West coast of Newfoundland capelin (*Mallotus villosus* M.) and Atlantic herring (*Clupea harengus harengus* L.) larval survey, part 2: Abundance estimates and marine community analyses of the data collected in partnership with the industry (Barry Group) in July 2004

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WEST COAST OF NEWFOUNDLAND CAPELIN (*Mallotus villosus* M.) AND ATLANTIC HERRING (*Clupea harengus harengus* L.) LARVAL SURVEY, PART 2: ABUNDANCE ESTIMATES AND MARINE COMMUNITY ANALYSES OF THE DATA COLLECTED IN PARTNERSHIP WITH THE INDUSTRY (BARRY GROUP) IN JULY 2004

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ABSTRACT

Grégoire, F., W. Barry, and J. Barry. 2006. West coast of Newfoundland capelin (*Mallotus villosus* M.) and Atlantic herring (*Clupea harengus harengus* L.) larval survey, Part 2: Abundance estimates and marine community analyses of the data collected in partnership with the industry (Barry Group) in July 2004. Can. Tech. Rep. Fish. Aquat. Sci. 2650: viii + 50 pp.

In collaboration with the Barry Group in Corner Brook, a larval survey was conducted from 15-17 July 2004 between Bonne Bay and Port-au-Port Bay on the west coast of Newfoundland. The survey's main objective was to describe the fish egg and larva distribution from this area and measure the larva abundance of commercial species including capelin (*Mallotus villosus*) and Atlantic herring (*Clupea harengus*). During the survey, the eggs from three species and three groups of species were identified as well as the larvae from 20 species, including capelin, cunner (*Tautogolabrus adspersus)*, Atlantic herring, flounder (Pleuronectidae spp.), Atlantic cod (*Gadus morhua*) and Atlantic mackerel (*Scomber scombrus* L.). The average abundance of capelin larvae was estimated by kriging to be 694 larvae / 1,000 m^3 compared with 211 larvae / 1,000 m^3 for Atlantic herring. Various biodiversity measurements indicate that the larval community structure was characterized at the time of the survey by the occurrence of a large number of scarce species and by commercial species concentrated in different areas. Cluster and ordination analyses applied to the Bray-Curtis similarity index helped establish groups of stations characterized by the occurrence and abundance of certain species in particular. Significant differences in average temperature and salinity were recorded between these groups. However, these differences aren't large enough to show a link between the specific larval composition at each group of stations and these two environmental variables.

RÉSUMÉ

Grégoire, F., W. Barry, and J. Barry. 2006. West coast of Newfoundland capelin (*Mallotus villosus* M.) and Atlantic herring (*Clupea harengus harengus* L.) larval survey, part 2: Abundance estimates and marine community analyses of the data collected in partnership with the industry (Barry Group) in July 2004. Can. Tech. Rep. Fish. Aquat. Sci. 2650: viii + 50 pp.

En partenariat avec le Groupe Barry de Corner Brook, un relevé larvaire a été réalisé du 15 au 17 juillet 2004 entre les baies de Bonne Bay et de Port au Port sur la côte ouest de Terre-Neuve. L'objectif principal visé par ce relevé était de décrire la distribution des œufs et des larves de poissons présents dans cette zone et de mesurer l'abondance des larves des espèces commerciales comme le capelan (*Mallotus villosus*) et le hareng (*Clupea harengus*). Lors du relevé, les œufs de trois espèces et de trois groupes d'espèces différents ont été identifiés de même que les larves de 20 espèces différentes dont celles du capelan, de la tanche-tautogue (*Tautogolabrus adspersus*), du hareng, de la plie (Pleuronectidae spp.), de la morue (*Gadus morhua*) et du maquereau (*Scomber scombrus* L.). L'abondance moyenne des larves de capelan a été estimée par krigeage à 694 larves / 1000 m^3 comparativement à 211 larves / 1000 m^3 pour celle du hareng. Différentes mesures de biodiversité indiquent que la structure de la communauté larvaire était caractérisée au moment du relevé par la présence d'un grand nombre d'espèces peu abondantes et par des espèces commerciales qui étaient concentrées à des endroits différents. Des analyses de groupement et d'ordination appliquées sur l'indice de similarité de Bray-Curtis ont permis d'établir des groupes de stations caractérisés par la présence et l'abondance de certaines espèces en particulier. Des différences significatives dans les températures et les salinités moyennes ont été mesurées entre ces groupes. Cependant, ces différences ne permettent pas d'établir de liens entre la composition larvaire spécifique à chacun des groupes de stations et ces deux variables environnementales.

1.0 INTRODUCTION

Data concerning the biology of commercially exploited marine species stem mainly from research surveys and sampling at sea or from dockside catches (Hilborn and Walters, 1992). The two main objectives related to the collection of these data are abundance assessment and producing scientific advice for resource managers. In general, most of these data are incomplete because they are only associated with the adult component of the evaluated species (Fuiman, 2002). A more complete and ecological approach to the situation would be studying the development of these species, where they reside and grow, and the relationships they have with other species.

Studying the early developmental stages of marine fish has significantly contributed to generating the basic concepts of stock management (Rutherford, 2002). For instance, plankton surveys have helped to describe distribution, determine the spawning period and calculate the abundance, mortality and growth of eggs, larvae and juveniles from several commercial species (Hempel, 1973). Such surveys contributed to increasing the knowledge of the biology of several commercial species, their movements, and the different habitats they use for wintering, spawning and feeding (Rutherford, 2002).

The occurrence of fish eggs and larvae can be strongly correlated to adult abundance (Rutherford, 2002). Hensen (Smith, 1994), in the 1880s, was the first to suggest measuring adult abundance according to egg quantities found in spawning areas. The first abundance assessment of a commercial species, plaice (*Pleuronectes platessa*) from the southern part of the North Sea, was conducted according to this approach in the early 1900s by Buchanan-Wollaston (1923). Since then, fish egg and larva sampling has also been used to measure the decline or the abundant return of several species such as striped bass (*Morone saxatilis*) in Chesapeake Bay (Rutherford, 2002), capelin (*Mallotus villosus*) in Barents Sea (Fossum, 1992) and Atlantic herring (*Clupea harengus harengus*) on Georges Bank (Overholtz et al., 2004). In the last case, the abundance index stemming from larva sampling was even used for calibrating a sequential population analysis. The abundance of eggs measured at spawning sites was also used to calculate the reproductive biomasses of mackerel (*Scomber scombrus* L.) in the northern Atlantic since 1977 (ICES, 2003) and the northern Gulf of St. Lawrence since 1983 (DFO, 2004).

Because of the absence of an abundance survey for capelin and Atlantic herring off the west coast of Newfoundland, detailed and complete scientific advice concerning their abundance and acceptable catch levels can no longer be issued (DFO, 2005a, 2005b). This is a delicate situation because these two species are important to the economy of several communities in this region. However, thanks to the financial support of the Barry Group in Corner Brook, NL, a plankton survey was conducted in July 2004 in order to describe the distribution and measure larva abundance for these two species. The area covered by this survey was just off-shore between Bonne Bay and Port-au-Port Bay (Figure 1). This region off the west coast of Newfoundland, which is associated with capelin and Atlantic herring spawning areas, had never been covered by this type of survey. The data collected was also used to measure specific abundance and to describe the biological diversity of the ichthyoplankton community present in this study area. A data compilation is presented in Grégoire et al. (2005).

2.0 MATERIAL AND METHODS

2.1 Study area and sampling procedures

The survey was conducted between 15 and 17 July 2004 on board the *Ocean Provider*, a large seiner, in an area just off the coast between Bonne Bay and Port-au-Port Bay (Figure 1). There is an active commercial fishery in this area from April to June and from September to December. The spring fishery is associated with the successive migrations of Atlantic herring and capelin that move toward the coast to spawn. In the fall, the commercial fishery in this same area is mostly characterized by large mackerel catches (*Scomber scombrus* L.) (DFO, 2005c).

The 39 stations to be sampled were distributed evenly over the entire study area (Figure 2). At each station, plankton was collected using a bongo-type sampler (Posgay and Marak, 1980) equipped with two nets, each having a 61-cm opening and 333-micron mesh. A General Oceanics flowmeter was installed near the opening of one of the two nets to measure the volume of water filtered. Tows lasted a minimum of 10 minutes and followed a saw-tooth pattern (Hempel, 1973) between the surface and a maximum depth of 50 m, or down to 5 m off-bottom for shallower stations. A CTD probe (Sea-Bird Electronics, Inc.) was permanently installed on the sampler's frame to obtain salinity and temperature readings for the sampled portion of the water column. On deck, the nets were hung and washed with salt water. Plankton samples from one of the two nets were fixed in a diluted solution (4-5%) of buffered formaldehyde (Hunter, 1985) and those from the other net in a concentrated ethanol solution (95%).

2.2 Laboratory analyses

Plankton sorting was carried out in the laboratory at the Maurice-Lamontagne Institute (Fisheries and Oceans, Mont-Joli, QC) in the fall of 2004. To reduce the time required for analysis, each sample was fractioned according to the Van Guelpen beaker technique (Van Guelpen et al., 1982). The criteria used for identifying fish eggs and larvae are described in Fritzsche (1978), Elliott and Jimenez (1981), and Fahay (1983). Egg and larva counts were recorded, validated and standardized to 1,000 m^3 of filtered water.

2.3 Geostatistical abundance estimates of the most important commercial species

Abundance data (no./1,000 m^3) for eggs and larvae from the most important commercial species were compared between different pairs of stations using a semi-variance calculation defined as follows:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} \left[z(x_i) - z(x_i + h) \right]^2$$

where:

h = a distance vector with a value and a direction
$N(h)$ = the number of pairs of stations used for the $\gamma(h)$ calculation

and

$z(x_i)$ and $z(x_i + h)$ are the abundances measured at the sampling stations where position coordinates are (x_i) and $(x_i + h)$.

The $\gamma(h)$ semi-variance was calculated for various h values using the GS^+ software (Robertson, 1998). The extreme abundance values were not used in this calculation (Isaaks and Srivastava, 1989). Variograms were modelled using values of $\gamma(h)$ as a function of the h values. The choice of a model is based on the spatial pattern at the time of sampling. The occurrence of anisometry, i.e., a different relationship between semi-variance and distance based on the direction of the stations, was verified by the semi-variance calculation for all possible pairs of stations and for different directions (Isaaks and Srivastava, 1989).

The average abundances of eggs and larvae for the sampled areas, or kriging averages, as well as their variances were calculated with the EVA II software (Petitgas and Lafont, 1997) using the variogram parameters calculated by GS^+ as: (1) range, A_0, (2) nugget effect, C_0, and (3) C, which corresponds to the value of the plateau, C_0+C, minus the value of the nugget, C_0. The C and C_0 parameters were corrected for the variograms that were modelled without extreme abundance values. The correction factor, q, that was applied to these parameters is defined as follows:

$$q = \left[{S_b^2}/{S_a^2} \right]$$

where:

S^2_b represents the variance associated with all data and S^2_a the variance calculated without the extreme values. The new parameters used in EVA II were calculated in the following way:

$$C_0^{'} = q \; C_0$$

and

$$C^{'} = q \; C$$

2.4 Biodiversity measures

The structure of the larval community in the study area was described by examining the number of species per abundance class, the total number of species (species richness) and of individuals (Hill number) found per station as well as by the four following diversity indices: (1) Shannon, (2) Brillouin, (3) Fisher, and (4) Margalef. These indices, which are among the most widely used, help measure different attributes of the larval community (Clarke and Warwick, 2001).

The Shannon index is defined in the following way (Legendre and Legendre, 1998):

$$H' = \sum_i p_i \log(p_i)$$

where:

p_i represents the proportion of larva abundance of species i. This index, which was measured at each sampling station, assumes that every species present in the area will be found in a randomly taken sample (Legendre and Legendre, 1998). If this is not the case, Pielou (1966) suggested using the Brillouin (1956) index, which is defined as follows:

$$H_B = \frac{\log N! - \sum_i \log n_i!}{N}$$

where:

N represents the total number of larvae and n_i the number of larvae from species i.

The Fisher index (Fisher et al., 1943) is used when species abundance values follow a logarithmic distribution. This index is calculated as follows:

$$F = a\ x \log\left(1 + \frac{N}{a}\right)$$

where:

a is a shape parameter. Finally, the Margalef (1951) index, which measures species richness, is written as follows:

$$d = (S - 1) / \log(N)$$

where:

S represents the total number of species.

These indices were calculated for each sampled station. The results were compared among stations and for the entire study area.

2.5 Marine community analyses

The larval communities present in the study area were also studied according to the multivariate approach. The Bray-Curtis (S_{jk}) similarity index was first calculated between each pair of stations.

This index is strongly recommended by Clarke and Warwick (2001) for studying marine communities. It 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 of species i from station j (i=1,2,...,p; j=1,2,…,n) and y_{ik} the abundance of species i from station k. Because larval abundance can greatly vary from one species to another, the y_{ij} values were standardized by dividing the abundance of a species at one given station by the sum of all abundances for this same species at all the stations.

2.5.1 Cluster analysis

Groups of stations were formed using the Bray-Curtis index and the hierarchical cluster analysis according to average association (UPGMA) (Legendre and Legendre, 1998). The use of this type of analysis presupposes that there is no gradient in community structures (McGarigal et al., 2000). The results concerning various similarity levels were examined because there is no consensus regarding the methods for determining the number of data clusters (McGarigal et al., 2000).

2.5.2 Species contribution

Groups defined by cluster analysis were described in terms of each species' contribution. To achieve this, the average abundance of each species was calculated for all stations belonging to each group.

2.5.3 Multi-dimensional scaling

In order to better define the possible relationships between different groups defined by a cluster analysis, Clarke and Warwick (2001) suggest that ordination techniques be applied to the same data. These techniques are also used in the presence of a regular gradient in ecological communities structures (McGarigal et al., 2000). In the case of the current study, the non-metric multidimensional scaling was used since, according to Everitt (1978), it represents the best technique for describing in a small number of dimensions the complex relationships that may exist in community structures. The effectiveness of non-metric multidimensional scaling to describe theses relationships was measured by using stress, a parameter that is described by Clarke and Warwick (2001). The Bray-Curtis index calculation, the cluster analysis and the non-metric multidimensional scaling were performed using the PRIMER software, version 5.2.9 (Clarke and Gorley, 2001).

2.6 Water temperature and salinity

Average temperature and salinity for the first 10 metres were calculated and compared between the various groups defined by cluster analysis. For all the stations, the first 10 m represent the layer of water above the thermocline (Grégoire et al., 2005).

3.0 RESULTS

3.1 Stations and set characteristics

The 39 stations of the study area were all sampled during the survey. The Bay of Islands stations were visited first followed by those offshore in the direction of Port-au-Port Bay (Figure 2). Stations located near the coast were sampled towards the end of the survey, from Port-au-Port Bay to the Bay of Islands. Sampling was conducted during the day at an average depth of 34.6 m (Table 1). The average tow length was 11 minutes and filtered volumes varied between 175 m^3 and 395 m^3.

3.2 Egg distribution and abundance

Fish eggs were found at every sampling station. Three species and three different groups of species were identified. The largest group was CYT (cunner [*Tautogolabrus adspersus*] and yellowtail flounder [*Limanda ferruginea*]), with an average abundance of 5,910 eggs per 1,000 m^3, compared with CHW (Atlantic cod [*Gadus morhua*], haddock [*Melanogrammus aeglefinus*] and witch flounder [*Glyptocephalus cynoglossus*]) and H4B (hake [*Urophycis* spp.], fourbeard rockling [*Enchelyopus cimbrus*] and butterfish [*Peprilus triacanthius*]), with respective average abundances of 581 and 257 eggs per 1,000 m^3 (Table 2). Next in abundance were mackerel (*Scomber scombrus* L.), with 73 eggs per 1,000 m^3, followed by American plaice (*Hippoglossoides platessoides*) and windowpane flounder (*Scophthalmus aquosus*), with respective average abundances of 9 and 8 eggs per 1,000 m^3.

Mackerel eggs and those from the CYT and CHW groups were found at almost every station (Figure 3). Most of the American plaice eggs were found at the Bay of Islands stations, whereas the H4B group and windowpane flounder eggs were found at the Port-au-Port Bay stations.

3.3 Larva distribution and abundance

Fish larvae were also found at every sampling station. Among the 20 identified species, the most abundant were capelin (*Mallotus villosus*), cunner (*Tautogolabrus adspersus)*, Atlantic herring (*Clupea harengus harengus)*, flounder (Pleuronectidae spp.) and Atlantic cod (*Gadus morhua),* with respective average abundances of 790, 277, 216, 53 and 45 larvae per 1,000 m^3 (Table 3).

Capelin larvae were found at 38 of the 39 sampled stations. Stations with the fewest larvae from this species were located in the northeastern part of the study area (Figure 4). Stations with the most cunner larvae were those found at the head of the Bay of Islands and Port-au-Port Bay. Atlantic herring larvae were mostly found in the northeastern part of the study area compared with flounder and Atlantic cod larvae, which were more abundant at stations located offshore from Port-au-Port Bay.

Mackerel larvae were found mostly in the southwestern part of the study area. Larvae from the radiated shanny (*Ulvaria subbifurcata*) were not very abundant but were found almost everywhere compared with larvae from the Arctic shanny (*Stichaeus punctatus*), sand lance (*Ammodytes* sp.) and snailfish (*Liparis* sp.), which were mostly found in the northeastern part of the study area. Certain less abundant larvae were mostly found at the head of the Bay of Islands and Port-au-Port Bay, such as fourbeard rockling and winter flounder (*Pseudopleuronectes americanus*), whereas others were only found at a few stations.

3.4 Abundance of the most important commercial species as derived by geostatistics

The spatial variations in the abundance data variance were modelled using a spherical variogram for eggs from American plaice and from the CHW group as well as for Atlantic cod larvae; an exponential variogram was used for capelin, Atlantic herring and mackerel larvae (Table 4, Figure 5). All these variograms had high correlation ratios and no anisometry was recorded.

