Fisheries and Oceans Canada | Pêches et Océans Canada
Science | Sciences

C S A S | **S C C S**

Canadian Science Advisory Secretariat | **Secrétariat canadien de consultation scientifique**

Research Document 2006/093 | **Document de recherche 2006/093**

Not to be cited without permission of the authors *

Ne pas citer sans autorisation des auteurs *

Distribution, Abundance, and Life History of *Malacoraja senta* (Smooth Skate) in Canadian Atlantic Waters With Reference to its Global Distribution

Répartition, abondance et cycle biologique de *Malacoraja senta* (raie à queue de velours) dans les eaux atlantiques canadiennes par rapport à sa répartition globale

Kulka, D.W.[1], D. Swain[2], M.R Simpson[1], C.M. Miri[1], J. Simon[3], J. Gauthier[4], R. McPhie[5]
J. Sulikowski[6] and L. Hamilton[3]

Fisheries and Oceans Canada

[1]Northwest Atlantic Fisheries Centre, P.O. Box 5667
St. John's, NL, Canada A1C 5X1

[2]Gulf Fisheries Centre, P.O. Box 5030
Moncton, NB, Canada E1C 9B6

[3]Bedford Institute of Oceanography, P.O. Box 1006
Dartmouth, NS, Canada B2Y 4A2

[4]Institut Maurice-Lamontagne, C.P. 1000
Mont-Joli, QC, Canada G5H 3Z4

[5]Dahousie U.
1355 Oxford St. Halifax NS, Canada B3H 4J1

[6]U. New England
11 Hills Beach Rd., Biddeford, ME 04005

ISSN 1499-3848 (Printed / Imprimé)

Canada

ABSTRACT

Under the Canadian *Species At Risk Act* (SARA), the *Committee On the Status of Endangered Wildlife In Canada* (COSEWIC) is responsible for assessing extinction risk of terrestrial and aquatic species that occur within Canada including in the surrounding oceans within jurisdictional limits. As part of the initial process of assessing extinction risk for an aquatic species, the Department of Fisheries and Oceans Canada examines pertinent data for which they are the custodian. Available information is reviewed regarding the taxonomy, distribution, abundance, life history and ecology of *Malacoraja senta* (*Smooth skate*) in Canadian Atlantic shelf waters as well as anthropogenic influences. Our study also includes adjacent USA waters to encompass the global range of the species. *M. senta* ranges from Lat 40^o, southern Georges Bank to Lat. 56.5^o in the Hopedale Channel on the Labrador Shelf. It most commonly occurs in the troughs separating banks within a depth range of 70-480 m, considerably shallower than it four congeners. It commonly occupies a temperature range of 2.7-10^o C, seldom found in <0^o C. It occupied 585,000 km2 (total area where it was observed between 1971 and 2005). It occurred in five distinct areas (treated here as Designatable Units or DU's) separated by large areas where none were observed. It is uncertain whether the five DU's constituted separate reproductive, genetically distinct units. Each of the five concentrations underwent changes in abundance to varying degrees and the largest decline occurred in the Funk Island Deep.

RÉSUMÉ

En vertu de la *Loi canadienne sur les espèces en péril* (LEP), le *Comité sur la situation des espèces en péril au Canada* (COSEPAC) est chargé d'évaluer le risque de disparition des espèces terrestres et aquatiques occupant les eaux du Canada, y compris celles à l'intérieur des limites de compétence canadienne. Dans le cadre du processus initial d'évaluation du risque de disparition d'une espèce aquatique, le ministère des Pêches et des Océans du Canada examine les données pertinentes dont il a la garde. Il passe en revue les renseignements disponibles concernant la taxonomie, la répartition, l'abondance, le cycle biologique et l'écologie de *Malacoraja senta* (raie à queue de velours) qui fréquente les eaux du plateau atlantique canadien ainsi que les incidences anthropiques. Sont également incluses au processus les eaux adjacentes des États-Unis puisqu'elles font partie de l'aire de répartition globale de l'espèce. Cette aire s'étend du 40^{o} de latitude, au sud du banc Georges, jusqu'au $56,5^{o}$ de latitude, dans le chenal Hopedale, sur le plateau continental du Labrador. La raie à queue de velours occupe généralement des creux entre les bancs, à des profondeurs s'étendant de 70 à 480 m, et fréquente donc des zones beaucoup plus profondes que ses quatre congénères. Elle préfère généralement des eaux dont la température varie entre 2,7 et 10^{o} °C et a rarement été observée dans des eaux affichant une température < 0^{o} C. Elle occupe une superficie de 585 000 km^2 (aire totale où elle a été observée entre 1971 et 2005). Cette espèce a été trouvée dans cinq zones distinctes (appelées unités désignables ou UD) qui sont séparées par de larges zones où aucun individu n'a été observé. On ne sait pas avec certitude si les cinq UD constituent des unités de reproduction génétiquement distincte. L'abondance de chacune des cinq unités a fluctué à des degrés variables, le plus important déclin ayant été enregistré dans la fosse de l'île Funk.

INTRODUCTION

The smooth skate *Malacoraja senta* (Garman 1885), formerly included in the genus *Raja* was moved to *Malacoraja* by McEachran and Dunn (1998). This genus, collectively known as soft skates due to the small size and paucity of body spines contains only four species, distributed solely in the Atlantic Basin. *M. senta* is endemic to the shelf off North America having been recorded from the Carolinas to the Labrador Shelf (Kulka et al. 1996; McEachran 1973; McEachran and Musick 1975; Templeman 1965). Other congeners are *M. spinacidermis* (Barnard 1923), also inhabiting the northwest Atlantic slope waters, *M. kreffti* (Stehmann 1977), found only in the northeast Atlantic and mid-Atlantic Ridge and *M. obscura* recently discovered on the Brazilian continental slope (de Carvalho et al. 2005).

All species of the genus *Malcoraja* are relatively small. *M. senta* is distinguished from its congeners by spines that are larger toward the front of the tail but disappear with age on the posterior extent of tail, by few scapular spines and a group of small spines in front of and around each eye. Adults have one mid-dorsal row of numerous small spines extending forward to the area behind the eyes and one row of small spines on each side. Juveniles have two distinctive pale crossbars on the tail, each outlined by a dark band. Colouration is variable, the upper surface pale brown with irregular markings. The lower surface of the disk is white with few small dusky spots (McEachran and Dunn 1998; Campagno 1999). It is one of the smallest (66 cm TL_{max}, 1.2 kg) species of skates endemic to the northwest Atlantic Ocean (McEachran 2002).

Although there are no directed commercial fisheries for *M. senta* over its range, it is taken in mixed fisheries or as bycatch in fisheries targeting other species (NOAA 2000a; Kulka 1986). However, vulnerability to exploitation, even when incidentally captured at low levels has been documented for various elasmobranch species. Frisk et al. (2001) with their analyses for several northwest Atlantic skates supported the notion that long-lived, slower growing, late maturing species are vulnerable to exploitation as evidenced by world declines in this taxon (Dulvy et al. 2000; Dulvy et al. 2002; Roberts and Hawkins 1999). Low reproductive potential brought about by to slow growth, late sexual maturation, low fecundity, and long reproductive cycles (referred to as K-selected, Winemiller and Rose 1992) result in low intrinsic rates of increase (Smith et al. 1998) and is thought to lead to low resilience to fishing mortality (Hoenig and Gruber 1990; Musick et al. 2000; Musick 2004).

COSEWIC (the Committee on the Status of Endangered Wildlife in Canada) has chosen to evaluate the status of this species in Canadian waters in terms of risk of extinction. However, as is typically the case for elasmobranch species, published information on *M. senta* is limited. Information on maturity has only recently been reported by Sulikowski et al. (in press) for the Gulf of Maine. Generalized habitat preferences have been summarized by Packer et al. (2003)

for the same area. Information on diet was described by González et al. (2006) for the Flemish Cap and by McEachran (1973), McEachran et al. (1976), Bowman et al. (2000), McEachran (2002) and Garrison and Link (2000) for the Gulf of Maine. Little is known about their distribution, population structure or age and growth. Previously, the only information on distribution and trends in abundance were those reported for the Gulf of Maine (NOAA 2000b), in the southern Gulf of St. Lawrence (Swain et al. 2005) and on the Scotian Shelf (Simon and Comeau 1994).

The purpose of this paper is to examine the distribution and trends in abundance over its global range (Fig. 1) and consolidate what is known about the life history of the species, in particular, growth, maturity, population structure and other information that can be used in formulating appropriate conservation and management actions in terms of extinction risk.

METHODS

SURVEYS

Scientific surveys in the Canadian Atlantic are presently administered by four different Regions: 1) Newfoundland and Labrador (NL); 2) Quebec; 3) Gulf; and 4) Maritimes. This administrative separation has led to differences in survey trawl gears used with different catchability, seasons and years surveyed over the global distribution of *M. senta*. Figure 2 illustrates the delineation of these Regions, and the Northwest Atlantic Fisheries Organization (NAFO) statistical Divisions that are traditionally used in commercial fishery assessments to subset these areas. However, there is a degree of consistency: all Regions use trawl gear and a stratified random survey design. Given the regional nature of survey activity by Fisheries and Oceans, the information is presented on a regional basis. As well, an integrated analysis at the point of overlap of Regions was attempted. The following sections elaborate the regional differences in survey time periods, gears, and seasons.

NL Region

Several demersal trawl gears have been deployed over the life of the NL Region surveys for the purpose of estimating biomass and abundance: Yankee-41.5 trawl, spring surveys until 1983; Engel-145 Hi-lift, fall surveys from 1977 to 1995 and for spring surveys, 1984-96; a Campelen-1800 shrimp trawl, fall of 1995 to date for both spring and fall surveys. While survey design has remained constant, additional strata have been included in recent years along with modifications to some of the original strata (Bishop 1994). One of the recent significant changes in the surveys is the addition of shallower (<~50 m) and deeper strata (>~700 m) after 1993 although sets at depths <50 m were occasionally recorded in earlier years (Table 1).

NL demersal trawl surveys employed a random stratified design, strata based on depth and latitude. A summary of the stratified-random survey design (adopted by the DFO - NL Region after 1970) can be found in Doubleday (1981). The surveys were originally designed to provide estimates of abundance for the major groundfish species such as cod (*Gadus morhua*). However, *M. senta* distributes in a similar set of depth and latitude ranges and thus, the survey footprint adequately covers the range of *M. senta*.

Survey series from Labrador Shelf to Grand Banks were used to estimate abundance of *M. senta* in spring 1975-2005 (Divs. 3LNOPs) and fall 1977-2005 (Divs. 2HJ3KLM) corresponding to periods when the areas were surveyed consistently (Fig. 2-4). Calculations were done separately for *M. senta* <48 cm (juveniles) and adults (>=48 cm) and indices were expressed as number per standard tow.

STRAP2 is a routine that calculates areal expansion of survey tracks to the total area within a series of predefined strata related primarily to depth (Smith and Somerton 1981). These stratum estimates are added over the survey area to yield an index of stock size. Similarly, STRAP1 (Smith and Somerton 1981) was used to estimate numbers at length for predefined depth strata, facilitating length-based analyses. Total abundance at length was then calculated as the sum of the stratum estimates for each length group over the survey area.

The most significant alteration in NL survey design was a change in gear in the autumn of 1995 from Engel-145 to Campelen-1800 trawl. Visual inspection of the size composition and catch rate of captured *M, senta* indicate that the two gears have very different catchability for *M. senta*. While size-based conversion factors were derived from comparative surveys for major commercial fish species, this exercise was not done for “minor” species, including skates. Thus, estimates of survey catch rate for the periods prior to the fall of 1995 and post-1995 are on a different scale.

Due to variations in the surveyed strata among years, estimates of catch rates were calculated for the entire survey (= ALL), and for a restricted series of strata (= INDEX) that were sampled every year over the entire time period.

