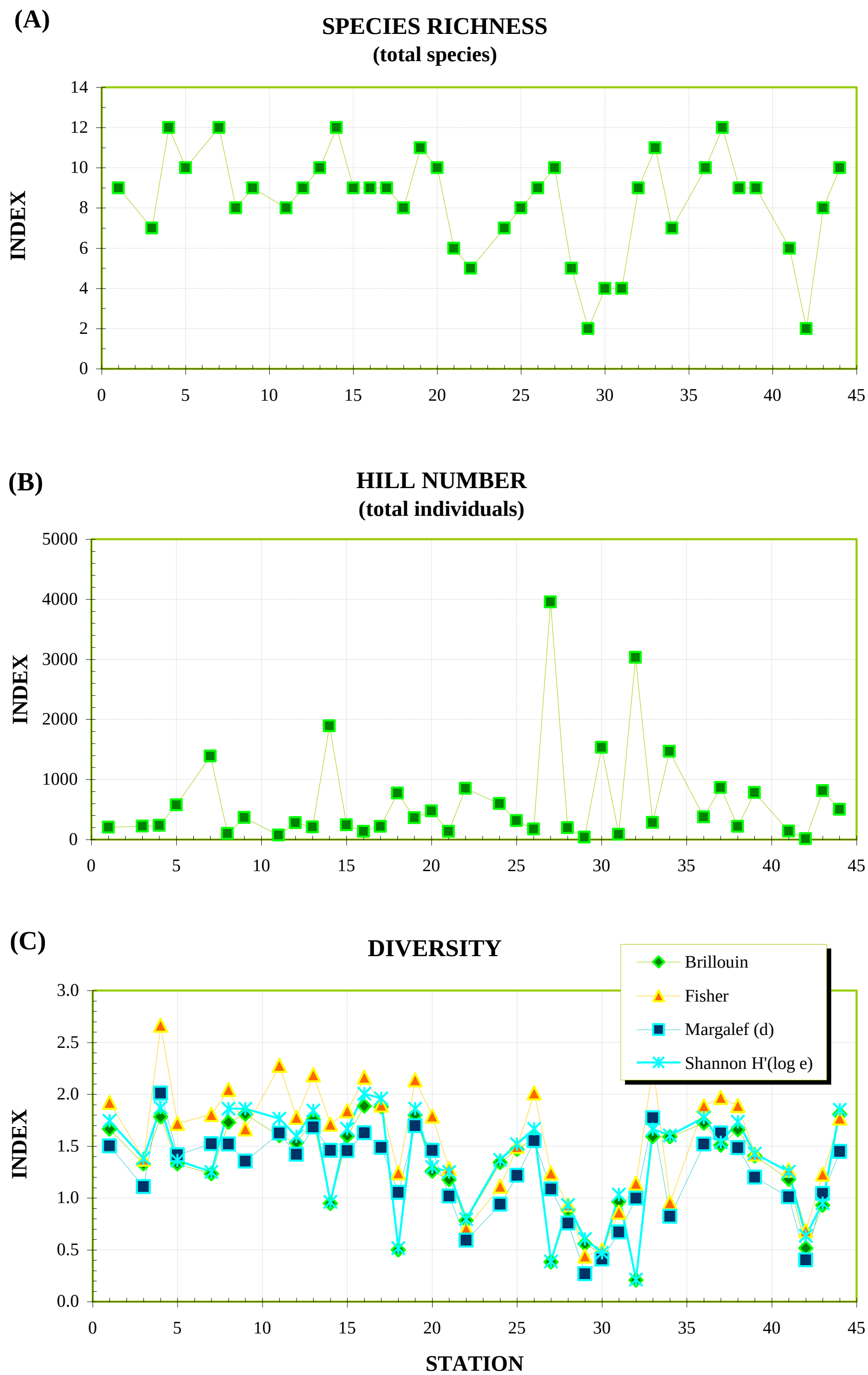


Figure 14. Total species (A), total individuals (B), and four diversity indices (C) calculated for the stations sampled during the fish egg and larval survey of July 2009 on the west coast of Newfoundland.

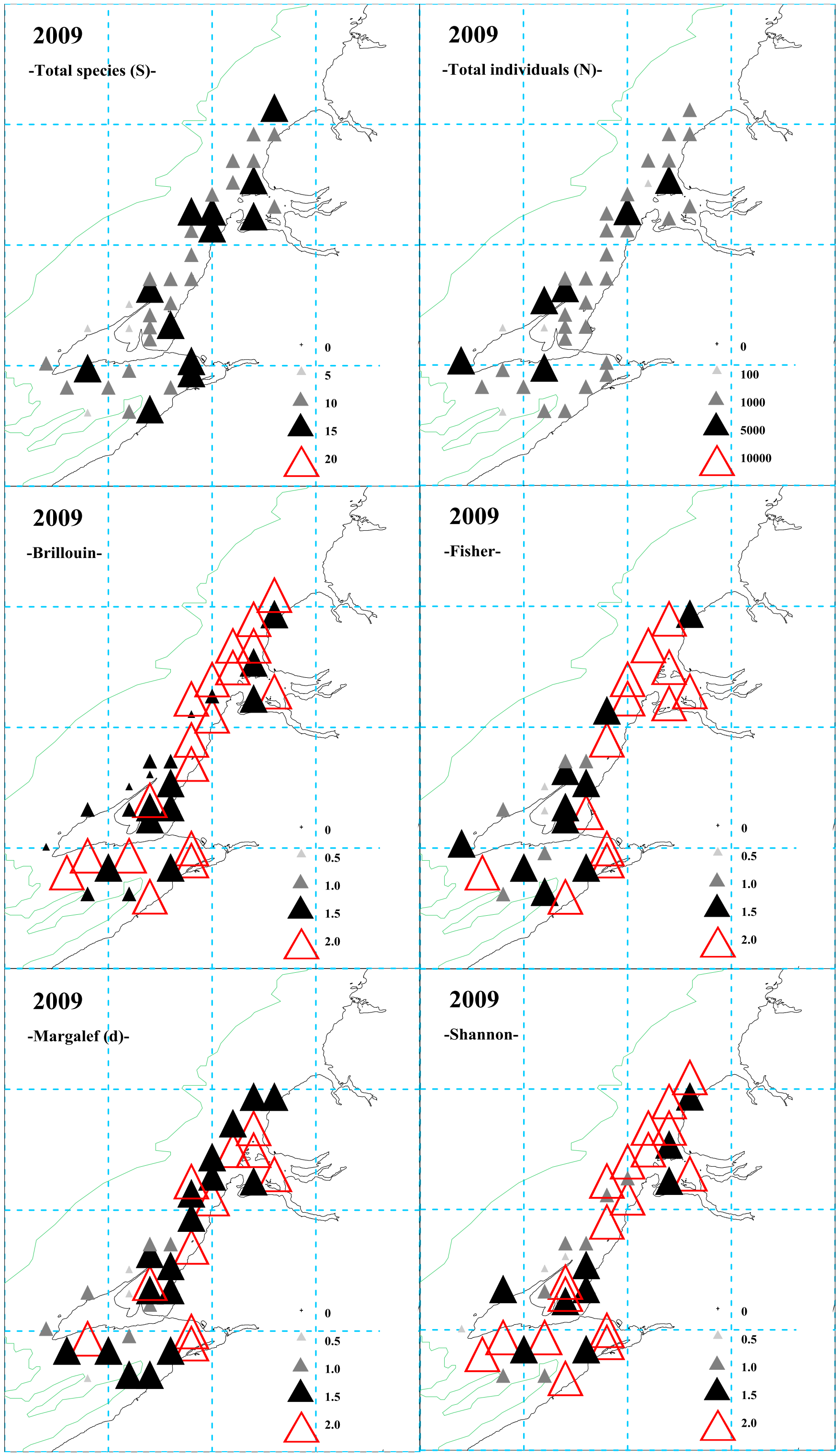
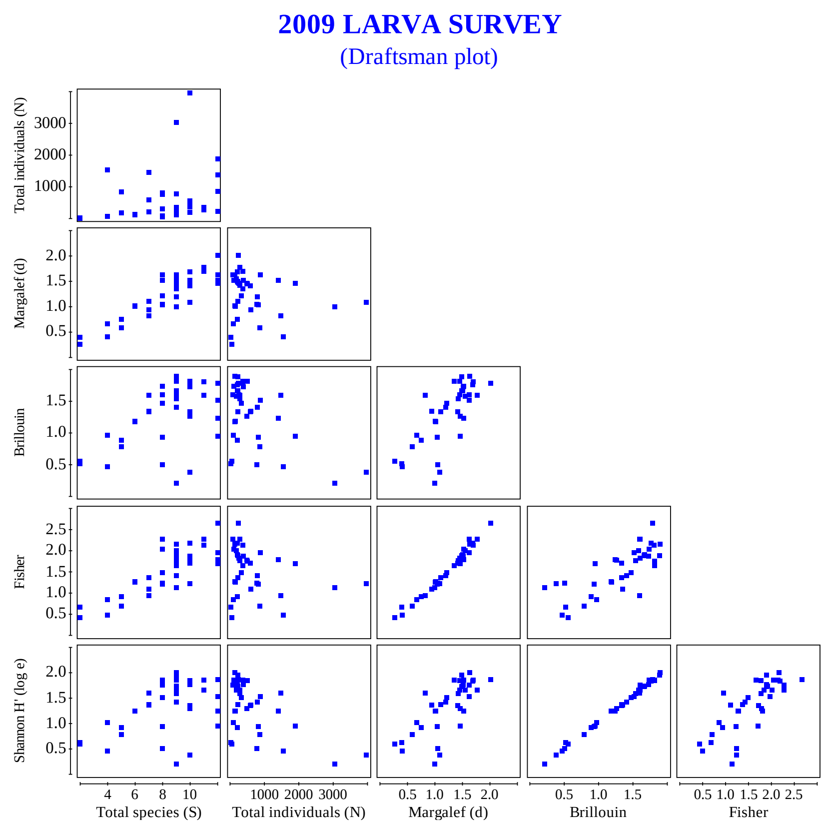