Kriging maps indicate that abundance areas for these species were located in different regions of the study area. Atlantic herring larvae were mostly found in the Bay of Islands area, followed by capelin larvae in the south and mackerel larvae in the Port-au-Port Bay area (Figure 6). The highest abundances of CHW eggs and Atlantic cod larvae were mostly recorded offshore. Finally, most of the American plaice eggs were found in the immediate Bay of Islands region.

The average abundances calculated by kriging show results similar to those obtained using the arithmetic average (Table 5). However, kriging considerably reduced the variance around the average values (Figure 7). In the case of pelagics, average abundances estimated by kriging were 693.7 larvae / 1,000 m^3 for capelin and 211.0 larvae / 1,000 m^3 for Atlantic herring (Table 5).

3.5 Biodiversity

The survey was characterized by the presence of a large number of larval species with low abundance and a smaller number of species with higher abundance (Figure 8). The number of sampled species varied greatly from one station to another (Figure 9A). Stations with the lowest number of species were mostly observed in Port-au-Port Bay (Figure 10). A very high number of larvae were also sampled at certain stations near the coast (Figure 9B). The four diversity indices show identical trends (Figure 9C). The highest values were found in the Bay of Islands region (Figure 10).

3.6 Cluster analysis, ordination, and species contribution

Different groups of stations were formed according to the cluster analysis results and four similarity levels: 40%, 50%, 60% and 70% (Figure 11). A total of four groups were created at the 40% and 50% similarity levels. In terms of abundance, these groups feature the following species: group A, flounder, Atlantic cod and capelin larvae; group B, capelin larvae; group C, cunner larvae; and group D, Atlantic herring and capelin larvae (Figure 12).

A total of eight groups of stations were formed at the 60% similarity level. These groups feature the following species: group A, flounder, Atlantic cod and capelin larvae; group B, Atlantic herring and Atlantic cod larvae; group C, Atlantic cod, capelin and snailfish larvae; group D, Atlantic cod larvae and eight other less abundant but equal species; group E, capelin larvae; group F, capelin and Atlantic herring larvae; group G, cunner and capelin larvae; and group H, Atlantic herring and capelin larvae (Figure 13).

Finally, at the 70% similarity level, 14 groups of stations were formed with the following characteristics: group A, flounder, capelin and Atlantic cod larvae; group B, flounder, Atlantic cod, fourbeard rockling and capelin larvae; group C, Atlantic cod, flounder, Atlantic herring and capelin larvae; group D, Atlantic cod and Atlantic herring larvae; group E, Atlantic cod, capelin and snailfish larvae; group F, Atlantic cod with species of lesser significance; group G, capelin larvae; group H, capelin and cunner larvae; group I, capelin, radiated shanny and flounder larvae; group J, capelin and winter flounder larvae; group K, capelin and snailfish larvae; group L, capelin, Atlantic herring and flounder larvae; group M, cunner and capelin larvae; and group N, Atlantic herring and capelin larvae (Figure 14).

The groups defined according to the four similarity levels occupy different areas within the study area (Figure 15). As an example, for similarity levels of 40% and 50%, group A stations (flounder, Atlantic cod and capelin) are found offshore and in the northeast portion of the study area. Group B stations (capelin) are mostly found in the Port-au-Port Bay and Bay of Islands region compared with a few stations located at the head of these bays for group C (cunner). Finally, stations 10 and 18 forming group D (Atlantic herring and capelin) are found near the coast and in the northeastern portion of the study area.

The groups of stations defined by non-metric multidimensional scaling were rather consistent with those obtained with cluster analysis (Figure 16). The stress value measured was 0.13, which indicates that similarity relationships between stations are well represented in a two-dimensional reduced space (Clarke and Warwick, 2001). Stress values between 0.2 and 0.3 must be treated with caution, and those above 0.3 indicate that the position of the stations in the reduced space is arbitrary.

3.7 Water temperature and salinity

Average temperatures and salinities that were calculated per group of stations (Tables 6 and 7, Figure 17) show significant differences at the similarity levels of 40% and 50% (temperature: ANOVA, $F=99.44$, $p<0.0001$; salinity: ANOVA, $F=63.79$, $p<0.0001$). Tukey's a posteriori test indicates that only groups A and C do not show any significant average temperature difference compared with groups B and D and C and D for average salinity.

Significant average temperature and salinity differences were recorded between groups of stations defined at the similarity level of 60% (temperature: ANOVA, $F=43.97$, $p<0.0001$; salinity: ANOVA, $F=31.25$, $p<0.0001$). For average temperatures, the Tukey's test indicates that group G is different from all other groups; group E is different from all other groups except for F and H. Significant differences were also recorded between groups A and F. For average salinity, significant differences were only recorded for groups B, C, D, for groups A and B, and finally for groups E, F, G, H.

Significant differences in average temperature and salinity were also recorded for groups of stations defined by the similarity level of 70% (temperature: ANOVA, $F=25.88$, $p<0.0001$; ANOVA, $F=34.54$, $p<0.0001$). Among all the groups for which significant differences were recorded using the Tukey's test, groups M for average temperature and J for average salinity were significantly different from all the other groups.

4.0 DISCUSSION

The sampling of fish eggs and larvae in the Gulf of St. Lawrence was carried out for the first time during the Dannevig expedition of 1914-1915 (Dannevig, 1919). At that time, only 23 stations were sampled along two transects, the first between Prince Edward Island and the eastern tip of Anticosti Island and the second from the eastern tip of Anticosti to the west coast of Newfoundland. Several other surveys of fish egg and larva distribution in general or for a particular species have been conducted since the early 1960s, albeit with limited space and time coverage (Bergeron and Lacroix, 1963; Kennedy and Powles, 1964; Lacroix and Bergeron, 1964; Bailey et al., 1975; Jacquaz et al., 1977; Able, 1978; Leggett, 1978; Beacham and Schweigert, 1980; de Lafontaine et al., 1981; 1984; Johnson and Morse, 1988; Fortier et al., 1991; 1992; Kenchington, 1991; Ouellet et al., 1997 and Sévigny et al., 2000). The first large-scale surveys were carried out between 1965 and 1975 by Kohler et al. (1974a, 1974b, 1975, 1976, 1977) for the southwestern Gulf of St. Lawrence and by Ouellet (1987) from 1985 to 1987 and Ouellet et al. (1994) in 1991 and 1992 for the northern and northwestern Gulf. During the Kohler and Ouellet surveys, a certain number of stations were sampled in St. George's Bay off the west coast of Newfoundland. This bay was also sampled during the Hodder and Winters (1972) survey as well as during the mackerel abundance surveys in 1989 (M. Castonguay, pers. comm.) and 2004 (F. Grégoire, unpublished data). However, the area sampled in July 2004 had never previously been covered by a bongo net survey, of which the main objective was to collect capelin and Atlantic herring larvae. The results from this survey can therefore not be compared with other surveys that may have been carried out in this area.

A large number of eggs and larvae of different fish species were sampled during the July 2004 survey. Capelin larvae dominated by their abundance as well as by their distribution range. In fact, they were found at 38 of the 39 stations sampled. The other species of commercial interest included Atlantic herring, Atlantic cod and mackerel larvae, with the highest concentrations found in different regions of the sampled area. A few mackerel larvae had been sampled during the 1989 survey in St. George's Bay. The presence of mackerel eggs and larvae in this bay as well as in the sampled area in 2004 shows that adults were present in this region as early as July. This observation is important because it is generally accepted that mackerel spawning occurs mostly in the southern Gulf of St. Lawrence (Sette, 1943; Arnold, 1970; MacKay, 1979). It is also accepted that spawning can occur all along the mackerel's spring range, from the Scotian Shelf towards the Gulf of St. Lawrence. For example, eggs had previously been sampled during a survey with industry in St. Margaret's Bay near Halifax, Nova Scotia, in 1999 (Bernier and Lévesque, 2000). Mackerel larva abundances measured in July 2004 were inferior to those measured in the southern Gulf (F. Grégoire, unpublished data), which could mean: (1) that there were few adults at this time of year, or (2) that spawning was almost over. However, because the first large commercial catches are only made at the end of August, it is possible that few adults were present in the study area at the time of the July 2004 survey.

Other surveys will have to be carried out in this area to compare the abundances measured as well as egg and larva distribution to values recorded in 2004. Even if significant differences were found in terms of average water temperature and salinity among the different groups of stations defined by cluster and ordination analysis, there can be no conclusion as to the possible links between these environmental data and the abundance and distribution data. Other more in-depth analysis will have to be carried out on this subject.

The July 2004 survey was conducted with the active collaboration of industry. It represents a concrete example of the type of partnership that is possible between the users of the resource and scientists, whose primary role is to evaluate the condition of this resource.

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Table 1. Description of the stations and sets sampled during the capelin and Atlantic herring larval survey of July 2004 on the west coast of Newfoundland.

STATION NUMBER	DATE (yyyy-mm-dd)	TIME OF THE DAY (hh:mm) (NDT)	LATITUDE °N (degrees minutes)	LONGITUDE °W (degrees minutes)	DEPTH Station bottom (m)	DEPTH Maximum sampled (m)	TOW DURATION (min)	VOLUME OF WATER FILTERED (m^3)
1	2004-07-15	09:05	49° 09'	58° 12'	118	46	11.0	273
2	2004-07-15	09:55	49° 12'	58° 12'	112	43	10.0	231
3	2004-07-15	15:40	49° 27'	58° 12'	30	25	10.7	268
4	2004-07-15	16:19	49° 30'	58° 12'	30	28	10.7	259
5	2004-07-15	16:53	49° 33'	58° 12'	60	49	11.8	255
6	2004-07-17	11:50	49° 06'	58° 18'	70	54	11.9	332
7	2004-07-17	11:15	49° 09'	58° 18'	125	46	11.7	256
8	2004-07-17	10:35	49° 12'	58° 18'	125	51	12.8	316
9	2004-07-15	10:48	49° 15'	58° 18'	83	56	10.0	240
10	2004-07-15	13:06	49° 18'	58° 18'	25	19	10.6	274
11	2004-07-15	13:43	49° 21'	58° 18'	39	35	10.4	240
12	2004-07-15	14:19	49° 24'	58° 18'	47	45	11.8	288
13	2004-07-15	14:57	49° 27'	58° 18'	53	50	10.8	244
14	2004-07-15	20:58	49° 09'	58° 24'	50	47	11.4	395
15	2004-07-15	20:20	49° 12'	58° 24'	40	33	11.7	284
16	2004-07-15	11:32	49° 15'	58° 24'	40	38	12.0	270
17	2004-07-15	12:23	49° 18'	58° 24'	30	28	12.0	244
18	2004-07-17	09:05	49° 03'	58° 30'	48	45	11.0	279
19	2004-07-16	07:31	49° 06'	58° 30'	80	61	10.4	240
20	2004-07-16	06:51	49° 09'	58° 30'	82	53	12.3	298
21	2004-07-15	19:37	49° 12'	58° 30'	65	53	12.2	257
22	2004-07-17	06:25	48° 51'	58° 36'	45	40	10.8	175
23	2004-07-17	07:07	48° 54'	58° 36'	20	16	10.4	272
24	2004-07-17	07:46	48° 57'	58° 36'	35	31	10.5	263
25	2004-07-16	09:27	49° 00'	58° 36'	50	46	11.3	268
26	2004-07-16	08:51	49° 03'	58° 36'	48	46	10.9	252
27	2004-07-16	08:15	49° 06'	58° 36'	52	46	11.6	281
28	2004-07-16	17:36	48° 39'	58° 42'	25	23	12.1	300
29	2004-07-16	20:14	48° 45'	58° 42'	20	16	10.4	260
30	2004-07-16	13:23	48° 48'	58° 42'	15	11	10.9	244
31	2004-07-16	13:58	48° 51'	58° 42'	15	12	11.5	258
32	2004-07-16	10:56	48° 54'	58° 42'	30	22	9.8	245
33	2004-07-16	10:19	48° 57'	58° 42'	30	24	10.3	253
34	2004-07-16	18:23	48° 36'	58° 48'	15	11	10.0	256
35	2004-07-16	19:06	48° 39'	58° 48'	15	12	10.6	268
36	2004-07-16	16:38	48° 42'	58° 48'	15	13	11.4	251
37	2004-07-16	12:38	48° 48'	58° 48'	20	13	10.3	247
38	2004-07-16	11:46	48° 51'	58° 48'	42	39	10.9	249
39	2004-07-16	15:52	48° 51'	58° 54'	15	14	10.4	245
Mean					47.7	34.3	11.0	264.9
Std. Dev.					31.3	15.4	0.8	33.5
Minimum					15	11	9.8	175
Maximum					125	61	12.8	395
n					39	39	39	39

Table 2. Abundance of eggs (no./1000 m^3) from the samples collected during the capelin and Atlantic herring larval survey of July 2004 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	59	59	264	3 140	0	29
2	0	39	208	2 324	0	0
3	0	34	1 015	1 344	60	0
4	0	302	1 454	62	0	0
5	0	28	1 069	0	0	0
6	24	24	361	1 975	24	0
7	23	125	125	10 946	125	0
8	25	82	304	2 585	0	0
9	0	67	467	4 602	33	0
10	11	73	467	4 347	29	0
11	0	125	1 066	200	0	0
12	0	111	890	28	0	0
13	0	33	916	0	0	0
14	20	46	202	2 488	20	0
15	28	7	901	1 098	0	0
16	11	55	355	4 350	30	0
17	33	115	687	654	0	0
18	0	169	294	12 051	22	0
19	0	25	699	2 931	0	0
20	0	30	1 637	617	0	0
21	31	86	1 681	0	0	0
22	46	63	228	3 792	0	0
23	0	143	74	22 125	471	15
24	0	175	365	17 537	0	30
25	0	0	239	30	0	0
26	0	8	1 395	63	0	0
27	28	11	2 876	28	0	0
28	0	90	160	1 625	1 199	0
29	0	73	0	32 013	3 448	0
30	0	213	426	15 847	196	0
31	0	39	371	9 132	186	124
32	0	45	261	293	0	0
33	0	0	379	0	0	0
34	0	43	157	532	501	0
35	0	4	0	29 729	90	30
36	0	72	0	13 586	3 245	32
37	0	247	259	27 855	65	0
38	0	0	385	96	0	0
39	0	0	0	457	294	65
Mean	8.7	73.3	580.5	5 909.8	257.3	8.3
Std. dev.	15.1	71.0	595.9	8 921.7	759.9	23.4
Minimum	0	0	0	0	0	0
Maximum	59	302	2 876	32 013	3 448	124
n	39	39	39	39	39	39

Table 3. Abundance of larvae (no./1000 m^3) from the samples collected during the capelin and Atlantic herring larval survey of July 2004 on the west coast of Newfoundland.

STATION	American plaice	Arctic shanny	Atlantic mackerel	Capelin	Cod	Cottidae	Cunner	Fourbeard rockling	Atlantic herring	Poacher	Redfish	Righteye flounder
1	0	0	4	55	11	0	0	7	15	0	4	4
2	0	0	9	3 504	22	0	178	17	17	0	0	13
3	0	0	0	284	7	0	15	11	0	0	0	26
4	0	0	0	23	46	0	0	35	4	0	4	77
5	0	0	0	59	24	4	0	8	0	0	0	79
6	0	0	9	283	6	0	554	12	0	0	0	27
7	0	0	4	281	31	0	1 251	4	4	0	0	20
8	0	0	0	4 968	51	0	659	6	48	0	0	10
9	0	4	0	442	17	0	29	4	58	0	0	13
10	0	0	4	51	0	0	15	33	171	0	0	0
11	0	0	0	12	37	0	4	0	37	0	0	8
12	0	0	0	35	90	0	3	3	3	0	0	17
13	0	0	8	0	20	0	0	8	4	0	0	8
14	0	0	3	91	10	0	5	3	8	0	0	18
15	0	4	4	387	120	0	21	4	197	0	0	109
16	0	0	0	303	44	0	15	15	141	0	0	11
17	0	12	0	37	78	0	20	8	12	0	0	65
18	0	4	18	3 300	75	0	133	4	6 599	0	0	61
19	0	0	4	71	71	0	8	4	29	0	4	142
20	0	0	7	181	174	0	3	7	74	3	0	121
21	0	0	0	39	101	0	0	8	70	0	0	62
22	0	0	0	640	0	0	160	17	0	0	0	34
23	0	0	37	7 885	11	0	875	0	15	0	0	147
24	0	0	0	1 949	38	0	183	0	746	0	0	160
25	0	0	0	157	149	0	7	0	0	0	0	202
26	0	0	4	79	83	0	12	4	40	0	0	111
27	0	0	4	132	135	0	4	4	32	0	4	139
28	0	0	3	360	3	0	163	17	13	0	0	7
29	0	0	27	496	0	0	5 541	92	0	0	0	8
30	0	0	37	372	0	0	12	8	8	0	0	53
31	0	0	15	244	8	0	104	0	0	0	0	19
32	0	0	0	1 834	0	0	8	0	0	0	0	57
33	0	0	0	229	119	0	0	0	0	0	0	142
34	4	0	0	211	0	0	125	8	31	0	0	8
35	0	0	0	49	0	0	127	26	4	0	0	0
36	0	0	4	199	0	0	270	20	8	0	0	4
37	0	0	129	704	20	0	190	8	36	0	0	8
38	0	0	8	822	160	0	92	0	8	0	0	84
39	0	0	0	37	0	0	16	4	0	0	0	0
Mean	0.1	0.6	8.7	789.8	45.2	0.1	277.0	10.5	216.2	0.1	0.4	53.2
Std. dev.	0.6	2.2	21.9	1 588.8	51.4	0.6	904.3	16.0	1 056.2	0.5	1.2	55.7
Minimum	0	0	0	0	0	0	0	0	0	0	0	0
Maximum	4	12	129	7 885	174	4	5 541	92	6 599	3	4	202
n	39	39	39	39	39	39	39	39	39	39	39	39

Table 3. (Continued).

