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Ecologically and biologically significant areas in the Estuary and Gulf of St. Lawrence: small pelagic fishes

Zones d'Importance Écologiques et Biologiques dans l'Estuaire et le Golfe du St. Laurent : les petits poissons pélagiques

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ABSTRACT

The aim of this study was to define ecologically and biologically significant habitat for small pelagic fishes within the GSL, as part of a coordinated, nationwide effort by DFO. We summarized the basic ecological and biological information from the literature relative to each species and, where data permitted, described the principle spatial and temporal patterns for each biological function of each species within both the northern (nGSL) and southern Gulf of St. Lawrence (sGSL) ecosystems. From the 12 species examined relative to the five ecological functions (feeding, spawning/breeding, nursery, migration, seasonal refugia), 73 important areas (IA) were identified. These IAs were rated at the species-level in relation to the property criteria of uniqueness, aggregation and fitness and combined within the five ecological functions using a spatial model. This produced a composite surface map from which 14 EBSA candidates were identified, seven at the species level and seven at the pelagic-community level. Most EBSAs in the nGSL were associated with the channel slopes. In the sGSL, the inshore shallow estuaries and bays (Chaleur Bay, Shediac Valley and Northumberland-St. Georges Bay area) stand out as important areas, mostly from the diversity of species that utilise these habitats, and for the important ecological functions that are preformed there. The Strait of Belle Isle was also highlighted as an important spawning area for autumn herring, as well as for aggregations of sand lance and capelin. This area is a known foraging area fish-eating species of dolphins and whales.

RÉSUMÉ

Le but de cette étude était de définir les plans écologique et biologique des habitats importants pour les petits poissons pélagiques au sein de la GSL, dans le cadre d'un effort coordonné et national par le MPO. Nous avons résumé les informations écologiques et biologiques de base de la littérature relative à chaque espèce et, le cas des données le permettait, a décrit les tendances principales spatiales et temporelles pour chaque fonction biologique de chaque espèce à la fois dans le nord (nGSL) et du sud du golfe du Saint-Laurent (sGSL) écosystèmes. Sur les 12 espèces étudiées par rapport aux cinq fonctions écologiques (alimentation, reproduction, pouponnière, migration, refuges saisonnières), 73 zones importantes ont été identifiées. Ces zones importantes ont été évaluées à l'échelle des espèces en relation avec les critères de propriété d'unicité, d'agrégation et de « fitness » et combinés dans les cinq fonctions écologiques en utilisant un modèle spatial. Cela a produit une carte de la surface composite à partir de laquelle 14 candidats de ZIEB ont été identifiés, sept au niveau des espèces et sept au niveau de la communauté pélagique. La plupart des ZIEB dans le nGSL ont été associées à des pentes du canal. Dans le sud du Golfe, les estuaires côtiers et baies peu profondes (la baie des Chaleurs, la vallée de Shédiac et de la région de Northumberland-Baie St. Georges) se distinguent comme des domaines importants, surtout par la diversité des espèces qui utilisent ces habitats, et par les importantes fonctions écologiques qui y sont préformé. Le détroit de Belle-Isle a également été souligné comme une zone de frai importante pour le hareng d'automne, ainsi que des agrégations de lançon et le capelan. Cette zone est une zone de recherche de nourriture connus pour les espèces piscivores de dauphins et baleines.

INTRODUCTION

This study was part of a coordinated, nationwide effort by DFO to identify ecologically and biologically significant areas (EBSA) for species and species groups in marine ecosystems throughout Canadian waters. The present document summarises a spatial analysis of the available distributional information pertaining to one component of the Gulf of St Lawrence ecosystem: small pelagic fishes.

A comprehensive identification of EBSAs for pelagic fishes in the Gulf of St. Lawrence and Estuary (GSL) would necessitate many years of dedicated investigation. In effect, the identification of such areas would entail the description of the ecological role of pelagic fish and their habitat throughout the Gulf, roles that vary seasonally and with the ontogeny of each species. Ecologically or biologically important habitats for species or populations have not only a variable spatial component, but also a highly variable temporal component. Areas that encompass important functions may not be important all the time. This temporal variability must be considered when drawing lines on a map. An area that was important in the past, or during certain seasons may no longer be at present, and vice versa. However, an area that is no longer occupied by a given species for a given biological or ecological function may still require special designation. In principal, it would remain potential habitat for the function in question in the event of a re-colonisation of the area, assuming that the function of that habitat had not changed. Such areas should therefore have similar status as occupied habitat.

For the purposes of this study, the GSL was divided into two ecosystems. This division follows essentially the St. Lawrence Channel from the Cabot Strait to the St. Lawrence Estuary (Figure 1), effectively dividing the GSL into the northern Gulf and Estuary (nGSL) and the southern Gulf of St. Lawrence (sGSL). This natural separation was considered necessary because of the striking differences in topography, oceanography and to some extent species composition and concentration between the nGSL and the sGSL. Although many pelagic species occupy habitats in both ecosystems, some are principally or in some cases solely found in one or the other, e.g. butterfish (*Peprilus triacanthus*), rainbow smelt (*Osmerus mordax*) and alewife (*Alosa pseudoharengus*) in the southern Gulf and pollock (*Pollachius virens*) and white barracudina (*Arctozenus risso*) in the northern Gulf.

The sGSL is essentially a shallow basin with two principal depressions, one in the northwest (Chaleur Bay and Shediac Valley) and one in the southeast (Cape Breton Trough). This ecosystem covers an area of 83,000 km^2 is dominated by the physical dynamics within the mixed surface layer. In contrast, the 152,000-km^2 nGSL is characterised by three major, deep-water channels (the Laurentian, Esquiman and Anticosti Channels) that mark the topography and direct the deep oceanic waters into the nGSL. These channels dominate the nGSL and along with the cold intermediate layer (CIL), influence the distribution of the species that inhabit it. The slopes along the major channels become important topographic features that are associated with many species in the nGSL. In that context, the southern slope of the Laurentian Channel can be considered as part of the northern Gulf ecosystem, even though it also defines the northern border of the southern Gulf. The sGSL will therefore be limited to the shelf habitat, i.e. those depths less than ~100 m.

The objectives of this study were (1) to identify important areas (IAs) for pelagic fishes in both the northern and southern GSL ecosystems, and (2) to evaluate the relevance of each identified IA as an EBSA following the guidelines set out for that purpose and according to the criteria outlined in DFO (2004). We first identified a series of IAs for each species based on the species distribution relative to the area's ecological function, i.e. feeding, spawning, nursery, migration and refugia. The significance of each IA would first be evaluated on an individual-species level, and then on a pelagic-community level, based on common and multiple habitat use, i.e. those areas used intensively by many species and for multiple purposes. In what follows, important areas and important habitat will be used synonymously. Any area that is deemed important for one of the five major functions of feeding, spawning/breeding, nursery, migration and refugia are considered as important habitat for the species or population's survival and/or productivity. As outlined in DFO (2004), to be recognized as an EBSA requires that the IA confers to the population a high rating in one of the five ecological functions, a qualification which will be the subject of the following exercise. The identified IAs will, to the degree that the available data will allow, be associated with populations, as the basic unit. In most cases, this will encompass the distribution of the entire species within each ecosystem, since little or no information is available on population structure to allow more detailed designations. However, in the case of herring, where more extensive information was available on population structure, the population will be the basic unit, e.g. sGSL spring- and autumn-spawning herring form two populations.

The scope of the exercise was purposely restricted to the definition of EBSAs on a broad geographic scale, i.e. the St. Lawrence Gulf and Estuary, concentrating on regions where data collection was primarily systematic. Distributional data from local, small-scale coastal studies were in general not included, mainly because the localised, concentrated coverage of these studies would have introduced spatial bias relative to large-scales surveys. These areas, although having local ecological and biological significance were also considered too small scale to have an influence on the scale of the GSL. However, there were a few exceptions to this general restriction. For example, even though the two systematic, quasi-annual herring (*Clupea harengus*) acoustic surveys conducted in the sGSL and nGSL can be considered local and coastal, they were nonetheless designed to cover the main distributional area of the respective coastal and commercially exploited populations and were therefore included here. Likewise, the winter sGSL juvenile herring survey did not extend over the entire sGSL, but was presumed to cover the spatial distribution of the targeted population life stage.

MATERIAL AND METHODS

CHOICE OF SPECIES

Pelagic fishes comprise those species 'living in open waters, in contrast to bottom-living or inshore species' (Scott and Scott 1988). In the GSL, the principal species of commercial importance that meet this criterion are herring, capelin (*Mallotus villosus*) and mackerel (*Scomber scombrus*). However, there are many pelagic species that are of little or no commercial value, but which have ecological importance either because they are important forage species or are dominant species within their habitat.

The species included in the following analyses (Table 1) were primarily those listed as pelagic species by Savenkoff et al. (2004a, b) for the development of trophic models in the northern and southern GSL, although they categorised them according to trophic role, i.e. large pelagic feeders, piscivorous small pelagic feeders and planktivorous small pelagic feeders. The majority of these species are represented in the catches of the annual DFO bottom-trawl surveys (BTS), both in the nGSL and the sGSL and are included in the DFO research-catch database (Table 2). Therefore, apart from herring, capelin and mackerel, we have also included several semi-pelagic (pollock, silver hake and spiny dogfish), mesopelagic (white barracudina) and anadromous (rainbow trout, alewife) species, as well as sand lance that have a truly benthic or sub-benthic phase, borrowing in the sand, and a pelagic phase while feeding. We also wished to assemble information on as many species as possible, regardless of commercial importance. Several species are harvested elsewhere (e.g. pollock, silver hake, butterfish) although they are of minor commercial importance and their distribution is at best marginal, being intermittent visitors in the GSL. In all, twelve species were retained (Table 1) as having sufficient data to produce distributional maps for at least one function.

DATABASES

We have attempted to identify IAs and EBSAs based on species distributions from research surveys to infer habitat use. Given the general lack of directed research on pelagic fishes and their habitat in the GSL, and that no directed, gulf-wide distributional studies have ever been conducted on most pelagic fishes in the GSL, this was a challenge. We will therefore attempt to indicate areas of potential importance based mainly on data obtained from incidental catches or indirect sampling to infer habitat occupation and use. By far the longest time-series of gulf-wide distributional catch data available on fish species originates from annual large-scale summer research BTSs conducted by DFO, which target demersal species but which capture pelagics fishes associated with the sea-floor (Table 2). The two main surveys are conducted annually (from 1971 in the sGSL and 1990 in the nGSL, to the present), principally to assess groundfish and shrimp biomass (Benoît and Swain 2003, Bourdages et al. 2004). Others, such as the now-terminated nGSL winter survey was a shorter time series and covered much less of the GSL due to interannual variability in ice-extent (Rollet et al. 1994).

Still, these data sources are somewhat paradoxical for the study of pelagic fish density and distribution. By definition, pelagic fishes are by-catch in these BTSs; catchability coefficients have estimated to be in the range of only 0.009% and 2.48% for pelagic fish, depending on species (Harley et al. 2001). McQuinn (2009) showed that incidental catches of pelagic fish in bottom trawls can be severely influenced by variations and trends in their vertical distribution near the seafloor, affecting their catchability. As an example, research BTS catches of herring, capelin and sand lance increased exponentially on the Scotian Shelf and in western Newfoundland with the decrease in cod abundance in the 1990s (Bundy 2004). However, the increase in research bottom-trawl herring catches in western Newfoundland proved not to be related to their abundance, but rather to their increased occupation of the suprabenthic habitat following the cod decline. Likewise, McQuinn (2009) also showed that the increase in research bottom-trawl herring catches on the western Scotian Shelf exhibited the opposite trend of the stock assessment for that same population, i.e. changes in distribution of bottom-trawl catches of pelagic fishes primarily reflect changes in benthic habitat use and not necessarily abundance. Therefore, although these spatial datasets may reveal large-scale, gross distributional patterns, bottom-trawl catch data are not reliable indicators of pelagic fish abundance and trends should be interpreted with caution. As these were often the only data available to us for the present study, they are used here as an index of spatial distribution and for drawing inferences regarding habitat occupation and use in the general sense. We acknowledge that temporal trends in this index may also be affected by an increase in suprabenthic habitat use by pelagic species.

This core data source was however supplemented by various other sources that either helped to complete the spatial coverage or that were used in support of patterns observed from the trawl data. Primary amongst these were directed acoustic surveys on Atlantic herring in the sGSL and nGSL (LeBlanc et al. 2006, McQuinn and Lefebvre 1995, 1999). These surveys were designed to encompass the principle distribution of the herring populations in these zones in the fall. Therefore, despite being coastal in extent, they were valuable sources of basic information on these important populations (Table 3).

Further, a supplementary data source was available in selected years from the simultaneous collection of acoustic data during the previous described, gulf-wide BTSs and Atlantic Zonal Monitoring Program (AZMP) surveys. These undirected, opportunistic data collections had the advantage of having a wide-geographic coverage. However, the data were not validated to species, although classification into species groups was possible (see Data Standardization and Representation) and only three years were available.

Although the gulf-wide trawl and acoustic surveys covered the majority of the offshore sector of the two ecosystems (Figures 2, 3), several key species and areas were not sampled adequately - or at all - by these gears. Sand lance is believed to be an important forage species in the GSL, but they are not effectively caught by bottom trawls and are not readily identifiable with the acoustic frequencies used. However, some distributional information was available for sand lance from a large-scale, stomach content database (D.Chabot, DFO, unpubl. data) including predators such as cod and turbot. Stomach content data was available between 1993 and 2004 (Table 2) from research conducted on cod captures during the summer surveys. These data included 11,285 cod stomachs from 647 tows in sGSL and 18,881 stomachs from 1,482 tows in the nGSL (see Chabot et al. 2007). Although the sampling distribution in these data is biased due to the non-random distribution of the sampler (cod), it was felt that clusters of prey in cod stomachs would indicate clusters of prey in the habitat and therefore concentrated habitat use.

Finally, data from a few, highly relevant regional studies were also included for their information content relative to specific species functions. A juvenile herring surveys (LeBlanc et al. 1998) was conducted between 1991 and 1995 in the winter (Dec) that we used as an indication of the seasonal refugia of juvenile herring. Likewise, a regional acoustic spawning-bed survey (Claytor 2001) was used to supplement information on the seasonal use of specific habitat in relation to the larger picture within the sGSL.

SPATIAL/TEMPORAL COVERAGE

Only data from surveys conducted with either a random or a systematic survey design were analysed to minimize biases in aerial coverage. This included the major GSL bottom trawl surveys and in the case of herring, the annual southern and northern Gulf systematic-stratified or random-stratified acoustic surveys. Even though these latter surveys only covered targeted areas of high herring concentration (Figure 3a,b), they were the core source of information on the autumn distribution of these important populations. Nonetheless, it is assumed that these surveys cover the majority of the respective populations (southern Gulf and west coast of Newfoundland herring). Some validation of this assumption was provided by the opportunistic acoustic surveys (OAS) in the nGSL and sGSL in August and September, respectively (see Results).

Temporal coverage varied from one database to the next. The annual, summer sGSL (1971-2005), nGSL (1990-2005) and winter nGSL (1980-1994) BTSs represented the longest continuous time series (Table 2). Other datasets were more restricted in time, from only three years for the undirected acoustic surveys to 12 years for the sGSL acoustic survey (1994-2005) and stomach content study (1993-2004).

The two main data-collection methodologies used in this exercise – bottom trawl and acoustic – do not share the same sampling efficiency for pelagic fishes and therefore in principal are not directly comparable. While the acoustic data is much more efficient for pelagics, in the case of the coastal, stock-assessment surveys, the spatial coverage is inferior to the BTSs. We have therefore based the general distributional patterns on the more large-scale multiannual trawl data, and used the more regional, targeted acoustic data to validate the general patterns.

DATA STANDARDIZATION AND REPRESENTATION

The principal metric from the BTSs was species catch per area per standard tow, preferentially in units of biomass - kg/m^2 - but occasionally in numbers - indiv/m^2 - when the former was not available (Table 2).

Acoustic analysis of directed Atlantic herring surveys are detailed in McQuinn and Lefebvre (1999) for western Newfoundland (nGSL) and LeBlanc et al. (2006) for Chaleur Bay, PEI and the Magdalen Islands (sGSL). The principal methodology involved sounding on herring concentrations following a systematic-stratified or random-stratified design and validating the acoustic signal from concurrent pelagic-trawl, purse-seine or bottom-trawl net hauls, depending on gear availability and the behaviour of the herring.

For undirected, OAS data collections during BTS or AZMP monitoring surveys, the classification of organisms was accomplished by comparing signal amplitudes (volume backscatter) between 38 ($S_{v,38}$) and 120 ($S_{v,120}$) kHz and estimating the "dB difference" (see ICES 2000, Kang et al. 2001). This method is useful for separating fluid-like organisms such as crustaceous zooplankton ($S_{v,120}$-$S_{v,38}$ > 5) from “gas-bladdered” fish ($S_{v,120}$-$S_{v,38}$ < 5) such as herring and capelin, but not mackerel, which have no swimbladder. Depending on geographic location, most strong-signalled, gas-bladdered pelagic fish were assumed to be herring, but may have been capelin in some instances (to be discussed in the Results section).

All data were collated in a geographic information system (GIS) by species, survey, location, year and season. These geo-referenced trawl-catch and acoustic densities were grouped in quartiles of non-zero values (>0-25%, 26-50%, 51-75% and 76-100%) and mapped to represent zones of varying relative levels of biomass aggregation. Density data were expressed in quartiles rather than proportional catch per set to normalize for interannual variations in relative catch density, whether caused by interannual changes in abundance or in catchability. In addition, units of absolute density would not be comparable among species, nor within species with strong year effects in abundance. The use of quartiles also had the advantage of smoothing the data, i.e. deemphasizing extreme values, and focusing on where the majority of elevated catches were made.

However, this quartile metric would not differentiate between an expansion and a retraction of areal extent versus disproportionate changes in vertical extent from the BTS catch. In other words, a species may appear to expand its horizontal range, but may have simply lowered its center of mass to include to a higher degree the suprabenthic habitat. This however would reflect a significant adaptation by the species to its available habitat and therefore is a significant element in the identification of IAs and EBSAs in themselves, although it must not be confused with an increase or decrease in abundance.

An exception to this general data presentation was the acoustic data from the undirected surveys. These data were presented in composite maps of acoustic aerial density interpolated into a surface plot using the kriging method. The metric was the nautical area scattering coefficient (NASC=m^2nm^{-2}) – a linear scale proportional to biomass – integrated throughout the water column.

IMPORTANT AREA DEFINITION AND IDENTIFICATION

With these potential biases in mind, distributional maps were produced from these data for each species to identify areas of higher local densities[1] and thus higher habitat use and to define species-specific function-based important areas (IA). It was assumed that areas where the highest density of individuals aggregated for feeding, spawning, etc. would be synonymous with areas of importance for those functions.

Within each dataset, the annual density data were combined. However, when temporally combining abundance data, it is important to recognize the different weightings implicit within each dataset. There may be important year-effects, whereby certain abundant years will dominate catches and mask distributional patterns from less abundant years. A preliminary exploration of the data was therefore undertaken in which the aerial density data of each time series was plotted for each species and year to assess their spatial and temporal coherence, i.e. compared for similar distributional patterns between adjacent years to identify periods with similar distributional patterns. If the centers of concentrations were similar in extent, data from adjacent years were combined temporally into “like” periods (Table 3). This exercise also permitted the identification of temporal trends in distribution, i.e. an expansion, a retraction or a displacement of habitat use over time that allowed the qualification of aggregations as principal or marginal. In many cases, there was a marked transition between the distributions in the 1980s and the 1990s - coincident with the decline of GSL groundfish - and again around 1998-1999 (Table 3).

To define IAs of concentrated habitat use for a given ecological function for each species and time period, the spatial extent of observations within the top 25% of catches (4^{th} quartile) that were spatially cohesive (an agglomeration of points) was roughly circumscribed by polygons to identify areas of highest species occurrence. In most cases, ecological function was assumed, given known or assumed patterns in the annual life cycle of the species in question. For example, capelin distribution in the month of August was assumed associated with feeding, given that in general, the majority of spawning has been completed by May or June[2]. Seasonal refugia were determined primarily from overwinter distributions as identified from annual winter BT surveys (Dec-Jan; Table 3). This categorization was based on the observation that many pelagic fishes retreat to areas of more stable environmental conditions (e.g. deep channels) to overwinter, areas in which

[1] Keeping in mind that even the highest BTS catch densities were very low on an absolute scale
[2] Through the course of this exercise, it became evident that several IAs were reoccurring species after species, so that the same polygon was used to define the same IA for several species, if found appropriate, to limit the creation of a series of IAs with only slightly differing borders.

metabolism is low but less variable. In these refugia, feeding is much reduced and movements are minimised to conserve energy, therefore increasing, relative to the rest of the year, the vulnerability of possibly entire populations to perturbations.

EBSA DEFINITION

Each IA was rated according to the ecological properties of uniqueness, aggregation and fitness (Table 4) as defined in (DFO 2004) and based on information from the available data (Table 5 – Supporting data). The ratings – 3: high, 2: medium (or unknown), 1: low – for each species-specific IA were summed to produce a cumulative ‘property rating’– between three and nine – to determine candidates for species-level EBSAs. If an IA had a cumulative property rating of seven or more (Table 5), it was considered a first-order or species-level EBSA based on its importance to the species/population in question, irrespective of the IA’s significance for other species. This threshold value was arbitrary, based on the three highest possible ratings; however, it identifies areas where the ecological properties are the most sensitive if not of critical importance for the populations involved. This criterion also presumes that an area should be identified as an EBSA if it confers a significant role in the well-being of a single species. At this stage, the cumulative ratings of the two ecological qualifiers - fragility, naturalness - were also assessed for each IA (Table 5), although they were not directly used in the total cumulative importance ratings in the present analyses (Table 6; EBSA-IA # 1-7).

A second-order assessment was then conducted to determine EBSAs at the pelagic community level, based on common and multiple use of habitat, i.e. to determine what areas are used intensively by many species and/or for multiple purposes. The identified species-level IAs were spatially combined by overlaying and summing their cumulative property rating by pixel according to their ecological function, e.g. feeding (Figure 4a), to produce surfaces of cumulative property ratings across species. Since the amount of data available and therefore the number of IA layers was quite variable depending on ecological function, the IAs were spatially summed within functions to produce a composite surface for each to avoid attributing more weight to a function simply based on the quantity of information available (Figure 4b). These surfaces were then categorized into three classes of IAs based on three relative levels of importance: low, medium and high, according to the natural breaks within the observed cumulative rating (ArcMap ®). This method, known as Jenks’ optimisation (Jenks 1967) determines the class breaks statistically by minimizing the sum of absolute deviations about class means. The method seeks to reduce the variance within classes and maximize the variance between classes. We thereby classified the cumulative function-specific surfaces into three “like” levels of low, medium and high cumulative property rating.

These three-level cumulative surfaces (function-level IAs) were mapped and subsequently rated, again according to the property criteria of uniqueness, aggregation and fitness used for the single species IAs (Table 4). As with the species-level IAs, these property ratings were summed to determine candidates for community-level EBSAs. IAs with a cumulative property rating of seven or more (Table 6; EBSA-IA # 8-24) were considered second-order or pelagic community-level EBSAs based on their importance to the pelagic community.

RESULTS

The following sections summarize the basic ecological and biological information from the literature relative to each species and, where data permits, describe the principle spatial and temporal patterns for each biological function of each species within each ecosystem.

ATLANTIC HERRING (*Clupea harengus*)

Atlantic herring are distributed throughout the northwestern Atlantic and are arguably the most important component of the pelagic community with the Gulf of St. Lawrence. Although this species is the most studied of all pelagics in the Gulf and is certainly the most important commercially, much is still unknown concerning its habitat use and areas of concentration due to the lack of dedicated gulf-wide survey effort. Therefore, much of the gulf-wide distributional information has been deduced from incidental catches in the annual summer BTSs. However, as mentioned earlier, these patterns are most likely biased to varying degrees by the inability of these surveys to sample herring schools efficiently and to changes in catchability of pelagic species since the decline and reduction in distribution of the sympatric cod populations (McQuinn 2009).

Herring in the GSL are believed to constitute three populations (sGSL, western Newfoundland and the Quebec north shore), each comprised of two spawning components, spring and autumn, which have asynchronous life cycles (Hay *et al.*, 2001). Therefore, when assigning a function to herring in a given area, one must make a distinction between the two spawning components. For example, distributional data collected during April-May would be associated with spawning for the spring spawners and feeding for the autumn spawners. Likewise, in August-September, distributional patterns would be associated with feeding for the spring spawners and spawning for the autumn spawners. Since spawning group was not differentiated from the August survey data, it is not a straightforward matter to assign a function to the IA. However, in general ecological function for the summer survey data will be assigned feeding, except in areas where autumn spawning is known to take place.

<u>Feeding (adult):</u>

<u>Northern Gulf and Estuary:</u>

With the above stated caveats, distributional data collected in summer-autumn (Jun-Oct) was assumed to represent feeding concentrations, with the exception of summer-autumn spawning herring whose reproductive season peaks in August.

According to the BTS data, from 1990 to 1995, increased catch densities were concentrated in the northern sections of the Gulf (Figure 5a). These data indicate that the important summer feeding areas in the nGSL were at the heads of the major channels (Esquiman and Anticosti) and in the Strait of Belle Isle, as well as around the fringe of the Anticosti Gyre along the shelf slope. Between 1996 and 2000, there appeared to be an expansion toward the LSLE and on the shelf edge in the Esquiman Channel, along the western and southwestern Newfoundland shore (Figure 5b). After 2001, this expansion became a displacement, which continued toward the south and away from the Strait of

Belle Iles, along with a marked decrease in the incidental catches in the Jacques Cartier Strait on the Quebec middle North Shore (Figure 5c).

The other major database available for the northern GSL was the biannual herring acoustic survey (1995-2002). Although this dataset is restricted to the western Newfoundland shelf (mainly 10 - 80 m), the survey was designed to encompass the principle distribution of the herring population in this zone at that time of the year (Figure 6a). These data underline the strong coastal nature of these populations, at least with respect to its late-autumn feeding distribution. Within the confines of the western shelf, concentrations of herring can be found almost anywhere along the coast. It also underlines the coverage bias for this species with the BTS, conducted 1-2 months previous, which does not sample within the 20 m isobath where the most herring are found. Finally, these data show the importance of the nearshore banks for these populations in the fall, which is the principle period for the accumulation of fat stores before moving offshore to overwinter (McQuinn and Lefebvre 1995).

This pattern concerning western Newfoundland is supported to some extent by the opportunistic acoustic survey (OAS) data collected during the BTS between 2005 and 2009 (Figure 6b). These data summarize all swim-bladdered pelagic fish (SBPF) classified acoustically, which could include capelin as well as herring. The acoustic data showed major concentrations of SBPF on a gulf-wide scale in the Strait of Belle Isle and in the Mecatina Trough. The latter area is not sampled by the bottom trawl due to untrawlable bottom in this area. They also show abundant schools along the southern half of the NFLD coast. However, these data are also important for what they do not show, that is to say high-density schools in the troughs and along the slopes around the fringe of the Anticosti Gyre and into the St. Lawrence Estuary (SLE) area which show up consistently in the bottom-trawl data.

Finally, stomach content data showed a similar distribution as the summer acoustic data, in that the there were occurrences in cod stomachs along the southern half of the NFLD coast out to the slope and in the Strait of Belle Isle (Figure 6c).

Southern Gulf:

Herring in the sGSL were captured by the late-summer BTS mainly in the northwest (Chaleur Bay, Shediac Valley) between 1971 and 1983, with few significant catches elsewhere (Figure 7a). Between 1984 and 1989 (Figure 7b), there was an expansion in catches towards the southeast (PEI, St. Georges Bay) followed by a reduction in catches in the northwest between 1990 and 1993 (Figure 7c). Starting in 1994, there was a general increase in catches throughout the sGSL and a further expansion toward the northeast along the Cape Breton Trough, with few concentrations around the Magdalen Islands (Figure 7d). This increase coincided with the general demise of the southern Gulf cod population, and is most likely a consequence of an increase in catchability following an increase use of the suprabenthic habitat by herring (McQuinn 2009).

Data from the September acoustic surveys was limited to the most recent period (1995-2005) and did not necessarily cover all the principle areas of distribution, and therefore are considered partial (Figure 8). These surveys, although more spatially limited, are more able to assess the major concentrations and do confirm the general patterns seen in the OAS and BTS data (see Figures 6,7). Higher concentrations of herring were recorded inshore in the southern portions of the sGSL, from the Shediac Valley along northern PEI and into St. Georges Bay, with few concentrations around the Magdalen Islands (Figure 8). However, these data also show a considerable concentration in Chaleur Bay and off Miscou at the beginning of the period (Figure 8a,b), and which seems to have decreased over time (Figure 8c,d).