Quebec Region

For the northern Gulf of St. Lawrence, data from four annual demersal trawl surveys were examined. In general, the surveyed area includes the Div. 4RS, Subdiv. 3Pn as well as strata deeper than 183 m (100 fathoms) in Div. 4T, including the Lower St. Lawrence Estuary (Fig. 2 and 5). The sampling methodology follows a depth-stratified random survey design as described above (Fig. 6). These series are not directly comparable because a number of conditions have changed over time: vessel, gear, time of year and surveyed area

(Table 2). Catches for each survey series were adjusted to respective survey standard tow.

Gadus Atlantica surveys were conducted yearly in January from 1978 to 1994 with an Engels-145 trawl (no survey in 1982). The area surveyed varied over the series, mainly due to ice cover preventing fishing. The average area covered is 62,550 km^2 with the smallest area in 1992 amounting to 31,737 km^2 and the largest in 1980 at 100,400 km^2. Coverage of Subdiv. 3Pn and Div. 4R was relatively consistent over the series while coverage in Div. 4T and 4S were more variable. The estuary contained within strata 409–414 (Fig. 6) was not surveyed. This survey was abandoned in 1994.

Lady Hammond surveys took place in August from 1984 to 1990. A Western-IIA trawl was used for this series. The total area surveyed was fairly constant from 1985 to 1989 averaging 95,700 km^2. However, 1984 (75,400 km^2) and 1990 (43,500 km^2) were not equally covered. In this survey Subdiv. 3Pn was not sampled and the estuary strata were only well covered in 1987 and 1988.

From 1990 to 2005, the survey was conducted by the *Alfred Needler* equipped with a URI (University of Rhode Island) shrimp trawl (Bourdages et al. 2003). A comparative fishing experiment was conducted between the *Lady Hammond* and the *Alfred Needler* but conversion factor have not been developed for *M. senta*. Even for species for which they were estimated, conversion factors could not be calculated for the smaller size groups, given the very different selectivity of the gears.

Additional shallow strata (37-92 m, 20–50 f) were added at the onset of the *Alfred Needler* survey. Over the series, the surveyed area averaged 111,300 km^2, the minimum area covered was in 1990 (95,070 km^2) and the maximum in 1995 (119,000 km^2). Subdiv. 3Pn was sampled from 1994 to 2003 and the estuary was well covered. A comparative fishing experiment was planned for 2004 in an attempt to change from the *Alfred Needler* –URI survey to *Teleost* – Campelen. However, the *Alfred Needler* was unavailable for 2004. The *Teleost* surveyed the northern Gulf in 2004 and the comparative fishing survey was postponed to 2005. A conversion factor at length was calculated for *M. senta* but the converted data were not ready for this review.

In 2004-06, the northern Gulf of St. Lawrence has been surveyed with the *Teleost* equipped with a Campelen gear (Bourdages et al. 2004). The surveyed area varied from 91,600 to 116,115 km^2 but Subdiv. 3Pn was not covered.

Gulf Region

Annual demersal trawl surveys were conducted in the southern Gulf of St. Lawrence in September since 1971. Surveys used a stratified random design, with stratification based on depth and geographic region (Fig. 7). Trawling was conducted at 63-74 sites each year from 1971 to 1983, 82-132 sites in 1984-88 and 141-202 sites in 1989-2005 (except 2003, when only 83 stations were successfully fished). The target fishing procedure in all years was a 30-min tow at 3.5 knots. All catches were adjusted to a standard tow of 1.75 nautical miles.

Survey coverage was expanded in 1984 to include three inshore strata (401-403, Fig. 7). Analyses presented here are restricted to the 24 strata fished since 1971 (strata 415-439). Of these 24 strata, two (424 and 428) were not fished in 1978, while stratum 421 was not fished in 1983 and 1988. In order to maintain a consistent survey area, in the years when these strata were not fished their weights were added to those of neighboring strata in the same depth zone in calculations of stratified mean catch rates and distribution indices. For example, in 1978, half the weight associated with stratum 424 was apportioned to stratum 423 and half was apportioned to stratum 422. In 2003, strata 438 and 439 were not fished. In this case, predicted values for the mean catch rate in these strata were obtained using generalized linear models with terms for year and stratum. Models used a log link and assumed a Poisson error distribution allowing for over-dispersion. This analysis was restricted to 2002–04 to avoid effects of changes in *M. senta* distribution.

Surveys were conducted using a Yankee-36 trawl from 1971 to 1985 and a Western-IIA trawl since 1985. The research vessels conducting the survey were the *E. E. Prince* from 1971 to 1985, the *Lady Hammond* using a Western-IIA trawl in 1985-91, the *Alfred Needler* in 1992-2002, the *Wilfred Templeman* in 2003, and both the *Alfred Needler* and the *Teleost* in 2004 and 2005. Comparative fishing experiments conducted in the southern Gulf during or shortly before the September survey in 1985, 1992, and 2004-05 failed to detect any differences in fishing efficiency for *M. senta* among these vessels (and gears). No comparisons were conducted with the *Wilfred Templeman* using a Western-IIA trawl.

Fishing was conducted only during daylight hours (07:00-19:00) in 1971-84 but 24-h per day since 1985. Catches were adjusted for diel differences in fishing efficiency, as described in Benoît and Swain (2003). *M. senta* had higher catchability at night than in day, and night catches were adjusted to be equivalent to day catches. The adjustment required appeared to be independent of length.

Maritimes Region

Five trawl survey data sources from the Scotian Shelf were examined for the presence of *M. senta*. The summer, 4VWCOD and Georges Bank research trawl surveys commenced in 1970, 1986 and 1986 respectively. The fall RV survey was conducted from 1978 to 1984, while the deep-sea redfish survey was conducted from 198 to 1988. Details for each of the individual survey series, in terms of location, gear type, time of year, duration and sampling effort, were documented during the winter skate National Assessment Process (NAP) in 2003 (Simon et al. 2003). Described below, they cover virtually all of the continental shelf waters in NAFO Div. 4VWX and 5Z, except untrawlable bottom and near shore waters (Fig. 8).

The summer survey uses a stratified random design based on depth and geographic area (Fig. 8 and 9). In 1995, coverage was expanded into three deep strata at the edge of the Scotian Shelf, but data from these areas have not been included in our analyses given the very low catches of *M. senta*. From 1970 to 1981, the survey was conducted by the *A.T. Cameron* using a Yankee-36 trawl. In 1982, the *A.T. Cameron* was replaced by the *Lady Hammond* using the Western-IIA as the new standard trawl. In 1983, the *Lady Hammond* was replaced by the *Alfred Needler* using the Western-IIA trawl. In 2004, the *Teleost* replaced the *Alfred Needler*. The 2005 survey was conducted by both the *Teleost* and the *Alfred Needler* to investigate differences in catchability between vessels for a number of species. No significant differences were noted for *M. senta* although the total number of samples was small for this species. Due to potential problems with the rigging of the Western-IIA trawl during 2004, this estimate is presented as a separate point.

The 4VWCOD (spring) survey has been conducted since 1986 on the eastern half of the Scotian Shelf in Div. 4VsW. This survey incorporates a stratification scheme that was meant to optimize the abundance estimates of cod in 4VsW (refer to Fig. 39a for strata map). From 1986 to 2003, the survey was conducted by the *Alfred Needler* using the same Western-IIA trawl as the summer survey. No surveys were held in 1998 or 2004. In 2005 and 2006, the survey was completed using the Western-IIA by the *Alfred Needler* and as well the survey was conducted by the *Teleost* using the same standard gear for comparative purposes. Deep water strata (395-400) in the Laurentian Channel were added to this survey in 1993 and although corresponding data were not included in abundance trend analyses, they were included in the distribution maps.

The Georges Bank survey in Div. 5Z commenced in 1986 using the same standard gear and stratification scheme as the previous two surveys and was conducted in February/March. The *Alfred Needler* has been the primary vessel except in 1993 and 2004 when its sister ship the *Wilfred Templeman* was used. In 2005 and 2006 comparative surveys between the *Alfred Needler* and the *Teleost* were conducted but no correction factors have been applied to the catches of *M. senta* for this series. The survey concentrates on the Canadian side of the bank.

Two additional DFO series from the Scotian Shelf were examined for the presence of *M. senta*. A fall RV survey that covered the entire Scotian Shelf was conducted from 1978 to 1984. The survey was conducted by the *Lady Hammond* from 1978 to 1982 and the *Alfred Needler* from 1983 and 1984 using the same sampling protocols as the summer survey. A deep-sea redfish survey was conducted from 1982 to 1988. Sampling was restricted to the edge of Scotian shelf in 4VWX and extended into the southern portion of the Laurentian Channel.

An additional four industry/science surveys were also evaluated. Distributional data is presented only for the longline 4VsW Sentinel survey and the otter trawl 4VsW skate survey due to possible problems with species identification during the other two surveys. Details for each of the individual survey series, in terms of location, gear type, time of year, duration and sampling effort, were documented during the winter skate NAP in 2003 (Simon et al. 2003).

USA

Research surveys of the east coast of the USA and the southern half of the Scotian Shelf have been conducted by National Marine Fisheries Service (NMFS) each fall since 1963 and each spring since 1968. Both surveys use a stratified random design similar to the Canadian summer RV survey. Two research vessels the *Albatross IV* and the *Delaware II* have been the primary survey vessels with the *Atlantic Twin* surveying the inshore areas from autumn 1972 to spring 1975. Generally a Yankee 36 has been the standard survey gear except a modified Yankee 41 was used during the spring survey from 1973 to 1981.

As well, there was a change in the trawl doors in 1985. No size based conversion factors are available for this species.

GEOGRAPHIC DISTRIBUTION AND HABITAT ASSOCIATIONS

NL Region

SPANS GIS (Anon. 2003) was used to investigate spatial distribution of *M. senta* with research trawl survey data. Details of potential mapping used for point-to-surface transformation (geo-referenced numbers per tow to areas depicting differential density of the species) is described in Kulka (1998). The DFO survey trawl gear changes (noted above) resulted in the scale of maps representing a different catch rate after fall 1995. In addition, extra sets that were not part of standard research surveys have been added to some strata in 1985-94 for a diurnal study in Div. 3LNO. Although these diurnal sets are a deviation from the proportional allocation of sets in the estimation of abundance using random stratified design, the same sampling protocol was used. Their addition increased sampling intensity but did not affect the point to surface transformation. Thus, they are included in the present mapping of *M. senta* distributions.

Survey data were grouped into four periods chosen to correspond to periods of differing population status for the Funk and Laurentian Designatable Units or DU's (see descriptions of DU's under Results): 1971-77 - when *M. senta* were relatively abundant but sampling coverage was poor; 1978-84 - relatively abundant and Yankee gear was used; 1985-89 - period of decline when Engel gear was used; 1990-spring 1995 - low abundance when Engel gear was used and fall 1995-2005 - low abundance when Campelen gear was used.

A single legend (break points in density) comprising fifteen strata was set for a baseline (average) year then applied across all years to show inter-annual variation (method described in Kulka 1998). To smooth the surface transition from one density stratum to another, a linear decay function was applied to this potential mapping thereby giving points on the periphery of scanning circles increasingly less weight in the averaging function.

For the resultant maps, darkest (red) areas represent highest densities of skates (highest catch per tow) these fade to green representing the lowest catch rates. Grey depicts sampled areas with no skate catches and blank depicts unsampled areas.

In addition, the geographic distribution of skates was point mapped using the data visualization software ACON (http://www.mar.dfo-mpo.gc.ca/science/acon), entailing expanding symbol plots to provide a decadal summary of survey sets where *M. senta* were captured. This mapping approach was done for consistency of method with other Regions.