STATION	Radiated shanny	Sand lance	Snailfish	Stichaeidae	Windowpane flounder	Winter flounder	Witch flounder	Yellowtail flounder	Broken larvae	Not identified
1	0	4	15	0	0	26	0	0	0	0
2	13	4	35	0	0	0	0	0	0	0
3	4	0	0	0	0	0	0	0	0	0
4	8	15	0	0	0	8	0	0	0	0
5	0	4	20	0	0	0	0	0	4	0
6	3	0	0	0	0	12	0	0	0	0
7	0	0	35	0	4	23	0	0	0	0
8	0	0	25	0	0	13	0	0	0	0
9	0	0	13	0	0	42	0	0	0	17
10	47	4	0	0	0	0	7	4	4	0
11	4	8	0	0	0	8	8	0	0	0
12	17	7	31	0	0	7	0	0	0	0
13	0	4	4	4	0	4	0	0	0	0
14	8	0	46	0	0	0	0	0	8	0
15	11	4	4	0	7	0	4	0	0	0
16	30	4	7	0	0	37	0	0	18	0
17	12	4	0	0	0	4	0	0	0	0
18	18	0	7	0	0	32	0	0	18	0
19	12	0	8	0	0	0	0	0	4	0
20	3	0	10	0	0	0	0	0	7	0
21	16	4	35	0	0	0	0	0	0	0
22	0	0	6	0	0	6	0	0	0	0
23	51	0	0	0	15	7	0	0	0	0
24	8	0	15	0	8	0	0	0	0	0
25	37	0	22	0	0	0	0	0	0	0
26	8	0	20	0	4	4	0	0	4	0
27	11	4	4	0	4	0	0	0	11	0
28	10	0	0	0	3	0	0	0	0	3
29	23	0	0	0	0	62	0	0	0	0
30	86	0	4	0	12	16	0	0	4	0
31	35	0	4	0	4	54	0	0	4	0
32	0	0	0	0	0	0	0	0	0	8
33	47	0	0	0	0	0	0	0	0	0
34	4	0	0	0	4	4	0	0	0	0
35	0	0	0	0	0	4	0	0	0	0
36	20	0	0	0	0	4	0	0	4	0
37	32	0	0	0	16	97	0	0	4	0
38	40	0	12	0	0	92	0	0	0	4
39	0	0	0	0	0	0	0	0	0	0
Mean	15.9	1.8	9.8	0.1	2.1	14.5	0.5	0.1	2.4	0.8
Std. dev.	19.0	3.2	12.6	0.7	4.2	24.5	1.8	0.6	4.5	3.0
Minimum	0	0	0	0	0	0	0	0	0	0
Maximum	86	15	46	4	16	97	8	4	18	17
n	39	39	39	39	39	39	39	39	39	39

Table 4. Parameters of the isotropic variograms used to calculate the abundance estimates of some eggs and larvae from the samples collected during the capelin and Atlantic herring larval survey of July 2004 on the west coast of Newfoundland.

SPECIES	MODEL**	Nugget (C_0)	Sill (C_0 + C)	Range (A_0)	R^2	RSS*
EGGS						
American plaice	Spherical	99	260	32.4	0.91	1.469E+03
CHW	Spherical	100	192200	24.9	0.988	1.482E+08
LARVAE						
Capelin	Exponential	238000	579200	11.2	0.932	2.347E+09
Herring	Exponential	35	576	11.2	0.87	9.238E+03
Cod	Spherical	1350	3246	35.8	0.982	3.178E+04
Atlantic mackerel	Exponential	8	86	4.2	0.911	2.140E+01

* Residual sum of squares

** Spherical model
$$\gamma(h) = \begin{cases} 1.5\,\dfrac{h}{A_0} - 0.5\left(\dfrac{h}{A_0}\right)^3 \text{ if } h \le A_0, \text{ and 1 otherwise} \end{cases}$$

Exponential model
$$\gamma(h) = 1 - \exp\left(-\frac{3h}{A_0}\right)$$

Table 5. Abundance estimates (no./1000 m^3) of some eggs and larvae calculated by kriging from the samples collected during the capelin and Atlantic herring larval survey of July 2004 on the west coast of Newfoundland.

	KRIGING			95% CONFIDENCE INTERVAL	
	Average	Std. Dev.	CV	Lower Limit	Upper Limit
EGGS					
American plaice	9.92	1.6	0.16	6.72	13.11
CHW	593.88	25.3	0.04	544.34	643.41
LARVAE					
Atlantic mackerel	9.1	1.6	0.2	6.0	12.1
Capelin	693.7	199.3	0.3	303.1	1084.3
Cod	44.8	6.4	0.1	32.2	57.4
Herring	211.0	73.1	0.3	67.8	354.3

Table 6. Characteristics of the water temperature (°C) in the 0-10 m layer for the groups of stations defined by cluster analysis.

SIMILARITY	GROUP	TEMPERATURE (°C) (0-10m) N*	Minimum	Mean	Maximum	Standard Deviation	Range
40-50%	A	244	10.15	12.74	14.55	0.61	4.40
	B	322	9.58	13.31	15.17	0.76	5.59
	C	92	12.04	14.19	15.62	0.74	3.59
	D	29	12.54	13.16	13.75	0.48	1.21
60%	A	190	10.15	12.77	14.55	0.67	4.40
	B	18	12.14	12.60	13.19	0.34	1.05
	C	20	12.14	12.70	13.49	0.32	1.35
	D	16	12.45	12.55	12.70	0.08	0.25
	E	254	9.58	13.35	15.17	0.82	5.59
	F	68	12.19	13.13	14.23	0.43	2.04
	G	92	12.04	14.19	15.62	0.74	3.59
	H	29	12.54	13.16	13.75	0.48	1.21
70%	A	133	10.15	12.76	14.09	0.72	3.94
	B	18	11.50	13.02	14.55	0.75	3.05
	C	39	12.06	12.71	13.57	0.41	1.51
	D	18	12.14	12.60	13.19	0.34	1.05
	E	20	12.14	12.70	13.49	0.32	1.35
	F	16	12.45	12.55	12.70	0.08	0.25
	G	134	10.40	13.21	14.04	0.59	3.65
	H	100	9.58	13.53	15.17	1.09	5.59
	I	20	13.02	13.46	13.77	0.18	0.75
	J	16	12.19	13.11	13.91	0.48	1.72
	K	16	12.95	13.47	14.23	0.41	1.29
	L	36	12.33	12.99	13.99	0.34	1.67
	M	92	12.04	14.19	15.62	0.74	3.59
	N	29	12.54	13.16	13.75	0.48	1.21

* Number of temperature data recorded by 0.5 m in the 0-10 m layer of water

Table 7. Characteristics of the water salinity in the 0-10 m layer for the groups of stations defined by cluster analysis.

SIMILARITY	GROUP	SALINITY (0-10m)					
		N*	Minimum	Mean	Maximum	Standard Deviation	Range
40-50%	A	244	30.93	31.42	31.68	0.17	0.75
	B	322	29.80	31.18	31.75	0.32	1.96
	C	92	30.79	31.07	31.53	0.13	0.73
	D	29	31.09	31.19	31.28	0.06	0.19
60%	A	190	30.93	31.38	31.62	0.18	0.69
	B	18	31.45	31.50	31.56	0.03	0.11
	C	20	31.47	31.57	31.68	0.06	0.21
	D	16	31.56	31.57	31.59	0.01	0.03
	E	254	29.83	31.18	31.75	0.30	1.92
	F	68	29.80	31.17	31.50	0.38	1.70
	G	92	30.79	31.07	31.53	0.13	0.73
	H	29	31.09	31.19	31.28	0.06	0.19
70%	A	133	30.96	31.40	31.62	0.14	0.66
	B	18	31.12	31.45	31.61	0.15	0.49
	C	39	30.93	31.28	31.62	0.25	0.69
	D	18	31.45	31.50	31.56	0.03	0.11
	E	20	31.47	31.57	31.68	0.06	0.21
	F	16	31.56	31.57	31.59	0.01	0.03
	G	134	29.83	31.21	31.75	0.38	1.92
	H	100	30.68	31.13	31.60	0.18	0.92
	I	20	31.16	31.21	31.31	0.03	0.15
	J	16	29.80	30.58	31.23	0.39	1.43
	K	16	31.21	31.32	31.41	0.05	0.20
	L	36	31.27	31.37	31.50	0.09	0.23
	M	92	30.79	31.07	31.53	0.13	0.73
	N	29	31.09	31.19	31.28	0.06	0.19

* Number of salinity data recorded by 0.5 m in the 0-10 m layer of water

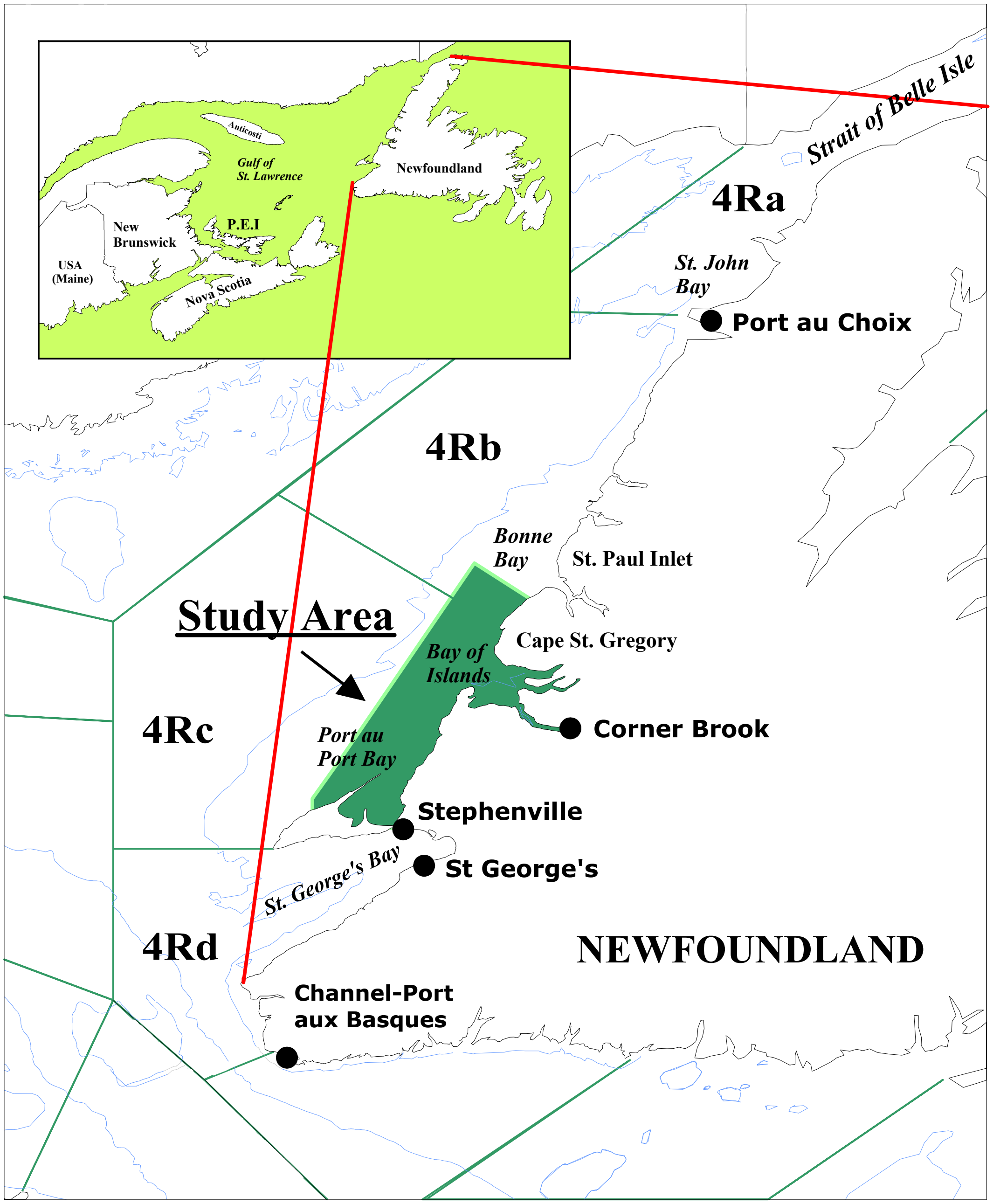


Figure 1. Map of the west coast of Newfoundland showing the study area and the other locations mentioned in the document.

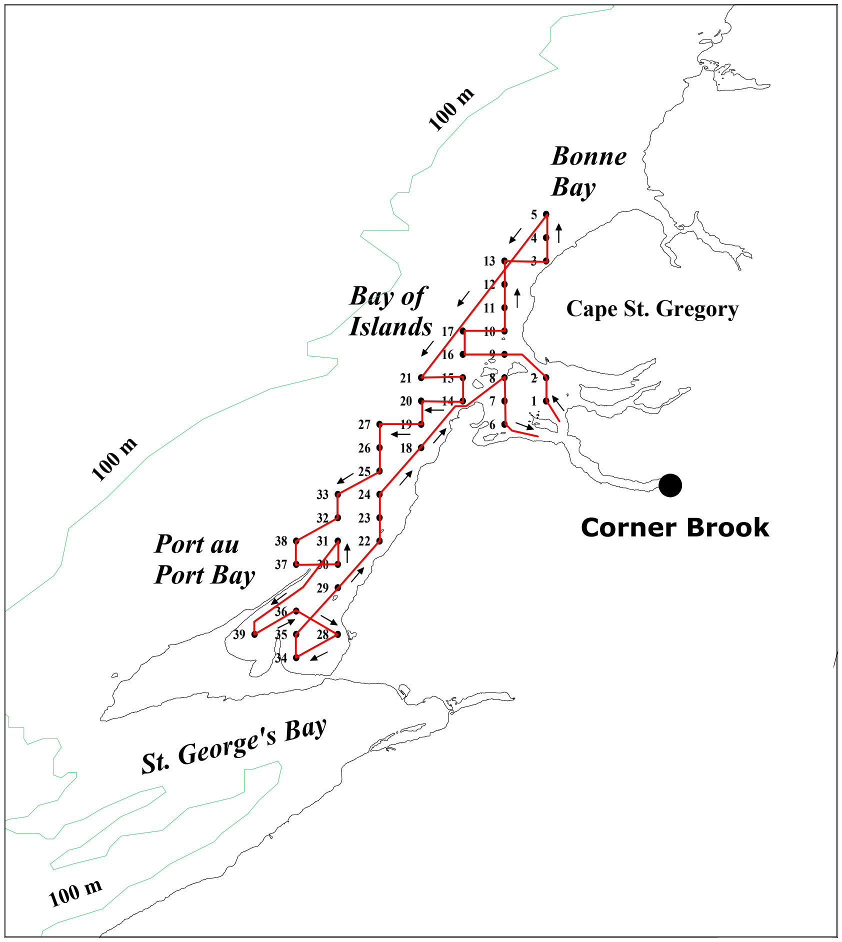


Figure 2. Map of the 39-station sampling grid of the capelin and Atlantic herring larval survey of July 2004 on the west coast of Newfoundland.

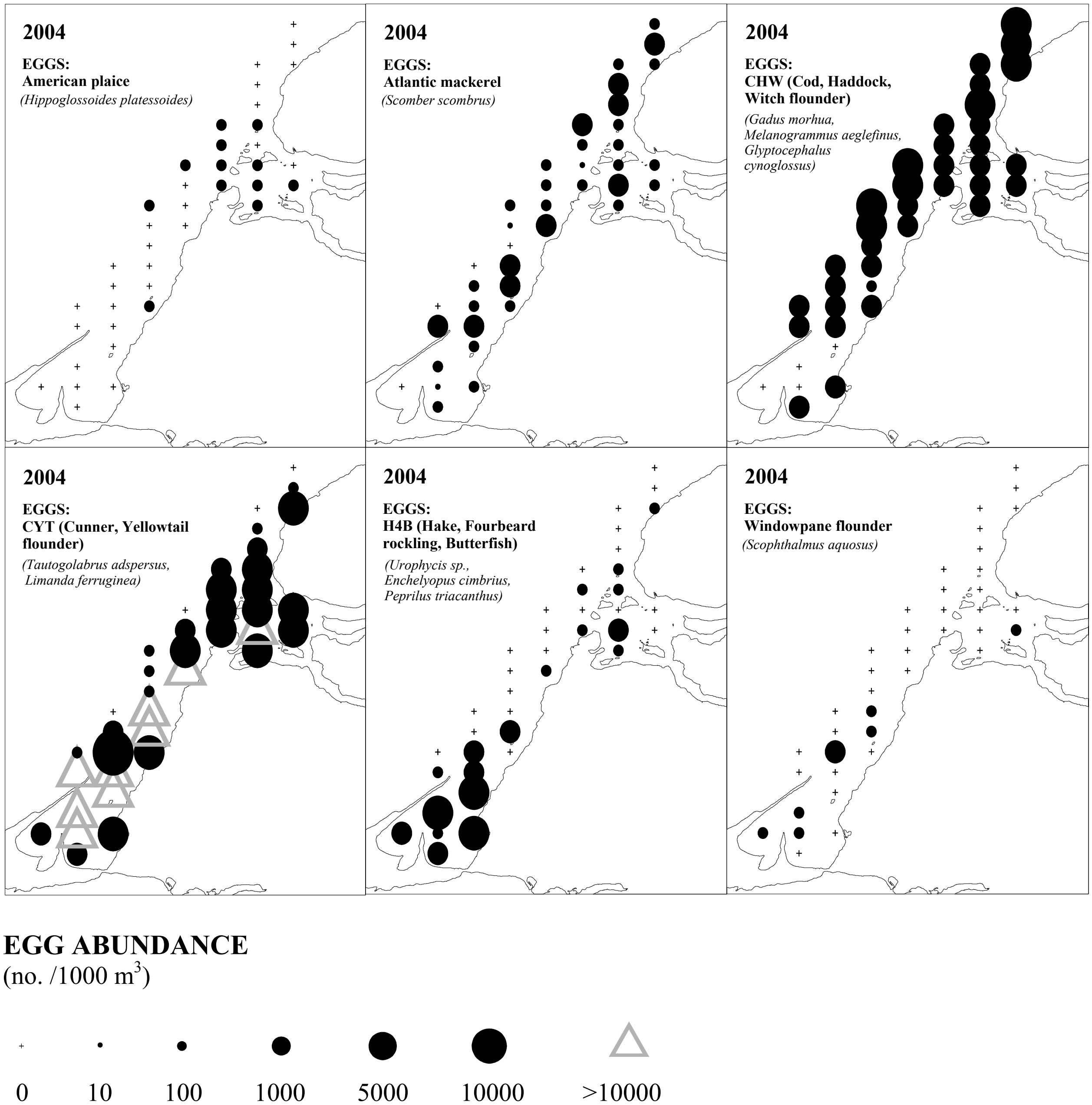


Figure 3. Maps of the egg abundance (no./1000 m^3) distributions from the capelin and Atlantic herring larval survey of July 2004 on the west coast of Newfoundland.