Data from opportunistic acoustic prospecting in June 2000 and 2005 as well as September 2005 (Figure 6b) confirm the decrease in the concentration along northern PEI and Chaleur Bay, as well as the presence of large shoals in the Cape Breton Trough and St. Georges Bay. Schools are systematically located in the Shediac Valley and the northwestern point of PEI, while St. Georges Bay seems to be occupied as well (possibly spawning activity). These data also underline the patchy distribution of significant herring schools, as opposed to the more widespread bottom-trawl catch data, which is more of an index of presence or absence.

Finally, stomach content data (Figure 6c) showed a similar distribution as the bottom-trawl data, especially in the sGSL (see Figure 7). Highest occurrence in cod stomachs corresponded to near shore in the Shediac Valley/nw PEI and the Cape Breton Trough. The correspondence with the OAS data is striking (see Figure 6b).

<u>IA – Feeding (Figure 9a):</u>

Maps were produced from the gulf-wide opportunistic acoustic surveys (OAS) to confirm the general patterns seen in other datasets (Figure 9b). The distribution of patches (shoals and schools) was compared to validate the IA boundaries determined from the longer time series BTS data for any gross inconsistencies.

1.1 **Chaleur Bay and the Shediac Valley**: These are shallow depressions in the northwest corner of the southern Gulf basin receive accumulations of primary and secondary production from the LSLE via the Gaspé current (Plourde and McQuinn 2009). The stock assessment acoustic survey shows that this is a region of annual recurrence of herring schools in late summer (Figure 8). This recurrence was also noted from the annual BTSs (Figure 7) and the stomach content data (Figure 6c), although with a limited extent in deeper waters towards the north.

1.2 **North shore of PEI, St. Georges Bay, Cape Breton Trough**: This area is notable by having some of the warmest waters in the sGSL and is an area of increasing habitat use according to the bottom-trawl data. Both acoustic time series as well as the stomach content data confirm that this is a fundamental feeding area for adult herring.

1.3 **The Magdalen Islands**: This area has not been systematically surveyed very often by the annual acoustic survey, but when it has been, higher than average yields have been found (Figure 8b). From the BTSs, there have been high-density catches on occasion throughout the time series, but especially in the most recent period (Figure 7d).

2.1 **Cabot Strait - Mouth of Esquiman Channel**: Higher-density catches have been occurring more and more in this slope region in summer (Figure 5). This area is a traditional migration route for many species in and out of the GSL.

2.2 **Head of Esquiman Channel**: The deeper waters at the head of the Esquiman Channel have been an area of higher-density BTS catches of herring throughout the time series (Figure 5), although this is not reflected in the acoustic data (Figure 6).

2.3 **Strait of Belle Isle**: The shallower waters of the Strait of Belle Isle show consistently higher summer densities of herring in all available datasets (Figures 5, 6).

2.4 **Anticosti Channel**: The slope region of this area produced widespread, higher BTS catches in the earlier surveys, although less so since 2001 (Figure 5). Acoustic prospecting since 2000 has shown little signs of dense herring schools in this area (Figure 6b).

2.5 **Pentecôte-Parent Bank-Honguedo Passage-South Anticosti (Anticosti Gyre)**: The arc around the Anticosti Gyre has also been an area of traditionally higher-density BTS catch, but again less so since 2001 (Figure 5). The area around Parent Bank has shown schools of SBPF also, as well as being a traditional summer whale feeding ground (Figure 6b).

2.6 **Gaspé Current-The Edge**: The southern slope of the Laurentian channel his shown higher than usual herring BTS catches in the recent period (2001-2005) as well as dense backscatter from both the opportunistic (Figures 6b) and the annual acoustic surveys (Figures 8), although more so before 2000.

2.7 **Estuary**: This area has had higher BTS catches since the mid-1990s in summer, although this has not been reflected in the acoustic data since 2000 (Figure 5).

2.8 **Port au Port-Bay of Islands-Bonne Bay**: Although this inshore area in not covered by the BTSs, it shows the highest acoustic densities in the nGSL from the summer survey (Figure 6b) as well as the biannual herring stock assessment surveys in early fall (Figure 6a).

2.9 **St. George's Bay**: The inner slope area of this bay is a traditional area of herring concentrations in the early to late fall (Figure 6a).

Nursery:

Southern Gulf:

Nursery areas are by definition areas of concentration of juveniles and subadults. The only database available for juvenile distributions for the sGSL was from the regular annual BTS from which data on juvenile catches were extracted (Figure 10).

IA - Nursery (Figure 9c):

3.1. **St. Georges Bay – Northumberland:** This area has produced a concentration of BTS catches throughout the time series (Figure 10), although this area seems to have grown in relative importance in recent years (Figure 10d).

3.2. **Head of Shediac Valley:** The selected juvenile BTS data underlines the importance of the head of the Shediac Valley at the mouth of the Miramichi Estuary as an area of persistent catches of young herring (Figure 10), which could extend to Miscou in some periods (e.g. 1984-1989).

3.3. **Chaleur Bay:** The head of Chaleur Bay has shown consistent catches since 1971 (Figure 10).

3.4. **PEI**: Northern PEI has shown variable occupancy of juveniles with no high catch in the period 1971-1983 (Figure 10a) and moderate use after that.

Spawning:

Northern Gulf and Estuary:

The only indications of spawning concentrations in the nGSL can be assumed for the distribution of herring from the summer BTS (Figure 5) in the Strait of Belle Isle, where spawning is known to occur at this time of the year (McQuinn and Lefebvre 1995). Other spawning concentrations may eventually be identified with information on spawning condition from this survey, although in most years only length and weight data were collected.

Southern Gulf:

Directed spawning bed surveys have been conducted in the sGSL (Claytor 2001) while some spatial information is available from the August BTS (Figure 7) during which the autumn spawners are mostly in spawning mode. The spawning bed surveys are essentially acoustic data collected by commercial fishermen during normal fishing operations and mapped for distribution. Since at that time of the year the schools are concentrated on spawning bed, they should reveal the main spawning activity within the range of the fishing effort.

In the sGSL, the industry based acoustic surveys are very limited in space and time, but nonetheless should represent the principle autumn spawning areas for the period in question (1999-2004). Main autumn-spawning activity with this period was observed off Chandler, Miscou, Escuminac, northwestern PEI, Fisherman's Bank, and in the Northumberland Strait (Figure 9d).

IA - Spawning (Figure 9d):

2.0 **Strait of Belle Isle:** An area of consistent BTS catches was inshore in the northern part of the Esquiman Channel toward the Strait of Belle Isle in August (Figure 5). From commercial catches, this is known as an autumn-spawning area for herring. There are other similarly nearshore concentrations in the northwestern GSL (Figure 5a), but it is unknown if these are spawning concentrations.

5.1 **Miscou,** 5.2 **Gaspé,** 5.3 **Escuminac,** 5.4 **Pictou,** 5.5 **Fisherman's Bank;** 5.6 **Western PEI:** These areas are traditional spawning sites (Figure 9d) where fishing-vessel based acoustic surveys have been conducted (Claytor 2001). It is recognized that the total area of the spawning grounds at each of these sights could be wider than indicated in Figure 9d and could vary somewhat from year to year, although these sites are believed to encompass a large part of the spawning area due to their bathymetric properties.

Refugia:

Northern Gulf and Estuary:

Between 1980 and 1994, a BTS was conducted in January in the nGSL. This survey was limited in spatial extent due to varying ice cover but in most years, sampling covered essentially the northwestern Gulf. Herring catches were concentrated in the Esquiman Channel and along the shelf edge off western Newfoundland. This appears to be the principal overwintering refugia for the nGSL herring population that inhabits the northwestern Gulf, as they move offshore and into deeper water at the end of the fall feeding season (McQuinn and Lefebvre 1995). There was also a pattern of higher catches in the Anticosti Channel and around Anticosti Island, although less important than in the Esquiman Channel.

There is some indication from this survey that part of the sGSL herring population is found along the northern slope of the Magdalen Shallows (the "Edge"), possibly on their way to their normal overwintering area off Sydney Bight, Cape Breton (Figure 11a).

Southern Gulf (juveniles):

From 1991 to 1995, a directed juvenile bottom trawl survey was conducted each December within selected areas of the sGSL (LeBlanc et al. 1995, LeBlanc et al. 1997). Particularly concentrated catches were made at the head of Chaleur Bay. Two other areas of lesser concentration, but with also lesser effort were at the head of the Shediac Valley and east of PEI. However, no other areas have been inventoried. These areas are considered refugia rather than nurseries are they are overwintering areas where presumably little feeding takes place during the winter months. In addition, juvenile herring most likely do not migrate out of the southern Gulf as do the adults of this population, therefore these areas are true refugia from the trials of winter for this segment of the population, since the entire Magdalen Shallows falls below zero during the winter months.

IA – Refugia (Figure 11c,d):

4.1. **St. Georges Bay–Northumberland:** The December BTS (Figure 11b) from 1991 to 1995 found juvenile herring in this area similar to the summer juvenile survey (Figure 10), consistent with the belief that juvenile herring do not migrate from the sGSL in winter.

4.2. **Head of Shediac Valley:** This area also showed concentrations of juvenile herring overwintering (Figure 11b) where they were also picked up during the summer.

4.3. **Chaleur Bay:** The head of Chaleur Bay is also known for juvenile herring spending the winter, as seen by the BTS catches in December (Figure 11b).

6.1. **Esquiman Channel:** It is believed that the nwGSL adult herring do not exit the Gulf in winter, as do the sGSL adult herring (McQuinn and Lefebvre 1995). Therefore the Esquiman channel would be the main if not the only winter refugia for this population (Figure 11a).

6.2. **Anticosti Channel:** Little is known of this area and catches were mainly in the 3rd quartile (Figure 11a), however, it is possible that this area acts as a winter refuge for the Quebec north shore population of herring.

6.3. **South Anticosti:** Likewise, there is no historical information on this area besides the January BTS, but this slope area shows signs of higher than average catch from the winter BTS series (Figure 11a).

6.4. **The Edge:** It is known that adult exiting the sGSL migrate along the southern slope of the Laurentian Channel in late fall (Beckett 1971). BTS catches in January (Figure 11a) may be a reflection of this migration route (i.e. late migrators) or an overwintering area for some portion of the sGSL population.

CAPELIN (*Mallotus villosus*)

In the northwest Atlantic, capelin is found along the coasts of Labrador and Newfoundland, on the Grand Banks and in the GSL. Further south, capelin are also found in the eastern portion of the Scotian Shelf and occasionally in the Bay of Fundy.

During the spawning period, capelin exhibit a pronounced sexual dimorphism. Males can be distinguished from females by their larger fins and by the appearance of two pairs of spawning carina (elongated scales), one dorsal and the other ventral. Following a massive migration towards the coast, spawning occurs inter-tidally on beaches as well as in deeper water, in temperatures between 6-10°C and predominantly at night. When on the beaches, capelin literally “roll” on the sand or fine gravel to lay their reddish-coloured eggs, which adhere to the substrate. The incubation period varies according to ambient temperature, lasting for approximately 15 days at 10°C. Upon hatching, larvae quickly adopt a planktonic existence and remain near the surface until the arrival of winter. The most significant growth period occurs during the first year. Males are longer than females, with maximum lengths rarely above 210 mm. Capelin can spawn at 2 years of age, and nearly 100% of males die following reproduction.

Capelin represent a very significant link in the food chain as they facilitate the transfer of energy from primary and secondary producers to higher trophic levels. It is believed that this small fish is the principal forage species in the northern Gulf of St. Lawrence marine ecosystem (Savenkoff et al. 2004d), although their biomass has never been directly assessed.

Capelin is also the subject of a commercial fishery in the GSL. The main indicators of the status of the capelin fishery are the performance of the west coast of Newfoundland purse seine fleet, the mean length of females caught by this fishery and an index of dispersion (not abundance) based on the catches of the two summer BTSs. No directed surveys have been conducted on the distribution and abundance of capelin since Bailey et al. (1977) and no analytical assessment for GSL capelin has been produced. Therefore, we were limited to bottom-trawl bycatch from the summer bottom-trawl surveys and the cod-stomach database for our analysis.

Feeding:

Northern Gulf and Estuary:

From 1990 to 1996, four principle zones stand out as IAs for capelin summer feeding: the head of the Esquiman and Anticosti Channels in deep water, the western tip of Anticosti, including the slope of the Anticosti Gyre and to a lesser extent, the SLE (Figure 12a). Between 1997 and 2005, there appeared to be an expansion from the Gaspé Current along the southern edge of the Laurentian Channel, possibly spilling over into the sGSL and at the southwestern tip of Newfoundland (Figure 12b).

The available data from a cod stomach contents covered the nGSL (August) as well as the sGSL (September) between 1987 and 2005. In the period 1987-1994 (Figure 12c), capelin was a consistent prey item in cod stomachs principally in the Strait of Belle Isle, along the lower north shore of Quebec and along western Newfoundland, a pattern which was not reflected in the bottom-trawl catches. This inconsistency between the two datasets could be due to the lack of adequate coverage (poor areal sampling) from the BTS in the Strait of Belle Isle and the lower north shore, although this would not explain the difference with western Newfoundland. The difference is marked with essentially no capelin captured by the BTS in this area since 1990. Essentially, where capelin are caught in the BTS, there are no cod. Conversely, where capelin were found in cod stomachs, they were not caught in the BTS. This could be explained by capelin moving off bottom where cod are present, but being nonetheless preyed upon while inhabiting the suprabenthic habitat when cod are absent. This pattern would be accentuated are cod abundance declined in the 1990s.

Southern Gulf:

Historically, at least from 1971 to 1983, very little capelin was captured in the BTS in the sGSL, and those few sets with capelin were situated in or about Chaleur Bay (Figure 13a). However from 1984, catches began to increase until between 1991 and 1998, the presence of capelin became a common occurrence in the northwestern corner of the sGSL. Prevalence also increased in the Cape Breton Trough throughout this period. This territorial expansion can also be detected from the stomach-content data which showed very little capelin in cod stomachs from 1987-1994 (Figure 12c) while after 1995, they occurred in the Shediac Valley and Cape Breton Trough (Figure 12d). As in the nGSL, this increase in capelin catches coincided with the decline of the sGSL cod population. However the quick response on capelin expansion suggests downward shift in vertical distribution and therefore an increase in their catchability in the BTS as proposed by McQuinn (2009). The prevalence and extent of capelin caught in the BTS continued to increase throughout the early 2000s, with more capelin appearing in on the Magdalen Shallows. Again as in the nGSL, BTS catches in the sGSL (Figure 13c,d) were highest on the Magdalen Shallows, where few cod were caught and capelin were found in cod stomachs mostly on the Shediac Valley, where they were not caught in the BTS (Figure 12d). Also, the OASs showed schools of SBPF between Gaspé and the Magdalen Islands (Figure 6b) which is not an area known for herring schools and therefore may have been capelin in this instance. Catches increased in the Cape Breton Trough in the 1990s in both the BTS and the cod stomachs.

IA – Feeding (Figure 14c):

1.1 **Orphan Bank-Bradelle Bank-Chaleur Bay:** This area has seen increasing catches of capelin since 1983 (Figure 13).

1.2 **Cape Breton Trough:** Catches also increased west of Cape Breton from almost nothing in 1983 to consistent occupancy from 1990-2005 (Figure 13).

2.1 **Mouth of Esquiman Channel:** Few capelin have been caught in this area from the BTS, although more so in the recent period (Figure 12a,b), although cod stomachs from the same catch series has shown an area of capelin occupancy all along the shelf break (Figure 12c).

2.2 **Head of Esquiman Channel:** Consistent catches have been noted throughout the channel head (Figure 12a,b), although capelin have appeared in cod stomachs only along the channel slopes (Figure 12c).

2.3 **Strait of Belle Isle:** BTS sampling has been more sporadic in this area (Figure 12a,b), but again, shows a general lack of capelin in the catches. This is not reflected in cod stomachs which show a general profusion of capelin throughout the Strait (Figure 12c).

2.4 **Mécatina Trough:** There are no BTS samples (therefore no cod stomachs) from the Mécatina Trough proper because of an untrawlable bottom. However, again capelin was present in the cod stomachs sampled on both sides of the Trough (Figure 12c).

2.5 **Anticosti Channel-Jacques Cartier Strait:** This channel shows a constant occupancy of capelin from 1990 to 2005 (Figure 12a,b), although once again this pattern is not reflected in the cod stomachs (Figure 12c).

2.6 **Pentecôte-Parent Bank-South Anticosti:** The nwGSL is another area of consistent capelin catches throughout the BTS time series (Figure 12a,b), however, capelin does not constitute an important part of the cod diet in this area (Figure 12c), either because it is not as accessible or other prey is more sought after. The only schools of SBPF encountered during the OASs were on Parent Bank (Figure 6b) and may have been capelin.

2.7 **Gaspé Current-The Edge:** Capelin exhibit a quasi-continuous occupancy of the nearshore slope along the Gaspé peninsula towards the southeastern Laurentian Channel (the Edge) in the BTS catches (Figure 12a,b). There were however too few cod stomachs from the area to confirm or refute this pattern (Figure 12c).

2.8 **Estuary:** The estuary in a known area of capelin spawning (DFO, 2011) and juvenile residency (Bailey et al. 1977). The BTS also showed consistent presence of capelin in this area, although not from the OAS.

Refugia:

Northern Gulf and Estuary:

Capelin catches from the winter BTS were analysed for the years 1984-1994 to ascertain their partial winter distribution. These data are partial because of the variable ice cover which in most years, limited the sampling to the western portion of the nGSL, and in many years, to the southwestern portion (Rollet et al. 1994).

<u>IA – Refugia (Figure 14d):</u>

2.0 **Head of Esquiman Channel:** As with Atlantic herring, capelin were found mainly in the northeastern Esquiman Channel and to some extent along the slope edge off western Newfoundland (Figure 14b) in the most recent period. They were however very sparse in these areas before 1984 (Figure 14a). There were also patches of capelin catches to the west of Beaugé Bank on the Quebec north shore (Figure 14b).

ATLANTIC MACKEREL (*Scomber scombrus*)

Atlantic mackerel are another pelagic summer visitor in the GSL. Among the three species of the genus *Scomber*, Atlantic mackerel has the most northerly distribution. They are found in the waters of the North Atlantic, from the Mediterranean to Norway in the east and from North Carolina to Newfoundland in the west. Atlantic mackerel is also the only one of the three *Scomber* species without a swim bladder, requiring it to swim continually in order to maintain its hydrostatic balance. This biological feature along with its high swimming speed helps it to change direction rapidly, making it difficult to catch compared with other pelagic fish species. During its long annual migrations, mackerel sometimes travel in very dense schools, especially in the spring and fall. These schools allow mackerel to escape their prey more easily while also facilitating foraging.

From late fall and into the winter, mackerel is found in deeper warmer waters at the edge of the continental shelf. During spring and summer, they are found in inshore waters to feed and reproduce. In American waters, spawning occurs between the coasts of Rhode Island and Virginia. In Canadian waters, though some spawning does take place along the coasts of Nova Scotia during the spring migrations, most mackerel enter the GSL every summer, preferring warmer waters. Spawning mainly occurs in the sGSL in June and July, although there is evidence that their spawning distribution has shifted to other areas, including the nGSL and even outside the GSL.

The largest concentrations of eggs are found in waters south of the Laurentian Channel, west of Magdalen Islands. At the peak of the spawning period, spawning occurs asynchronously near the surface at any time of day or night when water temperatures vary between 10° C and 12° C. At these temperatures, egg incubation time lasts around one week. At 50 mm, the larvae transform into juveniles that form into schools. Some of these schools can be found near the coast, which indicates that juveniles migrate from the spawning grounds to the inshore. Not much is known about what proportion of the juvenile population participates in this migration, nor about what roles these inshore habitats play in determining juvenile growth and survival.

Mackerel are a very fast-growing species. Small and large zooplankton are their main prey, followed by northern shrimp and capelin. By the end of their second year (age 1+), average length and weight can reach 257 mm and 197 g, respectively. Growth can vary from one year to another, as well as from one year-class to another, often depending on year-classes size. Compared with other fish species, mackerel reach sexual maturity early in life. At one year old, almost 40% of mackerel can be mature while all of them are mature at age 4.

Feeding:

Southern Gulf:

Judging from the occasional catches in the sGSL BTS, mackerel in feeding mode have shifted preference from the Shediac Valley between 1971 and 1983 to east of the Magdalen Islands and the Northumberland Strait-St Georges Bay area between 1984 and 1992 (Figure 15). This apparent expansion continued into the mid-1990s, with a prevalence of mackerel catches along the northern shore of PEI.

IA – Feeding (Figure 15d):

1.1 **Shediac Valley:** This area has shown relatively consistent catches of mackerel throughout the time series of BTSs (Figure 15).

1.2 **St. Georges Bay:** This bay has shown increasing occurrences of mackerel catches since 1984 (Figure 15b,c).

1.3 **PEI:** Around PEI is a traditional area of mackerel catches, both in the BTSs and in the tourist hand-line industry. As with St. Georges Bay, BTS catches have increased slightly since 1984 (Figure 15b,c).

1.4 **Magdalen Islands:** As around PEI, traditionally mackerel have been caught commercially around the Magdalen Islands in summer. This can also been seen in the BTSs since 1971 (Figure 15).

SAND LANCE (*Ammodytes americanus*)

Two species of sand lance inhabit eastern Canada. Northern sand lance, *Ammodytes dubius* is mostly associated with offshore sand banks while American sand lance, *A. americanus* is more coastal, although their distributions overlap. While most of our data was not identified to species, *A. americanus* is believed to be the dominant species in the GSL, therefore we consider our data represents the American sand lance.

Sand lance is a semi-pelagic species that forms schools for pelagic feeding, while burrowing into the sediment as refuge from predators and to rest (Meyer et al. 1979). Very little is known about the distribution and abundance of these species although they are believed to be one of the main forage prey species within the coastal/shelf habitat being consumed by the majority of predators within the GSLE (Savenkoff et al. 2004c). Generally speaking, they are distributed from Labrador to North Carolina, including the GSL and Hudson Bay (Meyer et al. 1979, Scott and Scott 1988). In the GSL, they are found in the estuary, the North Shore, in the sGSL (e.g. Miramichi, Magdalen Islands). Their habitat consists of porous sandy bottoms which allows them to burrow (Meyer et al. 1979).

Sand lance commonly grow to 18 cm as adults, but have been known to reach 24 cm in the Gulf of Maine (Meyer et al. 1979). Although heavily exploited in the North Sea by several hundred thousand tons annually, there is virtually no exploitation in the northwest Atlantic (Mercille and Dagenais 1987).

Feeding:

Northern Gulf and Estuary:

Sand lance is not regularly caught in the annual BTS despite their assumed large abundances and can be difficult to differentiate from young capelin, hence no reliable capture data exists for the GSL. Therefore, we have relied on cod stomach-content data for gulf-wide distributional information. Areal coverage has been relatively extensive throughout the database for the nGSL except for the estuary, where few cod stomachs have been sampled (Figure 3d). Despite this large areal coverage, significant prevalence of sand lance in cod diets has occurred principally along the banks off western Newfoundland, to a lesser extent at the mouth of the Strait of Belle Isle and Beaugé Bank and a few isolated inshore samples along the north shore of Quebec, i.e. the northeastern Gulf (Figure 16a). No significant amounts have been found in cod stomachs in the northwestern Gulf.

Southern Gulf:

Although the availability of suitable habitat (loose sandy bottoms) in the sGSL should be more prevalent than in the nGSL, and sampling has been more intense in the sGSL, the occurrence of sand lance in cod stomachs was greater in the nGSL (Figure 16a). This is also surprising given that capelin are more prevalant in the nGSL and may compete for the attention of cod.

IA – Feeding (Figure 16b):

2.1 **Western Newfoundland:** Sand lance are picked up in cod stomachs on the shelf banks all along the west coast of Newfoundland (Figure 16a).

2.2 **Strait of Belle Isle-Mécatina Trough:** This area also showed relatively high occurrences of sand lance in cod stomachs, along both the Quebec lower north shore and western Newfoundland.

2.3 **Beaugé Bank:** This relatively shallow bank projects into the northern GSL and separates the Esquiman and Anticosti Channels. The bank is (presumably) of sandy bottom and shows higher then average occurrences of sand lance in cod stomachs.

BUTTERFISH (*Peprilus triacanthus*)

The butterfish is a small pelagic fish that forms loose schools, often near the surface (Cross et al. 1999). This species is eurythermal (4.4 – 21.6°C) and euryhaline (5 – 32 ppt) and is commonly found over sand, mud and mixed substrates. Butterfish are fast-growing and short-lived. Adult butterfish have an average length of 15 to 23 cm and few individuals live beyond 3 years (Cross et al. 1999). Butterfish are preyed upon by some important commercial species including haddock, silver hake (Scott and Scott 1988) and by swordfish (Scott and Tibbo 1968).

Butterfish are distributed from Newfoundland and the GSL to Florida but they are most abundant from the Gulf of Maine to Cape Hatteras (Cross et al. 1999). In the northwestern Atlantic Ocean, north of Cape Hatteras, butterfish have a seasonal inshore-offshore north-south migration in response to water temperature changes. During the warmer months, May to November, they move north and inshore to feed and reproduce. Butterfish is therefore a seasonal visitor to the GSL, occurring sparsely throughout the years almost exclusively in the southern part of the Gulf (Nozères et al. 2010) where they prefer the sandy bottom areas (Scott and Scott 1988). During the winter, they move south and offshore in depths up to 200 m (Cross et al. 1999).

There is no commercial fishery for butterfish in Canadian Atlantic waters although the incidental catches are processed for fishmeal and pet food (Scott and Scott 1988). In the United States, there has been a fishery for butterfish since the late 1800s (Cross et al. 1999). From 1920 to 1962, the annual domestic harvest averaged 3,000 t. In the 1960s foreign fleets began to exploit butterfish and the annual landings increased up to a record 19,500 t in 1973 (Cross et al. 1999). Between 1977 and 1986, foreign fishing was reduced and butterfish landings averaged 6,300 t. Since 1987, landings decreased gradually, going from 3,000 t in the early 1990s to 0.5 t in the middle of the 2000's (Overholtz 2006).

Feeding:

Southern Gulf:

BTS catches of butterfish in summer have been restricted to the southern-most regions of the sGSL, located mainly in the Northumberland Strait, St, Georges Bay and a few isolated areas along northern PEI.

IA – Feeding (Figure 17b):

1.1 **St. Georges Bay – Northumberland:** This area boasts the highest temperatures in the GSL and eastern Canada. The summer intrusion of butterfish is thus restricted to the warmest waters of the sGSL (Figure 17a).

SPINY DOGFISH (*Squalus acanthias*)

The spiny dogfish is a relatively small, schooling shark usually found in coastal and inshore waters in cold and temperate seas and is tolerant to low salinities, allowing the ascent of estuaries (Scott and Scott 1988). This species is slow-growing and long-lived; the males can live up to 30 years and reach a size of 96 cm while females can live for 40 years and reach a length of 120 cm (Nammack et al. 1985). Spiny dogfish smaller than 60 cm are uncommon in Canadian Atlantic waters (Scott and Scott 1988). Dogfish appear to have few predators. Juveniles and adults may be preyed upon by predaceous bony fishes like the swordfish and by marine mammals such as the grey seal (Scott and Scott 1988).

The spiny dogfish is widely distributed throughout the world, particularly in the Atlantic and Pacific oceans. In the northwestern Atlantic, it is found from southern Greenland southward to Florida and are considered to constitute a single northwest Atlantic population (Campana et al. 2007). The groups found in the GSL are at the extreme northern end of their distribution, although they can also be found along eastern Newfoundland. They appear off Nova Scotia and southwestern Newfoundland in June and moving into the GSL and into southern Labrador in July and late summer on their feeding migrations. In late fall, they begin to move out of the Canadian waters, going south for reproduction.

The spiny dogfish has always been considered a nuisance by commercial fishermen. They can destroy nets (and the catch) and consume bait from longline fishing, rendering gear useless. However, they are fished commercially by otter trawl and longlines in the eastern Atlantic and used as food in Europe and elsewhere in the world (Scott and Scott 1988).

Feeding:

Northern Gulf and Estuary:

Catches of spiny dogfish in research surveys in the nGSL have been sporadic over the time period 1995 to 2005, therefore the data series were combined. The catches nonetheless show a consistent pattern of association with the slopes along the main channels and the shelf in the Strait of Belle Isle (Figure 18a).