Figure 15. Maps showing distributions of total species, total individuals, and four diversity indices for the stations sampled during the fish egg and larval survey of July 2009 on the west coast of Newfoundland.

(A)



(B)

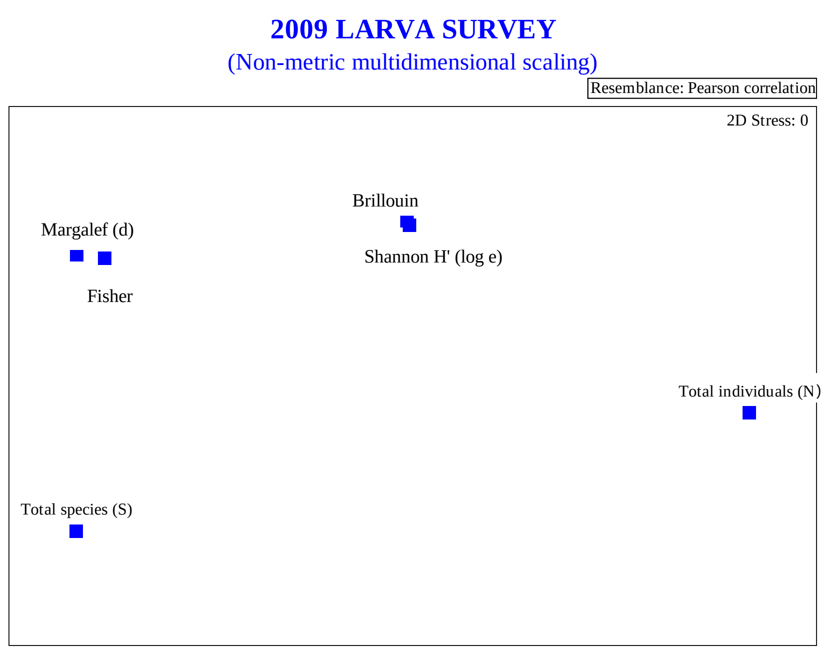
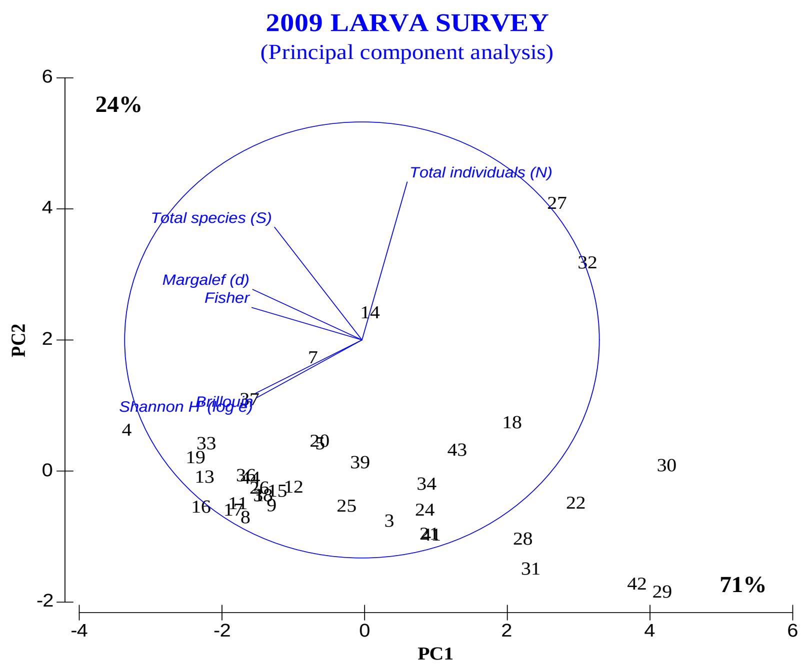


Figure 16. Draftsman (A), non-metric multidimensional scaling (B), and principal component analysis (PCA) (C) plots for the diversity indices calculated from the data collected during the fish egg and larval survey of July 2009 on the west coast of Newfoundland.