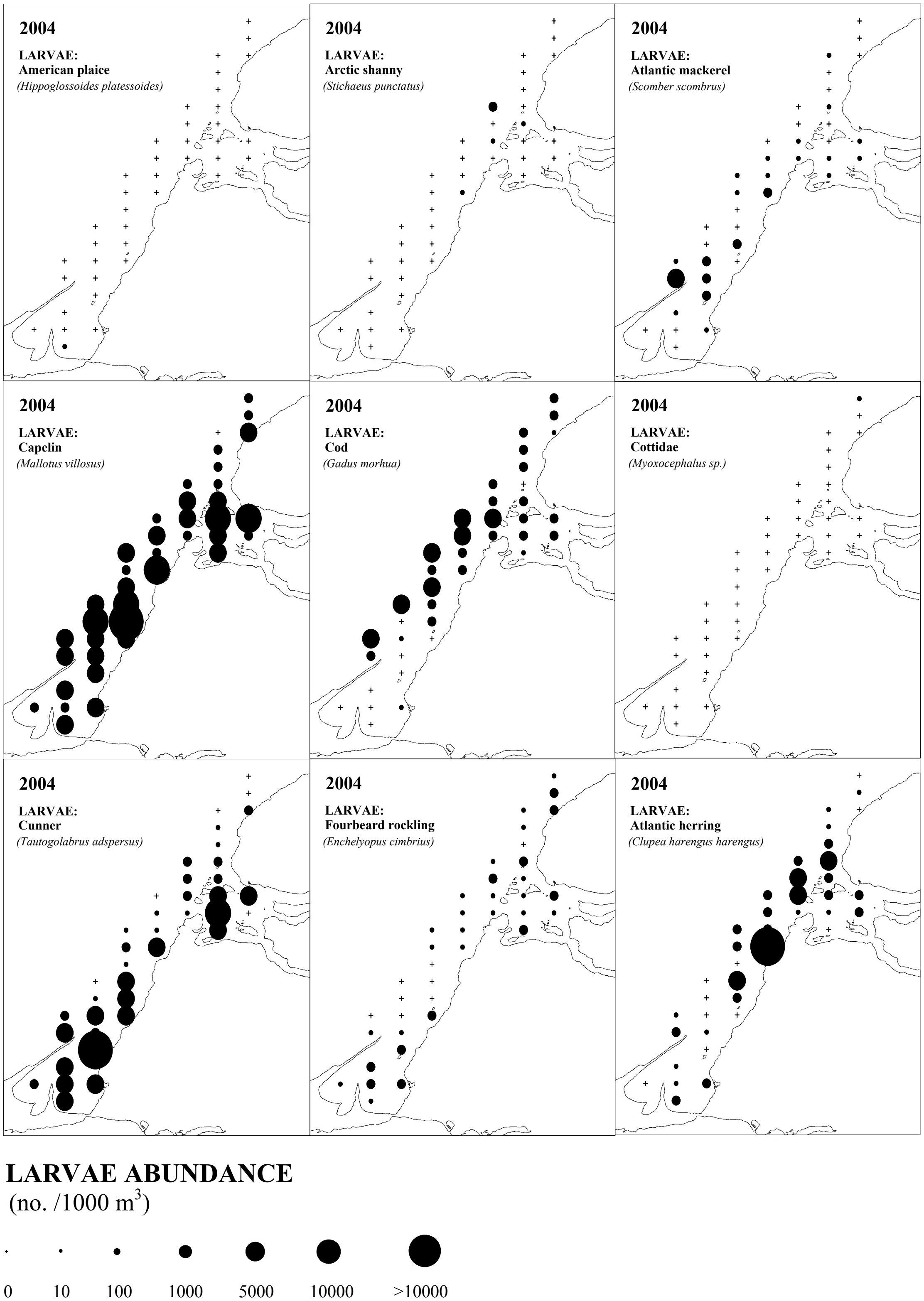


Figure 4. Maps of the larva abundance (no./1000 m^3) distributions from the capelin and Atlantic herring larval survey of July 2004 on the west coast of Newfoundland.

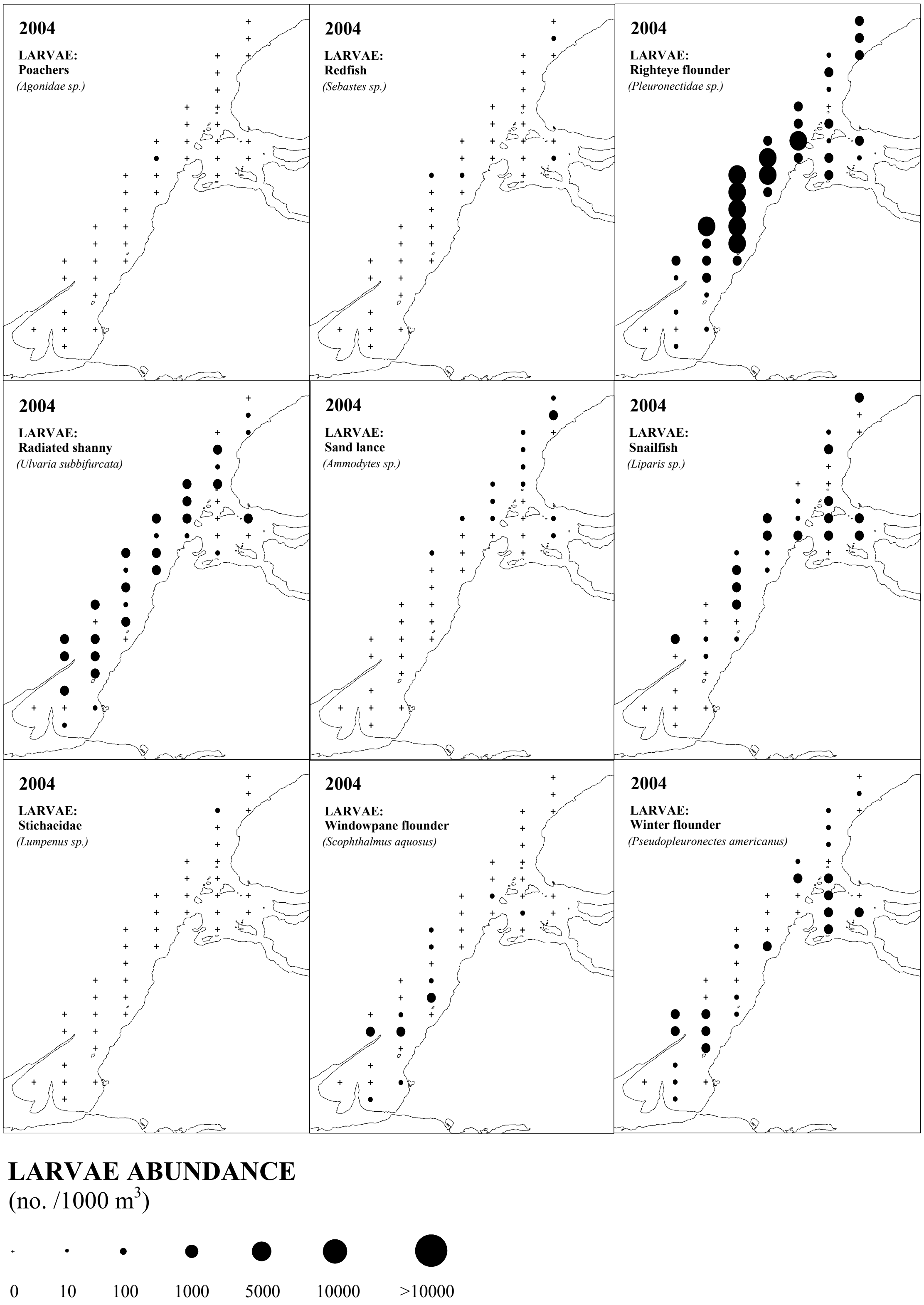


Figure 4. (Continued).

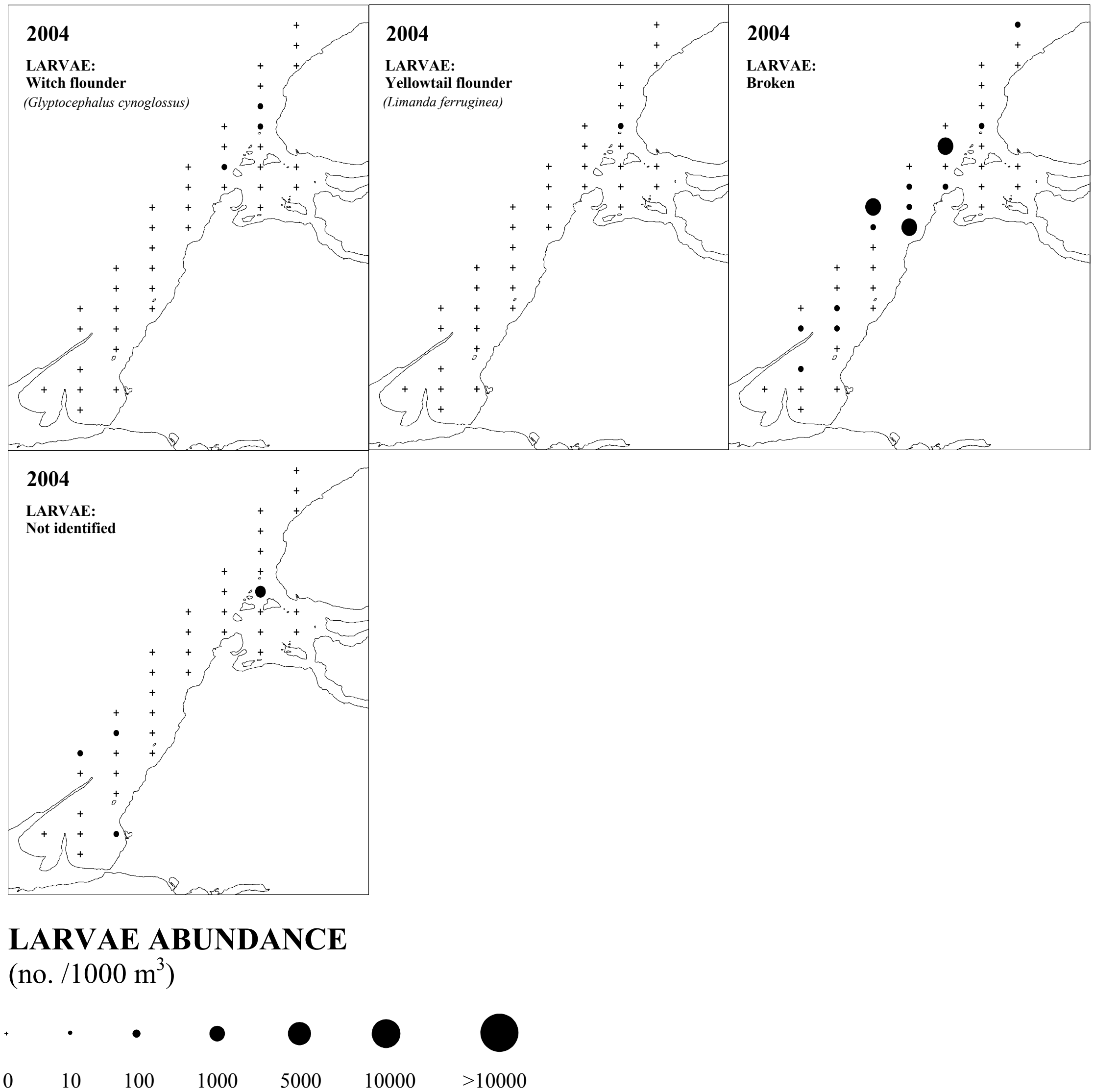


Figure 4. (Continued).

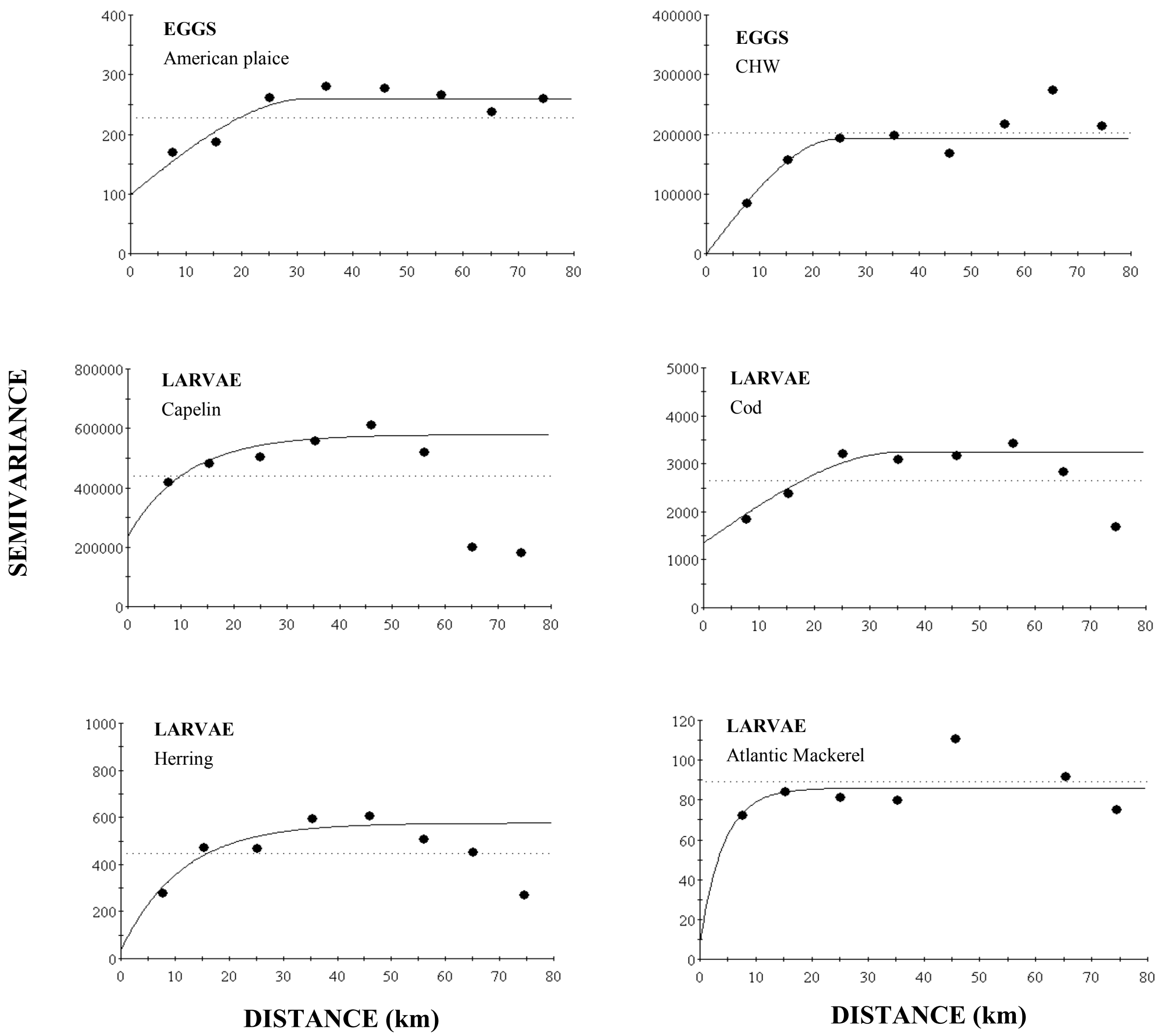


Figure 5. Isotropic variograms of abundance estimates for the eggs and larvae of some species sampled during the capelin and Atlantic herring larval survey of July 2004 on the west coast of Newfoundland (dashed lines represent the variance of the data).

