

# Journal of Northwest Atlantic Fishery Science



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Northwest Atlantic Fisheries Organization  
2 Morris Drive, Suite 100, Dartmouth, Nova Scotia  
Canada B3B 1K8  
Tel.: (+1 902) 468-5590 • Fax: (+1 902) 468-5538  
Email: journal@nafo.int • Website: <http://journal.nafo.int> • [www.nafo.int](http://www.nafo.int)



# Journal of Northwest Atlantic Fishery Science

Scientific publications by ICNAF and NAFO have been in existence since ICNAF began in 1949 with the ICNAF Special Publication series dealing with proceedings of scientific symposia. The *ICNAF Research Bulletin* was started in 1964 to provide a means of publishing results of scientific research relevant to ICNAF. The ICNAF Research Bulletin was terminated in September 1979 after the issue of Number 14. The first volume of the NAFO *Journal of Northwest Atlantic Fishery Science* was published in December 1980, after NAFO came into force replacing ICNAF in 1979.

The Northwest Atlantic fisheries have a rich history, and a great deal of research has been sponsored and encouraged by NAFO and its predecessor ICNAF. NAFO has been a leader amongst international organizations in the application of science to fishery management and in the regulation of fisheries in areas beyond national jurisdiction. In accordance with its mandate to disseminate information on fisheries research to the scientific community, the Scientific Council of NAFO publishes the *Journal of Northwest Atlantic Fishery Science*, which contains peer-reviewed primary papers, and *NAFO Scientific Council Studies*, which contains unrefereed papers of topical interest and importance to the Scientific Council. Lists of these and other NAFO publications are given on the back of this issue.

## Editorial Policy

The Journal provides an international forum for the primary publication of original research papers, with emphasis on environmental, biological, economic and social science aspects of fisheries and their interactions with marine habitats and ecosystems. While the Journal is intended to be regional in scope, papers of general applicability, and methodological and review papers, irrespective of region, are considered. Space is available for notes and letters to the editor to facilitate scientific discussion of published papers. Both practical and theoretical papers are eligible. All papers are peer-reviewed to determine their suitability for primary publication. Associate Editors arrange for the peer-reviews and ensure that the papers accepted for publication meet the high standards required for the Journal. Manuscripts approved for publication are accepted with the understanding that they are not copyrighted, published or submitted elsewhere except in abstract form. There are no page charges.

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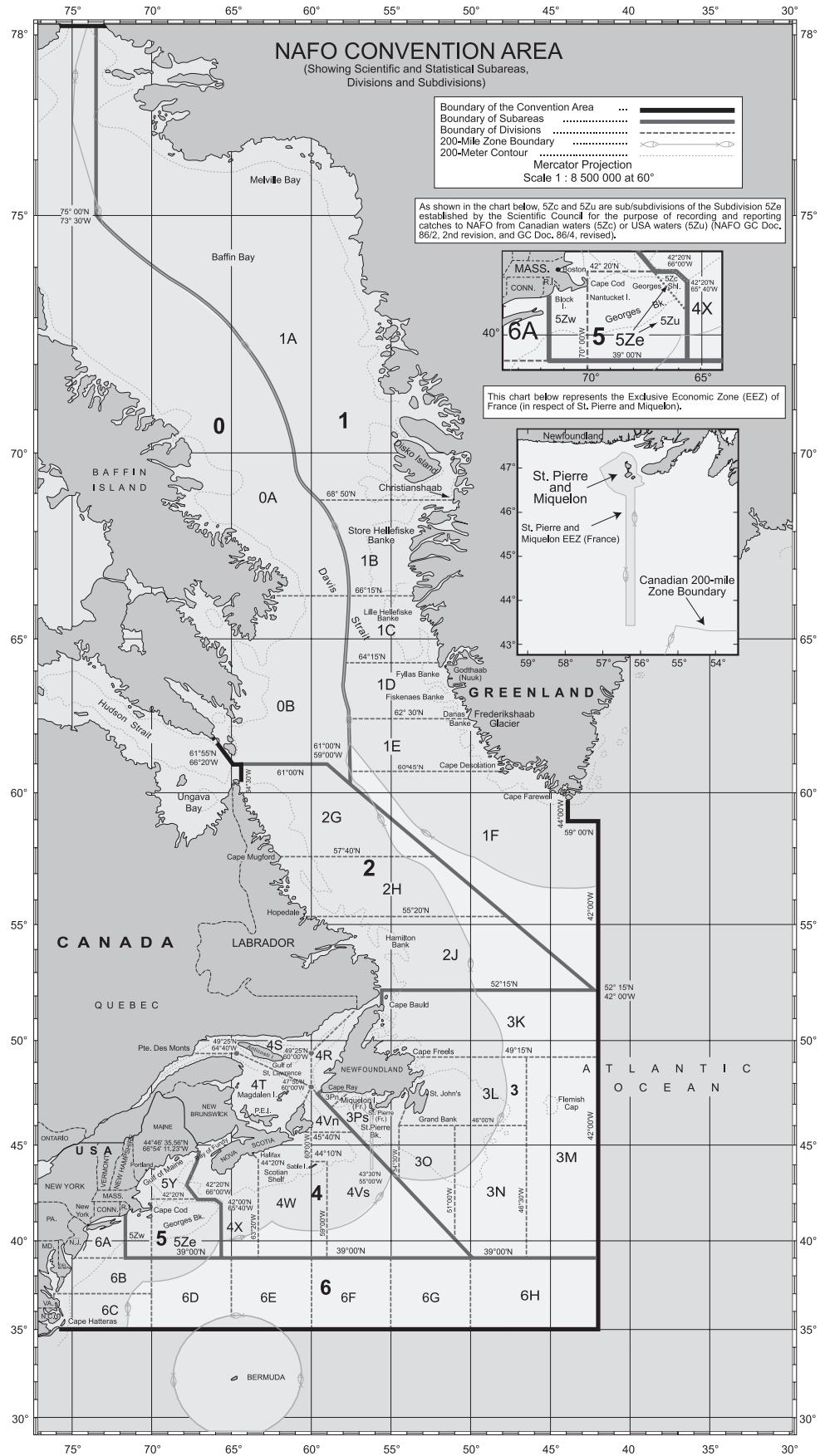
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## Foreword

The Scientific Council of NAFO publishes the Journal of Northwest Atlantic Fisheries Science, containing peer reviewed primary literature detailing original research of relevance to fisheries science and management in the northwest Atlantic Ocean. Articles are published electronically under a Creative Commons 2.5 license and are freely available at <http://journal.nafo.int>. NAFO Scientific Council has resolved to produce annual bound print volumes, and these represent a compilation of the web based articles published throughout the year. Additionally, the journal supports the use of digital object identifiers (doi) for electronic media and encourages others to support this initiative.

As always, this issue covers a range of topics representing ongoing research in the northwest Atlantic, including the population biology of American plaice, the groundfish assemblage of the Flemish Cap, selectivity of shellfish gears and long-term trends in the zooplankton community of the US continental shelf.

I would like to extend my thanks to all the authors who submitted works during 2013, to the Associate Editors who make the administration of the journal such a pleasure, to the various reviewers who give up their time and to Alexis Pacey, publications manager at the NAFO Secretariat, for all her assistance.

I hope you find this volume of JNAFS enjoyable and informative.

December 2013

Neil Campbell  
General Editor,  
*Journal of Northwest Atlantic Fishery Science*



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# Long-Term Abundance and Distribution Trends of the Cladoceran *Penilia avirostris* in the US Northeast Shelf Ecosystem

Joseph Kane

NOAA, National Marine Fisheries Service

28 Tarzwell Drive, Narragansett, Rhode Island, USA

Phone: 401-782-3244; Fax 401-782-3201; Email: joe.kane@noaa.gov

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## Abstract

The average spatial distribution and interannual abundance patterns of the cladoceran *Penilia avirostris* are described from samples collected in the waters of the US Northeast continental shelf ecosystem. Integrated water column samples were collected with a bongo net from 1977–2009 on broad scale surveys of the shelf conducted approximately every two months. Collections were also made with a Continuous Plankton Recorder towed at 10 m depth along two routes; one that crossed the Gulf of Maine (1961–2009), and the other from New York City south-eastward toward Bermuda (1976–2009). *P. avirostris* was found to have a strong seasonal cycle in the southern half of the ecosystem. High coastal concentrations suddenly appear there in July–August, forming distinct onshore-offshore abundance gradients. The population slowly declines in the autumn months, essentially disappears from the zooplankton community during winter, and does not return again until its abrupt appearance in summer. Only low abundances in isolated patches were found in the northern half of the ecosystem and in the slope waters sampled by the CPR. Both samplers showed that annual abundance levels were variable with no long-term trend evident, nor were environmental measures or broad scale climate indices correlated to these variations. The cladocerans' summer population surge was significantly correlated with surface temperature and water column stratification indices. This is the first study to record the presence of *P. avirostris* in the Gulf of Maine region.

**Keywords:** abundance, distribution, *Penilia avirostris*, temperature, Gulf of Maine

## Introduction

The marine cladoceran *Penilia avirostris* is seasonally abundant and distributed worldwide in the waters of tropical and subtropical oceans. Due to parthenogenetic reproduction and short generation times, *P. avirostris* populations can exhibit explosive growth and quickly eclipse the seasonal numbers and biomass of copepods that are usually more common in the same ecosystems. The cladoceran can persist year round in tropical waters, while it occurs seasonally in more temperate regions. The temperate populations will switch from parthenogenetic to sexual reproduction under adverse conditions, eventually producing resting eggs which sink to the bottom and hatch when conditions are more favorable again. Of the eight cladoceran species that have colonized the marine environment, *P. avirostris* is unique in that it is the only filter-feeder. This allows it to consume a wide range of prey size (Atienza *et al.*, 2006), from minute nanoplankton (2–20 µm) to larger cells (>20 µm) that include dinoflagellates and diatoms.

Even though it is one of the most abundant zooplankton species found in nearshore waters of low and mid latitude regions, *Penilia avirostris* has not been widely studied and its importance to community dynamics appears to be under-appreciated. Research has focused primarily on copepods, which have traditionally been considered as the main link between primary producers and upper trophic levels in marine food webs. However, in tropical coastal waters annual production of *P. avirostris* has been estimated to be similar to the third most productive species in the copepod community (Rose *et al.*, 2004). Moreover, *P. avirostris* probably plays a key role in food chain dynamics because it consumes organisms as small as bacterivorous flagellates (Katechakis *et al.*, 2004), and is in turn fed on by carnivorous zooplankton, fish larvae, and planktivorous fish (Tang *et al.*, 1995).

Recent reports indicate that *Penilia avirostris* appears to be extending its northward distribution on both sides of the Atlantic. In 1999, large numbers suddenly appeared in the North Sea for the first time and have now become

a regular component of the region's autumn zooplankton community (Johns *et al.*, 2005). The authors correlated the arrival with rising sea surface temperatures, and proposed that warmer conditions allowed resting eggs to survive through the winter, enabling them to establish a permanent population. The first appearance of *P. avirostris* in Canadian waters was reported for the Gulf of St. Lawrence in the autumns of 2000 and 2001 (Bernier and Locke, 2006). This represents a 5° range extension (1130 km) from its previously reported northernmost occurrence on southeastern Georges Bank (Colton, 1985). The authors cautioned that this may not have been a natural extension of its distribution, but an expansion caused by ballast transport (Bernier and Locke, 2006).

NOAA Fisheries has monitored the zooplankton populations of the US Northeast Shelf Ecosystem since 1977 with dedicated broadscale surveys conducted approximately every two months (Sherman, 1980; Kane, 2011). *Penilia avirostris* has the fourth highest mean abundance (12 671/100 m<sup>3</sup>) of all zooplankton taxa collected

during the entire 1977–2009 time series. Zooplankton in the region has also been monitored with monthly surveys using a Continuous Plankton Recorder (CPR) along two transects that crossed northern and southern portions of the region from 1961 and 1976 onward, respectively (Jossi and Benway, 2003). In this paper, data from these two programs are combined to present an inter-decadal examination of the distribution and abundance variability of *P. avirostris* throughout the ecosystem. Furthermore, an attempt is made to couple the observed patterns with survey measurements of environmental variables and the variability of climatic indices.

## Methods

### Broad Scale Surveys

This analysis is based on the sorting results of 23 795 zooplankton samples that were collected on broad scale surveys of the U.S. Northeast Shelf ecosystem for 33 years, 1977–2009 (Fig. 1). All samples were collected with

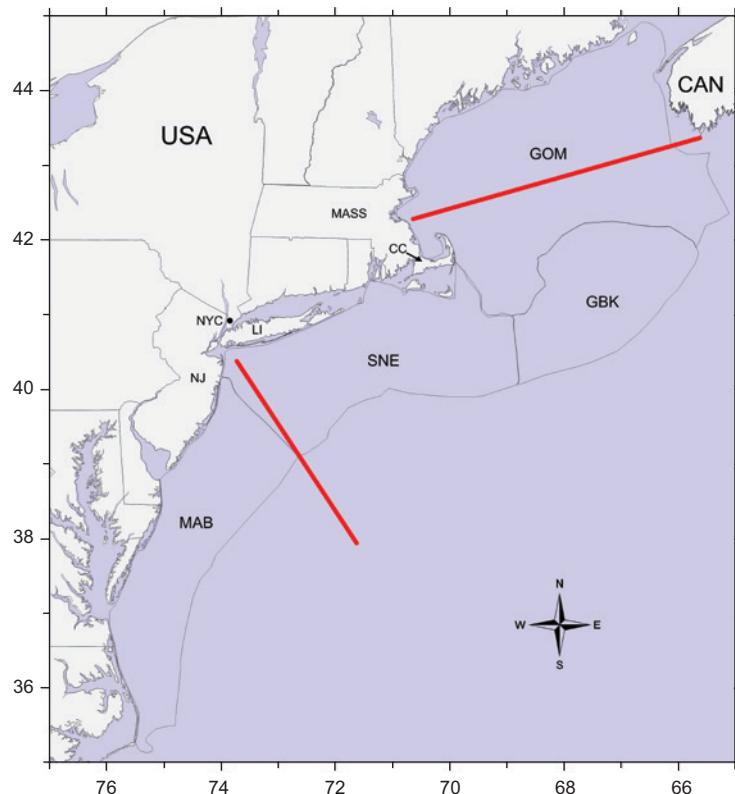


Fig. 1. Orientation map of area sampled during broad scale plankton surveys of the U.S. Northeast shelf ecosystem. The survey area was divided into four subareas: 1) Gulf of Maine (GOM), 2) Georges Bank (GBK), 3) Southern New England (SNE), and 4) Middle Atlantic Bight (MAB). The horizontal red lines are the approximate location of the Gulf of Maine and Mid-Atlantic CPR transects. Place name abbreviations: NJ = New Jersey, NYC = New York City, LI = Long Island, CC = Cape Cod, MASS = Massachusetts

a 0.333 mm mesh net fitted on one side of a 61 cm Bongo frame that was equipped with a calibrated flowmeter to measure the volume of water filtered during the tow. The gear was towed at approximately 1.5 knots while it was lowered to within a few meters from the bottom, or to a maximum depth of 200 m, and back to the surface. Cruise tracks and detailed sampling procedures for plankton and other measurements on surveys before 1988 were summarized by Sibunka and Silverman (1984, 1989). The only major change in sampling methodology after 1987 was attaching a CTD instrument above the Bongo frame to monitor the tow profile and collect simultaneous oceanographic data. The different survey sampling schemes employed during the time series have been described by Kane (2003).

Laboratory analysis began with the reduction of each sample to approximately 500 specimens with a modified box splitter. The aliquot was then sorted and zooplankton taxa were identified to the lowest taxonomic classification possible. *Penilia avirostris* life stages cannot be defined readily because they hatch from the egg as miniature adults and simply increase in size as they moult toward the adult stage. Therefore, all specimens were summed together and expressed here as numbers/100 m<sup>3</sup>. Contoured bimonthly and seasonal distribution maps of abundance were generated using the Surfer 9 software package (Golden Software) to interpolate abundance surfaces with natural neighbor gridding methods.

Analysis of the cladocerans' abundance variability was facilitated by dividing the ecosystem into four subareas whose boundaries are defined by oceanographic characteristics (Ingham *et al.*, 1982): the Gulf of Maine (GOM), Georges Bank (GBK), Southern New England (SNE), and the Middle Atlantic Bight (MAB) (Fig. 1). Interannual abundance variability was examined by calculating yearly abundance indices for each region. The data were log<sub>10</sub>(n+1) transformed and the average annual abundance cycle was computed by fitting a spline curve function to the time series bimonthly mean abundance values. Anomalies from the seasonal cycle were then averaged over each year to produce an annual abundance index. Sampling was too infrequent to calculate the annual anomaly in the MAB from 1989–94 and in the SNE region for 1989.

### CPR Surveys

*Penilia avirostris* abundance data were also analyzed from samples collected with a Continuous Plankton Recorder (CPR) towed at about 10 m depth (Hardy, 1939). Surveys were conducted at approximately monthly intervals along two transects across the ecosystem (Fig. 1). The Gulf of

Maine (GOM) transect extends from the Massachusetts coast across the Gulf of Maine to Cape Sable, Nova Scotia. Data were collected from 1961–2009, except for an interval from 1974–1977. The Mid-Atlantic (MA) transect extends from just offshore of New York City, across the continental shelf and slope towards Bermuda. Data were collected from 1976–2009, with the exception of 1980.

The methods used on the CPR surveys along these two routes have been described by Jossi and Benway (2003). Briefly, plankton is filtered through bolting silk with a wet-mesh aperture of 0.225 mm x 0.234 mm. In the laboratory, the silk was cut into pieces representing 18.5 km sections that were assigned geographic positions and reference distance values (km from standard transect origin). Alternate sections of silk were examined for zooplankton using techniques described by Colebrook (Colebrook, 1975). CPR counts are reported here as numbers/100 m<sup>3</sup>. Annual abundance anomalies were calculated using the same methods that were described earlier for broad scale surveys. Data collected along the MA transect were partitioned into shelf and slope water regions (>200 km from transect origin) to facilitate comparisons with Bongo net surveys.

### Environmental Data

Temperature and salinity measurements were routinely made on all broad scale surveys. Surface temperature measurements were made with a stem thermometer from a surface bucket sample from 1977–1998; values collected thereafter were recorded via a thermistor attached to the vessel. Samples for bottom temperature, surface salinity, and bottom salinity were collected with Niskin bottles from 1977–1986, while later years collected data with a CTD instrument. Annual anomalies for these variables were calculated using the same methods described earlier for the zooplankton abundance index.

Temperature profiles of the water column were obtained at one hour intervals along the CPR transects with an expendable bathythermograph (XBT) from 1977 onward. Ten meter temperature values before and after the central location of the CPR sample were distance weighted to interpolate a value for that position, essentially approximating the temperature where *Penilia avirostris* was captured by the CPR.

Climate variability was indexed with the winter phase of the North Atlantic Oscillation (NAO), the Gulf Stream North Wall Index (GSI), and the Atlantic Multidecadal Oscillation (AMO). The NAO is an index which is based on the difference of normalized sea level pressures between Lisbon, Portugal and Stykkisholmur/Reykjavik,

Iceland from the months of December through March (Hurrell, 1995). The GSI is a measure of the position of the north wall of the Gulf Stream as it diverges from the North American coastline (Taylor *et al.*, 1995). The AMO is a mode of natural variability occurring in the North Atlantic that is primarily associated with long duration changes in sea surface temperature (Kerr, 2000). These three indices of climate variability are all known to affect physical and biological measurements across the North Atlantic and are readily available online.

Spearman's rank correlation coefficients between the annual anomalies of *Penilia avirostris* abundance and the environmental variables were calculated within each broadscale survey subarea and along each CPR transect to measure the strength of association between them. Abundance anomalies were also correlated with one and two year lag periods of environmental measures to determine if conditions in preceding years affect the cladoceran's density. Additionally, bimonthly subsets of data were analyzed to determine if any of the factor(s) trigger seasonal abundance pulses.

## Results

### Broad Scale Surveys

*Penilia avirostris* abundance explodes in the southernmost waters of the ecosystem during summer (Fig. 2). Large numbers of the cladoceran suddenly appear in the MAB region during July–August, where near-shore samples frequently have more than one million individuals per 100 m<sup>3</sup>. *P. avirostris* numerically dominates the zooplankton community during these months, usually accounting for nearly 50% of the total mesozooplankton. Its numbers decline slowly through the autumn months and few are found during the winter and spring. Further north in the SNE region, its mean numbers are lower and they peak later in the year during September–October (Fig. 2). They also become nearly absent there during winter and measurable numbers do not reappear until the following summer. *P. avirostris* is not a major component of the GBK or GOM zooplankton community. It is usually absent from samples throughout most of the year, except for isolated and light catches that are most frequent in early autumn.

High numbers of *Penilia avirostris* can usually be found in coastal waters during July–August in decreasing south-north and onshore-offshore abundance gradients (Fig. 3). The inshore concentrations extend further northward into SNE waters during September–October, forming three

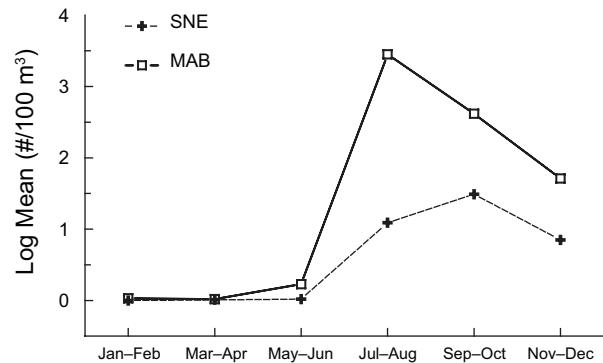


Fig. 2. The time series average annual  $\log_{10}$  abundance cycle of *Penilia avirostris* for the Southern New England (SNE) and Middle Atlantic Bight (MAB) subareas of the U.S. Northeast shelf ecosystem.

to four bands of decreasing inshore-offshore abundance gradients south of Cape Cod. The bands begin to weaken in November–December, dissolving into isolated pockets of high numbers in MAB inshore waters (Fig. 3). Low catches of *P. avirostris* were captured throughout GBK and most of the GOM at some points in the time series, especially during early autumn. Moderate concentrations were occasionally found in coastal waters near Cape Cod. During the first half of the year, *P. avirostris* is sparsely distributed throughout the ecosystem and is often absent over widespread areas (Fig. 3).

No persistent, long-term abundance trends of *Penilia avirostris* were evident for the time series. Patterns were similar ( $r = 0.56$ ,  $p < 0.01$ ) in both the MAB and SNE regions; with mostly above average levels in the late 1970s and early 1980s, low from the mid-1980s into the early 1990s, and highly variable thereafter through 2009 (Fig. 4). *P. avirostris* abundance in the GBK and GOM regions was too sparse to measure meaningful interannual trends.

Distribution maps contrasting the first and last decades of the time series suggest that the summer distribution of *Penilia avirostris* has changed in recent years (Fig. 5). During the 2000s, there was a northward and offshore extension of the high concentrations typically found in the MAB during the summer season. From 1977–86, the northern extent of the high density cluster was located in central New Jersey, while in the 2000s it had moved northward to about 75 km off Long Island (Fig. 5). The maps also indicate that the cladoceran had a more widespread distribution over the northern half of the ecosystem during the 2000s (Fig. 5).

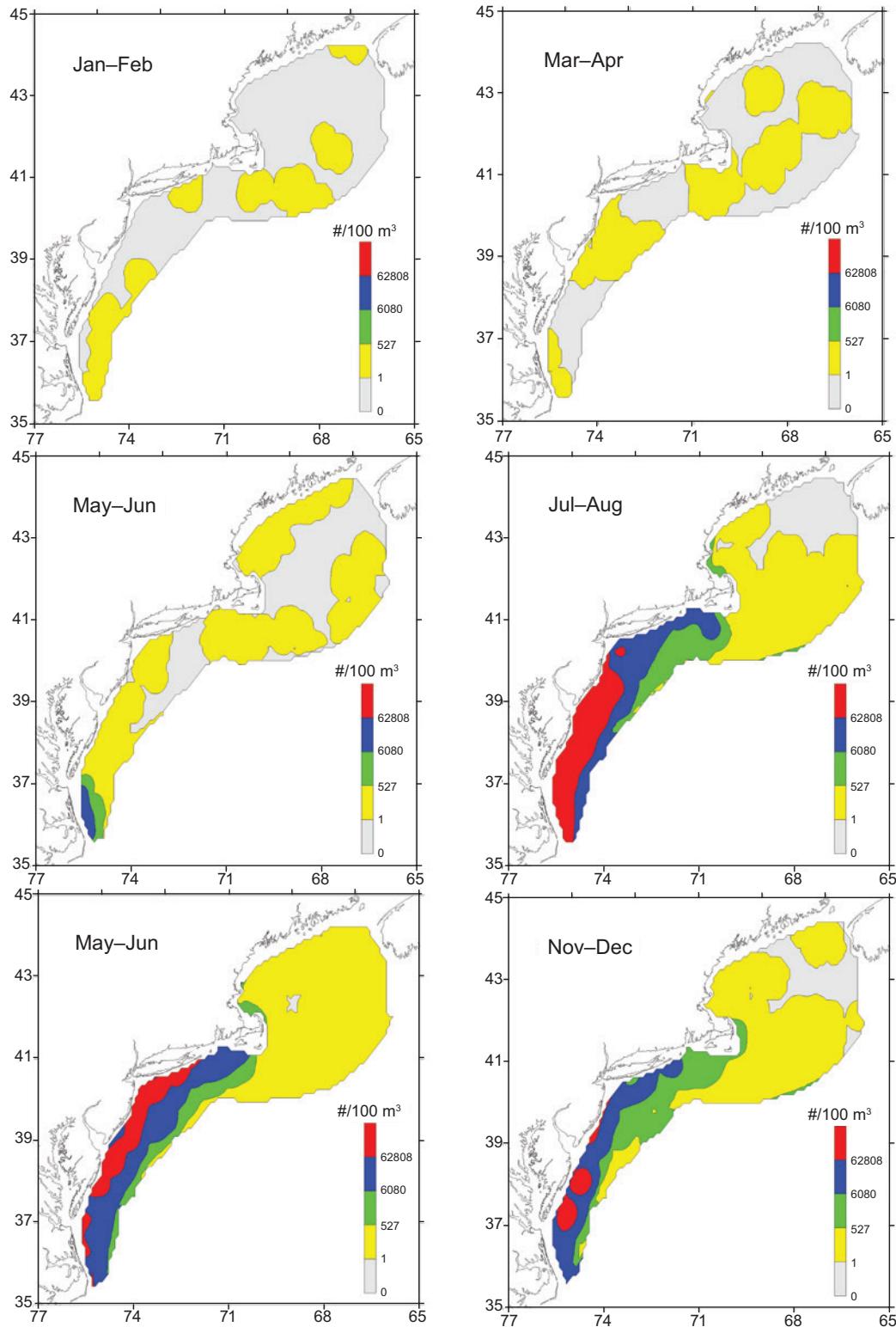


Fig. 3. Bimonthly composite distribution and abundance of *Penilia avirostris* in the U. S. Northeast shelf ecosystem.

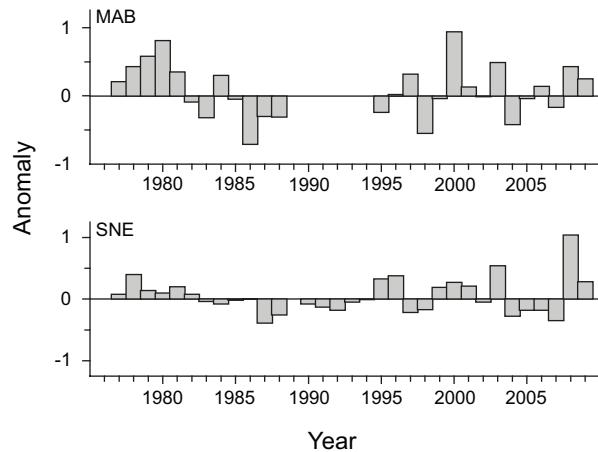


Fig. 4. Annual anomalies of *Penilia avirostris* abundance in the MAB (Middle Atlantic Bight) and SNE (Southern New England) regions. Each bar represents the annual mean of survey log abundance anomalies.

### CPR Surveys

High numbers of *Penilia avirostris* abruptly appear in MA CPR shelf samples during August, with concentrations located in coastal waters (Fig. 6). Numbers slowly decline through the early autumn months, decline sharply in late autumn, and are completely absent from January through June. It was captured on only one July survey (2008) during the 34 year sampling period. The cladocerans' abundance was much lower in slope waters (Fig. 6), identified on only 1.6% of the silk segments examined there during the time series. In 1985, it was first identified seaward of the shelf break and since then has been present in over half of the years. *P. avirostris* has never been found in GOM CPR samples.

Interannual variability in MA shelf samples waters was similar (Fig. 7), but not identical to the broadscale survey patterns (Fig. 4). Low years were more prevalent in the late 1970s-early 1980s, while above average years dominated the 1990s. Distribution along the transect was stable throughout the time series, with no major shifts in spatial patterns (data not shown).

### Environmental and Climate Variables

There were no significant ( $p < 0.01$ ) correlations between the annual anomalies of *Penilia avirostris* abundance and the environmental variables measured in both the MAB and SNE regions. Lagging the environmental variables from one to three years did not improve correlations. The results were the same when the cladocerans' interannual patterns were compared to the annual and lagged values of the NAO, GSI, and AMO indices.

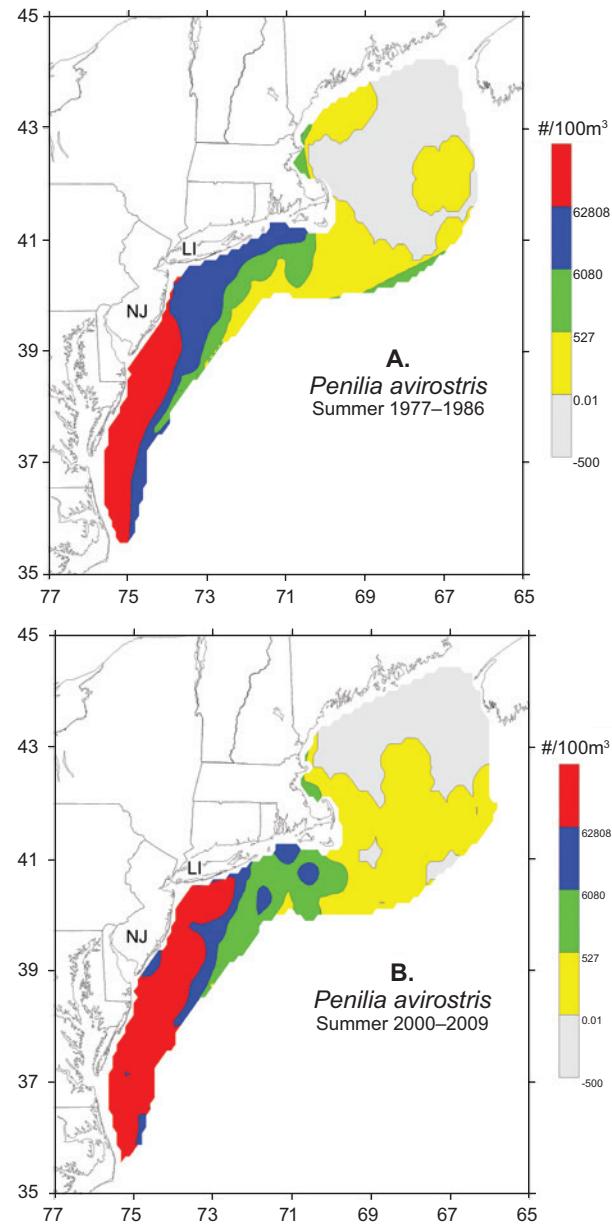


Fig. 5. Average summer (July–August) distribution and abundance of *Penilia avirostris* in the U. S. Northeast shelf ecosystem during A) 1977–1986 and B) 2000–2009.

A correlation analysis applied to data collected exclusively in July and August revealed that surface temperature and water stratification were both significantly correlated ( $p < 0.01$ ) with *Penilia avirostris* abundance in the MAB and SNE regions, though correlation coefficients were only moderately high (Table 1). Similar to *P. avirostris*, these variables both reach their seasonal peak during this time period. The relationship between the variables are not strongly linear, but temperature and stratification have a key role defining the animals life history.

Partitioning the data by 4°C intervals readily shows the cladocerans' abundance is strongly associated with elevated temperatures (Fig. 8). The cladocerans' density was also significantly negatively correlated with surface salinity measurements (Table 1).

In August, abundance along the shelf portion of the MA CPR transect was significantly correlated ( $p = 0.02$ ) with water temperature at 10 m depth, though the correlation coefficient was also only moderate ( $r = 0.23$ ). The two variables were not significantly correlated in the other eleven months.

## Discussion

*Penilia avirostris* has a distinct seasonal cycle in the southern half of the US Northeast shelf ecosystem. It suddenly appears in July–August with the highest numbers found in coastal regions. It forms a dense population that slowly diminishes through the autumn months. The cladoceran then essentially disappears from the zooplankton community during winter and does not return until its abrupt appearance in summer. This seasonal unimodal pattern is the typical annual cycle observed for *P. avirostris* in temperate waters (Lochhead, 1954; Lipej *et al.*, 1997; Atienza *et al.*, 2008).

Temperature probably is the major factor that controls *Penilia avirostris* distribution because its populations are restricted to the warmer waters of its northern and southern ranges (Atienza *et al.*, 2008). This is true in the US northeast ecosystem, where numbers are highest in the warmer, southernmost waters of the region; minimal in the cooler waters of the more northern GBK and GOM regions. This study also found significant correlations between abundance and temperature during its summer pulse, though coefficients were only moderately high. Coefficient values were likely depressed by the cladocerans sometimes, highly irregular or patchy distribution. During the summer months, *P. avirostris* occasionally will be absent at stations adjacent to ones where concentrations of over one million individuals per 100 m<sup>3</sup> have been measured.

Table 1. Spearman partial (bottom depth) correlation coefficients between *Penilia avirostris* Log<sub>10</sub> abundance and environmental variables measured on broad scale surveys during July–August. An asterisk indicates the correlations were significant ( $p < 0.01$ ). (Abbreviation key: temp.= temperature, strat.= stratification)

Region	Surface temp.	Bottom temp.	Surface salinity	Bottom salinity	Strat
MAB	0.16*	-0.01	-0.08	-0.01	0.22*
SNE	0.35*	-0.01	-0.25*	0.03	0.34*

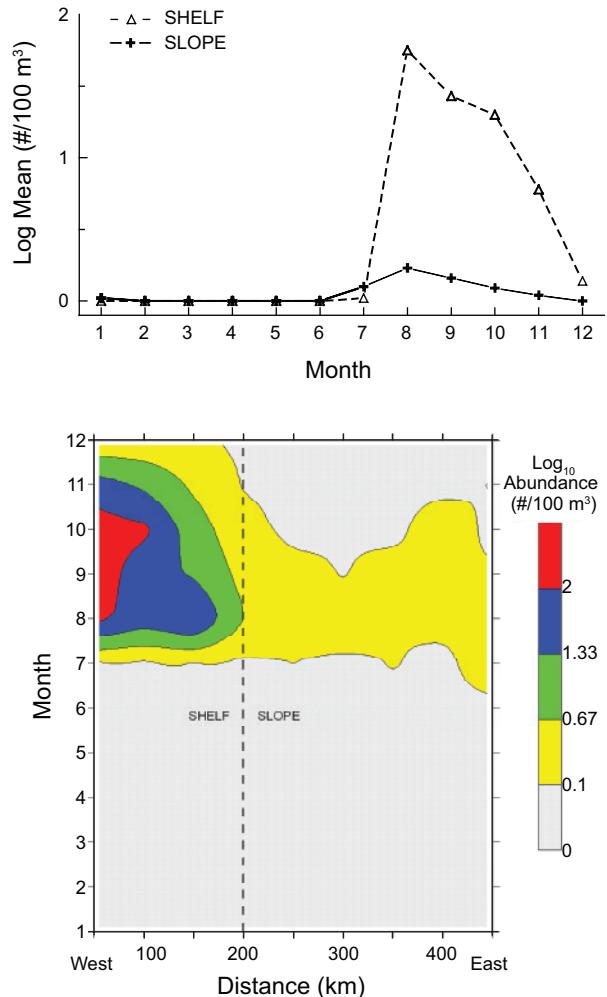


Fig. 6. Time series shelf and slope water monthly mean abundance (upper panel) and seasonal distribution (lower panel) of *Penilia avirostris* along the Mid-Atlantic CPR transect.