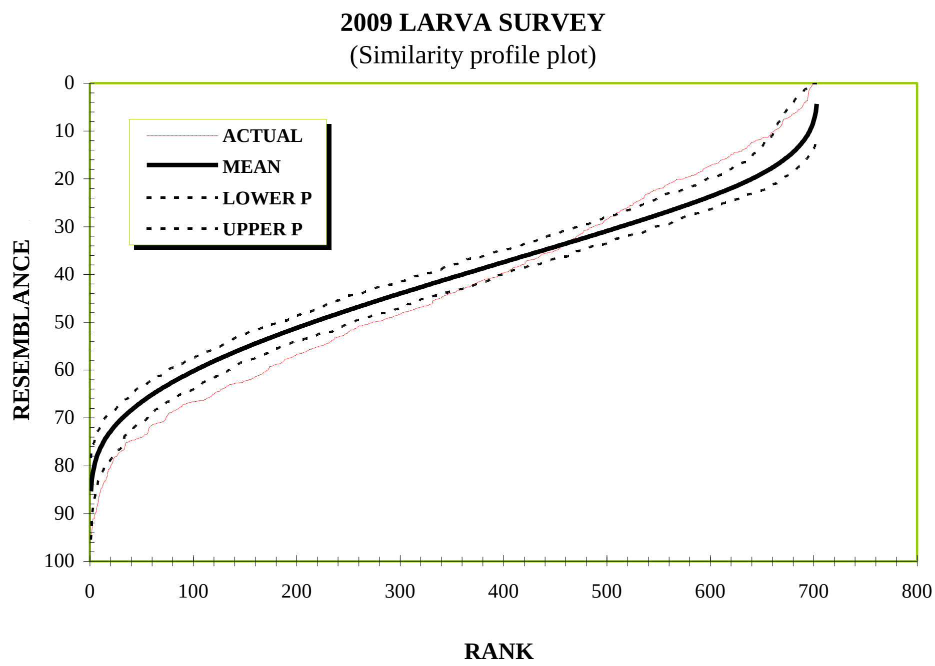
(C)



Variable	Eigenvectors	
	PC1	PC2
Total Species (S)	-0.368	0.517
Total Individuals (N)	0.190	0.725
Margalef (d)	-0.461	0.232
Brillouin	-0.448	-0.244
Fisher	-0.464	0.149
Shannon H'(log e)	-0.447	-0.267

Figure 16. (Continued).

(A)



(B)

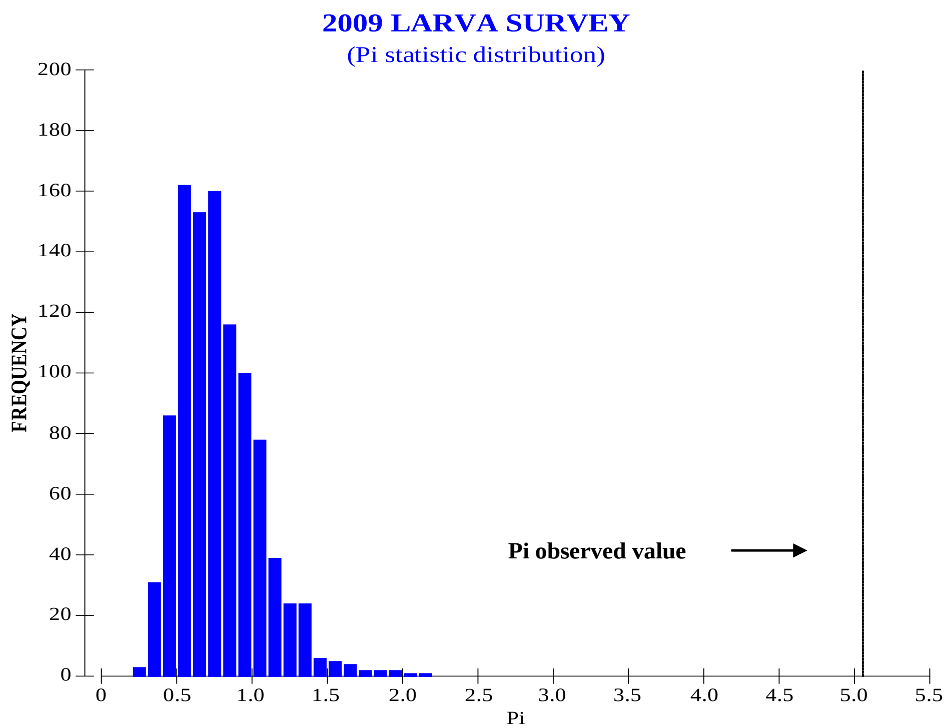


Figure 17. Similarity profile (A) and *Pi* statistic distribution (B) testing for evidence of internal group structure in the full set of stations sampled during the fish egg and larval survey of July 2009 on the west coast of Newfoundland.

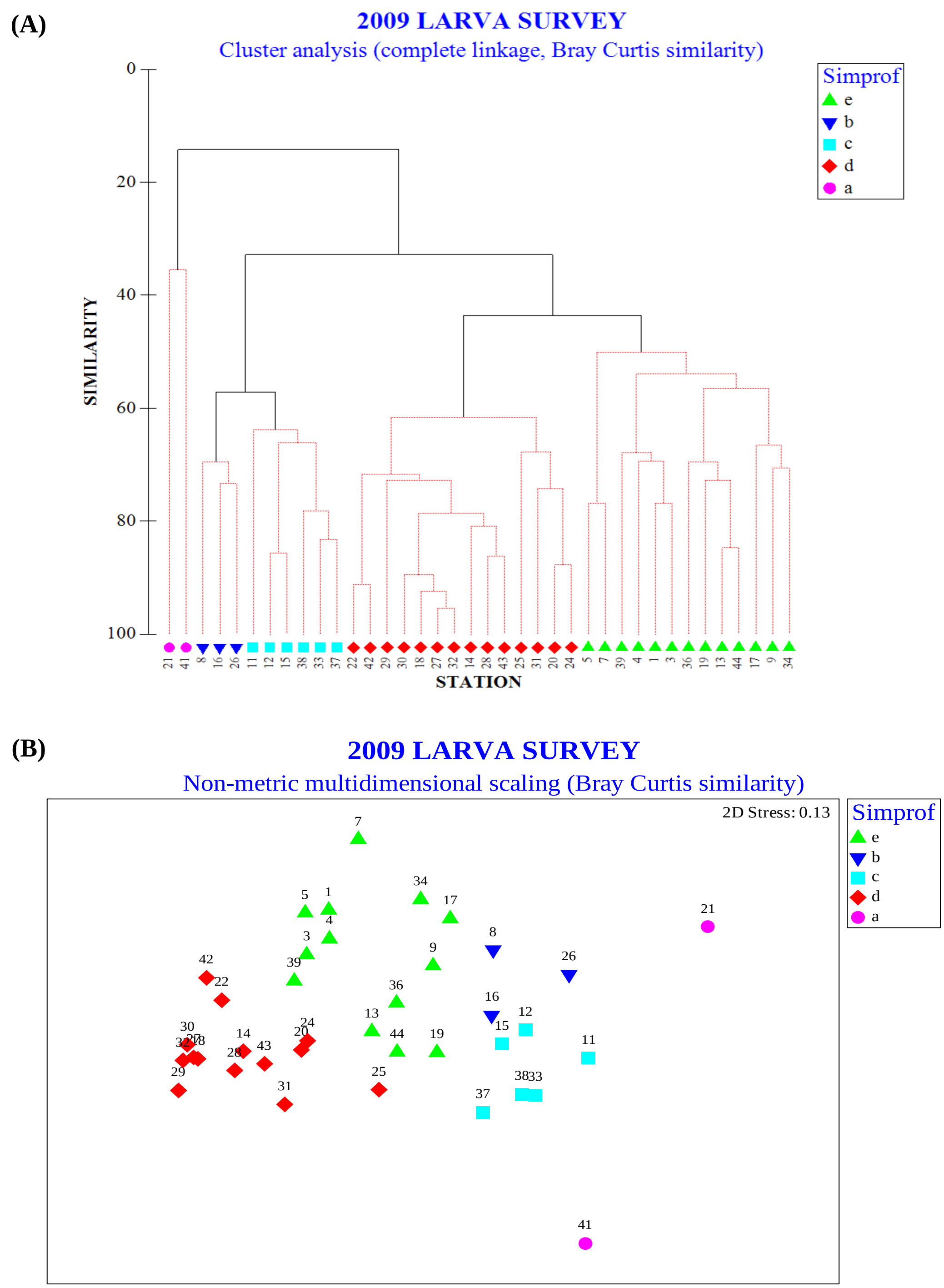


Figure 18. Results of the cluster analysis (A) and non-metric multidimensional scaling (B) applied on the Bray Curtis similarities calculated among the stations sampled during the fish egg and larval survey of July 2009 on the west coast of Newfoundland (groups of stations were defined by the SIMPROF procedure).