Southern Gulf:

The summer feeding distribution in the sGSL varied somewhat in extent between the 1980s, the 1990s and the 2000s, although the centres of concentration were essentially the same, i.e. the Shediac Valley, east of the Magdalen Islands, north and southeast of PEI including St. Georges Bay (Figure 18b,c,d). As seen with several other small pelagic species, the catches increased during the 1990 although possibly not for the same reasons. Whereas other small pelagics such as herring and capelin seemed to have profited by the decline in cod abundance to expand there vertical distribution towards the bottom, spiny dogfish may have followed their small-pelagic prey to these depths, as their IAs in the sGSL correspond closely to those for herring (Figures 5,7,10) and mackerel (Figure 15).

IA – Feeding (Figure 19):

1.1 **Shediac Valley:** This area showed the most important BTS catches of spiny dogfish in the GSL, especially in the 1991-1998 period (Figure 18c).

1.2 **St. Georges Bay:** This is an area of that has shown declining occurrences of dogfish catch in the most recent period (Figure 18d).

1.3 **PEI:** Northeastern PEI has shown occurrences of dogfish over the entire period (1971-2005) although not necessarily in the same locality from one period to the next (Figure 18).

1.4 **Magdalen Islands:** Again, the southeastern side of the Magdalen Islands is an area of residence for pelagic forage species (herring and mackerel) and also appears to be a foraging area for spiny dogfish (Figure 18).

2.1 **The Edge:** In the nGSL, the slope breaks showed higher than average catches of spiny dogfish (Figure 18a).

2.2 **Mouth of Esquiman Channel:** At the southern entrance of the nGSL, spiny dogfish are also relatively concentrated along the slope (Figure 18a).
2.3 **Strait of Belle Isle:** Spiny dogfish are also found in BTS catches on the gulf-side of the Strait of Belle Isle (Figure 18a).

2.4 **Beaugé Bank:** BTS catches were higher along the shelf slope formed by Beaugé Bank (Figure 18a).

ALEWIFE (*Alosa pseudoharengus*)

The alewife is an anadromous fish that lives most of its adult life at sea, entering fresh water to spawn, where it has become landlocked in many parts of eastern North America. Its activities at sea are not well documented but it is known to frequent coastal waters and is captured more often at depths of 56 to 110 m and at temperatures around 4°C (Scott and Scott 1988). This species seems to be found at greater depths during the day indicating a vertical migration following the diel movement of zooplankton in the water column. The alewives caught in Atlantic Canada average 25 to 30 cm in length (Scott and Scott 1988) while Jessop et al. (1983) found fish from the Saint John River, NB to be as old as 10 years. When abundant during spawning runs, alewives can be preyed on by seabirds and predacious fishes such as striped bass and Atlantic salmon (Scott and Scott 1988).

The alewife occurs only in northwest Atlantic and tributary fresh waters (Scott and Scott 1988). They are present mostly in the southern part of the GSL (Nozères et al. 2010) and in the fresh waters of the Great Lakes and the St Lawrence River (Scott and Crossman 1973). Young fishes also occur in rivers and lakes tributary to the sea in many parts of Atlantic Canada.

The Canadian commercial fishery for alewife occurs mostly in the rivers of the Maritime Provinces during the spawning runs. The fish are caught in weirs, traps, gills nets and dip nets and are considered easy to catch. The flesh may be marketed for human consumption, used for pet food or as bait in the lobster and snow crab fisheries (Scott and Scott 1988).

Feeding:

Southern Gulf:

Alewife being an anadromous species is associated with the nearshore warmest waters in the sGSL. The available data analysed is from the September BTS (Figure 20), therefore well passed their normal spawning season in early summer and are thus in post-spawning, feeding mode.

IA – Feeding (Figure 21):

1.1 **Shediac Valley:** This area has shown a contraction of the zone occupied by alewife since 1999 (Figure 20d), having been the most important in the GSL before 1983 (Figure 20a).

1.2 **St. Georges Bay:** Alewife have always been found in the bottom of this bay (Figure 20), except before 1983 when sampling was poor (Figure 20a).

1.3 **PEI:** This species is now found all around the eastern end of PEI (Figure 20d) whereas it was common only in the Northumberland Strait before 1984 (Figure 20a).

RAINBOW SMELT (*Osmerus mordax*)

The rainbow smelt is a small, anadromous schooling species that ascends fresh water streams in the spring to spawn. Landlocked populations also exist and successfully live in fresh water throughout their lives. Although a coastal species, smelt prefer cooler waters during the summer and can move offshore in deeper water during this period (Scott and Scott 1988). They grow rapidly and saltwater fish attain greater lengths than most inland forms. McKenzie (1964) reported lengths of 18.0 and 20.6 cm for 5-year-old males and females, respectively. The schooling behaviour and abundance of the rainbow smelt make it a source of food for many larger species of fish like cod, salmon, trout and perch and for aquatic birds and seals (Scott and Scott 1988).

The rainbow smelt occurs along the North American Atlantic coast in bays and estuaries, from Labrador to New Jersey (Scott and Scott 1988). In the GSL, they are found on the north shore (Québec region), along the New Brunswick and Nova Scotia coasts as well as around the Prince Edward Island (Chaput and LeBlanc 1996, Nozères et al. 2010, Scott and Scott 1988).

The rainbow smelt has been extensively fished commercially and recreationally in the GSL since the turn of the century (Chaput and LeBlanc 1996). The major fishery is located in New Brunswick, especially in the Miramichi River estuary (Chaput and LeBlanc 1996, Scott and Scott 1988). The commercial smelt fishery occurs generally from October to February in open water or under the ice (Cairns 1989, McKenzie 1964). The landings in the Miramichi River, between 1989 and 1993, averaged 300 tons (Chaput and LeBlanc 1996).

Feeding:

Southern Gulf:

Rainbow smelt are captured throughout the BTS time series in the nearshore of the sGSL (Figure 22a) where it finds its preferred habitat, shallow coastal waters.

IA – Feeding (Figure 22b):

1.1 **Northumberland Strait:** This relatively shallow portion of the Northumberland Strait has had concentrations of BTS catches throughout the time series (Figure 22a).

1.2 **Head of Shediac Valley:** Another area of concentration of rainbow smelt is in the shallowest depths at the head of the Shediac Valley, west of PEI (Figure 22a).

1.3 **Head of Chaleur Bay:** As with Shediac and Northumberland, rainbow spelt are consistently found at the head of Chaleur Bay in the shallowest water (Figure 22a), catches dropping off quickly upon exiting the bay.

WHITE BARRACUDINA (*Arctozenus risso*)

The white barracudina is a pseudoceanic/ mesopelagic species and adults are found in cold water, mainly in depths of 200-1000 m (Scott and Scott 1988). They travel singly or in small schools of a few hundred individuals (Post 1984) and are frequently encountered during commercial midwater trawling operations. This species is said to attain a maximum size of about 30 cm in the northern Atlantic cold waters (Muus and Nielsen 1999).

The white barracudina is distributed worldwide from the Arctic to the Antarctic, on both sides of the North Atlantic Ocean (Scott and Scott 1988) and is commonly encountered in the GSL (Nozères et al. 2010, Scott and Scott 1988). This species has a significant importance as food for commercial species such as cod, pollock and redfish (Scott and Scott 1988) and is also preyed on by seals (Boulva and McLaren 1979).

<u>Feeding:</u>

<u>Northern Gulf and Estuary:</u>

In the GSL, white barracudina is distributed mainly in the deep channels and along their slopes (>200 m) and as such is totally absent from the sGSL. However, although they were widely distributed throughout the deep channels of the nGSL in the early 1990s and even expanded their distribution in the late 1990s (Figure 23b), in the early 2000s they were all but absent in catches at the head of the Esquiman Channel and in Anticosti Channel (Figure 23c). This general decline in prevalence also occurred along the Laurentian Channel (Figure 23d).

<u>IA – Feeding (Figure 24b):</u>

2.1 **Deep Channels:** The deep channels of the nGSL are the preferred habitat of white barracudina (Figure 23) where they are ubiquitous.

2.2 **Head of Esquiman Channel:** White barracudina have been prevalent in this area early on in the BTS time series, but have disappeared from the catches since 2000 (Figure 23c), despite the increase in shrimp in this area, their preferred prey.

<u>Refugia:</u>

<u>Northern Gulf and Estuary:</u>

The distribution of white barracudina in the nGSL in winter did not differ essentially from the summer distribution in the northeastern Gulf, although there would appear to have been an exodus from the northwestern Gulf (Figure 24a). However, the existing winter data (1980-1994) corresponds to the period when there were fewer catches in the west in summer as well (1990-1995).

IA – Refugia (Figure 24b)

2.0 **Deep Channels:** In winter as in summer, white barracudina is mesopelagic, residing in the deep channels in the nGSL. The BTS catches suggest a displacement to the east compared to the summer distribution (Figure 24a); however, this could be an artefact of the restricted sampling to the west due to ice cover.

POLLOCK (*Pollachius virens*)

The pollock is a gadoid fish that has a more pronounced pelagic phase than other cod-like fishes (Scott and Scott 1988). On the Scotian Shelf and in the Gulf of Maine, pollock are found at depths from 35 to 380 m and in temperatures ranging from 5 to 8°C (DFO, 2009). Their growth is rapid; adults are commonly between 30 and 110 cm long (maximum 130 cm) and have a maximum reported age of 25 years (Cohen et al. 1990). Young pollock, called "harbour pollock" (0-1 yr old and up to 20 cm long) move inshore in the summer and offshore in the winter. Mature pollock follow a more north-south migration, moving south in the fall or early winter to spawn (Steele 1963).

The pollock occurs on both sides of the North Atlantic. In the western North Atlantic, it is distributed from southwestern Greenland to Cape Hatteras, including southern Labrador, around Newfoundland and in the GSL (Nozères et al. 2010, Scott and Scott 1988). Predators of pollock include cod, white hake, monkfish, harbour seal, minke whale and other pollock (cannibalism) (Boulva and McLaren 1979, DFO 2009).

Pollock is fished commercially by otter trawl, gillnet, longline and handline. The Canadian fishery for pollock occurs on the Scotian Shelf, eastern Georges Bank and the Bay of Fundy. From 2000 to 2007, landings of pollock in these areas have averaged 6,000 tonnes (DFO 2009). There is also a sport fishery in some regions (Scott and Scott 1988). The flesh is sold fresh, frozen, salted and smoked and is usually marketed as Boston bluefish in Canada (Scott and Scott 1988).

Feeding:

Northern Gulf and Estuary:

Pollock is only occasionally caught in the GSL and has had a very restricted distribution (Figure 25). They are found only along the slopes of the Laurentian Channel where they presumably feed on euphausiids and copepods.

IA – Feeding (Figure 25c):

2.1 **The Edge:** This area is a known corridor for zooplankton exiting the GSL (Plourde and McQuinn 2009) which presumably attracts pollock.

2.2 **Cabot Strait - Mouth of Esquiman Channel:** This area is in theory a corridor for the entry of macrozooplankton into the GSL, although most pollock catches are at the mouth of the Cabot Strait.

Refugia:

Northern Gulf and Estuary:

BTS catches were much higher in the winter survey (Figure 26a), either due to an immigration of pollock into the area or a stronger association with the bottom of the semi-pelagic, schooling species.

IA – Refugia (Figure 26b)

3.2 **Cabot Strait - Mouth of Esquiman Channel:** Similar to the summer distribution, this area attracts concentrations of pollock along the slope of the Laurentian and Esquiman Channels (Figure 26a).

SILVER HAKE (*Merluccius bilinearis*)

The silver hake is a North American benthic marine and semi-pelagic species that can reach a maximum age of 12 years and a common length of 37 cm for males and 65 cm for females (maximum reported size of 76 cm) (Cohen et al. 1990, Scott and Scott 1988). This abundant species occurs over a wide range of depths (55 to 914 m), determined mostly by its preference for warmer waters (6 to 8 °C) (Lloris et al. 2005 , Scott and Scott 1988). On the Scotian Shelf, they move to shallow, warmer waters as the summer progress and move offshore in the fall as waters cool, in search of warmer waters. This inshore-offshore movement is characteristic of silver hake populations along the Atlantic coast (Scott and Scott 1988). The silver hake can be cannibalistic and young silver hake may represent up to 12.6 percent of the large silver hake diet (Langton and Bowman 1980). This species is also preyed upon by cod, pollock, swordfish and spiny dogfish (Scott and Scott 1988).

The silver hake distribution ranges from the Strait of Belle Isle to the Bahamas (Bailly 2011). However, it is most common from southern Newfoundland and the southern and eastern part of the Gulf of St Lawrence to South Carolina (Nozères et al. 2010, Scott and Scott 1988). This species supports a fishery by many countries including Russia, Cuba, USA and Canada, and between 2005 and 2010, 16,000 to 19,000 tonnes were caught annually (Cohen et al. 1990). The flesh is used for human consumption, marketed fresh, smoked or frozen (Frimodt 1995, Scott and Scott 1988).

Feeding:

Northern Gulf and Estuary:

Silver hake is another sparsely distributed resident in the nGLS (Figure 27a) and like pollock tends to concentrate along the channel slopes. They can be found throughout the Laurentian Channel including into the estuary, although mainly on the south side toward the west. In the Esquiman Channel, silver hake follow the slope to about 49° N.

Southern Gulf:

Silver hake are found occasionally in the sGSL mainly on the eastern side at the entrance from Cabot Strait, however also in the shallower areas in the head of the bays (Figure 27b). As a predator of small pelagic fishes, it tends to overlap the distribution of herring, mackerel, alewife, and rainbow smelt (Figures 7,10,15,20,22).

IA – Feeding (Figure 27c):

1.1 **St. Georges Bay:** This area has quite shallow water but is an area of concentrated catches of small pelagic fishes, including juvenile herring (Figure 10), butterfish (Figure 17) and alewife (Figure 20), which would be suitable prey for silver hake.

2.1 **The Edge-Cape Breton Trough:** The slope area of the Laurentian channel and the Cape Breton Trough are known areas of accumulation of forage species (Figure 6b) such as capelin (Figure 13) and squid (Chabot et al. 2007).

2.2 **Cabot Strait - Mouth of Esquiman Channel:** As with other predatory pelagic fishes (spiny dogfish, pollock and white barracudina), this area shows a concentration of silver hake (Figure 27a) where there are also concentrations of prey, such as herring (Figure 5) and meso- and macrozooplankton (Plourde and McQuinn 2009).

Refugia:

Northern Gulf and Estuary:

The winter distribution of silver hake catches in the nGSL (Figure 28a) resembles a contracted version of the summer distribution (Figure 27a). They seem to remain along the Esquiman Channel slope and in the adjacent Cabot Strait, as do pollock (Figure 26a) as fish of several species migrate out of the nGSL for the winter.

IA – Refugia (Figure 28b)

2.0 **Cabot Strait - Mouth of Esquiman Channel:** This area is a zone of convergence for many species, prey and predators alike, that migrate from the shallow shelf areas of the nGSL toward the Cabot Strait in fall and winter to avoid the cold surface waters.

EBSA IDENTIFICATION FOR SMALL PELAGIC SPECIES

Species Level

From the 12 species examined relative to the five ecological functions (feeding, spawning/breeding, nursery, migration, seasonal refugia) in the two ecosystems (sGSL, nGSL), a total of 73 IAs were identified (Table 5, Figure 29). The rating of the species-level IAs in relation to the property criteria of uniqueness, aggregation and fitness are shown in Table 5. Seven EBSA candidates were identified at the first-order, species level (Figure 30), i.e. seven IAs had a cumulative property rating greater than or equal to seven. These seven candidate EBSAs were considered to have a significant importance to the particular species/population independent of other species.

Community Level

The second-order, pelagic-community level analysis to determine EBSAs based on common and multiple use of habitat was conducted on the 73 species IAs. They were first combined relative to ecological function by spatially summing their ecological property ratings. The cumulative ratings were then categorized into three levels (low, medium and high) following natural breaks as outlined in the methods. In effect, only the functions of feeding (Figure 31a) and to lesser extent, seasonal refugia (Figure 31b) had enough IAs layers to warrant this intermediate step. The resulting, 3-level function-specific IAs were also rated by the property criteria before summing across functions to give equal weight to each function. Finally, these surfaces (pixels) were spatially summed over ecological function to produce a single, small-pelagic species ecological and biological importance surface composite (Figure 31c). This cumulative-ratings surface was in turn categorized into three classes of IAs based on the same three levels of relative importance: low, medium and high, using Jenks' optimisation to produce a surface of IAs across functions and species (Figure 32). The highest-level IAs were considered EBSA candidates at the pelagic-community level (Table 6).

From these results, several general patterns do emerge. Firstly, most community EBSAs in the nGSL were associated with the channel slopes. These are known areas of accumulation of forage biomass (Plourde and McQuinn 2009) and are used by small pelagic fishes for feeding and winter refuge (herring, capelin, spiny dogfish, white barracudina, pollock and silver hake). The slope area of the Esquiman Channel stands out as a particularly critical area being a migration route for small pelagic predators, such as pollock, spiny dogfish and silver hake as well as demersal predators such as cod, white hake, thorny skate and witch flounder (Castonguay and Valois 2007).

Second, in the sGSL the inshore shallow estuaries and bays (Chaleur Bay, Shediac Valley and Northumberland-St. Georges Bay area) stand out as important areas, mostly from the diversity of species that utilise these habitats, but also for the ecological functions that are preformed there. These areas are used by several species for spawning, as nurseries, for summer feeding, but also as important winter refugia for juveniles in the sGSL, which experiences sub-zero temperatures in winter. In addition, the deep channels of the nGSL act as winter refugia for the adult segment of coastal species (herring and capelin) to escape the cold mixed layer, which covers the nearshore banks in winter.

Finally, the Strait of Belle Isle and its approaches is a very active area in summer. Besides being an important spawning area for autumn herring and possibly capelin, there are also aggregations of sand lance, which all told most likely attract spiny dogfish. This is also a known foraging area fish-eating cetaceans such as dolphins and humpback whales (Lesage et al. 2007).

DISCUSSION AND CONCLUSIONS

The aim of this study was to define ecologically and biologically significant habitat for small pelagic fishes within the GSL, given the constraints of the available data. The present study represents a first attempt to investigate and define EBSAs in the GSL for generally understudied pelagic species and is the first compilation of all available distributional data - including some original sources - for the various species present in these ecosystems. However, as pointed out in the introduction, we recognise that these defined IAs and

EBSAs have limited spatial and temporal meaning, given that the analysed data are static in time and restricted in space and that they are associated with biological functions which are also dynamic in time and space. We also recognize that the patterns revealed by the present analyses were directly a reflection of the predominance of the BTS datasets available to us. Acknowledging that these bottom-trawl data were far from ideal for this purpose due to the suprabenthic nature of the gear, the distribution and relative importance of some species in some areas may be biased and should be interpreted with caution. Undoubtedly, some results would have been qualitatively different in detail if specific data from directed distributional studies of small pelagic fishes at the scale of the GSL had been more extensive. The opportunistic acoustic survey data was a first step in this direction, however, much more could be done with a directed, multifrequency acoustic monitoring program.

Our semi-quantitative, spatial-modelling approach was in part an attempt to mitigate for possible spatial biases inherent in the available datasets by incorporating data from as many sources as possible to identify underlying commonalities and consistencies. We believe that through this approach several patterns have emerged that reflect veritable significantly important areas. In some cases, the patterns seen from the BTS data were confirmed by the acoustic data, e.g. sGSL herring. However, the BTS catches were most recurrent in the channels, where few pelagic schools were detected, apart from the channel slopes. Recognising that the majority of pelagic fish biomass occurs in schools suggests that the pelagic catches in the BTSs, especially in the nGSL may represent a marginal portion of these populations. As an example, few significant schools of herring or capelin are detected acoustically in the nwGSL, whereas consistent catches are observed in the BTS. This may therefore be evidence of a sub-group of the population with a more suprabenthic distribution, rather than the main concentration. Further large-scale acoustic surveys as well as detailed biological observations should shed light on this paradox.

Although this first attempt at identifying EBSAs using an analytical method combined the spatial information in a linear, additive manner by assuming that all ecological functions had equal weight, the spatial analyses could be refined by weighting of the IA property ratings according to ecological function, dataset quality, etc. when combining the function layers. One could decide, for example that certain function-specific IAs, e.g. life-cycle “bottleneck” or critical functions such as spawning and nurseries, should have more ecological importance than say, feeding and therefore should be given more weight. This value judgment could then be reflected in the model by increasing the weight for these functions (Figure 4b).

Further, there was a close parallel between the cumulative-feeding surface (Figure 31a) and the cumulative-pelagic surface (Figure 31c), which was a direct consequence of the quantity of data available for the feeding function relative to other functions, despite our attempts to de-emphasize this category by normalising the property ratings. In addition, although the ecological qualifiers were coded for their relative importance (Table5), they were not included in the present spatial model. This was a collective decision for the purposes of the present exercise, although the model permits their inclusion. Finally, if data that is more explicitly directed to pelagic species distribution becomes available, the model could be easily reapplied.

We have defined EBSAs on a first-order or species level - important areas for the well-being of a species or population - and at the community level - areas commonly used by a variety of species for various reasons, therefore significant for the ecosystem. At the species level, an IA can have a population-critical importance independent of its importance to the pelagic community and therefore be considered an EBSA. We believe that the analytical method employed for this study captured some of the diverse and variable habitat use by pelagic species in the GSL. The exercise also underlines the spatial dynamic between species and permits the investigation of species interactions.

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Table 1. Pelagic species retained for analyses, with the database and time periods (seasons and years) and sampling gears.

Species name			DFO Species Code	Functional group*
English	French	Latin		
Atlantic herring	Hareng atlantique	*Clupea harengus*	150	Small pelagic
Capelin	Capelan	*Mallotus villosus*	187	Small pelagic
Atlantic mackerel	Maquereau bleu	*Scomber scombrus*	572	Small pelagic
Butterfish	Stomatée à fossettes	*Peprilus triacanthus*	783	Small pelagic
Pollock	Goberge	*Pollachius virens*	443	Large pelagic
Silver Hake	Merlu argenté	*Merluccius bilinearis*	449	Large pelagic
Spiny Dogfish	Aiguillat commun	*Squalus acanthias*	24	Large pelagic
Sand lance	Lançons	*Ammodytes* spp.	692	Bentho-pelagic
White barracudina	Lussion blanc	*Arctozenus risso*	320	Mesopelagic
Alewife	Gaspereau	*Alosa pseudoharengus*	151	Anadromous
Rainbow smelt	Éperlan d'Amérique	*Osmerus mordax*	188	Anadromous

* Based on the species groupings of GSL trophic models from Savenkoff et al. (2004a,b)

Table 2. Sources of available data used to describe distributional patterns of small pelagic fishes. Reference no. refers to Table 5 and pattern codes refer to datasets in Table 3.

Ref. No.	Code	Gear	Year	Ecosystem	Month	Species	Variable
1		Bottom trawl	1971-2005	sGSL	Sep	herring (juv+adu)	biomass or numerical density
3		Bottom trawl	1986-1992	sGSL	Apr-Jun; Oct-Dec	pelagics	biomass density
4		Acoustic	1994-2005	sGSL	Sep-Oct	herring	biomass density or NASC
5		Bottom trawl	1991-1995	sGSL	Dec	herring (juv)	numerical density
6		Acoustic	1999-2005	sGSL	Sep	herring	biomass density or NASC
7		Bottom trawl	1990-2005	nGSL	Aug	pelagics	biomass density
8		Bottom trawl	1980-1994	nGSL	Jan	pelagics	biomass density
9		Acoustic	1995-2002	nGSL	Sep-Oct	herring	NASC
10		Acoustic	2000, 2005, 2006	GSL	Jun, Aug, Sep	pelagics	NASC
11		Stomach content	1987-2005	GSL		sandlance	fullness

Table 3. Annual coverage of sampling gears for each database and species.

Species	Database	Sampling Gear
Atl. herring	sGSL_Sep	Bottom trawl
(Adult)	sGSL_AllSeasons	Bottom trawl
	sGSL_Jun	Acoustic
	sGSL_Sep-Oct	Acoustic
	sGSL_Aut_spawn	Acoustic
	nGSL_Aug	Bottom trawl
	nGSL_Aug	Acoustic
	nGSL_Sep-Oct	Acoustic
	nGSL_Jan	Bottom trawl
	Cod stomachs	Stomach
(Juvenile)	sGSL_Sep	Bottom trawl
	sGSL_Dec (Juv)	Trawl
Capelin	sGSL_Sep	Bottom trawl
	sGSL_Jun	Acoustic
	sGSL_AllSeasons	Bottom trawl
	nGSL_Aug	Bottom trawl
	nGSL_Aug	Acoustic
	nGSL_Jan	Bottom trawl
	Cod stomachs	Stomach
Atl. mackerel	sGSL_Sep	Bottom trawl
Sand lance	Cod stomachs	Stomach
Butterfish	sGSL_Sep	Bottom trawl
Spiny dogfish	sGSL_Sep	Bottom trawl
	sGSL_AllSeasons	Bottom trawl
	nGSL_Aug	Bottom trawl
	nGSL_Jan	Bottom trawl
Alewife	sGSL_Sep	Bottom trawl
Rainbow smelt	sGSL_Sep	Bottom trawl
	sGSL_AllSeasons	Bottom trawl
White barracudina	sGSL_Sep	Bottom trawl
	nGSL_Aug	Bottom trawl
	nGSL_Jan	Bottom trawl
Pollock	sGSL_Sep	Bottom trawl
	sGSL_AllSeasons	Bottom trawl
	nGSL_Aug	Bottom trawl
	nGSL_Jan	Bottom trawl
Silver hake	sGSL_Sep	Bottom trawl
	sGSL_AllSeasons	Bottom trawl
	nGSL_Aug	Bottom trawl
	nGSL_Jan	Bottom trawl

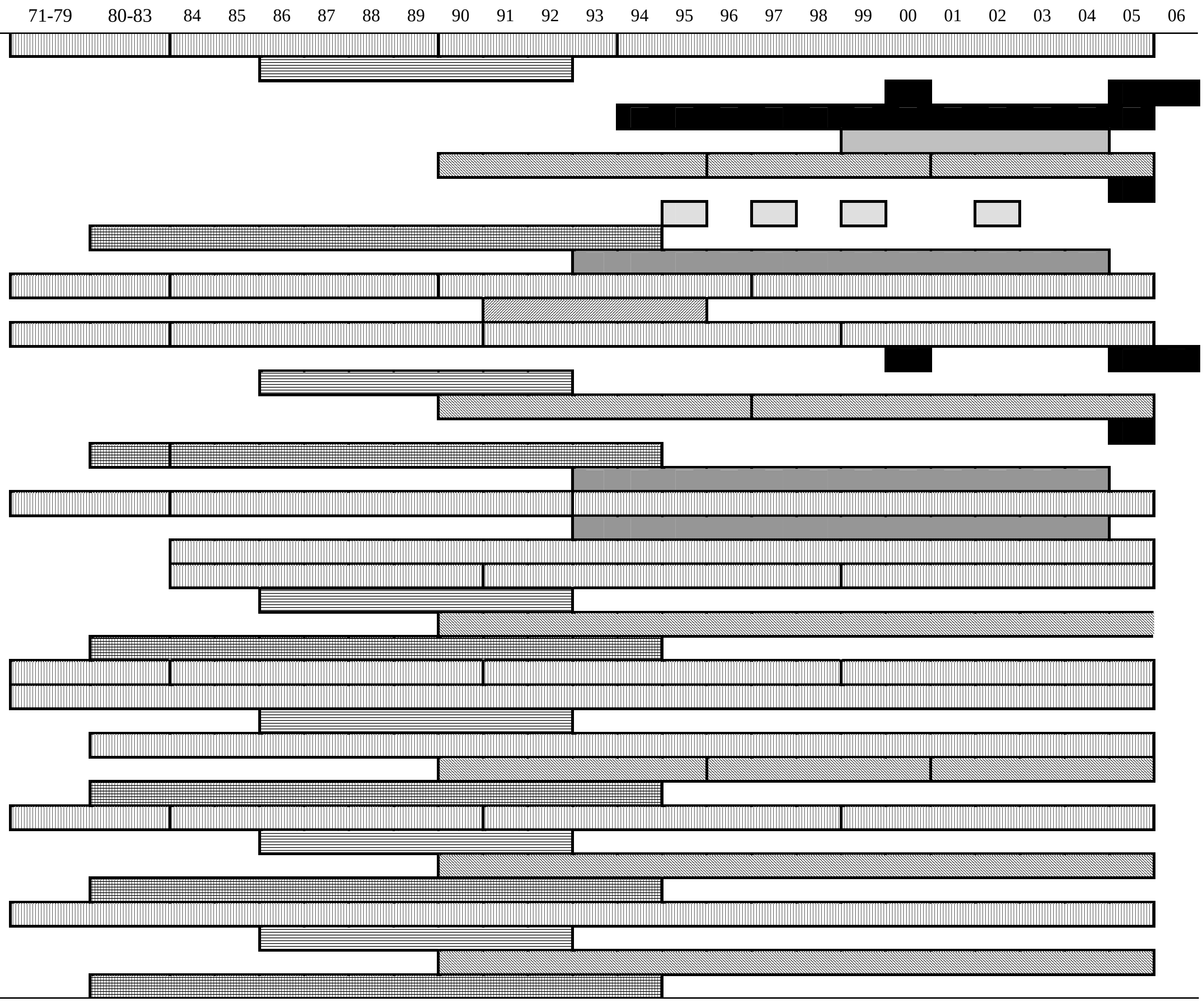

Table 4. Criteria used to rate the properties and qualifiers that were considered in the evaluation of important areas for their ecological and biological significance in relation to various ecological functions.