The population of *Penilia avirostris* must be renewed each year by the successful production and hatching of its resting eggs. The cladocerans' strong seasonal cycle suggests that temperature is the key factor initiating egg hatching. After finding no *P. avirostris* in the GOM and seaward of the shelf break during 1980 and 1981, Colton

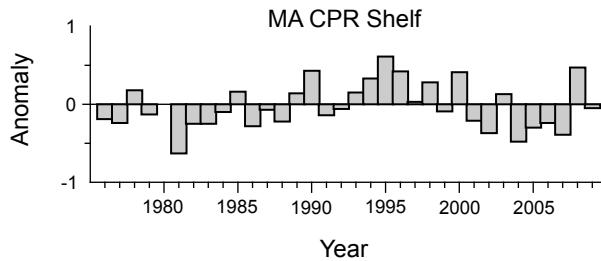


Fig. 7. Annual anomalies of *Penilia avirostris* shelf water abundance along the Mid-Atlantic CPR transect. Each bar represents the annual mean of survey log abundance anomalies.

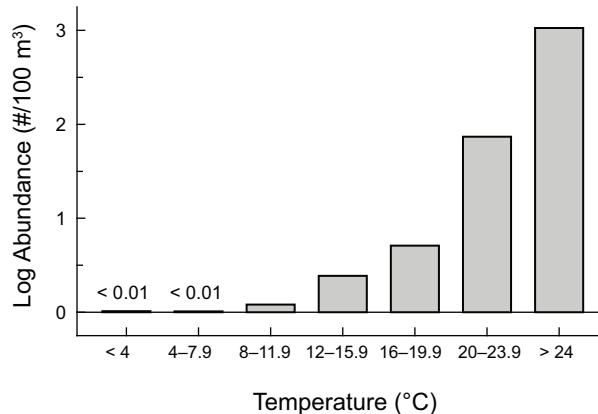


Fig. 8. Broad scale survey mean abundance of *Penilia avirostris* by surface temperature interval.

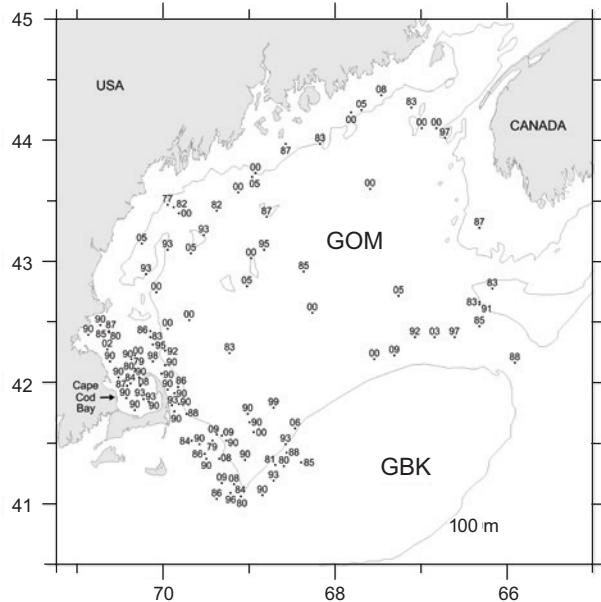


Fig. 9. Locations of Gulf of Maine stations where *Penilia avirostris* was identified in samples collected on broad scale surveys of the region from 1977–2009. Points are labeled with year of capture.

(1985) suggested that bottom temperatures must be at least 10°C before development of resting eggs begins. However, this study found no correlation between *P. avirostris* abundance and bottom temperatures during the summer awakening period. High numbers of the cladoceran were often found in offshore waters where the bottom temperatures were below 10°C. However, maybe these specimens were advected offshore from warmer inshore areas by prevailing westerly winds. Furthermore, as noted earlier, the cladocerans' patchy distribution could mask significant correlations between variables. Laboratory studies are needed to verify that the hatching success of *P. avirostris* resting eggs is independent from bottom temperature values.

Decades ago Lochhead (1954) reviewed the literature and observed that *Penilia avirostris* becomes permanently established only where the mean surface temperature reaches at least 21°C. He hypothesized that this is the minimal temperature necessary to build up a minimum population density sufficiently high to assure the survival of at least a few individuals, or resting eggs, through winter. This hypothesis is applicable today in the Northeast Atlantic shelf ecosystem. Persistent breeding populations have yet to be established in the GOM and GBK regions where mean surface temperature peaks at 16.8°C and 17.4°C respectively, while further south where *P. avirostris* thrives, it rises above the 21°C threshold during summer. Further evidence for this temperature minimum can be found further north in the Gulf of St Lawrence off Prince Edward Island. *P. avirostris* transported there by ballast waters has been able to establish a permanent breeding community because a warm microclimate elevates temperatures there to 21°C (Bernier and Locke, 2006). However, this does not explain why *P. avirostris* abundance was low and sparsely distributed in slope waters where surface temperatures exceed 21°C for several months of the year (Jossi and Benway, 2003). Another factor other than water temperature probably limits its distribution and abundance in offshore waters. Since there usually is an eight-fold decrease in phytoplankton biomass across the shelf-slope front in ecosystem waters (O'Reilly and Zetlin, 1998), food limitation may restrict its offshore abundance.

Other studies have also proposed that food availability is an important factor affecting the spatial distribution and seasonal cycle of *Penilia avirostris* (Lipej *et al.*, 1997; Calbert *et al.*, 2001). Further support for this hypothesis can be inferred from the strong decreasing inshore-offshore abundance gradients observed in this study, echoing the phytoplankton gradients that characterize the region (O'Reilly and Zetlin, 1998). This study also found

that *P. avirostris* abundance was closely aligned with the seasonal cycle of water column stratification. In the highly stratified waters of summer, thermocline concentrations of chlorophyll *a* are often several times higher in the waters above and below it (O'Reilly and Zetlin, 1998). This subsurface maximum is fueled by adequate light and food supplied through diffusion from nutrient rich waters below or from nearshore mixing events. This productive layer is ubiquitous and represents a concentrated source of nutrition for all herbivores (O'Reilly and Zetlin, 1998). It is especially rich in nanoplanktonic autotrophs, the preferred prey of *P. avirostris* (Atienza *et al.*, 2006). The high temperatures and phytoplankton biomass found in stratified waters likely combine to fuel the explosive growth of *P. avirostris* during summer.

Analysis of data collected on broad scale surveys in 1980–1981 found isolated patches of *Penilia avirostris* on GBK, establishing its first recorded occurrence in the region and an eastward extension of its previous-reported distribution (Colton, 1985). It was absent in the GOM and, since earlier plankton surveys of the region also did not report its presence (Bigelow, 1926; Fish and Johnson, 1937; Sherman, 1980), Colton (1985) was able to 'state unequivocally that *Penilia* does not occur in the Gulf of Maine'. However, the present study identified *P. avirostris* in 112 GOM samples (occurrence = 1.8%). It was first recorded in 1977 and has been found present in all but five years of the time series. These were usually light catches (<1000/100 m<sup>3</sup>) at isolated stations, predominately found in the southeastern waters of the region during autumn months (Fig. 9). It was most abundant in 1990 when dense concentrations were recorded in Cape Cod Bay on Oct. 24 (55 196/100 m<sup>3</sup>) and again on Nov. 2 (118 434/100 m<sup>3</sup>). In all, *P. avirostris* was identified at 23 stations along the Massachusetts coast during October–November of 1990 (Fig. 9).

*Penilia avirostris* now ranges northward into the GOM, though it does not appear to have established a persistent, breeding population in the region. *P. avirostris* has also not become strongly established on GBK, where it is found in only low numbers at scattered locations (occurrence = 1.6%). However, if the current warming trend in the region continues (Friedland and Hare, 2007), it may become a permanent resident and be more abundant. Already, the high summer concentrations in southern waters have begun to expand northward in the 2000s. Since certain aspects of its life history enable it to quickly become established in regions that are warming, *P. avirostris* may be a sentinel species for climate change in the North Atlantic. Future monitoring efforts will need to focus on the spread and influence of this prolific cladoceran within ecosystem waters.

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## References

- ATIENZA, D., E. SAIZ, A. SKOVGAARD, I. TREPATI and A. CALBET. 2008. Life history and population dynamics of the marine cladoceran *Penilia avirostris* (Branchiopoda: Cladocera) in the Catalan Sea (NW Mediterranean). *J. Plankton Res.*, **30**: 345–357. <http://dx.doi.org/10.1093/plankt/fbm109>
- ATIENZA, D., E. SAIZ and A. CALBET. 2006. Feeding ecology of the marine cladoceran *Penilia avirostris*. Natural diets, daily ration and prey selectivity. *Mar. Ecol. Prog. Ser.*, **315**: 211–220. <http://dx.doi.org/10.3354/meps315211>
- BIGELOW, H. B. 1926. Plankton of the offshore waters of the Gulf of Maine. *Bull. Bur. Comm. Fish.* **XL** Part 2. Gov't Printing Office, Washington, D. C., 509 p. <http://dx.doi.org/10.5962/bhl.title.4192> PMid:17773664
- BERNIER, R. and A. LOCKE. 2006. New record of distribution of *Penilia avirostris* Dana 1849, in the Northwest Atlantic. *Crustaceana*, **79**: 949–959. <http://dx.doi.org/10.1163/156854006778815928>
- CALBERT, A., E. GARRIDO, M. SAIZ, M. ALCARAZ and C. M. DUARTE. 2001. Annual zooplankton succession in coastal NW Mediterranean waters: the importance of the smaller size fractions. *J. Plankton Res.*, **23**: 319–331. <http://dx.doi.org/10.1093/plankt/23.3.319>
- COLEBROOK, J. M. 1975. Continuous plankton recorder survey: Automatic data processing methods. *Bull. Mar. Ecol.*, **8**: 123–142.
- COLTON, J. B., JR. 1985. Eastward extension of the distribution of the marine cladoceran (*Penilia avirostris*) in the Northwest Atlantic: a case of ecesis? *J. Northw. Atl. Fish. Sci.*, **6**: 141–148. <http://dx.doi.org/10.2960/J.v6.a14>
- FISH, C. J. and M. W. JOHNSON. 1937. The biology of the plankton populations in the Bay of Fundy and Gulf of Maine with special reference to production and distribution. *J. Biol. Board Can.*, **3**: 189–322. <http://dx.doi.org/10.1139/f37-015>
- FRIEDLAND, K. D. and J. A. HARE. 2007. Long-term trends and regime shifts in sea surface temperature on the continental shelf of the northeast United States. *Cont. Shelf Res.*, **27**: 2313–2328. [http://dx.doi.org/10.1016/j csr.2007.06.001](http://dx.doi.org/10.1016/jcsr.2007.06.001)
- HARDY, A. C. 1939. Ecological investigations with the continuous plankton recorder. Object, plan, and methods. *Hull. Bull. Mar. Ecol.*, **1**: 1–57
- HURRELL, J. W. 1995. Decadal trends in the North Atlantic Oscillation: Regional temperatures and precipitation. *Science*, **269**: 676–679. <http://dx.doi.org/10.1126/science.269.5224.676> PMid:17758812
- INGHAM, M. C., R. S. ARMSTRONG, J. L. CHAMBERLIN, *et al.* 1982. Summary of the Physical Oceanographic Processes and Features pertinent to Pollution Distribution in

- the Coastal and Offshore Waters of the Northeastern United States, Virginia to Maine. *NOAA Tech. Mem.*, NMFS-F/NEC-17 322 p.
- JOHNS, D. G., M. EDWARDS, W. GREVE and A.W. G. SJOHN. 2005. Increasing prevalence of the marine cladoceran *Penilia avirostris* (Dana, 1852) in the North Sea. *Helgoland Mar. Res.*, **59**: 214–218. <http://dx.doi.org/10.1007/s10152-005-0221-y>
- JOSSI, J. W. and R. L. BENWAY. 2003. Variability of Temperature and Salinity in the Middle Atlantic Bight and Gulf of Maine based on data collected as part of the MARMAP ships of Opportunity program, 1978–2001. *NOAA Tech. Mem.*, NMFS-NE-172, 92 p.
- KANE, J. 2003. Spatial and temporal abundance patterns for late-stage copepodites of *Metridia lucens* (Copepoda: Calanoida). *J. Plankton Res.*, **25**: 151–167. <http://dx.doi.org/10.1093/plankt/25.2.151>  
2011. Inter-decadal variability of zooplankton abundance in the Middle Atlantic Bight. *J. Northw. Atl. Fish. Sci.*, **43**: 81–92. <http://dx.doi.org/10.2960/J.v43.m674>
- KATECHAKIS, A., H. STIBOR, U. SOMMER and T. HANSEN. 2004. Feeding selectivities and food niche separation of *Acartia clausi*, *Penilia avirostris* (Crustacea) and *Doliolum denticulatum* (Thaliacea) in Blanes Bay (Catalan Sea, NW Mediterranean). *J. Plankton Res.*, **26**: 589–603. <http://dx.doi.org/10.1093/plankt/fbh062>
- KERR, R. A. 2000. A North Atlantic climate pacemaker for the centuries. *Science*, **288**: 1984–1985. <http://dx.doi.org/10.1126/science.288.5473.1984>. PMid:17835110
- LIPEJ, L., P. MOZETIC, V. TURK and A. MALEJ. 1997. The trophic role of the marine cladoceran *Penilia avirostris* in the Gulf of Trieste. *Hydrobiol.*, **360**: 197–203. <http://dx.doi.org/10.1023/A:1003180030116>
- LOCHHEAD, J. H. 1954. On the distribution of a marine cladoceran, *Penilia avirostris* Dana (Crustacea, Branchiopoda), with a note on its reported bioluminescence. *Biol. Bull.*, **107**: 92–105. <http://dx.doi.org/10.2307/1538633>
- O'REILLY, J. E. and C. ZETLIN. 1998. Seasonal, horizontal, and vertical distribution of phytoplankton chlorophyll *a* in the Northeast U.S. Continental Shelf Ecosystem. *NOAA Tech. Rep. NMFS* 139, 128p.
- ROSE, K., J. C. ROFF and R. R. HOPCROFT. 2004. Production of *Penilia avirostris* in Kingston Harbour, Jamaica. *J. Plankton Res.*, **26**: 605–615. <http://dx.doi.org/10.1093/plankt/fbh059>
- SHERMAN, K. 1980. MARMAP, a fisheries ecosystem study in the NW Atlantic: fluctuations in the ichthyoplankton-zooplankton components and their potential for impact on the system. In: Advanced Concepts on Ocean Measurements for Marine Biology, F. P. Diemer, F. J. Vernberg and D. Z. Mirkes (eds.), Belle W. Baruch Institute for Marine Biology and Coastal Research, University of South Carolina Press, Columbia, S.C., p. 9–37.
- SIBUNKA, J. D. and M. J. SILVERMAN. 1984. MARMAP surveys of the continental shelf from Cape Hatteras, North Carolina, to Cape Sable, Nova Scotia (1977–1983). Atlas No. 1. Summary of operations. *NOAA Tech. Mem.*, NMFS-F/NEC-33.  
1989. MARMAP surveys of the continental shelf from Cape Hatteras, North Carolina, to Cape Sable, Nova Scotia (1984–1987). Atlas No. 3. Summary of operations. *NOAA Tech. Mem.*, NMFS-F/NEC-68.
- TANG, K. W., C. C. CHEN and C. K. WONG. 1995. Distribution and biology of marine cladocerans in the coastal waters of southern China. *Hydrobiol.*, **507**: 99–107. <http://dx.doi.org/10.1007/BF00032001>
- TAYLOR, A. H. 1995. North-south shifts of the Gulf Stream and their climate connection with the abundance of zooplankton in the UK and its surrounding seas. *ICES J. Mar. Sci.*, **52**: 711–721. [http://dx.doi.org/10.1016/1054-3139\(95\)80084-0](http://dx.doi.org/10.1016/1054-3139(95)80084-0)

# Efficacy of an egress window to reduce the capture of undersize waved whelk (*Buccinum undatum*) in conical traps: laboratory experiments on the effect of vertical surge and trap angle during haul back.

Scott M. Grant

Centre for Sustainable Aquatic Resources  
Marine Institute of Memorial University of Newfoundland  
PO Box 4920, St. John's, Newfoundland, Canada A1C 5R3  
Email: scott.grant@mi.mun.ca

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## Abstract

The objective of this study was to develop a means to reduce the capture of undersize waved whelk (*Buccinum undatum*) in small mesh (51–64 mm) conical traps. To achieve this, egress windows were incorporated above the bottom ring of a trap to produce openings of sufficient width to allow undersize whelk to be released as a string of traps is being hauled to the surface. Analysis of the passage of undersize whelk through three egress window sizes revealed that a 30 mm wide window was most suitable. Simulations of two vertical surge distances and two trap angles were carried out in a controlled environment to provide a better understanding of trap performance. Experiments revealed that when a trap is oriented at an angle of 40–45° a substantial percentage (29–36%) of undersize whelk can be removed at vertical surge distances of 0.3–1 m. Few (3–4%) legal size whelk were emitted at a trap angle of 40–45° and all whelk emitted from a trap were observed to pass through an egress window. Increasing the angle of the trap to 70–75° resulted in loss of legal size whelk through the entrance located on top of the trap. The results of these simple experiments are promising but require verification through fishery trials before they can serve management decisions. Trap modifications and a trap line configuration that will maximize the egress of undersize whelk during fishing trials are discussed.

*Keywords:* *Buccinum undatum*; conical trap; egress window; undersize whelk

## Introduction

The waved whelk (*Buccinum undatum*) is a small marine gastropod that occurs on both sides of the North Atlantic Ocean. Waved whelk represents a fairly large and recent fishery in the Newfoundland and Labrador region. In 2008, a competitive quota of 5 000 t was established in offshore waters of St. Pierre Bank (NAFO Subdivision 3Ps) and this fishery has accounted for approximately 90% of the landings within the region in recent years (DFO, 2011). Currently, annual landings of waved whelk remain high, but there are indicators that the resource is declining; average catch rates have decreased, fishermen are expanding the geographic range of effort to new grounds, and there is an increasingly large amount of small whelk being landed annually. Further, life-history characteristics of waved whelk make them particularly susceptible to over exploitation. Fecundity is low, eggs

are laid on the ocean floor, and young hatch directly into a juvenile stage (Martel *et al.*, 1986; Himmelman and Hamel, 1993). Direct development and a benthic habit leads to a much more limited dispersal than species with young that are released as pelagic free-floating larvae. Limited dispersal may not only lead to overfishing over small geographic scales, but also limit the renewal process as only whelk within the immediate area can replenish localized populations. This can be further exacerbated by unaccounted fishing mortality of large numbers of undersize juveniles.

The minimum legal size for waved whelk captured on the St. Pierre Bank is a shell length of 63 mm (DFO, 2011). The St. Pierre Bank trap line fishery uses conical traps with a bottom diameter of 95 cm and there are no regulations on minimum mesh size or the use of escape mechanisms. Traps are currently fitted with small mesh

(51–64 mm) which facilitates the movement of whelk up the side and into the entrance located on top of the trap (Ram *et al.* 1993). This mesh size allows only the smallest of whelk (<35 mm shell length) to pass through the mesh opening during escapement or as a trap is being hauled back through the water column. Further, the conical frame construction results in a progressive reduction in the size of the opening of the diamond mesh from the lower to upper region of a trap. This limits the egress of even the smallest undersize whelk as a trap fills. Ultimately, the use of small mesh traps leads to the capture of substantial numbers of undersize whelk which has led to research into the development of an on board whelk grader that mechanically separates smaller whelk from the catch. Unfortunately, the use of mechanical devices can damage the shell and operculum and severe damage can lead to mortality from predation and disease (Mensink *et al.*, 2000). Discarding of undersize individuals on unsuitable habitat may also negatively influence survival (Grati *et al.*, 2010).

The movement of waved whelk towards a baited trap (Himmelman, 1988) and the effective area fished by a trap (McQuinn *et al.*, 1988) have been investigated but selective properties of various mesh sizes or modifications to trap design to facilitate the egress of undersize waved whelk have not been studied. Lack of studies on the selective properties of waved whelk traps may in part be related to fishing practices in Atlantic Canada. Waved whelk traps are usually tended within 24–48 hours allowing little time for voluntary escapement of whelk. Further, in most instances there is still bait remaining in a trap when it is hauled, particularly where bait protection devices are used. Size selectivity experiments in gastropod trap fisheries with 24 hour soak times have demonstrated some success however it is not clear whether small individuals are able to escape voluntarily or if the main selection occurs during hauling procedures (Grati *et al.*, 2010). Even size selectivity studies in a gastropod trap fishery with soak time of about one week found the best results were obtained from a trap that provided the added benefit of the egress of small whelk as they tumbled out of the trap during haul back (Park *et al.*, 2007).

The current study used the same construction principal as the double hoop trap introduced by Park *et al.* (2007) to produce egress windows of uniform width around the bottom ring of a conical waved whelk trap. Experimental procedures combined studies to determine the egress window size and trap angle most suitable for the release of undersize whelk with minimal loss of legal size individuals. Experiments were carried-out in a controlled environment where the egress of whelk could be visually

monitored during simulations of the vertical surge which occurs during haul back of a string of whelk traps.

## Materials and methods

Fast frozen waved whelk captured on the St. Pierre Bank in autumn of 2009 were used in this study. The foot of frozen whelk was observed to be retracted in a manner commonly observed for live whelk when they are captured in trap fisheries. Once the foot is retracted shell-size dictates the optimal dimension of an egress window. Thus, egress experiments conducted with frozen whelk were considered to be a suitable proxy for live whelk. Shell length and shell width measurements ( $\pm 1$  mm) were obtained by Vernier caliper for a total of 512 non-damaged waved whelk (Fig. 1). Least squares regression was used to examine the relationship between shell width and shell length.

Three egress window widths were studied based on regression analysis of the shell width ( $\pm 5$  mm) at the maximum shell length of undersize waved whelk (*i.e.* 62 mm). In an attempt to maximize the potential for release while still providing adequate area for whelk to crawl up the side of a trap a total of three egress windows of the same width were incorporated into a conical waved whelk trap by welding a steel bar between every second diagonal frame support (Fig. 2). The pots were fitted with 64 mm mesh netting which was extended around the bottom ring between each egress window to provide a means for whelk to crawl up on the trap (Fig. 2). Recapture

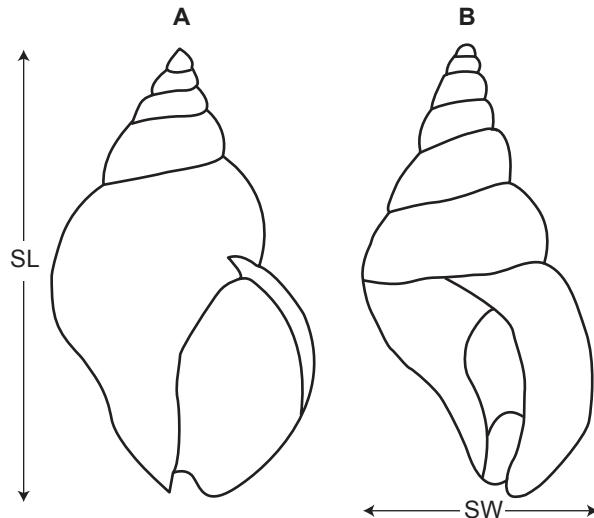


Fig. 1. Apertural view A) and lateral view B) of a waved whelk shell illustrating shell length (SL) and shell width (SW) measurements.



Fig. 2. Photographs of A) waved whelk trap frame showing egress windows at three locations above the bottom ring of a trap and B) netting extending around the bottom ring of the trap between egress windows.

rate isopleths, obtained as a function of distance waved whelk traveled to a baited trap (Himmelman, 1988; McQuinn *et al.*, 1988), demonstrate that a portion of the netting around the bottom ring of a modified trap will fall within the active space created by the bait plume.

Aerial dry-run tests of the performance of different size egress windows were conducted. This was accomplished by sorting frozen whelk into 10 mm shell length bins. The dry-run test procedure consisted of placing a sample of frozen whelk of known weight from each shell length bin into a modified trap. The trap was raised to a 70–75° angle from horizontal and gently moved up and down until no whelk passed through an egress window. Whelk that passed through a window were weighed to obtain the percent removed. This procedure was repeated for each 10 mm shell length bin and egress window size.

Table 1. Contribution of each 10 mm shell length bin to the undersize waved whelk category.

Shell length bin (mm)	Weight (kg)	Percent of sub-legal size category
31–40	2.5	32.5
41–50	2.3	29.9
51–60	2.4	31.2
61–62	0.5	6.5
Totals	7.7	

Vertical surge simulation experiments utilized a 23.7 kg sample of previously frozen whelk. The sample consisted of 7.7 kg of undersize (<63 mm) and 16 kg of legal size ( $\geq 63$  mm) whelk. Thus, undersize whelk accounted for 32.5% of the sample. The contribution of each 10 mm length bin to the undersize category is summarized in Table 1. The 23.7 kg sample was placed in a modified trap and lowered into a tank (5.5 m  $\times$  4.0 m  $\times$  4.0 m; L  $\times$  W  $\times$  D) filled with freshwater. The tank possessed a large viewing window. A net bag was suspended under the trap to collect whelk that were emitted from the trap.

The vertical surge experiments tested the effect of the angle of the trap in the water column and the vertical distance a trap was raised and lowered in the water column (*i.e.*, vertical surge distance). Two trap angle treatments (40–45° and 70–75° from horizontal) and two vertical surge distance treatments (0.3 m and 1 m) were tested. During each experimental trial a trap was gently raised and lowered the vertical surge distance for two minutes with each surge cycle lasting approximately 8–10 seconds. Once an experiment was complete the whelk in the net bag were retrieved and sorted into undersize and legal size categories and weighed. Three replicates were performed for each of the two trap angle and vertical surge distance treatments. Independent-samples *t*-tests were used to test for differences in the percentage of legal and undersize whelk removed from modified traps. An arcsine square-root transformation was performed upon the data.

## Results

Least squares regression analysis demonstrated a strong linear relationship between shell width and shell length of waved whelk (Fig. 3). The linear equation for the line of best fit (Fig. 3) indicates the maximum undersize shell length of 62 mm coincides with a shell width of 30.4 mm. Therefore, the three egress window widths used in the dry-run tests were 25 mm, 30 mm, and 35 mm.

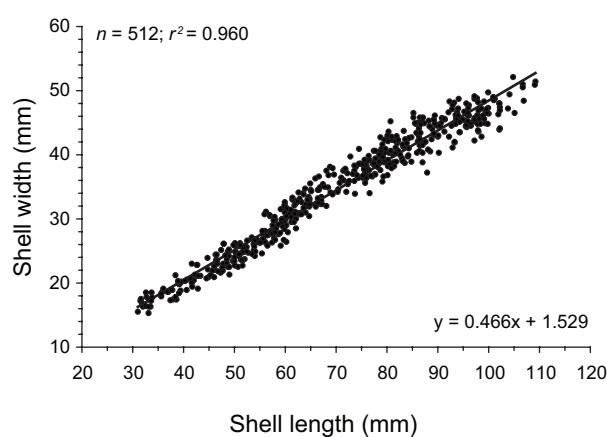


Fig. 3. Shell width to shell length relationship for St. Pierre Bank waved whelk. The total number of whelk examined ( $n$ ), correlation coefficient ( $r^2$ ), and equation for the line of best fit is also shown.

During the dry-run tests it quickly became apparent that traps with egress window widths of 25 mm and 35 mm

would not be suitable. The trap with a 25 mm egress window allowed individuals from only the smallest 10 mm shell length bins to be removed while 96–100% of the whelk from the 61–70, 71–80, and 81–90 mm length bins were removed from the trap with the 35 mm egress window (Table 2). The 30 mm wide egress window exhibited the best performance, excluding all whelk from the <60 mm bins, retained nearly 50% of the whelk from the 61–70 mm bin, and retained all whelk from the >80 mm bins (Table 2). It was therefore decided that the vertical surge experiments would continue with the trap that possessed the 30 mm wide egress window.

The vertical surge experiments demonstrate that when as little as 32.5% of the catch is comprised of undersize whelk an average of 24.7–40.2% of these whelk can be removed (Table 3). Observations from the viewing window revealed that at a trap angle of 40–45° whelk were emitted from the lower egress window only at both the 0.3 m or 1 m vertical surge distance. However, at a trap angle of 70–75° whelk were emitted through the lower egress window and the entrance located on top of

Table 2. Summary of dry-run experiments to determine the most suitable egress window width to use in the vertical surge experiments.

Width of egress window	Shell length bin (mm)	Weight retained (kg)	Weight retained (kg)	Weight retained (kg)	Percent emitted
25 mm	31–40	2.51	1.87	0.64	25.5
	41–50	2.62	2.33	0.29	11.1
	51–60	5.72	5.44	0.28	4.9
	61–70	2.49	2.49	0	0
	71–80	2.99	2.99	0	0
	81–90	3.46	3.46	0	0
	91–100	3.84	3.84	0	0
30 mm	31–40	2.51	0	2.51	100
	41–50	2.62	0	2.62	100
	51–60	5.72	0	5.72	100
	61–70	2.49	1.33	1.16	46.6
	71–80	2.99	2.63	0.36	12.0
	81–90	3.46	3.46	0	0
	91–100	3.84	3.84	0	0
35 mm	31–40	2.51	0	2.51	100
	41–50	2.62	0	2.62	100
	51–60	5.72	0	5.72	100
	61–70	2.49	0	2.49	100
	71–80	2.99	0.13	2.86	95.7
	81–90	3.46	0.13	3.33	96.2
	91–100	3.84	2.43	1.41	36.7

Table 3. Summary of vertical surge experiments carried-out on a conical waved whelk trap with a 30 mm wide egress window. Percent emitted is specific to each whelk size category.

Trap angle	Vertical surge distance	Whelk size category	Trial 1		Trial 2		Trial 3		Mean	
			Weight emitted (kg)	Percent emitted						
40–45°	0.3 m	<63 mm	2.6	33.7	3.3	42.9	2.5	32.5	2.8	36.4
		≥63 mm	0.5	3.1	0.4	2.5	0.5	3.1	0.5	3.1
	1.0 m	<63 mm	2.0	26.0	2.4	31.2	2.2	28.6	2.2	28.6
		≥63 mm	0.7	4.4	0.5	3.1	0.5	3.1	0.6	3.8
70–75°	0.3 m	<63 mm	1.6	20.8	2.1	27.3	1.9	24.7	1.9	24.7
		≥63 mm	0.8	5.0	1.1	6.9	0.7	4.4	0.9	5.6
	1.0 m	<63 mm	2.9	37.7	3.1	40.3	3.2	41.6	3.1	40.2
		≥63 mm	2.8	17.5	2.6	16.3	2.1	13.1	2.5	15.6

the trap at both the 0.3 m and 1 m vertical surge distance. Observations at a trap angle of 40–45° also revealed that most of the whelk were emitted from the lower egress window within the first minute of a trial.

At a trap angle of 40–45° there was a low percentage (3.1–3.8%) of legal size whelk emitted from the legal size component at both the 0.3 m and 1 m vertical surge distances (Table 3). Variability in shell width at length (Fig. 3) accounts for the passage of some of the smaller legal size whelk. There was also a low percentage (5.6%) of legal size whelk emitted when the trap was oriented at an angle of 70–75° and exposed to a vertical surge distance of 0.3 m. However, the percentage of legal size whelk emitted at a trap angle of 70–75° increased substantially to 15.6% when the vertical surge distance was increased to 1 m. This increase is attributed to loss of whelk through the entrance of the trap.

Analysis of the effect of vertical surge distance at a trap angle of 40–45° indicated there was no significant difference in the percentage of undersize ( $t_4 = 2.189$ ,  $p = 0.094$ ) or legal size ( $t_4 = 1.352$ ,  $p = 0.248$ ) whelk emitted from a modified trap. Analysis of the effect of vertical surge distance at an angle of 70–75° indicated a significantly higher percentage of both undersize ( $t_4 = 6.729$ ,  $p = 0.003$ ) and legal size ( $t_4 = 6.992$ ,  $p = 0.002$ ) whelk were emitted from the traps at the higher vertical surge distance of 1 m. Overall, these results indicate that increased vertical surge distances associated with inclement weather conditions will have a significant effect on the removal of both undersize and legal size whelk when a modified trap is oriented at an angle of 70–75°.

## Discussion

Undersized waved whelk are highly susceptible to capture in baited traps with reports of undersize individuals accounting for as much as 80% of the catch in conical traps. Onboard sorting of large quantities of undersize whelk is a challenge and can inadvertently result in variable quantities of undersize individuals being landed. The mesh size of conical traps used in the St. Pierre Bank fishery is not regulated and studies on mesh size selectivity have not been undertaken to reduce the retention of undersize individuals. In the current study, the egress windows incorporated into a conical waved whelk trap were successful at removing a substantial percentage of undersize whelk under controlled conditions where the mechanism by which the whelk were emitted could be visually observed. Observations under controlled conditions not only lower the cost of evaluating new gear designs at sea, but also provide the opportunity to investigate specific features and performance of modified gears (Winger *et al.*, 2006). The ability to make direct observations of the egress of whelk from a trap was important as modified traps will need to be affixed to the mainline so that a trap is oriented at an angle during haul back in order to expose whelk to the egress window. In the absence of direct observations, the loss of legal size whelk through the entrance would have gone undetected at a trap angle of 70–75° and there would have been uncertainty with regard to the loss of whelk at a trap angle of 40–45°. These findings indicate that while a substantial loss of legal size whelk can occur through the entrance at a trap angle of 70–75°, there was no loss of whelk through the entrance at a trap angle of 40–45°.

In the current study, a conical whelk trap was raised and lowered in the water column to simulate a vertical surge during haul back. Waved whelk fishermen indicate vertical surge distances of 0.3 m are common during haul back and vertical surges intermittently expose new whelk to the egress window increasing the probability of egress of undersize individuals. The experiments also simulated a vertical surge duration of two minutes. The period of time a trap will be exposed to vertical surges during haul back in a bottom trap line fishery will primarily depend upon the number of traps in the water column which is a function of bottom depth and distance between traps. However, bottom trap lines generally do not hang vertically during haul back so the number of traps in the water column tends to exceed the bottom depth to distance between traps ratio. Bottom depth ranges from about 60–80 m for most of the St. Pierre Bank (Dalrymple *et al.*, 1992) and whelk are captured to depths of up to 180 m in Atlantic Canada (Kenchington and Glass, 1998). A vertical surge in a trap line will occur as the pitch and roll of the vessel is transferred to the trap line when the power to the hauler is disengaged to allow the contents of a trap to be dumped and sorted. The greater the number of traps in the water column the greater will be the effect of vertical surges at exposing undersize whelk to an egress window.

Distance between whelk traps in the St. Pierre Bank trap line fishery is variable with industry typically using the same trap line attachment configuration utilized in the snow crab fishery where the attractive distance to a baited trap has been estimated at about 37 m (E. Dawe, pers. comm., Fisheries and Oceans Canada). Studies of the movements of waved whelk toward a baited trap indicate shorter attractive distances of 10–18 m over a 24–48 hour period, respectively (Himmelman, 1988). Effective area fished by a baited waved whelk trap over a 24 hour period was highly variable with estimates ranging between 18–278 m<sup>2</sup> and was found to depend on current speed and direction, depth, and seasonal variations in feeding rates and reproductive activity (Himmelman, 1988; McQuinn *et al.*, 1988). Overall, studies of the movements of waved whelk toward a baited trap suggest the distance between traps in the St. Pierre Bank trap line fishery could be reduced to 18 m without negatively influencing catch rates. This reduction would expose at least three to four traps to a vertical surge over most of the St. Pierre Bank waved whelk fishing grounds during haul back of a trap line.

Susceptibility of undersize gastropods to capture in small mesh baited traps (Ram *et al.* 1993; Park *et al.* 2007; Grati *et al.* 2010) makes them highly vulnerable to overfishing and the percent contribution of undersize individuals will increase as the biomass of legal size individuals decreases.