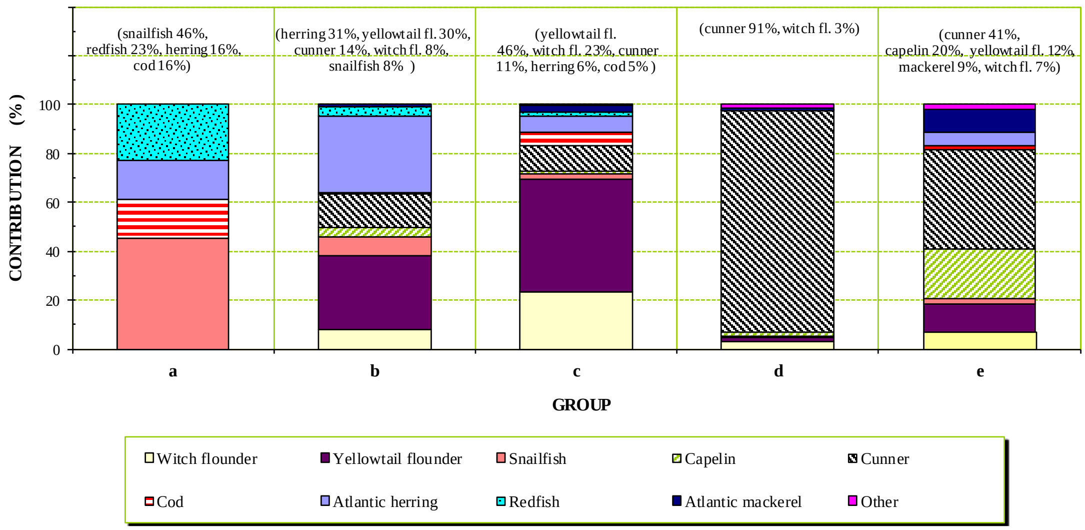
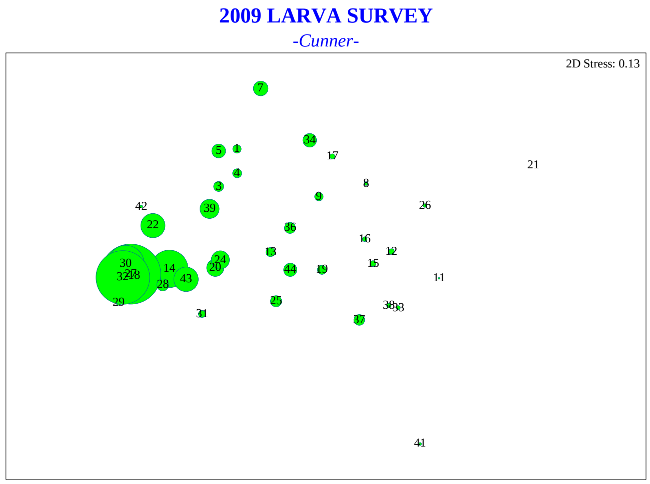
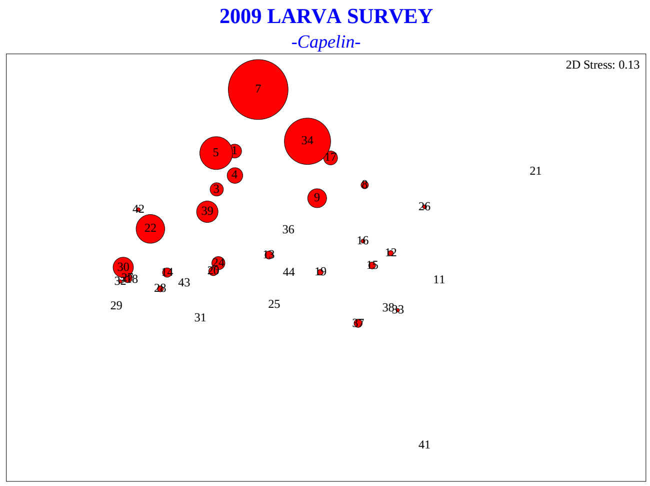


Figure 19. Relative contribution (%) of the main species of fish larvae to the similarity of each group of stations defined by cluster analysis.

(A)



(B)



(C)

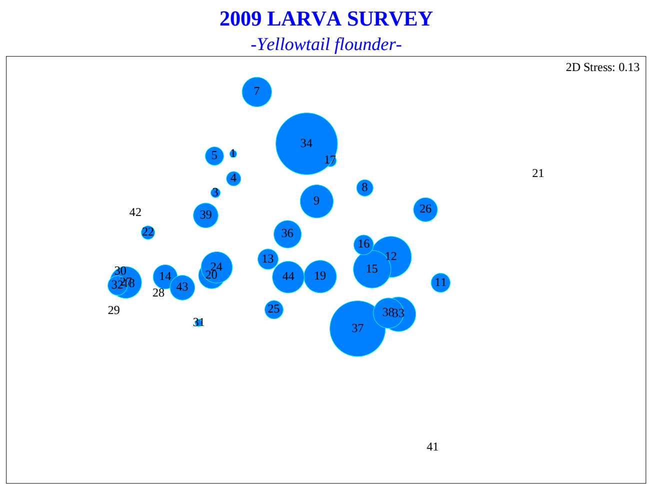
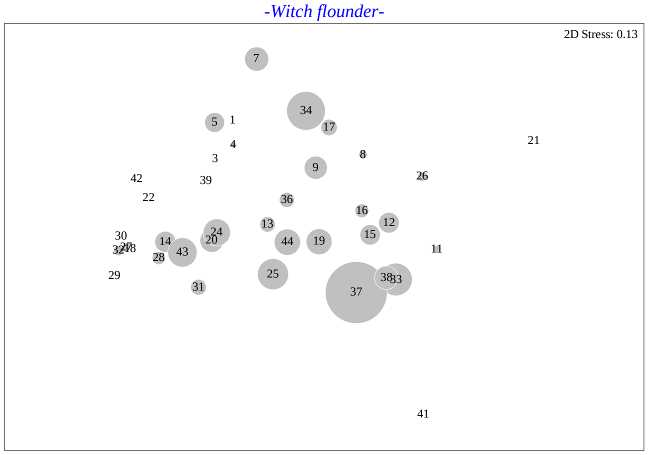


Figure 20. Non-metric multidimensional scaling showing the position and abundance (size of the circles) of the species with the greatest contribution (%) to their respective groups (A: cunner, B: capelin, C: yellowtail flounder, D: witch flounder, E: Atlantic herring, F: snailfish, and G: redfish). Station numbers are indicated.