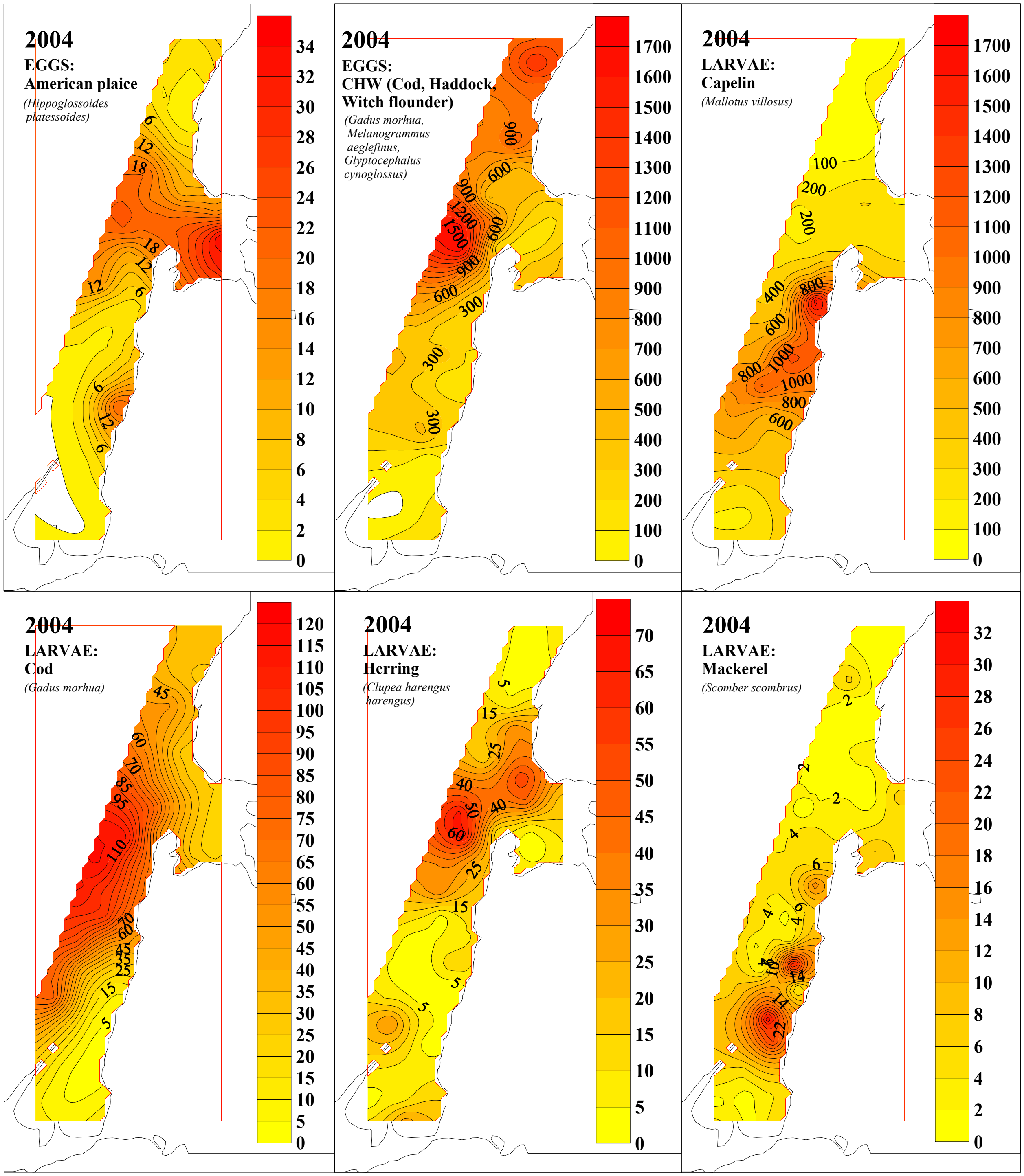


Figure 6. Abundance distribution maps (no./1000 m^3) as derived by kriging of the eggs and larvae of some species sampled during the capelin and Atlantic herring larval survey of July 2004 on the west coast of Newfoundland.

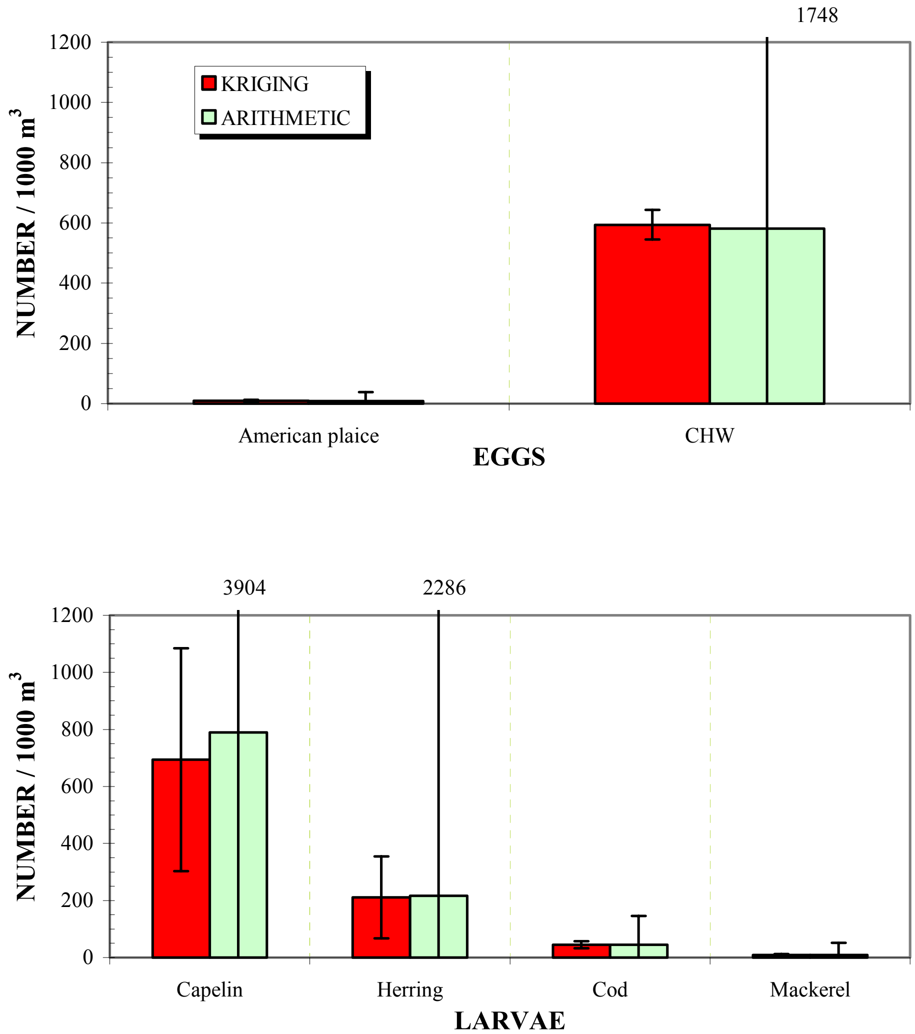


Figure 7. Mean abundance estimates (no./1000 m^3) (with 95% confidence intervals) of the eggs and larvae of some species sampled during the capelin and Atlantic herring larval survey of July 2004 on the west coast of Newfoundland.

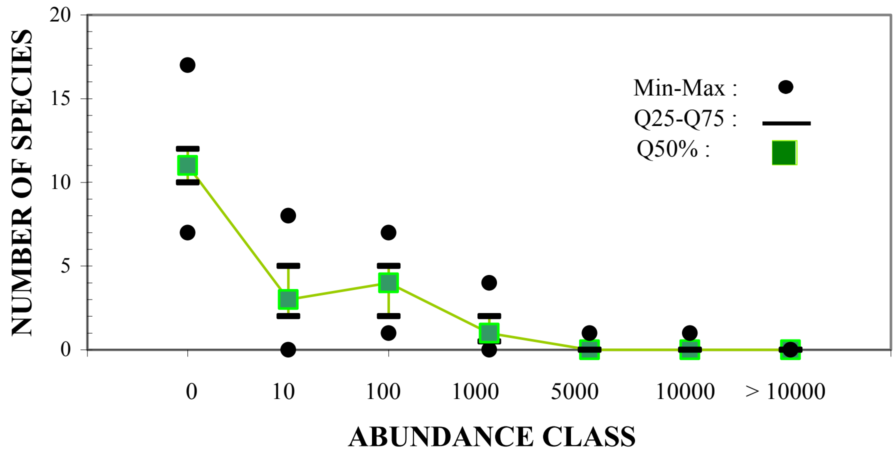


Figure 8. Plots of the number of larval species by abundance class (no./1000 m^3) for the stations sampled during the capelin and Atlantic herring larval survey of July 2004 on the west coast of Newfoundland.

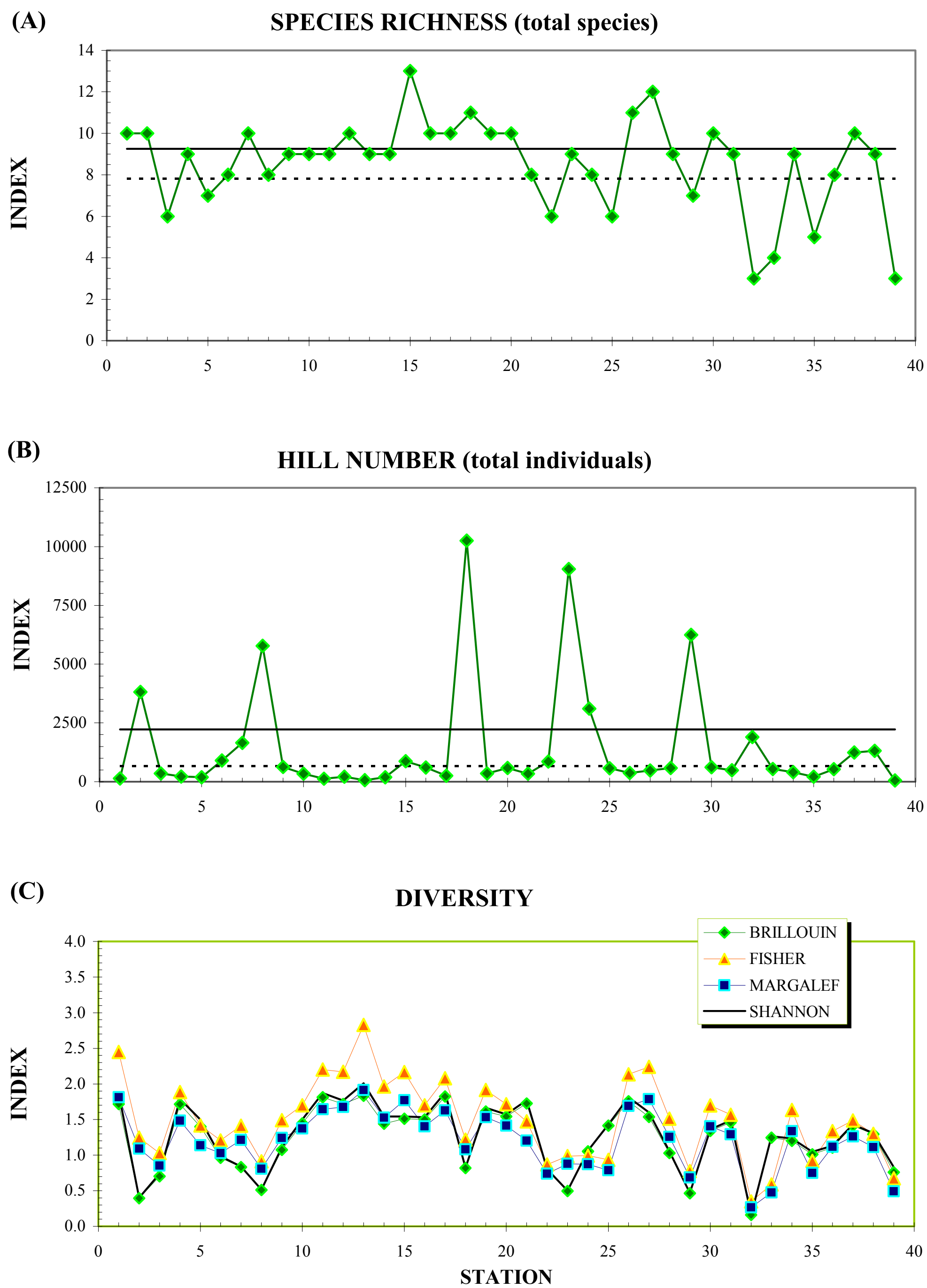


Figure 9. Total species (A), total individuals (B), and diversity indices (C) for the stations sampled during the capelin and Atlantic herring larval survey of July 2004 on the west coast of Newfoundland. The horizontal lines in A and B indicate upper and lower limits of the confidence interval (95%) of the mean of all the stations.

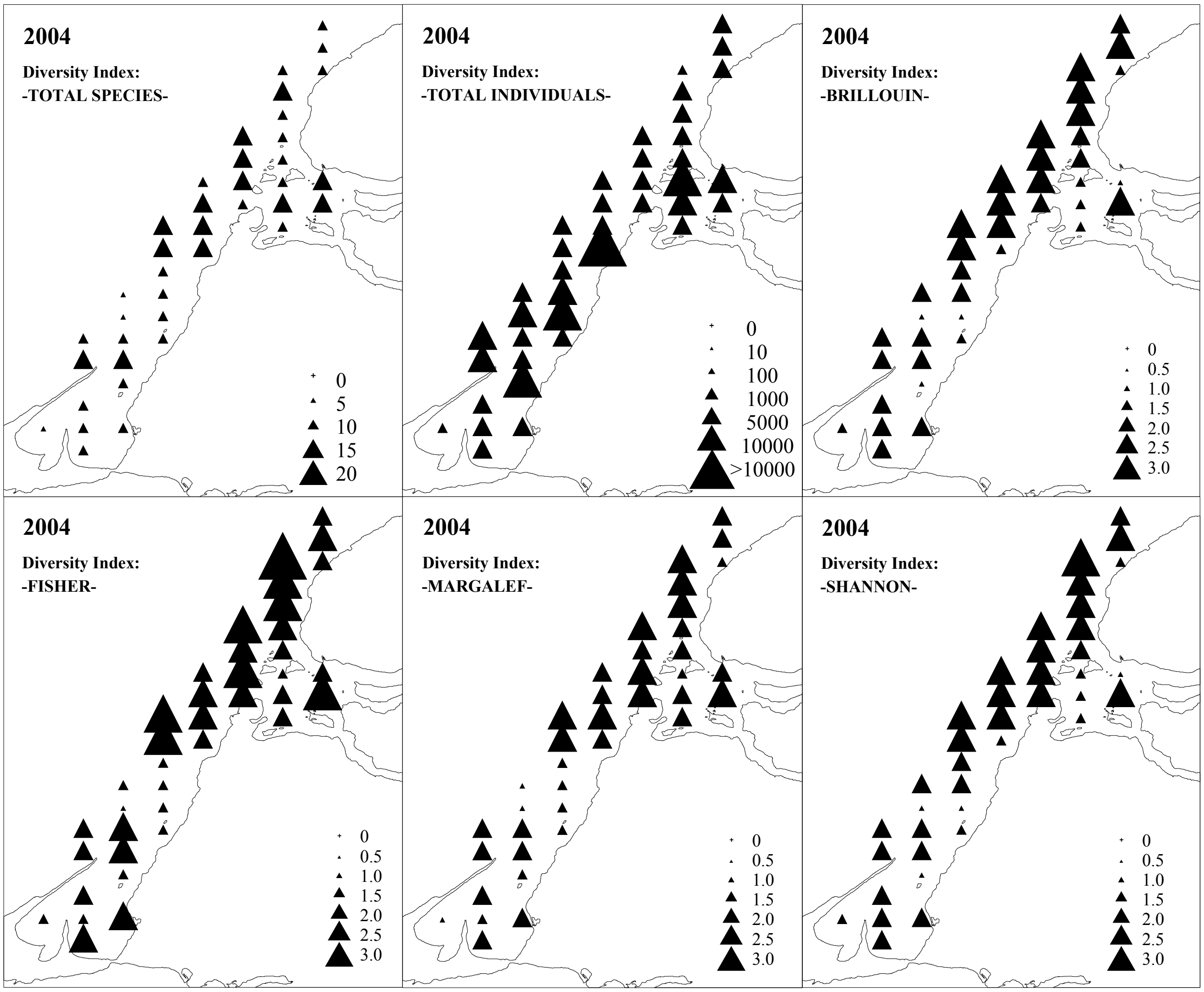


Figure 10. Maps showing the distributions of the total species, total individuals, and diversity indices for the stations sampled during the capelin and Atlantic herring larval survey of July 2004 on the west coast of Newfoundland.

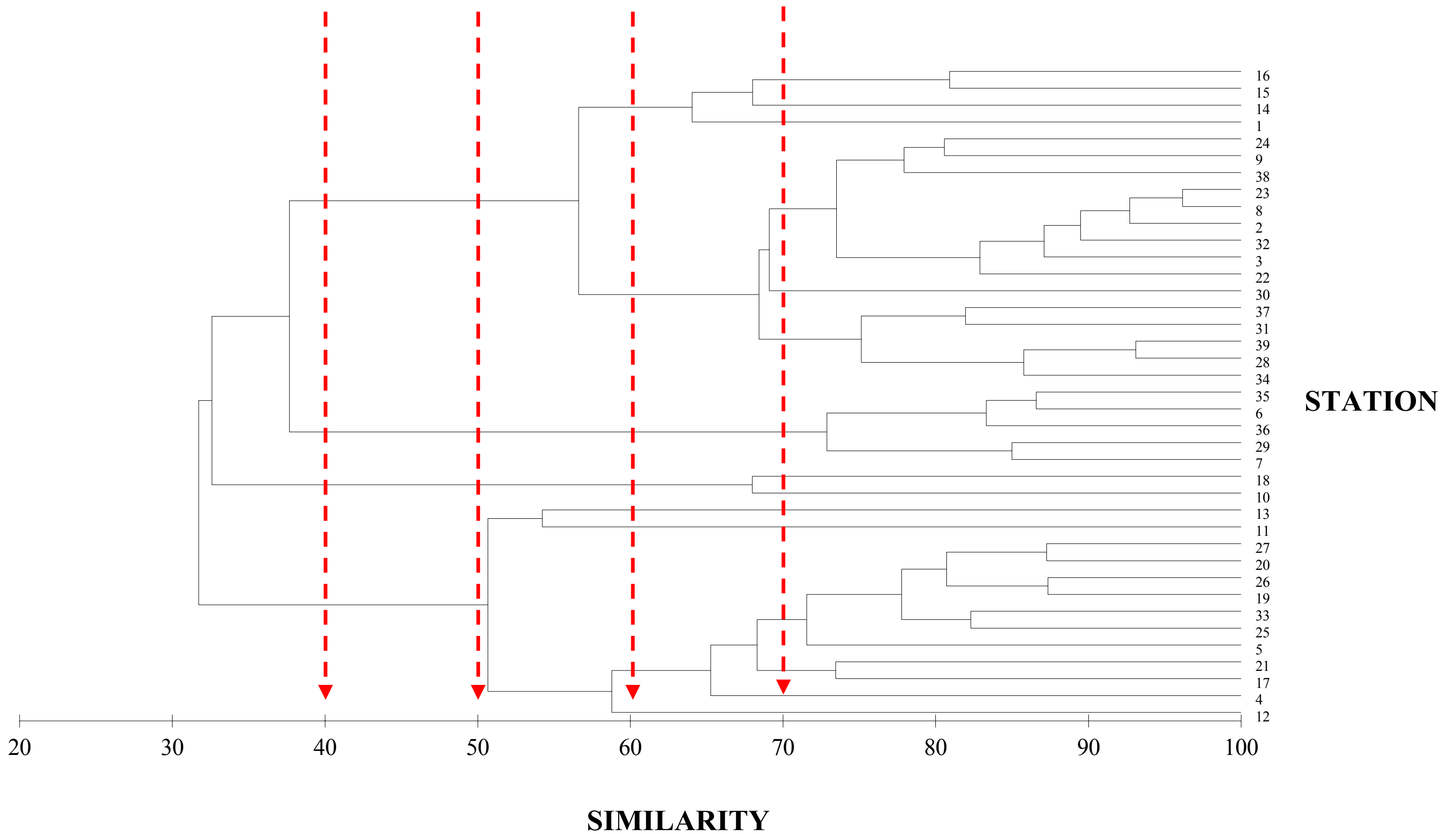


Figure 11. Dendrogram of the 39 stations using group-average linking of Bray-Curtis similarities on the standardized larval abundance estimates from the capelin and Atlantic herring larval survey of July 2004 on the west coast of Newfoundland.