Results presented in the current study show that egress windows are unlikely to remove all undersize whelk from a conical trap. The proportion of undersize whelk emitted from an egress window will not only depend on total catch weight but also the contribution and size distribution of undersize whelk to the catch. In the current study, observations of the passage of waved whelk through the egress window showed that the effect of vertical surge duration was largely limited to the first minute which is also likely to be influenced by catch characteristics. Catch rates of 9–16 kg of legal size whelk per trap are considered to be satisfactory in the St. Pierre Bank fishery. The current study simulated the upper range of catch rates for legal size whelk however, the contribution of undersize whelk is considered to be at about the midpoint between the lower and upper range commonly reported in commercial catches.

This study has demonstrated that at sea experiments on the efficacy of egress windows to reduce the catch of undersize individuals are warranted. Indeed, the results require verification through fishery trials before they can serve management decisions. Although three egress windows were used in the current study whelk were only emitted from the lower egress window when a trap was oriented at an angle of 40–45°. Therefore it is advised that a single egress window be used in future studies. Use of a single window would also likely limit the entry of undersize whelk through the egress window. During fishery trials it is advisable to attach modified traps to the mainline at 18 m intervals and verify the method of attachment orients the traps at an angle of 40–45° during haul back. To achieve a 40–45° angle, traps will require a simple modification of the bridle attachment from the mainline. Use of three points of attachment from the bridle to the top of the trap and reducing the length of the attachment that is centered over the egress window will achieve the desired trap angle and expose whelk to the egress window during haul back. Members of the fishing industry should be an integral component of future fishery trials as they will be the best judge of the efficacy of the egress window and operational limitations of modifications to the trap line configuration.

Conical traps are ideal for commercial applications because they take up less space than square or rectangular traps when they are stacked allowing several traps to be carried during a fishing trip. This is an important consideration in extended trips associated with offshore fisheries. Construction of a conical trap with an egress window requires only a minor modification over the current trap design and addition of an egress window does not influence storage capacity.

Damage to the shell and operculum of whelk could occur during the capture and sorting process and the effects of coming in contact with and passing through an egress window are unknown. Anti-chaffing rope is used around the bottom ring of commercial traps to protect the netting. Extending the use of anti-chaffing rope around the egress window frame will reduce the potential for shell and operculum damage during a vertical surge. Nevertheless, studies of the unaccounted fishing mortality are recommended and should be comprehensive, identifying haul back and onboard sorting, grading, and discard processes that are most likely to result in shell and operculum damage that leads to mortality.

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### References

- DALRYMPLE, R. W., E. M. LCGRESLEY, G. B. J. FADER and B. D. PETRIE. 1992. The western Grand Banks of Newfoundland: Transgressive Holocene sedimentation under the combined influence of waves and currents. *Mar. Geol.*, **105**: 95–118. [http://dx.doi.org/10.1016/0025-3227\(92\)90184-J](http://dx.doi.org/10.1016/0025-3227(92)90184-J)
- DFO 2011. Subdivision 3Ps offshore whelk: a preliminary assessment of male size at maturity. *DFO Can. Sci. Advis. Sec. Sci. Advis. Rep.*, 2011/023, 8 p.
- GRATI, F., P. POLIDORI, G. SCARELLA and G. FABI. 2010. Estimation of basket trap selectivity for changeable nassa (*Nassarius mutabilis*) in the Adriatic Sea. *Fish. Res.*, **101**: 100–107. <http://dx.doi.org/10.1016/j.fishres.2009.09.012>
- HIMMELMAN, J. H. 1988. Movements of whelks (*Buccinum undatum*) towards a baited trap. *Mar. Biol.*, **97**: 521–531. <http://dx.doi.org/10.1007/BF00391048>
- HIMMELMAN, J. H. and J. R. HAMEL. 1993. Diet, behaviour and reproduction of the whelk *Buccinum undatum* in the northern Gulf of St. Lawrence, eastern Canada. *Mar. Biol.*, **116**: 423–430. <http://dx.doi.org/10.1007/BF00350059>
- KENCHINGTON, E. and A. GLASS. 1998. Local adaptation and sexual dimorphism in the waved whelk (*Buccinum undatum*) in Atlantic Nova Scotia with applications to fisheries management. *Can. Tech. Rep. Fish. Aquat. Sci.*, No. 2237. 43 p.
- MARTEL, A., D. H. LARRIVÉE and J. H. HIMMELMAN. 1986. Behaviour and timing of copulation and egg-laying in the neogastropod *Buccinum undatum*. *L. J. Exp. Mar. Biol. Ecol.*, **96**: 27–42.
- MCQUINN, I. H., L. GENDRON and J. H. HIMMELMAN. 1988. Area of attraction and effective area fished by a whelk (*Buccinum undatum*) trap under variable conditions. *Can. J. Fish. Aquat. Sci.*, **45**: 2054–2060. <http://dx.doi.org/10.1139/f88-239>
- MENSINK, B. P., C. V. FISHER, G. C. CADÉE, M. FONDS, C. C. TEN HALLER-TJABBES and J. P. BOON. 2000. Shell damage and mortality in the common whelk (*Buccinum undatum*) caused by beam trawl fishing. *Jour. of Sea Res.*, **43**: 53–64. [http://dx.doi.org/10.1016/S1385-1101\(00\)00003-4](http://dx.doi.org/10.1016/S1385-1101(00)00003-4)
- PARK, H., R. MILLAR, H. AN and H. KIM. 2007. Size selectivity of drum-net traps for whelk in the Korean coastal waters of the east sea. *Fish. Res.*, **86**: 113–119. <http://dx.doi.org/10.1016/j.fishres.2007.05.008>
- RAM, N., K. NASHIMOTO, K. YAMAMOTO, and T. HIRAIshi. 1993. Size selectivity and catching efficiency of three different traps for whelks *Neptunea arthritica* in Shiriuchi, Hokkaido. *Nippon Suisan Gakk.*, **59**: 1313–1318. <http://dx.doi.org/10.2331/suisan.59.1313>
- WINGER, P. D., H. DELOUCHE, and G. LEGGE. 2006. Designing and testing new fishing gears: the value of a flume tank. *Mar. Tech. Soc. Jour.*, **40**: 44–49. <http://dx.doi.org/10.4031/002533206787353240>



# Persistence and Variation on the Groundfish Assemblages on the Southern Grand Banks (NAFO Divisions 3NO): 2002–2011

<sup>1</sup>Adriana Nogueira, Xabier Paz<sup>2</sup> and Diana González-Troncoso<sup>2</sup>

<sup>1</sup>Campus do Mar. Universidad de Vigo. Lagoaz s/n, 36310 Vigo, Pontevedra  
Email: adriana.nogueira@uvigo.es

<sup>2</sup>Instituto Español de Oceanografía, P.O. Box 1552. Vigo, Spain

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## Abstract

Data from EU-Spain (Instituto Español de Oceanografía) bottom trawl surveys in the NAFO Regulatory Area (2002–2011) were analyzed to examine patterns on the South of Grand Banks (NAFO Div. 3NO) of groundfish assemblage structure and diversity in relation to depth. The 1160 hauls from the slope surveys spanned between 38 and 1460 m in depth. We focused on the 28 most abundant species, which made up 92.6% of the catch in terms of biomass.

Assemblage structure was strongly correlated with depth. For the most part, changes in assemblages seem to be fairly continuous, although there were more abrupt changes at 300 m. Five assemblages were identified. Two shallow assemblages were found in the shelf. Assemblage I (Shallow) comprises the strata with depths lesser than 150 and include yellowtail flounder (*Limanda ferruginea*), American plaice (*Hippoglossoides platessoides*), Northern sand lance (*Ammodytes dubius*), moustache sculpin (*Triglops murrayi*), capelin (*Mallotus villosus*) and web sculpin (*Hemitripterus americanus*). Assemblage II (Shallow) includes the strata with depths between 151 and 300 m and comprises Atlantic cod (*Gadus morhua*), American angler (*Lophius americanus*), wolffish (*Anarichas lupus*) and thorny skate (*Amblyraja radiata*). Assemblage III (Intermediate) contains the depth strata between 301 and 600 m. Redfish (*Sebastes* spp.), spotted wolffish (*Anarichas minor*), Arctic eelpout (*Lycodes reticulatus*), Northern wolffish (*Anarichas denticulatus*), white hake (*Urophycis tenuis*), witch flounder (*Glyptocephalus cynoglossus*) and longfin hake (*Phycis chesteri*) were included in the intermediate assemblage. Finally, we found two deep clusters: Assemblage IV (Deep) contains the depths between 601 and 1000 m, and Assemblage V (Deep) the depth strata greater than 1001 m. Greenland halibut (*Reinhardtius hippoglossoides*), marlin-spine (*Nezumia bairdii*), roughhead grenadier (*Macrourus berglax*) and spinytail skate (*Bathyraja spinicauda*) formed Assemblage IV. Snubnosed spiny eel (*Notacanthus chemnitzii*), blue antimora (*Antimora rostrata*), Northern cutthroat eel (*Syphanobranchus kaupii*), roundnose grenadier (*Coryphaenoides rupestris*), black dogfish (*Centroscyllium fabricii*), Arctic skate (*Amblyraja hyperborea*) and longnose chimera (*Harriotta raleighana*) made up the deepest assemblage. Despite dramatic changes in biomass and abundance of the species in the area, the boundaries and composition of the assemblages seem to be similar to the period before the collapse. Although some changes were evident, the main ones were replacements of the dominant species in several assemblages and bathymetric range extension of distribution of some species. Yellowtail flounder appears to be the dominant species in the shallowest assemblage instead of Atlantic cod and American plaice that were dominant in the period before the collapse in the area; redfish is the dominant species in the second shallow and intermediate assemblages.

Diversity appears inversely related to biomass in the different assemblages. Despite the fishing effort in the deep waters of the Grand Banks, the overall pattern of demersal fish assemblages remains similar over time. This pattern is similar in other Atlantic areas; it indicates that changes in the fish populations in Northwest Atlantic have been produced on a large scale and are not limited to specific areas.

**Keywords:** fish diversity, trawl survey, accumulation curve, depth zonation, size-depth relationship

## Introduction

Changes in ocean climate combined with direct and indirect effects of harvesting can dramatically and rapidly alter the composition of marine fish communities (Hutchings and Reynolds, 2004). The global crisis in overexploitation of fisheries has resulted in calls for multispecies or “ecosystem-based” assessment and management of fish stocks and assemblages (Jennings and Kaiser, 1998; Pauly *et al.*, 2002; Worm *et al.*, 2009). An ecosystem approach to fisheries management in marine waters has long been advocated to gain a better understanding of the structure and functioning of ecosystems and to eventually restore and sustain them (Tolimieri and Levin, 2006). A first step towards ecosystem management is to reduce the complexity of the ecosystem and search for patterns by describing species abundance and distribution to identify species assemblages and the biological and environmental conditions associated with these assemblages (Mahon and Smith, 1989; Gomes *et al.*, 1992; Tolimieri and Levin, 2006). Implementation of multispecies approaches requires improved understanding of the community ecology of fish assemblages, but this information has rarely been explicitly incorporated into management practices. Although single-species management is still commonly practiced, in recent decades, numerous papers have described demersal fish assemblages: in tropical areas (Bianchi, 1991); in the Scotian Shelf and the Gulf of St Lawrence (Bundy, 2005); Norwegian Sea (Lekve *et al.*, 1999); in the Mediterranean Sea (Moranta *et al.*, 1998); in the NW Iberian Peninsula (Fariña *et al.*, 1997); off the East coast of North America (Mahon *et al.*, 1998; Tolimieri and Levin, 2006); off the West coast of North America (Cope and Haltuch, 2012); in the mid-Atlantic (Azores Archipelago-Menezes *et al.*, 2006). Mahon and Smith (1989) identified ten offshore assemblages of relatively similar species composition on the Scotian Shelf and Bay of Fundy, from 1970 to 1981; in the Flemish Cap (NAFO Div. 3M) three main assemblages were identified (Paz and Casas, 1996; González-Troncoso *et al.*, 2006); Villagarcía (1995) studied the structure and distribution of demersal fish assemblages on the Northeast Newfoundland and Labrador Shelf; Gomes *et al.* (1992) found six assemblages over 16 years (1971–1982, 1984–1987) on the Grand Banks of Newfoundland.

Rose (2003) provides an overview of the fisheries resources and science in Newfoundland and Labrador. The Southern Grand Banks (NAFO Div. 3NO), part of the Labrador Newfoundland Large Marine Ecosystem (Fig.1), is an internationally known fishing ground most noted for cod, but haddock, redfish, flatfish (including halibut), mackerel and herring are also caught. There was a rapid expansion of distant water fleets during the late 1950s, as

well as an intensification of fishing effort. This has affected the major fish stocks of the shelf. Overfishing of Atlantic cod, haddock, redfish and major flatfish in the 1960s and 1970s led to fisheries collapses. In 1977, fishing by foreign fleets was reduced with the establishment of Canada's 200 nautical mile exclusive economic zone (Pinhorn and Halliday, 1990). The fishing effort of Canadian fishing fleets increased in the 1980s. A general stock decline led to a second phase collapse, 1985–1993 (Kennet *et al.*, 2004). In 1992, the collapse of cod stocks led to the imposition of a moratorium on fishing cod over most of the Newfoundland and Labrador banks, including the Grand Banks. Some limited fishing was resumed in 1998, but almost all cod stocks are still at very low levels and have not yet recovered. The collapse of Newfoundland's Northern cod fishery in 1991–1992 coincided with unusual ice conditions and a broadening of the cold intermediate layer of the Labrador Current. This coincidence fueled speculation that cold water had killed or driven out the cod (Young and Rose, 1993). In some quarters, the speculation was hopeful: perhaps nature, and not overfishing, was to blame for this ecological disaster. But on finer scales, the cold water distribution appeared patchy, and even at its greatest extent, there remained vast areas still suitable for cod (Haedrich and Barnes, 1997). Careful analysis reached the conclusion that overfishing alone best explains the Northern cod collapse (Hutchings and Myers 1994, 1995; Sinclair and Murawski, 1997). Cold water could have facilitated overfishing, however, by concentrating the cod and making them easier to catch (Martin, 1995). After the collapse of traditional demersal fisheries, fishermen adapted by pursuing alternative species, often invertebrates such as lobster, crab and shrimp (some of which had once been the prey of groundfish). In the 1970s, shellfish comprised less than 5% of Newfoundland's landings by weight, and just over 10% by value. After the 1992 codfish collapse, shellfish landings climbed steeply. By 1995 shellfish accounted for 64% of Newfoundland's landings by weight and 89% by value (Hamilton and Haedrich, 1999).

A Spanish bottom-trawl fishery has been developed along the continental slope to the East of the Grand Banks of Newfoundland. This area fits within the one that has normally been used by the Greenland halibut fishery (González-Costas and González-Troncoso, 2009). Since 2001, the distribution of the Greenland halibut fishery has been quite consistent (for further details on the evolution of the fishing effort distribution, see González-Troncoso *et al.*, 2007). Different fisheries were conducted in the period 2005–2011 in NAFO Div. 3NO depending on the target species, area, depth and gear (mesh size). One is a mixed fishery with demersal 130 mm mesh size at depths less than 200 m with different catch composition in

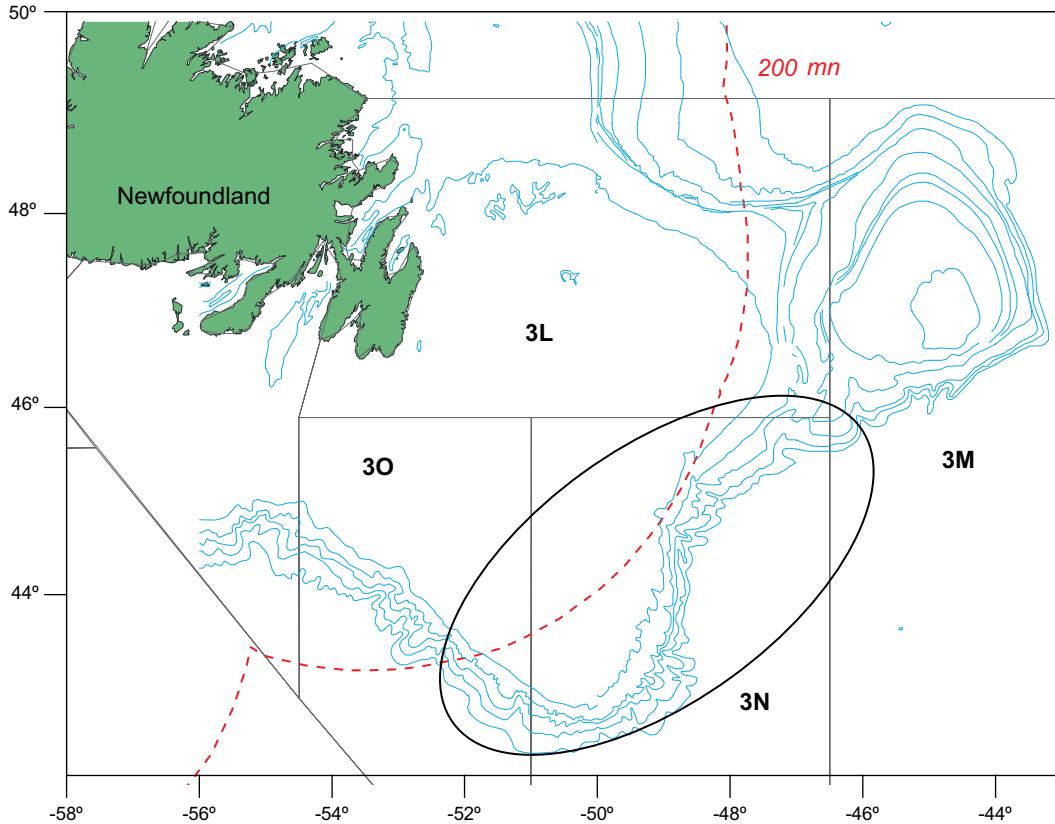


Fig. 1. Chart of the Grand Banks NAFO Div. 3LNO. Spanish bottom trawl area in NAFO Regulatory Area, Div. 3NO, is marked by the ellipse.

Div. 3N (56% American plaice, 26% yellowtail flounder, 10% cod and 6% skates) than in Div. 3O (57% redfish, 14% American plaice, 12% skates and 7% witch flounder). In Div. 3NO, with 280 mm mesh size at less than 200 meters depth, the target species was skate (63%), with American plaice (19%), yellowtail flounder (10%) and cod (6%) as main bycatch species (González-Costas, 2012).

With the extension of deep-sea fisheries, there has been increased interest in the ecology of deep-sea species (Priede *et al.*, 2010). Previous studies have examined the fish assemblages on the Grand Banks. These studies, however, covered limited depths (Gomes *et al.*, 1992), were spatially limited (Snelgrove and Haedrich, 1985), or used sampling techniques that limit the biodiversity of the catch (*e.g.*, long-lining (Murua and Cárdenas, 2005)). Moreover, they are not current (Gomes *et al.*, 1992) and, therefore, unable to detect potential temporal changes in assemblage structure in recent years.

The Spanish Administration has performed a bottom trawl survey on the Southern Grand Banks since 1995<sup>1</sup> (NAFO Regulatory Area Div. 3NO) (Fig. 2) (Paz *et al.*, 2002). Here, we use data from this survey to examine biomass distribution, to describe the assemblage structure of the dominant fish fauna in the Southern Grand Banks during the period 2002–2011, and to explore the possible changes that have taken place in the communities over this period, including species composition and interaction as well as depth distribution and diversity. This study was intended to identify, describe and map broad groundfish assemblage areas over a wide depth range (38–1460 m), further expanding on previous works in the area. Specifically, we (i) extend the bathymetric range for the identification and description of fish assemblages; (ii) determine whether the species assemblages of demersal fish follow similar depth patterns in temporal scale in the area; and (iii) ask whether there were any changes in the dominant species in each assemblage.

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## Material and Methods

### Material

We used data from the Spanish Survey conducted by the Instituto Español de Oceanografía (IEO) to estimate abundance and biomass of demersal resources in the Div. 3NO of the NAFO Regulatory Area. This survey has been carried out every year since 1995 in late spring (May–June). From 1995 to 2001, it was conducted on board the CV *Playa de Menduiña* using the *Pedreira-type* net, and, since 2002, the RV *Vizconde de Eza* has replaced the former vessel in conducting surveys using a *Campelen* bottom trawl. In 2001, a comparative survey between the two vessels was made in order to transform the historic time series into the new vessel index, making 92 paired hauls. The survey indices of the most important species were transformed to use the whole time series in the assessments of these species. For details of the indices transformation, see Paz *et al.* (2002). In this study species that are not usually assessed have been used, although the transformation of their indices is not available. For this reason we used data from 2002 to 2011 (Table 1). Hauls were made following the stratification charts described in Bishop (MS 1994). Sets were allocated in accordance with the area of the strata, with a minimum of two planned hauls per stratum. Trawl positions were chosen randomly. Abundance and biomass for all species were estimated by the swept area method (Cochram, 1997). The sampling unit consisted in 30-minute hauls at a speed of 3.0 knots

using a *Campelen* 1800 otter trawl gear. The mesh size was 44 mm for the net and 12 mm for the cod end. The mean horizontal opening was 26 m and the vertical opening was 4.1 m. The otter trawl was monitored using a Scanmar net control system. For temporal series details see Paz *et al.* (2002). Around 120 valid hauls are made each year. In each haul all the individuals caught are systematically sorted by species and the length distribution is obtained (González-Troncoso *et al.*, 2004). The mean of the initial and final depth has been used to define the bottom depth of each haul. The mean depth varies from 38 to 1460 m. A total of 1160 hauls were made in the survey between 2002 and 2011 (Table 1 and Fig. 2).

We included the 28 most abundant species in the survey in our analyses: 26 demersal species, one pelagic species (capelin, *Mallotus villosus*) and one mesopelagic genus (redfish, *Sebastes* spp.)<sup>2</sup> were included (Table 2). They consisted of commercial and non-commercial species, but they were potentially dominant species in a given region or potential forage for other species. These 28 species amounted to 92.64% of the total catch of the survey. All species were present at least in 6.29% of the total observed tows. A complete list of species considered in this study is given in table 2.

### Methods

Before determining groundfish assemblages, some exploratory analysis were conducted to examine if

Table 1. Number of hauls, depth covered, dates and number of species by year. RV *Vizconde de Eza* has been used in all years.

Year	Valid hauls	Depth range (m)	Dates
2002	125	39–1460	April 29–May 19
2003	118	38–1460	May 11–June 02
2004	120	43–1449	June 06–June 24
2005	119	49–1402	June 10–June 29
2006	120	45–1457	June 7–June 27
2007	110	46–1373	May 29–June 19
2008	122	40–1435	May 27–June 16
2009	109	44–1386	May 31–June 18
2010	95	40–1390	May 30–June 18
2011	122	44–130	June 5–June 24
<b>2002–2011</b>	<b>1160</b>	<b>38–1460</b>	

<sup>2</sup>There are three redfish species in the study area, *S. fasciatus* (Acadian redfish), *S. mentella* (deepwater redfish), and *S. marinus* (golden redfish). Due to the difficulty of visual identification of different species, the catches are usually reported by genus as *Sebastes* spp. In NAFO, the *S. fasciatus* and *S. mentella* are managed as an only species and *S. marinus* is not yet regulated.

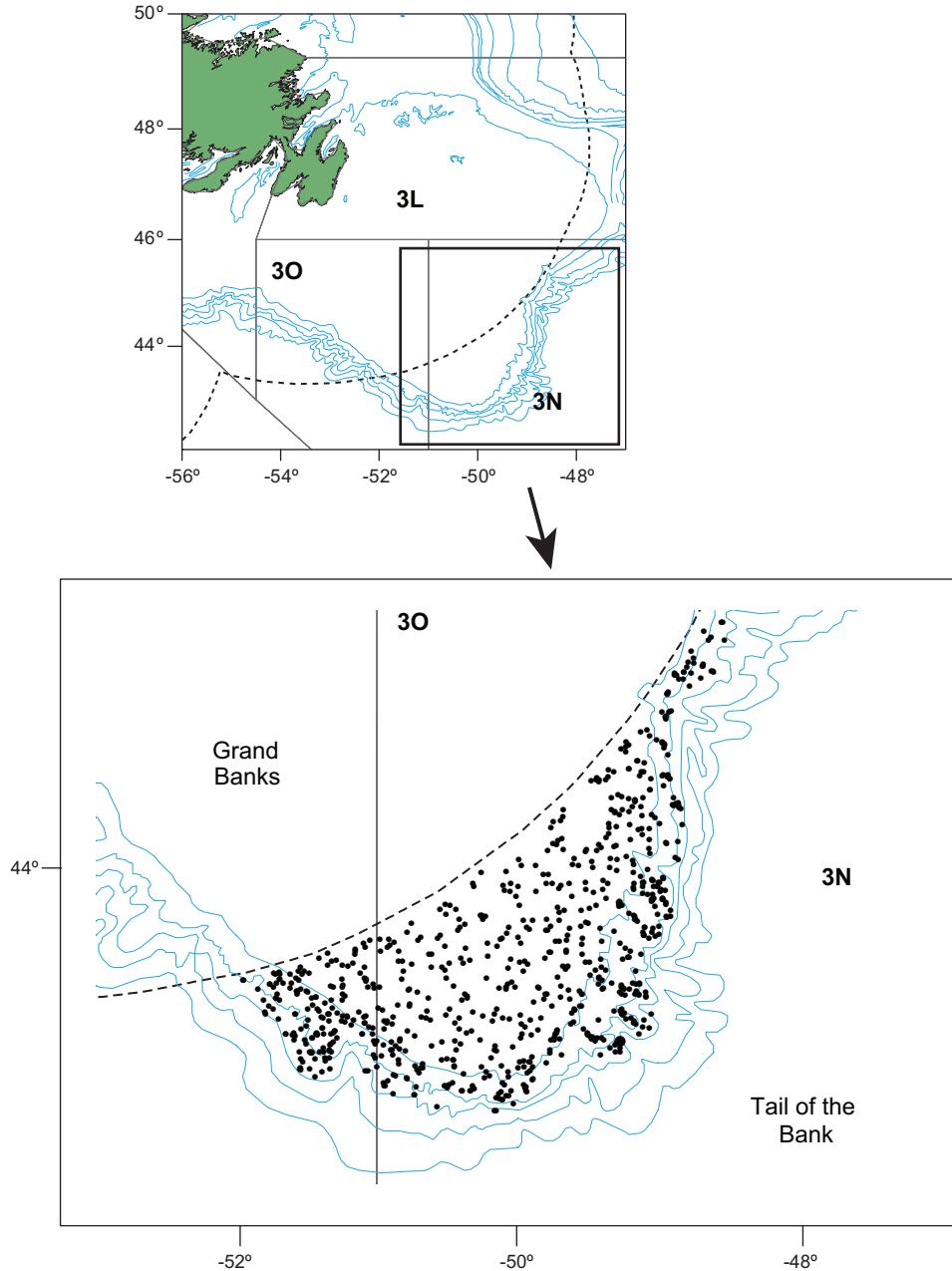


Fig. 2. Hauls position in the Spanish Spring Survey in Div. 3NO in the whole period (2002–2011).

zonation existed, how species were distributed by depth and where depth boundaries existed. The chi-square test, as described by Gardiner and Haedrich (1978), was used for a preliminary investigation of zonation. An analysis of box-plots was performed in order to have an initial descriptive statistical analysis of catches by depth. To describe semi-quantitative trends in biomass with depth, we constructed graphs of the cumulative distribution of the catches and compared with the empirical cumulative distribution of the depths of the hauls. Finally, in order

to quantify zonation, the potential boundaries of depth were examined by calculating the percentage similarity (PS) between the regions involved. Then multivariate analyses were conducted to identify species assemblages. We used cluster analysis to confirm the boundaries found in the PS analysis. Two other multivariate analyses were used in order to confirm the cluster analysis results and to determine which species make up each assemblage: Correspondence Analysis (CA) and Principal Component Analysis (PCA). To investigate the structure within each

Table 2. Vertical ranges and catch data for fish species taken by bottom trawls in the Spanish 3NO surveys 2002–2011 including all valid hauls.

Main Fish Species	Common name	FAO Code	Depth range	Weight (kg)	No. Of Stations	Occurrence (%)
<i>Sebastes</i> sp.	Redfish	RED	46–1460	378 039	489	42
<i>Limanda ferruginea</i>	Yellowtail flounder	YEL	38–190	149 196	435	37
<i>Hippoglossoides platessoides</i>	American plaice	PLA	38–1460	132 409	771	66
<i>Gadus morhua</i>	Atlantic cod	COD	40–1355	51 787	549	47
<i>Mallotus villosus</i>	Capelin	CAP	38–454	33 938	487	44
<i>Amblyraja radiata</i>	Thorny skate	RJR	38–1449	31 892	753	65
<i>Ammodytes dubius</i>	Northern sand lance	SAN	38–229	25 143	404	35
<i>Macrourus berglax</i>	Roughhead grenadier	RHG	119–1449	12 629	528	45
<i>Reinhardtius hippoglossoides</i>	Greenland halibut	GHL	43–1449	9 777	732	63
<i>Antimora rostrata</i>	Blue antimora	ANT	215–1460	8 694	403	35
<i>Synaphobranchus kaupii</i>	Northern cutthroat eel	SSK	62–1460	6 707	445	38
<i>Nezumia bairdii</i>	Marlin–spike	NZB	58–1460	4 133	537	46
<i>Anarhichas lupus</i>	Wolfish (Catfish)	CAA	44–635	4 037	287	25
<i>Glyptocephalus cynoglossus</i>	Witch flounder	WIT	43–1460	3 930	576	50
<i>Centroscyllium fabricii</i>	Black dogfish	CFB	232–1457	3 867	232	20
<i>Coryphaenoides rupestris</i>	Roundnose grenadier	RNG	225–1460	2 071	362	31
<i>Urophycis tenuis</i>	White hake	HKW	58–980	1 994	136	12
<i>Anarichas denticulatus</i>	Northern wolfish	CAB	56–1434	1 446	283	24
<i>Lycodes reticulatus</i>	Arctic eelpout	LCT	48–1299	1 233	370	32
<i>Lophius americanus</i>	American angler	ANG	47–1230	821	88	8
<i>Phycis chesteri</i>	Longfin hake	GPE	168–1355	812	257	22
<i>Harriotta raleighana</i>	Longnose chimera	HCR	440–1448	779	108	9
<i>Bathyraja spinicauda</i>	Spinytail skate	RJQ	233–1401	760	73	6
<i>Tryglops murrayi</i>	Moustache sculpin	TGM	38–566	743	502	43
<i>Amblyraja hyperborea</i>	Arctic skate	RJG	312–1448	640	121	10
<i>Hemitripterus americanus</i>	Web (whip) sculpin	SP1	44–334	614	105	9
<i>Anarhichas minor</i>	Spotted wolfish	CAS	110–823	576	98	8
<i>Notacanthus nasus</i>	Snubnosed spiny eel	NNN	409–1460	543	273	24

community and possible changes, we calculated the index of diversity, the total biomass and the CPUE, and the percentage of the total biomass and occurrence for dominant species found in each group resulting from these analyses. Since most of these species co-occur in several assemblages, we explored size depth trend or bigger-deeper phenomenon of some species. Regression on individual species was performed to establish whether a correlation between size and depth of occurrence existed.

The surveyed area outside the EEZ does not completely cover the species distribution in the area, especially on the continental shelf. Therefore, although the sampling in

the shallow zone can be considered significant in terms of the specific catch composition or weight of the species present in it, their relative composition could vary if the total area of the continental shelf is considered. Moreover, bottom trawls are both species and size selective, and it is impossible to adjust this type of selectivity without knowing the behaviour of most species or the real age/size structure of populations.

The chi-square test (Gardiner and Haedrich, 1978) was applied to the presence or absence of the species. Bottom trawl hauls available were arranged in order of increasing depth, and the area studied was arbitrarily divided into

10 depth regions of 150 m depth ranges ( $\leq 150$  m, 151–300 m, 301–450 m, 451–600 m, 601–750 m, 751–900 m, 901–1050 m, 1051–1200 m, 1200–1350 m,  $\geq 1351$  m). The number of species that appeared for the first time in each region (upslope boundaries) was recorded. This method tests the distribution across the area of upslope boundaries using the formula:

$$\chi^2 = \frac{Q}{K} \left( V - \frac{K^2}{Q} \right) \text{ with } Q-1 \text{ degrees of freedom}$$

where:

$Q$  = number of regions into which the area was randomly divided

$K$  = total number of species

$V$  = sum of squares over all regions of the number of upslope boundaries

The null hypothesis is that the locations of upslope boundaries are uniformly distributed along with the gradient and that there is no tendency towards clustering.

An analysis with box-plot graphs was performed in order to determine the percentiles of the catches by depth. In the box-plot graphs, catches were represented as a function of depth by haul. For identifying associations between catches of the representative species and bottom depth, we characterized the general frequency distribution of the habitat variable (depth) by constructing its empirical cumulative distribution function (cdf). Commonly, the probability associated with each observation in a cdf is  $1/n$ , but the stratified random survey design results in a probability of  $1/n_h$  within each stratum. However, the stratification can be ignored when the allocation of sets is strictly proportional to stratum size (Perry and Smith, 1994). If there were no clear association between fish distribution and depth within the area surveyed, then the cumulative distribution function for each species would be almost identical to the function for depth. Conversely, when the fish were associated with a small depth range, these functions would be very different.

In order to quantify the zonation, the potential boundaries suggested by the patterns in the cumulative curves were examined by calculating PS between the regions involved. PS was calculated between each region of 150 m intervals up to 1050 m and the regions between 1051 m and 1460 m with the boundary at 1200 m. PS is a commonly-used measure of faunal overlap and was calculated following the formula of Whittaker and Fairbanks (1958):

$$PS = 100 \left( 1.0 - 0.5 \sum |P_{ia} - P_{ib}| \right)$$

where:

$P_{ia}$  = the proportion observed by species  $i$  in sample a

$P_{ib}$  = the proportion observed by species  $i$  in sample b

It is known that PS is not sensitive to sample size, but highly sensitive to the relative number of species among the regions involved. So, for example, if the sample size varies excessively among strata and the species number is closely related to sample size, it will lead to a downwardly biased perception of affinities among strata (Koslow, 1993).

We conducted cluster analysis to identify species assemblages and to confirm the boundaries found in the PS analysis. One of the more common types of cluster analysis, tree clustering, was employed. This method uses the dissimilarities or distance between objects when forming the clusters, in which samples were arranged into groups with a similar biotic composition (Clifford and Stephenson, 1975). As the number of hauls (1160) would make interpretation difficult, we grouped into a 150 m depth bin for every two years. These class depths or strata were labelled with the maximum depth value of the class. Therefore, for every two years (2002–2003, 2004–2005, 2006–2007, 2008–2009, 2010–2011) there were 10 strata named: 150, 300, 450, ..., 1350, 1500, resulting in a total of 50 strata. The mean number of specimens per strata for each species was root-root transformed ( $x^{1/4}$ ) to dampen the influence of abundant species (Field *et al.*, 1982). We use Bray-Curtis similarity, which ignores joint absences that are common in marine survey data where many of the species are absent from the majority of the samples (Field and McFarlane, 1968). Moreover, with the root-root transformation and the Bray-Curtis measure, the similarity coefficient is invariant to a scale change (Stephenson and Burges, 1980). The dissimilarity matrix of the data was calculated in R (R Development Core Team, 2011) and cluster analysis was carried out using Statistica (Statsoft Inc, 1998).

In order to confirm the results of the cluster analysis and to describe which species make up each assemblage, two more multivariate techniques were used, Correspondence Analysis (CA) and Principal Component Analysis (PCA). There are other ordination methods that were developed specifically for ecological data (Ter Braak, 1986; Zuur *et al.*, 2007) and have been used successfully in other studies of demersal fishes (e.g. Bianchi, 1992). We used PCA to facilitate the comparison with previous works in near areas (Mahon, 1998; Lorenzo, 2011). Species loadings on the principal components (PCs) were used to identify groups of species that tend to co-occur (*i.e.* assemblages).