(D)

2009 LARVA SURVEY

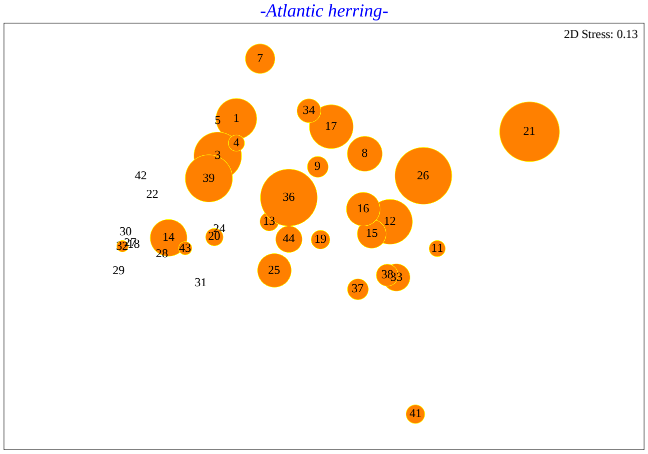
-Witch flounder-



(E)

2009 LARVA SURVEY

-Atlantic herring-



(F)

2009 LARVA SURVEY

- Snailfish-

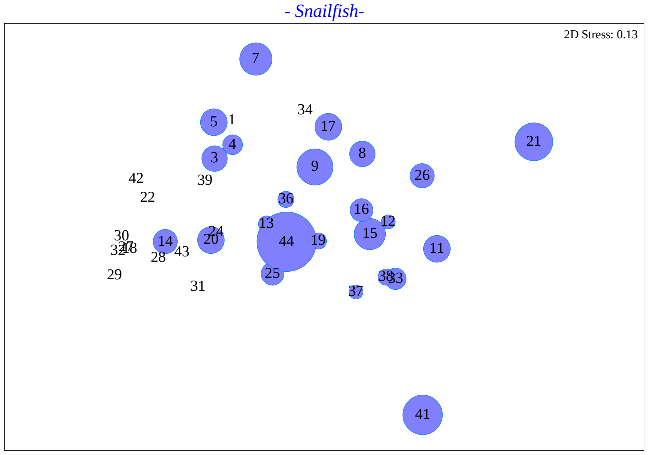


Figure 20. (Continued).

(G)

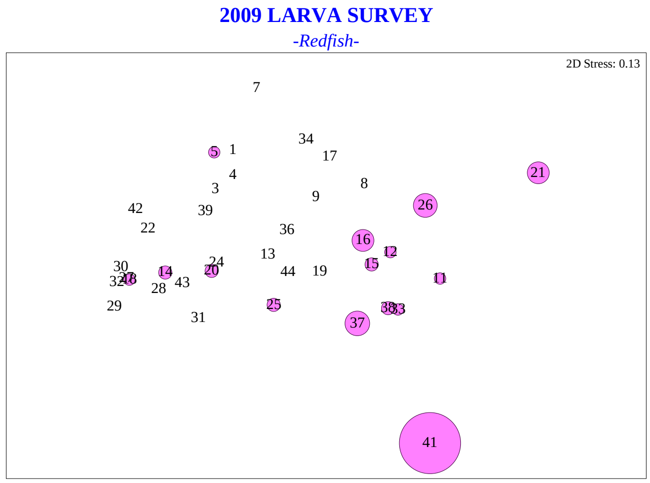


Figure 20. (Continued).

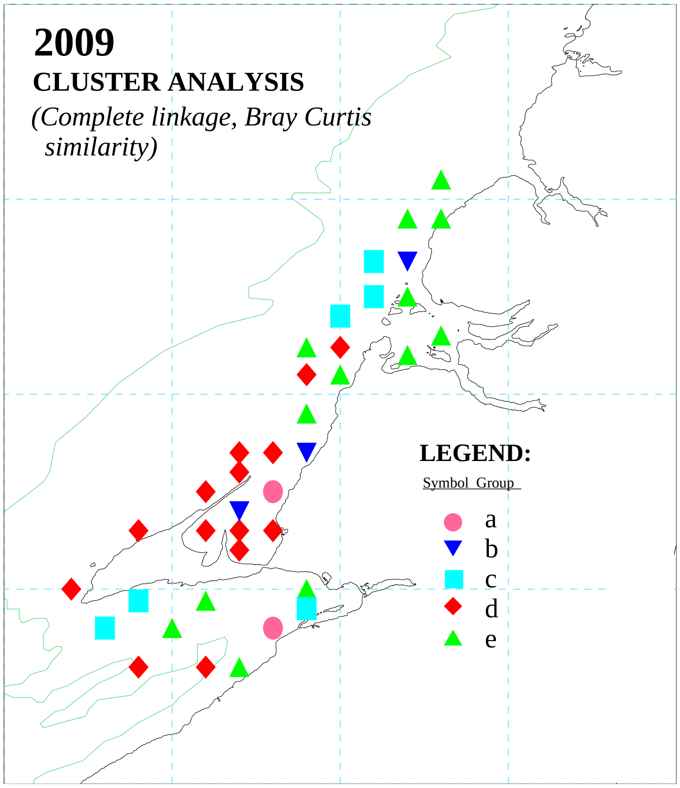


Figure 21. Map of the fish larval assemblages (groups) defined by the cluster analysis.