		Property			Qualifier	
Ecological Function	Rating	Uniqueness	Aggregation	Fitness Consequences	Fragility	Naturalness
Feeding	1	F1:A key food source isn't available elsewhere	F1:High concentration of prey	F1:Feeding critical to an organism's fitness / Area used consistently	F1:Production of prey dependent on small scale processes	F1:Production of food does not depend on man-made structures or activities
	2	F2:Prey distribution is patchy or unknown	F2:High concentration of prey found occasionally or unknown occurrence	F2:Feeding adds significantly or of unknown proportion to the populations fitness	F2:Production of prey organisms depends on ephemeral, medium scale or unknown processes	F2:Alteration of food web dynamics may have negative or unknown consequences
	3	F3:Prey have a wide distribution	F3:Prey have a low standing biomass with very low productivity	F3:Presence of prey is sporadic	F3:Production of prey organisms depends on large-scale dynamic mechanisms	F3:Human activities have altered the food web
Spawning / Breeding	1	S1:Only one suitable site known	S1:High percentage of total population	S1:Semelparous or limited age distribution	S1:Spawning site use once disturbed may take generations to recover	
	2	S2:Suitable spawning sites are limited or unknown	S2:Majority or an unknown proportion of the population present	S2:Strong recruitment events are limited	S2:Spawning site fidelity demonstrates a significant or unknown level of fragility	
	3	S3:Suitable spawning sites are widespread	S3:Only a small portion of the population present	S3: Reproduction occurs at many sites and/or over many years.	S3:Spawning site fidelity demonstrates a high level of stability	
Nursery / Rearing	1	N1:Only nursery / rearing area	N1:Larvae/juveniles are found in high concentrations	N1:Larvae/juveniles have superior survivorship/fitness		
	2	N2:Principal nursery / rearing area	N2:Larvae/juveniles are found in moderate or unquantified concentrations	N2:Larvae/juveniles fitness is average or unknown compared to adjacent habitats		
	3	N3:Marginal nursery / rearing areas	N3:Larvae/juveniles widespread or found evenly over a large area	N3:Larvae/juveniles fitness is comparable to adjacent habitats		

Ecological Function	Rating	Property: Uniqueness	Property: Aggregation	Property: Fitness Consequences	Qualifier: Fragility	Qualifier: Naturalness
Migration	1	M1:The route is an obligatory passage	M1:Most individuals in the population travel along the route	M1:The route itself or its endpoints favour population fitness	M1:A disruption to the migration pathway would result in an irrevocable lose of the route	M1:The migration is carried out by a native species
	2	M2:Only a few routes are known	M2:A significant portion of the population uses the route	M2:The route probably favours population fitness	M2:Disruption of the route would require significant time to be re-established	M2:The migration has been modified in the past with significant but reparable consequences
	3	M3:The migration uses several routes	M3:Only a small fraction of a population uses the route	M3:The migration has no effect on fitness	M3:If temporally disrupted, the route could be re-established readily	M3:The migration is carried out by an introduced species
Seasonal Refugia	1	R1:Refuge utilized by a rare, endemic or unusual species	R1:Refuge contains a high proportion of a single population	R1:Refuge necessary for survival of the species, population, or individuals using it	R1:Conditions inside refuge demonstrate the same level of fragility as conditions outside refuge	R1:Refuge exists independent of human intervention
	2	R2:Refuge utilized with variable or unknown site preference	R2:Refuge contains a significant or unknown proportion of a single population	R2:Refuge enhances significantly or by an unknown amount to the survival of the population	R2:Conditions inside the refuge demonstrate a significant or unknown level of fragility	R2:Refuge has been modified in the past with significant but reparable or unknown consequences
	3	R3:Refuge utilized by commonly occurring species or populations	R3:Refuge only utilized by a small proportion of a population	R3:Alternate refugia are available, suitably distributed and easily accessible	R3:Conditions inside the refuge demonstrate a high level of stability	R3:Refuge created or maintained by humans

Table 5. Biological and functional significance of pelagic fish IAs relative to three ecological properties (P) of uniqueness (U), aggregation (A), fitness consequences (FC) and the two qualifiers (Q) of resilience (R) and naturalness (N). Supporting data reference no. refer to Table 2. Grey boxes identify cumulative property ratings ≥ 7 (i.e. species-level EBSAs) and cumulative qualifier ratings ≥ 3.

Species		Ecosystem	IA		Season	Life phase	Ecological function	Support. data	Property			P rating Sum	Qualifiers		Q rating Sum
English	Latin		Description	ID				(ref)	U	A	FC	(3-9)	R	N	(2-6)
Atlantic herring	*Clupea harengus*	sGSL	Chaleur Bay-Shediac Valley	1.1	Summer	Adult	Feeding	1, 3, 4, 10, 11	2	3	2	7	2	2	4
		SGSL	St. Georges Bay - Northumberland - PEI - Cape Breton Trough	1.2	Summer	Adult	Feeding	1, 4, 10, 11	2	2	2	6	1	2	3
		sGSL	Magdellan Islands	1.3	Summer	Adult	Feeding	1, 4, 10, 12	2	1	1	4	2	2	4
		nGSL	Strait of Belle Isle	2.0	Summer	Adult	Spawning / Breeding	10	2	3	2	7	1	3	4
		nGSL	Cabot Strait - Mouth of Esquiman Channel	2.1	Summer	Adult	Feeding	7, 10, 11	2	2	2	6	2	3	5
		nGSL	Head of Esquiman Channel	2.2	Summer		Feeding	7	2	2	2	6	1	3	4
		nGSL	Strait of Belle Isle	2.3	Summer	Adult	Feeding	7, 10	2	2	2	6	3	3	6
		nGSL	Anticosti Channel	2.4	Summer	Adult	Feeding	7, 10	2	2	2	6	1	3	4
		nGSL	Pentecôte-Parent Bank-Honguedo Passage-South Anticosti	2.5	Summer	Adult	Feeding	7, 10	2	2	2	6	1	3	4
		nGSL	Gaspé Current-The Edge	2.6	Summer	Adult	Feeding	3, 7	2	2	2	6	1	3	4
		nGSL	Estuary	2.7	Summer	Adult	Feeding	7	2	2	2	6	2	2	4
		nGSL	Port au Port -Bay of Islands - Bonne Bay	2.8	Fall	Mixed	Feeding	9	2	2	2	6	3	2	5
		nGSL	St. George's Bay	2.9	Fall	Mixed	Feeding	9	2	2	2	6	3	2	5
		sGSL	St. Georges Bay - Northumberland	3.1	Summer	Juvenile	Nursery / Rearing	1, 4	2	2	2	6	2	2	4
		sGSL	Head of Shediac Valley	3.2	Summer	Juvenile	Nursery / Rearing	1, 4	1	2	2	5	2	3	5
		sGSL	Chaleur Bay	3.3	Summer	Juvenile	Nursery / Rearing	1, 4	1	2	2	5	2	2	4
		sGSL	PEI	3.4	Summer	Juvenile	Nursery / Rearing	1, 4	1	1	1	3	2	2	4

Species		Ecosystem	IA		Season	Life phase	Ecological function	Support. data	Property			P rating	Qualifiers		Q rating
English	Latin		Description	ID				(ref)	U	A	FC	Sum (3-9)	R	N	Sum (2-6)
Atlantic herring	*Clupea harengus*	sGSL	St. Georges Bay - Northumberland	4.1	Winter	Juvenile	Seasonal Refugia	5	2	1	3	6	2	2	4
		sGSL	Head of Shediac Valley	4.2	Winter	Juvenile	Seasonal Refugia	5	2	1	3	6	2	2	4
		sGSL	Chaleur Bay	4.3	Winter	Juvenile	Seasonal Refugia	5	2	2	3	7	2	2	4
		sGSL	Miscou	5.1	Fall	Adult	Spawning / Breeding	6	2	1	2	5	1	2	3
		sGSL	Gaspé	5.2	Fall	Adult	Spawning / Breeding	6	2	1	2	5	1	2	3
		sGSL	Esquminac	5.3	Fall	Adult	Spawning / Breeding	6	2	1	2	5	1	2	3
		sGSL	Pictou	5.4	Fall	Adult	Spawning / Breeding	6	2	1	2	5	1	2	3
		sGSL	Fishermans Banc	5.5	Fall	Adult	Spawning / Breeding	6	2	1	2	5	1	2	3
		sGSL	PEI	5.6	Fall	Adult	Spawning / Breeding	6	2	1	2	5	1	2	3
		nGSL	Esquiman Channel	6.1	Winter	Adult	Seasonal Refugia	8	2	3	3	8	2	2	4
		nGSL	Anticosti Channel	6.2	Winter	Adult	Seasonal Refugia	8	2	2	2	6	2	2	4
		nGSL	South Anticosti	6.3	Winter	Adult	Migration	8	2	2	2	6	2	3	5
		nGSL	The Edge	6.4	Winter	Adult	Migration	8	2	2	2	6	2	3	5
Capelin	*Mallotus villosus*	sGSL	Orphan Bank-Bradelle Bank-Chaleur Bay	1.1	Summer	Adult	Feeding	1, 3, 11	2	2	2	6	2	2	4
		sGSL	Cape Breton Trough	1.2	Summer	Adult	Feeding	1, 3, 11	2	2	2	6	2	2	4
		nGSL	Head of Esquiman Channel	2.0	Winter	Adult	Seasonal Refugia	8	2	2	3	7	2	2	4
		nGSL	Mouth of Esquiman Channel	2.1	Summer	Adult	Feeding	7, 10, 11	2	2	2	6	2	2	4
		nGSL	Head of Esquiman Channel	2.2	Summer	Adult	Feeding	7, 10, 11	2	2	2	6	1	2	3
		nGSL	Strait of Belle Isle	2.3	Summer	Adult	Feeding	7, 10, 11	2	3	2	7	3	2	5
		nGSL	Mécatina Trough	2.4	Summer	Adult	Feeding	10, 11	2	2	2	6	3	2	5
		nGSL	Jacques Cartier Strait	2.5	Summer	Adult	Feeding	7, 10	2	2	2	6	2	2	4
		nGSL	Pentecôte-Parent Bank-Honguedo Passage	2.6	Summer	Adult	Feeding	7, 10	2	2	2	6	1	2	3

Species (English)	Species (Latin)	Ecosystem	IA Description	IA ID	Season	Life phase	Ecological function	Support. data (ref)	Property U	Property A	Property FC	P rating Sum (3-9)	Qualifiers R	Qualifiers N	Q rating Sum (2-6)
Capelin	*Mallotus villosus*	nGSL	Gaspé Current-The Edge	2.7	Summer	Adult	Feeding	7	2	2	2	6	2	2	4
		nGSL	Estuary	2.8	Summer	Adult	Feeding	7	2	2	2	6	2	2	4
Atlantic mackerel	*Scomber scombrus*	sGSL	Shediac Valley	1.1	Summer	Mixed	Feeding	2	1	2	2	5	1	3	4
		sGSL	St. Georges Bay	1.2	Summer	Mixed	Feeding	2	1	2	2	5	1	3	4
		sGSL	PEI	1.3	Summer	Mixed	Feeding	2	1	2	1	4	1	3	4
		sGSL	Magdellan Islands	1.4	Summer	Mixed	Feeding	2	1	2	1	4	1	3	4
Sand lance	*Ammodytes* sp.	nGSL	Western Newfoundland	2.1	Summer	Mixed	Feeding	11	2	2	2	6	2	2	4
		nGSL	Strait of Belle Isle-Mécatina Trough	2.2	Summer	Mixed	Feeding	11	2	2	2	6	3	2	5
		nGSL	Beaugé Bank	2.3	Summer	Mixed	Feeding	11	2	2	2	6	2	2	4
Butterfish	*Peprilus triacanthus*	sGSL	St. Georges Bay - Northumberland	1.1	Summer	Adult	Feeding	2	3	2	2	7	2	2	4
Spiny dogfish	*Squalus acanthias*	sGSL	Shediac Valley	1.1	Summer	Adult	Feeding	1, 3	2	2	2	6	1	2	3
		sGSL	St. Georges Bay	1.2	Summer	Adult	Feeding	1, 4	2	2	2	6	1	2	3
		sGSL	PEI	1.3	Summer	Adult	Feeding	1, 5	1	1	1	3	2	2	4
		sGSL	Magdellan Islands	1.4	Summer	Adult	Feeding	1, 6	2	2	2	6	1	2	3
		nGSL	The Edge	2.1	Summer	Adult	Feeding	1, 7	2	2	1	5	2	2	4
		nGSL	Mouth of Esquiman Channel	2.2	Summer	Adult	Feeding	7	2	2	1	5	2	2	4
		nGSL	Strait of Belle Isle	2.3	Summer	Adult	Feeding	7	2	2	1	5	2	2	4
		nGSL	Beaugé Bank	2.4	Summer	Adult	Feeding	7	2	2	1	5	2	2	4
Alewife	*Alosa pseudoharengus*	sGSL	Shediac Valley	1.1	Summer	Adult	Feeding	2	2	2	2	6	2	2	4
		sGSL	St. Georges Bay	1.2	Summer	Adult	Feeding	2	2	2	2	6	2	2	4
		sGSL	PEI	1.3	Summer	Adult	Feeding	2	2	2	2	6	2	2	4
Rainbow smelt	*Osmerus mordax*	sGSL	Northumberland Strait	1.1	Summer	Mixed	Feeding	1, 3	2	2	2	6	2	2	4
		sGSL	Head of Shediac Valley	1.2	Summer	Mixed	Feeding	1, 3	2	2	2	6	2	2	4
		sGSL	Head of Chaleur Bay	1.3	Summer	Mixed	Feeding	1, 3	2	2	2	6	2	2	4

Species		Ecosystem	IA		Season	Life phase	Ecological function	Support. data	Property			P rating	Qualifiers		Q rating
English	Latin		Description	ID				(ref)	U	A	FC	Sum (3-9)	R	N	Sum (2-6)
White barracudina	*Arctozenus risso*	nGSL	Deep Channels	2.0	Winter	Mixed	Seasonal Refugia	8	2	2	2	6	1	2	3
		nGSL	Deep Channels	2.1	Summer	Mixed	Feeding	1, 7	1	1	2	4	2	2	4
		nGSL	Head of Esquiman Channel	2.2	Summer	Mixed	Feeding	7	2	2	1	5	2	2	4
Pollock	*Pollachius virens*	nGSL	The Edge	2.1	Summer	Adult	Feeding	1, 3	2	2	1	5	1	2	3
		nGSL	Cabot Strait - Mouth of Esquiman Channel	2.2	Summer	Adult	Feeding	7	2	2	1	5	1	2	3
		nGSL	Cabot Strait - Mouth of Esquiman Channel	3.2	Winter	Adult	Seasonal Refugia	8	2	1	1	4	1	2	3
Silver hake	*Merluccius bilinearis*	sGSL	St. Georges Bay	1.1	Summer	Adult	Feeding	1, 3	2	1	1	4	2	2	4
		nGSL	Cabot Strait - Mouth of Esquiman Channel	2.0	Winter	Adult	Seasonal Refugia	8	2	1	1	4	1	2	3
		nGSL	The Edge-Cape Breton Trough	2.1	Summer	Adult	Feeding	1, 3, 7	2	1	1	4	1	2	3
		nGSL	Cabot Strait - Mouth of Esquiman Channel	2.2	Summer	Adult	Feeding	7	2	1	1	4	1	2	3

Table 6. Description of the 14 proposed ecologically and biologically significant areas (EBSAs) among the 24 important areas (IAs) for small pelagic fishes in the GSL. Supporting data reference no. refer to Table 2. Grey boxes identify cumulative property ratings ≥ 7 (i.e. species- or community-level EBSAs).

	EBSA - IA							Supporting Data	Rating	
Ecosystem	No.	Description	Characteristic	Level	Season	Life Phase	Ecological Function	(ref. no.)	Max	Sum
sGSL	1	Chaleur Bay-Shediac Valley	Principal feeding area for southern Gulf herring. High concentration of prey (calanus, euphausiids)	Species	Summer	Adult	Feeding	1, 3, 4, 10, 11	3	7
nGSL	2	Strait of Belle Isle	Most northerly spawning area for Gulf herring (edge of distribution) and principal spawning area for autumn spawniing population.	Species	Summer	Adult	Spawning / Breeding	10	3	7
sGSL	3	Chaleur Bay	Principal winter refuge for juveniles of southern Gulf herring.	Species	Winter	Juvenile	Seasonal Refugia	5	3	7
nGSL	4	Esquiman Channel	Only known winter refuge for northern Gulf herring	Species	Winter	Adult	Seasonal Refugia	8	3	8
nGSL	5	Head of Esquiman Channel	Only known winter refuge for Gulf capelin	Species	Winter	Adult	Seasonal Refugia	8	3	7
nGSL	6	Strait of Belle Isle	High concentration of capelin (large hauls and acoustic detections made during survey) and its predators (marine mammals).	Species	Summer	Adult	Feeding	7, 10, 11	3	7
sGSL	7	St. Georges Bay - Northumberland	The only area of feeding for this isolated Butterfish population in the GSL	Species	Summer	Adult	Feeding	2	3	7
sGSL	8	Shediac Valley	High concentration of species (alewife, spiny dogfish, adult and juvenile herring, mackeral, rainbow smelt) for multiple biological function (feeding, refugia, spawning)	Community	Summer	Mixed	Feeding	1, 3, 4, 6, 10, 11	3	8
sGSL	9	St. Georges Bay - Northumberland	High feeding concentration of species (alewife, spiny dogfish, adult and juvenile herring, mackeral, Butterfish, rainbow smelt and silver hake) as well as spawning for herring	Community	Mixed	Mixed	Mixed	1, 3, 4, 6, 10	3	8
nGSL	10	Strait of Belle Isle	High feeding concentration of species (spiny dogfish, herring, capelin and sand lance) as well as spawning for herring	Community	Mixed	Mixed	Mixed	7, 9, 10, 11	3	7
nGSL	11	The Edge	Area of importance for multiple biological functions (feeding, migration, refugia) for many species	Community	Mixed	Mixed	Mixed	1, 3, 7, 8, 10	3	7
sGSL	12	Chaleur Bay	Co-occurrence of several pelagic species for feeding	Community	Mixed	Mixed	Mixed	1, 3, 4, 6, 10	2	5
sGSL	13	North PEI	Co-occurrence of several pelagic species for feeding	Community	Summer	Adult	Feeding	1, 3, 4, 6, 10	2	5

Ecosystem	EBSA - IA No.	Description	Characteristic	Level	Season	Life Phase	Ecological Function	Supporting Data (ref. no.)	Rating Max	Rating Sum
nGSL	14	Gaspé Current	Co-occurrence of several pelagic species for feeding	Community	Summer	Adult	Feeding	4, 7, 10	2	5
nGSL	15	Beaugé Bank Slope	Co-occurrence of several pelagic species for feeding	Community	Mixed	Mixed	Mixed	7, 8, 10, 11	3	7
nGSL	16	Laurentian Channel Northern Slope	Co-occurrence of several pelagic species for feeding	Community	Summer	Adult	Feeding	7, 10, 11	2	5
nGSL	17	Anticosti Channal	Co-occurrence of several pelagic species for feeding	Community	Mixed	Mixed	Mixed	7, 8, 10, 11	2	5
nGSL	18	Cabot Strait - Mouth of Esquiman Channel	Co-occurrence of several pelagic species for feeding, migration and refugia	Community	Mixed	Mixed	Mixed	7, 10, 11	2	5
nGSL	19	Head of Esquiman Channel	Co-occurrence of several pelagic species for feeding	Community	Mixed	Mixed	Mixed	7, 9, 10, 11	3	7
nGSL	20	Strait of Belle Isle	Co-occurrence of several pelagic species for feeding	Community	Summer	Adult	Feeding	7, 9, 10, 11	2	5
nGSL	21	Cabot Strait - Mouth of Esquiman Channel	Co-occurrence of several pelagic species for feeding	Community	Mixed	Mixed	Mixed	7, 10, 11	3	7
nGSL	22	The Edge	Co-occurrence of several pelagic species for multiple functions	Community	Mixed	Mixed	Mixed	1, 3, 7, 8, 10	2	6
sGSL	23	Shediac Valley	Co-occurrence of several pelagic species for feeding	Community	Mixed	Mixed	Feeding	1, 3, 4, 10, 11	2	6
sGSL	24	St. Georges Bay - Northumberland	Co-occurrence of several pelagic species for multiple functions	Community	Mixed	Mixed	Mixed	1, 3, 4, 6, 10	2	6

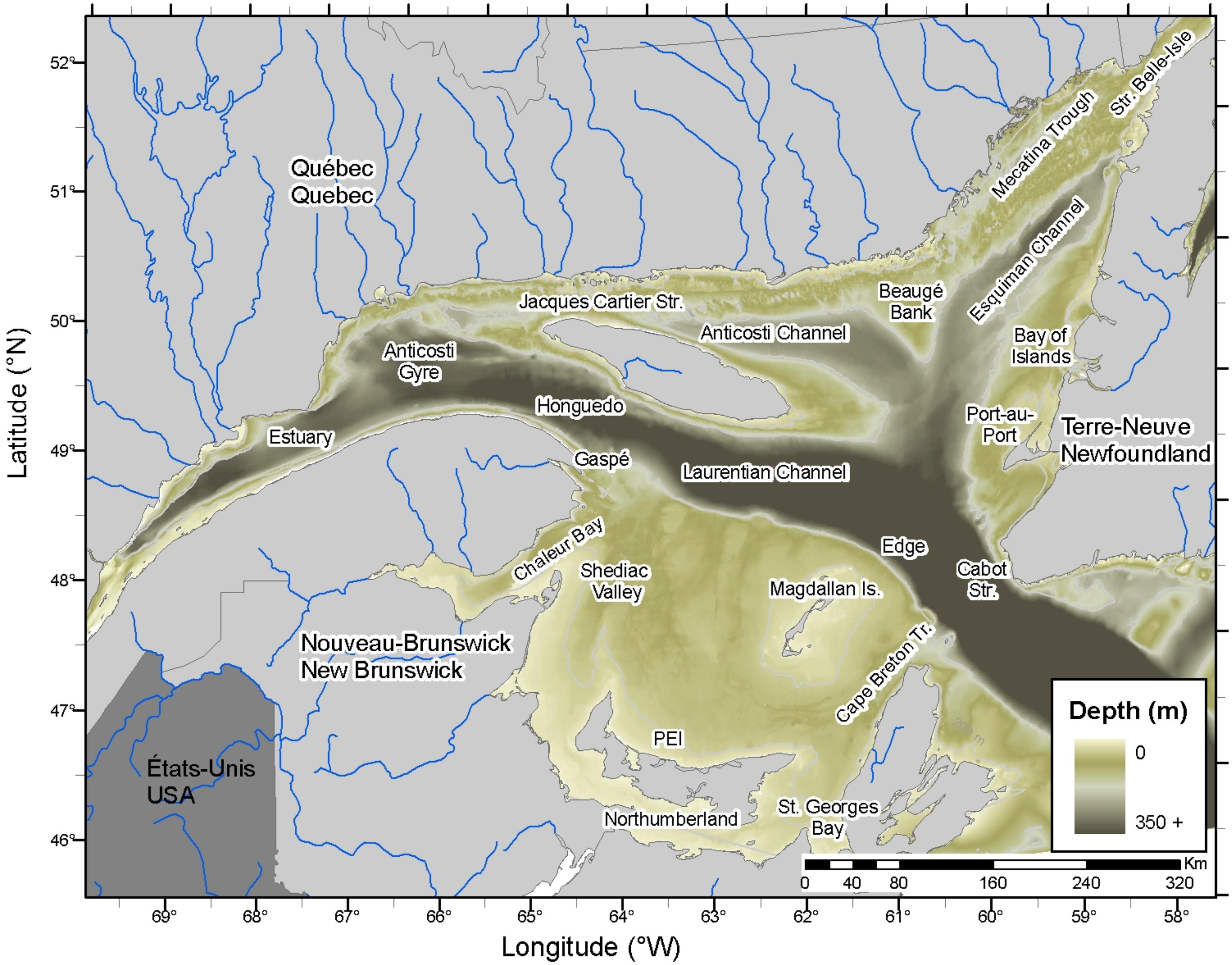

Figure 1. Bathymetry and major geographic features of the Gulf of St. Lawrence.

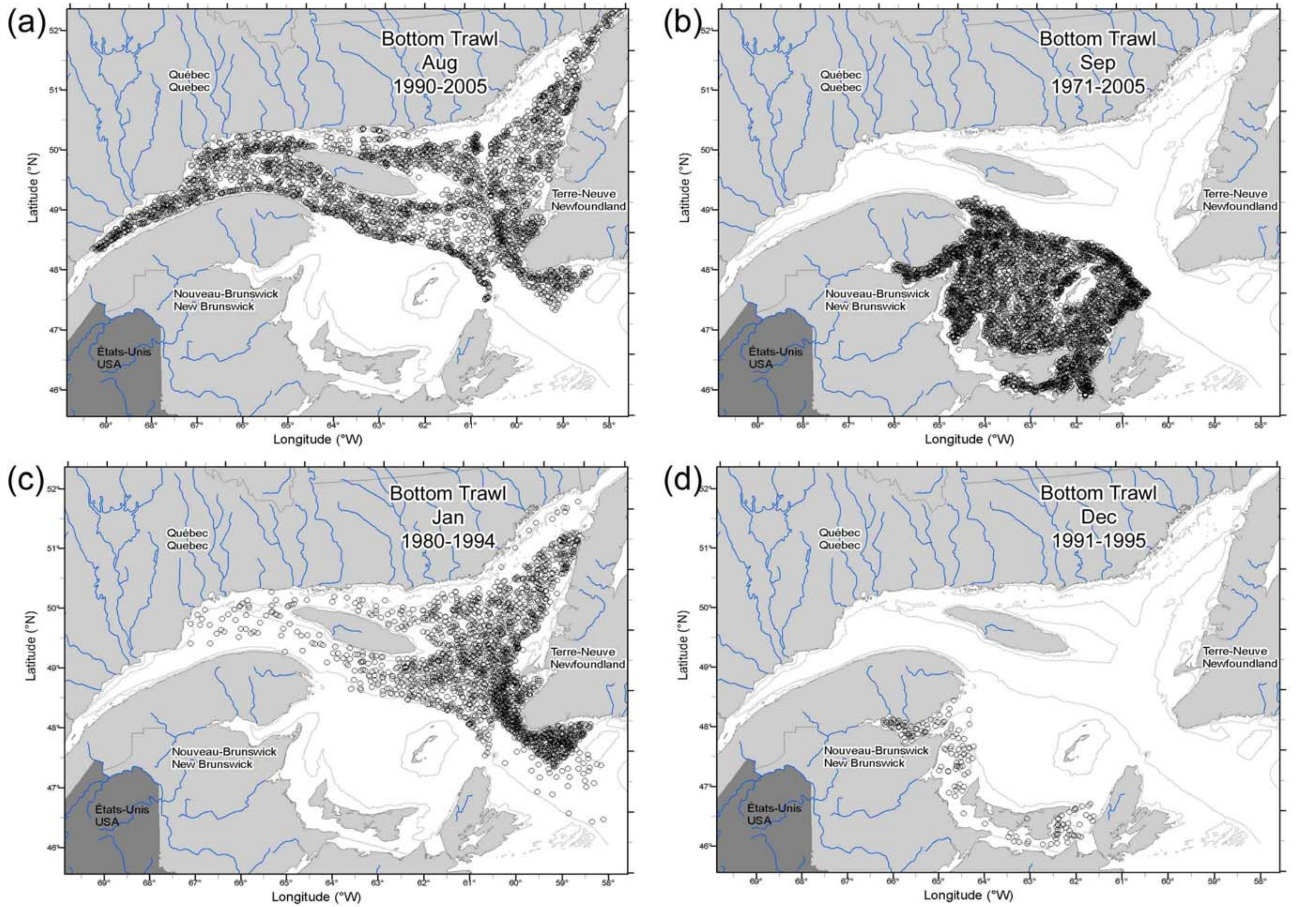

Figure 2. Distribution of sampled stations from research surveys used to identify IAs: (a) nGSL bottom trawl survey from Aug 1990-2005 (b) sGSL bottom trawl survey from Sep 1971-2005 (c) nGSL bottom trawl survey from Jan 1990-2005 (d) sGSL bottom trawl survey from Dec 1991-1995.