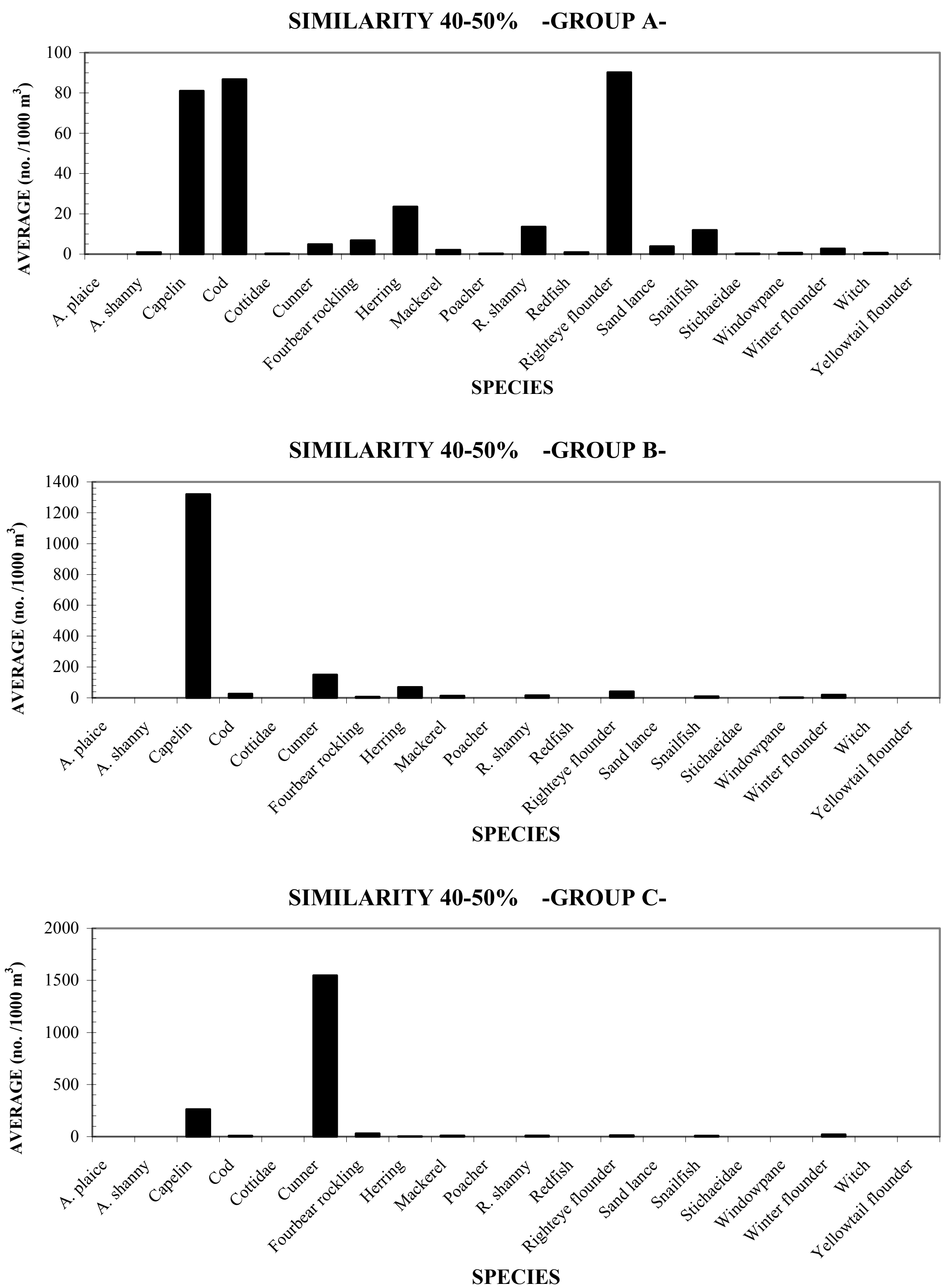


Figure 12. Average abundance estimates (no./1000 m^3) of the larval species present in each group of stations defined by cluster analyses and Bray-Curtis similarities of 40% and 50%.

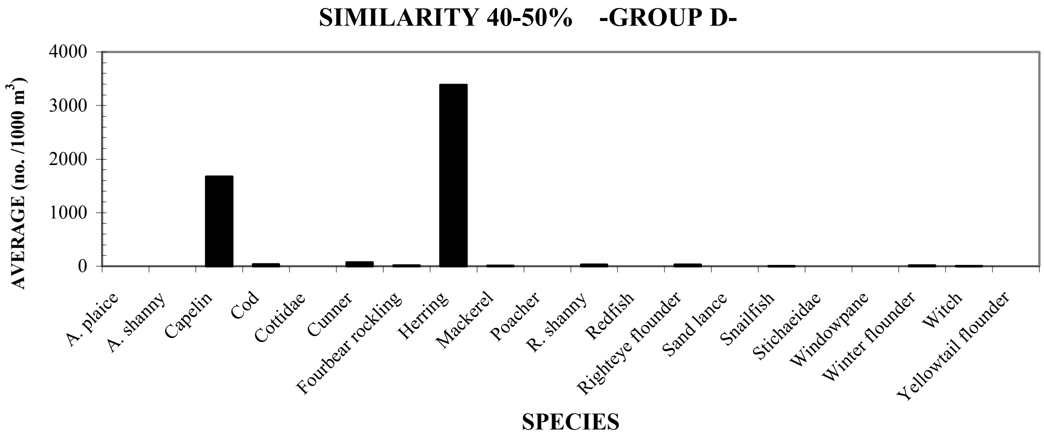


Figure 12. (Continued).

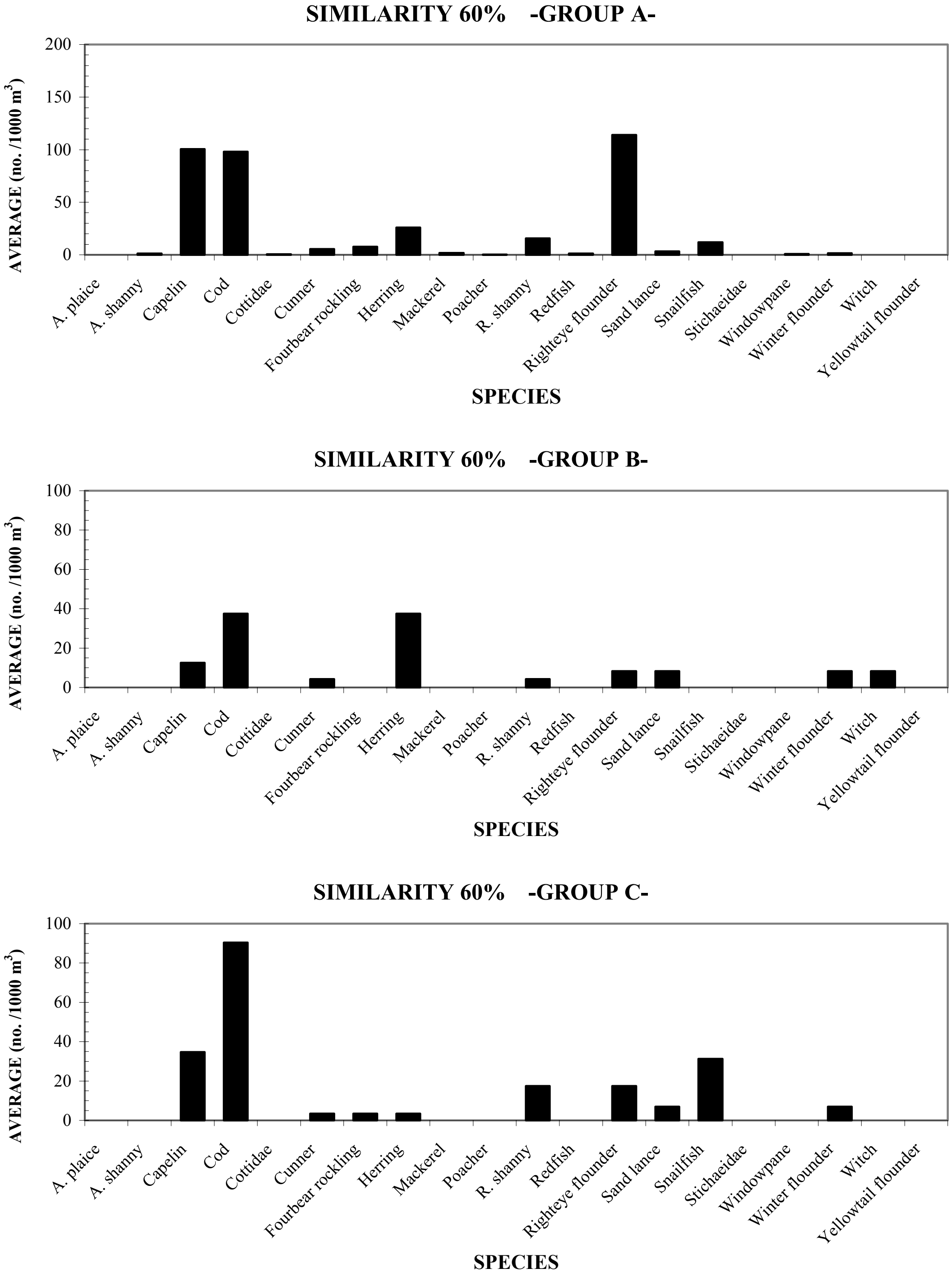
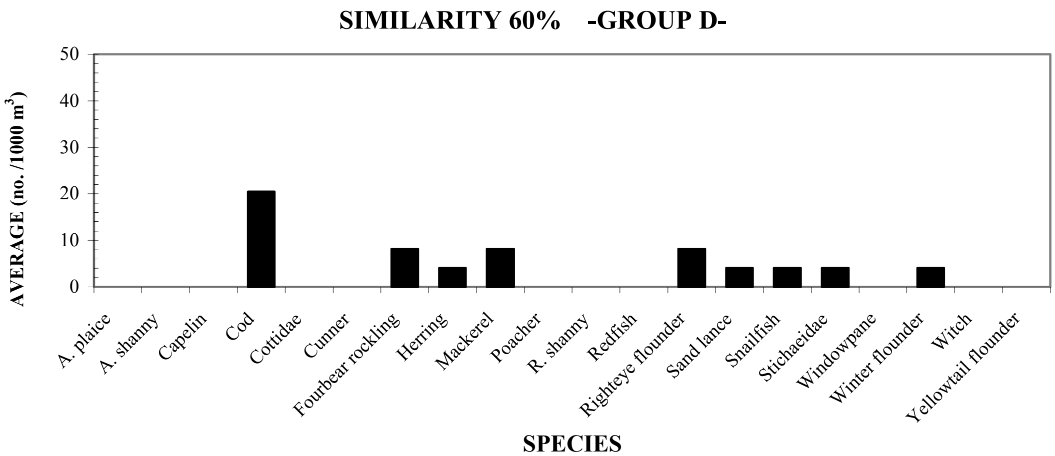
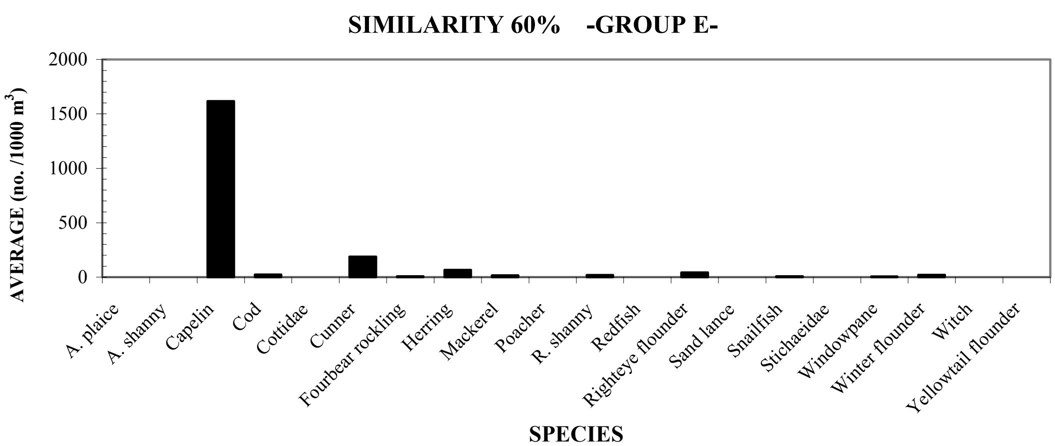


Figure 13. Average abundance estimates (no./1000 m^3) of the larval species present in each group of stations defined by cluster analyses and a Bray-Curtis similarity of 60%.





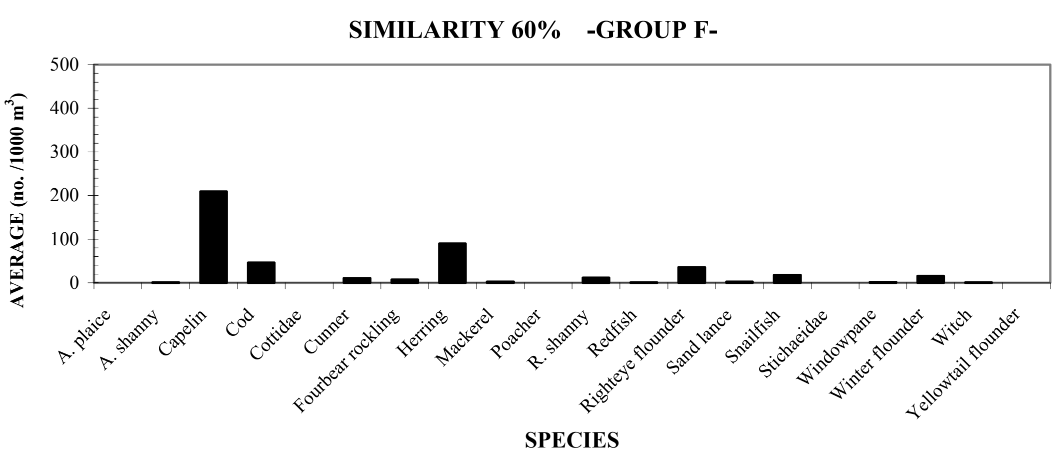
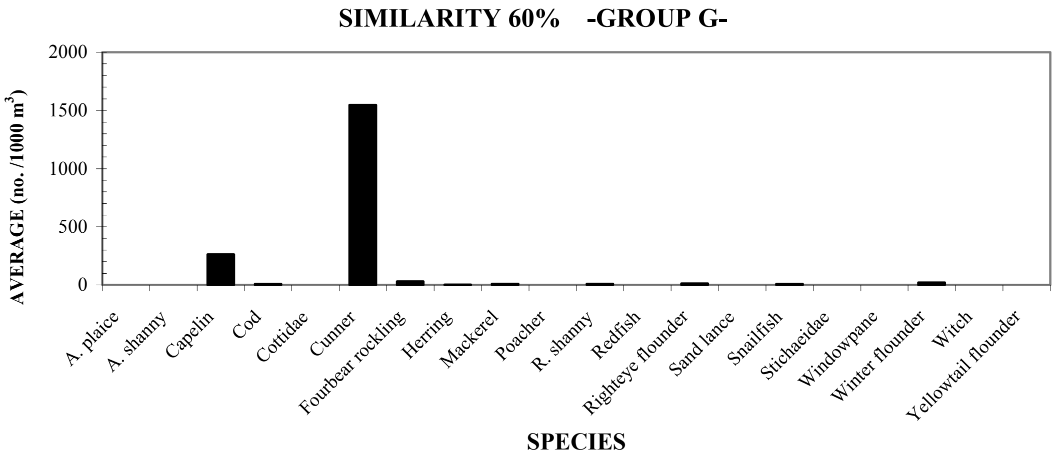


Figure 13. (Continued).



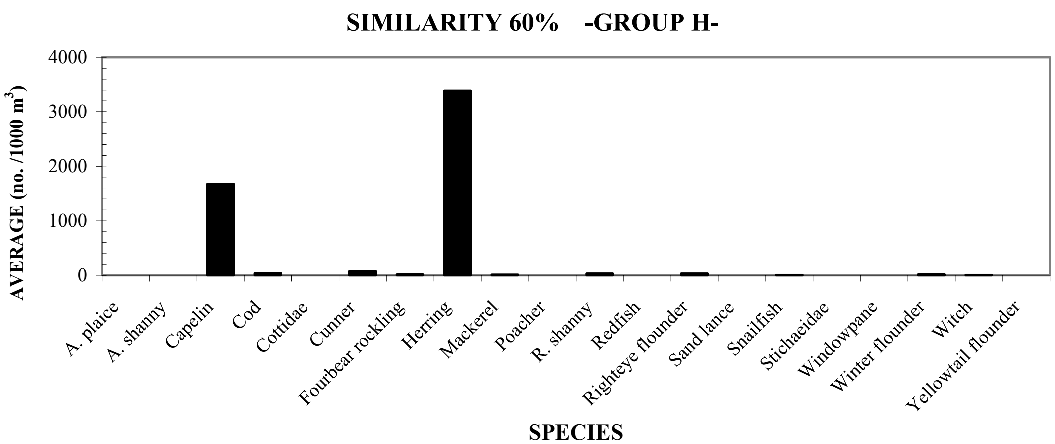


Figure 13. (Continued).