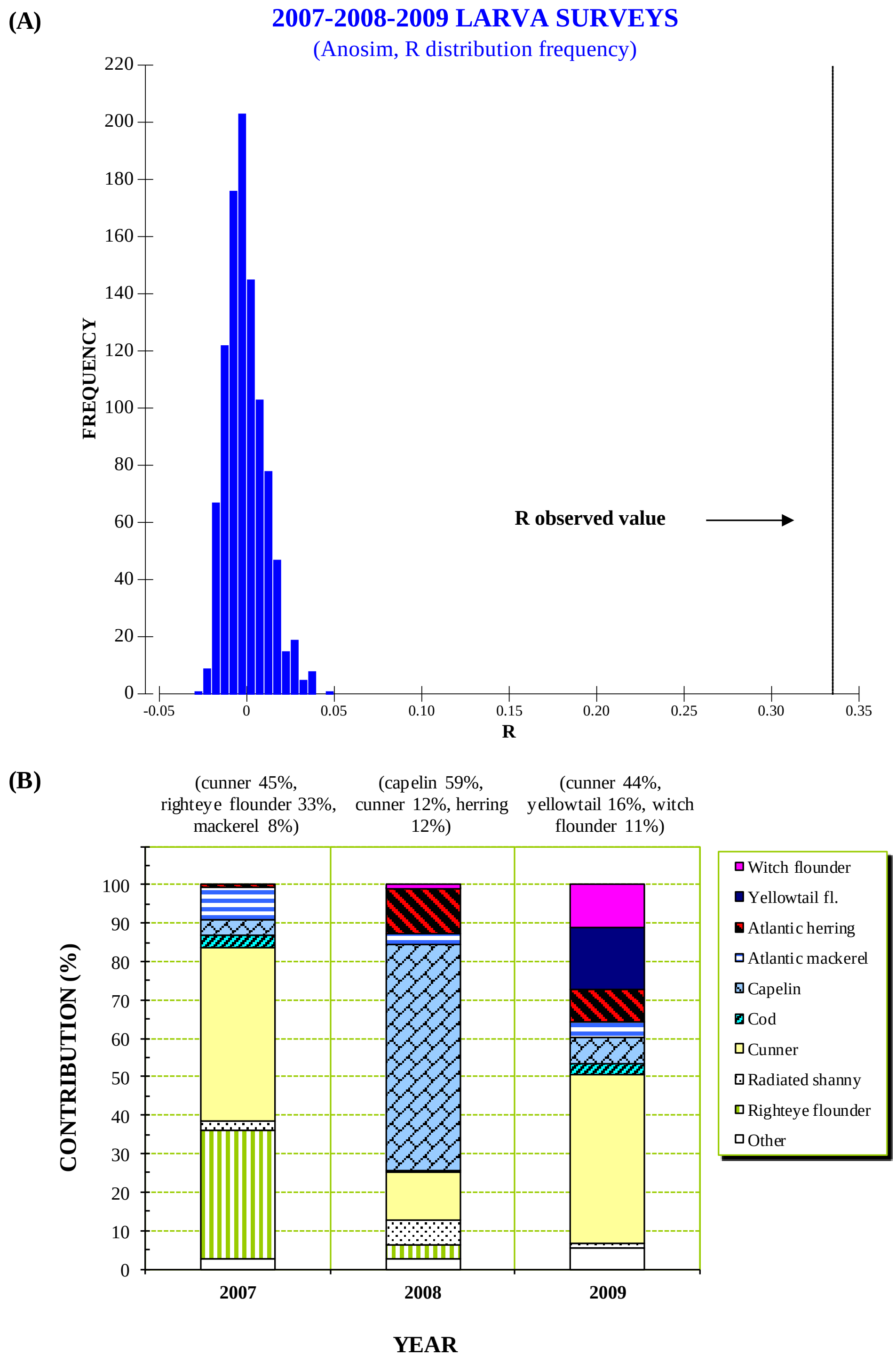
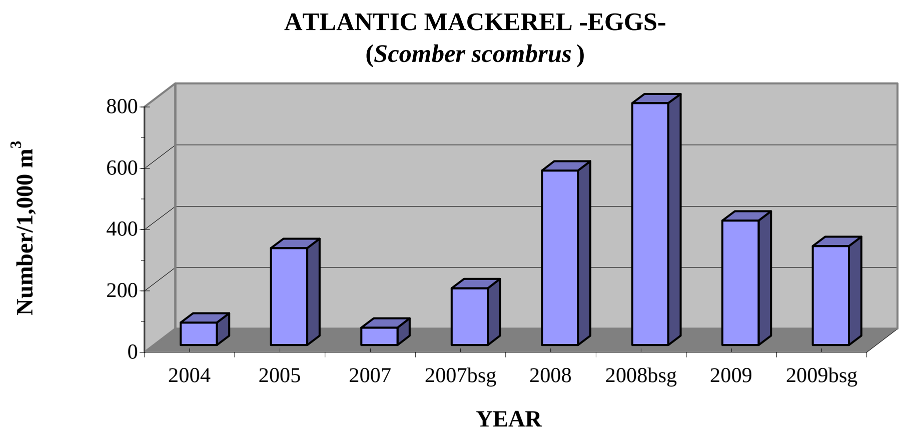
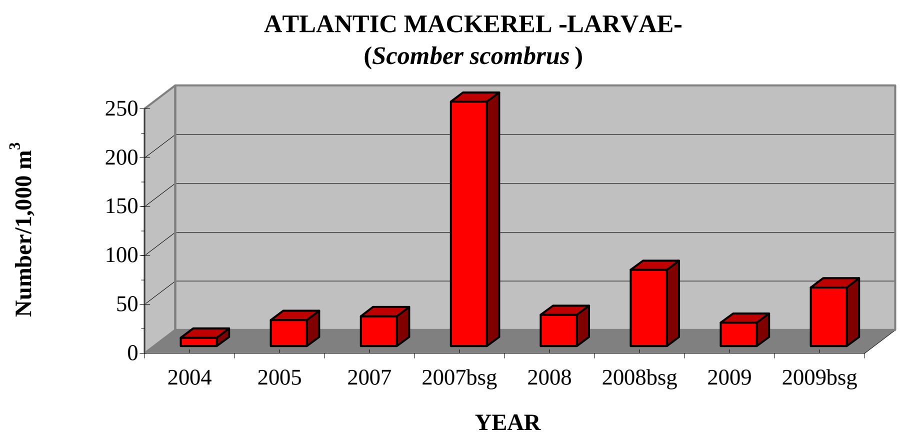
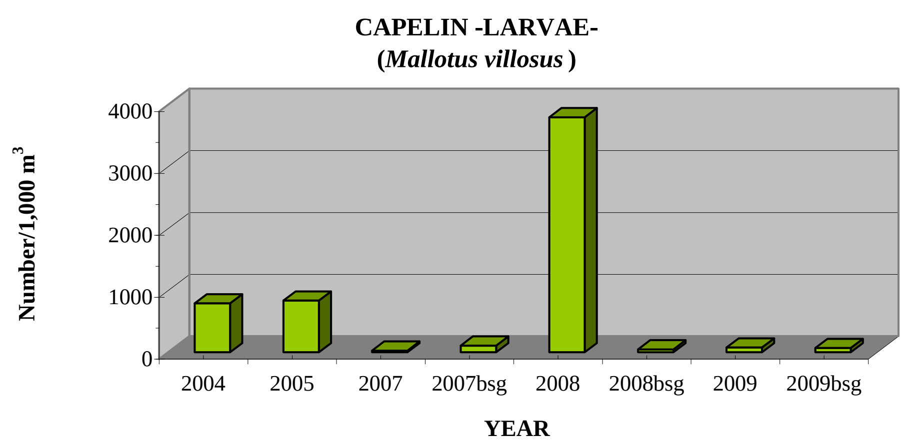


Figure 22. Results of the one-way ANOSIM procedure testing the null hypothesis that there are no larval assemblage differences between the groups of stations defined by cluster analyses and sampled in 2007, 2008, and 2009 (A) and relative contribution (%) of the main fish larvae to the similarity of each assemblage (B).

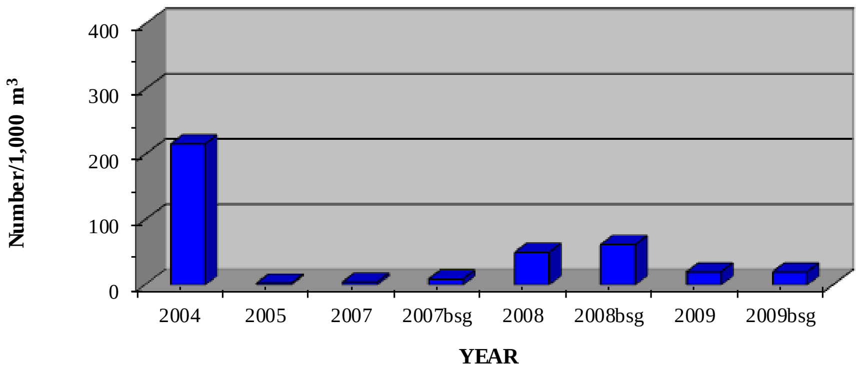
Appendix 1. Mean egg and larval abundance (number/1,000 m^3) of the main commercial species of fish sampled during the capelin and Atlantic herring larval surveys of July 2004, 2005, 2007, 2008, and 2009 on the west coast of Newfoundland (note: bsg = St. George's Bay).