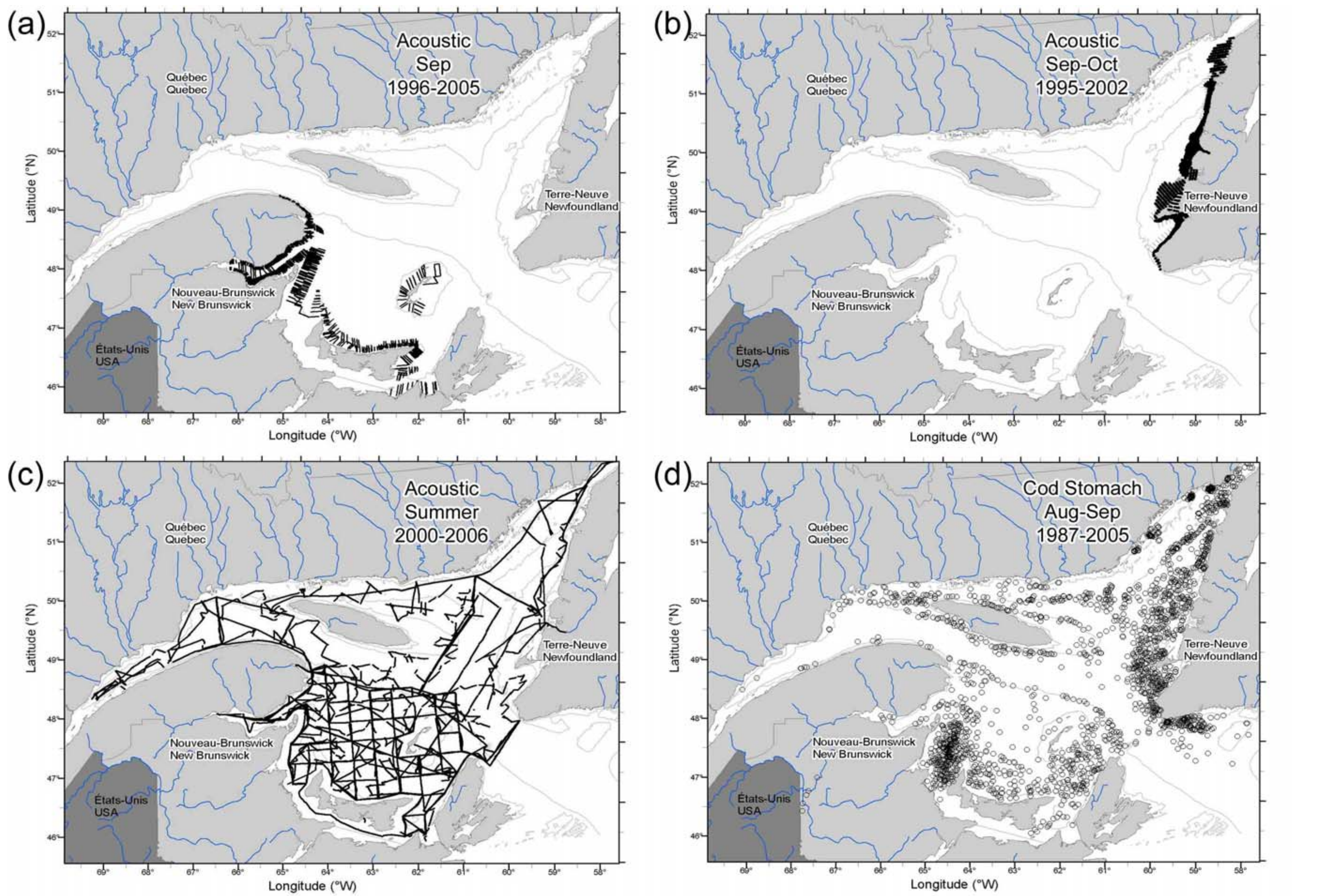

Figure 3. Distribution of sampled transects from research surveys used to identify IAs: (a) sGSL acoustic survey from Sep 1996-2005 (b) nGSL acoustic survey from late Sep-Oct 1995-2002 (c) GSL opportunistic acoustic surveys from summer 2000-2006 and (d) distribution of sampled stations from nGSL (1993-2005) and sGSL (1987-2004) bottom trawl surveys with cod stomachs containing food.

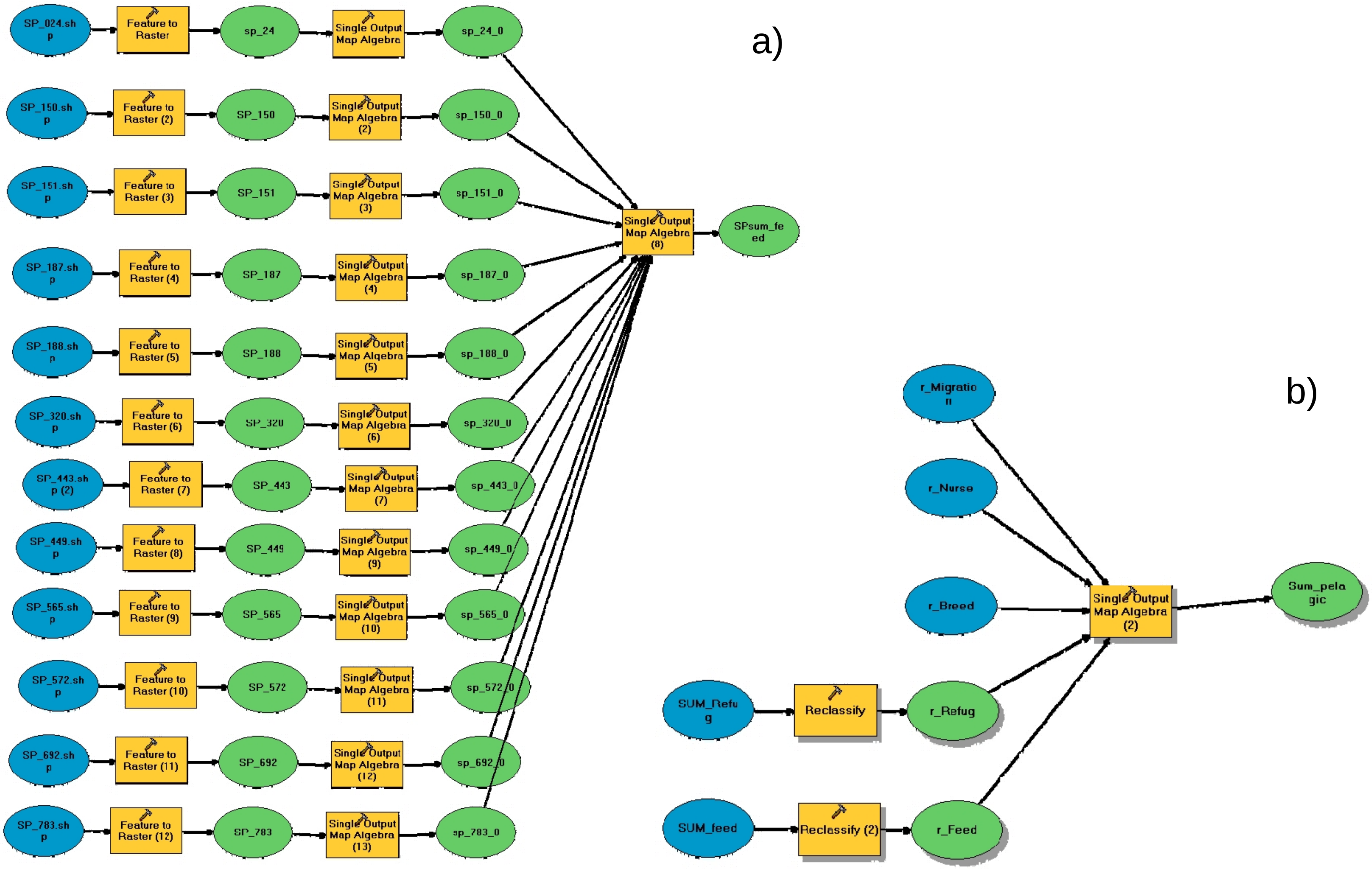

Figure 4. Structure of spatial model used to combine IAs (a) across species for a given ecological function (e.g. feeding) and (b) across functions for cumulative ecological rating for pelagic species as a whole. Weighting of ecological functions would be applied during function-based summation. Blue ovals are IAs, yellow boxes represent spatial operations and green ovals represent cumulative property ratings.

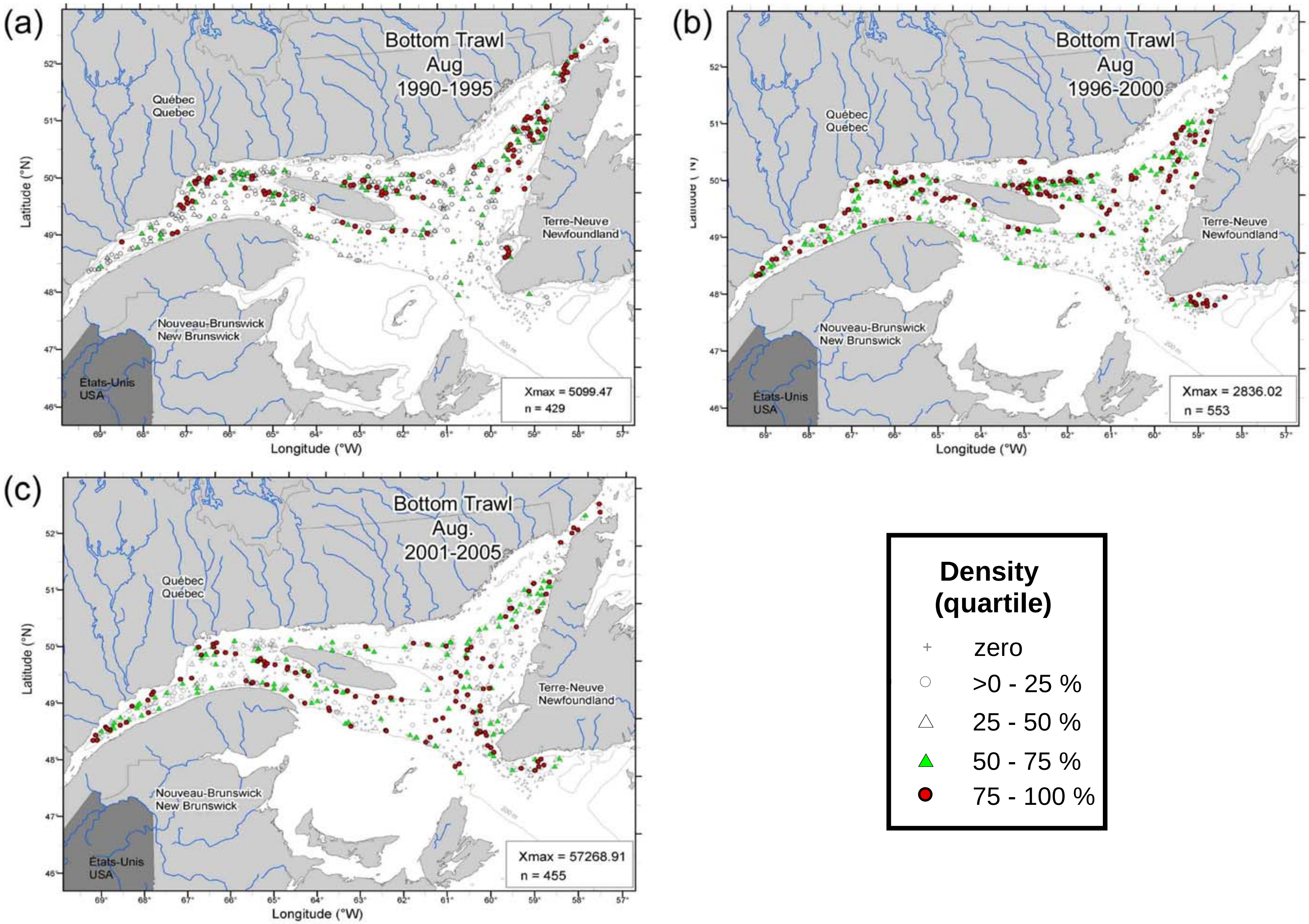

Figure 5. Adult herring distribution by quartile from research bottom trawl catches in the nGSL in summer between (a) 1990-1995 (b) 1996-2000 and (c) 2001-2005. (Xmax = maximum density in units from Table 2; n = number of non-zero values).

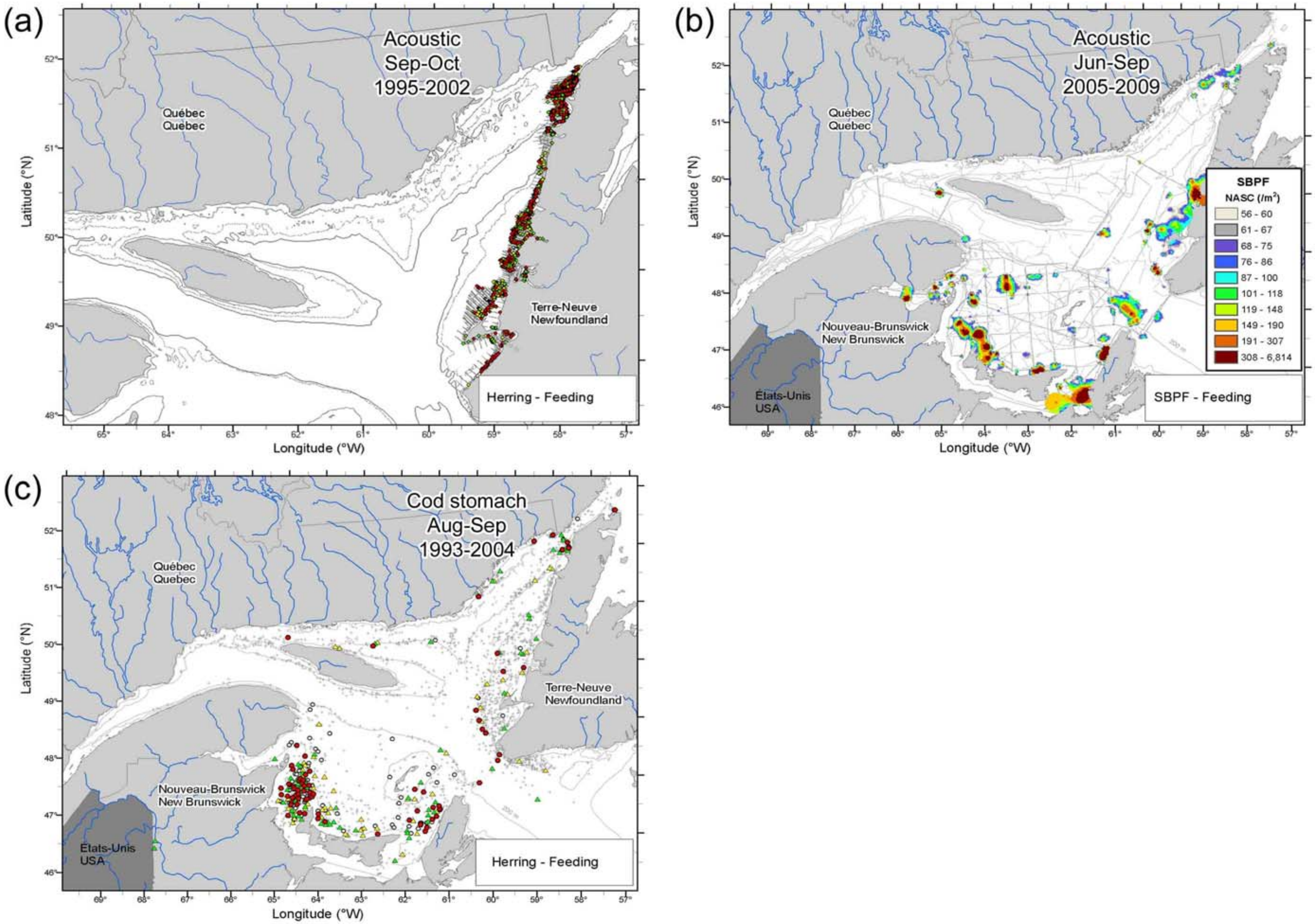

Figure 6. (a) Herring distribution by quartile from research acoustic backscatter in the nGSL in autumn between 1995-2002, (b) SBPF distribution from acoustic backscatter in the GSL in summer between 2000-2006 and (c) presence of herring by quartile (see Figure 5 for symbol scale) in cod stomachs in summer between 1993-2004.

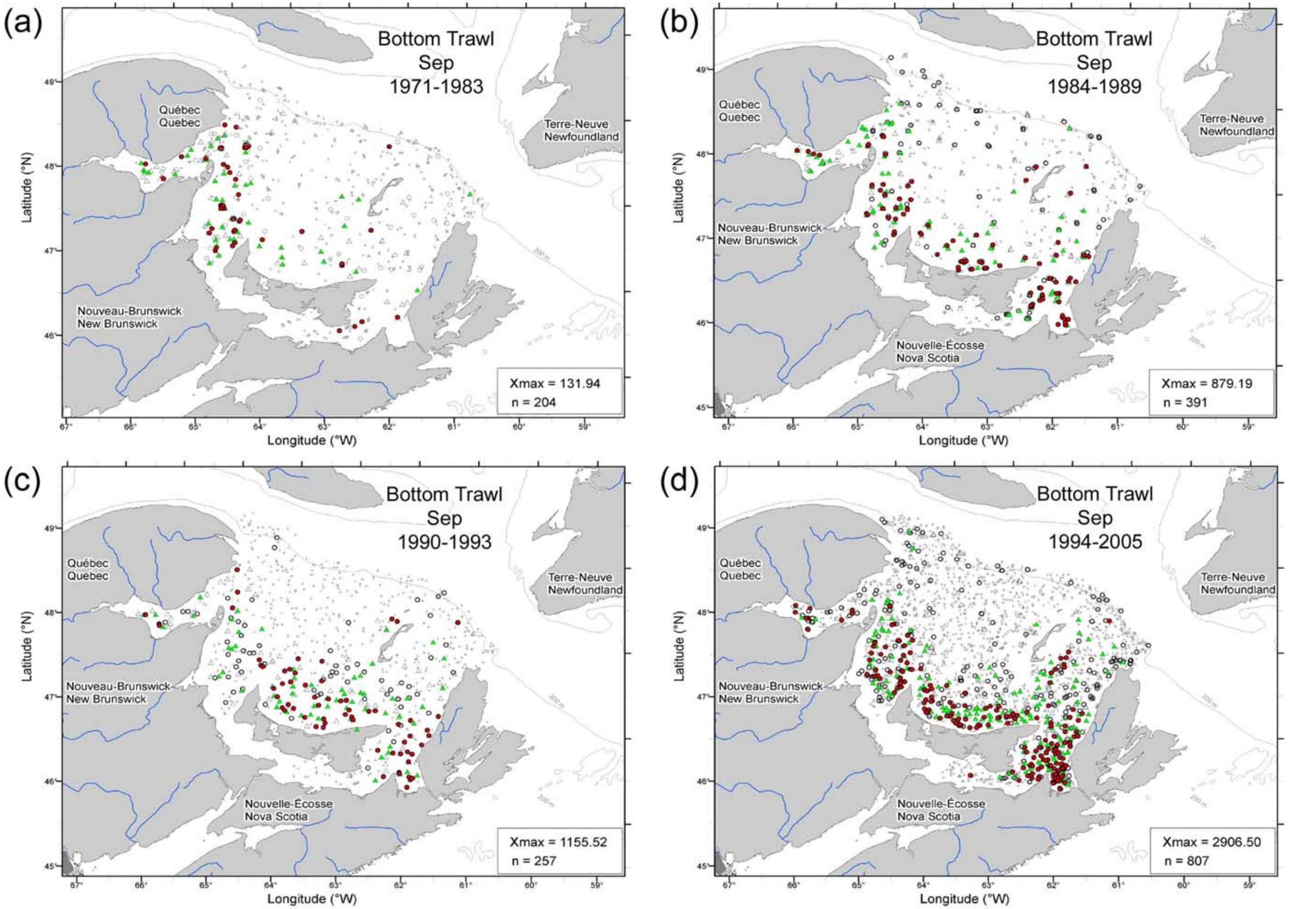

Figure 7. Adult herring distribution by quartile (see Figure 5 for symbol scale) from research bottom trawl catches in the sGSL in summer between (a) 1971-1983 (b) 1984-1989 (c) 1990-1993 and (d) 1994-2005.

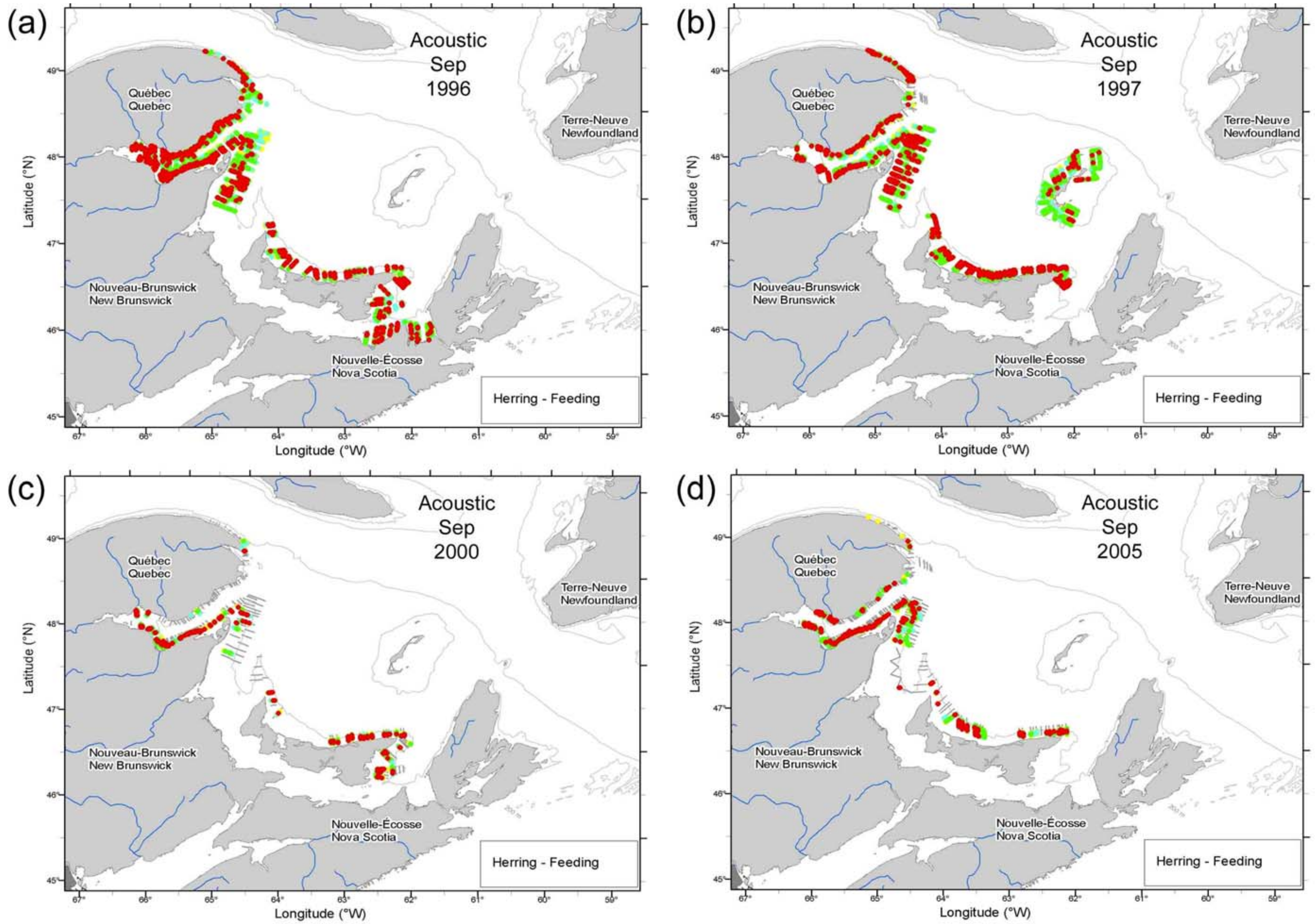

Figure 8. Herring distribution by quartile (see Figure 5 for symbol scale) from research acoustic backscatter in the sGSL in September in (a) 1996, (b) 1997, (c) 2000 and (d) 2005.

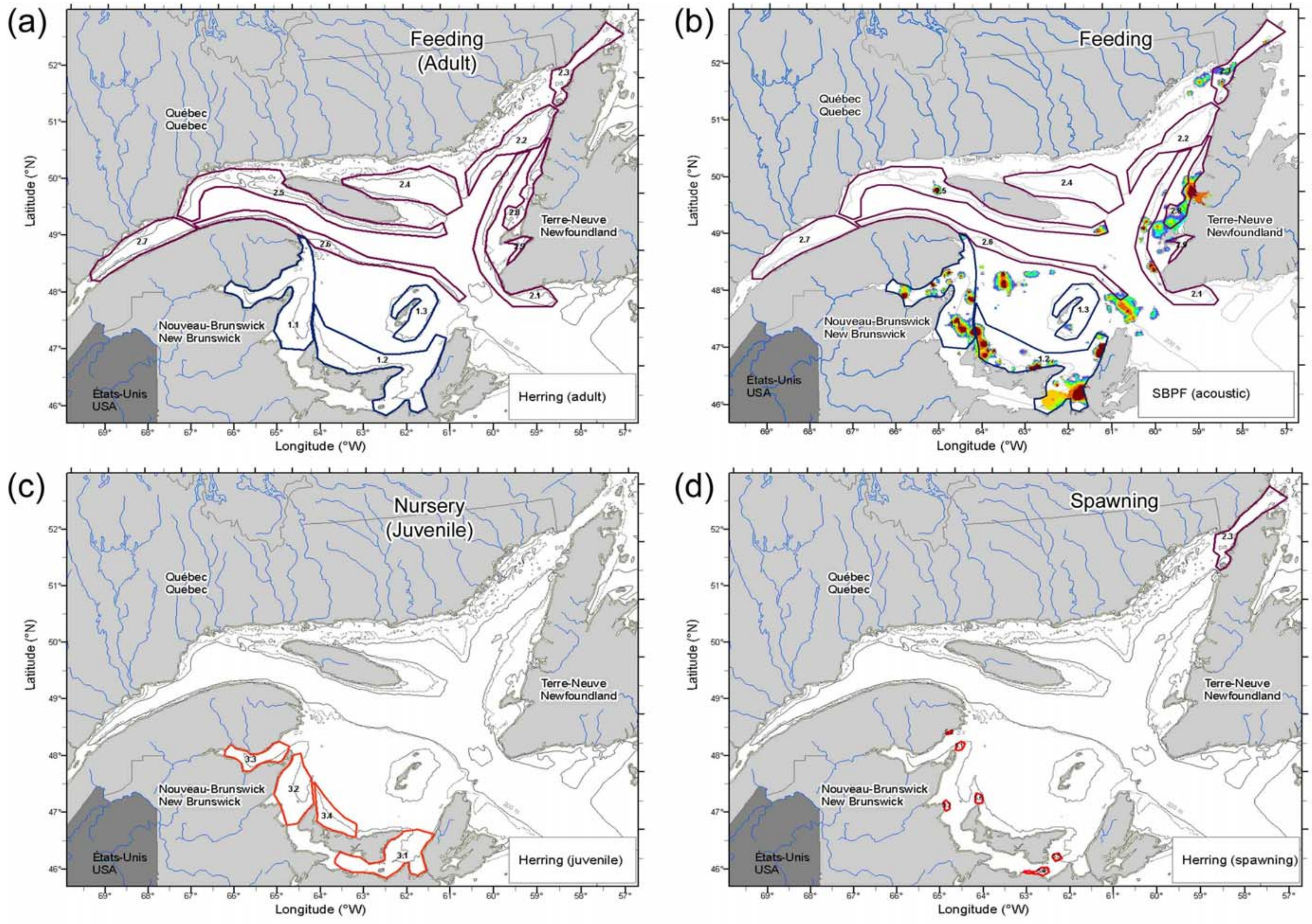

Figure 9. Feeding IAs for (a) nGSL (red) and sGSL (blue) adult herring in summer (b) and with acoustic backscatter distribution (see Figure 6b for colour scale) from swimbladdered pelagic fish between 2000 and 2006, (c) nursery IAs for sGSL juvenile herring and (d) spawning IAs for GSL herring in summer (i.e. autumn spawners). Area no. refers to IA ID no. in Table 5.