Previous analyses have shown that ubiquitous species may be a member of more than one assemblage, and PCA allows a species to be associated with more than one component. The PCs with eigenvalues  $>1$  are considered to represent statistically significant assemblages (Jolliffe, 1986). VARIMAX rotation was used for the PCs having eigenvalues  $>1$  in the unrotated PC extraction (Jolliffe, 1986). Every assemblage can potentially be present at every site, as the assemblages are not mutually exclusive in space. The data and the transformations used in these analyses were the same as those used in the cluster analysis and were performed by Statistica program.

To examine changes in the structure and composition of the groundfish species assemblage, for each assemblage described, the index of diversity (Shannon and Weaver, 1963), the total biomass and the CPUE, and the percentage of the total biomass and occurrence for the dominant species found were calculated. The Shannon-Wiener index is sensitive both to the number of species and to their relative abundance. A high value of diversity will occur with a high number of equally abundant species, a low value with a low number of species and a species composition dominated by one or a few species.

The “bigger-deeper” phenomenon, in general, refers to the distinct trends in body size over environmental gradients. As a general rule, there is a positive relationship between size and depth. Intra-specific bigger-deeper trends have been identified in Collins *et al.* (2005) and in previous works (*e.g.* Macpherson and Duarte 1991). To analyze the bathymetric trends of demersal fishes, regressions on individual species were performed. Size was estimated from the mean weight of the species at each set.

## Results

A total of 938 201 kg was caught during the 10-years time series (2002–2011), of which 877 874 kg were fishes, corresponding to the 93.56% of the total capture, and representing 240 taxa (221 fish species) belonging to 86 families. Species were caught in depths between 38 to 1460 m. The highest catch corresponded to redfish. The most present species (% occurrence) was American plaice. Over the last few years of the studied period, the estimated indices for yellowtail flounder and redfish increased (Fig. 3). In 2011, Atlantic cod and American plaice continued to be below historical levels.

Fish species were not randomly distributed across depths ( $\chi^2 = 21.67$ ,  $df = 9$ ,  $p < 0.01$ ), and showed three different patterns of distribution in relation to depth (Fig. 4). Some species presented a limited shallow distribution (*e.g.*, yellowtail flounder, sea raven, Northern sand lance, capelin, moustache sculpin, Atlantic wolffish). Other

species presented wider bathymetric distribution (*e.g.* witch flounder, Northern wolffish). The rest of the species were restricted to a deep range distribution (*e.g.* black dogfish, Arctic skate, rat fish). Median depth was less than 300 m for 14 species, between 301 and 1000 m for eight species, and deeper than 1001 m for six species.

Second analysis was made via empirical cumulative distribution functions for observed depth and depth weighted by the biomass of specimens caught of each species. It was observed that species presented different behaviour with respect to depth. Species appeared divided into three main groups. Some species presented a distribution above the function for depth; those species presented cumulative occurrence percentages higher than 80% in depths less than 300 m. Cumulative distribution of those species was plotted in Fig. 5, group A (Shallow). Other species showed no particular association between fish distribution and depth within the area surveyed. This group comprised species with very different behaviour and variability in a wide range of depth (Fig. 5, group B (Intermediate)). One species, witch flounder, had a random distribution in terms of the depth. Other species presented a distribution below the function for depth, with a cumulative occurrence percentage higher than 80% in depths greater than 1001 m (Fig. 5, group C (Deep)).

Percentage similarities for each depth boundary were given in Table 3. All PS boundaries values were higher than 50% except 150 m and 600 m. The results suggested high zonation at these boundaries.

A cluster analysis was performed to contrast these results. The examination of the dendrogram revealed the existence of five groups associated with the continental shelf and the slope (Fig. 6). Cluster I and II (Shallow or “Continental Shelf”) comprised the strata with depths lesser than 150 m and between 151 and 300 m; cluster III (Intermediate or “Upper Continental Slope”) contained the depth strata between 301 and 600 m, cluster IV (Deep or “Medium Slope”) the depth strata between 601 and 1000 m and Cluster V (Deep or “Lower Slope”) the depths greater than 1001 m. In agreement with the PS, the dendrogram indicated less zonation at the boundaries of 150 m and 600 m because the boundaries in these depths appeared at a low level of dissimilarity (37% and 28% respectively).

Correspondence Analysis (Fig. 7) showed five different groups in agreement with the five clusters of the dendrogram. In the Principal Components Analysis (Fig. 8), the first three principal components accounted for 84% of the variation in fish assemblage structure (and had eigenvalues  $>1.0$ , Table 4), with the first two components accounting for more than 79%. We found five groups of species, which were the same as in the CA.

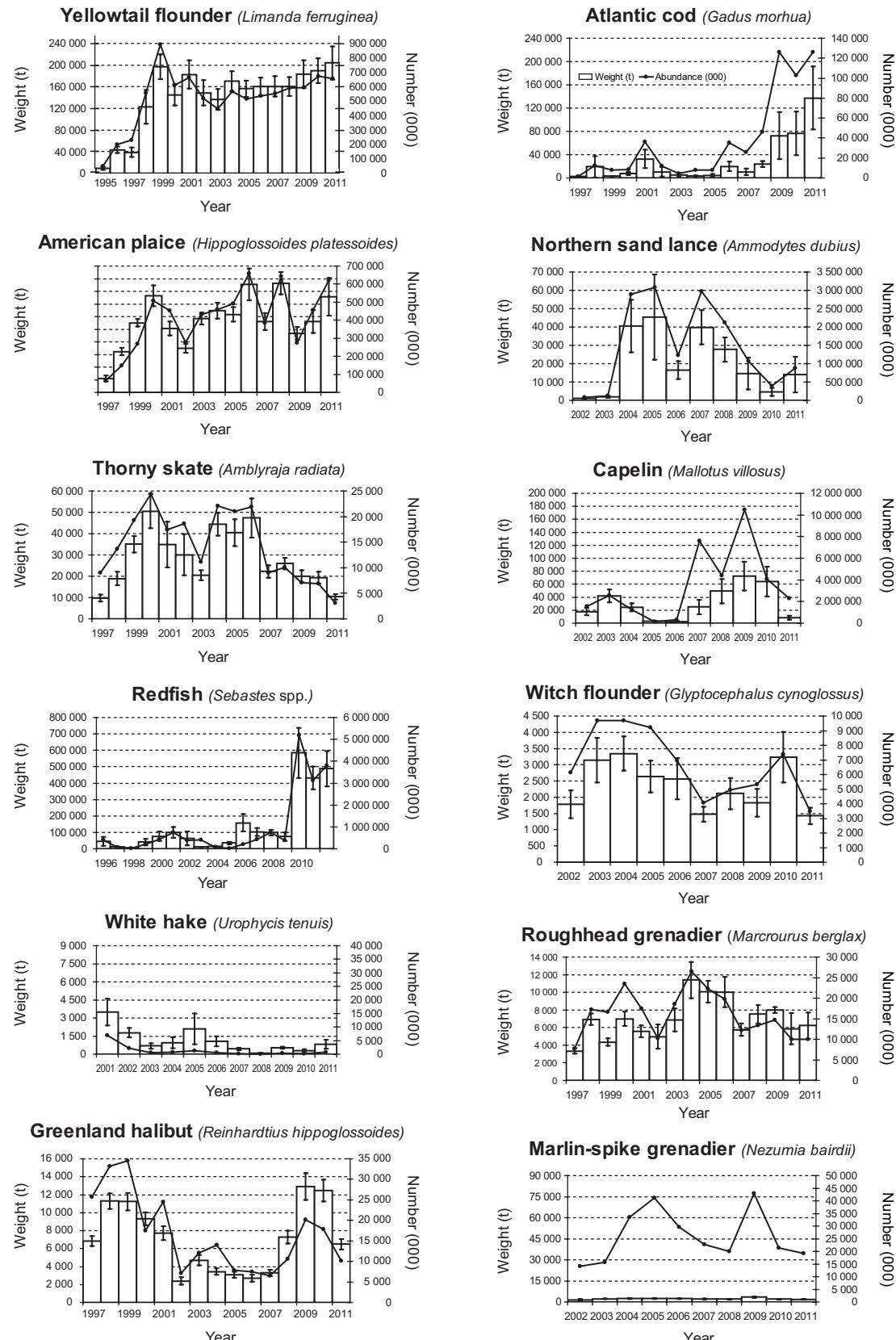


Fig. 3. Abundance and Biomass estimates for the main species from Spanish bottom trawl survey 3NO, 2002–2011.

From these analyses, five assemblages appeared: Shallow assemblages comprised first Shelf Group I (comprising sets shallower than 150 m) and second Shelf Group II (comprising sets between 151 and 300 m); Intermediate assemblage (Upper Continental Slope) Group III, comprising sets between 301 and 600 m; Slope Group IV between 601 and 1000 m and Deep assemblage (Continental Slope) Group V, comprising sets deeper than 1001 m. The three main groups: Shallows, Intermediate and Deeps agree with the three different patterns found in the cumulative distribution.

Yellowtail flounder, American plaice, Northern sand lance, moustache sculpin, capelin and web sculpin formed the first assemblage (Group I, Shallow). The second assemblage (Group II, Shallow) comprised the Atlantic cod, American angler, wolffish and thorny skate. Redfish, spotted wolffish, Arctic eelpout, Northern wolffish, white hake, longfin hake and witch flounder were included in the third assemblage (Group III, Intermediate). The fourth assemblage (Group IV, Deep) comprised four species: marlin spike, spinytail skate, Greenland halibut and roughhead grenadier. Box-Plot graphs and cumulative distribution graphs also defined

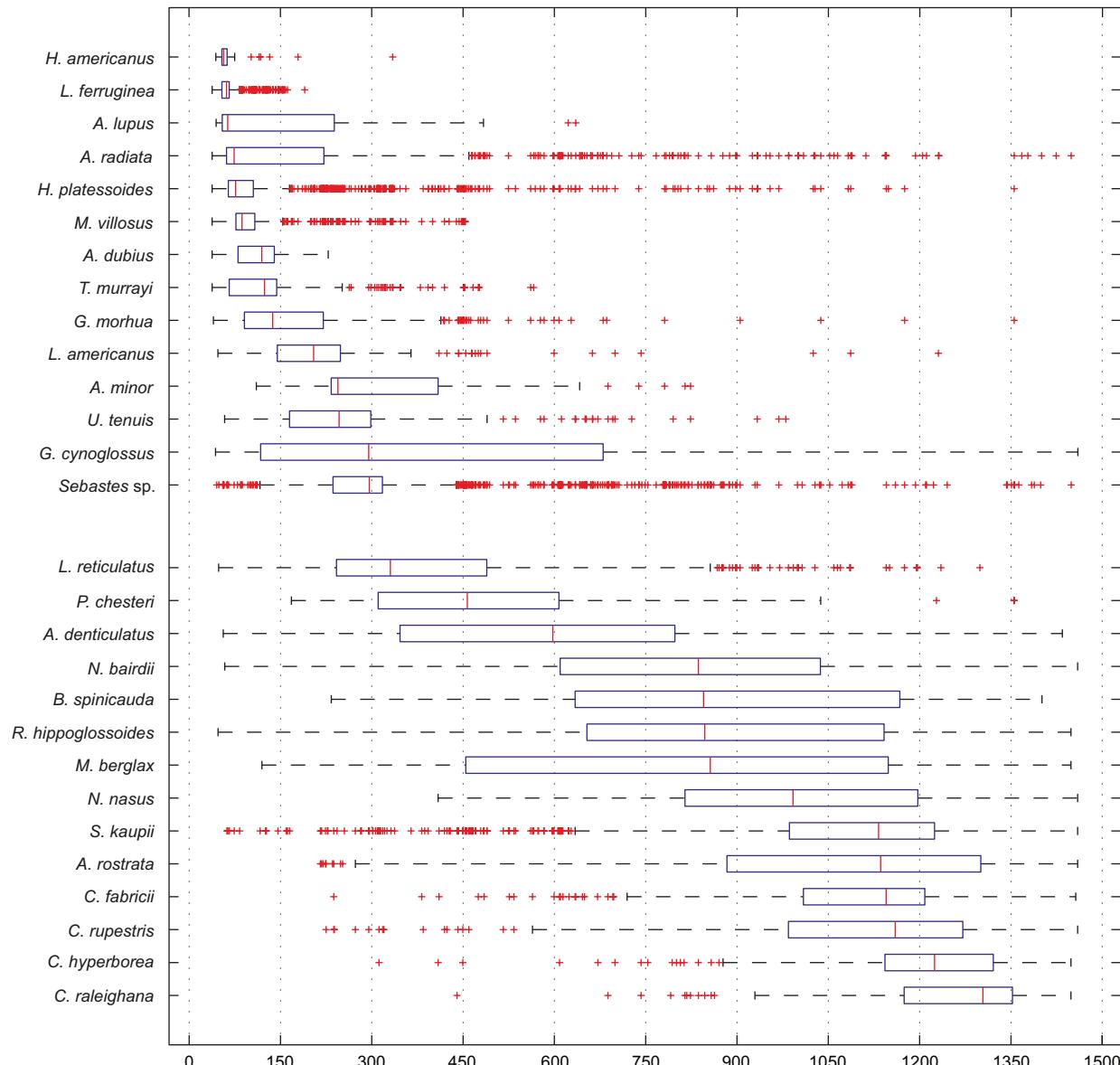


Fig. 4. Box-Plots of depth distribution of the most abundant species caught in the deep water trawl survey in NAFO Div. 3NO, 2002–2011. Median and quartiles were represented. Species graphs were ordered by increasing median depth catches value so we observed an increasing gradient of depth for each one.

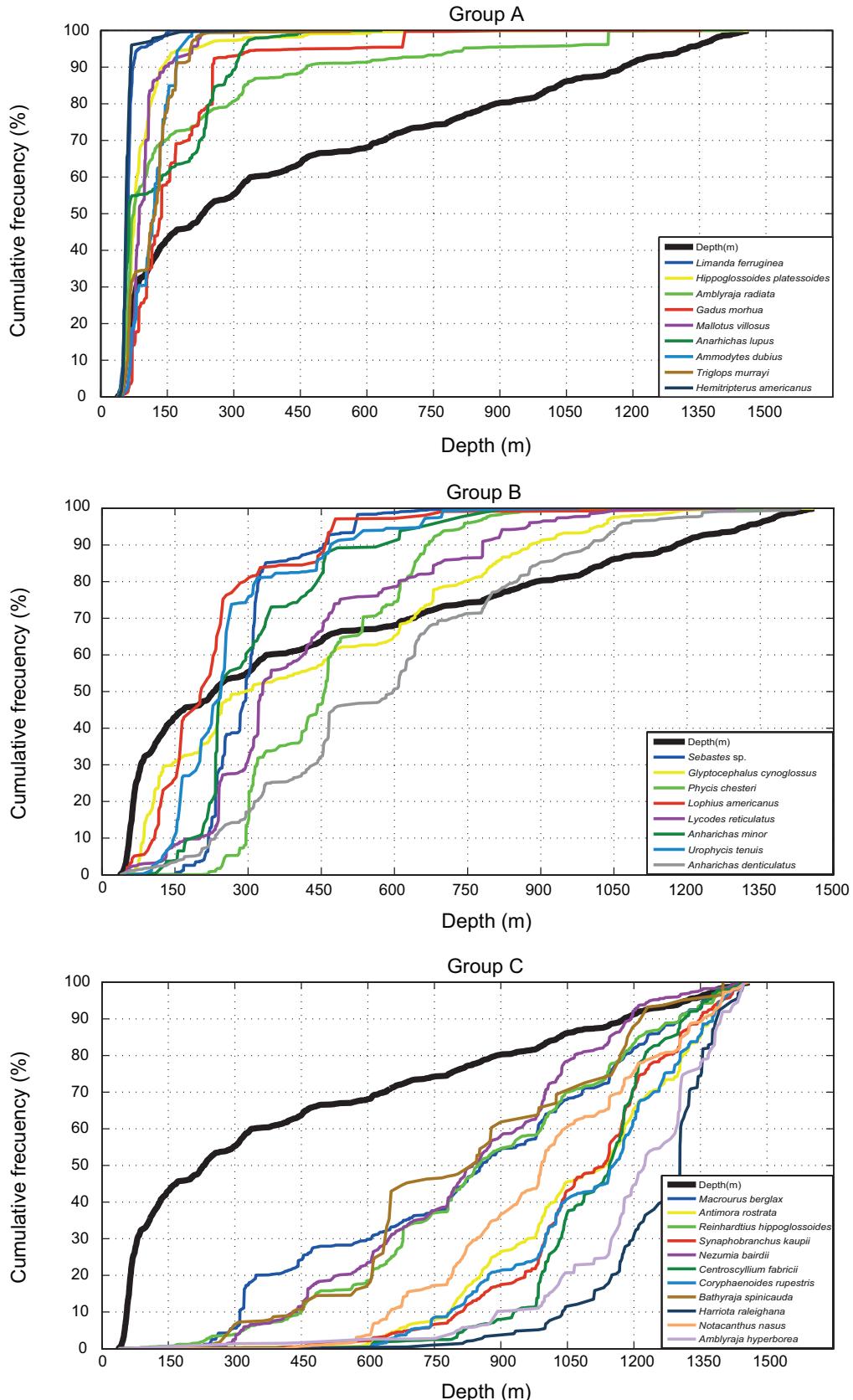


Fig. 5. Cumulative frequency distribution of habitat variable (bottom depth and catch data from the Spanish bottom-trawl survey: 2002–2011 NAFO Div. 3NO).

Table 3. Percentage of similarity among regions of 150 m.

Regions intervals (m)	Boundaries (m)	PS (%)
38–150/151–300	150	16
151–300/301–450	300	86
301–450/451–600	450	93
451–600/601–750	600	40
601–750/751–900	750	53
751–800/901–1050	900	78
901–1050/1051–1200	1050	85
1051–1200/1201–1460	1200	80

these subgroups: species that had the same medians and their curves were separated from the others, showing a very similar distribution. They followed a wide distribution, mainly deep. Snubnosed spiny eel, blue antimora, Northern cutthroat eel, roundnose grenadier, black dogfish, Arctic skate and longnose chimera formed the fifth and deepest assemblage (Group V, Deep).

Tables 5 and 6, respectively, show the most abundant demersal species (as a percentage of total biomass) percentage of occurrence and the index of diversity in the five depth zones considered and the overall community parameters. The highest value is reached in the deeper assemblage, with diversity  $H = 2.23$ .

In assemblage I, yellowtail flounder and American plaice were dominant with an occurrence higher than 85%; redfish was the dominant species in assemblage II with a very high proportion of biomass in comparison with the proportion of others species in the same group. In this assemblage, Atlantic cod and American plaice had a very high occurrence, more than 89%, although their percentage of biomass is very low (less than 10 times redfish biomass). In group III, redfish was also the dominant species in terms of biomass but Greenland halibut and marlin spike had an occurrence higher than 91%. In assemblage IV, Greenland halibut and roughhead grenadier were the dominant species. In group V, blue hake was the dominant species, although Northern cutthroat eel and roughhead grenadier reached similar biomass and occurrence values.

In general, the most important and present taxon was redfish. Although the species number was similar in the five groups, redfish biomass was very high in the assemblages II and III, whereas the proportion of species was most homogeneous in deeper assemblages

(III and IV). For those reasons biodiversity index was higher in deeper groups (Table 6).

Some species like marlin-spike and Greenland halibut showed a well marked “bigger-deeper” distribution (Table 7). Blue hake showed less marked length dependent distribution. One species, *Glyptocephalus cynoglossus*, showed a significant negative correlation.

## Discussion

We found a strong association between the assemblage structure of groundfishes and depth. Analysis of 10-years from the Spanish trawl surveys data collected in the South of the Grand Banks of Newfoundland (NAFO Regulatory Area) identified five main assemblages that varied in their depth characteristics. The five groups obtained in the cluster analysis (Fig. 6) can be associated with the shelf (Groups I and II, between 38 and 300 m), upper slope (Group III, between 301 and 600 m), the middle slope (Group IV, between 601 and 1000 m) and lower slope (Group V, below a depth of 1001 m).

### Species richness

The 240 taxa caught from 86 families represented a bigger fish fauna diversity than the 137 fish taxa identified on continental slopes in New Zealand along a depth gradient from 50 to 1200 m (Zintzen *et al.*, 2012), the 39 fish species caught in bottom trawls on the Newfoundland continental slope at depths from 204 to 2345 m near Carson Submarine Canyon (Snelgrove and Haedrich, 1985), and the 82 species collected off the Balearic Islands (Moranta *et al.*, 1998). Diversity was similar to that of the Gulf of Tehuantepec (Mexico) and the Gulf of Papagayo (Costa Rica) where surveys caught 230 species (Bianchi, 1991), and the Eastern North Pacific where 265 individual fish taxa were identified on the U.S. West coast groundfish bottom trawl survey between 2003 and 2010 (Keller *et al.*, 2012). However, it represents only 71% of the 310 fish species obtained in 1991 in depths between 200 and 1400 m in the continental slope off western Australia during a demersal trawling survey, and between 1989 and 1991 during commercial fishing operations (Williams *et al.*, 2001).

### Changes in species composition

According to Spanish surveys in the NAFO Divisions 3NO, the biomass and abundance of the main commercial species showed a change since 1995 when the surveys started (Fig. 3). About twenty years after the moratorium, even some important commercial species (*e.g.* Atlantic

cod and American plaice) showed some signs of recovery but did not reach their historical levels from before the collapse. Yellowtail flounder increased above their previous historical levels and redfish showed a large variability, although its surveys biomass index has been increasing since the mid-2000s. Some similar signs over the last few years appeared in Flemish Cap, which is close to the studied area. For instance, the Atlantic cod increased, redfish reached very high biomass levels and only American plaice maintained the depressed situation (Casas and González-Troncoso, MS 2011). Major changes in the abundance of the dominant species (cod, American plaice) have led to modification in species composition of demersal assemblages.

### Depth patterns and species distribution

Most of the studies on demersal fish assemblages have indicated that the main faunal changes occur along the depth gradient, so depth is the factor which most influenced the distribution of the species (Murua and De Cardenas, 2005; Bianchi, 1991; Moranta *et al.*, 1998; Labrapoulou and Papaconstantinou, 2004; Tomilieri and Levin, 2006). Changes in relation to depth were probably related to change in temperature and oxygen levels (Tomilieri and Levin, 2006). Physical characteristics of water masses, as well as bottom type, light intensity, pressure, etc., are mostly depth-dependent, and depth obviously reflects the combined effects of these factors (Bianchi, 1991). Most of

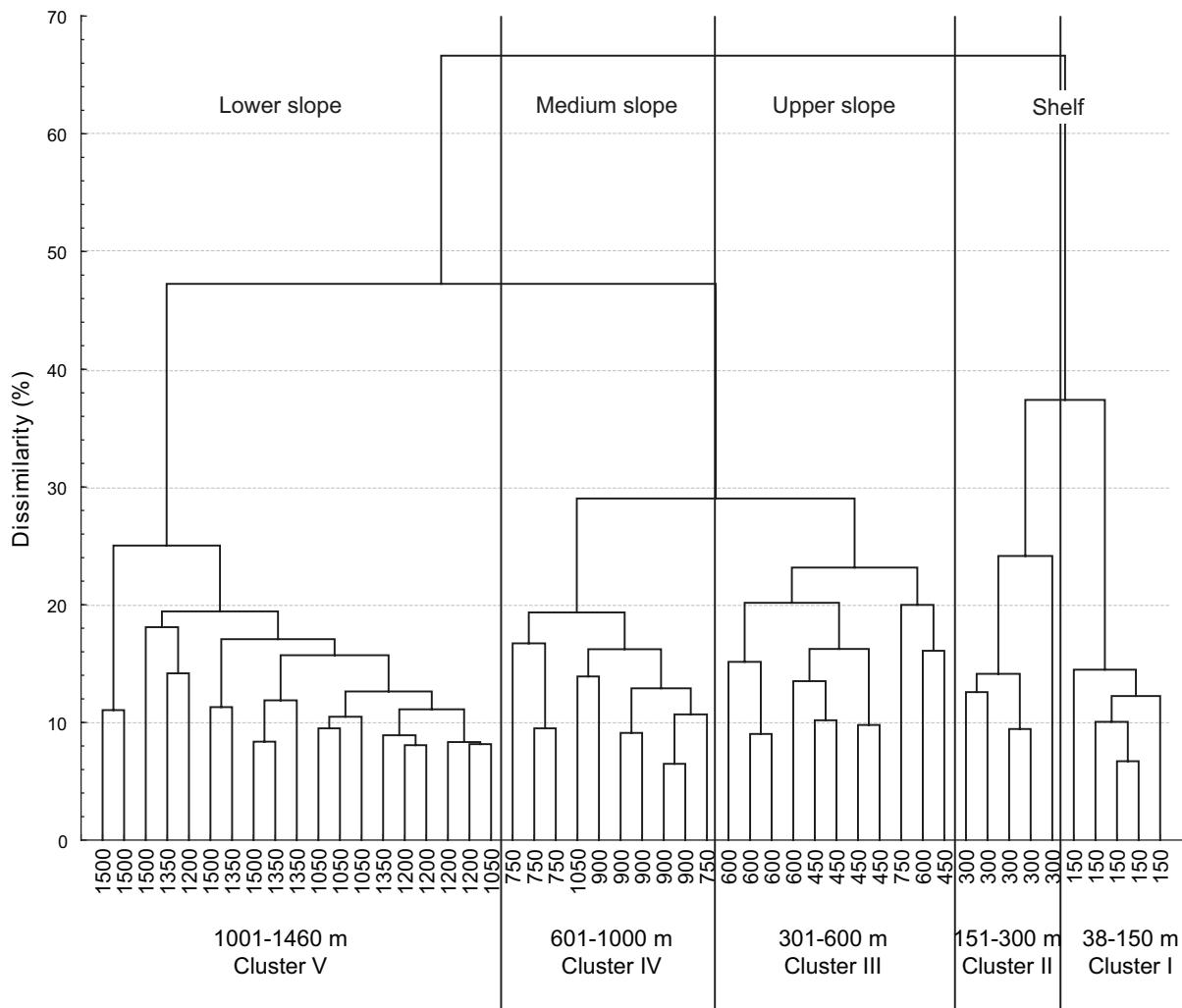


Fig. 6. Dendrogram showing the classification of 1160 sets grouped in 10 depth class of 150 m by two years (2002–2003, 2004–2005, 2006–2007, 2008–2009, 2010–2011) based on mean abundance of fish fauna species composition by depth class. Catch was root-root transformed before comparing stations using the Bray-Curtis measure, and the dendrogram formed by group-average sorting. Five clusters are distinguished.

the species present a wide range distribution, but they tend to be dominant in a given depth. Despite the collapse of species, some among them maintained a wide bathymetric range and we even observed an increase in this range for the main commercial species. Snelgrove and Haedrich (1985) found that Atlantic cod occupied depths ranging from 204 to 307 m in the Carson Submarine Canyon, and Gonzalez-Troncoso *et al.* (2006) found depth range from 126 to 343 m for the same species in Flemish Cap. In our analysis, we found that this species occupied very wide depths, from 40 m to 1455 m. For Greenland halibut, a typical deep species, a wide depth distribution was found, from 43 m to 1449 m (maximum depth surveyed). Similar findings were observed by Murua and De Cardenas (2005) with a depth range from 200 to 2000 m combining results from different surveys carried out in the NAFO Area, and Casas and González-Troncoso (MS 2011) found this species in all the depth ranges surveyed (120 to 1400 m) in Flemish Cap. Even in the species that presented a wide

range distribution, catch was concentrated around a strictly depth range, shallow or deep in most cases (Fig. 4).

González-Troncoso *et al.* (2006) and Paz and Casas (1996) found a strictly shallow distribution for American plaice, Atlantic cod and wolffish in Flemish Cap. This is consistent with our results. Other species such as black dogfish and longnose chimaera showed a strictly deep distribution, as reported by Murua and De Cardenas (2005).

Along with this we also observed that some species, as American plaice, considered strictly shallow, showed a large range of occurrence. The same case was observed by Iglesias *et al.* (1996) with information of catches in 1991 and during the second half of 1990 as well as in years 1992 and 1993 collected by observers on board the Spanish trawl fleet in Divs. 3LN M from the Regulatory Area of NAFO. American plaice presented a record occurrence

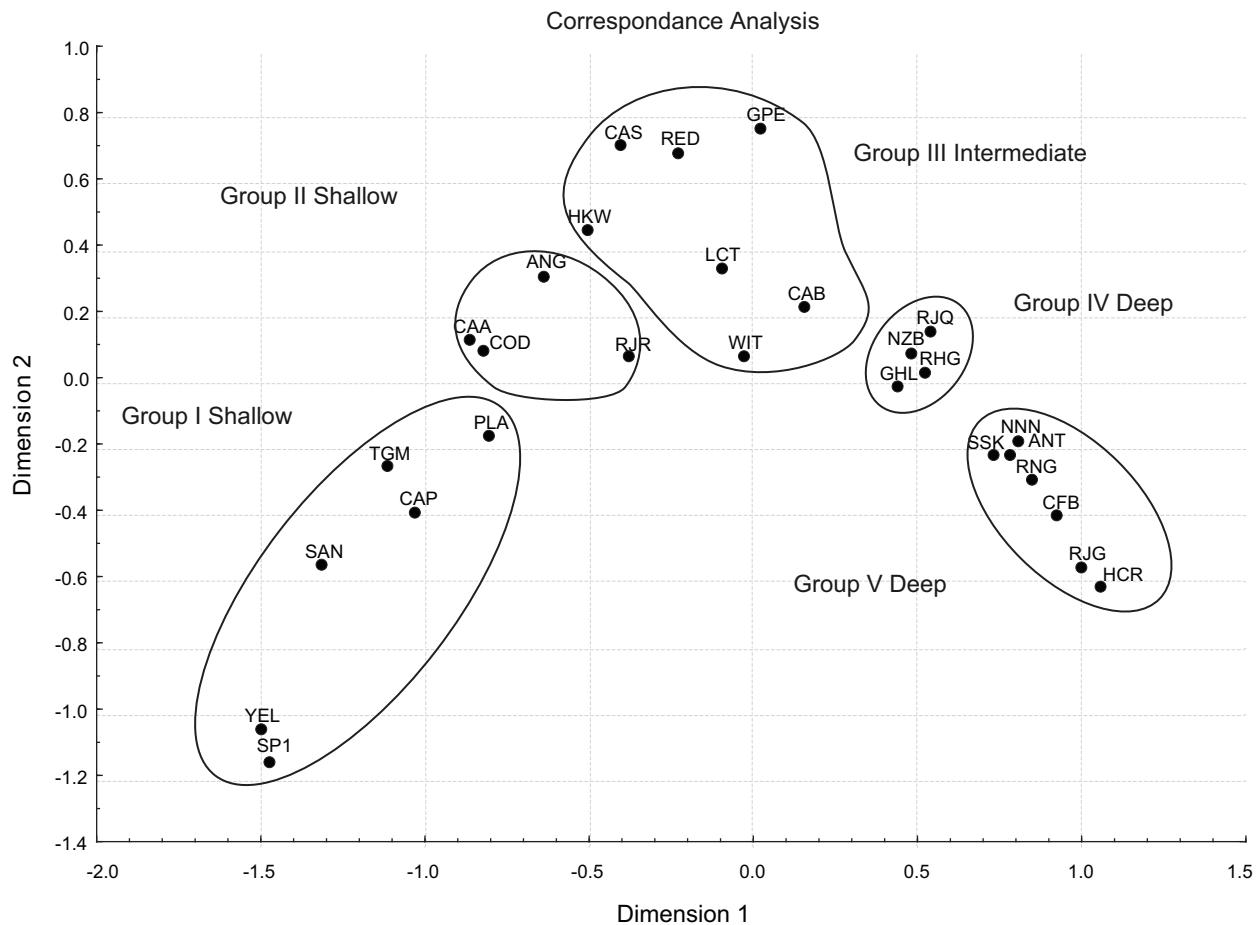


Fig.7. Data on species assemblages and distribution from Southern Grand Banks in 2002–2011, all years combined. Correspondence Analysis ordination plot of axes I and II relating abundance variations to the depth range: 38–1460 m. Hauls number: 1160.

in depths greater than the limits observed in the literature (deepest occurrence at over 1400 m).

### Fish assemblages

Five assemblages were distinguished to which we can apply qualitative depth description. The boundaries established in 150 m and 600 m by the cluster analysis coincide with zones with a lower Percentage of Similarity index (16% in 150 m and 40% in 600 m). The most important boundary for all areas was located around

the depth separating the species of the continental shelf from those of the upper slope. The main determining feature associated with the structure of the demersal fish assemblages is depth, as it reflects the changes from continental shelf to continental slope (Labropoulou and Papaconstantinou, 2004). PS at the rest of boundaries was high, that suggested less zonation. For the general zonation pattern, five groups (Shallow, Intermediate and Deep) were identified. Even if our study analysed a mayor deep range boundaries and species composition were similar to those found in the previous studies in this area (Gomes

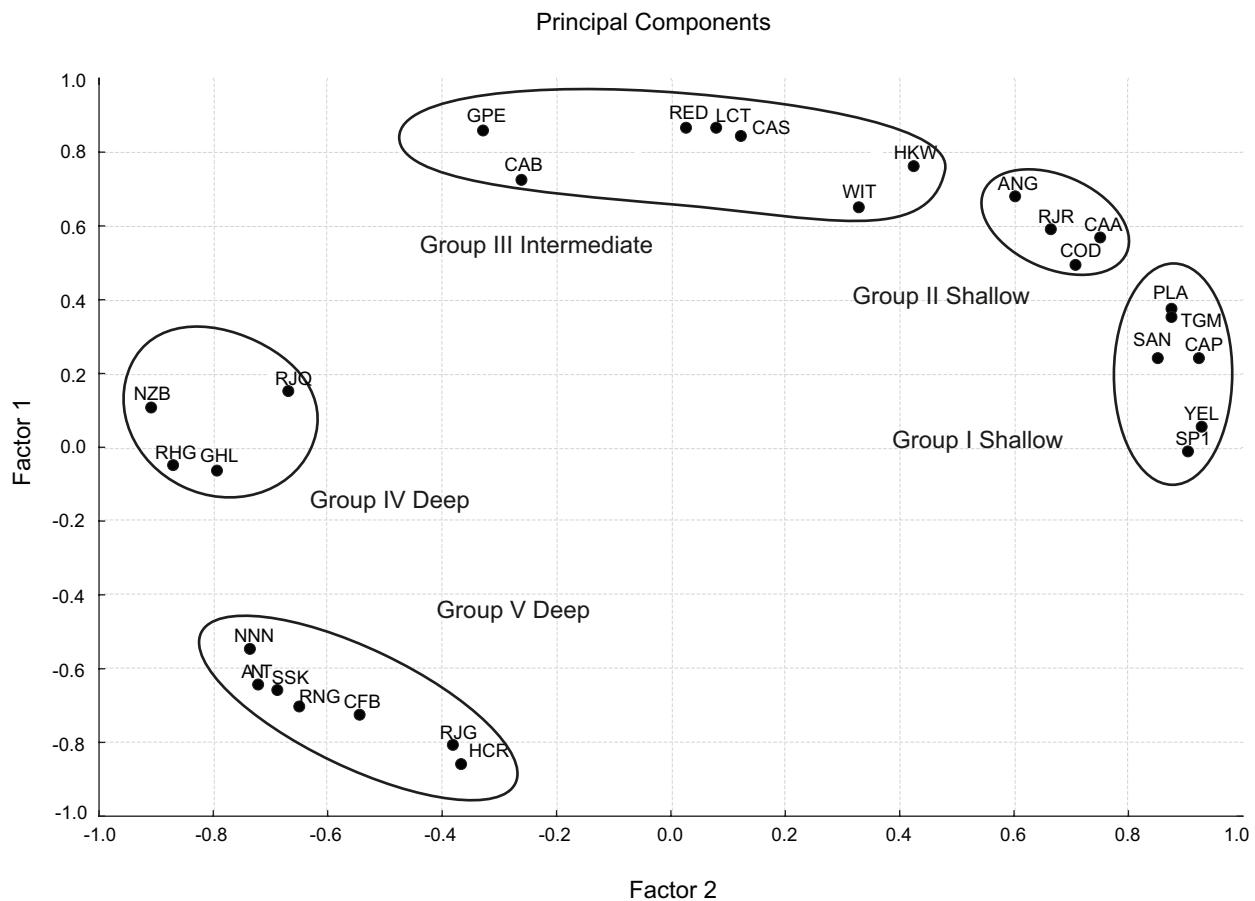


Fig.8. Data on species assemblages and distribution from Southern Grand Banks in 2002–2011, all years combined. Principal Components Analysis ordination plot of axes I and II relating abundance variations to the depth range: 38–1460 m. Hauls number: 1160.