Area of occupancy index was calculated in two ways and compared. The first method, used by all Regions comprises an addition of the area of survey strata where *M. senta* were recorded in at least one set. See below under Gulf Region for a mathematical description of this method. The other method was to calculate the precise area corresponding to where sets contained *M. senta*, within the surface created by the GIS SPANS. The surface extent is defined by survey locations containing *M. senta* and is not based on addition of areas within large strata portions of which may not contain *M. senta*. The GIS approach only calculates locations where *M. senta* were recorded. Thus, the method provides a more precise estimate of area occupied.

Quebec Region

Maps of the distribution of *M. senta* were produced using differentially coloured expanding symbols for all four survey series. Data were generally grouped into five-year blocks for each survey. Area occupied was calculated as described under the Gulf Region Section.

Gulf Region

The geographic distribution of skates was mapped using the data visualization software ACON. Shaded contours were drawn using Delaunay triangles.

Area of occupancy (A_t) was calculated for each size class of skates in year *t* as follows:

$$(4)\ A_t = \sum_{k=1}^{S} \sum_{j=1}^{N_k} \sum_{i=1}^{n_j} \frac{a_k}{N_k n_j} I \quad \text{where } I = \begin{cases} 1 \text{ if } Y_{ijkl} > 0 \\ 0 \text{ otherwise} \end{cases}$$

where a_k is the area of the stratum *k*, and other variables are as defined above.

Area of occupancy (as defined above) will decrease as population size decreases even if there is no increase in geographic concentration (Swain and Sinclair 1994). In order to describe changes in geographic concentration, for each size class of skates we also calculated the minimum area containing 95% of skates, following Swain and Sinclair (1994). First, we calculated catch-weighted cdf's of skate catch in each year:

$$(5)\ F(c) = 100 \frac{\sum_{i=1}^{n} w_i y_i I}{\sum_{i=1}^{n} w_i y_i} \quad \text{where} \quad I = \begin{cases} 1 & \text{if } y_i \le c \\ 0 & \text{otherwise} \end{cases}$$

where *c* is a level of skate catch (i.e. number per standard tow), w_i is the weighting factor for tow *i* (i.e. the proportion of the survey area in the stratum fished by tow *i* divided by the number of tows made in that stratum), *n* is the number of trawl tows in the survey, and y_i is the number of skates caught in tow *i*. *F*(c) is an estimate of the percent of skates that occur at a local density of *c* or less. We also calculated cumulative area in relation to skate catch:

$$(6)\ G(c) = \sum_{i=1}^{n} \alpha_i I \quad \text{where} \quad I = \begin{cases} 1 & \text{if } y_i \le c \\ 0 & \text{otherwise} \end{cases}$$

where α_i is the area of the stratum fished by tow *i* divided by the number of tows made in that stratum. We evaluated *F* at intervals of 0.01, and calculated the density c_{05} corresponding to *F*=5. *G*(*c*) is the estimated area containing the most sparsely distributed 5% of skates (including areas where no skates were caught). Thus, the minimum area containing 95% of skates (D_{95}) is given by:

$$(7)\ D_{95} = A_S - G(c_{05})$$

where A_S is 70,075 km^2, the total survey area.

Associations of *M. senta* with depth were described using cumulative distribution functions and generalized additive models. See Swain and Benoît (2006) for details on methods.

Maritime Region

The geographic distribution of skates was mapped as expanding symbols using the data visualization software ACON. Area occupied was calculated as described under the Gulf Region Section.

PRELIMINARY DNA ANALYSIS

Tissues samples from 86 fish were collected from the Grand Banks and the Scotian Shelf. DNA was extracted using DNeasy column kit (Qiagen) with RNase treatment, the final elution volume was 100µL and two elutions were done. The concentration of the samples was assayed using PicoGreen kit (Invitrogen). The concentrations were quite variable and for many samples were very low.

Twenty-two loci, isolated from *L. ocellata* and thornback ray (*Raja clavata*) were tested on *M. senta* samples. There was amplification for 12 loci but with further optimization, only 4 loci (Loc05, Loc09, Loc15 and Loc19) were polymorphic with alleles within a size range that could be used for population analyses with no obvious null alleles. These four loci were then applied to the samples.

ABUNDANCE INDICES AND SIZE COMPOSITION

All Regions

Length distributions were determined for each tow in 1 cm (NL, Maritimes) or 3 cm intervals (Quebec, Gulf). For each year, the stratified mean catch per tow was calculated for each length interval:

$$(8)\quad \overline{Y_l} = \sum_{k=1}^{S} \sum_{j=1}^{N_k} \sum_{i=1}^{n_j} \frac{w_k}{N_k n_j} Y_{ijkl}$$

where Y_{ijkl} is the number of fish in length interval l caught in tow i at site j in stratum k, w_k is the proportion of the survey area covered by stratum k, N_k is the number of sites sampled in stratum k, n_j is the number of tows conducted at site j, and S is the number of strata. The total stratified mean catch per tow and its standard error in each year was also calculated for two length groups: <48 cm and ≥ 48 cm in total length (TL). Based on studies of length at maturity in other areas, the larger size group corresponds roughly to the mature population. Stratified mean length distributions were also converted to biomass using annual length-weight relationships.

An exponential decay model was also fitted to the time series using nonlinear least squares:

(9) $N_t = N_0 e^{-\delta \cdot t}$

where N_0 is abundance or biomass in the first year of the time series (1971), t is the time since the first year and δ is the estimated rate of decline. δ was also estimated from the linear regression of $\log_e N_t$ versus t. In the latter analysis, zeros were replaced by half the minimum nonzero value before taking the log. δ can be used to calculate an estimate of the percent decline over t years (Δ):

(10) $\Delta = 100 \cdot (1 - e^{-\delta \cdot t})$.

Laurentian DU: Integrated analysis

Data from 1970 to 2006 July surveys of the Scotian Shelf (restricted to the standard Div. 4VW strata for this analysis), 1971-2005 September surveys of the southern Gulf (strata 415-439), 1976-2005 spring surveys of NAFO (Sub)div. 3Ps and 3NO (using index strata sampled in all years, omitting 1983 when only 3Ps was sampled) and the 1991-2003 and 2005 August surveys of the northern Gulf were integrated in the analysis.

Abundance Trends

Analyses were restricted to adults (>= 48 cm TL). An attempt was made to standardize the 3NOPs surveys for changes in gear. Based on the ratio of mean catch rates in the first three Campelen surveys (1996-98) and the last three Engels surveys (1993-95), fishing efficiency of the Campelen for adult *M. senta* was estimated to be 3.6 times that of the Engels. Based on limited comparative fishing data for all sizes of thorny skate, *Amblyraja radiata* (Simpson and Kulka 2005), the Yankee 41 trawl was assumed to be 1.4 times as efficient as the Engels trawl in catching adult *M. senta*. Mean catch rates by the Yankee 41 and the Campelen were adjusted to be equivalent to those by the Engels by dividing by 1.4 or 3.6, respectively. No attempt was made to adjust for differences in fishing efficiency between surveys.

Two approaches were taken to estimate an overall rate of change for this DU. In the first approach, a single model was fit to the indices from all surveys. Survey was included as a factor and year as a covariate with a common slope over all surveys. Observations were weighted by the proportions of the combined survey area covered by each survey. The area covered by the August survey varied somewhat (by about 15%) from year to year, the average area covered by this survey was used to calculate the weights. A generalized linear model with a log link and Gamma error was used. The analysis was conducted over two periods, 1971-2005 and 1976-2005.

In the second approach, a separate slope was estimated for each survey and a weighted average slope was calculated based on the proportion of the total survey area covered by each survey. This analysis was conducted for three periods: 1971-2005 using only the 4VW and 4T surveys, 1976-2005 using these and the 3NOPs surveys, and 1991-2005 using all the surveys. In this analysis, slopes were again estimated using a generalized linear model with a log link and Gamma error.

Area Occupied

Area occupied (AO) within the Laurentian DU was estimated by summing the design-based estimates for each survey (equation 4). This analysis was conducted for all size classes of skates combined. Analyses of data from the Gulf surveys suggest that areas occupied by adults alone would be considerably smaller than those reported here for all sizes (see above). An attempt was made to adjust for a possible increase in the probability of catching adult *M. senta* with Campelen gear relative to the Engels gear. This was done by dividing areas occupied in the Campelen surveys by 2.1, the ratio of AO for the first three years of the Campelen surveys divided by AO for the last three years of the Engels survey. No attempt was made to adjust for differences in fishing efficiency between surveys.

GROWTH AND MATURITY

NL Region

In addition to specimens collected during research surveys, samples of *M. senta* were acquired by Canadian Fisheries Observers for assessment of age, sex, maturity and morphological and meristic characters. With respect to ageing, thoracic vertebrae were extracted from each specimen, cleaned, embedded in epoxy resin, and sectioned with a low-speed Isomet saw (Buehler Inc.) using three diamond blades separated by 0.6 mm spacers. Thin vertebral sections were then mounted on glass slides with Crystalbond adhesive 509 (Ted Pella Industries) and polished with aluminum oxide lapping film (3M Company) to remove saw striations. Mounted sections were digitally photographed under reflected light (Nikon SMZ1000) using Image Pro Plus 5.1 (Media Cybernetics) software. Vertebral images were then enhanced with Adobe Photoshop CS2 to enhance contrast, sharpness and clarity of the growth bands (Fig. 10). Translucent bands (winter growth) deposited along the "best" corpus calcarium were counted by one reader with no prior knowledge of the specimen's size/sex or date/place of capture. A second reader independently viewed a subsample of vertebral sections to assess the precision of age estimates.

The von Bertalanffy growth function:

$$(11)\quad L_t = L_\infty \left[1 - \exp\left(-k(t - t_0)\right)\right]$$

was used to model a preliminary estimate of growth based on 64 specimens obtained mainly from the southern Grand Bank and aged from vertebral centra where Lt=length at age Lt, L_∞=asymptotic or maximum length, k=growth coefficient, and t0=theoretical age when length equals zero.

Maturity stage was ranked based on Stehmann (1984) scale of gonad condition and related secondary characteristics. Maturity ogives were produced relative to length at maturity and age at maturity.

Quebec and Gulf Regions

Maturity estimates were based on work done in other Regions and previous studies.

Maritimes Region

Maturity and estimation of growth were similar as described under NL Region above Samples were taken from the Scotian Shelf.

USA

Age and growth estimates were derived from 306 vertebral centra (see preparation methods above) from skates caught off the coast of Maine, New Hampshire, and Massachusetts, USA. This area of concentration of is contiguous with fish in the Bay of Fundy and possibly the southwestern Scotian Shelf. Thus, information on growth and maturity from this are relates to Canadian waters. Methods used to determine age and maturity and calculation of von Bertalanffy growth parameters (equation 11) is very similar to what is described above for the Canadian Regions.

THREATS

NL Region

Canadian landings were compiled using Canadian statistical records in Zonal Interchange File Format (ZIFF) database since 1989. Catches of *M. senta* from Canadian fisheries were calculated by calculating the proportion of directed catch (kept fish) in the Canadian Fisheries Observer database to the corresponding directed species landings in ZIFF and using this ratio to raise the amount of *M. senta* recorded by fishery observers on a fishery by fishery basis (by directed species, by gear, by area).

An Index of Exploitation or relative F (commercial catch/relative biomass) was calculated using a ratio of reported catch to the fall (for the Funk DU) and spring (for the Laurentian DU, NL sector) research survey biomass index for 1998-2005. Commercial catch was estimated from fishery observer data adjusted to total landings as described above.

Changes in the relative abundance were examined in relation to the location of trawl effort for the Funk and Laurentian DU (NL sector). Annual trawl ground maps derived from Kulka and Pitcher (2001) were overlaid on distribution (survey number per tow values) of *M. senta*. Changes in abundance within areas of intense trawling, moderate trawling and untrawled grounds were compared.

Quebec Region

Reported skate landings for Div. 4R (west coast of NL) and 4S (Quebec North Shore) were compiled using ZIFF data files. The proportion of *M. senta* to the total skate population was derived from the DFO *Teleost* survey (2004-06). The proportion was calculated for skates ≥60 cm to account for commercial sizes. Landings of *M. senta* were estimated by applying the calculated proportion of 0.5% to the total landings of unspecified skates.