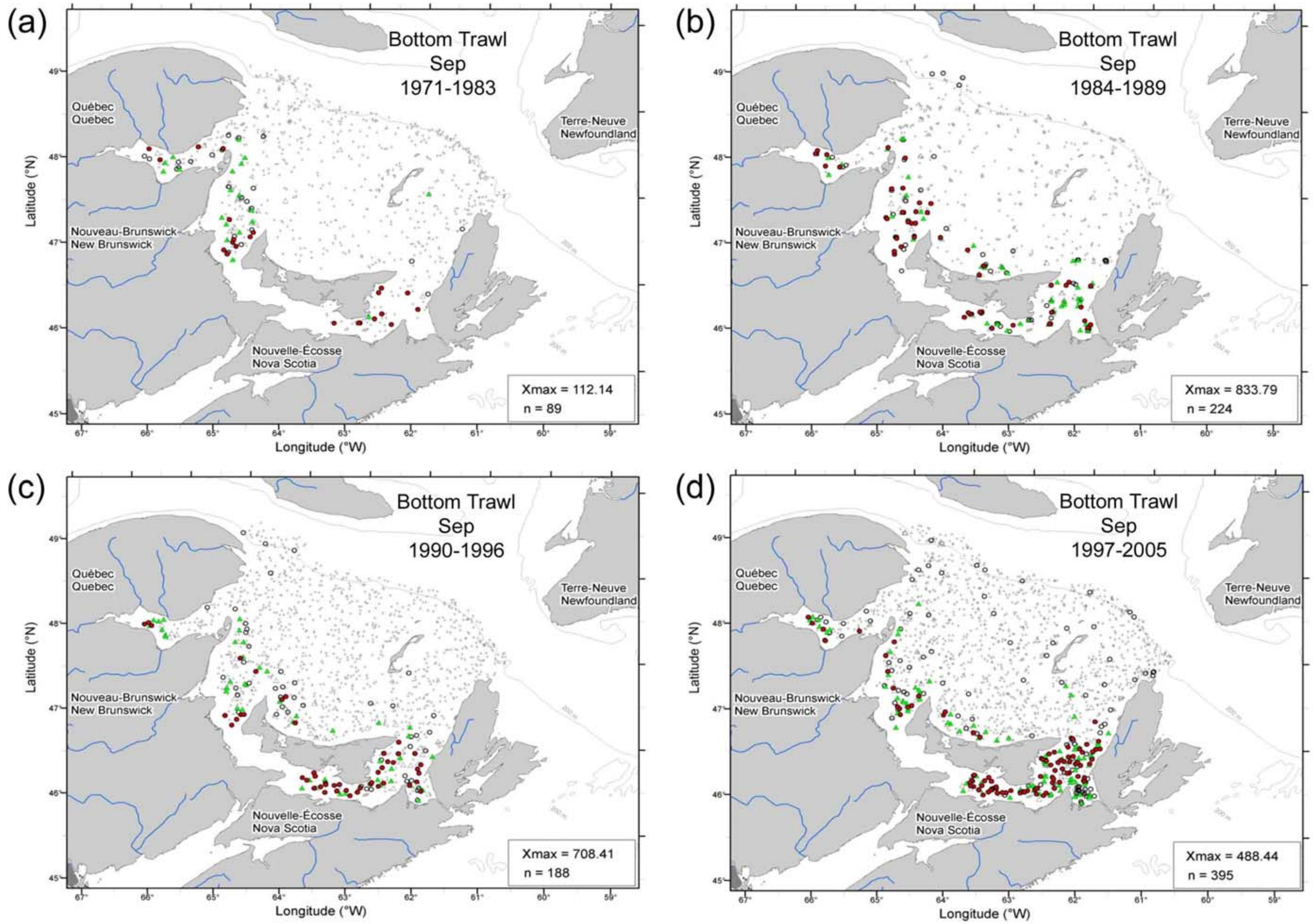

Figure 10. Juvenile herring distribution by quartile (see Figure 5 for symbol scale) from research bottom trawl catches in the sGSL in summer between (a) 1971-1983 (b) 1984-1989 (c) 1990-1996 and (d) 1997-2005.

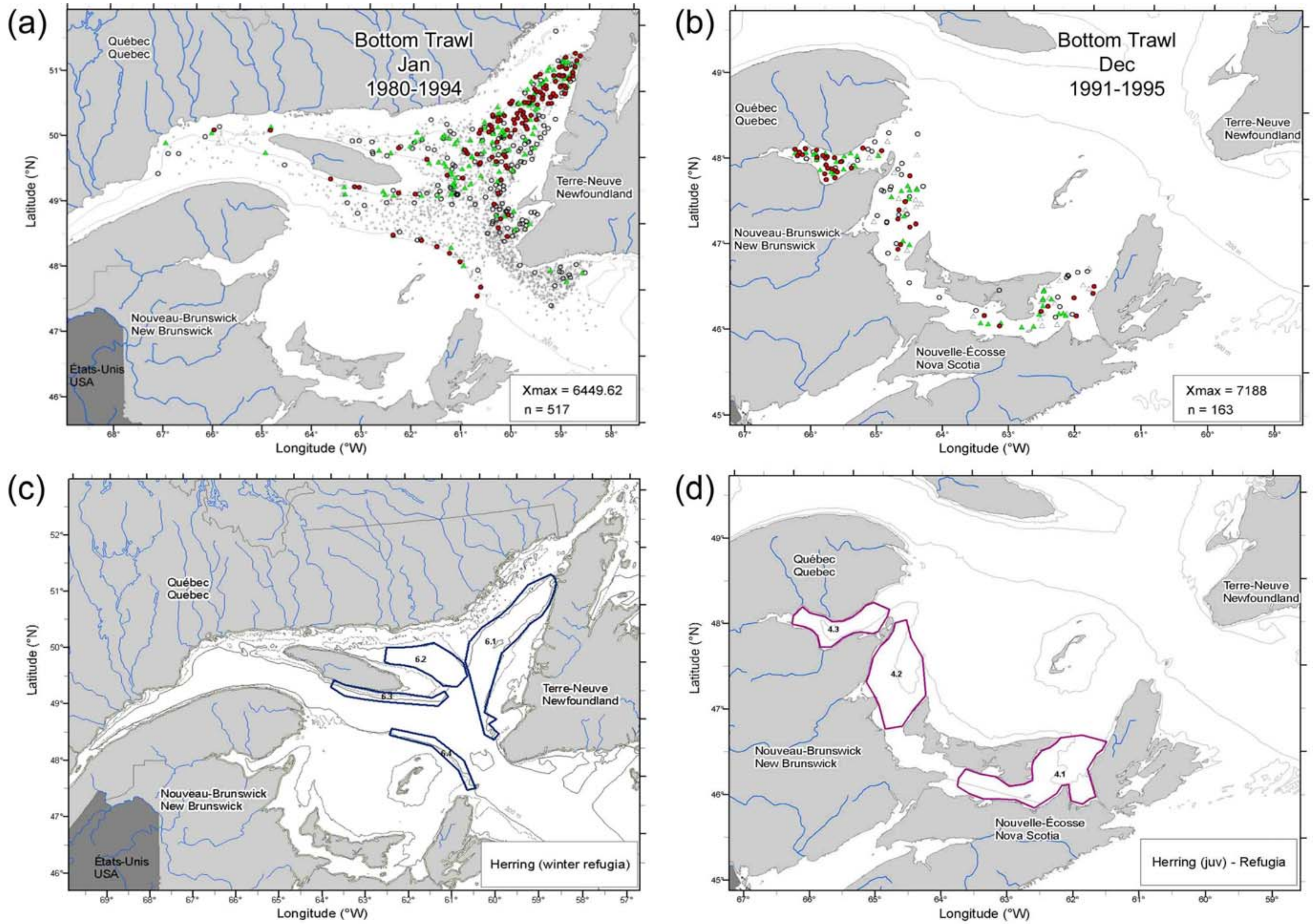

Figure 11. Distribution by quartile (see Figure 5 for symbol scale) of research bottom trawl catches in winter of (a) nGSL adult herring and (b) sGSL juvenile herring and associated refugia IAs for (c) nGSL adult herring and (d) sGSL juvenile herring. Area no. refers to IA ID no. in Table 5.

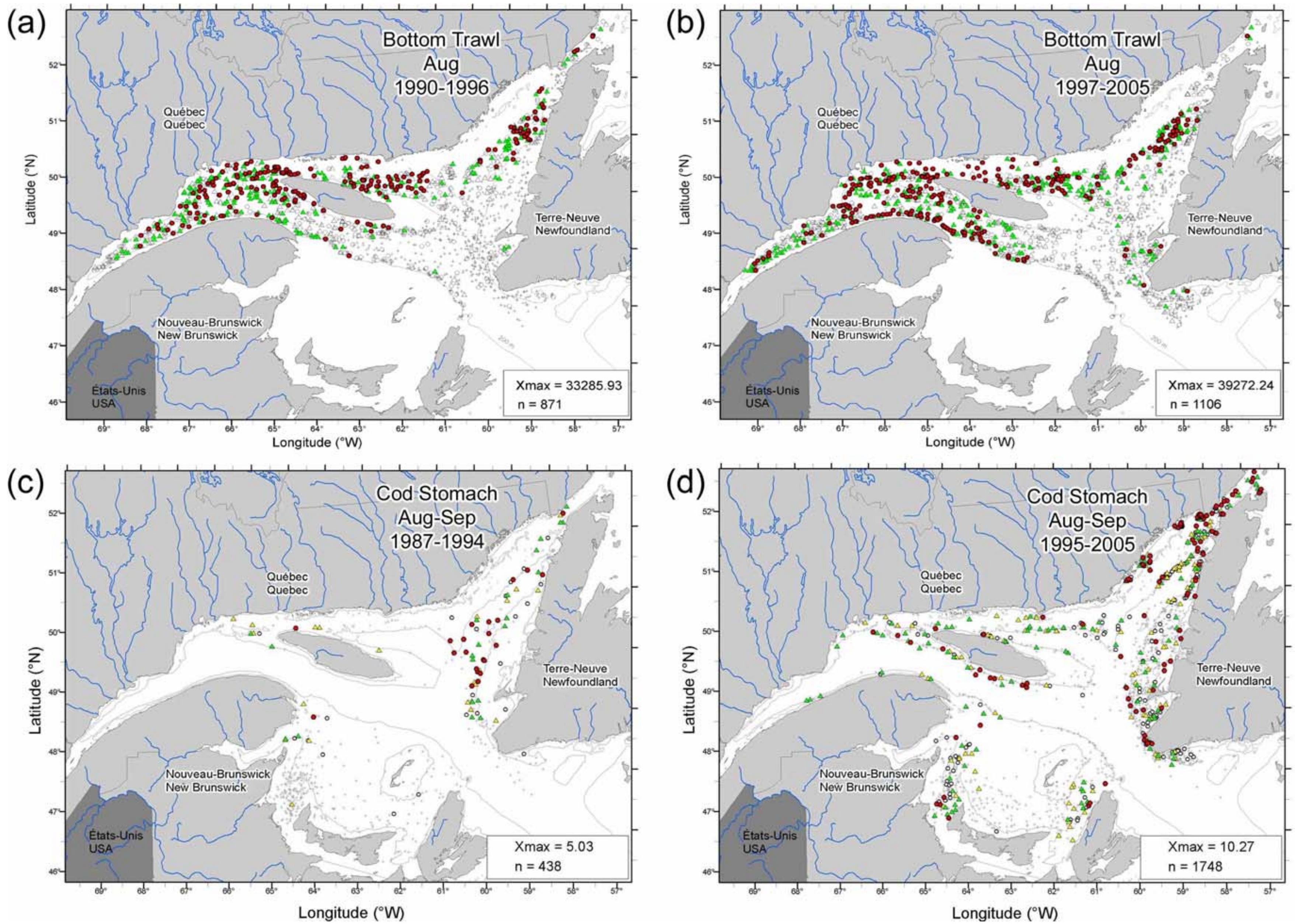

Figure 12. Capelin distribution by quartile (see Figure 5 for symbol scale) from research bottom trawl catches in the nGSL in summer between (a) 1990-1996 and (b) 1997-2005, (c) presence of capelin in cod stomachs by quartile in summer between 1987-1994 and (d) between 1995-2005.

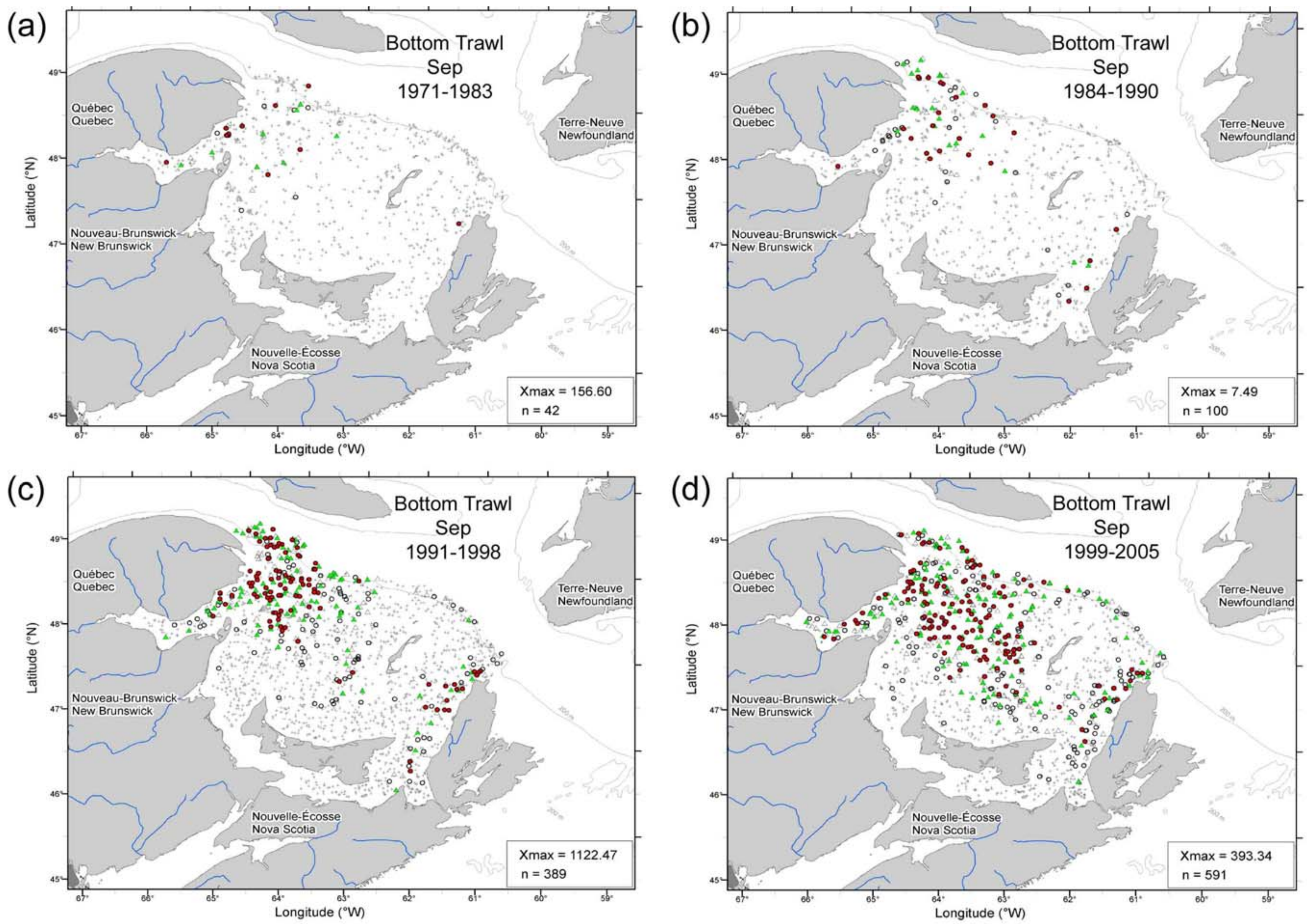

Figure 13. Capelin distribution by quartile (see Figure 5 for symbol scale) from research bottom trawl catches in the sGSL in summer between (a) 1971-1983, (b) 1984-1990, (c) 1991-1998 and (d) 1999-2005.

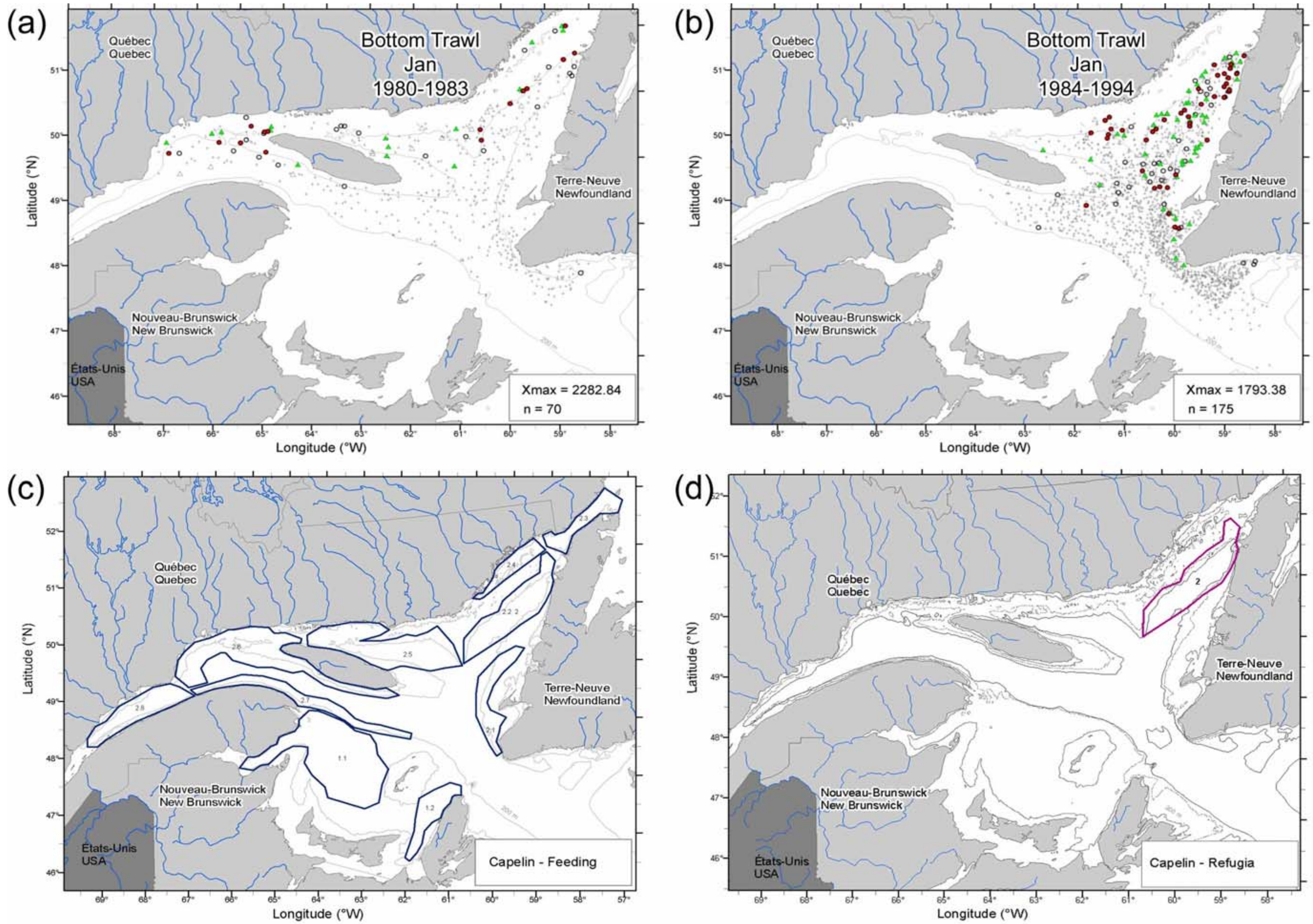

Figure 14. Capelin distribution by quartile (see Figure 5 for symbol scale) from research bottom trawl catches in the GSL in winter between (a) 1980-1983 and (b) 1984-1994 (c) feeding IAs for GSL capelin and (d) refugia IA for GSL capelin. Area no. refers to IA ID no. in Table 5.

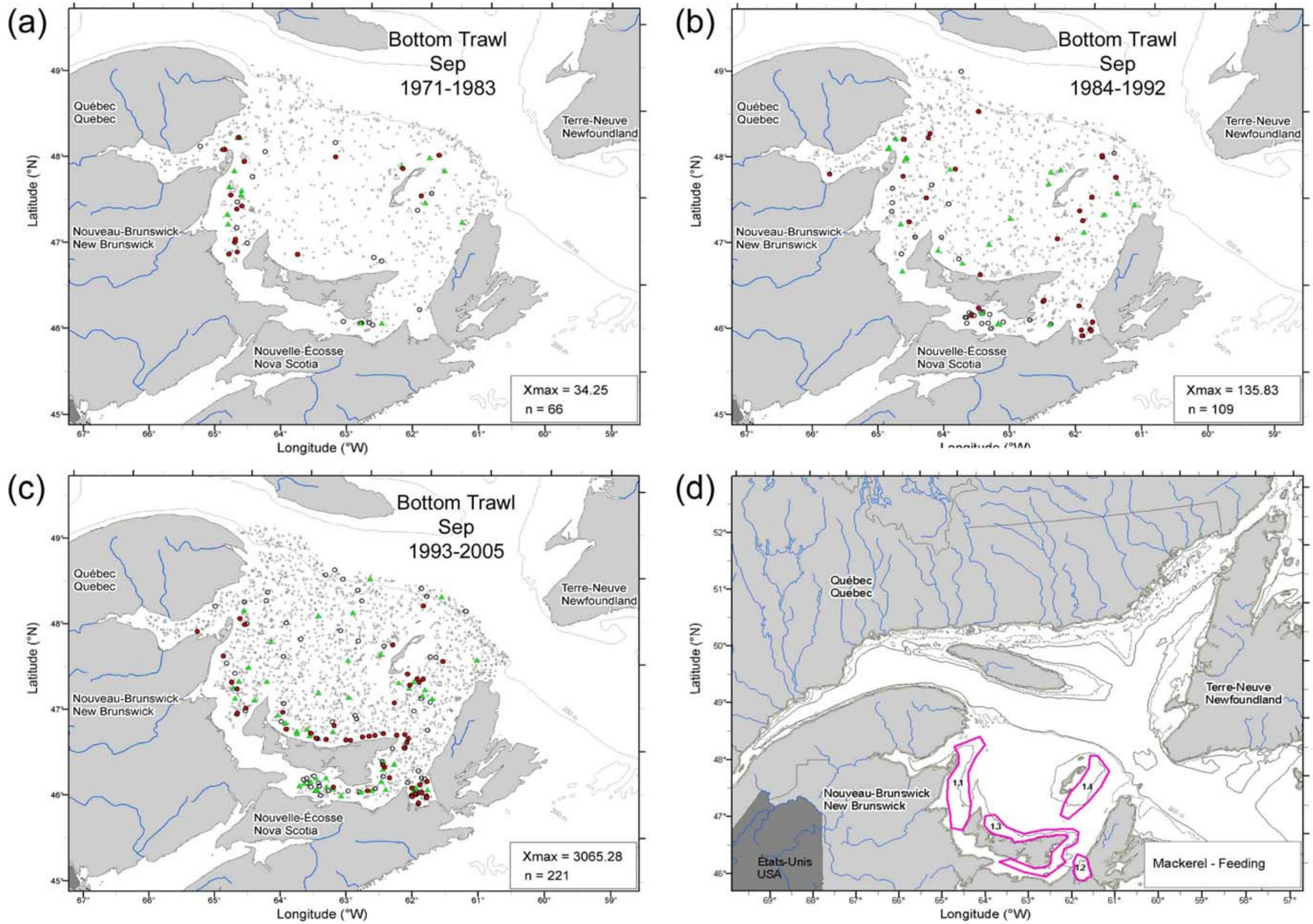

Figure 15. Mackerel distribution by quartile (see Figure 5 for symbol scale) from research bottom trawl catches in the sGSL in summer between (a) 1971-1983 and (b) 1984-1992, and (c)1993-2005 and (d) associated feeding IAs for sGSL mackerel. Area no. refers to IA ID no. in Table 5.

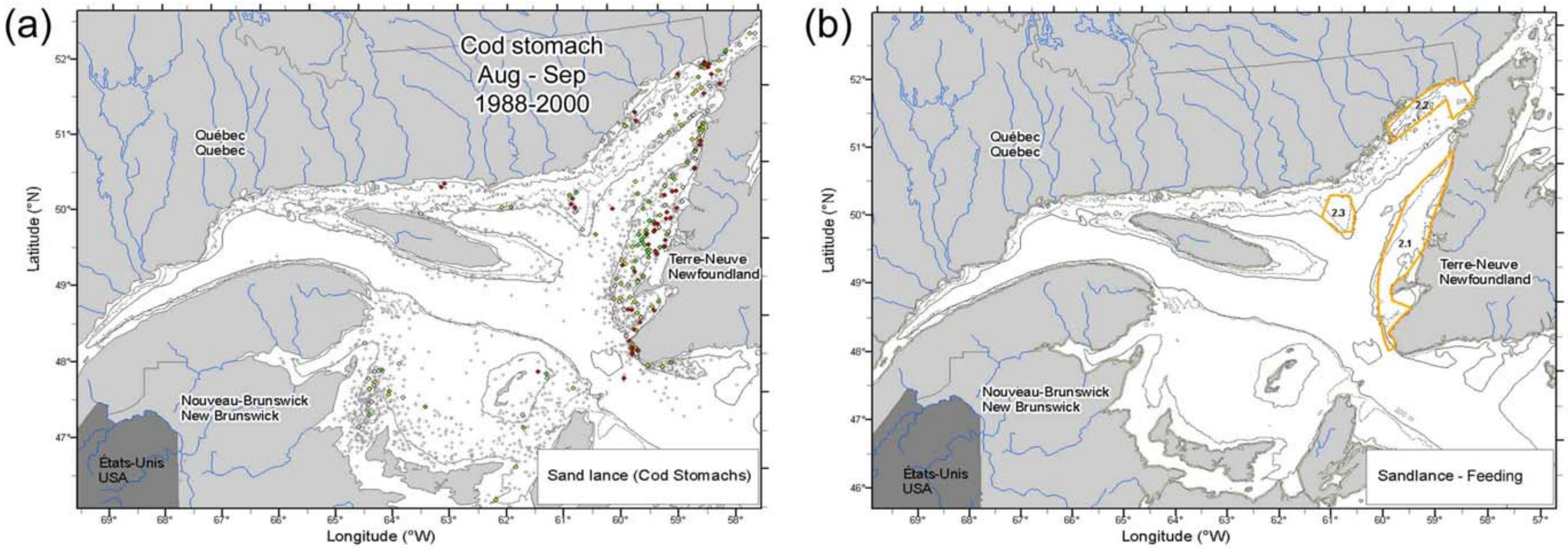

Figure 16. (a) Sand lance distribution by quartile (see Figure 5 for symbol scale) from their presence in cod stomachs in the GSL in summer between 1988-2000 and (b) associated feeding IAs for GSL sand lance. Area no. refers to IA ID no. in Table 5.