ATLANTIC MACKEREL -EGGS-
(Scomber scombrus)
Number/1,000 m3
800
600
400
200
0
2004
2005
2007
2007bsg
2008
2008bsg
2009
2009bsg
YEAR

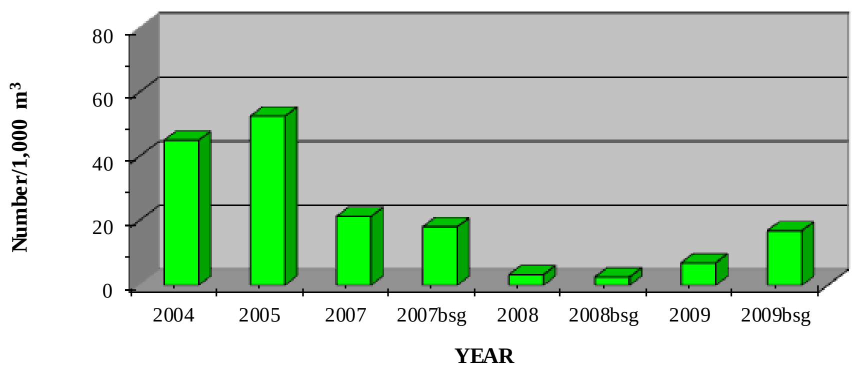

ATLANTIC MACKEREL -LARVAE-
(Scomber scombrus)
Number/1,000 m3
250
200
150
100
50
0
2004
2005
2007
2007bsg
2008
2008bsg
2009
2009bsg
YEAR


CAPELIN -LARVAE-
(Mallotus villosus)
Number/1,000 m3
4000
3000
2000
1000
0
2004
2005
2007
2007bsg
2008
2008bsg
2009
2009bsg
YEAR

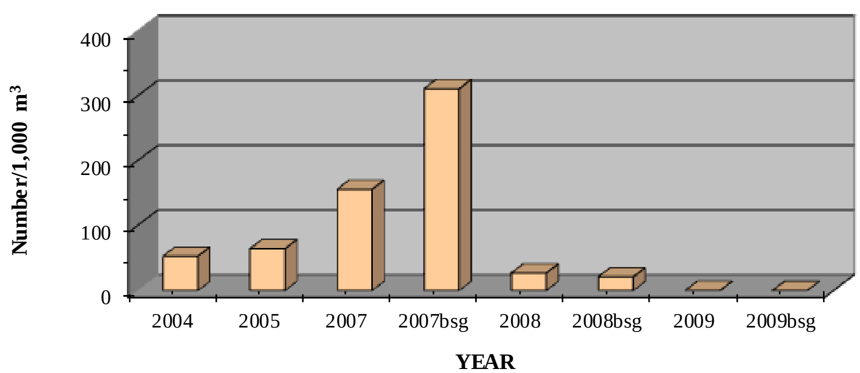
HERRING -LARVAE-
(*Clupea harengus harengus*)



COD -LARVAE-
(*Gadus morhua*)



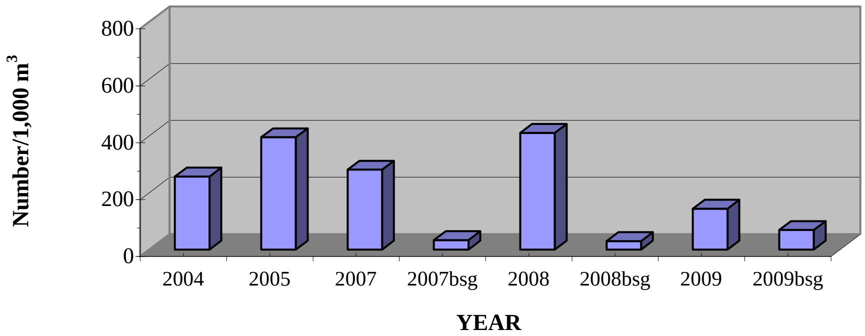
RIGHTEYE FLOUNDER -LARVAE-
(Pleuronectidae)



Appendix 2. Mean egg abundance (number/1,000 m^3) of the other species of fish sampled during the capelin and Atlantic herring larval surveys of July 2004, 2005, 2007, 2008, and 2009 on the west coast of Newfoundland (note: bsg = St. George’s Bay).

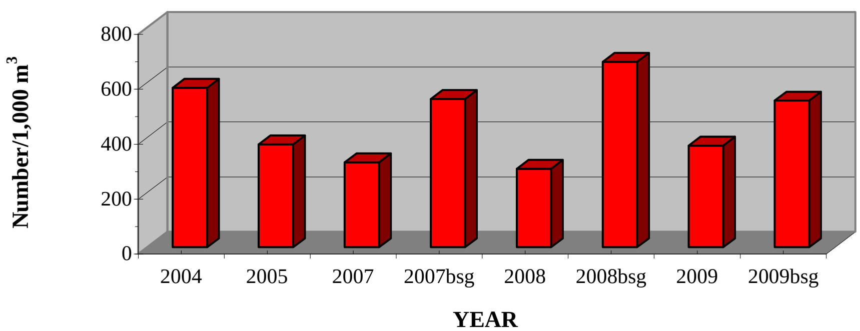
H4B -EGGS-

-Hake (*Urophycis* spp.), fourbeard rockling (*Enchelyopus cimbrius*), and butterfish (*Peprilus triacanthus*)-



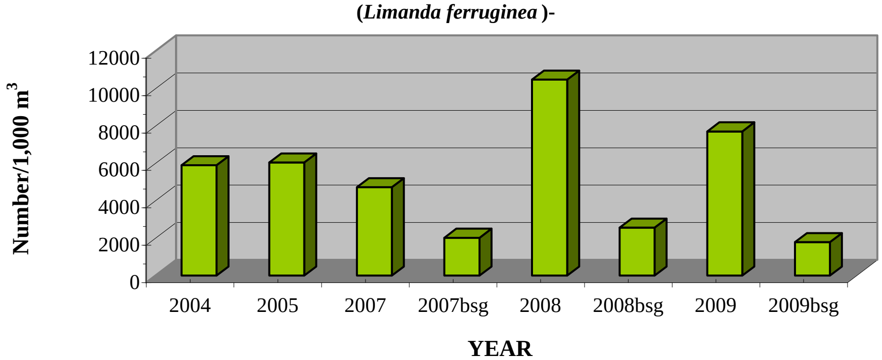
CHW -EGGS-

-Cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), and witch flounder (*Glyptocephalus cynoglossus*)-

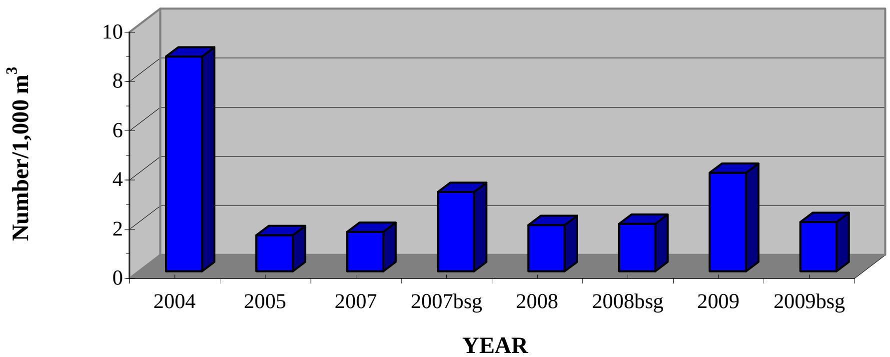


CYT -EGGS-

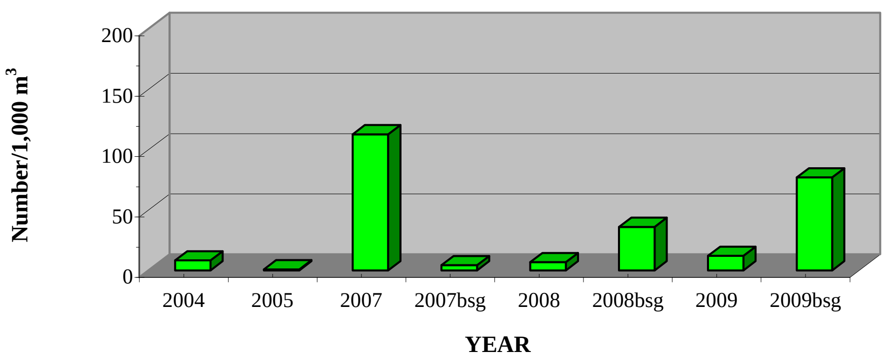
-Cunner (*Tautogolabrus adspersus*) and yellowtail flounder (*Limanda ferruginea*)-