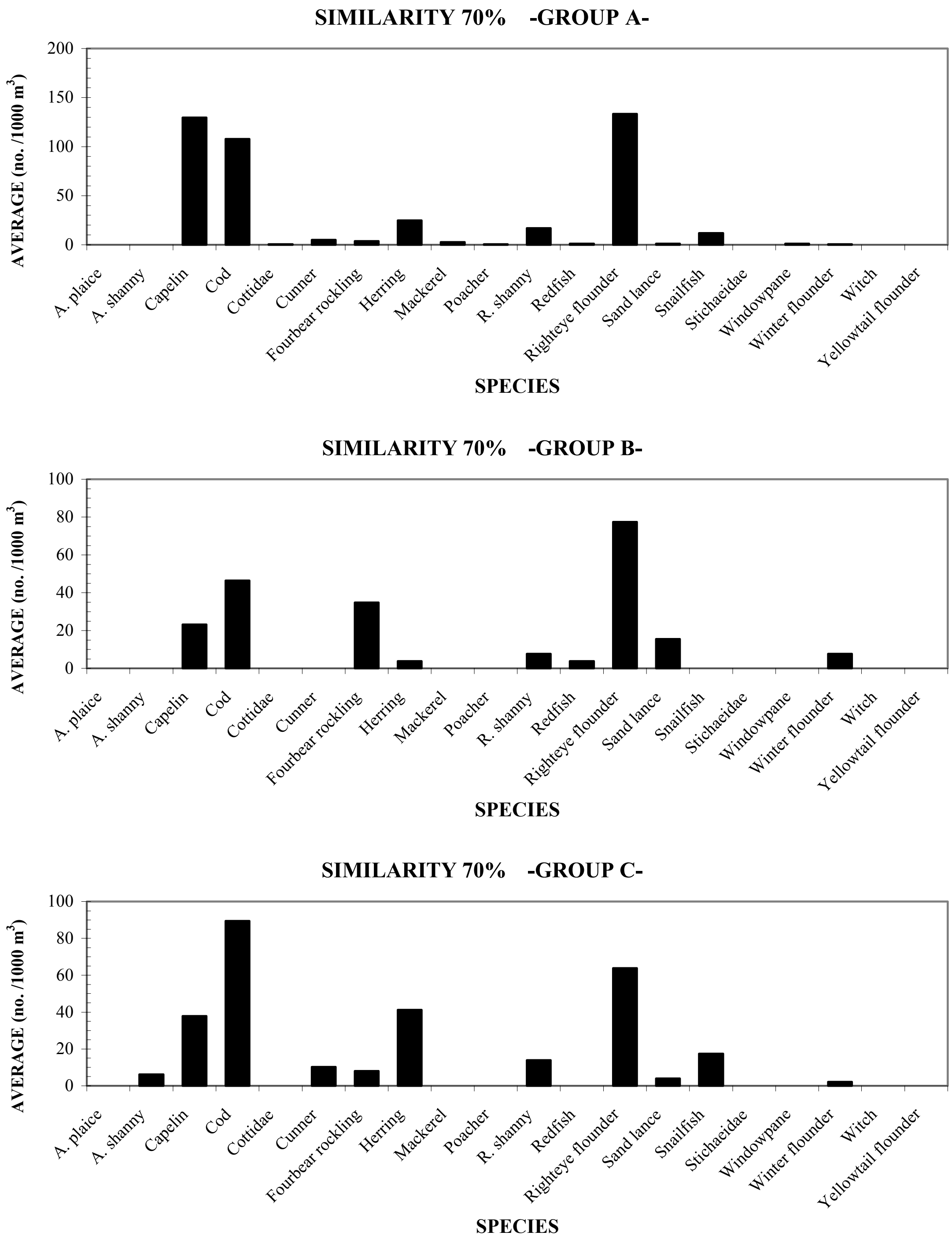
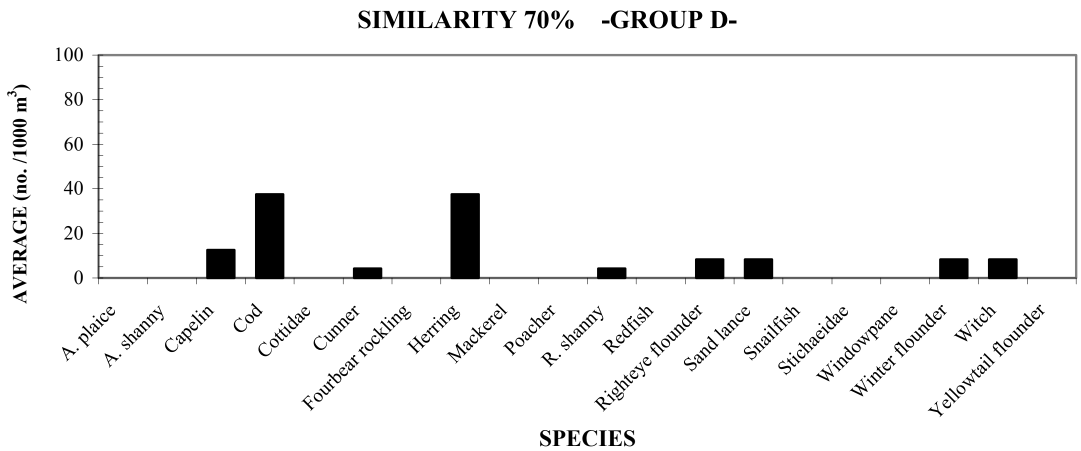
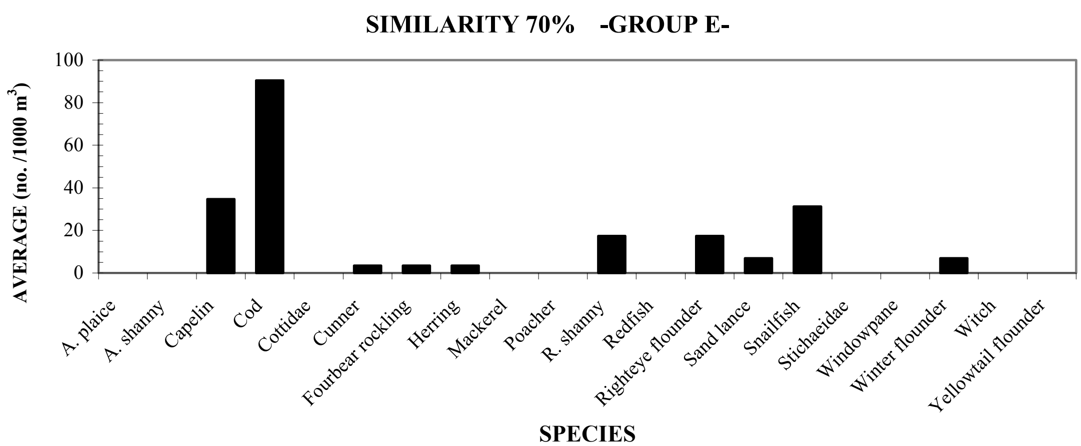
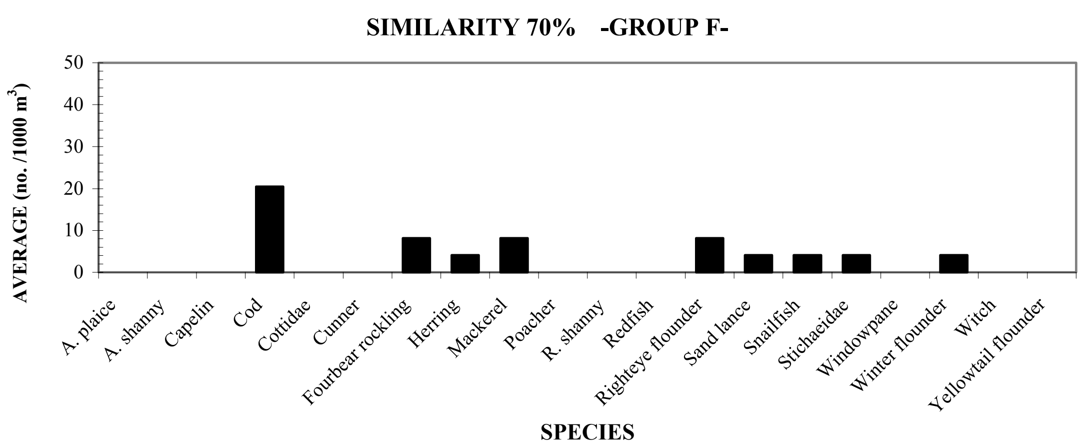


Figure14. Average abundance estimates (no./1000 m^3) of the larval species present in each group of stations defined by cluster analyses and a Bray-Curtis similarity of 70%.







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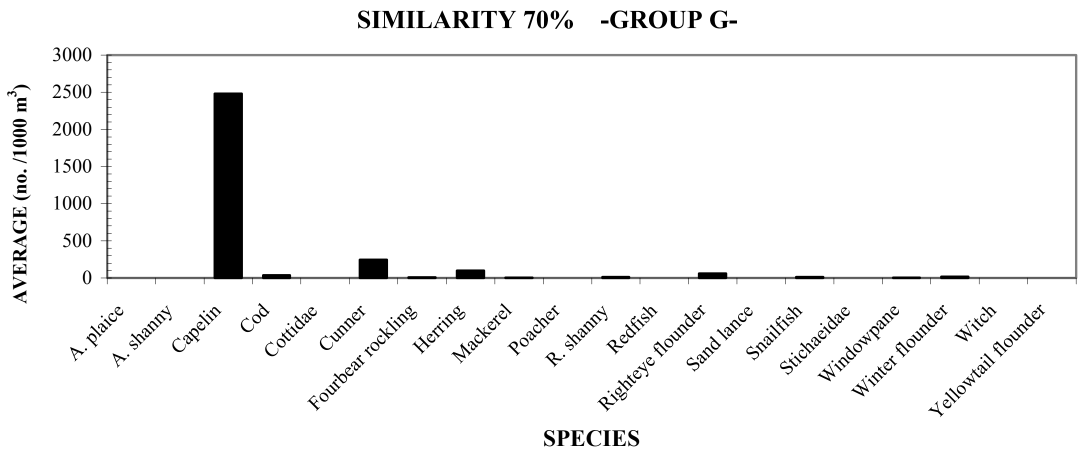

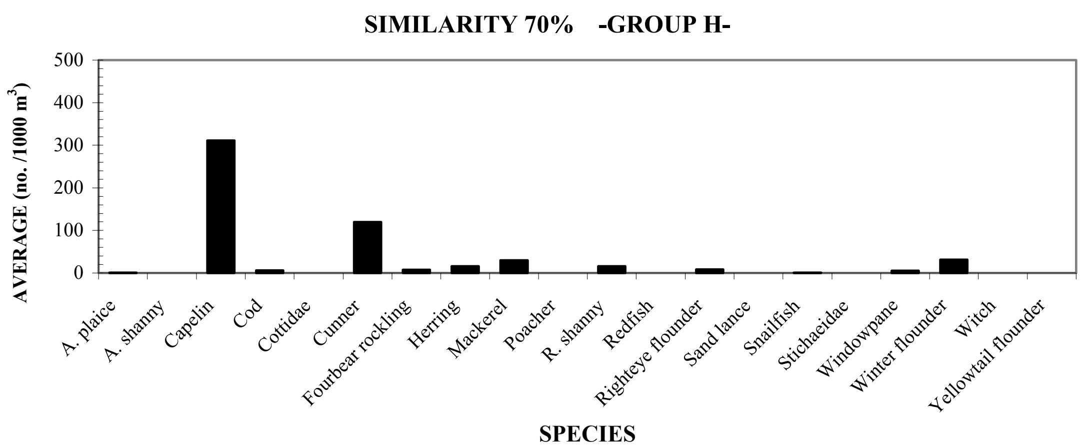

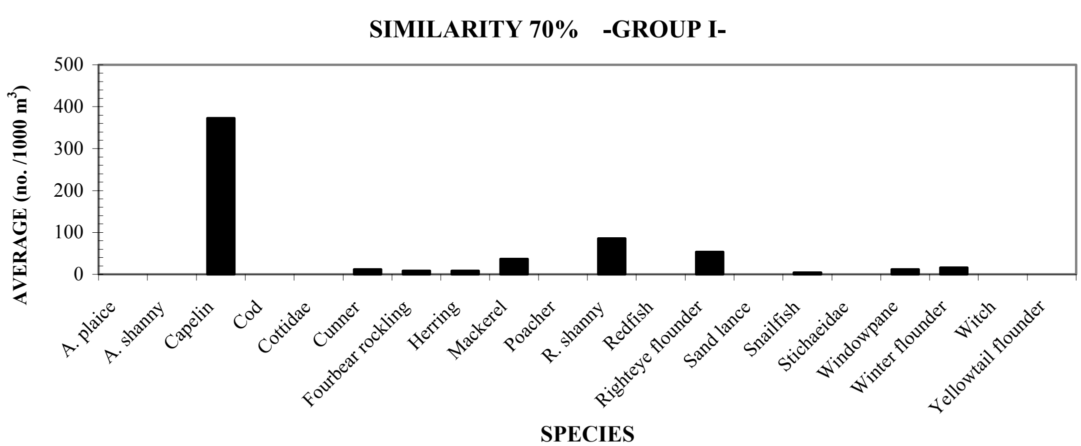

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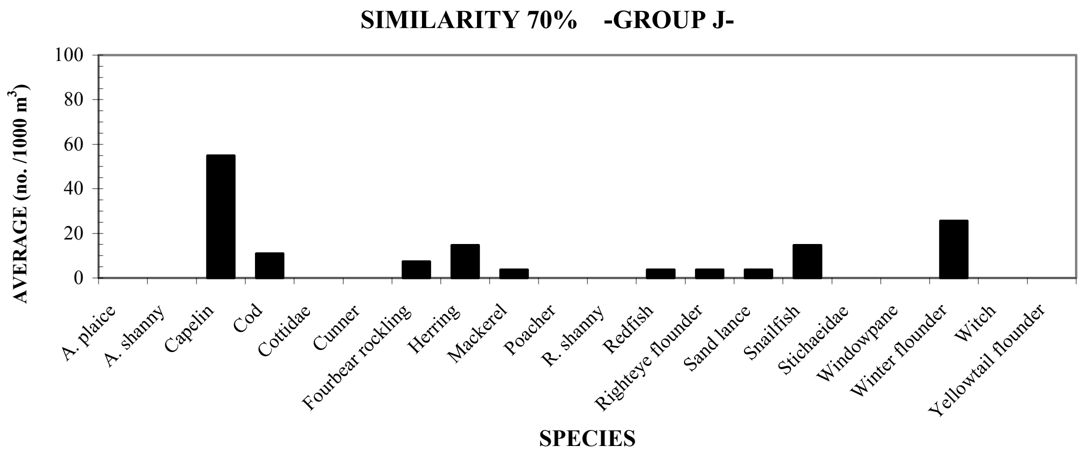
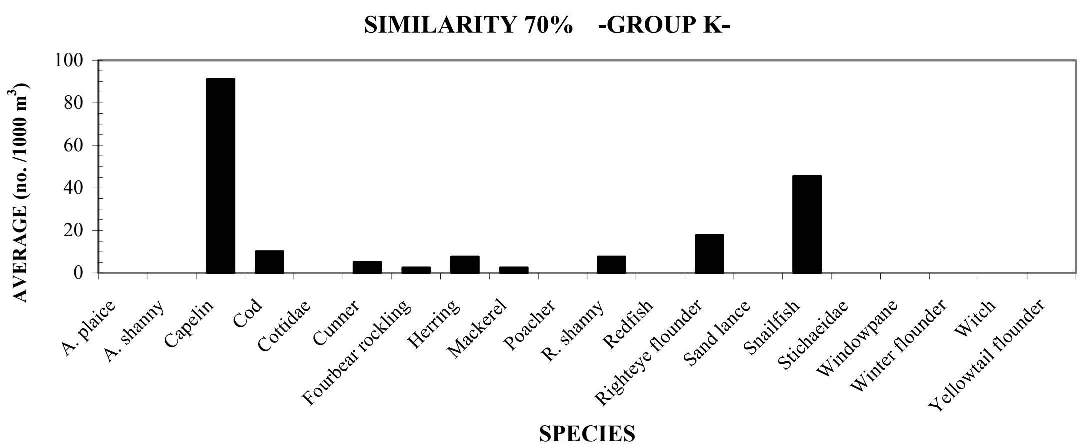