Table 4. Eigenvalues from the Principal Component Analysis

Value	Eigenvalue	% Total Variance	Cumulative Eigenvalue	Cumulative %
1	16.84	60.156	16.843	60.156
2	5.320	19.000	22.163	79.156
3	1.567	5.5978	23.731	84.754

*et al.*, 1992) and in Flemish Cap (González-Troncoso *et al.*, 2006). Cope and Haltuch (2012) also found persistence of assemblages through time in the west coast of U.S. even under fishing pressure and variable environmental conditions that suggests predictable relationships between species.

In the area of the Grand Banks of Newfoundland, different fish assemblages at depths from 40 to 500 m have been described by Gomes *et al.* (1992). Similar fish assemblages were also defined by Paz and Casas (1996) and González-Troncoso *et al.* (2006) in Flemish Cap. Although bathymetric ranges in those studies

were different and dramatic changes in abundance and biomass of species caused changes in dominant species of assemblages, we observed a persistence in the main features of the assemblages over the time.

### Species assemblages' composition

We observed changes in dominant species composition in each assemblage over time, especially for American plaice, Atlantic cod and thorny skate when comparing our results with assemblages found by Gomes *et al.* (1992). In that paper, the authors analysed data from stratified-random groundfish Spring surveys in most of the

Table 5. Most abundant fish species at the five depth zone considered. Values are percentages of total biomass and occurrence.

Dominant species	Bio (%)	Occur (%)	Dominant species	Bio (%)	Occur (%)
<b>Depths&lt;150 m (I)</b>					
<i>Limanda ferruginea</i>	39.09	85.57	<i>Sebastes</i> spp.	82.47	89.44
<i>Hippoglossoides platessoides</i>	32.12	99.80	<i>Gadus morhua</i>	7.19	89.44
<i>Mallotus villosus</i>	8.08	78.56	<i>Hippoglossoides platessoides</i>	2.85	96.48
<i>Gadus morhua</i>	8.01	64.73	<i>Ammodytes dubius</i>	2.07	23.24
<i>Amblyraja radiata</i>	5.91	86.37	<i>Amblyraja radiata</i>	1.33	85.21
<i>Ammodytes dubius</i>	5.28	74.35	<i>Mallotus villosus</i>	1.30	40.14
Total	98.49		Total	97.20	
<b>Depths between 151–300 m (II)</b>					
<i>Sebastes</i> spp.	91.24	100.00	<i>Reinhardtius hippoglossoides</i>	14.79	96.00
<i>Amblyraja radiata</i>	1.86	76.51	<i>Sebastes</i> spp.	14.65	70.29
<i>Macrourus berglax</i>	1.65	85.91	<i>Macrourus berglax</i>	14.63	96.57
<i>Hippoglossoides platessoides</i>	1.39	59.73	<i>Antimora rostrata</i>	10.80	96.57
<i>Reinhardtius hippoglossoides</i>	0.77	97.32	<i>Gadus morhua</i>	8.34	3.43
<i>Gadus morhua</i>	0.63	60.40	<i>Nezumia</i> sp.	6.55	96.57
<i>Nezumia</i> sp.	0.47	91.95	<i>Synaphobranchus kaupii</i>	6.35	94.86
<i>Lycodes reticulatus</i>	0.32	85.91	<i>Amblyraja radiata</i>	4.73	34.86
Total	98.33		Total	80.85	
<b>Depths between 301–600 m (III)</b>					
<i>Sebastes</i> spp.	19.51	95.38			
<i>Amblyraja radiata</i>	16.91	95.38			
<i>Macrourus berglax</i>	16.54	93.85			
<i>Reinhardtius hippoglossoides</i>	13.14	87.69			
<i>Centroscyllium fabricii</i>	10.79	80.51			
<i>Coryphaenoides rupestris</i>	5.26	94.36			
<i>Amblyraja radiata</i>	4.90	13.33			
<i>Nezumia</i> sp.	4.52	88.21			
Total	91.57				
<b>Depths &gt;1001 m (V)</b>					
<i>Antimora rostrata</i>	19.51	95.38			
<i>Synaphobranchus kaupii</i>	16.91	95.38			
<i>Macrourus berglax</i>	16.54	93.85			
<i>Reinhardtius hippoglossoides</i>	13.14	87.69			
<i>Centroscyllium fabricii</i>	10.79	80.51			
<i>Coryphaenoides rupestris</i>	5.26	94.36			
<i>Amblyraja radiata</i>	4.90	13.33			
<i>Nezumia</i> sp.	4.52	88.21			
Total	91.57				

whole Grand Banks, in NAFO Div. 3LNO, in a previous period (1971–82, 1984–87) to the second collapse of the Atlantic cod stocks (Rose, 2003; 2005). In our shallower assemblage (depth less than 150 m) yellowtail flounder was the most dominant species, while Gomes *et al.* (1992) found American plaice as the dominant species both in depths less than 70 m and in depths less than 200 m. Boundaries for our second and third assemblages were in 300 m and 600 m, and a similar approach could be found in Flemish Cap, near to Grand Banks, by Paz and Casas (1996) and González-Troncoso *et al.* (2006). The latter found boundaries between 300 and 500 m, and Paz and Casas (1996) between 300 and 600 m.

Dramatic decreasing on biomass of traditional target species for commercial fishing in the area, such as Atlantic cod and American plaice, can be a cause of changes in the composition of assemblages (Hutchings, 2000; González-Troncoso *et al.* 2006). In our assemblages, a huge increase of biomass catch for redfish, probably due to the constant decrease of its main predator species, like cod, can be

observed. A similar situation occurred in Flemish Cap, where Paz and Casas (1996) and González-Troncoso *et al.* (2006) found (1992–1994 and 1995–2002) that redfish was the dominant species in depths less than 300 m and in depths between 301 and 500 m. The reduction of Atlantic cod abundance and distribution on the eastern Scotian Shelf, where it had historically been the dominant piscivore, may have permitted one or more of its preys or competitor species to increase in abundance and thereafter impacting the recovery of Atlantic cod (Fisher and Frank, 2004). Thus, we appreciated that Atlantic cod was the second dominant species for Gomes *et al.* (1992) in their Shallow, Intermediate and Deep Assemblages. In our first and second assemblage, Atlantic cod represented only around 8% of the catch.

Regarding the fourth assemblage (600–1001 m), three species appeared as dominant in similar magnitudes: Greenland halibut, redfish and roughhead grenadier. In a more restricted range, off Flemish Cap, González-Troncoso *et al.* (2006) found that marlin spike was the

Table 6. Community parameters and catch rates for fish assemblages by depth strata on the Southern Grand Banks in the years 2002–2011.

	Depth strata (m)				
	38–150	151–300	301–600	601–1000	1001–1459.5
Number of species	20	25	26	24	21
Diversity, <i>H</i>	1.54	0.8	0.5	2.53	2.23
Number of stations	499	142	149	175	195
Total biomass (Catch kg)	379 133	248 075	185 110	29 009	27 914
CPUE (kg/30min tow )	760	1747	1242	166	143

Table 7. Regression parameters of mean weight per individual by species versus depth where the regression was significant.

Species	No. of Cases	Correlation coefficient	Significance	Parameters of Equation $y = ax + b$	
				<i>a</i>	<i>b</i>
<i>Limanda ferruginea</i>	434	0.107	<0.05	0.0004	0.2968
<i>Urophycis tenuis</i>	113	0.173	<0.05	0.0012	1.1127
<i>Coryphaenoides rupestris</i>	343	0.237	<0.05	0.0009	0.0171
<i>Ammodytes dubius</i>	193	0.346	<0.05	0.00005	0.0092
<i>Glyptocephalus cynoglossus</i>	574	0.414	<0.05	-0.0003	0.5232
<i>Sebastes</i> spp.	477	0.545	<0.05	0.003	0.4469
<i>Antimora rostrata</i>	369	0.647	<0.05	0.003	0.0645
<i>Nezumia bairdii</i>	442	0.792	<0.05	0.0004	0.0151
<i>Reinhardtius hippoglossoides</i>	731	0.825	<0.05	0.0009	0.0558

dominant species. In depths greater than 1001 m blue hake, Northern cutthroat eel and roughhead grenadier had a similar importance with catch resulting in 19.5%, 16.9% and 16.5% respectively, and each one had a 95% of occurrence.

In order to compare with the assemblages found by Gomes *et al.* (1992) in the Grand Banks, we carried out a cluster analysis considering the depth range truncated in 500 m. Fig. 9 shows the cluster results where we took into account only samples between 38 and 500 m. No changes in assemblage boundaries were found. In the resulting dendrogram three similar main zones found by Gomes *et al.*

were distinguished: Shallow assemblage at depths of less than 70 m, Intermediate assemblage at depths between 71 and 200 m and Deep assemblage at depths greater than 201 m. Yellowtail flounder is the most abundant species at depths of less than 70 m in our case, for Gomes *et al.* (1992) was the American plaice.

On the slope, the assemblage species composition was similar to the results of the recent by catch study in the Greenland halibut fishery (Patrocínio and Paz, 2011). Although the methodology is not comparable, their results can be considered indicative. A total of 51 taxa were identified in the discarded catch, 38 of which accounted

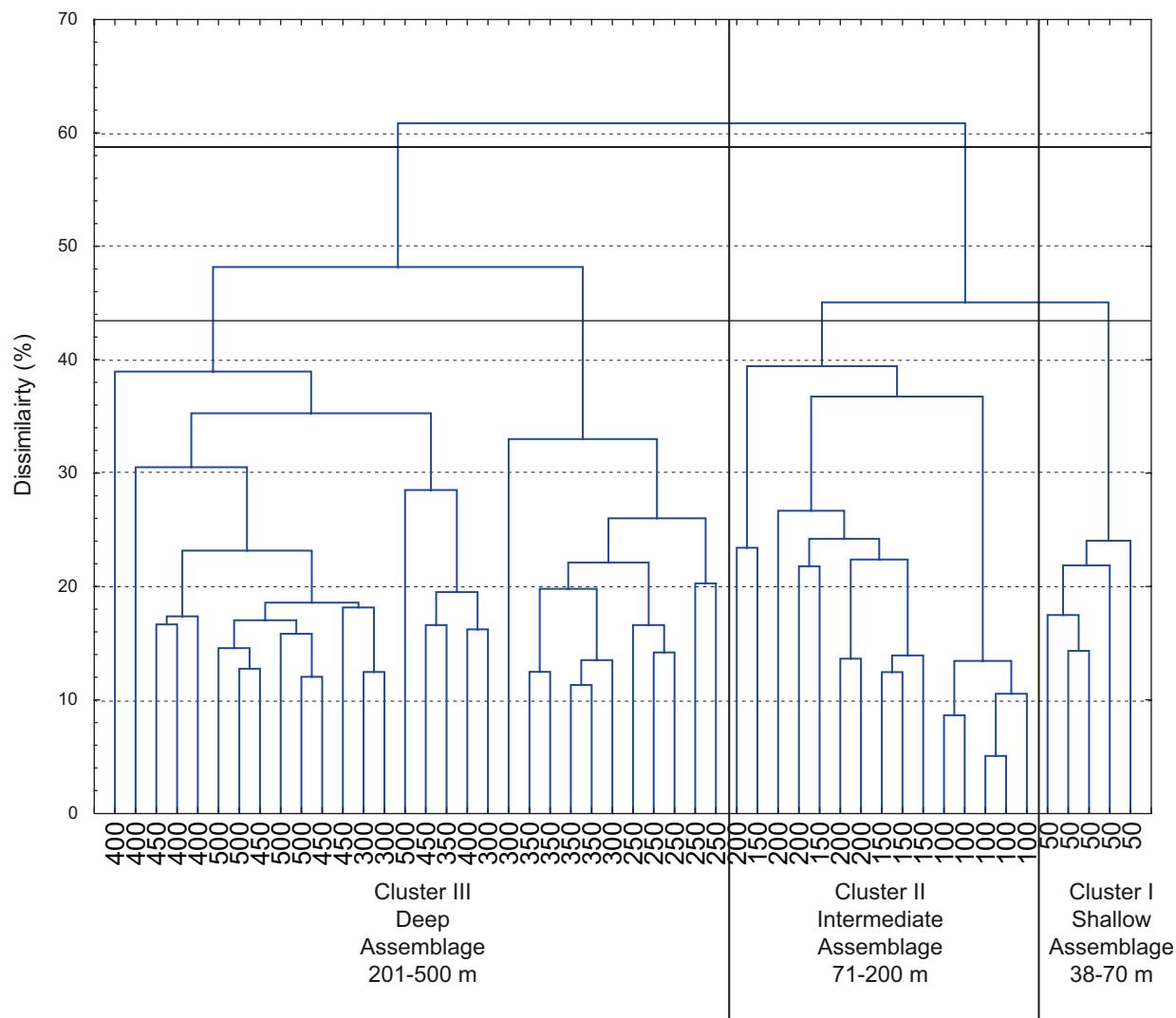


Fig. 9. Dendrogram showing classification of 773 sets grouped in 10 depth classes of 50 m over two years (2002–2003, 2004–2005, 2006–2007, 2008–2009, 2010–2011) based on mean abundance of fish fauna species composition by depth class. Catch was root-root transformed before comparing stations using the Bray-Curtis measure, and the dendrogram formed by group-average sorting. Three main clusters are distinguished at an arbitrary dissimilarity level of 44%.

for less than 0.5%. Discarded biomass represented 4.3% of the total catch. Discards composition was dominated, in biomass, by the macrourids; roughhead grenadier, marlin spike and roundnose grenadier, which together accounted for 61.2% of the total discarded biomass. The fourth species was blue hake. At depth ranges between 601 and 1460 m we found that Greenland halibut, redfish, roughhead grenadier, blue hake and Northern cutthroat eel were the main species. The presence of redfish and Northern cutthroat eel could be explained by the large difference in gear selectivity as trawl surveys used the *Campelen* gear, with vertical opening greater and mesh size much smaller than the gear used in fishing activities.

On the other hand, changes in dominant species in the different assemblages, redfish replacing Atlantic cod and American plaice, were observed. A similar pattern presented between Southern Grand Banks and Flemish Cap in the evolution of these fish assemblages indicates that changes in fish populations in the Northwest Atlantic have been produced on a large scale, affecting Large Marine Ecosystem, and not limited to specific areas.

In Icelandic waters, four major species assemblages were identified. Assemblages in the hydrographically stable deep waters North of the country were consistent during the study, while assemblage structure in the more variable shallow waters underwent some changes (Stefansdottir *et al.*, 2010). In our results, similar temporal persistence appears in the deeper assemblages. Despite the fishing effort in the deep waters of the Grand Banks, the overall pattern of demersal fish assemblages remains similar over time. Major changes in the biomass of the species (*e.g.* cod and American plaice), although affecting the assembly level, do so attenuated and do not substantially alter their general characteristics: range, composition, diversity. Our results confirm the temporal persistence of boundaries and composition fish assemblages in the area. That is in line with the findings of Overholtz and Tyler (1985) and Cope and Haltuch (2012), where assemblages persisted over the long-term and changed spatial configuration only slightly on a seasonal basis.

## Diversity

Biomass declined on the middle continental slope; in this region, the diversity was greater than in other zones. This coincides with the results found by González-Troncoso *et al.* (2006) and Paz and Casas (1996) in Flemish Cap. Magnussen (2002) also found that species diversity increased with depth in two main areas on the Faroe Bank. This fact has an important effect on fish community structure and eventually on the traditional fisheries (Gordon *et al.*, 1994). Commercially important species

tend to be present in low diversity communities where they reach a significant proportion in the total biomass (Haedrich, 1994). In line with this assertion, the Shelf and Upper Continental Slope presented the smallest diversity and were the regions where the traditional commercial species exploited in the area, such as Atlantic cod, redfish, yellowtail flounder and American plaice, are present.

In Icelandic waters, Stefansdottir *et al.* (2010) found that diversity was shown to be highly variable both temporally and spatially, while varying with depth. González-Troncoso *et al.* (2006) and Paz and Casas (1996) found that representative species from the middle continental slope of Flemish Cap were more homogeneously represented. We also found that catch of different deeper species (forth and fifth assemblage) were more homogeneously represented versus shallower species. However, Menevez *et al.* (2006) found a marked domination of one or two species in the deepest strata and similar abundance of many species in the shallow depths stratum in Azores. It must be noted that the selectivity of the longline used in their study can reduce the biodiversity of the catch.

The reduction in the biomass of major species fundamentally changed the groundfish community structure and reduced total species biomass by 90% from the 1950s to the 1990s (Casey, 2000). The increase in diversity with fishing pressure was not expected, but can be explained using the intermediate disturbance hypothesis (Huston, 1979). This hypothesis states that in the absence of environmental stress, such as fishing pressure, species diversity would be low as one or more species dominate the community. If the biomass of the dominant species is reduced (*i.e.* intermediate disturbance), more resources would be made available to other species thus increasing species diversity. In this case, the fishery acts as a keystone predator. Such predators actually facilitate the increase in species diversity by reducing competitive exclusion through species removal (Hacker and Gaines, 1990). The removal of cod and haddock allowed flatfish on the Southern Grand Banks to increase in biomass, thus increasing species evenness. The release of resources into the groundfish community may have allowed deepwater species, such as Greenland halibut and eelpout, to move into shallower depths, contributing to the increase in species richness.

## Bigger-deeper relation

Targeting large fish that are more valuable is suspected to modify the size structure and the functioning of fish assemblages, with important consequences for productivity and resilience of fish stocks (Gislansson, 2000). Early studies of the demersal deep-sea ichthyofauna indicated a

general pattern of increased size with depth (Polloni *et al.*, 1979), which came to be known as Heincke's Law (following Heincke's (1913) description of the size of plaice in the North Sea). However, subsequent works demonstrated that the phenomenon was not ubiquitous (Snelgrove and Haedrich, 1985), may be an artefact of sampling (Merrett *et al.*, 1991b) and in some regions a decline in size with depth has been reported (Stefanescu *et al.*, 1992). Collins *et al.* (2005) provide a clear summary of this issue.

Four species in our study show a clear relationship between the size and depth: Greenland halibut, marlin-spike, blue antimora and redfish. All show a very wide range of distribution and the first three are typical depth species. Snelgrove and Headrich (1985) observed a bigger-deeper relation for blue hake and roundnose grenadier. We also found this phenomenon in our analysis for blue hake and Greenland halibut. Wenner and Musick (1977) suggested that blue hake matures in shallow waters, but Snelgrove and Headrich (1985) sampled larger individuals at all depths and immatures could be seen only in shallow samples, creating the appearance of a bigger-deeper relation where it did not exist.

Witch flounder showed a significant negative correlation. Paz and Casas (1996) found the same correlation for this species in Flemish Cap. Burnett *et al.* (1992) found significant differences in distribution according to depth for juveniles and adults of this species in the Gulf of Maine-Georges Bank Region and, while adults maintained a mean depth constant throughout the year, juveniles were found at shallower depths than adults in winter and spring, and at greater depths in summer and fall. This is attributed to differences in prey distribution associated with differences in the diet (Bunnet *et al.*, 1992).

Understanding the patterns of body size across environmental gradients thus requires an understanding of both the ecology and physiological constraints of the species concerned.

Knowledge of the assemblages of fish can be used to improve the management of multispecies resources exploited, although the definition of assemblages in an area just explains the functioning of the ecosystem. For this reason, it would be necessary to conduct further studies in order to understand the interrelationships between species, such as feeding relationships and trophic guilds.

This study will contribute to the process of moving towards a more holistic approach to fisheries management by reducing the complexity of the Grand Banks ecosystem into fish assemblages that could be used as a possible tool in the management resources.

## Conclusions

- Some species on the Grand Banks in the last decade have a wide bathymetric distribution, although they tend to concentrate in relatively restricted depths.
- Despite the decline in abundance and biomass of the main commercial and non-commercial fishes, we observed persistence in the species composition and range of assemblages.
- From the 1980s, yellowtail flounder replaced American plaice and Atlantic cod and becoming the dominant species in shallow assemblages.
- Higher diversity was observed in deeper depths than in shallower assemblages showing an inverse relationship with biomass.
- Assemblage composition persistence and changes in the main dominant species were similar to the changes in near ecosystems such as Flemish Cap.
- The variation pattern in the fish assemblages in the Southern Grand Banks, similar to other Northwest areas, indicates that the changes in fish populations in the Northwest Atlantic have appeared on a large scale and have not been limited to specific areas.
- Not all species considered show a clear relationship between size and depth, although some species, mainly deeper species, exhibit a clear bigger-deeper relation: Greenland halibut, marlin-spike, blue antimora, redfish.

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## References

- BISHOP, C. A. 1994. Revisions and additions to stratification schemes used during research vessel surveys in NAFO subareas 2 and 3. *NAFO SCR Doc.*, No. 43, Serial No N2413, 23 p.
- BIANCHI, G. 1991. Demersal assemblages of the continental shelf and slope edge between the gulf of Tethuantepc (Mexino) and the Gulf of Papagayo (Costa Rica). *Mar. Ecol. Prog. Ser.*, **73**: 121–140. <http://dx.doi.org/10.3354/meps073121>

- BIANCHI, G. and T. HOISATER. 1992. Relative merits of using number and biomass in fish community studies. *Mar. Ecol. Prog. Ser.*, **85**: 25–33. <http://dx.doi.org/10.3354/meps085025>.
- BUNDY, A. 2005. Structure and functioning of the eastern Scotian Shelf ecosystem before and after the collapse of the groundfish stocks in the early 1990s. *Can. J. Fish. Aquat. Sci.*, **62**: 1453–1473. <http://dx.doi.org/10.1139/f05-085>
- BURNETT, J., M. R. ROSS and S. H. CLARK. 1992. Several biological aspects of the witch flounder (*Glyptocephalus cynoglossus* (L.)) in the Gulf of Maine-Georges Bank Region. *J. Northw. Atl. Fish. Sci.*, **12**: 49–62. <http://dx.doi.org/10.2960/J.v12.a2>
- CASAS, M. and D. GONZÁLEZ-TRONCOSO. 2011. Results from the bottom trawl survey on Flemish Cap of June–July 2010. *NAFO SCR Doc.* 11/21. Serial No N5904.
- CASEY, J. M. 2000. Fish community changes in an Exploited Ecosystem: Newfoundland Southern Grand Bank and St. Pierre Bank, 1951–1995. M.Sc. thesis, Department of Biology, Memorial University of Newfoundland, St. John's, NL. 111 p.
- CLIFFORD, H. T and W. STEPHENSON. 1975. An introduction to Numerical Classification. NY: Academic Press, 229 p.
- COCHRAM, W. G. 1997. Sampling techniques. J. Wiley and Sons, N.Y. 428 p.
- COPE, J. M. and M. A. HALTUCH. 2012. Temporal and spatial summer groundfish assemblages in trawlable habitat off the west coast of the USA, 1977 to 2009. *Mar. Ecol. Prog. Ser.*, **451**: 187–200. <http://dx.doi.org/10.3354/meps09595>
- COLLINS M. A., D. M. BAILEY, G. D. RUXTON and I. G. PRIEDE. 2005. Demersal deep-sea fish differential response in scavenging and non-scavenging. *Proc. R. Soc. B.*, 2005 (272): 2051–2057.
- DEYOUNG, B. and ROSE G. A. 1993. On recruitment and distribution of Atlantic cod (*Gadus morhua*) off Newfoundland. *Can. J. Fish. Aquat. Sci.*, **50**: 2729–2741. <http://dx.doi.org/10.1139/f93-298>
- FARIÑA A. C., J. FREIRE and E. GONZÁLEZ-GURRIARÁN, 1997. Demersal fish assemblages in the Galician continental shelf and upper slope (NW Spain): spatial structure and long-term changes. *Estuarine, Coastal and Shelf Sci.*, **44** (1997b): 435–454. <http://dx.doi.org/10.1006/ecss.1996.0148>
- FIELD, J. G. and G. MCFARLANE. 1968. Numerical methods in marine ecology. I. A quantitative similarity analysis of rocky shore samples in False Bay, South Africa. *Zool. Afr.*, **3**: 119–138.
- FIELD, J. G., K. R. CLARKE and R. M. WARWICK. 1982. A practical strategy for analysing multispecies distribution patterns. *Mar. Ecol. Prog. Ser.*, **8**: 37–52. <http://dx.doi.org/10.3354/meps008037>
- FISHER, J. A. D. and K. T. FRANK. 2004. Abundance-distribution relationships and conservation of exploited marine fishes. *Mar. Ecol. Prog. Ser.*, **279**: 201–213. <http://dx.doi.org/10.3354/meps279201>
- GARDINER, F. P. and R. L. HAEDRICH. 1978. Zonation in the deep benthic megafauna. Application of a general test. *Oecologia (Berl.)*, **31**: 311–317. <http://dx.doi.org/10.1007/BF00346250>
- GISLASSON, H., M. SINCLAIR, K. SAINTSBURY and R. O. BOYLE. 2000. Symposium overview: incorporating ecosystem objectives within fisheries management. *ICES J. Mar. Sci.*, **57**: 468–475. <http://dx.doi.org/10.2960/J.v37.m550>
- GOMES, M. C., R. L. HAEDRICH and J. C. RICE. 1992. Biogeography of groundfish assemblages on the Grand Bank. *J. Northw. Atl. Fish. Sci.*, **14**: 13–27. <http://dx.doi.org/10.2960/J.v14.a1>
- GONZÁLEZ-COSTAS, F. 2012. Spanish fisheries in NAFO Subarea 3. *NAFO SCR Doc.* 12/021, Serial No. N6045.
- GONZÁLEZ-COSTAS, F. and D. GONZÁLEZ-TRONCOSO. 2009. Spanish 2006–2008 Fisheries Footprint, scientific observers and surveys coverage and update of the standardized CPUE indices for Greenland Halibut. *NAFO SCR Doc.* 09/022, Serial No. N5657.
- GONZÁLEZ-TRONCOSO, D., C. GONZÁLEZ and X. PAZ. 2004. American plaice biomass and abundance from the surveys conducted by Spain in the NAFO Regulatory Area of Divisions 3NO, 1995–2003. *NAFO SCR Doc.*, 04/09, Serial No. N4954, 22 p.
- GONZÁLEZ-TRONCOSO, D., X. PAZ and X. CARDOSO. 2006. Persistence and Variation in the Distribution of Bottom-trawl Fish Assemblages over the Flemish Cap. *J. Northw. Atl. Fish. Sci.*, **37**: 103–117. <http://dx.doi.org/10.2960/J.v37.m550>
- GONZÁLEZ-TRONCOSO, D., M. SACAU and F. GONZÁLEZ-COSTAS. 2007. A study of Spanish Greenland Halibut commercial effort and CPUE in 3LMNO using GIS with comparisons to the Spanish Division 3NO survey and EU Flemish Cap survey catches. *NAFO SCR Doc.*, No. 54, Serial No. N5406. 12 p.
- GORDON, J. D. H., N. R. MERRET and R. HEADRICH. 1994. Environmental and biological aspects of slopedwelling fishes of the North Atlantic. In: Deep Water Fisheries of the North Atlantic Oceanic slope, A. G. Hopper (ed.). Proceedings of the NATO Advanced Research Workshop, March 1994, Kluwer, Dordrecht, The Netherlands.
- HACKER, S. D. and S. D. GAINES. 1990. Some implications of direct positive interactions for community species diversity. *Ecology*, **78**(7): 1999–2003.
- HAMILTON, L. C. and HAEDRICH, R. L. 1999. Ecological and population changes in fishing communities 1999. *Polar Research*, **18**(2): 383–388. <http://dx.doi.org/10.1111/j.1751-8369.1999.tb00318.x>
- HAEDRICH, R. L. 1994. Structure over time of an exploited deep water fish assemblage. In: Deep Water Fisheries of the North Atlantic Oceanic slope, A. G. Hopper (ed.). Proceedings of the NATO Advanced Research Workshop, March 1994, Kluwer, Dordrecht, The Netherlands.
- HAEDRICH, R. L. and S. M. BARNES. 1997. Changes over time of the size structure in an exploited shelf fish community. *Fisheries Research*, Aug. 1997. **31**(3): 229–239. [http://dx.doi.org/10.1016/S0165-7836\(97\)00023-4](http://dx.doi.org/10.1016/S0165-7836(97)00023-4)
- HEINCKE, F. 1913. Untersuchungen über die Scholle-Generalbericht I. Schollenfischerei und Schonmassregeln. Vorlaeufige kurze Uebersicht über die wichtigsten Ergebnisse des Berichts. Rapport et Procès-verbaux des Réunions du ICES **16**: 1–70.
- HUSTON, M. A. 1979. A general hypothesis of species diversity. *American Naturalist*, **113**: 81–101. <http://dx.doi.org/10.1086/283366>
- HUTCHINGS, J. A. and R. A. MYERS. 1994. What Can Be Learned from the Collapse of a Renewable Resource? Atlantic Cod, *Gadus morhua*, of Newfoundland and

- Labrador. *Can. J. Fish. Aquat. Sci.*, 1994, **51**(9): 2126–2146. <http://dx.doi.org/10.1139/f94-214>
- HUTCHINGS, J. A. and R. A. MYERS. 1995. The biological collapse of Atlantic cod off Newfoundland and Labrador: an exploration of historical changes in exploitation, harvesting technology, and management. In: The North Atlantic fisheries: successes, failures, and challenges. Edited by R. Arnason and L. Felt. Institute of Island Studies, University of Prince Edward Island, Charlottetown, P.E.I. p. 37–93.
- HUTCHINGS J. A., 2000. Collapse and recovery of marine fishes. *Nature*, Vol. **406**, 24 August 2000. www.nature.com.
- HUTCHINGS, J. A. and J. D. REYNOLDS. 2004. Marine fish population collapses: consequences for recovery and extinction risk. *BioScience*, **54**: 297–309. [http://dx.doi.org/10.1641/0006-3568\(2004\)054\[0297:MFPCCF\]2.0.CO;2](http://dx.doi.org/10.1641/0006-3568(2004)054[0297:MFPCCF]2.0.CO;2)
- IGLESIAS, S., X. PAZ and E. DE CARDENAS. 1996. Occurrence of American plaice (*Hippoglossoides platessoides*) at non-habitual depths in the northwest Atlantic, 1990–93. *NAFO. Sci. Coun. Studies*, **24**: 91–95.
- JENNINGS, S. and M. J. KAISER. 1998. The effects of fishing on marine ecosystems. *Adv. Mar. Biol.*, **34**: 203–352. [http://dx.doi.org/10.1016/S0065-2881\(08\)60212-6](http://dx.doi.org/10.1016/S0065-2881(08)60212-6)
- JOLLIFFE, I. T. 1986. Principal components analysis. Springer-Verlag. New York. <http://dx.doi.org/10.1007/978-1-4757-1904-8>
- KELLER A. A., J. R. WALLACE, B. H. HORNESS, O. S. HAMEL and I. J. STEWART. 2012. Variations in Eastern North Pacific demersal fish biomass based on the U.S. west coast groundfish bottom trawl survey (2003–2010). *Fish. Bull.*, **110**: 205–222.
- KENDRICK, T. H. and M. P. FRANCIS. 2002. Fish assemblages in the Hauraki Gulf, New Zealand. *N.Z. J. Mar. Freshwat. Res.*, **36**: 699–717. <http://dx.doi.org/10.1080/00288330.2002.9517124>
- KENNETH S., J. KANE and J. O'REILLY. 2004. Climate, ocean regimes and biomass yields of five North Atlantic large marine ecosystems. ICES CM 2004/M:05.
- KOSLOW, J. A., 1993. Community structure in North Atlantic Deep-Sea Fishes. *Prog. Oceanogr.*, **31**: 321–338. [http://dx.doi.org/10.1016/0079-6611\(93\)90005-X](http://dx.doi.org/10.1016/0079-6611(93)90005-X)
- LABRAPOULOU, M. and C. PAPACONSTANTINOU. 2004. Community structure and diversity of demersal fish assemblages: the role of fishery. *Sci. Mar.*, **68**(Suppl. 1): 215–226.
- LEKVE, K., N. C. STENSETH, J. GJØSAETER, J. M. FROMENTIN and J. S. GRAY, 1999. Spatio-temporal patterns in diversity of a fish assemblage along the Norwegian Skagerrak coast. *Mar. Ecol. Prog. Ser.*, **178**: 17–27. <http://dx.doi.org/10.3354/meps178017>
- LORENZO, M. I., J. M. D. ASTARLOA, W. NORBIS and M. B. COUSSEAU, 2011. Long term fish assemblages as units of management in a temperate estuary (Rio de la Plata-SW Atlantic Ocean). *Brazilian Journal of Oceanography*, **59**(1): 45–59.
- MACPHERSON, E. and C. M. DUARTE. 1991. Bathymetric trends in demersal fish size: is there a general relationship? *Mar. Ecol. Prog. Ser.*, 1991. **71**(2):103–112. <http://dx.doi.org/10.3354/meps071103>
- MAHON, R. and R.W. SMITH, 1989. Demersal fish assemblages on the Scotian Shelf, Northwest Atlantic: spatial distribution and persistence. *Can. J. Fish. Aquat. Sci.*, **46**(Suppl. 1): 134–152. <http://dx.doi.org/10.1139/f89-285>
- MAHON, R., S. K. BROWN, K. C. T. ZWANENBURG, D. B. ATKINSON, K. R. BUJA, L. CLAFLIN, G. D. HOWELL, M. E. MONACO, R. O'BOYLE and M. SINCLAIR. 1998. Assemblages and biogeography of demersal fishes of the east coast of North America. *Can. J. Fish. Aquat. Sci.*, **55**: 1704–1738. <http://dx.doi.org/10.1139/f98-065>
- MAGNUSEN, E. 2002. Demersal fish assemblages of Faroe Bank: species composition, distribution, biomass spectrum and diversity. *Mar. Ecol. Prog. Ser.*, **238**: 211–225. <http://dx.doi.org/10.3354/meps238211>
- MARTIN, C. 1995. The collapse of the northern cod stocks: whatever happened to 86/25? *Fisheries*, **20**(5): 6–8.
- MENEZES, G. M., H. M. SIGLER, M. R. SILVA and M. F. PINHO. 2006. Structure and zonation of demersal fish assemblages off the Azores Archipelago (mid-Atlantic). *Mar. Ecol. Prog. Ser.*, **324**: 241–260. <http://dx.doi.org/10.3354/meps324241>
- MERRETT, N. R., R. L. HAEDRICH, J. D. M. GORDON and M. STEHMAN. 1991B. Deep demersal fish assemblage structure in the Porcupine Seabight (Eastern North Atlantic): Results of single warp trawling at lower slope to abyssal soundings. *J. Mar. Biol. Assoc., UK*, **71**: 359–373. <http://dx.doi.org/10.1017/S002531540005164X>
- MORANTA, J., C. STEFANESCU, E. MASSUTÍ, B. MORALES-NIN and D. LLORIS, 1998. Fish community structure and depth-related and depth-related trends on the continental slope of the Balearic Islands (Algerian basin, western Mediterranean). *Mar. Ecol. Prog. Ser.*, **172**: 247–259. <http://dx.doi.org/10.3354/meps171247>
- MURUA, H. and E. D. E. CARDENAS. 2005. Depth-distribution of Deepwater Species in Flemish Pass. *J. Northw. Atl. Fish. Sci.*, **37**: 1–12. <http://dx.doi.org/10.2960/J.v37.m563>
- OVERHOLTZ, W. J. and A. V. TYLER. 1985. Long-term responses of the demersal fish assemblages of Georges Bank. *Fish. Bull.*, **83**: 507–520.
- PATROCINIO T. and X. PAZ. 2011. Discards and bycatch in Spanish fleet targeting Greenland halibut (*Reinhardtius hippoglossoides*) in NAFO. Divisions 3LMNO: 2008 and 2009. *NAFO SCR Doc.* 11/8. Serial No. N5888.
- PAULY, D., V. CHRISTENSEN, S. GUÉNETTE, T. J. PITCHER, U. RASHID SUMAILA, C. J. WALTERS, R. WATSON and D. ZELLER. 2002. Toward sustainability in world fisheries. *Nature*, **418**: 689–695 (8 August 2002) <http://dx.doi.org/10.1038/nature01017>
- PAZ, X. and J. M. CASAS. 1996. Zonation and Associations of Dominant Fish Fauna on Flemish Cap. *NAFO Sci. Coun. Studies*, **25**: 67–75.
- PAZ X., D. GONZÁLEZ-TRONCOSO and P. DURÁN. 2002 Comparative Exercise of Efficiency Between CV Playa de Menduiña and RV Vizconde de Eza in the NAFO Divisions 3NO in May 2001. *NAFO SCR Doc.* 02/5. Serial No. N4603.
- PERRY, R. I. and S. J. SMITH. 1994. Identifying habitat associations of marine fishes using survey data: an application to the Northwest Atlantic. *Can. J. Fish. Aquat. Sci.*, **51**: 589–602. <http://dx.doi.org/10.1139/f94-061>
- PINHORN, A. T. and R. G. HALLIDAY. 1990. Canadian versus