AMERICAN PLAICE -EGGS-
(*Hippoglossoides platessoides*)

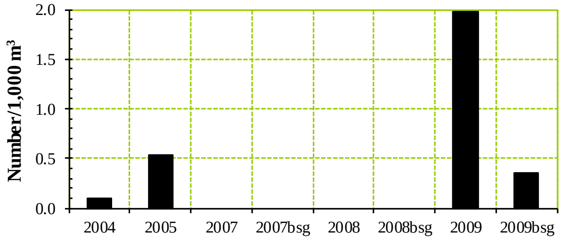


WINDOWPANE FLOUNDER -EGGS-
(*Scophthalmus aquosus*)

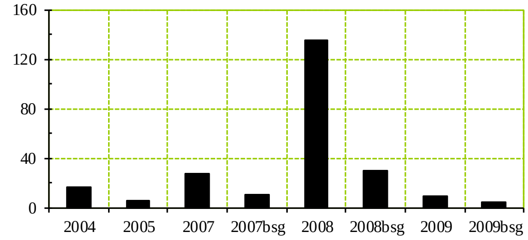


Appendix 3. Mean larval abundance (number/1,000 m^3) of the other species of fish sampled during the capelin and Atlantic herring larval surveys of July 2004, 2005, 2007, 2008, and 2009 on the west coast of Newfoundland (note: bsg = St. George's Bay).

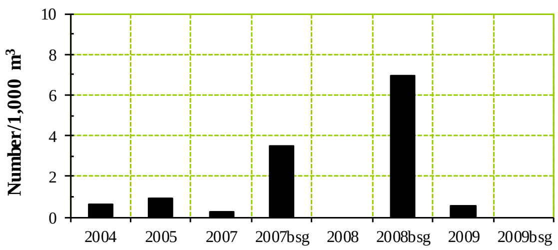
AMERICAN PLAICE
(*Hippoglossoides platessoides*)



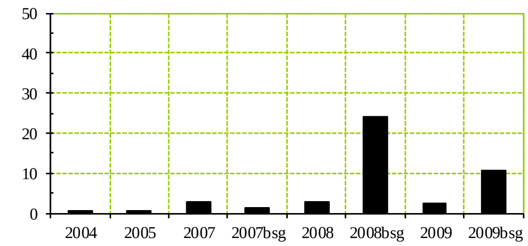
RADIATED SHANNY
(*Ulvaria subbifurcata*)



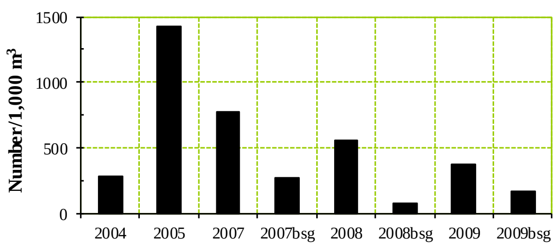
ARCTIC SHANNY
(*Stichaeus punctatus*)



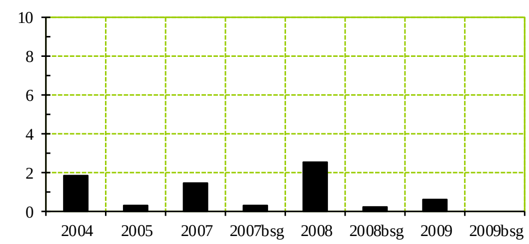
REDFISH
(*Sebastes* spp.)



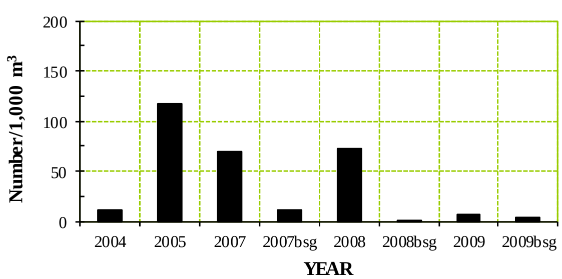
CUNNER
(*Tautogolabrus adspersus*)



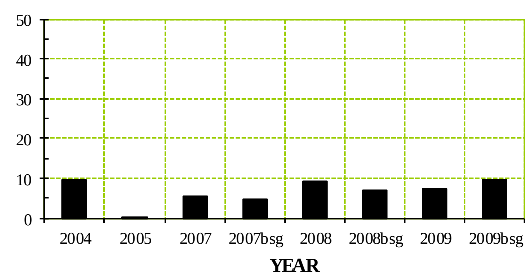
SANDLANCE
(*Ammodytes* spp.)



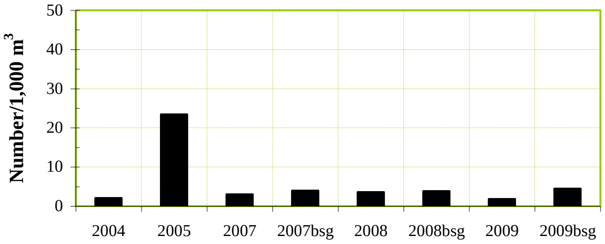
FOURBEARD ROCKLING
(*Enchelyopus cimbrius*)



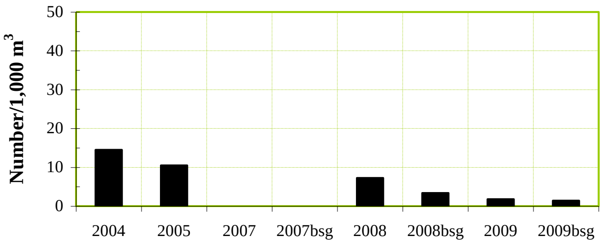
SNAILFISH
(*Liparis* spp.)



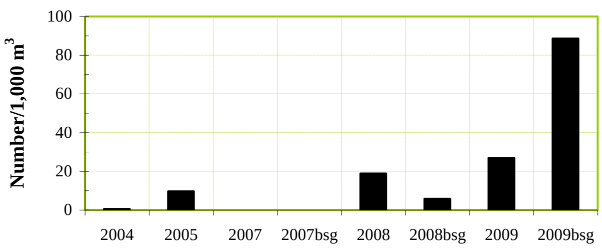
WINDOWPANE FLOUNDER
(*Scophthalmus aquosus*)



WINTER FLOUNDER
(*Pseudopleuronectes americanus*)



WITCH FLOUNDER
(*Glyptocephalus cynoglossus*)



YELLOWTAIL FLOUNDER
(*Limanda ferruginea*)