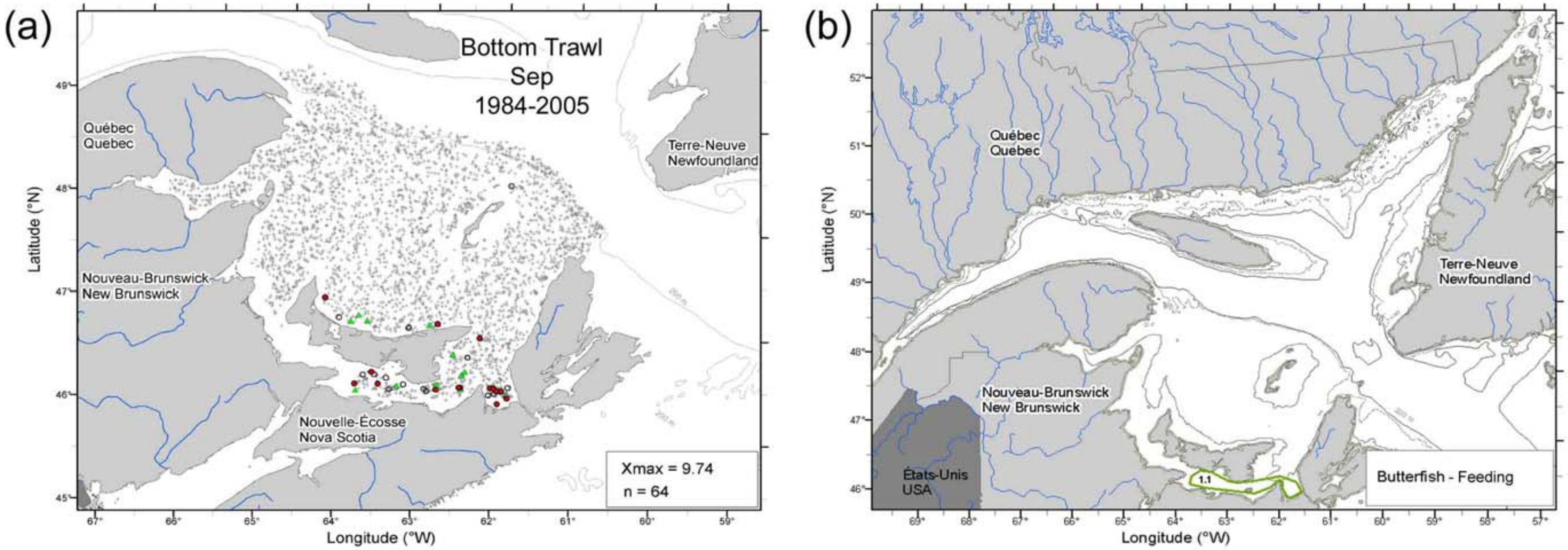

Figure 17. (a) Butterfish distribution by quartile (see Figure 5 for symbol scale) from research bottom trawl catches in the sGSL in summer between 1984-2005 and (b) associated feeding IAs for sGSL butterfish. Area no. refers to IA ID no. in Table 5.

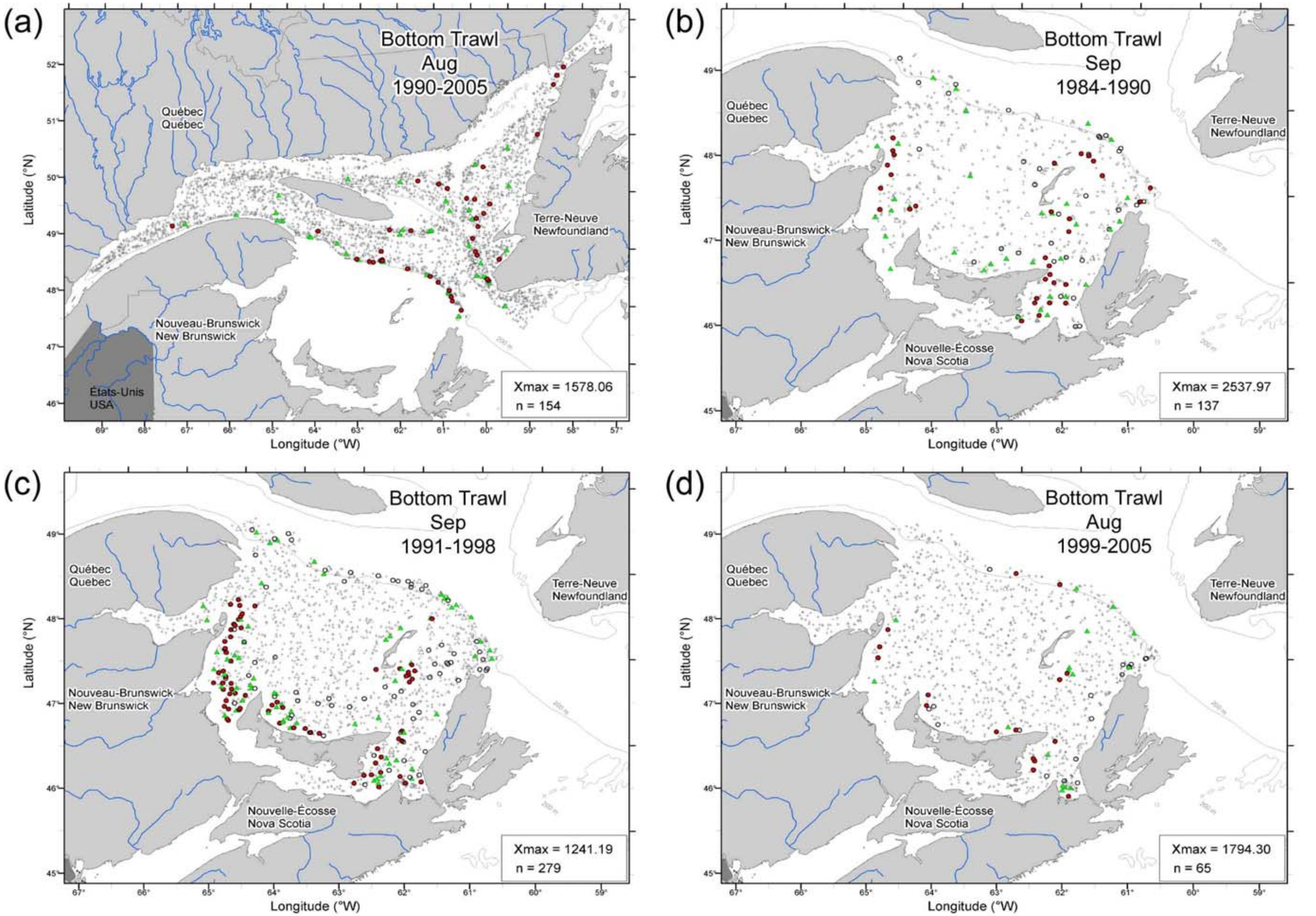

Figure 18. Spiny dogfish distribution by quartile (see Figure 5 for symbol scale) from research bottom trawl catches in summer (a) in the nGSL between 1990-2005; and in the sGSL between (b) 1984-1990 (c) 1991-1998 and (d) 1999-2005.

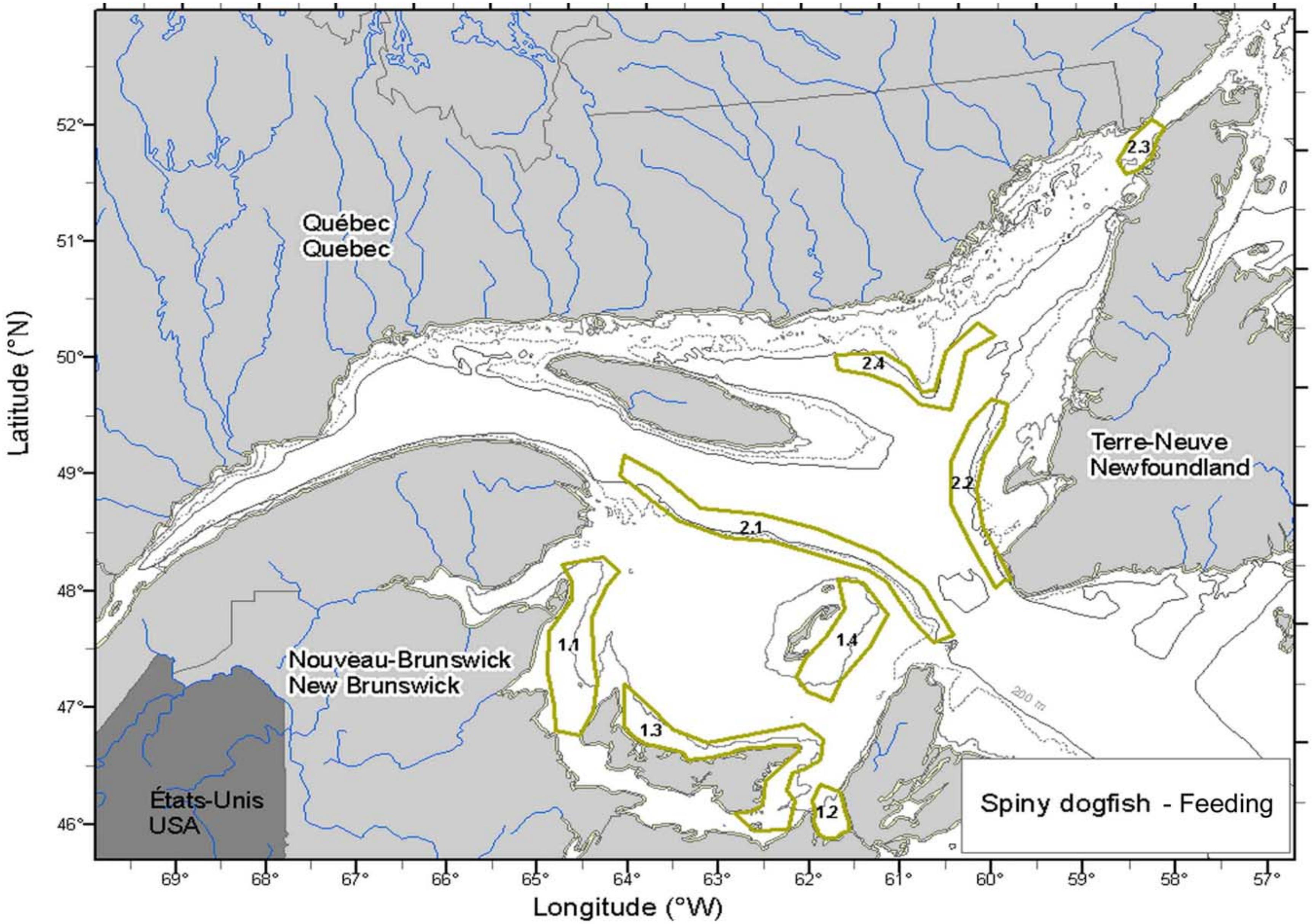

Figure 19. Spiny dogfish IAs for feeding in the GSL (ref Fig. 18). Area no. refers to IA ID no. in Table 5.

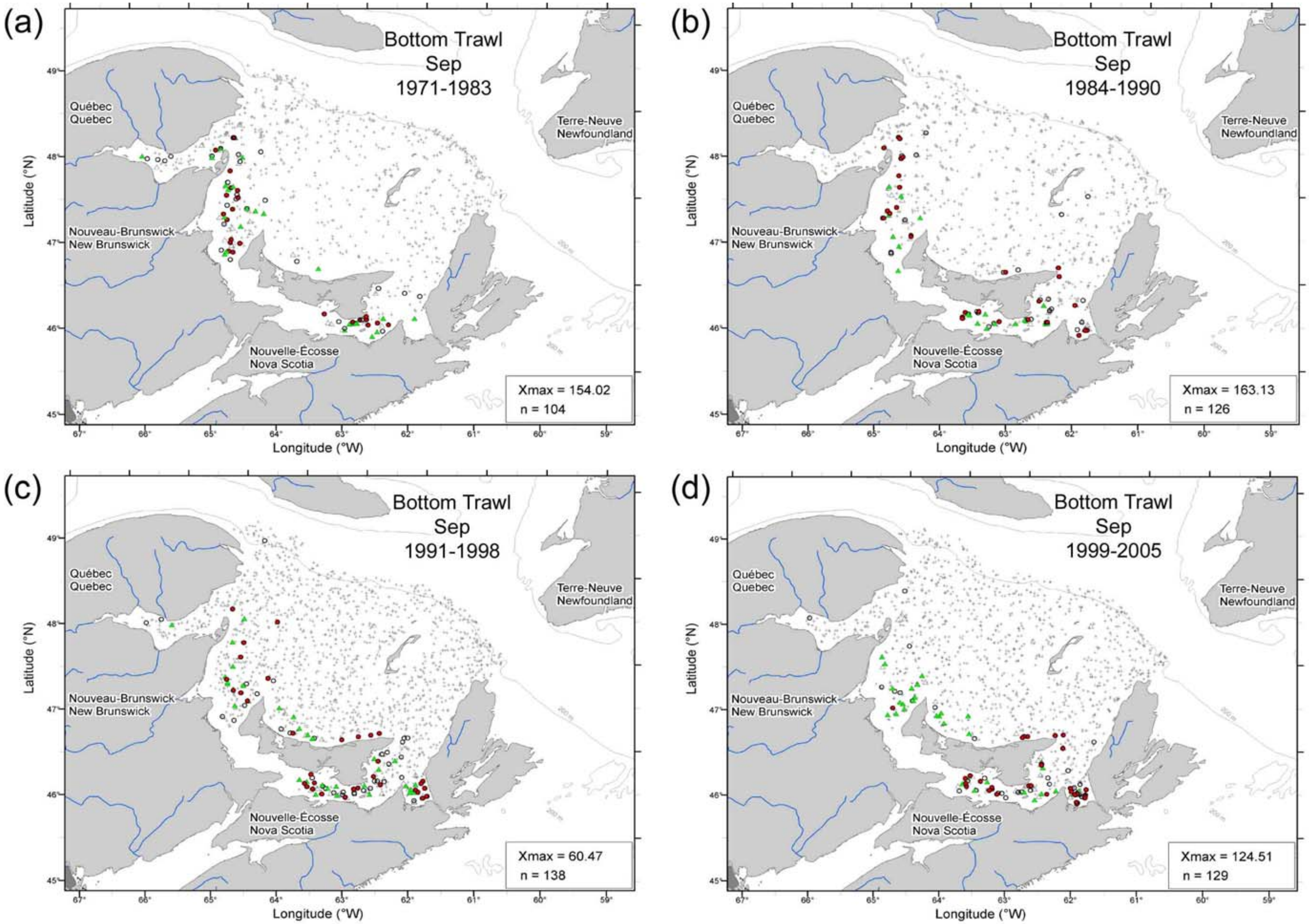

Figure 20. Alewife distribution by quartile (see Figure 5 for symbol scale) from research bottom trawl catches in the sGSL in summer between (a) 1971-1983, (b) 1984-1990 (c) 1991-1998 and (d) 1999-2005.

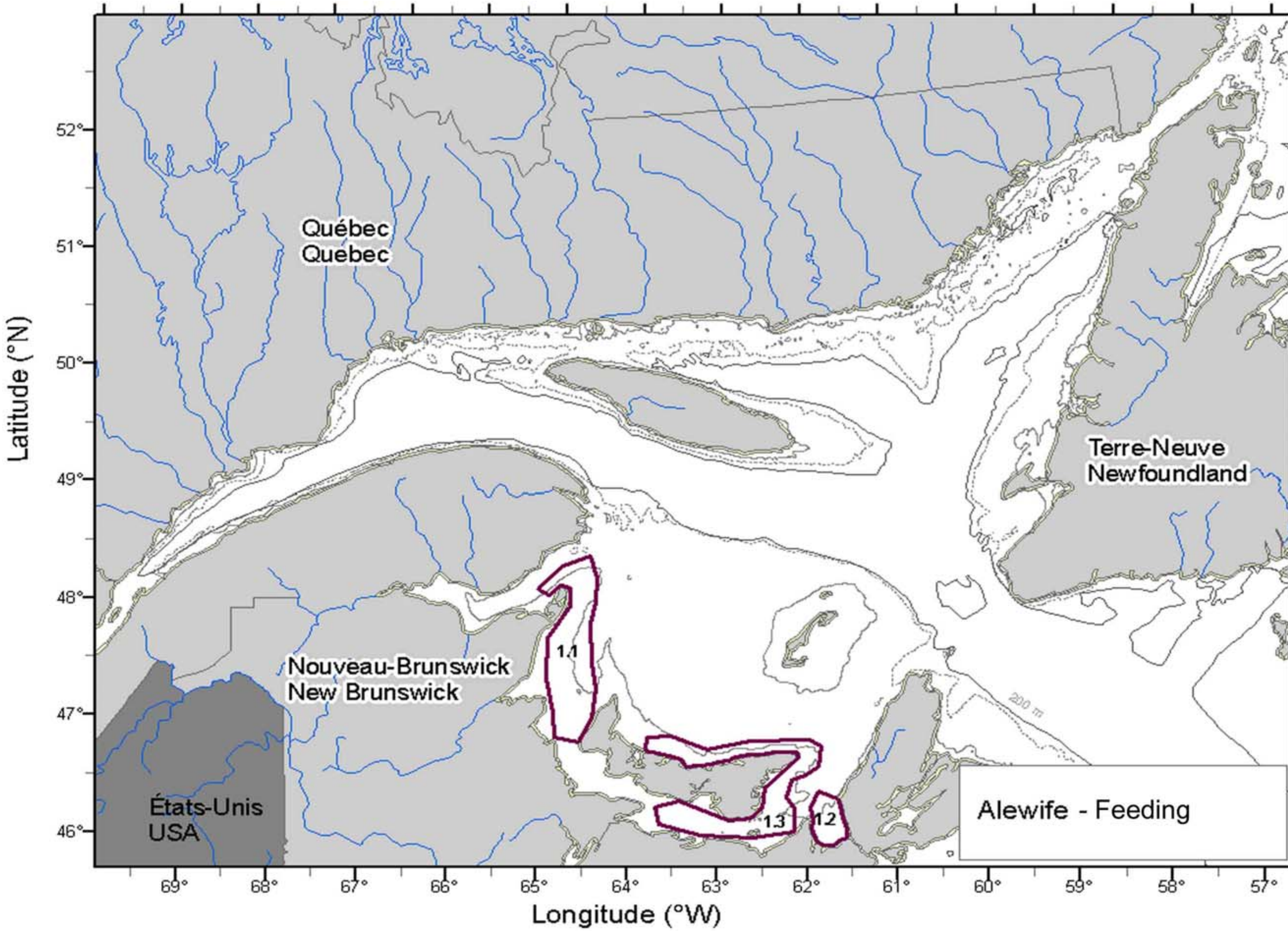

Figure 21. Alewife feeding IAs in the sGSL (ref Fig. 20). Area no. refers to IA ID no. in Table 5.

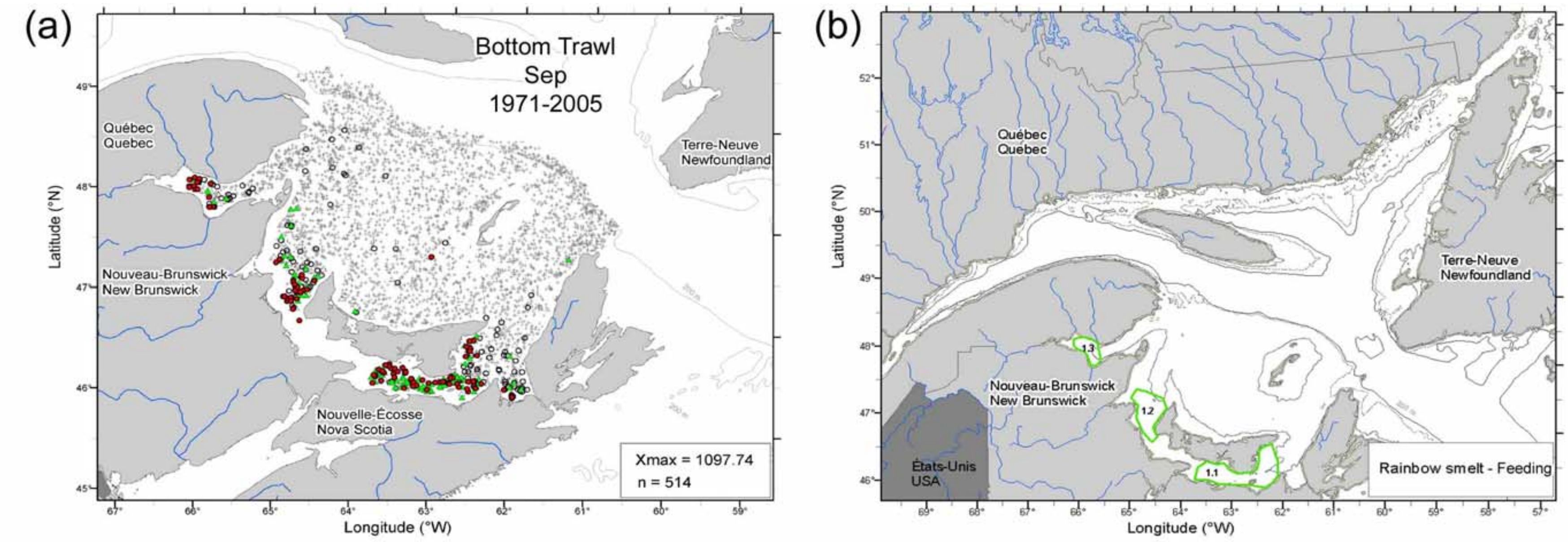

Figure 22. (a) Rainbow smelt distribution by quartile (see Figure 5 for symbol scale) from research bottom trawl catches in the sGSL in summer between 1984-2005 and (b) associated feeding IAs for sGSL rainbow smelt. Area no. refers to IA ID no. in Table 5.

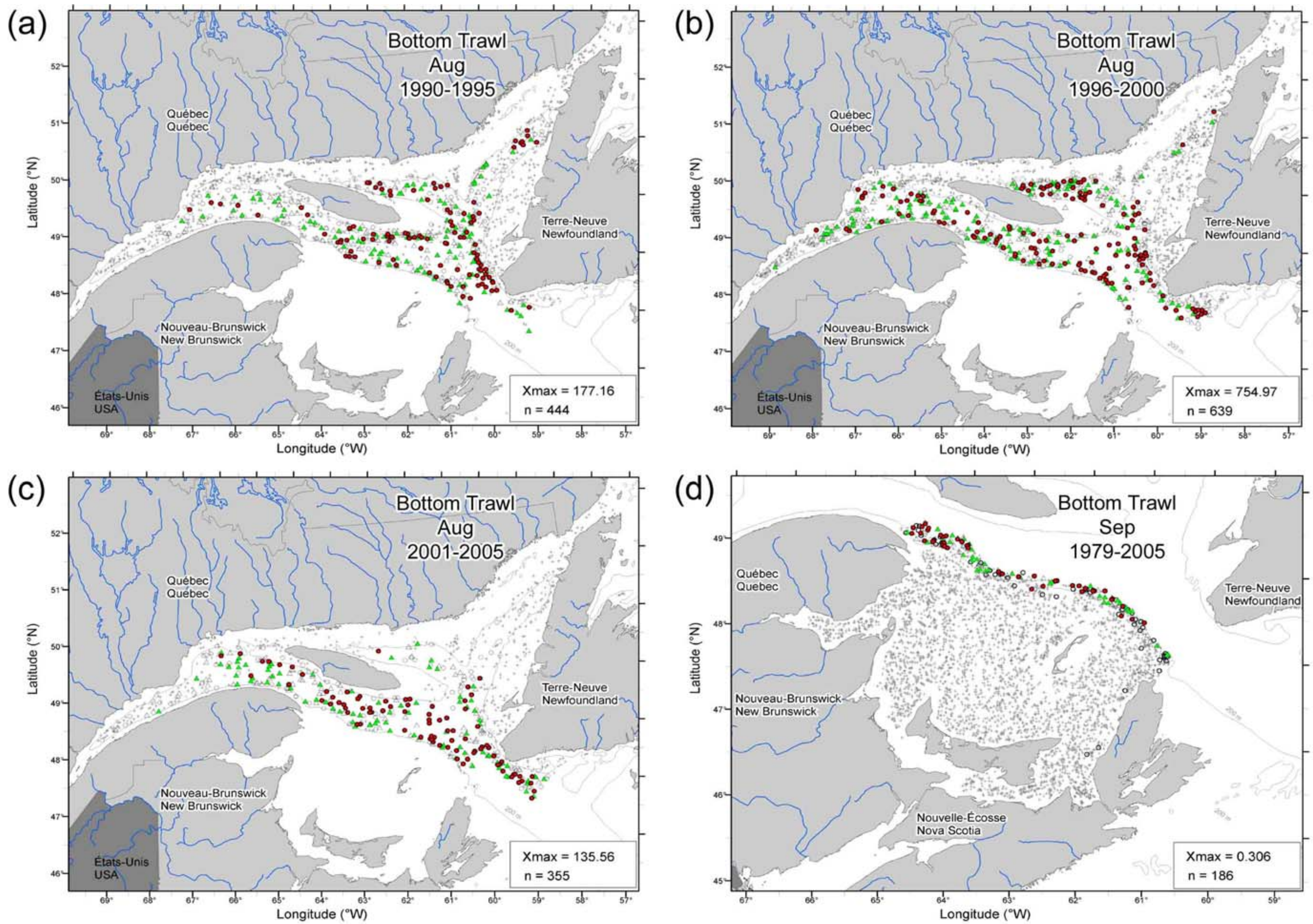

Figure 23. White barracudina distribution by quartile (see Figure 5 for symbol scale) from research bottom trawl catches in summer (a) in the nGSL between 1990-1995 and (b) 1996-2000 and (c) 2001-2005 and (d) in the sGSL between 1979-2005.

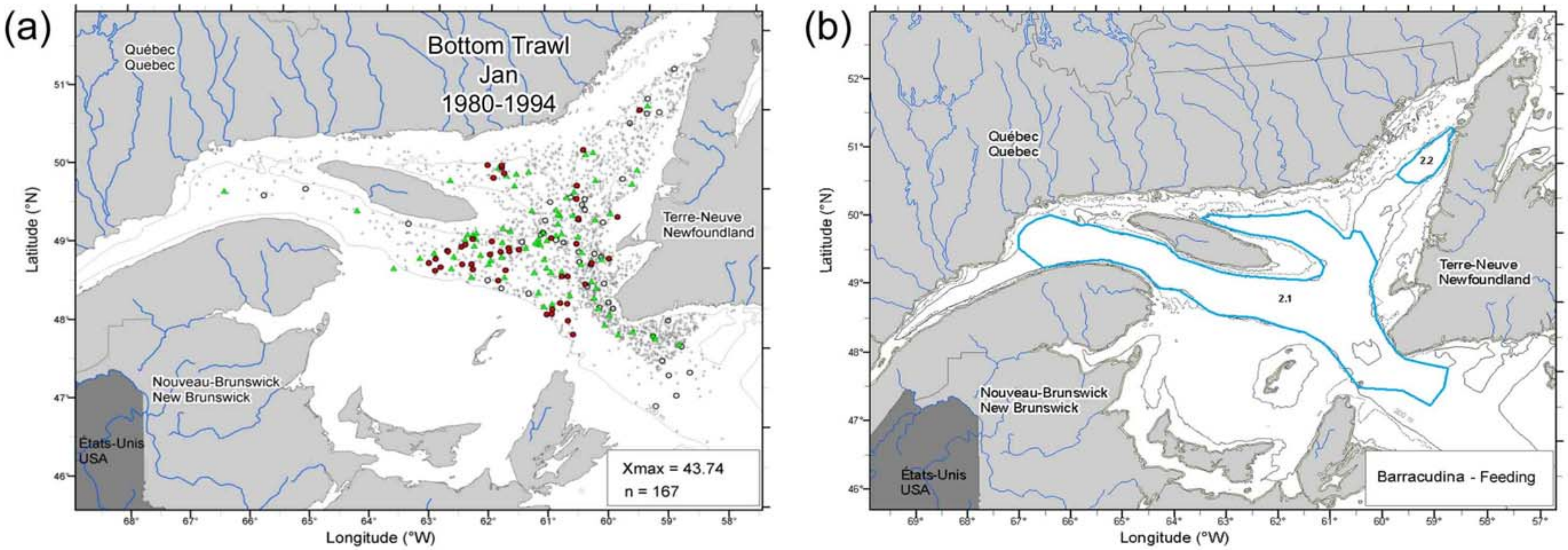

Figure 24. (a) White barracudina distribution by quartile (see Figure 5 for symbol scale) from research bottom trawl catches in the nGSL in winter between 1980-1994 and (b) feeding IAs for nGSL white barracudina (ref Fig. 23). Area no. refers to IA ID no. in Table 5.