Maritimes Region

Theoretical levels of annual removals of *M. senta* were calculated for the Scotian Shelf area assuming a constant bycatch of 0.5% or half of what was estimated for winter skate. Removals of winter skate recorded on Simon et al. 2003.

RESULTS

GEOGRAPHIC DISTRIBUTION AND HABITAT ASSOCIATIONS

The genus *Malacoraja* occurs only in the Atlantic Ocean basin and *M senta* in the shelf waters off Canada and the USA (Fig. 11a). *M. senta* is located primarily in the troughs separating shallower banks, from the Hopedale Channel on the Labrador Shelf south to the outer Georges Bank (Fig. 11b). Between Lat. 40^o and 56.5^o, 9% of all surveys sets contained *M. senta* (1971-2005 surveys), making it the second or third most common most common skate species throughout much of its range, after thorny skate, *Amblyraja radiata* and in some areas, after winter skate (*Leucoraja ocellata*). The northern most record is at Lat. 60^o but records beyond Lat. 56.5^o are rare (0.08% of survey sets north this latitude contains *M. senta*) and beyond that bound can be considered as vagrant. Similarly at the southern extent of its distribution, occurrences south of Lat. 40^o are also rare, found in 0.35% of survey sets. Total area occupied, all locations where *M. senta* occurred during 1971-2005 covered 547,000 km^2 or 47% of the shelf area within its range (Table 3).

M. senta is not distributed evenly within its global range. Rather, it forms four or five disjunct concentrations separated by wide areas where *M. senta* never occur (Fig. 11). At the northeastern extent of its range, *M. senta* is concentrated in the Hopedale Channel well separated from Funk Isl. Deep (and adjacent parts of the Northeast Newfoundland Shelf) and separate from the Flemish Cap/northeast Grand Bank. This configuration appears to be consistent over time. NL Region survey records going back to 1947 indicate similarly positioned concentration and disjunctions compared to more recent records (compare Fig. 11 b and c). However, at the southwestern end of the distribution, from the southeast Grand Bank, in the Laurentian Channel, Scotian Shelf, Bay of Fundy to the Gulf of Maine, the delineation of concentrations is less clear. The distribution there was more or less continuous and persistent from the southwest Grand Bank, into the Laurentian, Esquiman and Anticosti Channels and into the St. Lawrence Estuary. Whether this concentration is associated with the fish that inhabit the Scotian Shelf is unclear. There is a disjunction between Misaine/Banquereau and Sable Isl. Bank and between LeHave and Browns Bank. However, the degree of separation at these locations is much smaller than those observed to the north and may not be persistent. These separations may constitute recent fragmentation of a single large concentration (Southwest Grand Bank to the Gulf of Maine).

COSEWIC criteria indicate that species status assessment requires that populations below the species level be considered when appropriate and may include subspecies, varieties and “geographically or genetically distinct” populations in its definition of species thus allowing for listing of populations below the species level. For the purpose of this analysis, based mainly on geographic disjunction, the five concentrations described below and illustrated in Fig. 11b are treated as the DU's or population segments.

The northerly most concentration located in the Hopedale Channel extends 190 km at its widest extent (see Fig. 1 for geographic reference) with a maximum area of 11,600 km^2 or 2% of the global area occupied (Table 3). Hereafter, this concentration is referred to as the Hopedale DU. Over the life of the research trawl surveys, no records of *M. senta* were observed between the southern end of the Hopedale concentration (at Lat. 55.2^o), to the northern extent (Lat. 53.8^o) of the concentration covering much of the northeast Newfoundland Shelf (mainly in the Funk Island Deep and surrounding troughs, hereafter referred to as the Funk DU), a distance of 330 km. The widest extent of the Funk DU is 540 km (north to south) with a maximum extent of 106,400 km^2 or 18.2% of the global area occupied (Table 3). This DU is separated from the next concentration to the south, the Flemish Cap (occupying 40,600 km^2, 7% of the global extent) concentration by 170 km.

The remaining part of the distribution is more complex, where disjunctions are less obvious and more dynamic. *M. senta* form a continuous concentration from the southwest slope of the Grand Bank into the Laurentian Channel and adjacent shelf including the southwest coast of Newfoundland, the Esquiman Channel and into the St. Lawrence Estuary, the main body of what is designated as the Laurentian DU but is largely absent from the Magdelen Shallows in the southern Gulf (Fig. 1). It extends on to the Scotian Shelf but there it is fragmented. *M. senta* is sparse or absent between Misane and Banquereau Banks and also between Sable and LaHave Banks but the distance across these disjunctions is only about 20 km and variable over time.

For the purposes of this paper, that portion of the distribution from Sable Isl. Bank north and east has been assigned to the Laurentian DU but whether this portion is distinct from concentrations to the southwest is unclear. This Laurentian concentration forms the largest DU occupying 283,000 km^2 or 48.4% of the global area occupied. The remainder of the population, occupying LaHave/Browns Bank, Bay of Fundy and Gulf of Maine are designated as the Gulf of Maine (GoM) DU occupying 142,800 km^2 or 24.4% of the global area occupied (Table 3).

There were sufficient data available to examine changes in area occupied over time for three of the five DU's: Funk, Laurentian and GoM (note that in the regional analyses to follow, area occupied is also examined for segments of the various DU's). The Funk DU underwent the greatest decline presently occupying about 10% of the area previously occupied in the 1970's (Fig. 12). In contrast, the Laurentian DU was stable or slightly increasing. The GoM DU underwent a small decrease in the early 1980s and has been stable since.

Within its global range, *M. senta* is found over a wide range of depths although depth range is narrower at specific latitudes. The shallowest/deepest records of this species over its global range are 25/1436 m. However, 90% of survey sets containing *M. senta* occur between 70 and 480 m. The densest concentrations occurred between 150 to 450 m prior to 1995 and 150-550 m thereafter (Fig. 13a). *M. senta* is found over a relatively narrow range of temperatures avoiding the coldest of locations. The coldest/warmest records of this species over its global range are -1.3/15.7 ^{o} C although only 0.9% of occurrences of *M. senta* were associated with bottom temperatures <0^{o} C and 7% were associated with <2 ^{o} C. The densest concentrations and 90% of survey occurrences were found water bottom temperature was between 2.7 and 10^{o}C (Fig. 13a).

Depth range varies with latitude, *M. senta* tending to be found in shallower waters at the southern end of its distribution density peaking at 325 m in the GoM and 525 m at the Hopedale DU (Fig. 13b). The species distributes over a similar temperature range over their global distribution (Fig. 13b).

NL Region

Geographic distributions of *M. senta* in the NL survey Region, are shown for combined spring and fall surveys by ten year intervals from 1971 to 2006 (Fig. 4). *M. senta* is present in four distinct areas: Hopedale Channel; Funk Island Deep/northeastern NF Shelf; on the Flemish Cap/Pass and northeast Grand Bank; and on the southwestern Grand Bank and adjacent Laurentian Channel (Fig. 1 and 11).

Sufficient data were available to examine trends in the area of occupancy were for the Funk DU and the NL Region portion of the Laurentian DU (comprising the southwest portion of the Grand Bank and the southeast Laurentian Channel) but not for the Flemish Cap or Hopedale DU's. For the Funk DU, a continual decline in the area occupied was observed, similar in magnitude to the decline in abundance for that area (Fig. 15). Figure 16 illustrates the spatial decline (right column) in relation to bottom temperature (middle column) and depth (upper right panel) during four periods. The densest concentration of *M. senta* occurred in the troughs surrounding the banks where the temperature was warmer. The residual distribution (in 1995-2005) following the decline was located in the deepest parts of those troughs. Temperature was warmest in the troughs and warm areas were least extensive during 1985-94. During 1985-94, temperature at depth within the range where *M. senta* occurred was lower than during other periods and highest during 1995-2005 (Fig. 17). Area occupied (and abundance) continued to decline even when water temperature warmed after the mid-1990s.

For the Funk DU, survey catch rate (kg per tow) peaked at 350-400 m and was zero or near-zero at depths <200 and >800 m (Fig. 18, upper panel) confirming that *M. senta* concentrated in the troughs but was largely absent on the shallow banks or out along the shelf edge. This pattern was fairly consistent over time (Fig. 19). In terms of temperature association, highest concentrations occur at 2.6-3.0^{o} C and are nearly absent at <1.5 and >7^{o} C (Fig. 18). This pattern is similar over time except that during 1978-84, a warm period, *M. senta* tended to be distributed in slightly warmer temperatures (Fig.20).

The Laurentian DU (NL Region segment), the area of occupancy index, although variable, underwent a gradual increase (Fig. 21). Note that the GIS calculation of area occupied encompasses the entire DU while the strata sum was done for the NL Region segment of the DU. Refer to Fig. 13b for information on temperature and depth associations for the Laurentian DU which includes all Regional segments.

Quebec Region

Geographic distributions of *M. senta* in the northern Gulf of St. Lawrence from 1978 to 2006 are shown for four different survey series (Fig. 22–25). *M. senta* is present in the northern Gulf of St. Lawrence in the Laurentian, Esquiman and Anticosti Channels and in the estuary. The summer surveys indicate recurrent concentrations at the head of the Anticosti and Laurentian channels. During 1984-2005, *M. senta* were caught at depths ranging from 60 to 515 m, with 80 % in depths ranging from 175 to 350 m (Fig. 26). Yearly ranges of depth where *M. senta* were found, mean and median, ranged between 230 and 295 m.

Trends in area of occupancy in August in the northern Gulf of St. Lawrence are presented for the summer surveys (Fig. 27). The *Alfred Needler* series indicates a doubling of the area occupied during 1990-2005 with a maximum of about 39,000 km^2. This trend is similar for juveniles and adults (Fig. 28) with juveniles occupying a much larger area.

Similar increasing trends are observed for the index of geographic range, D_{95} (Fig. 29) for the period 1990-2005. This index is positively correlated with the relative abundance showing that the geographic range of *M. senta* in the northern Gulf expands and contracts as abundance increases and decreases.

Gulf Region

In September in the southern Gulf of St. Lawrence, *M. senta* are distributed in relatively deep waters in the Cape Breton Trough and along the slope of the Laurentian Channel (Fig. 30). Little geographic segregation is evident between length classes of *M. senta* in this area (Fig. 31).

Mean and median depths of September survey catches of *M. senta* varied between about 125 and 250 m (Fig. 32). The depth range containing 80% of the skate caught during the survey varied considerably from year to year, but in the southern Gulf, *M. senta* were rarely caught at depths shallower than about 75 m or deeper than about 325 m (Fig. 32). Little bathymetric segregation by size class is evident in the September survey catches (Fig. 33).

Depth distribution is summarized within decadal time periods using generalized additive models in Fig. 34. In the 1970s, a broad peak in density occurred from about 150 to 250 m. In the 1980s and 1990s, density peaked sharply at about 225 and 175 m, respectively. In recent years (2000-05), density peaked at a relatively low level at depths near 150-175 m and declined slowly with increasing depth. In all time periods, densities were very low at depths shallower than about 100 m. Density also declined to low values in the deep water along the offshore edge of the survey area. This decline in density in deep waters was less sharp in the most recent time period, though this mostly reflected the low peak density in this period.

Trends in area occupied in September in the southern Gulf differed between juveniles and adults (Fig. 35). For juveniles, area occupied averaged less than 2000 km^2 in the late 1970s, increasing in the early 1980s to values fluctuating around 6000 km^2 from the mid-1980s to the late 1990s. For adults, area occupied fluctuated widely around an average level near 2500 km^2 from the early 1970s to the mid-1990s, decreasing to a lower level in the late 1990s.