- international regulation of Northwest Atlantic Fisheries: Management practices, fishery yields, and resource trends, 1960–1986. *N. Am. J. Fish. Manage.*, **10**: 154–174. [http://dx.doi.org/10.1577/1548-8675\(1990\)010%3C0154:CVIRON%3E2.3.CO;2](http://dx.doi.org/10.1577/1548-8675(1990)010%3C0154:CVIRON%3E2.3.CO;2)
- POLLONI, P., R. L. HAEDRICH, G. T. ROWE and C. H. CLIFFORD. 1979 The size depth relationship in deep ocean animals. *Int. Rev. Ges. Hydrobiol.*, **64**: 39–46. <http://dx.doi.org/10.1002/iroh.19790640103>
- PRIEDE, I. G., J. A. GODBOLD, N. J. KING, M. A. COLLINS, D. M. BAILEY and J. D. M. GORDON. 2010. Deep-sea demersal fish species richness in the Porcupine Seabight, NE Atlantic Ocean: global and regional patterns. *Marine Ecology*, **31**: 247–260. <http://dx.doi.org/10.1111/j.1439-0485.2009.00330.x>
- R DEVELOPMENT CORE TEAM. 2011. R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria. ISBN 3-900051-07-0, <http://www.R-project.org/>
- ROSE G. A. 2003. Fisheries Resources and Science in Newfoundland and Labrador: An Independent Assessment. Royal Commission on Renewing and Strengthening Our Place in Canada. Royal Commission, St. John's, NL. 84 p.
2005. On distributional responses of North Atlantic fish to climate change. *ICES J. Mar. Sci.*, **62**: 1360–1374. <http://dx.doi.org/10.1016/j.icesjms.2005.05.007>
- SHANNON, C. E. and W. WEAVER, 1963. The mathematical theory of communication. Univ. of Illinois Press, Urbana.
- SINCLAIR, A. F. and S. A. MURAWSKI. 1997. Why have groundfish stocks declined in the northwest Atlantic? In: J. Boreman, B. Nakashima, H. Pauls, J. Wilson and R. Kendall [ed.]. Northwest Atlantic groundfish: perspectives on a fishery collapse. American Fisheries Society, Bethesda, Md. p. 71–93
- STATSOFT, INC, 1998. Statistica for Windows. Tulsa, OK. <http://www.statsoft.com>.
- STEPHENSON, W. T. and D. BURGES. 1980. Skewness of data in the analysis of species-in-sites-in-times. *Proc. R. Soc. Queensland*, **91**: 37–52.
- SNELGROVE, P. V. R. and R. L. HAEDRICH. 1985. Structure of the deep demersal fish fauna off Newfoundland. *Mar. Ecol. Prog. Ser.*, **27**: 99–107. <http://dx.doi.org/10.3354/meps027099>
- STEFANESCU, C., R. RUCABADO and D. LLORIS. 1992. Depth-size trends in western Mediterranean demersal deep-sea fishes. *Mar. Ecol. Prog. Ser.*, **81**: 205–213. <http://dx.doi.org/10.3354/meps081205>
- STEFANSOTTIR, L., J. SOLMUNDSSON, G. MARTEINSDOTTIR, K. KRISTINSSON and J. P. JONASSON. 2010. Groundfish species diversity and assemblage structure in Icelandic waters during recent years of warming. *Fisheries Oceanography*, **19**(1): 42–62. <http://dx.doi.org/10.1111/j.1365-2419.2009.00527.x>
- TER BRAAK, C. J. F. 1986. Canonical correspondence analysis: a new eigenvector method for multivariate direct gradient analysis. *Ecology*, **67**: 1167–1179. <http://dx.doi.org/10.2307/1938672>
- The R Project for Statistical Computing. <http://www.r-project.org>.
- TOLIMIERI, N. and P. S. LEVIN. 2006. Assemblage structure of Eastern Pacific groundfishes on the U.S. continental slope in relation to physical and environmental variables. *Trans. Am. Fish. Soc.*, **135**: 317–332. <http://dx.doi.org/10.1577/T05-092.1>
- VILLAGARCÍA, M. G. 1994. Structure and Distribution of Demersal Fish Assemblages on the Northeast Newfoundland and Labrador Shelf. M.Sc. Thesis, Department of Biology, Memorial University of Newfoundland, St. John's, Canada, 89 p.
- WENNER, C. A. and J. A. MUSICK, 1977. Biology of the morid fish *Antimora rostrata* in the western North Atlantic. *J. Fish. Res. Bd. Can.*, **34**: 2362–2368. <http://dx.doi.org/10.1139/f77-316>
- WILLIAMS, A., J. A. KOSLOW and P. R. LAST. 2001. Diversity, density and community structure of the demersal fish fauna of the continental slope off western Australia (20 to 35° S). *Mar. Ecol. Prog. Ser.*, **212**: 247–263. <http://dx.doi.org/10.3354/meps212247>
- WHITTAKER, R. H. and C. W. FAIRBANKS, 1958. A study of plankton copepod communities in the Columbia Basin, Southeastern Washington. *Ecology*, **39**: 46–59. <http://dx.doi.org/10.2307/1929966>
- WORM, B., R. HILBORN, J. K. BAUM, T. A. BRANCH, J. S. COLLIE, C. COSTELLO, M. J. FOGARTY, E. A. FULTON, J. A. HUTCHINGS, S. JENNINGS, O. P. JENSEN, H. K. LOTZE, P. M. MACE, T. R. MCCLANAHAN, C. MINTO, S. R. PALUMBI, A. M. PARMA, D. RICARD, A. A. ROSENBERG, R. WATSON and D. ZELLER. 2009. Rebuilding global fisheries. *Science*, **325**(5940): 578–585. <http://dx.doi.org/10.1126/science.1173146>
- ZINTZEN V., M. J. ANDERSON, C. D. ROBERTS, E. S. HARVEY and A. L. STEWART. 2012. Diversity and Composition of Demersal Fishes along a Depth Gradient Assessed by Baited Remote Underwater Stereo-Video. *PLoS ONE* **7**(10): e48522. <http://dx.doi.org/10.1371/journal.pone.0048522>
- ZUUR, A. F., E. N. IENO and G. M SMITH, 2007. Analysing Ecological Data. Springer, New York, NY, USA.



# Dispersion and seasonal movements of American plaice (*Hippoglossoides platessoides*) tagged in waters of the Gulf of St. Lawrence, Scotian Shelf and Bay of Fundy

G. M. Fowler

Department of Fisheries and Oceans, Science Branch  
Bedford Institute of Oceanography, P.O. Box 1006  
Dartmouth, Nova Scotia, Canada B2Y 4A2  
Email: Mark.Fowler@dfo-mpo.gc.ca

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## Abstract

Approximately 17 tagging studies were conducted on American plaice between 1958 and 1997 throughout the Southern Gulf of St. Lawrence, Scotian Shelf and Bay of Fundy. Only about half these studies were formally analysed and discussed in the literature, and many of those represented in the literature were characterised by appreciable recoveries made subsequent to publication. Analyses of previously untreated data and re-analysis of older studies with updated recoveries was conducted to create a synopsis of likely population identities and movements. These tagging studies demonstrate that American plaice in the Gulf of St. Lawrence are distinct from Scotian Shelf plaice, and support the hypothesis of discrete southern and northern sub-populations of American plaice within the southern Gulf of St. Lawrence. American plaice in Sydney Bight are also distinct from plaice in the Gulf of St. Lawrence, but it remains unknown if they are a discrete spawning group or derive from plaice spawning on Banquereau. Movements of plaice tagged in the vicinity of Passamaquoddy Bay provide some evidence that plaice in the Bay of Fundy might be associated with the Scotian Shelf, possibly by a spawning group on Browns Bank.

All the groups of plaice addressed in this study were combined as a single “Designatable Unit”, and assessed as “Threatened in a Species at Risk” context, by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC), due to excessive declines in abundance of mature individuals over 2–3 generations (~86% decline in the Gulf, ~67% decline on the Scotian Shelf). Observed long-term dispersion indicates that plaice has some potential to recolonize depleted areas, but such movements are displayed by fish older than are commonly found in the population in recent decades. Seasonal protection of spawning grounds might safeguard components of the population in the short-term until numbers of these older fish can be rebuilt.

**Keywords:** migrations, distribution, populations, species at risk, recovery potential

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## Introduction

Since 1958 at least 17 discernible tagging studies have been conducted on American plaice (*Hippoglossoides platessoides*) in Canadian waters of the Northwest Atlantic adjacent to Nova Scotia, New Brunswick and Prince Edward Island. Less than half of these mark: recapture studies have been reported in the literature (only the earliest 1958–1960 experiments). In all cases where objectives are known, discrimination of separable subpopulations as fishery stocks for assessment and management was always foremost. The current paper attempts to synthesize

all plaice tagging studies, including those unpublished, conducted west of the Laurentian Channel and east of the Gulf of Maine. Re-analysis of previously published 1958–1960 work (Martin, 1959; Martin, 1960; Anon., 1964; Powles, 1965) became necessary to incorporate new recovery information that was not available at the time of the earlier analyses. Existing notions about plaice stock structure relevant to fisheries are revised.

This overview could be pertinent to recovery potential assessments of populations of American plaice, given the recent evaluation of the species in Canadian waters as

"Threatened" by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC, 2009). COSEWIC defines two populations, or "Designated Units" (DU), of American plaice. One, the Newfoundland and Labrador DU, comprises plaice around Newfoundland and further north, but not including the Gulf of St. Lawrence. The second is the Maritimes DU, comprising plaice throughout the Southern and Northern Gulf of St. Lawrence (separated by the deep waters of the Laurentian Channel), Scotian Shelf, and Bay of Fundy. Plaice within the Maritimes DU, exclusive of the Northern Gulf of St. Lawrence, are the primary focus of this paper.

## Methods

### Data Sources

A total of 13 292 American plaice were tagged throughout the Southern Gulf of St. Lawrence, Scotian Shelf and Bay of Fundy between 1958 and 1997. Tag release details of all

but the 1997 tagging are given in Stobo and Fowler (2006). The 1997 tagging followed the same protocols established for the 1978–1985 tagging programs documented in Stobo and Fowler (2006).

The focus of the earliest Canadian tagging studies on American plaice in waters west of Newfoundland reflected the large fisheries of the time, concentrating on southern Gulf of St. Lawrence stocks of plaice. These investigations, conducted between 1958 and 1963 as a large-scale tagging program, covered a swathe across the top of the Magdalen Shallows in the Southern Gulf of St. Lawrence (Fig. 1). A total of 1959 plaice were tagged from Chaleur Bay to the Magdalen Islands during May–October, 1958–1960. This was followed by an attempt to cover waters from Sydney Bight through the Cape Breton Trough to the area between St. Georges Bay, New Brunswick and Souris, Prince Edward Island. But only 236 fish were tagged (in October of 1963), and only 19 of these were in or very close to Sydney Bight. These studies

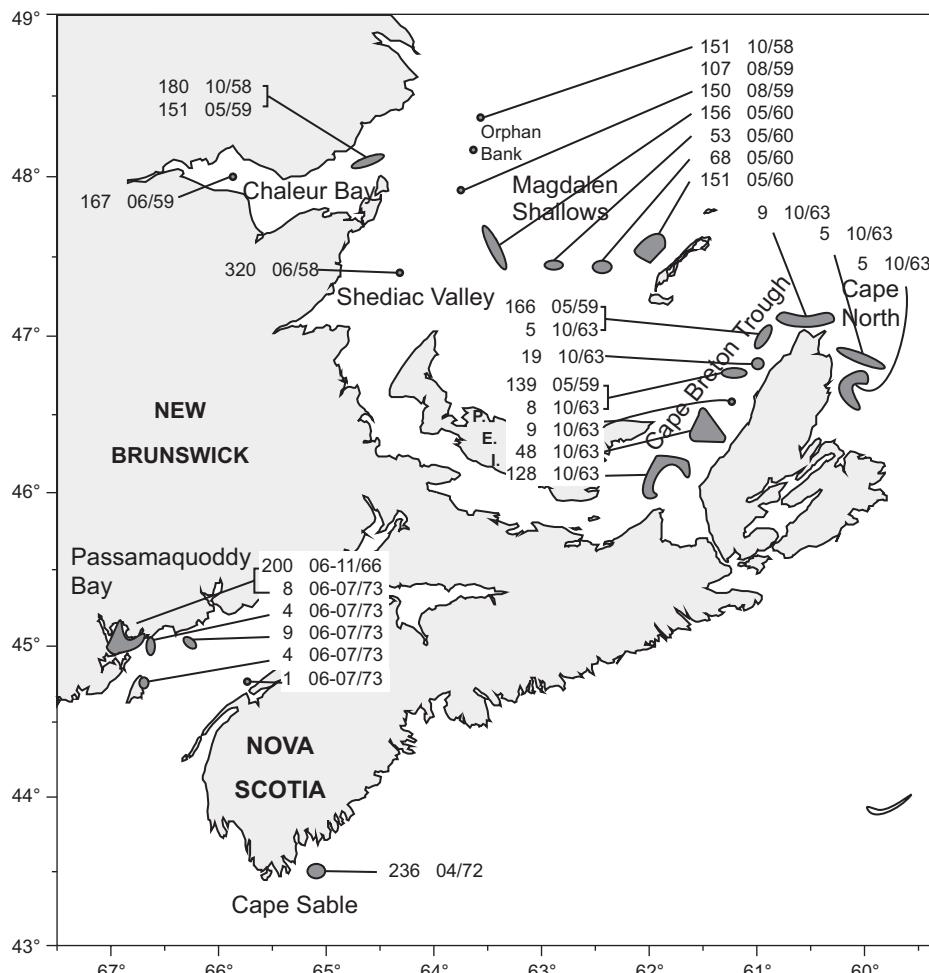


Fig. 1. Locations of tagging releases of American plaice in NAFO Subarea 4 between 1953 and 1973. The numbers of fish tagged and the month/year of release are given for each release location. In many cases several discrete releases of close geographic proximity and/or size range of fish were combined for this composite map.

were all reported in the secondary literature (Martin, 1959; Powles, 1959; Martin, 1960; Powles, 1963; Anon., 1964; Lettaconnoux, 1965), with one primary publication (Powles, 1965) discussing the results of the 1958–1960 tagging. Interpretations were based primarily on short-term recoveries (one or two years post-release), a common practice at the time. Appreciable numbers of longer-term recoveries made two or more years post-release were not considered in these accounts of plaice tagging, and these later recoveries have implications not revealed by earlier recoveries. As well, an indeterminate number of recoveries that occurred prior to publications were absent from the earlier studies, likely representing recaptures that were not immediately submitted for rewards (*e.g.* tag hoarding or collecting).

Between 1963 and 1979 no large-scale tagging efforts were directed on American plaice. Some tagging was conducted in the Bay of Fundy and off southwest Nova Scotia, reflecting growth of interest in plaice as commercial prospects outside the Gulf of St. Lawrence. A second large-scale tagging initiative on American plaice was conducted during 1979–1980, and essentially repeated the 1958–1963 exercise in the southern Gulf of St. Lawrence,

as well as targeting plaice off Halifax, Nova Scotia. The second tagging program in the Gulf of St. Lawrence was largely inspired by a developing appreciation for the potentially confounding role of short-term recoveries on interpretations of movements. The 1958–1963 tagging was conducted in the midst of the fisheries, such that immediate recoveries from nearby vessels were a large component of reported results. Conversely, during 1979–1980 the locations and timing of tagging operations avoided active fisheries, to ensure opportunity for fish to disperse before recapture. Coupled with historical changes in fisheries for American plaice, these experiments provide some new perceptions about movements and stock affiliation relative to the 1958–1963 studies.

The last large-scale tagging of American plaice occurred in 1997 in Sydney Bight, seeking to confirm if a discrete non-migratory population of American plaice was exclusive to the local waters of the Bight.

The first of the unpublished tagging studies (Fig. 2) were small-scale endeavours. In 1966, 200 plaice were tagged in Passamaquoddy Bay at the head of the Bay of Fundy, and another 26 fish were tagged mostly outside but near

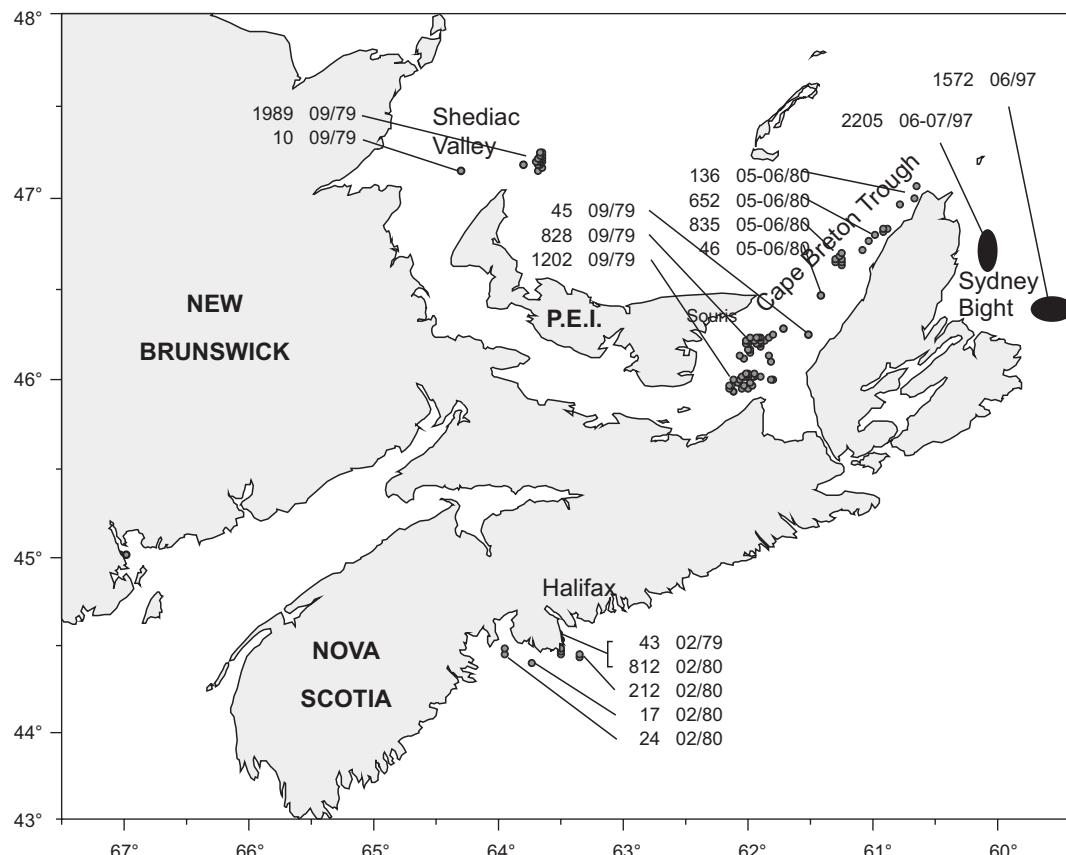


Fig. 2. Locations of tagging releases of American plaice in NAFO Subarea 4 between 1978 and 1997. The numbers of fish tagged and the month and year of release are given for each release location. In many cases several discrete releases of close geographic proximity and/or size range of fish were combined for this composite map.

Passamaquoddy Bay in 1973. In 1972, 236 plaice were tagged near Cape Sable, Nova Scotia.

In 1979–1980 a phase of large-scale tagging activity on American plaice occurred during February off Halifax, Nova Scotia (1108 fish), September tagging of 4074 fish off both ends of Prince Edward Island, and May–June tagging of 1669 fish in the northern portion of the Cape Breton Trough. The locations and timing of the tagging operations were chosen to isolate assumed or speculated populations, based on results of the 1958–1963 program, while at the same time avoiding active fisheries on plaice. This may have been achieved to a large extent, but no formal documentation could be found to indicate success or failure in this regard. Anecdotal information suggests that some to all of the May–June tagging in the Cape Breton Trough might have been conducted on plaice that were physiologically spent from recent spawning.

The last tagging study of American plaice in Canadian waters south of Newfoundland was conducted in June–July of 1997, when 3777 plaice were tagged in Sydney Bight. It was assumed that if a stationary, locally resident population of plaice existed in Sydney Bight, summer tagging might discern them from Gulf of St. Lawrence plaice, assuming Gulf plaice only co-habited the Bight during winter months.

### Processing and Analysis

Release and recovery data for all the studies treated in this paper was preserved over the years, and is currently maintained as a SQL database. The systematic nature

of tag-recovery programs conducted by the Maritimes Region of the Department of Fisheries and Oceans ensured that recoveries were processed regardless of their perceived relevance at any given time by specific researchers. Recoveries from tagging studies considered to be completed investigations continued to be logged in the same manner as previous recoveries. Thus we have all the data available to earlier researchers, as well as that for recoveries made subsequent to previously published analyses.

Preliminary analyses of the recoveries from the various releases were conducted independently on subgroups of the releases distinguishable by any difference in year/month of tagging or geographic discontinuities in tagging locations. Where tagging subgroups were proximate in timing and location of release and demonstrated compatible patterns of recoveries, they were combined to produce the 17 release groups defined in Table 1. These groups were intended to provide appropriate discrimination among tagging events to discern any differences in movements between potential subpopulations.

Most plaice tagged in the studies presented here were measured. Length of fish when tagged can have ramifications for subsequent movements and survival. Inclinations to migrate may not occur until maturation, and long periods of natural mortality may be sustained by smaller fish prior to recruitment to fisheries. Female plaice length at maturity ( $L_{50}$ ) differs by region and has generally declined over time (Beacham, 1983; COSEWIC, 2009). For this study we broadly label mature fish

Table 1. Release groups of American plaice investigated in this paper.

Location	Year	Month	Number Released	Number Recovered	Percent Recovered	Historical Literature
Shediac Valley	1958	Jun	319	217	68	Martin, 1959; Martin, 1960; Anon., 1964; Powles, 1965
Orphan Bank	1958	Oct	151	11	7.3	Martin, 1960; Anon., 1964; Powles, 1965
Chaleur Bay	1958	Oct	176	43	24.4	Martin, 1960; Anon., 1964; Powles, 1965
Cape Breton Trough	1959	May	299	166	55.5	Martin, 1960; Anon., 1964; Powles, 1965
Chaleur Bay	1959	May–Jun	317	184	58	Martin, 1960; Anon., 1964; Powles, 1965
Orphan Bank	1959	Aug	257	74	28.8	Martin, 1960; Anon., 1964; Powles, 1965
Magdalen Shallows	1960	May	418	100	23.9	Anon., 1964; Powles, 1965
Cape North	1963	Oct	19	8	42.1	Anon., 1964 (possibly); Powles, 1965
Cape Breton Trough	1963	Oct	209	79	37.8	Anon., 1964 (possibly); Powles, 1965
Passamaquoddy Bay	1966	Jun–Nov	195	34	17.4	
Cape Sable	1972	Apr	235	22	9.4	
Passamaquoddy Bay - Outside	1973	Jul	24	3	12.5	
Souris	1979	Sep	2 073	200	9.7	
Shediac Valley	1979	Sep	1 998	52	2.6	
Halifax	1979–1980	Feb	1 107	54	4.9	
Cape Breton Trough	1980	May–Jun	1 669	148	8.9	
Sydney Bight	1997	Jun–Jul	3 777	930	24.6	

according to typical female L50's as 41 cm or larger for tagging before 1970, and 31 cm or larger for later studies. Approximate ages were determined from length at release to investigate long-term trends in dispersal.

Recoveries from each release group exhibiting recapture locations of sufficient detail to pinpoint the recovery to within a NAFO/ICNAF Statistical Unit Area were plotted by month to portray seasonal movements. The precision of the recovery data, specifically possession of navigation technology adequate to provide Loran or Cartesian coordinates, can be non-randomly associated with geographically and temporally discrete fishery components. This was of particular concern in the earlier studies, where recovery information could be disregarded if location coordinates were not provided. In this analysis, where precise location data (latitude, longitude) were unavailable but Unit Area was reported, the overall mean recovery location of tags within the Unit Area was substituted. Tags reported only to the detail of NAFO Division were not plotted, but instead were tabulated on land or offshore regions of recovery plots.

Plotted recoveries were distinguished with respect to time at large as short-term (under a year), medium-term (over a year, under three years), and long-term (three or more years) to reduce the contribution of shorter-term recoveries to interpretations and enhance that of longer-term recoveries to discern redundancy in movement patterns over years, and discriminate long-term dispersal.

Recoveries were not weighted by commercial fishing effort. Most of the tagging studies investigated here were conducted between 1958 and 1980, years for which most of the commercial fishing effort was either not yet available or generalized geographically beyond a useful scale for weighting tag recoveries. Commercial landings data was tabulated by year since 1960 to whatever seasonal and spatial detail could be achieved, and this information aided in interpretation of recovery data for later years. Reported landings to the North Atlantic Fisheries Organization (NAFO) were used to cover 1960–1985, but summarize catches to broad-scale NAFO Divisions, which is inadequate to represent spatial effort patterns relevant to American plaice, especially in the Gulf of St. Lawrence. Summaries of regional landings in the southern Gulf of St. Lawrence were obtained for 1979–1983 (Rod Morin, DFO Science, Gulf Fisheries Centre, Moncton, NB, Can, pers. comm.), and used qualitatively to aid interpretations of tag recoveries. Since 1986 we have commercial landings reported to the International Commission of Northwest Atlantic Fisheries (ICNAF) at the finer scale of ICNAF Unit Areas (Fig. 3), adequate to represent spatial effort patterns, but too late for all but the 1997 Sydney Bight tagging. Commercial landings since 1992 have been adjusted for species identification problems (Fowler and Stobo, 1999; Fowler and Stobo, 2000). Deciphering recovery patterns for the 1958–1963 tagging relied heavily on descriptions of the fisheries provided in annual reports of the Fisheries Research Board of Canada. By the time of

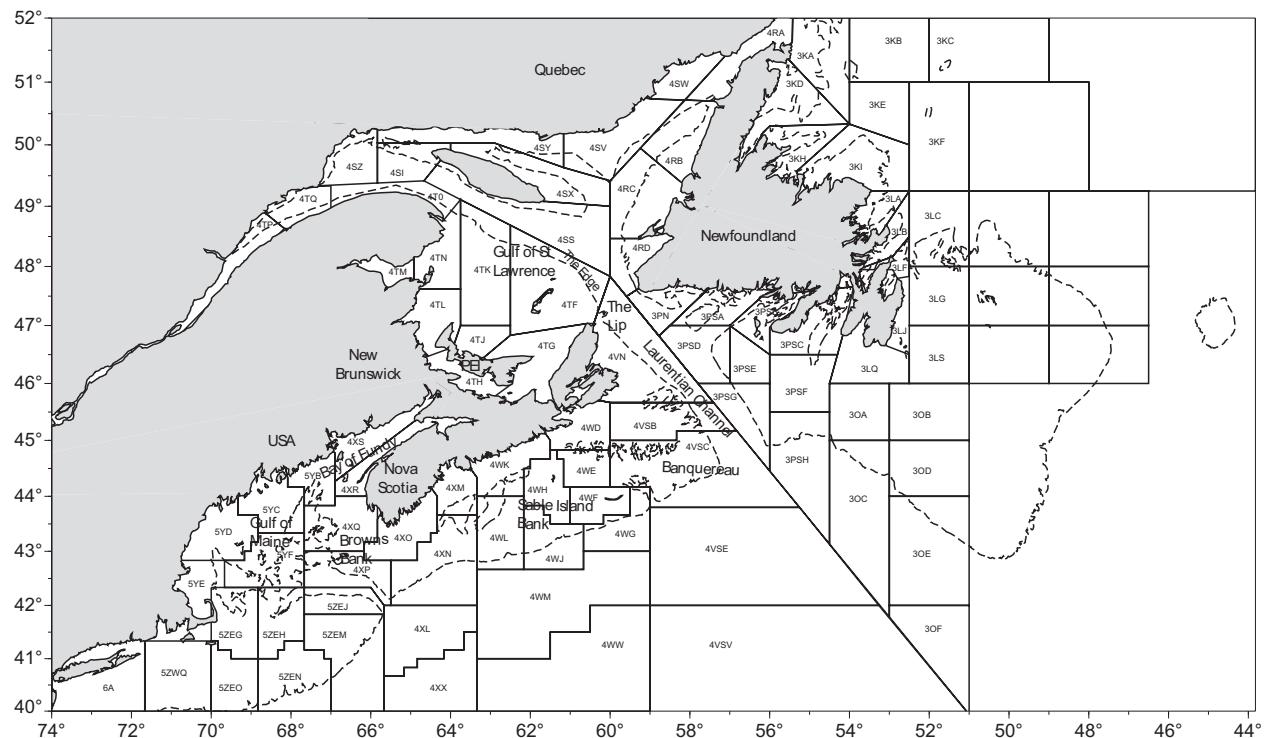


Fig. 3. Map of the northwest Atlantic, showing ICNAF unit area boundaries referred to in this report. Major topographical zones are delineated by 200 m depth contours (dashed lines).

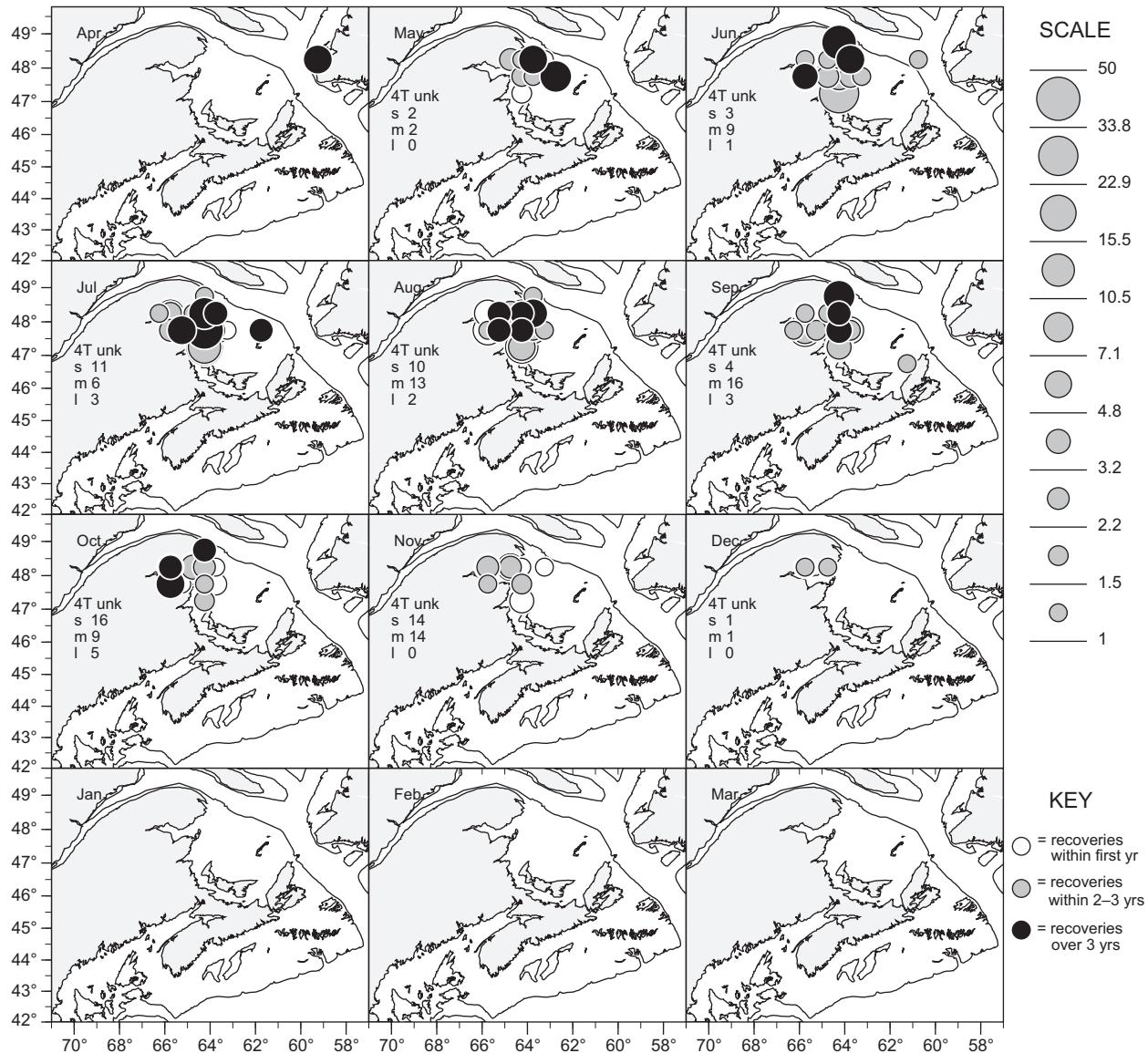


Fig. 4. Recoveries from American plaice tagged around Shedia Valley during June of 1958, on Orphan Bank during October of 1958 and August of 1959, and in or near Chaleur Bay during October of 1958 and May–June of 1959. Tags are aggregated over five minute squares as scaled circles, the size of the circle proportional to the number of recoveries. Tags at large less than one year are plotted as open circles, tags at large 1–3 years as grey circles, and longer-term recoveries as black circles. Unplottable tags with months and locations known to NAFO Subarea are tabulated as short (s), medium (m) or longterm (l) on applicable graphs.

the 1979–1980 tagging, stock assessments of commercial fish provided sufficient background on the geographic and temporal concentrations of fishing effort for our purposes.