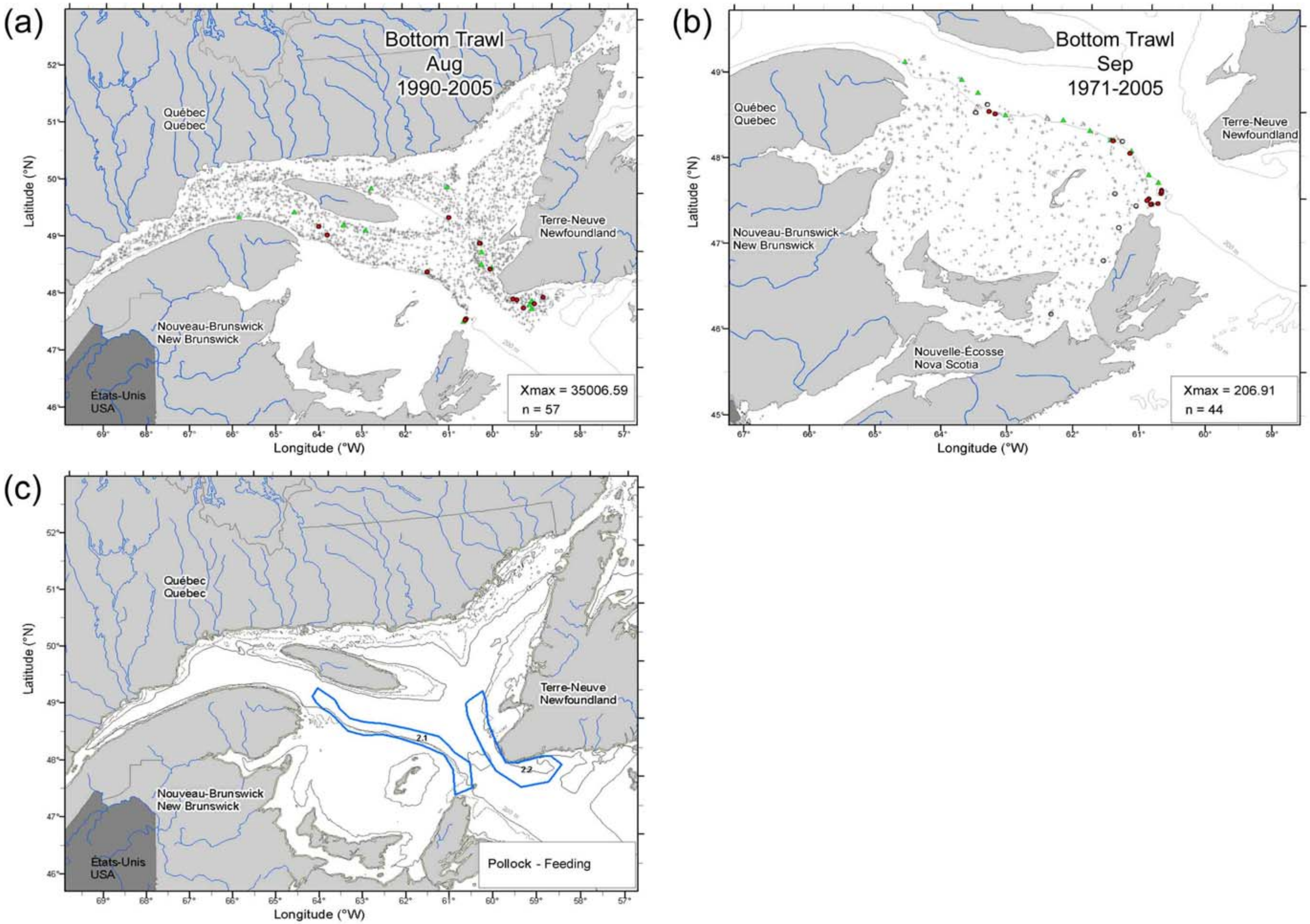

Figure 25. Pollock distribution by quartile (see Figure 5 for symbol scale) from research bottom trawl catches in summer (a) in the nGSL between 1990-2005 and (b) in the sGSL between 1971-2005 and (c) associated feeding IA for GSL pollock. Area no. refers to IA ID no. in Table 5.

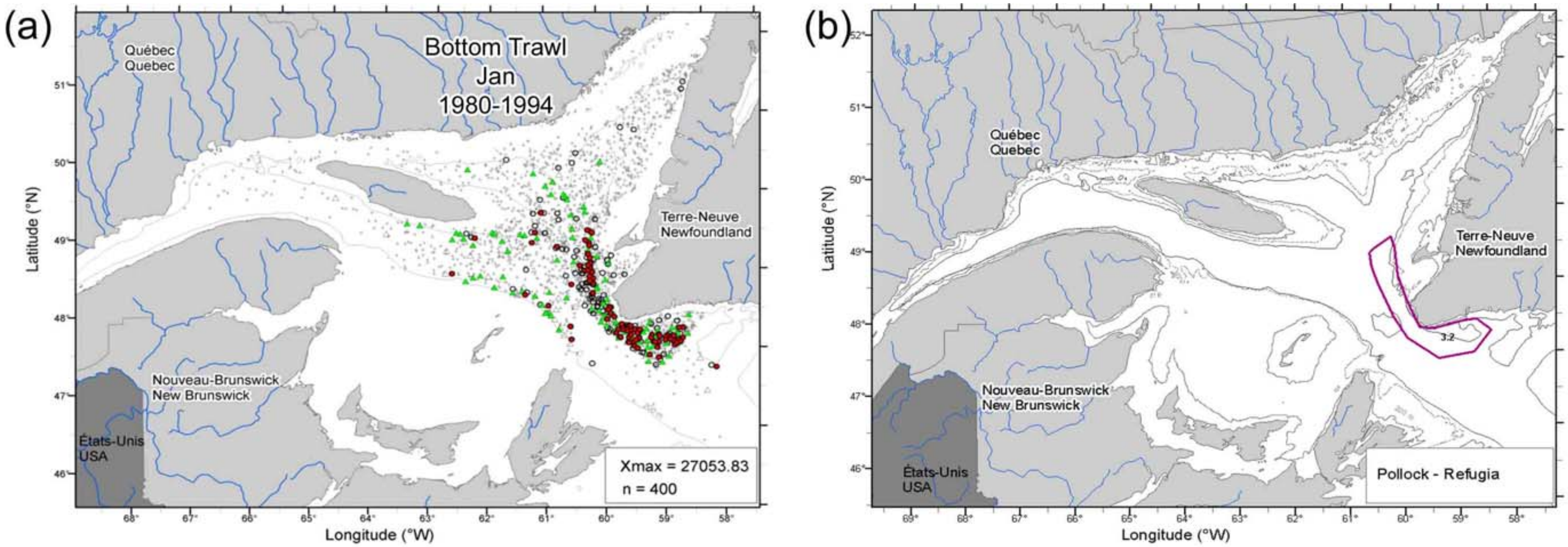

Figure 26. (a) Pollock distribution by quartile (see Figure 5 for symbol scale) from research bottom trawl catches in the nGSL in winter between 1980-1994 and (c) associated refugia IA for nGSL pollock. Area no. refers to IA ID no. in Table 5.

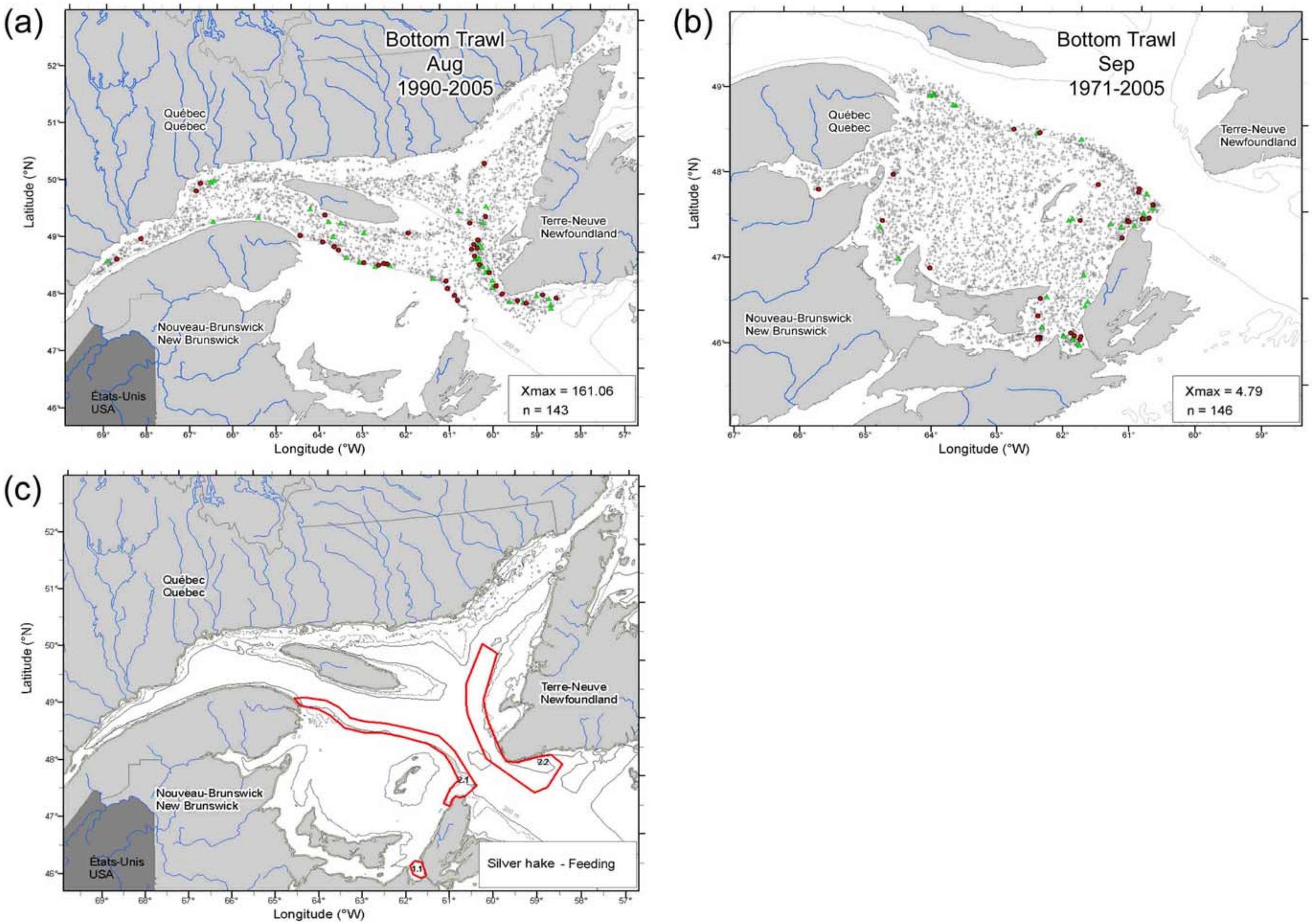

Figure 27. Silver hake distribution by quartile (see Figure 5 for symbol scale) from research bottom trawl catches in summer (a) in the nGSL between 1990-2005 and (b) in the sGSL between 1971-2005 and (c) associated feeding IA for GSL silver hake. Area no. refers to IA ID no. in Table 5.

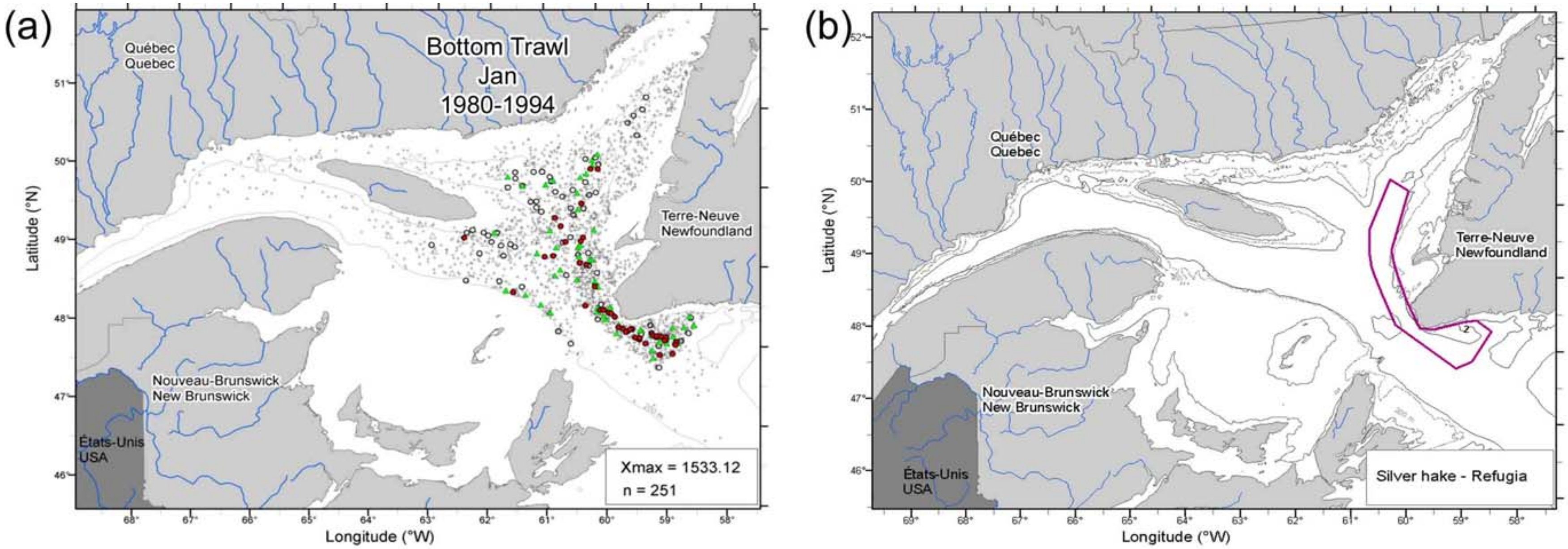

Figure 28. (a) Silver hake distribution by quartile (see Figure 5 for symbol scale) from research bottom trawl catches in the nGSL in winter between 1980-1994 and (c) associated refugia IA for nGSL silver hake. Area no. refers to IA ID no. in Table 5.

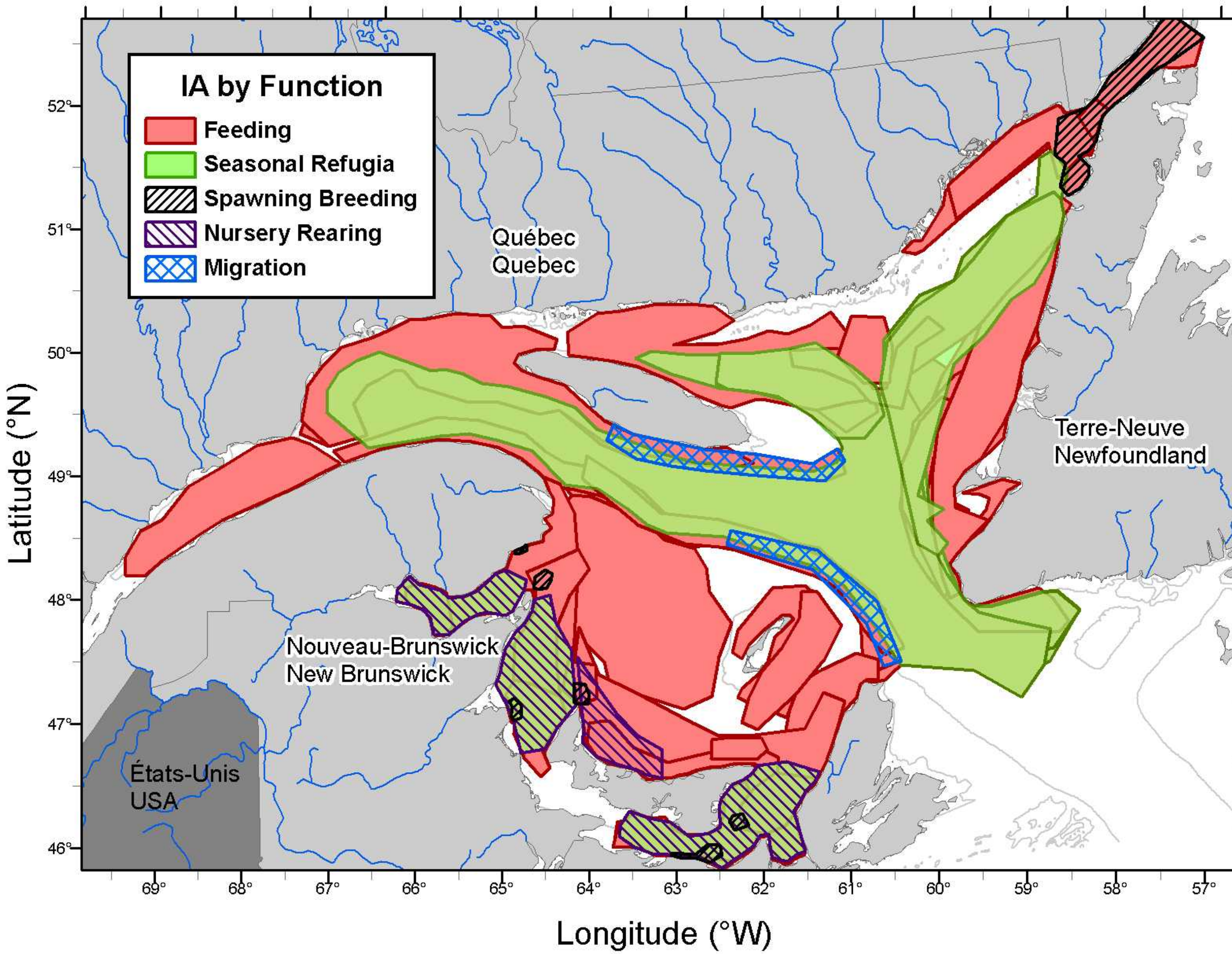

Figure 29. Species level IAs by function for small pelagic fishes in the GSL.

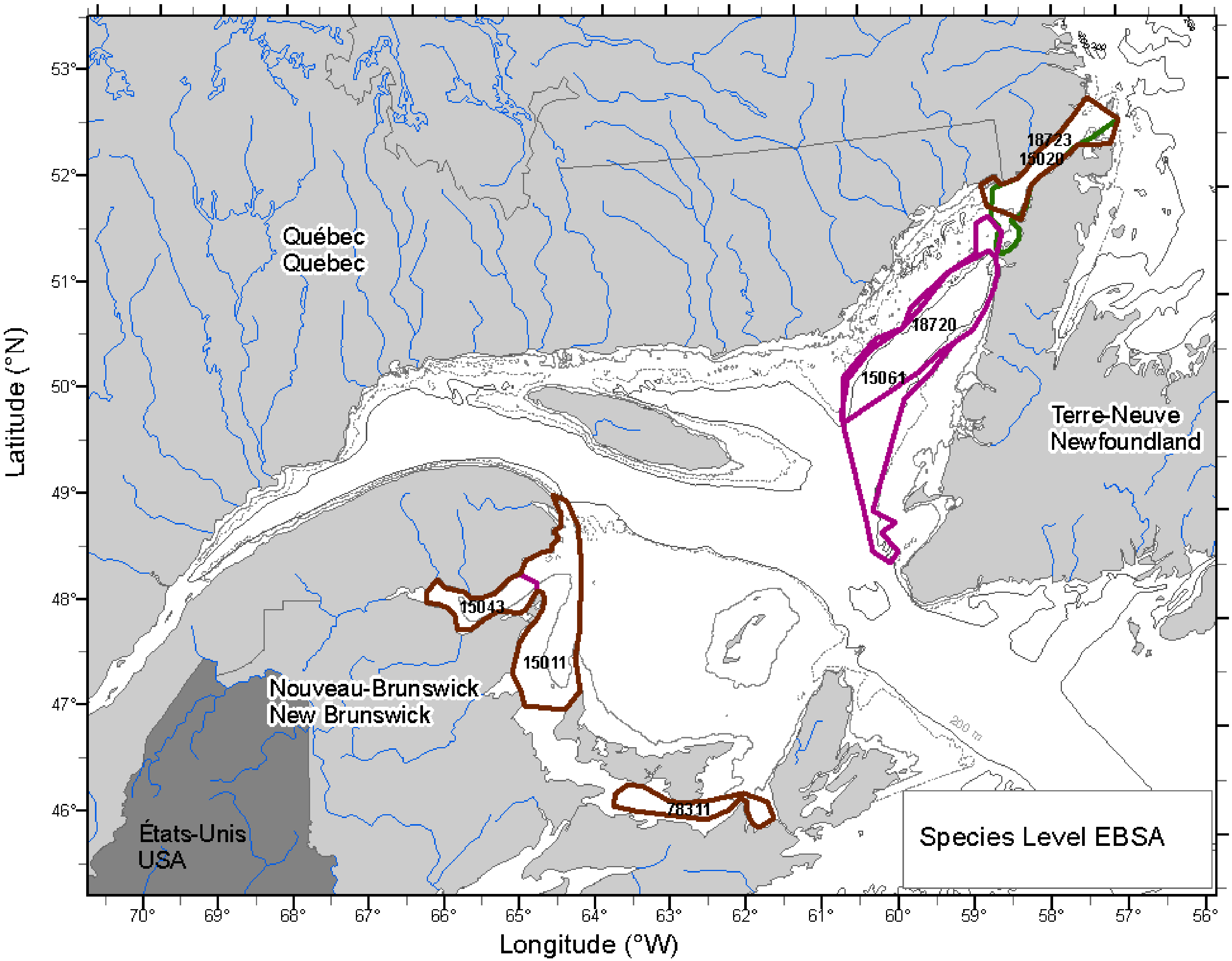

Figure 30. Proposed seven species-level EBSAs for small pelagic fishes in the GSL.

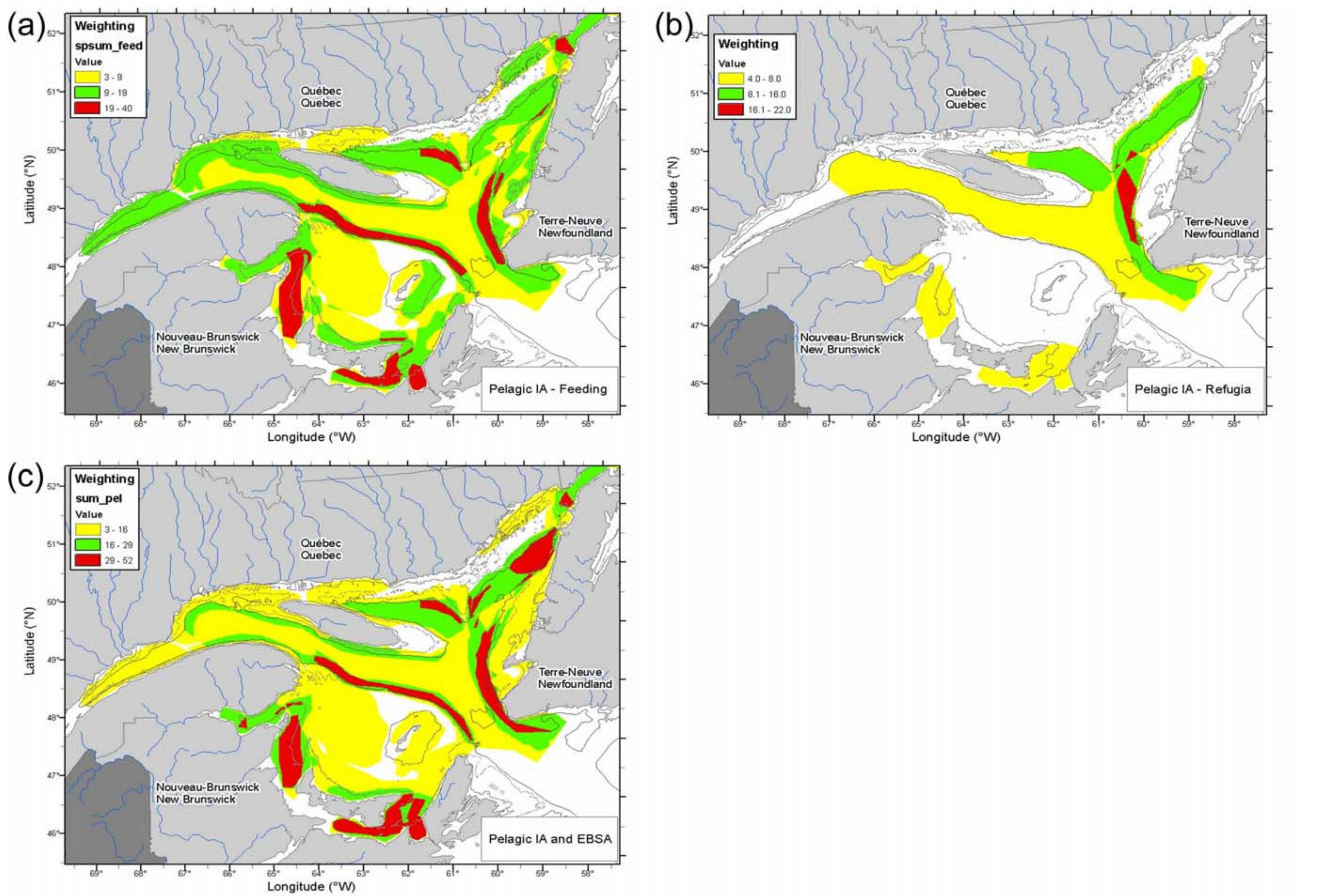

Figure 31. Community level IAs for pelagic with proposed EBSAs (dark red areas) for small pelagic fishes in the GSL based on (a) feeding IAs, (b) refugia IAs and (c) cummulative pelagic IAs.

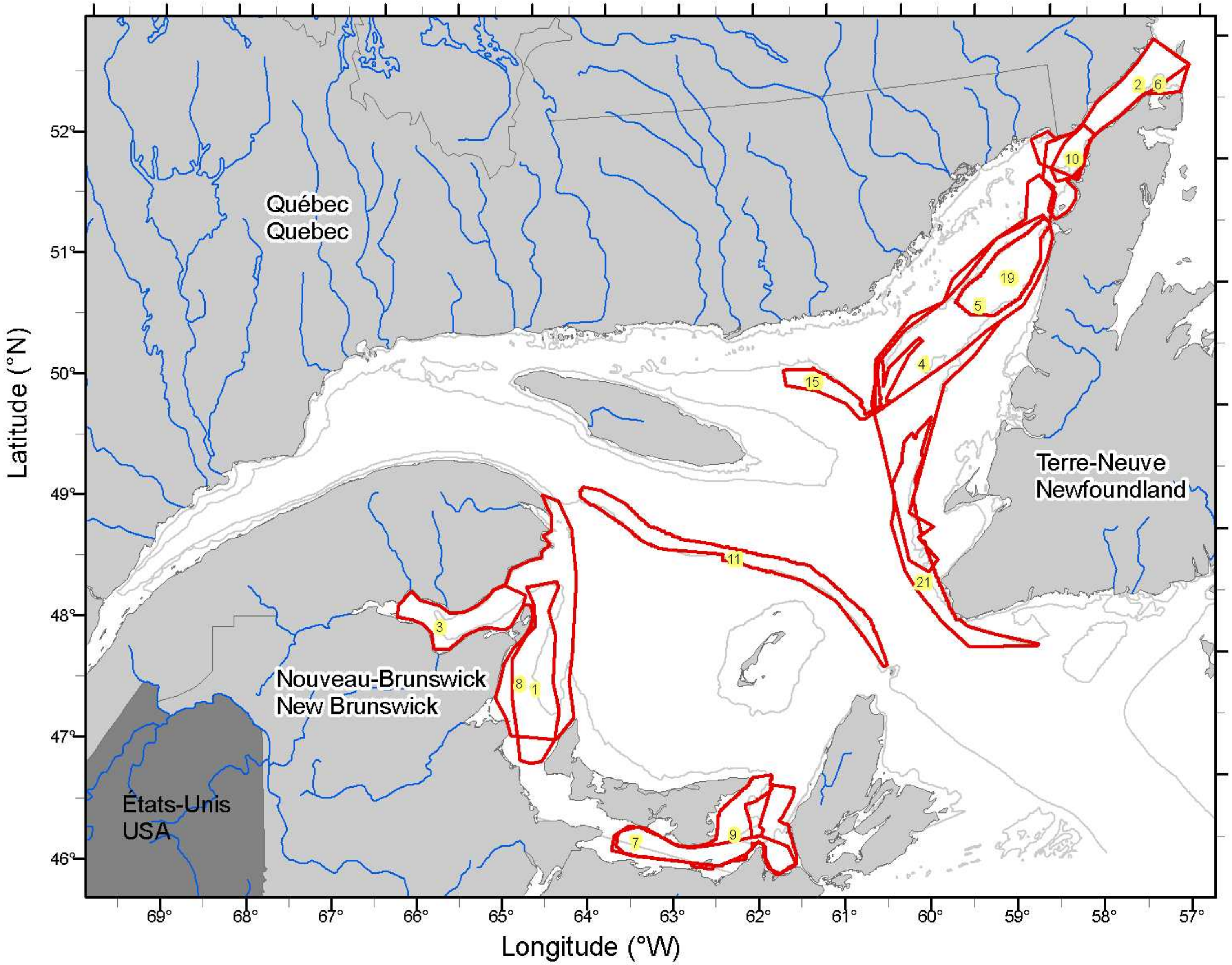

Figure 32. Proposed species- and community-level EBSAs for small pelagic fishes in the GSL. Numbers refer to Table 6.