Trends in D_{95}, an index of geographic range, were similar to the trends in area occupied (Fig. 36). D_{95} was positively correlated with abundance, indicating that the geographic range of *M. senta* in the southern Gulf expands and contracts as abundance increases and decreases.

Maritime Region

The composite distribution pattern revealed areas of *M. senta* concentration, notably the approaches and upper Bay of Fundy, north of Brown's Bank, the eastern banks and their adjoining slopes of the eastern Scotian Shelf and Gully and in Div. 4Vn (Fig. 37). The distribution data were further decomposed into 10-year time blocks, showing the persistence of concentration in the noted areas (Fig. 38). Abundance in the western portion of the 4X and in Div 4Vn appears to be stable, while the distribution of *M. senta* in the adjacent areas have become more fragmented as abundance has decreased (Fig. 37)

The apparent breaks in distribution on the Scotian Shelf were examined in more detail using other DFO and industry surveys. In 4Vs there is a break in the distribution in the area of the Stone Fence off the eastern side of Banquereau Bank. Although there are a few stations in this area the Stone Fence has been designated as untrawlable bottom for a number of years. This restriction is not in place for the 4VWCOD survey. This survey has been conducted using a stratification scheme different from the summer RV survey since 1986 (Fig. 39a). Additional sets were added to the survey in the deeper waters of the Laurentian Channel. The survey revealed an extension of the *M. senta* distribution along the Stone Fence and in the deeper waters of the Laurentian Channel (Fig. 39b). The Fall RV survey conducted from 1978 to 1984 was unable to help determine whether the two areas were connected due to lack of sampling in that area (Fig. 40). Other surveys examined were the deep-sea redfish RV survey that was conducted along the edge of the Scotian Shelf and in the Laurentian Channel from 1982 to 1988 (Fig. 41). Although sampling was not extensive in the area near the Stone Fence there were some *M. senta* present in 2 of 3 sets.

The fall 4VsW Sentinel Survey employing longlines has been conducted since 1995 (Fig. 42). Species identification has been problematic for skates in some years but these problems have usually been restricted to winter (*L. ocellata*) and little skate (*L. erinacea*). *M. senta* were infrequently caught on the survey with the highest concentration on the eastern half of Banquereau and on the Stone Fence. Two industry surveys have been conducted in 4VsW by the skate fishery participants since 1994 (Fig. 43). The spring (1995-2005) and fall surveys (1995-99) both revealed similar distributions with the majority of fish caught along the edges of the shelf. Although *M. senta* were caught in the area of the Stone Fence, abundance was lower than in other slope regions.

In the central Scotian Shelf, there appears to be a break in the distribution of *M. senta* on either side of the Div. 4X/4W line. As abundance has decreased, especially since the 1990's, the break has become more pronounced.

M. senta was distributed through Div. 4X in the 1970s. As abundance decreased in the 1980s (see below) the species distribution became fragmented with the Bay of Fundy becoming separated from fish east of Lon. 66^{o}. The apparent extent of this break may have been accentuated by the amount of "untrawlable" bottom on the western peak of Brown's Bank and to the area just north of there during the summer RV survey. The ITQ survey was examined, but species identification problems precluded its use. The 2002 and 2003 GEAC industry surveys only occasionally captured *M. senta* and thus are of limited use in defining distributional patterns (Fig. 44).

Stratified area occupied in Div. 4X from 1972 to 1985 was generally high, falling to low levels in the late 1980s to early 1990's and has been increasing over the last 10 years (Fig. 45). In 4VW, the area occupied was highest in the late 1970s and has been decreasing since (Fig. 46). The 2005 estimate was lowest on record. Estimates of area occupied based on the summer survey indicated that in Sydney Bight (strata 440-446), fluctuated without trend (Fig. 47). On the central Scotian Shelf (strata 447-481), after peaking in the late 1970s, the area occupied declined. In the Bay of Fundy (strata 482-495), the area occupied widely without trend.

Temperature anomalies from Div. 4X (Lurcher) were generally above normal from 1973 to 1986 (Fig. 48). Since 1987, the temperature, on average, has been below normal. In Div. 4VW (Misaine, 100m), from 1963 to 1974, temperature was below normal followed by temperatures above normal until 1984. From 1985 to 1997 temperatures were the lowest in the time series. In 1998, the environment changed again and temperature reverted to above normal. How these changes in temperature have affected species abundance and distribution in both areas is unclear, but there have been extensive changes in species composition in 4VW since 1985.

PRELIMINARY GENETIC ANALYSIS

Preliminary genetic analyses yielded only limited information on the population structure of *M. senta*. With three exceptions, samples were only available from the area designated as the Laurentian DU. While there was 100% amplification (at all loci) for all 22 samples from the Scotian Shelf, only 7 out of the 64 Grand Bank samples amplified at the 4 loci. Loc19 which appeared to have potentially 3 alleles appears to be virtually monomorphic and would not be useable for population analyses.

There were only a very limited (3) number of winter skate, and no thornback ray loci that would be suitable for use in population genetic studies of *M. senta*. In addition, there was a very high failure rate for the microsatellite loci from Newfoundland. Thus there were insufficient results from the microsatellite loci (only 7/64 individuals that amplified) to do any population analyses.

None of the samples from NL (Grand Banks) that amplified showed the StyI RFLP pattern at the RajaCOI locus that was seen in the Scotian Shelf samples. While there is no indication that this is a result of a technical problem, sequencing this PCR product from some NL samples would help confirm this result and allow more detailed look at the sequence difference in and between these samples and the Scotian Shelf *M. senta*. From this preliminary work this is the only indication of difference between the Grand Banks and Scotian Shelf *M. senta*. While the absence of the StyI restriction site in the RajaCOI PCR product may reflect a genetic difference between the Scotian Shelf and Grand Banks components, this is only a preliminary result and needs further investigation to determine if this is a valid conclusion.

ABUNDANCE INDICES AND SIZE COMPOSITION

Gear Catchability

Catchability of skate by research trawl gear has been considered low given the sedentary nature of the group and likely underestimate the presence of

M. senta. Skate have been observed to hug the bottom when fishery gear approaches. The Yankee-36 and Western-IIA gears have large rollers which allows skate to escape below the footgear. When comparing catch rates between the Maritimes RV survey and the skate survey, which uses rockhopper footgear, the skate survey rates were ~7 times higher. We have an opportunity to more directly compare rockhopper gear with the standard RV gear. In 2002 and 2003 industry conducted surveys using a Campelen trawl which were coincident with the Maritime Region 4VWCOD surveys. However, insufficient numbers of fish were caught during the industry surveys to make a valid comparison.

NL Region

Abundance indices for the Hopedale and Flemish Cap DU's are confounded by lack of annual sampling. Although current indices for Hopedale exceed those observed in the late 1970s (Fig. 49), differences in fishing gears used confounds long term comparison of survey catch rates. Similarly, abundance indices for the Flemish Cap DU are presented for illustration only given the lack of consistent sampling.

Abundance indices (numbers per standard tow) for the Funk DU increased from 1977 to 1999 then declined during the early 1980s and have been relatively stable at a low level since the mid-1990s (Fig. 50). The period of decline corresponds with the coldest period in the area (Fig. 16 and 17). The estimated rate of decline for both adults and juveniles for this DU was 91%, based on a log model fit to all years, 1977-2005 (Fig. 51, Table 5a).

In contrast, the adult and juvenile abundance indices for the NL Region segment of the Laurentian DU comprising the southern Laurentian Channel/southwestern Grand Bank fluctuated until the early 1990s but has increased steadily since about 1995 (Fig. 52). A conservative estimate of population increase was 12-28% (Fig. 53, Table 5). Prior to the change in survey gear (pre-1996), abundance indices in this DU fluctuated but were relatively stable over the long term. At the time of the gear change, the juvenile series showed a pronounced knife edge change while for the adults, values of the last Engel and first Campelen years were similar making it is difficult to differentiate gear affect from inter-annual change. Without knowledge of whether this gear change affected catchability of *M. senta* (especially at younger life stages/smaller sizes), comparisons between past and present abundance indices are problematic. It should also be noted that these survey indices include a small area outside Canada's 200-mile-limit on the Tail of the Grand Bank.

In terms of relative abundance (minimum estimate of numbers of fish of all sizes), annual average number of fish of all sizes in the Funk DU based on the Engel fall survey was 3.58 million fish between 1978 and 1987. In 1995-2004, the Campelen minimum abundance annual average was 0.36 million fish. The

Campelen appears to be more efficient at catching particularly small *M. senta* than the Engel gear and thus the two minimum estimates are not comparable.

Given the same caveats as above, the estimate of minimum number of fish based on the spring survey in Div. 3NOPs (the NL portion of the Laurentian DU) was 0.7 million in 1978-87 and 2.66 million in 1995-2004. The index increased from 2.6 million in 1996 to 3.5 million in 2005. In both cases, catchability (q) of either trawl gear is thought to be very low for skates (see discussion of Gear Catchability above) and thus the abundance numbers presented here likely considerably underestimate actual population numbers, even for the more efficient Campelen gear.

Quebec Region

Abundance index (numbers per tow) derived from the *Gadus Atlantica* winter survey of the northern Gulf of St. Lawrence is presented only for Div. 4R and Subdiv. 3Pn due to high variation in the surveyed area for the other Divisions (Fig. 54). Catch rates of smooth skates of all sizes were low, averaging <1 fish per tow and quite stable during 1978-94.

The abundance index of *M. senta* of all sizes fluctuated in the *Lady Hammond* summer survey (Fig. 55) and no clear trend is apparent in this short series (1984-90). In contrast, trend in abundance for the 1990-2005 period (*Alfred Needler* survey) shows an increase for *M. Senta* of all sizes. Similar trends are observed for both juveniles and adults. The estimated rate of change, based on a log model, show an increase of juveniles and adults of 152 and 220 % respectively (Fig. 55b and Table 5b).

The *Teleost* survey data are not informative to indicate trends due to a short time series (2004-06). However, the catch rates from this survey are much higher than the previous surveys indicating that the Campelen gear is more efficient at catching skates than the Uri, or the Western-IIA trawls. Minimum estimate of *M. senta*, population size derived from the catch per tow and the area covered by the surveys averaged 2.1 million fish based on the *Alfred Needler*-Uri survey (1991-2005) compare to 23 million fish for the *Teleost*-Campelen survey (2004-06). The ratio of juveniles to adults (≥48 cm TL) is close to seven for both surveys. The catchabilty for skate of both trawls in unknown but the ~10 fold difference in the minimum estimate of population size emphasizes once again the difficult task of joining two different survey series without an appropriate conversion factor.

Gulf Region

Relative abundance and biomass of *M. senta* of all sizes caught in the September survey fluctuated in the 1970s (Fig. 56), perhaps reflecting the low number of sites fished in these years and the restricted distribution of *M. senta* within the survey area. Catch rates were low at the start of the time series, increasing to a high value by 1974 and then declining to a low level in the early 1980s. Abundance increased throughout the 1980s and was relatively high throughout the early to mid-1990s, but declined in the early 2000s. Biomass showed similar trends, though the increase in the 1980s was not as substantial as the increase in abundance.

Trends in abundance differed between juveniles and adults (Fig. 57). Juvenile abundance increased throughout the 1980s, reaching high levels in the early to mid-1990s and then declining in recent years. In contrast, adult abundance was relatively high in the 1970s, and then declined to an intermediate level in the 1980s and 1990s and a low level in the early 2000s. The adult decline rate was estimated using either $\log_e$-transformed data and linear regression or untransformed catch rates and nonlinear regression. Both approaches yielded similar results, indicating a decline rate of about 5% per year, corresponding to a decline of about 80% since 1971 (Table 6). The fit of the linear model to the transformed data is shown in Fig. 58.

The mean survey catch per tow expanded to the total survey area provides a minimum estimate of population size. The mean catch rates for 2001-05 expanded to the survey area correspond to 168,000 juveniles and 26,000 adults adjusting to daytime catchability and 404,000 juveniles and 63,000 adults adjusting to nighttime catchability. Actual abundance is likely substantially higher because catchability to the survey is expected to be considerably <100%.