## Results

### Earliest Tagging Studies 1958–1963

#### *Southern Gulf of St. Lawrence North of Prince Edward Island*

(Tagging Groups: Shedia Valley, June, 1958; Orphan Bank, October, 1958 and August, 1959; Chaleur Bay, October, 1958 and May–June, 1959)

Almost all of the recoveries from the more northern tagging studies were made within the Gulf of St. Lawrence fishing season between May and December in the general vicinity of the tagging locations, with no recoveries between January and April (Fig. 4). This reflects the location and timing of fishing, as there was no winter fishery for plaice in or around the Gulf of St. Lawrence during this time period. The June recovery from the edge of the Laurentian Channel was made in 1960. The recovery from the Magdalen Islands near the edge of the Laurentian Channel in July occurred in 1961, and that from 4Rd (southwestern tip of Newfoundland, across the Laurentian Channel) in April of 1965. One recovery was

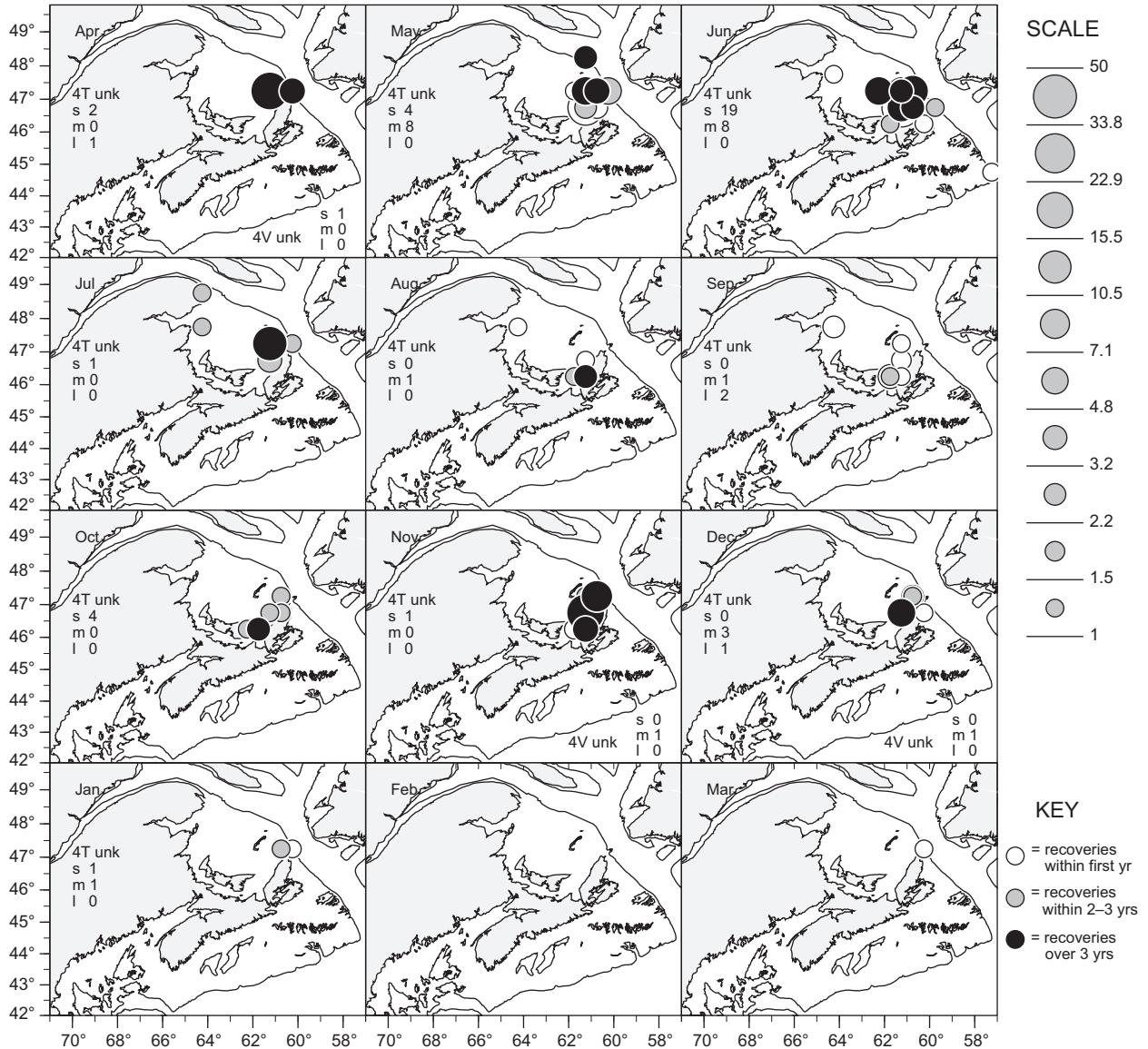


Fig. 5. Recoveries from American plaice tagged in the Cape Breton Trough during May of 1959 and October of 1963, and off Cape north in October of 1963. Tags are aggregated over five minute squares as scaled circles, the size of the circle proportional to the number of recoveries. Tags at large less than one year are plotted as open circles, tags at large 1–3 years as grey circles, and longer-term recoveries as black circles. Unplottable tags with months and locations known to NAFO Subarea are tabulated as short (s), medium (m) or longterm (l) on applicable graphs.

reported from 4S in 1960 with no information as to month or unit area of recovery.

#### Gulf of St. Lawrence South of the Magdalen Islands

(Tagging Groups: Cape Breton Trough, May, 1959 and October, 1963, and Cape North, October, 1963)

Most recoveries from these groups were made around the tagging area during the spring and fall Edge fisheries (Fig. 5; the Edge refers to the abrupt increase in depth along the Laurentian Channel) that target overwintering

plaice leaving from or returning to the southern Gulf shoals. Recoveries from the tagging area show redundancy over the years, and most of the recoveries from 1963 tagging occurred after the last published accounts. They associated strongly with the tagging area during the summer, with a shift toward the Lip (a protruding edge of the Laurentian Channel near Cape North, Fig. 3) in spring and fall. The Lip recoveries were most pronounced in the spring.

None of the recoveries outside the tagging area were accounted for in the literature. The June recovery on Banquereau occurred the month following tagging. Such a

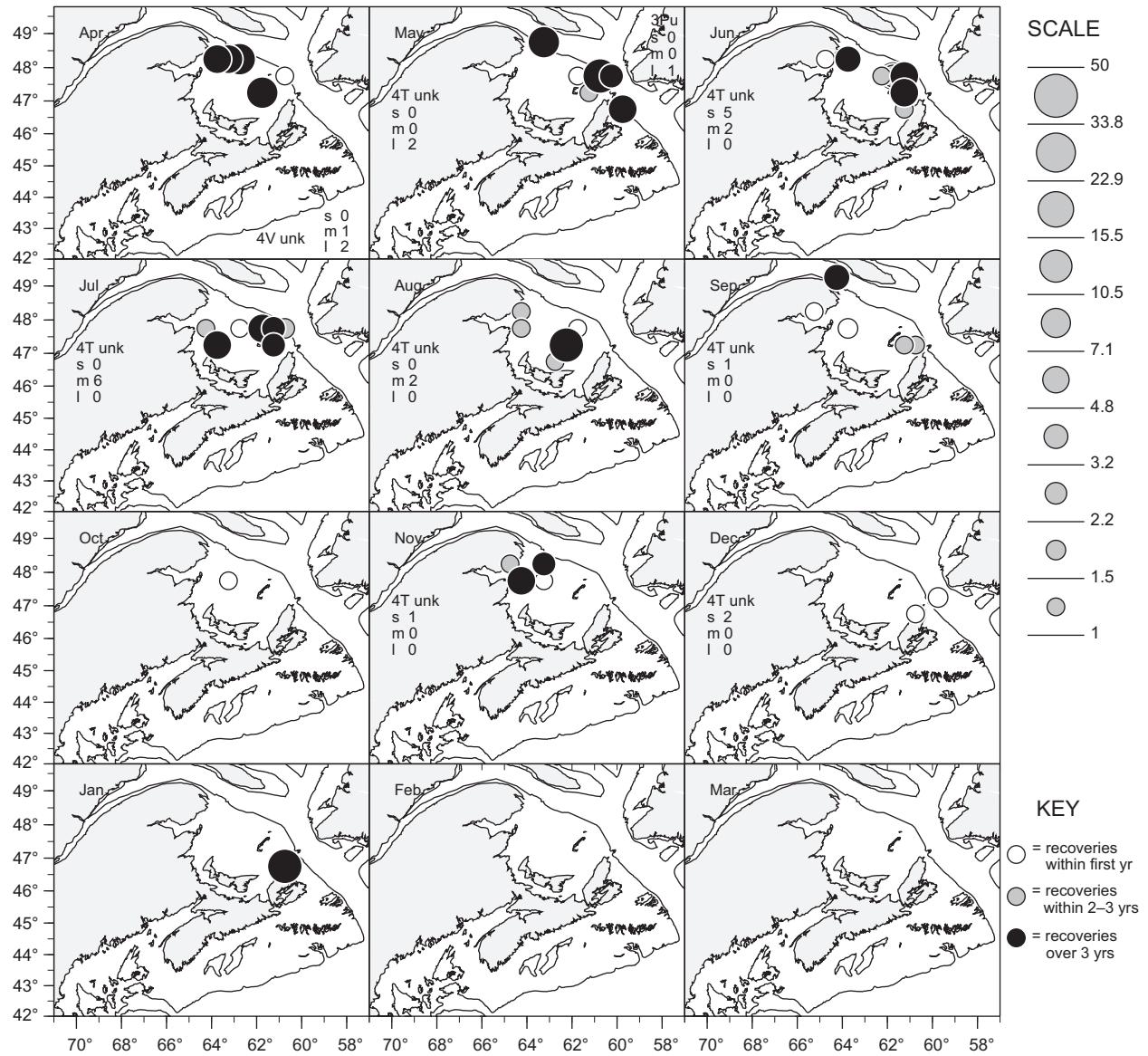


Fig. 6. Recoveries from American plaice tagged on the Magdalen Shallows during May of 1960. Tags are aggregated over five minute squares as scaled circles, the size of the circle proportional to the number of recoveries. Tags at large less than one year are plotted as open circles, tags at large 1–3 years as grey circles, and longer-term recoveries as black circles. Unplottable tags with months and locations known to NAFO Subarea are tabulated as short (s), medium (m) or longterm (l) on applicable graphs.

long distance in such a short time is unlikely. The August (one fish) and September (three fish) recoveries from the Chaleur Bay area were made in their 1959 tagging year, suggesting they might have been considered and disregarded in earlier analyses, but without tag receipt dates uncertainty remains. Reaching Chaleur Bay in a couple of months would not be an unreasonable movement for overwintering plaice returning to the Gulf. The two July recoveries from the Chaleur Bay area, also not accounted for in the literature, were recoveries in 1961 from 1959 tagging.

#### Magdalen Shallows, May, 1960

Recoveries from this group were prominent from a number of fisheries (Fig. 6). They featured strongly in the spring Edge fisheries along the Laurentian Channel, with a major concentration off the Magdalen Islands, and another off the Gaspé Peninsula where the Channel edge comes closest to land. In the summer they showed up strongly in both the Chaleur Bay area and in the vicinity of tagging around the Magdalen Islands. Returns favoured the Chaleur Bay area during the fall. By December–January

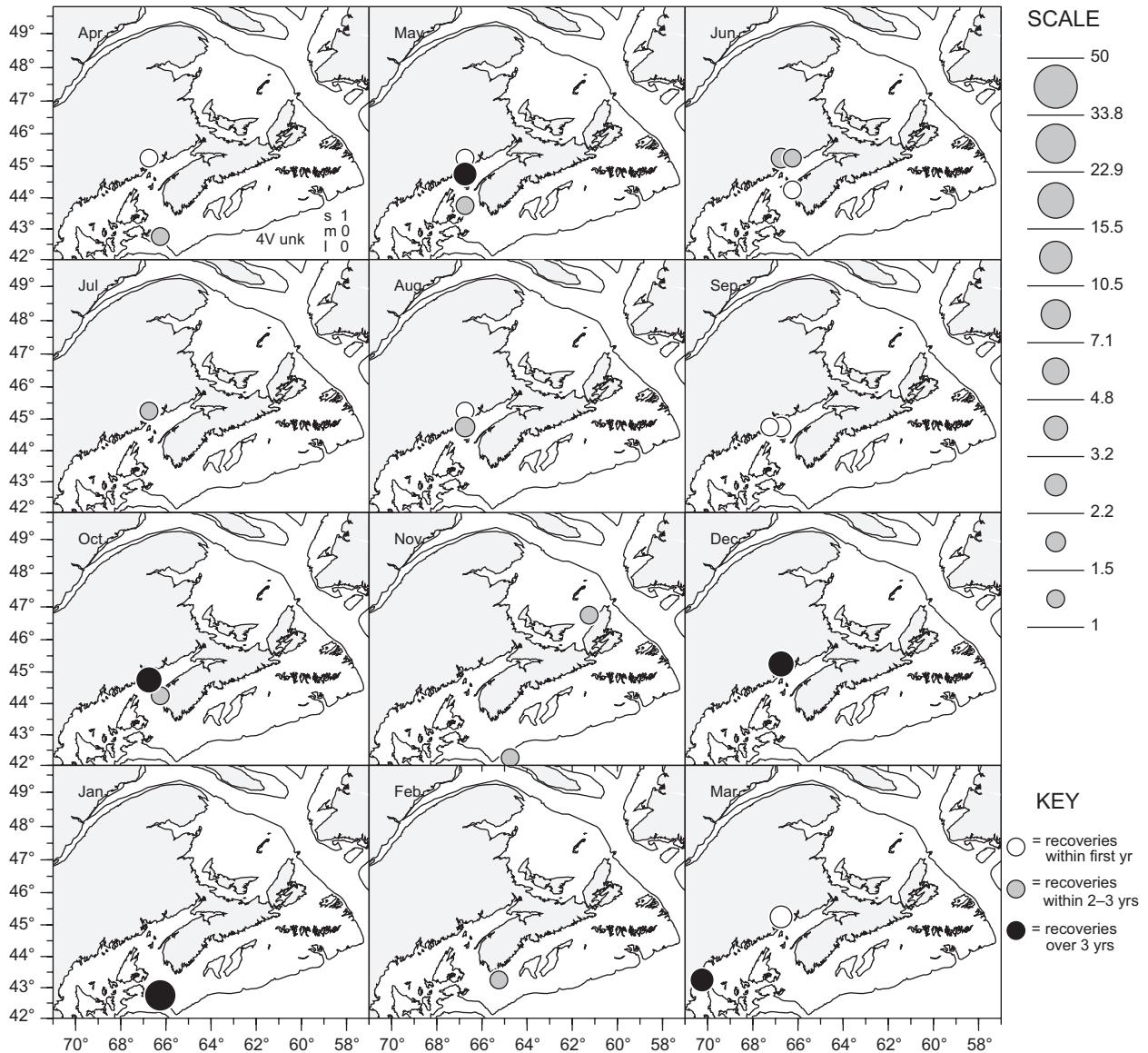


Fig. 7. Recoveries from American plaice tagged in Passamaquoddy Bay during June–November, 1966, and just outside Passamaquoddy Bay in July, 1973. Tags are aggregated over five minute squares as scaled circles, the size of the circle proportional to the number of recoveries. Tags at large less than one year are plotted as open circles, tags at large 1–3 years as grey circles, and longer-term recoveries as black circles. Unplottable tags with months and locations known to NAFO Subarea are tabulated as short (s), medium (m) or longterm (l) on applicable graphs.

we only had recoveries from the vicinity of Cape North at the entrance to the Gulf of St. Lawrence (border of 4T and 4Vn). No recoveries were made in February–March. Returns from the Cape North area became proportionately more important after 1961, the last year considered in published accounts (Powles, 1965).

Recoveries from the Magdalens shallows tagging continued for some time after any reference was made to them in the literature. Spring returns from 4V recurred over subsequent years, and a recovery was reported from

each of 4Sy (Quebec side of Anticosti Island) and 3P (Newfoundland side of the Laurentian Channel south of Cabot Strait), both in May of 1964.

#### Unreported Tagging Studies 1966–1997

##### *Passamaquoddy Bay, Inside, June–November, 1966 and Outside, July, 1973*

Initially recoveries from the 1966 group were localized to the tagging area, but starting in November, 1967 they began occurring from areas directly south, outside the

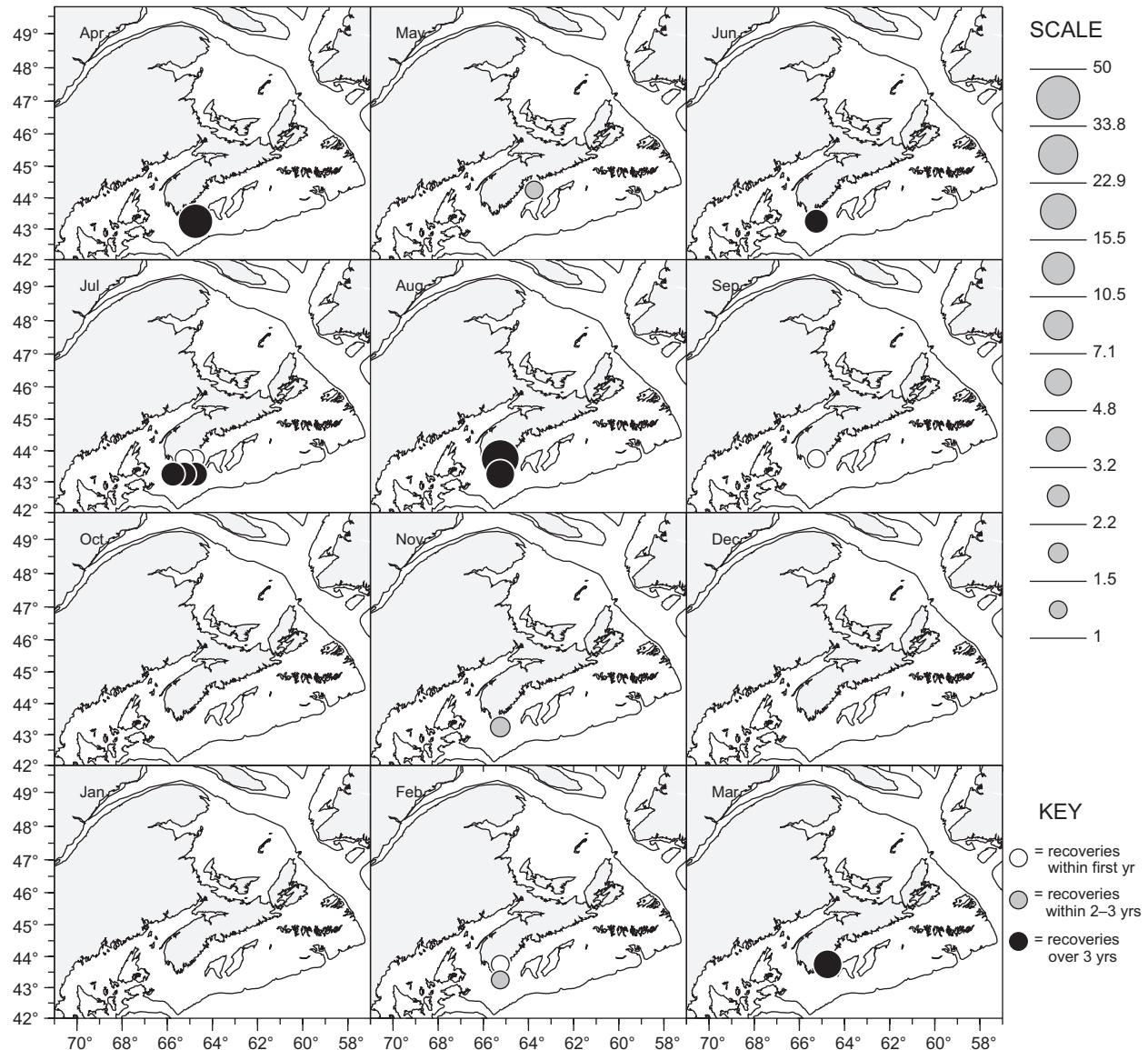


Fig. 8. Recoveries from American plaice tagged off Cape Sable during April of 1972. Tags are aggregated over five minute squares as scaled circles, the size of the circle proportional to the number of recoveries. Tags at large less than one year are plotted as open circles, tags at large 1–3 years as grey circles, and longer-term recoveries as black circles. Unplottable tags with months and locations known to NAFO Subarea are tabulated as short (s), medium (m) or longterm (l) on applicable graphs.

Bay of Fundy as far as Browns Bank on the Scotian Shelf (Fig. 7).

The 1973 group provided only three recoveries, and only one of these is plotted (it came from across the Bay of Fundy in October of 1974). A second tag was reported from the Jeffery Ledge area far to the west (near Portland, Maine) four years after tagging. Although anomalous, it is not implausible. The third tag lacked recovery information.

#### Cape Sable, April, 1972

These fish stayed very local to the tagging area (Fig. 8),

only one fish travelling far enough to leave 4Xo (recovered a little to the east in 4Xm). This impression is reinforced by consistency in locations of recaptures over successive years.

#### Shediac Valley, September, 1979

Successfully avoiding fisheries during the tagging process, the first recoveries from this group are the two November (1979) fish seen in the Chaleur Bay and Magdalen Shallows areas two months after tagging (Fig. 9). Other than these two fish, there were never any recoveries from October through March, even though recoveries from this group were plentiful and lasted for six years post-tagging.

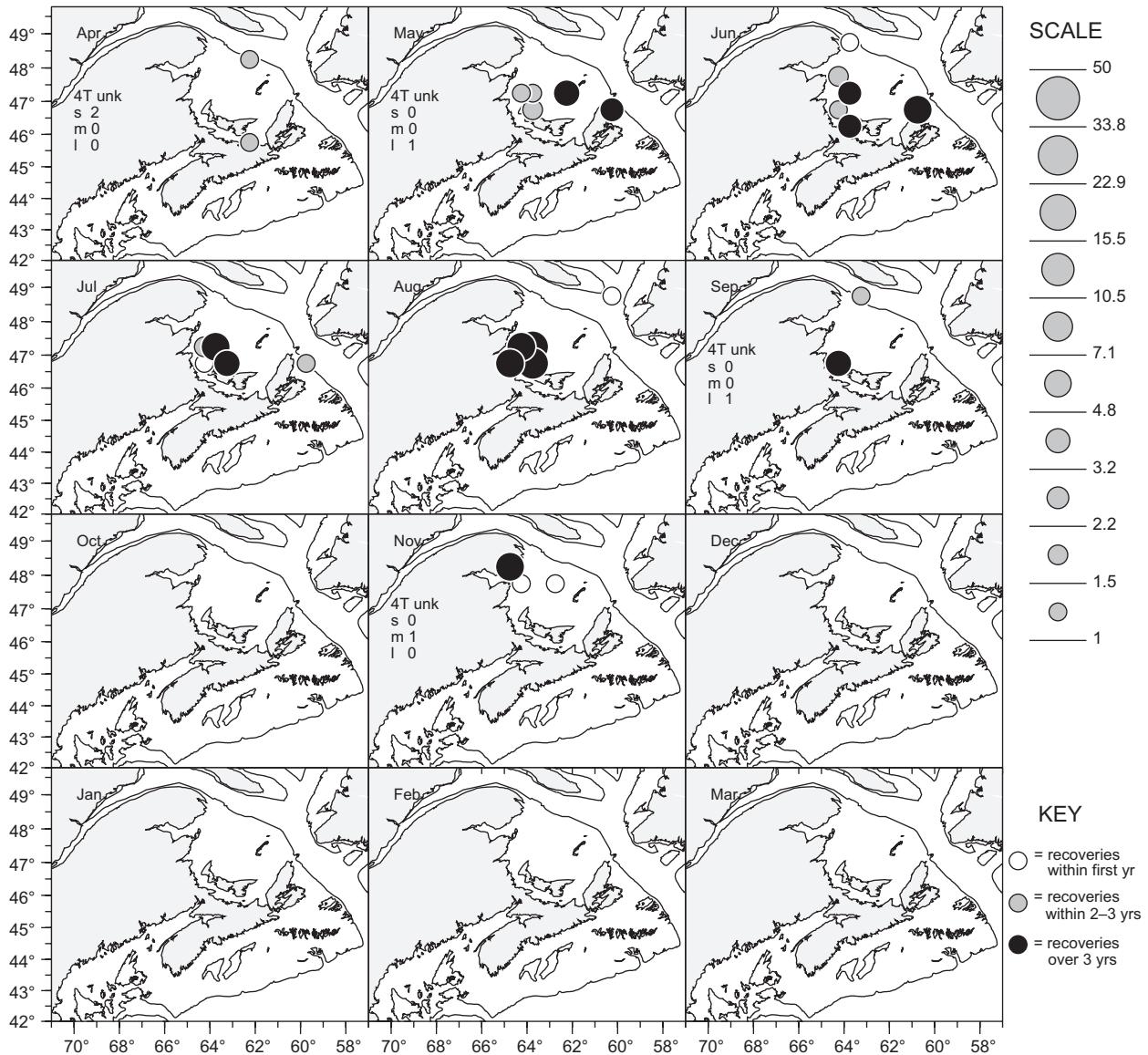


Fig. 9. Recoveries from American plaice tagged around Shediac Valley during September of 1979. Tags are aggregated over five minute squares as scaled circles, the size of the circle proportional to the number of recoveries. Tags at large less than one year are plotted as open circles, tags at large 1–3 years as grey circles, and longer-term recoveries as black circles. Unplottable tags with months and locations known to NAFO Subarea are tabulated as short (s), medium (m) or longterm (l) on applicable graphs.

They showed up in the Lip, Edge, Magdalen Shallows, Chaleur Bay and Shediac Valley fisheries in the spring and early summer. By July recoveries were concentrated in the Shediac Valley area where the fish were tagged. Returns were scarce from the area between Prince Edward Island and Cape Breton, which featured pronounced fishing on plaice throughout spring, summer and fall of 1979–1983 (Table 2).

#### Souris, September, 1979 and Cape Breton Trough, May–June, 1980

Fall tagging largely avoided active fisheries during Souris tagging operations, only 15 of the 200 recoveries from the Souris group occurring in the tagging year. The next recoveries from Souris fish start in April of 1980 and continue through 1987. The Trough tagging was immediately subject to active fishing, with a third of the recoveries occurring in the tagging year, but provided good returns through 1985. Recoveries of Souris and Trough fish exhibited a pattern of shifting their concentration from the Lip area in the spring to the Trough in the summer, back to the Lip in the fall, then with

some Laurentian Channel recoveries in the Sydney Bight area in November–December (Fig. 10). We never saw a recovery inside the Gulf during the typical period of sea ice formation from January to March. Nor did they appear in the Shetland Valley or Chaleur Bay fisheries, which were very active from May through September of 1980–1983 (Table 2). Two returns were reported from the southern coast of Cape Breton on the Scotian Shelf in September and November. In later years some of these fish were reported from Banquereau. A single August recovery on Browns Bank off southwest Nova Scotia occurred little over a year post-release. Such a long distance (over 400 miles) in such a short time seems unlikely.

#### **Halifax, February, 1979 and 1980**

Most of these fish were recovered locally, with a few moving offshore to Sable Island Bank (Fig. 11).

Table 2. Commercial landings (metric tons) in the southern Gulf of St. Lawrence, 1979–1983, by year, month and unit area. Does not consider landings unassociated with a specific month or unit area. (Data provided by Rod Morin, Gulf Fisheries Centre, Moncton, New Brunswick).

Area										Area									
Year	Month	4TF	4TG	4TH	4TJ	4TK	4TL	4TM	4TN	Year	Month	4TF	4TG	4TH	4TJ	4TK	4TL	4TM	4TN
1979	1	11	3				2	1		1982	1			0	1	3		3	
	2	15					2	1			2			1		0			
	3						5				3		20	0	3		0		
	4	238	23			229	0	0			4	11	63				1		
	5	231	382	8	1	44	87	211	52		5	112	297	27		12	257	10	46
	6	239	236	173	7	7	183	229	74		6	337	257	53	1	10	386	15	134
	7	180	344	240	2		85	14	17		7	386	216	19	4	32	131	9	80
	8	277	307	18	4	9	195	11	36		8	281	250	17	8	27	154	13	107
	9	17	176	97	2	74	380	42	26		9	185	236	23	4	45	153	14	106
	10	58	200	109	0	235	169	48	80		10	69	292	7	1	79	45	31	134
	11	85	303	1	0	249	32	19	92		11	12	360	0		18	13	5	104
	12	32	76	0		0	0	0			12	9	289			4	0		6
1980	1	1	0		0		3			1983	1		11	3				1	
	2						0				2		4	0			2		
	3						1				3		3	1			0		
	4	24	57			246	4		49		4	15	154			2		6	
	5	87	499	55	7	76	117	30	155		5	3	475	15		4	45		81
	6	204	548	143	9	3	176	2	104		6	119	413	43		24	349	17	78
	7	236	465	100	7	13	150	6	60		7	17	126	4	4	8	123	13	80
	8	171	323	54	3	58	261	34	82		8	69	187	4	4	15	312	27	36
	9	62	235	5	4	79	311	65	103		9	5	222	19	1	21	207	83	20
	10	21	290	29	0	65	165	63	259		10	22	292	1	3	31	70	41	93
	11	3	246	0	0	51	19	13	67		11	5	314			11	21	5	57
	12	16	68				2		3		12	13	119			0	3		
1981	1						4												
	2	0			1		1												
	3	6					0												
	4	131	70	0		39	4	0	11										
	5	54	409	103	21	11	232	19	53										
	6	31	343	100	18	48	324	7	30										
	7	183	449	85	7	62	167	4	28										
	8	78	555	44	2	126	388	14	58										
	9	118	298	3	1	168	426	50	79										
	10	18	320	16	2	137	62	49	108										
	11	2	114	9	0	39	24	3	60										
	12		133				0												

#### **Sydney Bight, June–July, 1997**

Recoveries from these fish were concentrated in the tagging area in every year from 1997 through 2000. Many were also taken by the Lip fishery throughout spring, summer and fall (Fig. 12). Small numbers were reported from near the Magdalen Islands and in the Cape Breton Trough during the summer, and from Banquereau in the fall. The only recovery during the months of December through April was a February report from 3Pd, directly across the Laurentian Channel from Sydney Bight.

#### **Discussion**

##### **General**

Interpreting results across widely disparate time periods, differing objectives, and changes in tagging strategies

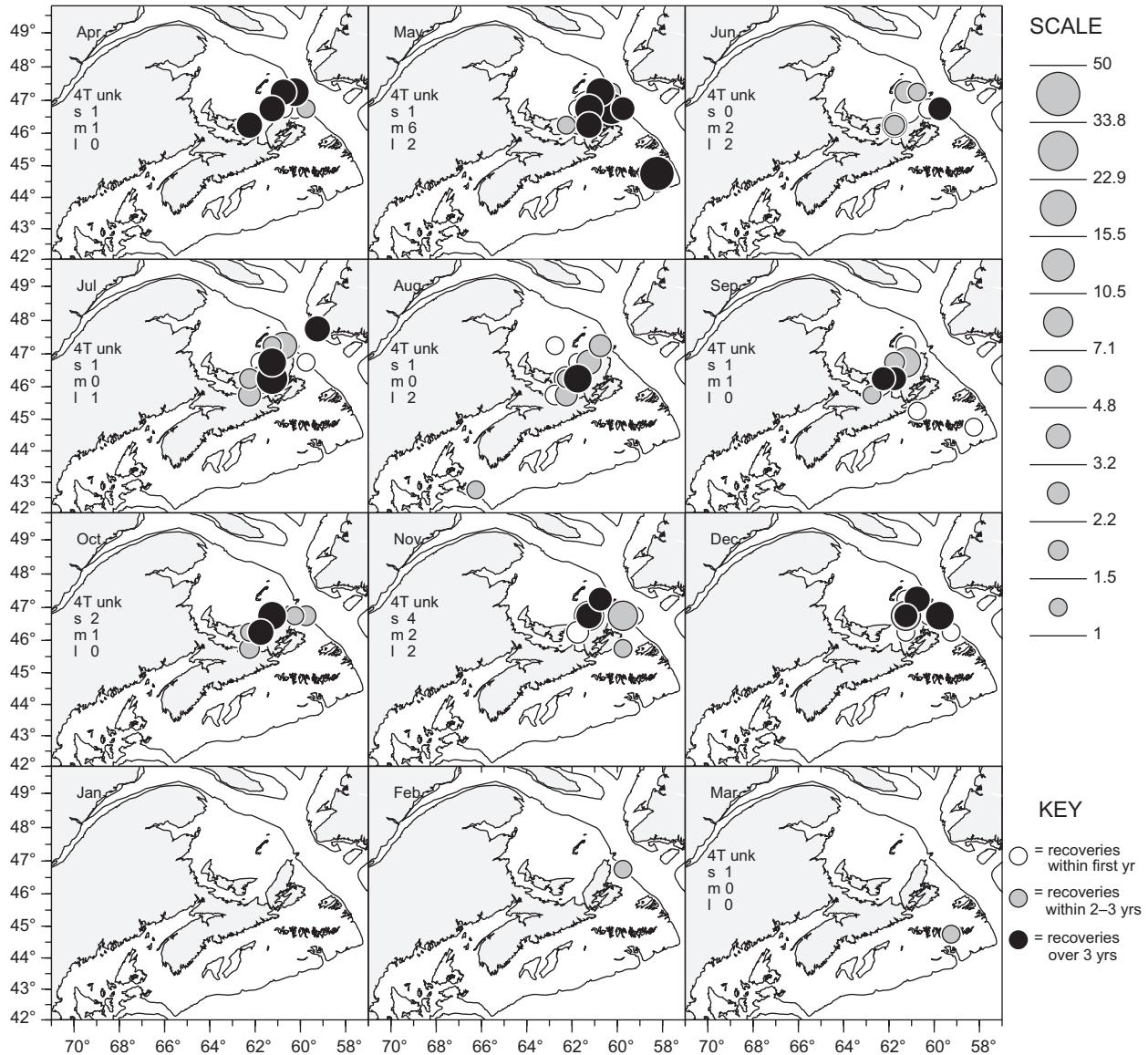


Fig. 10. Recoveries from American plaice tagged near Souris during September of 1979, and in the Cape Breton Trough during May–June of 1980. Tags are aggregated over five minute squares as scaled circles, the size of the circle proportional to the number of recoveries. Tags at large less than one year are plotted as open circles, tags at large 1–3 years as grey circles, and longer-term recoveries as black circles. Unplottable tags with months and locations known to NAFO Subarea are tabulated as short (s), medium (m) or longterm (l) on applicable graphs.

and methods, posed some considerations that have been addressed in earlier work and warrant some mention here. Tag recovery rates were much higher in the earliest years for all tagging studies, regardless of species. For plaice in the Southern Gulf of St. Lawrence about 41% of the tags attached during 1958–1963 studies were returned, while only about 7% of those applied during 1979–1980 studies were returned. Changes in the commonest tag types used, from Petersen discs prior to 1979, to T-bar anchor (spaghetti) tags since that time, would not have altered recovery expectations to the extents observed (Fowler and Stobo, 1991). In general, for all species the decline

was attributed as likely due to increasing automation in the processing of catches over time, coupled with decreasing inclination of the fishing industry by the late 1970s to return tags without knowing how the information might influence fishery management decisions (Fowler and Stobo, 1999). That recovery rates for plaice were among the most extreme examples of declines over time indicate a further effect of tagging strategy, the deliberate avoidance of active fisheries during the 1979–1980 tagging operations (*i.e.* the September 1979 Shediac Valley and Souris tagging, the February 1979 and 1980 Halifax tagging). Short-term recovery rates of plaice

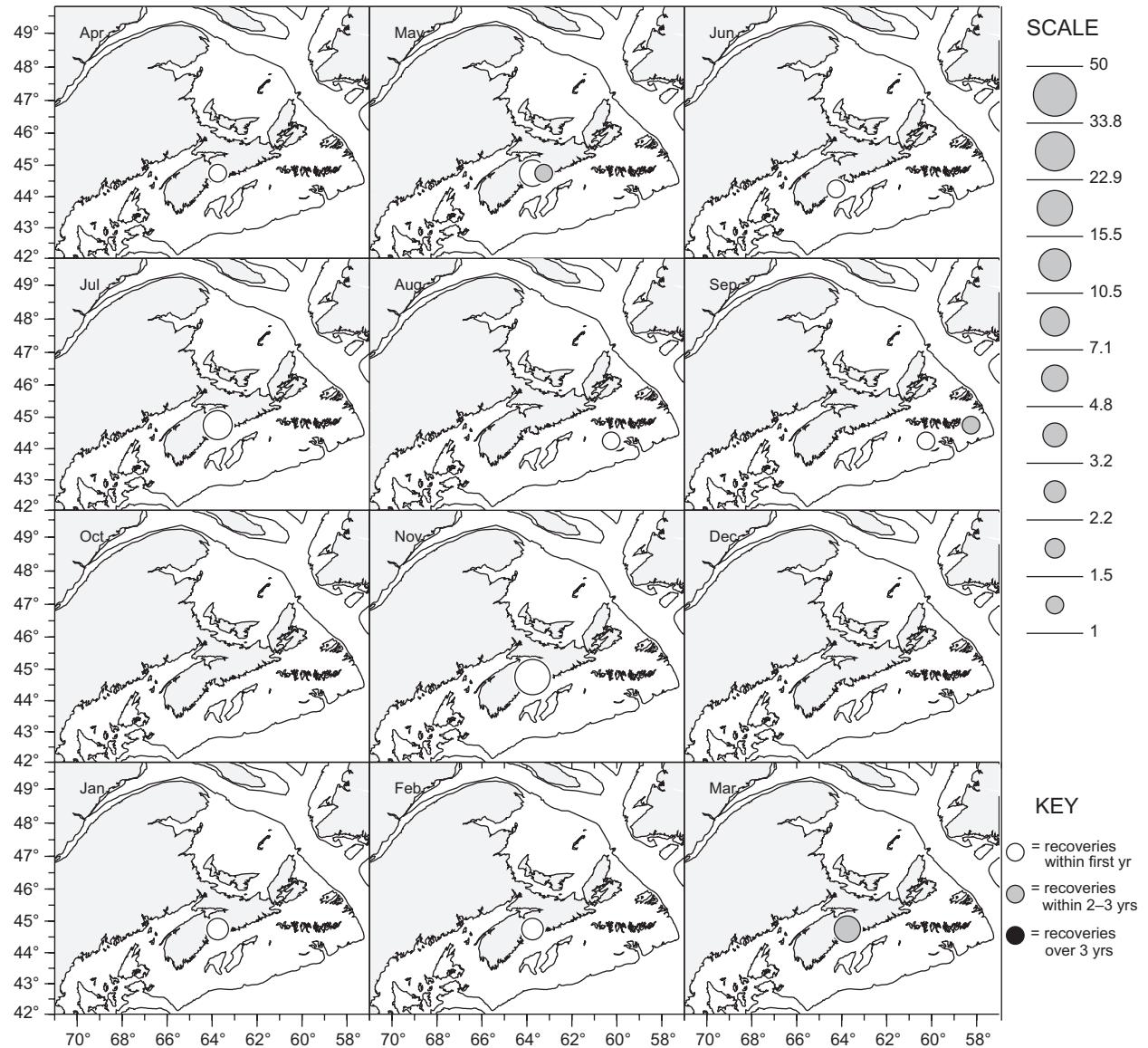


Fig. 11. Recoveries from American plaice tagged near Halifax during February of 1979 and 1980. Tags are aggregated over five minute squares as scaled circles, the size of the circle proportional to the number of recoveries. Tags at large less than one year are plotted as open circles, tags at large 1–3 years as grey circles, and longer-term recoveries as black circles. Unplottable tags with months and locations known to NAFO Subarea are tabulated as short (s), medium (m) or longterm (l) on applicable graphs.

from earlier tagging studies greatly exceeded those of the 1979–1980 tagging, while conversely long-term recovery rates from the 1979–1980 tagging exceeded those of the earlier tagging (Stobo and Fowler, 2006). Thus much of the difference in recovery rates for plaice between time periods is attributable to large proportions of recoveries that were temporally proximate to the tagging operations during the 1950s and 1960s.