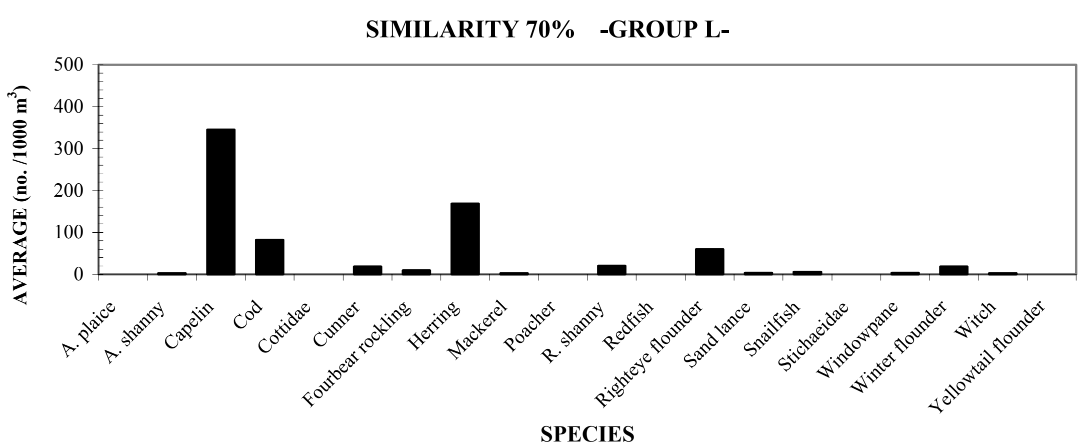
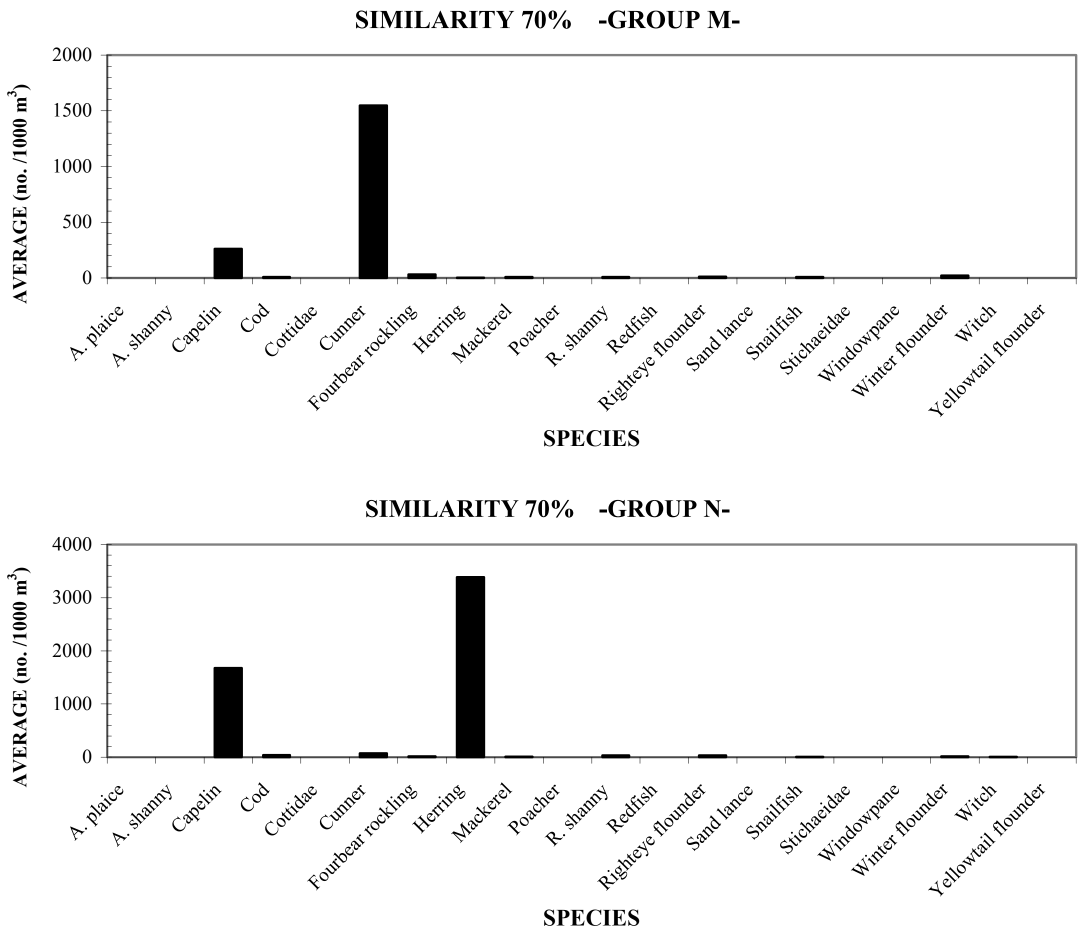


Figure 14. (Continued).



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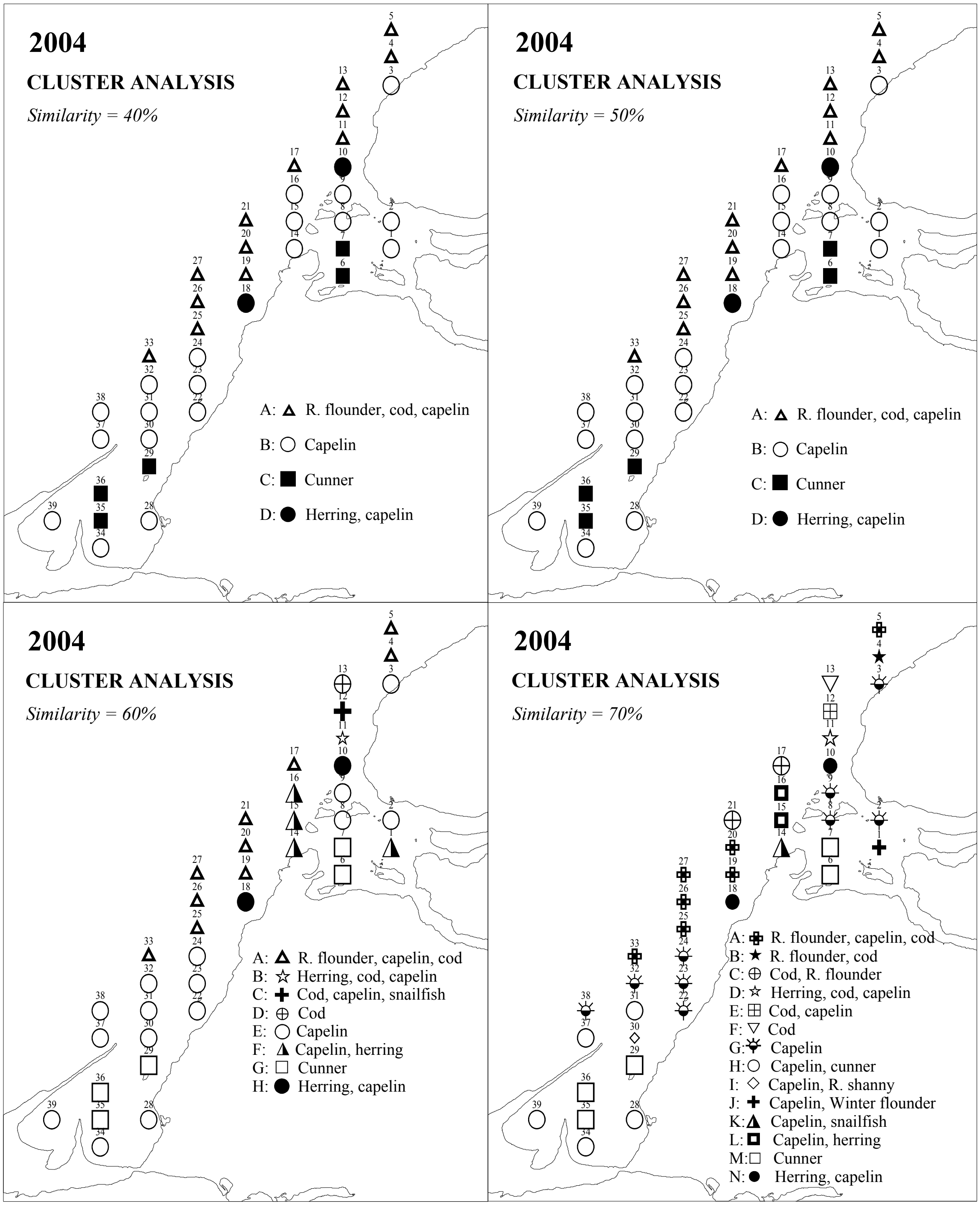


Figure 15. Maps of the groups of stations defined by cluster analyses for different levels of Bray-Curtis similarities on the standardized larval abundance estimates from the capelin and Atlantic herring larval survey of July 2004 on the west coast of Newfoundland.

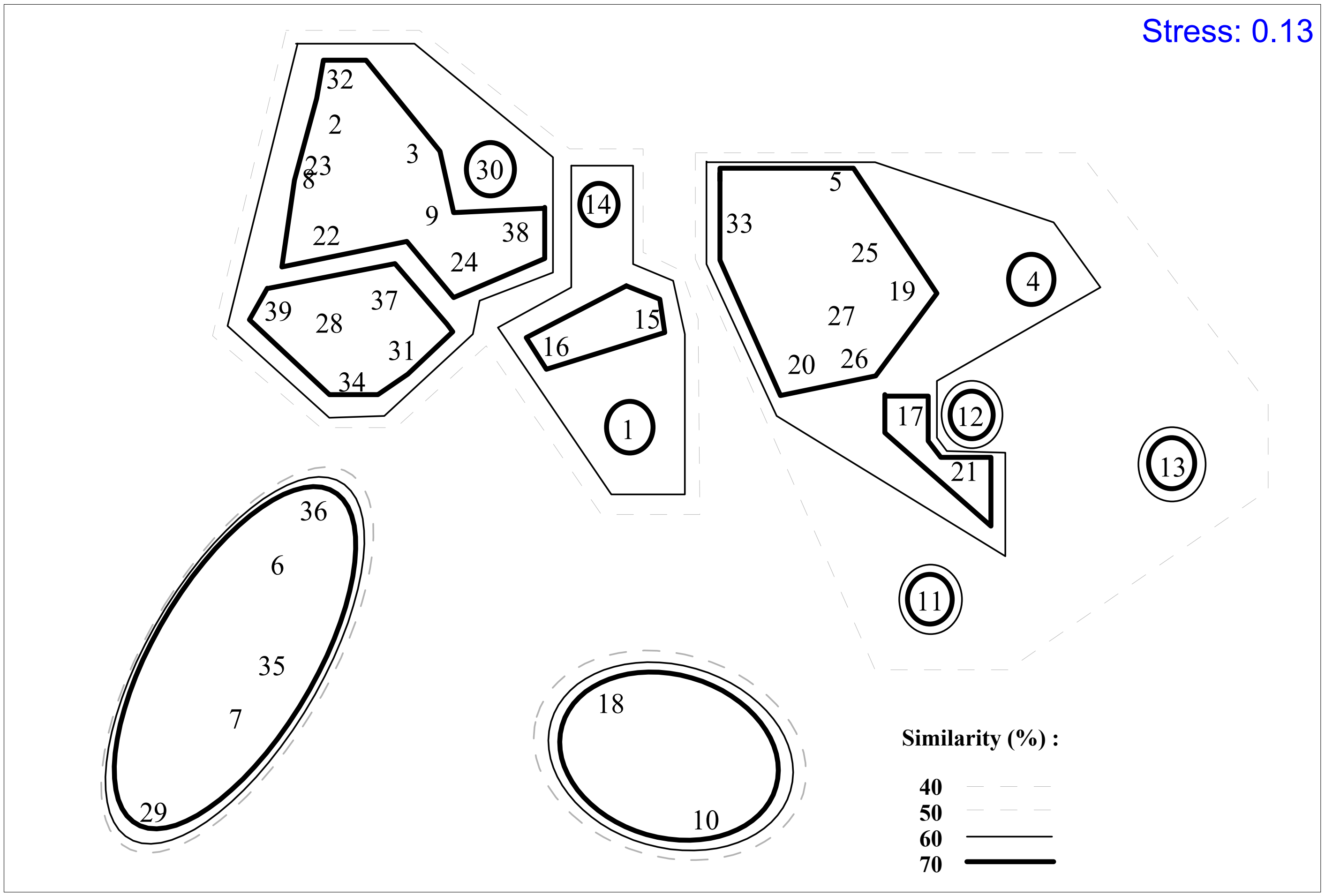


Figure 16. Non-metric multi-dimensional scaling of the 39 stations based on the Bray-Curtis similarities on the standardized larval abundance estimates from the capelin and Atlantic herring larval survey of July 2004 on the west coast of Newfoundland.

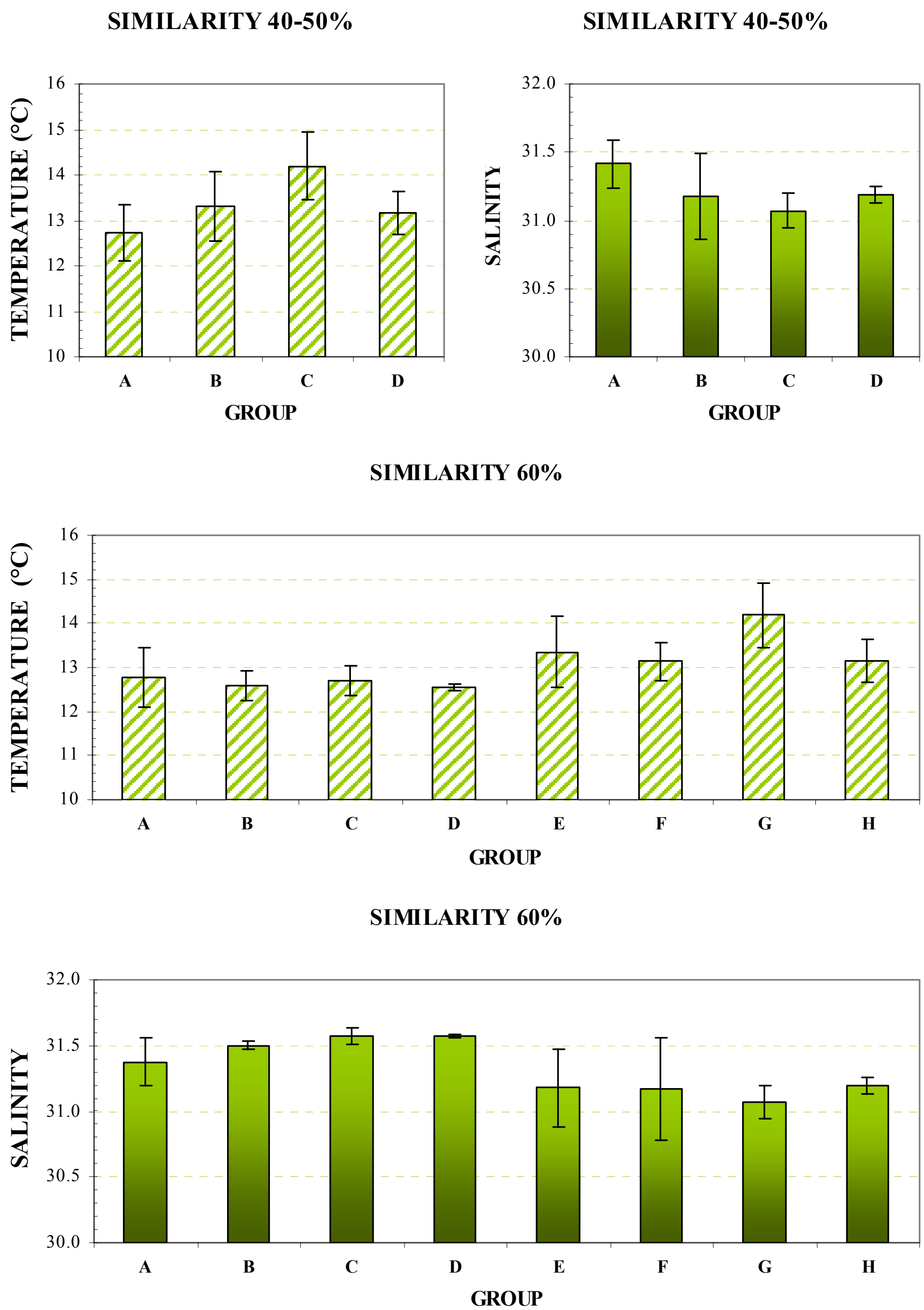
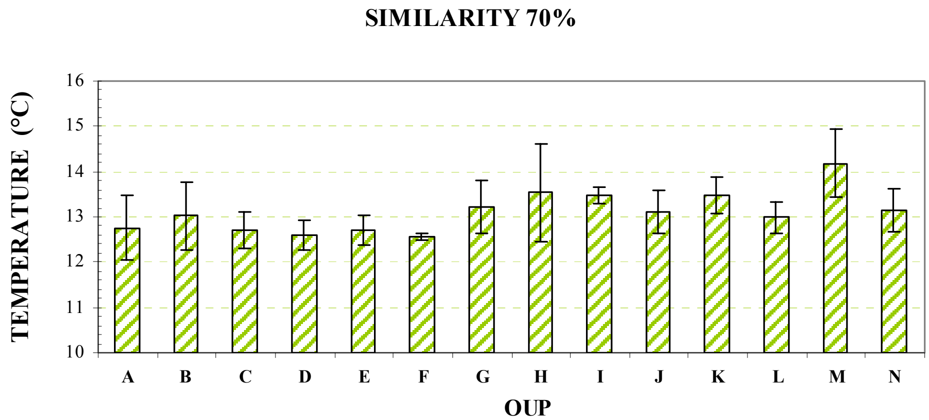


Figure 17. Average temperature (°C) and salinity for each group of stations defined by cluster analyses and Bray-Curtis similarities from the capelin and Atlantic herring larval survey of July 2004 on the west coast of Newfoundland (standard deviations are indicated by the vertical lines).



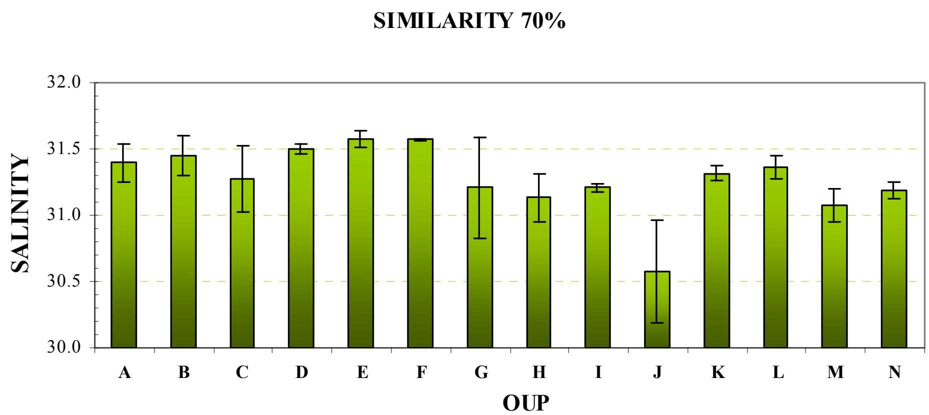


Figure 17. (Continued).