Maritimes Region

Discontinuities in the distribution of *M. senta* are observed on the Scotian Shelf. The locations with no skate are far smaller than what is observed on the Labrador Shelf to the Grand Banks (separating the Hopedale, Funk, Flemish Cap and Laurentian DUs) but have been increasing with time. These breaks may not represent disjunction between DUs but rather fragmentation of a single DU.

Based on the observed breaks in distribution on the Scotian Shelf, a number of abundance estimates were calculated. Initially, Subdiv. 4Vn was compared with Subdivs. 4VsW (Fig. 59). Abundance in Subdiv. 4Vn was higher in the early 1970s but declined to a level similar to those observed in Subdiv. 4VsW. Since 1980, mean catch per tow has generally been <1 fish per tow in both areas. Given the similarities in catch rates between Subdiv. 4Vn and 4VsW and the additional distributional information from other surveys, these two areas were combined (Fig. 60).

In Div. 4X, magnitude of survey catch rates were similar to those observed in Div. 4VW but the trends were different (Fig. 61). Catch rates fell from a peak in mid-1970s to close to zero in the early 1990's but have since rebounded. The 2006 estimate is the highest since 1976. Catch rates were calculated for Div. 4X and 4VW were dis-aggregated into immature and mature components, delineated at 48 cm (Fig. 62 and 63). Decline rates were calculated for all sizes as well as the mature lengths only. In Div. 4X, decline rates based on the long term log model for the all sizes over the entire time series was 56% and 74.5% for mature individuals. However, the survey estimates have been increasing in this area for the past 12 years. Breaking the time series into the period of decrease and increase, from 1970 to 1993 the estimated decline was 91% followed by an increase of 370% between 1993 and 2006. In Subdiv. 4Vn, the decline rate over the entire time series was 76.5% for all sizes and 93.9% for mature fish. There the indices have been stable low for 15 years.

An alternate scenario is to group the data using other observed breaks in distribution. This resulted in potentially five areas, Sydney Bight+ (strata 440-446), the remainder of 4Vs, 4W (447-466), the eastern half of 4X (470-481) and the Bay of Fundy (482-495) being examined (Fig. 64). Except for the Bay of Fundy, all other areas showed similar declines in abundance. Since the Sydney Bight+ area is closely aligned with the Laurentian Channel, this area was treated as a separate DU, a segment of the Laurentian DU. The two central Scotian Shelf strata groups (447-466 and 470-481) were combined and the Bay of Fundy (482-495) were considered separately.

Catch rates in Sydney Bight were highest in 1971, declining to <1 fish per tow and stable low since (Fig. 65). On the central Scotian Shelf, catch rates increased until the late 1970s, fell to low levels by 1985 and have remained stable since (Fig. 65). The 2006 estimate is the lowest on record. In the Bay of Fundy, no trend is evident over the time series (Fig. 65). Catches were very low from 1987 to 1993, but have generally rebounded. The 2006 estimate is the highest in the series. Decline rates were calculated for all three areas for all sizes. In Sydney Bight+ the decline rate was 72%, the Central Scotian shelf it was 85%, while in the Bay of Fundy the decline was 45%.

USA/Maritimes

Catch rates on Georges Bank and the Gulf of Maine were examined using the Canadian and USA research trawl survey data. Relatively few *M. senta* had been captured during the Canadian survey until 2000 (Fig 66). There was a strong increase in the number of mature and immature *M. senta* peaking in 2003 and 2004. Estimates have subsequently returned to historic values. The magnitude of change observed in 2003-04 seem biologically improbable unless immigration/emigration occurred and may not relate to actual changes in abundance.

Fall and spring US survey catch rates for all sizes indicate no strong signal (Fig. 67). The fall survey has a 29% decline based on the log model from 1963 to 2005. However, a visual examination of Fig. 67 suggests fluctuations without trend, with the exception of two high estimates of abundance occurring in 1965 and 1966.

Catches of *M. senta* during the spring survey were highest in the late 1960's to early 1970's, declined to low values until the late 1990's and since have generally increased (Fig. 67). The decline rate for the entire series calculated from the log model is 63%. However, by breaking the series into a period of decline, 1968-96 and the period of increase, 1996-2005, the calculated decline rate is 87.7% over 28 years followed by an increase of 729% over 10 years.

Catch rates for the mature portion of the population are presented for the fall and spring surveys using the length (56 cm) at maturity from the Gulf of Maine as well as the length (48 cm) at maturity estimate from the Scotian Shelf (Fig. 68). The declines in the fall survey were estimated to be 42% for the fish >= 48 cm and 68% from fish >= 56 cm. Length data from the spring survey is only available from 1976. The decline rates for this survey were 42 and 65% for the 48+ cm and 56+ cm series respectively. In both surveys very few fish >65 cm were caught.

Laurentian DU: Integrated analysis

The Laurentian DU, as defined in this analysis straddles all four Regions of DFO (Fig. 1 and 10a). Information is derived from several surveys employing different gears and time periods covering different portions of its range. An attempt was made to integrate information on abundance from the different surveys to obtain a view of overall trends in abundance and distribution in this DU.

Assuming a common rate of change for all surveys (Table 7, Fig. 69), the estimated rate of change was a decline of 4.7% (1971-2005) or 4.5% (1976-2005) per year. This corresponds to a decline of 79.5% in 34 years (1971-2005) or 72.6% in 29 years (from 1976 to 2005). In this model, decline in the early years (1971-75) is based only what occurred in Div. 4TVW. Predicted catch rates assuming a common rate of change over all surveys fit the observed rates well for the 4VW and 4T surveys (Fig. 60 and 57), except that the observed decline in 4VW was slightly steeper than the predicted decline from 1970 to 1990 and slightly shallower than the predicted decline since then. In Div. 3NOPs, observed and predicted declines were similar from 1976 to the mid-1990s but, in contrast to model predictions, observed catch rates have increased since the mid-1990s (Fig. 52). In contrast to model predictions, catch rates in 4RS have tended to increase since the early 1990s (Fig. 54 and 55b, c).

Area weighted average rates of change in the relative abundance of adult *M. senta* in the Laurentian DU are given in Table 8. Data are available over the entire 1971-2005 period for only the Div. 4VW and 4T surveys. Catch rates declined sharply over this period for both surveys, though the rate of decline appeared to be stronger in 4VW than in 4T. Averaged over both surveys, catch rates declined by 6.2% per year, corresponding to an 88% decline over the 34 years. Catch rates also declined in all three surveys with data spanning the 1976-2005 period, though the decline was steeper in the 4VW survey than in the 3NOPs survey. Averaged over all three surveys, catch rates declined by 4.75% per year during this period, corresponding to a 75% decline over 29 years. Data over the entire area are available only since 1991. During this recent period, no significant trends in adult catch rates occurred in the 4VW, 4T and 3NOPs surveys (P>0.2) whereas a marginally significant (P=0.044) increase in catch rates occurred in the 4RS survey. Averaged over all four surveys, catch rates increased by 0.9% per year, corresponding to a 13.8% increase over the recent 14-yr period.

AREA OCCUPIED

Area occupied was calculated for different combinations of the Laurentian DU (Fig. 70). For Div. 4TVW (southern Gulf and the eastern Scotian Shelf), area occupied fluctuated without trend from 1970 to 1999. Since then, it has fluctuated without trend at a lower level (about 35% lower). An alternate interpretation is a decline of about the same magnitude over the period observed. With the addition of the southwest Grand Bank and lower Laurentian Channel data (Div. 4TVW3NOPS), the area occupied fluctuated without trend. For the entire Laurentian DU, the area occupied increased by about 35% from 1990 to 2005. This pattern contrasted with the declines in abundance as calculated from the log model for the corresponding areas (Fig. 69).

SIZE, AGE AND GROWTH

NL Region

Length frequencies from NL Region trawl surveys captured *M. senta* in the range of 7 to 73 cm, which is likely close to the entire range of sizes found in the population (Fig. 71). Fish >63 cm were rare. The relationship of weight to length for fish collected in the NL Regions was W (weight in gm)=0.002 L (length in cm) $^{3.28}$, n=75. All sizes of *M. senta*, to varying degrees were found in each of the DUs. The Hopedale DU and the Laurentian Channel portion of the Laurentian Channel DU contained the highest portion of young juveniles (<20 cm).

It was also observed that a) the Campelen gear was much more efficient in capturing *M. senta* <20 cm (up to ~1 year olds, compare Fig. 71a to 71b) and b) neither the Engel or Campelen gear captured large proportions of intermediate sized juveniles. This resulted in a bimodal frequency dominated by mature fish and very young juveniles.

A sample of 71 fish mainly from the Laurentian DU, ranging from 9 to 60 cm were used in the age model. Ages of those fish ranged from 0 (newly hatched) to 17 years. Predicted parameters from the two parameter von Bertalanffy growth model were L_{∞}= 59.3, k=.16, and t_o=-1.67 (Fig. 72). Addition of the largest observed sizes, exceeding 70 cm, to the model would likely increase the value of L_{∞}.

Mapping of the average size of fish (weight/number for each set) from NL Regions Campelen surveys (1995-2005) confirmed a separation of stages in different parts of the range. The smallest fish were concentrated in the deepest areas, observed in the western Hopedale Channel in large numbers in recent years, the Channels around the Funk Island Bank and in the Laurentian Channel (in increasing numbers). The most discernible separation of sizes occurs in the Laurentian DU, the Grand Bank containing mainly larger fish (average size >0.6 kg, ~40 cm) while fish in the lower Laurentian Channel are mainly juveniles, average size <0.54 kg (Fig. 73a). Given the large mode of small fish observed on Div. 4RST3Pn (Fig. 74 and 75), this suggest that the concentration of juveniles in the lower Laurentian Channel extends north into the upper part of the Channel in the Gulf of St. Lawrence.

Average size of fish decreased with depth. Average weight of fish was about 0.6 kg (equivalent to a TL of 50 cm) at 50-150 m, <0.4 kg (45 cm) at >250 m and 0.2 kg (35 cm) at 500-600 m (Fig. 73b), indicating a distinct separation of fish with respect to size. This suggests that surveys using larger mesh gear and not reaching similar depths are underestimating the presence of smaller fish.

Quebec Region

Biological information collected since 1990 show a sex ratio close to 1:1 in the northern Gulf of St. Lawrence for *M. senta*. Weight to length relationship for the 2004-05 period is W(g)=0.003 $L(cm)^{3.13}$, n=1745. These data are similar to those observed for fish from the NL Region.

Length frequency distributions of *M. senta* are available since 1993 in the northern Gulf pf St. Lawrence, i.e. *Gadus Atlantica*-Engel*, Alfred Needler*-Uri and *Teleost*-Campelen surveys (Fig. 74). The difference in size selectivity for these gears is evident from Fig. 74 hence no comparison between surveys were attempted. The size range for *M. senta* in the *Gadus Atlantica* survey (1993-94) was between 13 and 55 cm with the highest catch rate at 37 cm. The length distribution for the *Alfred Needler* survey shows a range between 10 and 64 cm with mostly juvenile skates <31 cm. This is comparable between the 5 year interval blocks. Catch rates were highest at 13 cm for 1991-2000 and at 10 cm for the latest period. The same size range was observed between the different NAFO Divisions surveyed by the *Alfred Needler* (Fig. 75). The catch rates were highest in Div. 4T.

The size range and length distribution for *M. senta* captured on the *Teleost* survey are quite similar to those of the *Alfred Needler*, however the catch rate of the Campelen is much higher than the Uri trawl. Of note is the presence of a large mode of small juveniles and somewhat bimodal pattern in Div. 4RST3Pn, similar to what was observed in the adjacent area of Div. 4NOPs (Fig. 71b). This bimodal pattern may reflect fish availability rather than gear selectivity. This strong mode of small juveniles is not observed elsewhere in the Gulf or Scotian Shelf (Fig. 76-77 described below). This could suggest a degree of separation in the sizes (stages) of fish in the Laurentian DU, however the selectivity of the gear used in the southern Gulf of St. Lawrence (Western-IIA) and in the Maritimes (Yankee-IIA, Western-IIA) may also play a role in the observed differences in length distribution.