The length of a plaice when tagged has been shown to be related to subsequent probability of recovery, with

smaller fish giving lower recovery rates (Fowler and Stobo, 1999). The chances of recovering fish under about 36 cm are especially problematic. Generally a wide size range of fish were tagged in all releases in the studies considered here (between 10–69 cm with a single fish at 86 cm), the majority being between 23–55 cm. Most groups with appreciable numbers of plaice under 36 cm are also characterized by substantial numbers of larger plaice as well. The 1979–1980 tagging of plaice off Halifax had the largest proportion of fish under 36 cm (about 80%), likely contributing to the low recovery rate of 4.9% for

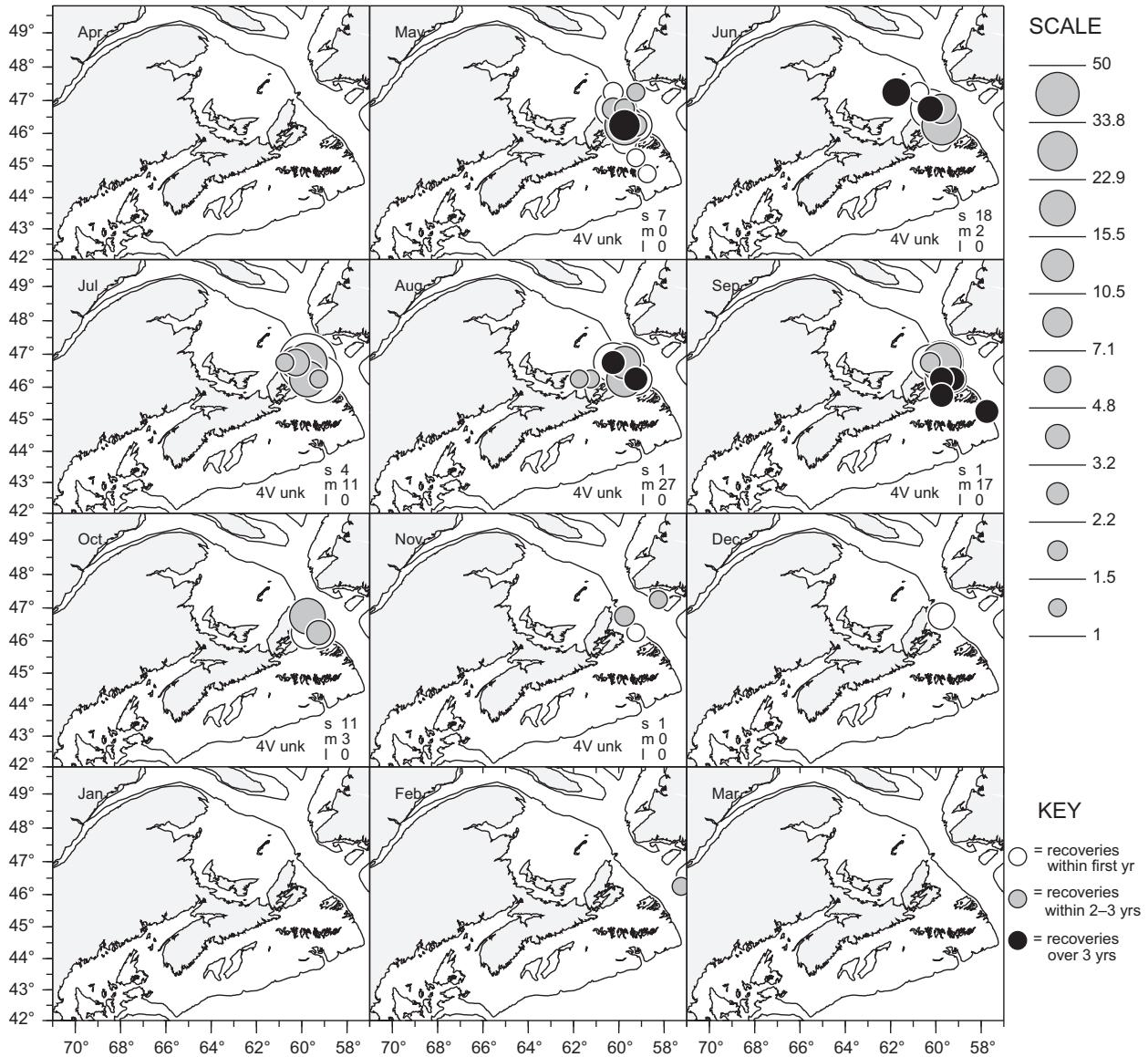


Fig. 12. Recoveries from American plaice tagged in Sydney Bight during June–July of 1997. Tags are aggregated over five minute squares as scaled circles, the size of the circle proportional to the number of recoveries. Tags at large less than one year are plotted as open circles, tags at large 1–3 years as grey circles, and longer-term recoveries as black circles. Unplotable tags with months and locations known to NAFO Subarea are tabulated as short (s), medium (m) or longterm (l) on applicable graphs.

this group. Within the few 36+ cm fish of this group the recovery rate was 21%.

#### Southern Gulf of St. Lawrence

The Canadian Research Report for 1958 reported 27% of tags recovered from June tagging in northern 4T (Martin, 1959), likely reporting on returns within the first year. The final recovery rate, unreported, was 42%. The Canadian Research Report for 1959 reported recoveries of 37% per

year in the Shippagan Gully area (lower mouth of Chaleur Bay) where concentrated fishing occurred in May–June (Martin, 1960). The Canadian Research Report for 1964 (Anon., 1964) reported that the study of American plaice in the Magdalen Shallows (shoal area between Chaleur Bay and the Magdalen Islands) was completed in 1963, concluding that two groups of plaice were present in the southwestern Gulf – a northern group in 4T (in and around Chaleur Bay) and a southern group in 4T/4V (Magdalen Islands/Sydney Bight). No details of temporal patterns

in movements were provided. It is unclear if the 1963 Cape Breton Trough and Cape North tagging studies were considered.

This analysis of all tagging studies in the Gulf of St. Lawrence combined (Fig. 13) also distinguishes the two subpopulations of plaice mentioned above, a southern group (Souris, Cape Breton Trough) and a northern group (Chaleur Bay, Shediac Valley, Orphan Bank). The region of the Magdalens Shallows near the Magdalen Islands seems a mixing area, demonstrating differing affiliations with northern and southern groups among tagging studies. From summer through fall, the northern group concentrates in waters encompassed by Prince Edward Island, Chaleur Bay, the Laurentian Channel, and the Magdalen Islands, while the southern group concentrates in the Cape Breton Trough area from Souris to Cape North. There appears to be a similar north/south separation during overwintering in the Laurentian Channel. Spring and late fall recoveries from southern studies were prevalent in the Lip fisheries (the protuberance in the Channel edge off Cape North), and winter recoveries were reported from the Sydney Bight area. Recoveries from northern studies are conspicuously absent or rare from the Lip fishery, and we never got an overwintering recovery from any of the northern groups of plaice (no recoveries were ever reported for January–March), suggesting they overwintered somewhere fishing did not occur, which would have been anywhere northwest of the Magdalens. Spring and fall tag returns from the northern studies may suggest the northern edge of the Channel near the Gaspe Peninsula might be the route of return, but this could be an artifact of lack of fishing effort along the edge of the Channel anywhere else north of the Magdalen Islands. Tallman (1991) also inferred that northern and southern Gulf plaice maintained a north-south orientation when overwintering in the Channel, postulating migratory routes perpendicular to the Channel based on relative distributions of size at age between areas. Concentrations of plaice in the Laurentian Channel near the Gaspe Peninsula are also evident from a November 1990 groundfish survey of the southwestern Gulf (Fig. 32b of Darbyson and Benoit, 2003).

Identification of two discrete groups of Gulf of St. Lawrence plaice concurs with the results of Powles (1965) investigation of the 1958–1963 tagging studies in the Gulf. Powles concluded northern and southern groups with no extensive movements by either group much beyond 4T. Lack of recoveries in the area between Prince Edward Island and the Magdalens is attributed to the rocky nature of the bottom, as plaice prefer sand/mud substrate. Although a 1965 paper, Powles only discusses the 1958–1960 tagging in any detail, and only through 1961 recoveries. Subsequently there were recoveries every year through 1969, with the last recovery in 1978. Powles mentions the 1963 tagging (George Bay), and notes mixing with North Bay (Cape Breton Trough) plaice

but none with northern 4T plaice, but does not present results as for the earlier tagging. Powles did not discuss overwintering locations or migration routes for these fish, and stated that interpretation of seasonal movements was confounded by the virtual absence of a fishery in winter. In Chaleur Bay fishing began in June and ended in November, while offshore and Magdalen Islands landings peaked in early summer and again in the fall. In later years the seasonal pattern to fishing effort underwent transition to favour stronger spring and fall Lip/Edge fisheries, a shift in effort reflected in the seasonal pattern of recoveries between time periods (Table 3). This probably denotes the greater offshore/weather durability and mobility of fishing effort in the more recent period, such that more effort could be directed on migratory concentrations in earlier and later months than previously. It may also reflect changing capabilities to fish at depth, as many of the plaice leaving for or returning from overwintering in the Laurentian Channel would be associated with greater depths than typically occupied on the shoals of the Gulf. A series of groundfish surveys conducted in the Channel during 1994–1996 depicted the depth and temperature preferences of plaice in January (Swain *et al.*, 1998), showing that overwintering plaice were rarely found shallower than 250 m, as compared to favouring depths well above 100 m in September.

Longer-term recoveries of the early Gulf studies that occurred after any published accounts offer some insight on the potential of older fish to migrate longer distances. Table 4 summarizes the proportions of fish by age, approximated from length at release then adding years at large, exceeding the mean overall distance of recoveries (28.3 nautical miles) from their tagging locations. Results

Table 3. Seasonal patterns in recoveries from Gulf of St. Lawrence tagging studies.

	1953–1963 Tagging Recoveries	1979–1980 Tagging Recoveries
January	1%	–
February	–	1%
March	–	1%
April	3%	8%
May	11%	17%
June	24%	9%
July	18%	15%
August	12%	11%
September	13%	9%
October	9%	10%
November	8%	13%
December	3%	7%

are tabulated by month to account for seasonal biases due to overwintering migrations of all ages to and from the Laurentian Channel. Older fish are generally recovered from more distant locations than younger fish, and the tendency to wander farther may be a continuous function of age (or size), as opposed to a simple change in behavior with maturity. The A50 of plaice in earlier studies was around 6/10 male/female, declining to around 4/6 by the time of the Sydney Bight tagging (COSEWIC, 2009), so the later studies may not offer contrast between juveniles and adults.

### Sydney Bight

An overwintering association between southern Gulf of St. Lawrence plaice and Sydney Bight (4Vn) was not discussed by Powles (1965). Assuming a cut-off date of 1961 to past analyses of recoveries from 1958–1960 studies, returns from outside the Gulf might have been too few to interpret comfortably. As well, there was no concern about the status or identity of Sydney Bight plaice at that time as there is today. Prior to 1963 Canadian fisheries anywhere in 4VW showed little interest in American plaice, while the Gulf of St. Lawrence supported a major fishery before any tagging studies were initiated (Fowler, 2012). Thus in 1965 when Powles reviewed the tagging results in light of fishing effort, 4Vn may not have been perceived as relevant to plaice fisheries. 4T plaice landings reported to NAFO during 1961–1965 were roughly two orders of magnitude higher than those from winter fishing in 4Vn. If we consider post-year-of-release recovery rates in 4T as proportionate to landings (effort), then winter landings of plaice in 4Vn were much too low to expect recoveries of any plaice overwintering there. Notably, Powles (1965) summarizes plaice landings for 1959–1961

to gauge ramifications of effort on expectations of recovery, yet only has headings for 4T areas, with no mention of any fishing in 4Vn.

By the time of the 1979–1980 tagging, fishing for plaice in 4Vn was well-established, with plaice subjected to quota management since 1974. Recoveries of southern 4T plaice (Trough and Souris tagging) in 4Vn became fairly common, and even a couple of northern 4T plaice were reported from 4Vn 3–4 years post-tagging. The general proportion of 4Vn recoveries increases with time post-release, and although showing some seasonal (spring and winter) bias, several show up as summer recaptures. Bight/Shelf recoveries from the 1979 Souris tagging were between 8 and 9% of total recoveries in 1980, but 24% of total recoveries for 1981–1987 combined. Similarly Bight/Shelf recoveries from the 1980 Trough tagging were 4% in 1980 and 25% for later years combined. This would fit with Powles (1965) observation that older fish show more mobility, it just appears more pronounced after plaice-directed fishing effort in 4Vn became common. This is also reflected in trends of increasing mean distance of recoveries from 4T tagging locations with time at large (Table 5). Distances are generally more pronounced for 1979–1980 tagging studies relative to the 1953–1963 tagging studies, as proportionately more recoveries came from outside the Gulf of St. Lawrence in the later period.

When the summer 1997 plaice tagging in 4Vn itself was conducted, there was little plaice fishing in 4T due to a cod moratorium. The 4T plaice TAC had been 10 000 t from 1978 until 1993, when it was halved to 5000 t. Then in 1996 it was reduced again to 2000 t, which has been the average TAC since that time. Most of the plaice caught in 4T since the closure of the cod fishery in 1993

Table 4. Dispersion with age. Recoveries of fish at liberty over one year, by month and age group, as proportions exceeding the mean distance of recoveries from the release location. Restricted to recoveries with latitude and longitude reported. Minimum three fish per cell.

Region	Age	Month								
		Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	
Gulf 1958–1963	6–9		0.40	0.25	0.00	0.40	0.11	0.00		
	10–13		1.00	0.14	0.47	0.33	0.17	0.25	0.33	
	14–16		0.33	0.26	0.25	0.50	0.25	0.50	0.20	
	17–29	1.00	0.80	0.57	0.75		0.66			
Gulf 1979–1980	6–10	1.00	0.44	1.00	0.40	0.13	0.30	0.40		
	11–14	0.33	0.25		0.63	0.38		0.60		
	15–21		0.57	0.80	0.50	0.20	0.00			
Sydney Bight	7–9		0.00	0.00	0.00	0.33	0.00	0.00		
	10–12		0.00	0.00	0.00	0.09				

have been taken in the eastern Gulf in Unit Areas 4Tf and 4Tg (Morin *et al.*, 2001). From 1997 through 2003 the 4VW TAC on all flatfish was 3000 t, of which plaice were typically about a third of the catch, a similar order of magnitude of effort to 4T. We see few recoveries of Sydney Bight tags outside the Bight, with only around 2% of total recoveries coming from 4T, suggesting that the plaice resident in Sydney Bight during the summer are largely distinct from 4T fish. As with the Souris and Trough groups tagged in 1979–80, the Bight plaice show an increasing proportion of distant recoveries with time (*e.g.* relative Gulf recoveries doubled from 1.4% in 1998 to 2.8% in 1999), which could reflect either a greater tendency to disperse with age or a higher mortality rate in the tagging area relative to adjacent waters.

The 1997 Sydney Bight tagging was informative, although recovery patterns may be somewhat confounded by lack of effort in historical fishing areas. We saw strong returns from the inner Bight area from May through November, as well as from the spring and fall Lip fisheries. However if these fish went deeper into the Gulf of St. Lawrence than observed, we still would not expect to see many recoveries from the western Gulf. The formerly strong fishery for plaice in the vicinity of Chaleur Bay went into sharp decline during 1992–1993, and fishing effort directed toward plaice has remained in the eastern Gulf since that time (Morin *et al.*, 2001). Nor might we expect to see recoveries from fish that moved south to Scotian Shelf waters, as landings of plaice from 4VsW almost ceased in 1993 due to moratorium regulations on cod and haddock. The magnitudes of effort in pertinent areas during 1997–2002 suggest weak prospects for recoveries beyond eastern Gulf of St. Lawrence waters and Sydney Bight. Over half the

recoveries are known to be attributable to just five boats (one the tagging vessel), and the proportions taken by these five boats remained high over all years but the last (0.55 in 1997, 0.46 in 1998, 0.69 in 1999, 0.80 in 2000, 0.50 in 2001, 0 in 2002). Most of the tags were recovered within the first three years. Of the few tags recovered from the Gulf of St. Lawrence (seven fish) and across the Laurentian Channel in Newfoundland waters (two fish), six of the seven Gulf recoveries could be substantiated.

We saw three successive years post-tagging of strong July–September returns from inner Sydney Bight waters. These are months for which southern Gulf plaice tagged in earlier years were conspicuously absent from Sydney Bight, and fishing effort was sufficient to expect recoveries of available plaice throughout all areas during the period of the 1979–1980 tagging studies. This demonstrates that the plaice resident in Sydney Bight during the summer are discrete from the southern Gulf of St. Lawrence plaice. However it provides no insight on whether they are also discrete from the subpopulation centred on Banquereau.

### Scotian Shelf and Bay of Fundy

Tagging information for Scotian Shelf and Bay of Fundy plaice derives entirely from inshore tagging studies, with no tagging of plaice on Banquereau, the densest concentration of plaice on the Shelf (Halliday, 1973; Scott, 1976). Returns from the inshore tagging suggest an inclination for the fish to eventually head offshore, but it does not look like a seasonally repeated movement. It appears to be a mix of random dispersal and directed movements towards preferred spawning and feeding grounds - Browns Bank for plaice tagged in the Bay of

Table 5. Mean distance (nautical miles) of recoveries from original tagging locations in the Gulf of St. Lawrence as a function of years at large.

Year at Large	1953–1963 Tagging		1979–1980 Tagging	
	Mean Distance	Recoveries	Mean Distance	Recoveries
1 <sup>st</sup>	19.36	420	31.59	137
2 <sup>nd</sup>	20.83	249	34.54	80
3 <sup>rd</sup>	34.28	79	39.67	52
4 <sup>th</sup>	30.10	40	32.03	26
5 <sup>th</sup>	57.33	21	37.72	18
6 <sup>th</sup>	32.95	9	42.42	3
7 <sup>th</sup>	66.37	8	—	3
8 <sup>th</sup>	8.82	3	52.81	2
9 <sup>th</sup>	60.09	6	—	—
10 <sup>th</sup>	28.73	1	—	—
12 <sup>th</sup>	40.99	2	—	—
13 <sup>th</sup>	76.48	2	—	—

Fundy, Sable Island Bank for plaice tagged near Halifax. The Browns Bank recoveries are especially interesting, as we have little more than historical fishery anecdotes to suggest that Browns Bank may have supported a discrete subpopulation of plaice in the past. We know from studies of mature female distributions (Neilson *et al.*, 1988) and the distributions of eggs and larvae (Nevinsky and Serebryakov, 1973) that it stands out as a likely spawning area, which might infer a locally resident population. If so, plaice in the Bay of Fundy may originate from drift of

Browns Bank spawning. Then as the fish grow and mature they become motivated to return to the spawning ground.

### Synthesis

The plaice currently defined as the Maritimes Designatable Unit by COSEWIC consist of three major known populations and two possible minor populations (Fig. 13). Gulf plaice show strong preferences over time for their original northern or southern affiliation, in terms of both

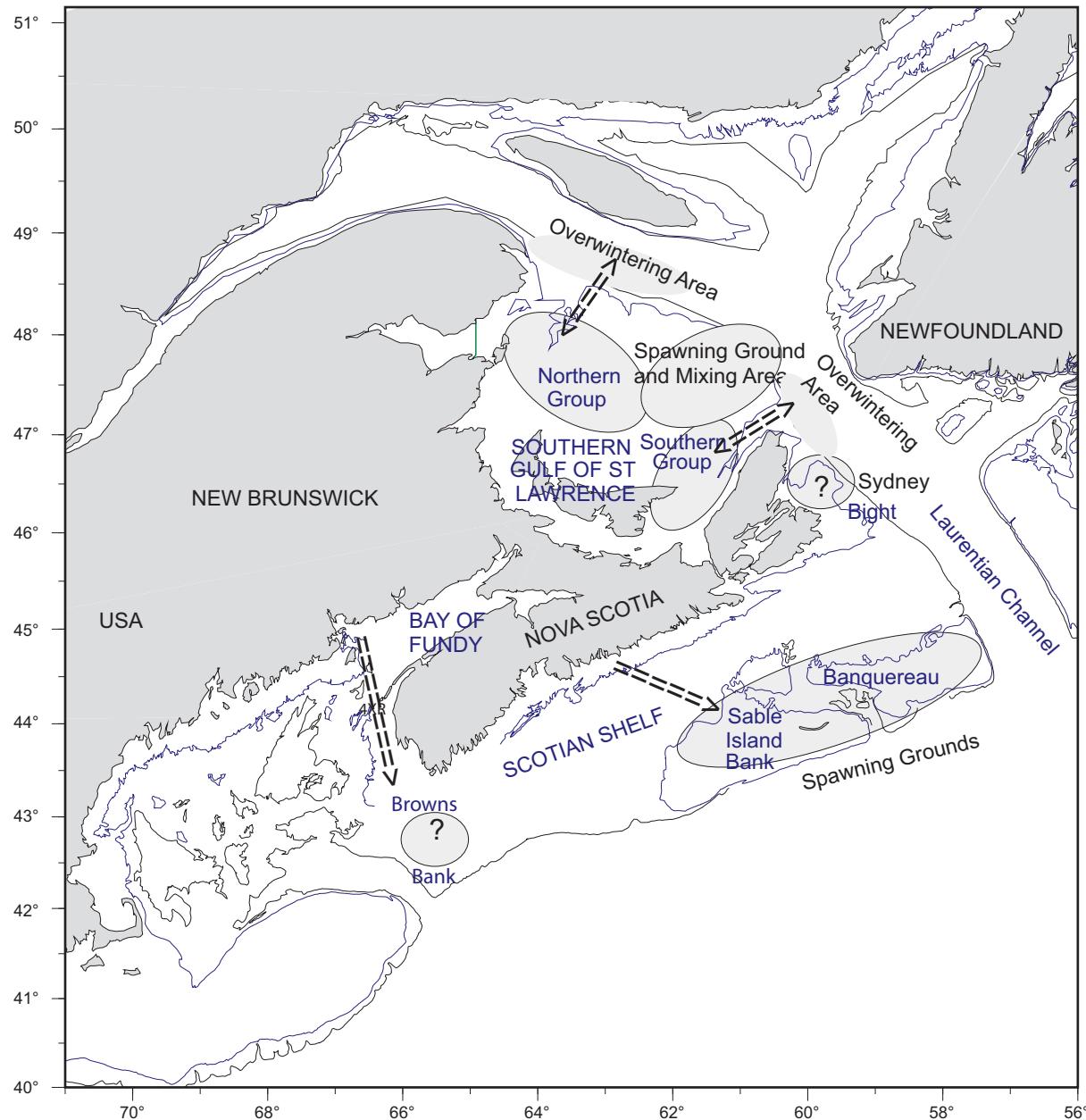


Fig. 13. Schematic portrayal of known and putative populations of plaice and principle movement patterns. Depth contours are at 100 m and 200 m.

summer feeding grounds and overwintering grounds. They mix to some extent in the spring on the spawning grounds of the Magdalen Shoals, but maintain their population coherence with limited crossover. Considering only recoveries that can be clearly distinguished by Unit Area as north (4Tl, 4Tk, 4Tl) or south (4Tg), all northern tagging groups combined produced 373 recoveries, of which only one came from 4Tg. And of 311 north-or-south recoveries from all southern tagging groups combined, eight (3%) came from 4Tkln.

Banquereau and Sable Island Bank together represent the centre of concentration of Scotian Shelf plaice, serving as both spawning and feeding grounds. As they have never been tagged on these grounds, we don't know how they might disperse, we can only see that inshore plaice tagged in adjacent areas will move offshore to them.

Sydney Bight plaice show a localized preference for the tagging area, and limited mixing with Gulf plaice. Of 707 recoveries, only seven came from the Gulf, and five of these were close to the border of 4Vn. We don't know, however, if Sydney Bight plaice are discrete from Banquereau plaice.

Spawning on overfished Browns Bank may be the primary source of plaice for the Bay of Fundy and waters off southwest Nova Scotia, but they could also derive from long-distance dispersal of Banquereau/Sable Island Bank larvae. The marginal abundances of plaice in 4X are equally supported by either hypothesis. Offshore movements of Bay of Fundy plaice in the direction of Browns Bank might argue for Browns Bank spawning as a source of 4X plaice, but this need not be exclusive of western Shelf spawning as a source.

### Conclusions

The possibility of long-term dispersion beyond stock boundaries suggested by plaice tagging might promote genetic mixing among populations of plaice, and offer some potential for recolonizing depleted areas. COSEWIC (2009) regards Gulf of St. Lawrence and Scotian Shelf plaice as belonging in the same Designatable Unit, with the caveat that they may be distinct populations (risk indices were calculated separately for the two components). As Gulf plaice are in greater jeopardy than Shelf plaice (rates of adult population decline over three generations of 92% in the Gulf versus 77% on the Shelf), prospects for recovery potential indicated by the tagging studies work in the wrong direction. The current evidence only demonstrates substantive movements of Gulf plaice to the Scotian Shelf, and not from the Scotian Shelf to the Gulf.

Sydney Bight plaice are our only example of movements into the Gulf from anywhere outside, and the identity of this component is in question. If Sydney Bight plaice are a discrete population, they are too few to consider as offering recovery prospects for the Gulf. As well, in

contrast to the long-term trends of declining tag recovery rates observed for plaice, and several other species of fish as well (Stobo and Fowler, 2006; Fowler and Stobo, 1999), about 25% of the Sydney Bight tags applied in 1997 were recovered. By today's standards that is a very high recovery rate, suggesting a high exploitation rate. Thus if Sydney Bight plaice are a discrete spawning component, the recovery rate may represent an unsustainable level of fishing mortality, and they could be in a worse state than the Gulf plaice. However if the plaice in Sydney Bight are marginal to the general population on the Scotian Shelf, this need not have implications for population status, it would just be local depletion.

The centre of concentration of plaice on the Scotian Shelf, Banquereau, has never been addressed by a tagging study, so it is not known how closely related these fish are to Sydney Bight plaice, or how they might contribute to recovery potentials of Gulf (or eastern Shelf) plaice. Further confounding attempts to predict recovery potential, the association between dispersal distance and age (Tables 4 and 5), coupled with the general loss of older fish across all major stocks of plaice (Busby *et al.*, 2007), would reduce likelihoods of movements between areas today relative to those observed in the past. At present, without knowing the movements of Banquereau plaice, it might be safest to assume larval survival and dispersal is more critical to recovery potentials than adult dispersal, at least in the short term, and protecting the spawning grounds could be pivotal to recovery of plaice populations.

Magdalen Shallows plaice mostly spawn mid-April to mid-May (Powles, 1965), a very brief spawning peak compared to plaice outside the Gulf of St. Lawrence. The timing of the spring return of Gulf of St. Lawrence plaice, reflected in monthly patterns of recovery rates (Table 3), coincides with that of spawning. This might imply that proportionately more of the population is available for reproduction in the Gulf of St. Lawrence than other populations of plaice. The short duration of the spawning period could facilitate spawning period/area closure to protect or enhance Gulf plaice.

On the Scotian Shelf spawning is protracted over several months, and we see no evidence from tagging of tightly-timed migrations to spawning grounds, just a general affinity of plaice for such areas at all times. The spawning grounds and the centres of abundance on the Shelf are synonymous, so directed movements to spawn are not critical to the population. A discrete Browns Bank spawning component, if it indeed did and still does exist, would be more vulnerable, and would likely require low fishing pressure over a fairly long period of time to re-establish a sustainable population.

A pervasive problem across all the tagging studies on plaice are temporal/spatial gaps in the possible occurrence of recoveries. As all the tags used in these studies require

that the fish be captured, we can perceive their movements only where fisheries are sufficiently prevalent. We cannot address movements of plaice in unfished areas (fishery undeveloped or under moratorium for an area). Today both Gulf and Shelf waters encompassing the largest concentrations of plaice are under fishery moratoriums or strictures that would confound the ability of capture tagging studies to determine movements. Newer satellite and acoustic tag technology, if sufficiently miniaturized, could be useful for filling in these gaps. When that occurs, the centre of abundance for Scotian Shelf plaice on Banquereau should be a top priority for investigation to determine their long-term affinities with Sydney Bight and Gulf of St. Lawrence plaice.

## References

- ANON. 1964. Canadian research report, 1964. B. Subarea 4. *ICNAF Ann. Proc.*, **14**, Part III: 39 p.
- BEACHAM, T. D. 1983. Variability in size and age at sexual maturity of American plaice and yellowtail flounder in the Canadian Maritimes region of the Northwest Atlantic Ocean. *Can. Tech. Rep. Fish. Aquat. Sci.*, **1196**: 75 p.
- BUSBY, C. D., M. J. MORGAN, K. S. DWYER, G. M. FOWLER, R. MORIN, M. TREBLE, D. M. PARSONS and D. ARCHAMBAULT. 2007. Review of the structure, the abundance and distribution of American plaice (*Hippoglossoides platessoides*) in Atlantic Canada in a species-at-risk context. *DFO Can. Stock Ass. Sec. Res. Doc.* 2007/069.
- COSEWIC. 2009. COSEWIC assessment and status report on the American Plaice *Hippoglossoides platessoides*, Maritime population, Newfoundland and Labrador population and Arctic population, in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. x + 74 p.
- DARBYSON, E. and H. P. BENOIT. 2003. An atlas of the seasonal distribution of marine fish and invertebrates in the southern Gulf of St. Lawrence. *Can. Data Rep. Fish. Aquat. Sci.*, No. **1113**: iii + 294 p.
- FOWLER, G. M. and W. T. STOBO. 1991. Comparative recoveries of spaghetti tags and Petersen disc tags on Atlantic cod (*Gadus morhua*) and American plaice (*Hippoglossoides platessoides*). *J. Northw. Atl. Fish. Sci.*, **11**: 39–42. <http://dx.doi.org/10.2960/J.v11.a4>
- FOWLER, G. M. and W. T. STOBO. 1999 (a). Effects of release parameters on recovery rates of tagged groundfish species. *Can. J. Fish. Aquat. Sci.*, **56**: 1732–1751. <http://dx.doi.org/10.1139/cjfas-56-10-1732>
- 1999 (b). Reconciliation of processed catch statistics with log data for 1992–1997 flatfish in 4vwx/5y. *DFO Can. Stock Ass. Sec. Res. Doc.*, **99/149**.
2000. Status of 4VW American plaice and yellowtail flounder. *DFO Can. Stock Ass. Sec. Res. Doc.*, **2000/144**.
- FOWLER, G. M. 2012. Investigating Reference Points for American Plaice on the Scotian Shelf (4VWX). *DFO Can. Sci. Advis. Sec. Res. Doc.*, **2012/030**. ii + 13 p.
- HALLIDAY, R. G. 1973. The flatfish fisheries of the Scotian Shelf. *ICNAF Res. Doc.* 73/102.
- LETTACONNOUX, R. H. 1965. Summaries of research and status of fisheries, by subareas for 1964. 3. Subarea 4. *ICNAF Ann. Proc.*, **14**: 38–40.
- MARTIN, W. R. 1959. Canadian research report, 1958. B. Subareas 4 and 5. *ICNAF Ann. Proc.*, **9**, Part III: 26–31.
1960. Canadian research report, 1959. B. Subareas 4 and 5. *ICNAF Ann. Proc.*, **10**, Part III: 25–31.
- MORIN, R., I. FOREST and G. POIRIER. 2001. Status of NAFO Division 4T American plaice, February 2001. *DFO Can. Sci. Advis. Sec. Res. Doc.*, **2001/023**.
- NEILSON, J. D., E. M. DEBLOIS and P. C. F. HURLEY. 1988. Stock structure of Scotian Shelf flatfish as inferred from ichthyoplankton survey data and the geographic distribution of mature females. *Can. J. Fish. Aquat. Sci.*, **45**: 1674–1685. <http://dx.doi.org/10.1139/f88-198>
- NEVINSKY, M. M. and V. P. SEREBRYAKOV. 1973. American plaice, *Hippoglossoides platessoides platessoides* Fabr., spawning in the Northwest Atlantic area. *ICNAF Res. Bull.*, **10**: 23–36.
- POWLES, P. M. 1959. Plaice studies. In: Annual Report and Investigators' Summaries, 1958–59. J. L. Hart [director]. Fisheries Research Board of Canada, Biological Station, St. Andrews, N.B. p. 56–58.
1963. Plaice tagging experiments, 1958–1961, Magdalen Shallows, 1962–63. In: Annual Report and Investigators' Summaries, J. L. Hart [director]. Fisheries Research Board of Canada, Biological Station, St. Andrews, N.B., p. C36–C39.
- POWLES, P. M. 1965. Life history and ecology of American plaice (*Hippoglossoides platessoides* F.) in the Magdalen shallows. *J. Fish. Res. Bd. Can.*, **22**: 565–598.
- SCOTT, J. S. 1976. Summer distribution of groundfish on the Scotian Shelf 1970–'74. *Fish. Mar. Serv. Res. Dev. Tech., Rep.*, **635**: 51p.
- STOBO, W. T. and G. M. FOWLER. 2006. Canadian tagging of commercial groundfish and small pelagic fish in the vicinity of the Scotian Shelf and Gulf of St. Lawrence, 1953–1985. *Can. Tech. Rep. Fish. Aquat. Sci.*, **2669**: xii + 137 p.
- SWAIN, D. P., G. A. CHOUINARD, R. MORIN and K. F. DRINKWATER. 1998. Seasonal variation in the habitat associations of Atlantic cod (*Gadus morhua*) and American plaice (*Hippoglossoides platessoides*) from the southern Gulf of St. Lawrence. *Can. J. Fish. Aquat. Sci.*, **55**: 2548–2561. <http://dx.doi.org/10.1139/f98-122>
- TALLMAN, R. F. 1991. Causes of within-season decline in the size at age of American plaice, *Hippoglossoides platessoides*. In J.-C. Therriault [ed.] The Gulf of St. Lawrence: small ocean or big estuary? *Can. Spec. Publ. Fish. Aquat. Sci.*, **113**: 269–275.



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