Growth has not been examined for the northern Gulf of St. Lawrence.

Gulf Region

In the 1970s and 1980s, most *M. senta* caught in the September survey in the south-western portion of the Laurentian Channel north of the Magdelen Shallows of were between 20 and 50 cm TL in length (Fig. 76). Catch rates were highest for fish of about 50 cm, with lower peaks between 20 and 35 cm. In the early 1990s, catch rates were highest at small sizes, between 10 and 35 cm, and were considerably reduced at greater lengths. In the late 1990s and early 2000s, catch rates were greatest at somewhat larger sizes, between 25 and 40 cm.

Growth has not been examined for the southern Gulf of St. Lawrence.

Maritimes Region

All sizes of *M. senta* appear to be available to the RV survey gear during the summer survey (Fig. 77) although young juveniles constitute only a very small proportion of the catch. Fish are caught from hatching length (~10 cm) to the maximum total length of ~62 cm. A peculiar aspect of the cumulative length frequency is the peak which is skewed to the right peaking around 48 cm. There appears to be a linear increase in catch rate from 10 to 45 cm. Whether this is due to selectivity, availability, a behavioural issue or spatial differences in size of fish is unknown.

Cross-sections of vertebrae were used to determine ages of fish ranging from ~10 to 60 cm, estimating the ages to be from 0 to 15 years. Predicted parameters from the von Bertalanffy growth model were L_∞= 60.7, k=.12 and t_o = -1.74 (Fig. 78).

USA

Males and females were aged to 15 and 14 years, respectively. Male and female growth diverged at both ends of the data range and the sexes required different growth functions to describe them. Both males and females required the use of back-calculated values to account for a lack of small individuals. Using this information, males followed a traditional growth scenario and were best described by a two parameter von Bertalanffy model with a set L_o (Fig. 79a), while females were best described by a three parameter model (Fig. 79b).

Gear Selectivity

Although a detailed analysis of differences in gear selectivity was not carries out, it is apparent from a comparison of Fig. 71 and Fig. 74-77 that the is a great deal of difference in the selectivity by size between the Campelen (most efficient across all sizes), URI (efficient in the smaller sizes) and the Engel, Yankee and Western Trawls (most efficient in larger sizes, very poor in smallest sizes). The use of different gears in different areas and at different times has confounded the analyses of abundance and size based spatial distribution to a degree.

MATURITY

NL Region

Samples from spring and fall research surveys and from commercial catches, primarily from the Laurentian DU, were used to determine size at maturity. Based on a limited sample (n=71), length at 50% maturity was estimated at 49 cm for males and 41 cm for females (Fig. 80). The female estimate is considerably lower than observed elsewhere but these estimates must be regarded as preliminary given the small sample size. Weight at 50% maturity is approximately 0.45 kg.

Quebec and Gulf Regions

Maturity was not evaluated for the northern and southern Gulf of St. Lawrence. However, of note, is the frequently observed presence of mature female with internal purses during the northern Gulf of St. Lawrence August survey.

Maritimes Region

Length at 50% maturity for males was 49.8 cm and 47.2 cm for females (Fig. 81). Given a minimum age of 8 at maturity and an assumed m of 0.2 the generation time of 8+1/m=13 years.

USA

Maturity ogives in the Gulf of Maine for males (n=130), for clasper length and proportion of mature spermatocytes within the testes, predict that 50% maturity occurs at a TL of 570 mm and near 10 years of age (Fig. 82a). For females (n=93), maturity ogives, for ovary weight, shell gland weight, and follicle size, predict that 50% maturity occurs at a TL of 540 mm and around 9.5 years of age (Fig. 82b).

The reproductive cycle of female and male *M. senta* was based on monthly samples taken off the coast of New Hampshire, USA, from May 2001 through April 2002. For males (n=81), histological stages III through VI (SIII-SVI) of spermatogenesis revealed no significant differences in the production and maintenance of mature spermatocysts (stage VI) within the testes over the course of the study (Fig. 83a). Shell gland weight, follicle size and egg case formation, were assessed for 79 female skates. In general, these reproductive parameters remained relatively constant throughout most of the year. Additionally, the size distribution of ovarian follicles in females captured each month did not vary significantly (Fig. 83b) with large pre-ovulatory follicles always present. Collectively, these findings indicate that the *M. senta* is reproductively active year round.

THREATS

NL Region

Catches of *M. senta* recorded in Canadian Fisheries Observer set records from the NL Region were adjusted to total landings. The average annual catch within all areas (DU's) within the NL Region jurisdiction (Fig. 2) combined amounted to 17 t annually during 1998-2005 and have declined since 2002 (Fig. 84a). Eighty-two percent of *M. senta* taken as bycatch in commercial fisheries came from the Laurentian DU (southwest Grand Bank and Laurentian Channel, Fig. 84a). Seventy percent of the bycatch came from the skate longline (Div. 3NOPs), crab pot (Div. 3LNOPs), cod otter trawl (Div. 3Ps) and scallop dredge (3LNOPs) fisheries (Table 9). The lowest observed values occurred in the most recent years, catches amounting to 2 t.

The index of exploitation or Relative F (catch as a percent of relative biomass of all sizes in the population) pertaining to all fishing gears for the Funk DU, from 1998 to 2005 averaged 1.4% and ranged from 0.12% to 2.3%, with the exception of 2000 with a value of 5% (Fig. 84b). For the Laurentian DU (NL sector), the values were similar in magnitude, averaging 1.4% and ranging from 0.1% to 1.6% with the exception of 1998, with a value of 3.8%. These values represent maximum estimates of F (given that the biomass values are minimum estimates).

As an example, Fig. 85 illustrates trawl effort location in two years. 1980 (no data available for the Gulf St. Lawrence) and 2000 (after Kulka and Pitcher 2001). These maps (and those of the other years between 1980 and 2000) show that trawl effort did not cover the entire shelf, concentrating in relatively small areas, particularly so in later years. Overlaying the distribution of *M. senta* on theses annual maps indicated that abundance declined in a similar fashion in untrawled, lightly trawled and heavily trawled areas in both the Funk and Laurentian (NL portion) DU's (Fig. 86). This analysis pertains only to trawls. Table 9 shows that longlines, gillnets, dredges, seines and pots also captured this species.

Quebec Region

Between 1994 and 2005, reported landings for unspecified skate averaged <2 t per year in Div. 4S and 105 t in Div. 4R (Table 10). Most of the reported landings in Div. 4R came from a small directed skate fishery with an annual averaged catch of 65 t. These catches have declined considerably in the last two years averaging 2 t. Based on research survey data, only 0.5 % of those reported landings are estimated to be *M. senta*, suggesting an average annual catch of less than 1 t per year. Estimates for other sources of fishing mortality such as unreported catches or discards are not available for *M. senta* for the northern Gulf of St. Lawrence.

Gulf Region

Threats have not yet been quantified for areas encompassed by the Gulf Region. However, reported landings of skate species in the southern Gulf of St. Lawrence have been low, <20 t in most years; maximum 130 t in the mid-1970s (see Swain et al. 2005 for details). However, reported landings are a small fraction of the actual catch of skates in the southern Gulf. Estimates of discarded bycatch of *M. senta* are not yet available for the fisheries in the southern Gulf.

Maritimes Region

On the eastern Scotian Shelf, there was a directed skate fishery from 1994 to 2005. Catches of unspecified skate species peaked in 1994 near 2200 t but declined to less than 100 t in 2005 due to decreasing quotas and a collapse of the market for skate. This fishery directed for winter and thorny skate >60 cm. Bycatch of *M. senta* in this fishery comprised <0.03% of all skate caught.

The Recovery Potential Assessment for winter skate (DFO 2006) derived bycatch estimates for all species of skate for a number of fisheries in 4VsW. The 4VsW analysis also revealed that *M. senta* was a relatively insignificant bycatch in most fisheries (Fig. 87). The same method as 4X to estimate suggested a bycatch rate of 0.5% for *M. senta*. This analysis must be considered only for illustrative purposes to give relative estimate of total removals. Using this rate would result in removals of 350 and 600 t respectively in 4VW and 4X/5Y in the mid-1980s when other fisheries were near their peak. Both estimates declined as the catches in the other fisheries declined. In 1993 the cod and haddock fisheries were closed in 4VW. Since 1995, total removals would be <200 t on the Scotian Shelf. If the bycatch rate is closer to 0.1%, the total removals would be less than 50 t.

DISCUSSION

Previous studies have examined aspects of the distribution and biology of *M. senta* but only over portions of its range, mainly in the Gulf of Maine (McEachran 1973; McEachran and Musick 1975; McEachran et al. 1976; Packer et al. 2003; Sosebee 2005 and Sulikowski et al. 2006). Only five studies have examined specific aspects of *M. senta* biology and distribution to the north, Templeman (1965), Kulka et al. (1996), and González et al. (2006) on the Grand Banks, Swain et al. (2006) in the southern Gulf of St. Lawrence and Simon and Comeau (1994) on the Scotian Shelf.

Our study extends over the entire range of the species, from Lat. 40^o on Georges Bank to Lat 56.5^o in the Hopedale Channel on the Labrador Shelf. We found that *M. senta* concentrated in the troughs separating shallower banks primarily between 70 and 480 m, thus is more shallowly distributed than its slope dwelling congeners (Carvalho et al. 2005*;* Packer et al. 2003). It distributes at a slightly greater range of depths in the northern part of its range possibly because of an association with warmer temperatures that only occur at greater depths to the north. Distribution and habitat associations reported by McEachran and Musick (1975) and Packer et al. (2003) for the Gulf of Maine/southern Scotian Shelf are consistent with the findings of this study, in the corresponding areas.

The species, although quite extensively distributed in Canadian and northern USA waters, is patchy. We have shown that *M. senta* forms several distinct and persistent concentrations separated by extensive disjunctions (where *M. senta* are never recorded), in contrast with the other species of skates that occur in Canadian waters which generally form more or less continuous distributions within their range, such as is the case for *A. radiata*, (Kulka et al. 2006).

At the northeastern extent of its range, the separation of concentrations is obvious and persistent. However, at the southwestern end of the distribution, from the southeast Grand Bank, in the Laurentian Channel, Scotian Shelf, Bay of Fundy to the Gulf of Maine, the delineation is less clear. Whether the fish in the Gulf of St. Lawrence are associated with the fish that inhabit the Scotian Shelf is unclear. There is a disjunction between Misaine/Banquereau and Sable Isl. Bank and between LaHave and Browns Bank. However, the degree of separation at these locations is much smaller than those observed to the north and may not be persistent. These separations may constitute recent fragmentation of a single large concentration (Southwest Grand Bank to the Gulf of Maine) given that the area occupied on at least the northeast Scotian Shelf has been declining over time.

It appears also that change in abundance was inconsistent in different areas of what we have delimited as the Laurentian DU. A decline was observed over all areas of this DU in the early part of the series (1970s) but the pattern has diverged since. In the northeastern sector (including the Grand Bank southwest slope and Laurentian and other Channels), the adult component has undergone a significant recovery since the early 1990s while abundance has remained low in the southern Gulf and northeast Scotian Shelf. This suggests the possibility of different populations within this DU, or complex spatial dynamics within a single population that are poorly understood.

Thus, there remains uncertainty whether the five DUs designated for the purpose of this analysis constitute separate reproductive, genetically distinct units or that the Laurentian and GoM DUs are appropriately partitioned. Preliminary genetic analyses on the Scotian Shelf and Grand Banks produced only limited information on the population structure of *M. senta*. Loc19 which appeared to have potentially 3 alleles appears to be virtually monomorphic and would not be useable for population analyses. However, the samples for that analysis came from only two areas, the southern Grand Bank and the Scotian Shelf.

As well, given the early life history of skates and lack of evidence of long distance migration suggests that genetic isolation is possible. Mark-recapture studies of skates species show maximum traveling distances in the order of low hundreds of km (Templeman 1984; Walker et al. 1997; Hunter et al. 2005), less than the distance between some of the disjunctions observed for *M. senta*. Further, skates produce few large eggs (purses) deposited on the bottom, therefore there is no chance for wide dispersion as is the case for teleost species that broadcast large numbers (thousands to millions) or eggs or larvae into the water column where they can disperse over very large distances. While it is possible that local strong bottom currents could move the large, semi-adherent egg cases over short distances, perhaps in on the scale of metres or kilometres, wide dispersion is unlikely. Thus, it seems unlikely that there is significant genetic interchange between the concentrations. As well, although, *M. senta* shows some segregation by size, within the five DU’s, a broad spectrum of sizes, both juveniles and adults is observed. Large females showing signs of having spawned have been observed within each of the DU’s. All this together suggests discreet breeding units but further sampling and analysis is required to definitively delineate population structure of *M. senta*.

Why *M. senta* distributes as disjunct concentrations can be explained only partly by (relatively narrow) depth and temperature associations. It is clear that much of the northern Grand Bank is devoid of *M. senta* because bottom temperatures there are largely >0^{o} C and much of the southern Grand Bank is too shallow. Although the species has specific habitat associations, the disjunctions also include areas with “suitable” temperatures and depths; along the shelf edge of the Labrador Shelf to Grand Banks, the Cartwright Channel and Marginal Trough of the Northeast Newfoundland Shelf (thermal conditions are appropriate within the depth range of *M. senta*). Thus, factors in addition to temperature and depth are influencing the distribution of the species. Feedings studies (McEachran 1973; McEachran et al. 1976; Bowman et al. 2000; McEachran 2002; González et al. 2006) indicate that *M. senta* is quite selective in its diet, eating primarily small crustaceans throughout most of its life, fish only at the largest sizes. This selective diet may further constrain where the species distributes and may relate to the size segregation observed. Bottom type associations were not examined for this study but it was noted that *M. senta* in the Gulf of Maine are found mainly on soft mud (silt and clay) bottoms in deeper areas, but also on sand, broken shells, gravel, and pebbles (Bigelow and Schroeder 1953, McEachran and Musick 1975).

Further, data from Campelen surveys (the gear that is most efficient at capturing the full size range of the species) indicates that this species is segregated by size, at least in part of its range. This size separation is observed for the Hopedale and Funk DU but is particularly evident in parts of the Laurentian DU although apparently less so on the Scotian Shelf and southern Gulf. This different perception may relate, at least in part to gear selectivity. The survey gears used in the southern Gulf, Scotian Shelf to Gulf of Maine (Yankee and Western trawls) catchability is low for small (<25 cm) fish. In other studies, little geographic segregation was evident between length classes of *M. senta* in the southern Gulf of St. Lawrence. However, this area comprises only a small fringe of a much larger concentration extending over a wider depth range in the Laurentian DU and the gears used for that study were Yankee and Western. Further south, Packer et al. (2003) reported a slightly deeper range of depths for juveniles compared to adults in the Gulf Maine, but not as pronounced as our findings at the northern end of the range. Again those surveys employed the Yankee trawl. An examination of seasonal surveys and previous studies indicate little seasonal variation in the geographic distribution at least in part of the range (Clay 1991*;* Darbyson and Benoît 2003).

Since the 1970s, *M. senta* has undergone a decline in abundance of adults (and juveniles in some cases) over much of its range, to varying degrees in different areas. However in some areas, it has subsequently undergone recovery in recent years, in some cases reaching near historic high levels over a very short period. In the Hopedale Channel, there is not a sufficient time series to quantify changes in abundance but preliminary data from the fall 2007 indicates that catch rates are among the highest observed for that area. In contrast, directly to the south, abundance of the Funk DU underwent the largest decline observed, 91% for both adults and juveniles. The period of decline corresponds with the coldest period in the area (Colbourne et al. 2006). However, there has been no sign of recovery during the recent warm period in spite of apparently very low fishing pressure observed since the late 1990s. A comparison of rates of decline in areas of high intensity trawling compared to areas of no trawling indicated no difference in decline rate suggesting the species was not cropped down during that time frame. Thus, it appears that although fishing removals clearly contributed to the decline, it is likely not the only factor contributing to the decline.

For the Laurentian DU, a decline of 80% was calculated for adults the 34 four year period 1971-2005 or 73% in 29 years, from 1976 to 2005. However, abundance trends were not consistent throughout the area and not all areas of the DU were included in the integrated analysis in the early period. Thus, the long term decline rate is influenced by areas where the decline appears to have been greatest (southern Gulf and Scotian Shelf). In contrast to the integrated log model prediction for the Laurentian DU, survey catch rates have increased (by 220% for adults in the northern Gulf of St. Lawrence and by ~200% on the southern Grand Bank for example) since the early to mid-1990s. Further, area occupied by the Laurentian DU did not show nearly as great a reduction as the log modeled abundances rates.

The southern most GoM DU straddles the Canada-USA border. The trend in abundance is similar on both sides of the line: the adult Canadian (Div.4X) and adjacent spring USA survey trends were similar, undergoing a decline in the 1980s (xx% in Div. 4X) then increasing since the 1990s (xx% in Div. 4X). The indices are presently near historic levels. The trend was less apparent in the fall USA survey, suggesting fluctuation without trend.

Analysis of causes of the observed declines is only dealt with in a preliminary manner for a only portion of the range of the species and one potential cause, fishery bycatch. Mortality due to fishing is quantified for a subset of gears, over a portion of the distribution and only during only recent years. As well, there is no absolute estimate of population size that would facilitate an estimate of F. However, it is clear that since fishing grounds overlap quite extensively with the distribution of *M. senta* and thus, mortality due to fishing has contributed to the population declines to varying degrees among areas and gears.

M. senta is one of the smallest skates that inhabits the northwest Atlantic reaching an L_{max} of about 70 cm although fish >63 cm are rare. The results of Sulikowski et al. (2006) in USA waters (southern extent of the GoM DU), summarized in this paper and compared to maturity studies on the Grand Banks and Scotian Shelf indicated similar results. Size at 50% maturity is about 80% of the L_{∞} predicted by the growth model indicating late sexual maturity and possibly low potential stock recovery rate. Sulikowski et al. (2006) also noted that *M. senta* is reproductively active year round. Seasonal patterns in reproduction have been observed to be quite variable among skate species (delineated, Richards et al. 1963, *L. erinacea* and Sulikowski et al. 2004, *L. ocellata* to non-delineated, Sulikowski et al. 2005, *A. radiata* 2006, *L. senta*).

SOURCES OF UNCERTAINTY

Although this paper represents the most comprehensive analysis of the species to date and we examine much of the data presently available, there are a number of there are a number of unresolved issues that introduce considerable uncertainty into this analysis. The following issues must be considered when referring to the information presented in this paper.

1) **Population structure –** Although, for the purpose of this paper, we have defined five DUs, they are defined largely on the basis of disjunctions in the distribution. In particular, how the Scotian Shelf fish are related to fish in the Gulf of St. Lawrence and Grand Banks to the north and to the Gulf of Maine to the south is uncertain. Population structure in this area is further complicated by apparent fragmentation as the abundance has declined. As well, within the Laurentian DU in particular, there are considerable differences observed in trends of abundance and area occupied, suggesting the likely hood of a more complex population structure than a single breeding unit within this area. The analyses of the trends in abundance in the Laurentian DU are not only complicated by the uncertainty in population structure but also by the use of five survey gears with very different sized based catchability attributes (see # 3 below).

2) **Population Dynamics –** Although some information on growth and maturity were presented, this based only on analyses from recent years and the only gears that captured significant numbers of young fish, one and two year olds, were the Campelen and URI trawls which were employed only in restricted space and time. Thus, such relationships as spawning stock/recruitment, changes in growth and age structure in the population could not be examined over the long term. It is this type of information that could help explain some of the changes that took place in the population(s).

3) **Estimating Decline –** A common approach to estimating rate of decline of populations is to log transform the survey catch rates and derive a rate of decline from the slope of the log transformed data, over the period of the surveys. However, log models (or any model for that matter) can only reliably predict rates of decline (or incline) when the model fits the data. For the log model, data with a monotonic pattern that approaches an asymptote were generally observed to fit the model. In this case, the model appropriately smoothes inter-annual fluctuations but did not diverge from the data from the

trajectory. However, changes in abundance quite often do not follow pattern of a reduction (or increase) reaching an asymptote. For example, when a population has undergone a decline but then has recovered, the log model over-predicts the degree of decline because it does not fit the period of increase. For example, in the Div. 4X estimate of decline where a single log fit estimates a long term decline of 75%, the current level of abundance is not greatly different from values at the start of the series. Best practice is to determine whether the model provides an appropriate fit (and therefore yields a reliable rate of decline) and can easily be determined by visual examination of the abundance trajectory and an examination of the residuals from the model. Considering the ramifications related to the decline rate derived (determination of level of risk of extinction), model fit is a key issue.

Another problem encountered was occurrence of different abundance trajectories in different parts of the Laurentian DU which not only confounded our perception of the status of this DU but raised the question whether it comprises more that a single DU. For example, since the early 1990s, the population of adults continued to decline or remained low in the southern Gulf and on the northeast Scotian Shelf while they increased in the northern Gulf, Laurentian Channel and the southwest Grand Bank. This suggests that either the DU may actually constitute more that a single population or that shifts may be occurring within the DU. That adults are declining while juveniles are increasing in the same area as was observed by Swain et al. (2005) in the southern Gulf suggests movement into and/or out of adjacent areas. A positive stock recruit relationship (trends in juveniles and adults positively correlated) seems likely for k selected species since each female is capable of producing only a few young each year. Movement in/out of the survey area might explain this observation in the southern Gulf.

4) **Gear Selectivity** – Although a detailed analysis of differences in gear selectivity was not carries out, it is apparent from a comparison of length frequencies among gears that the is a great deal of difference in the selectivity by size among gears. The use of different gears in different areas and at different times has confounded the analyses of size composition, abundance and size based spatial distribution over time.

   Mid-sized fish comprising larger juveniles appear to be under-sampled by most or all survey gears (ref. the persistent bimodal pattern observed with Campelen gear and the larger proportion of the adult fish than juveniles in other gears). It would be expected that adults would generally be less abundant than juveniles at least in some years. Whether this is an issue of catchability or relates to an unusual size structure in the population is unclear.

5) **Biology (Population structure, Growth, Maturity, Habitat Associations) –** Information on age and maturity of fish is available only in recent years and over a portion of the range. Thus, in this analysis we were unable to examine

changes in growth and size or age maturity over time. Considerably more work is required on nearly all aspects of the biology of this species.

6) **Threats –** Information on threats was limited to recent years and only a portion of the distribution. Data from the period of the decline was not available except in terms of spatial overlap of the trawl fishery in one DU. Thus, although mortality due to bycatch of this species in other fisheries clearly contributed to the decline we were unable to determine the proximal cause(s). For the Funk DU, which has undergone the greatest decline, rate of decline was shown to be similar in heavily trawled and untrawled areas. Thus, while trawling has resulted in mortality, it has not been demonstrated to be the proximal cause of the decline. Further, values of relative F for all gears is low in recent years, about 1.4% in both the Funk and the Laurentian DU (NL sector). During 1998-2005, at similar levels of relative due to fishing, the population has increased in the NL sector of the Laurentian DU but has remained at a very low level in the Funk DU. What is preventing recovery in the Funk DU is unclear.

ACKNOWLEDGEMENTS

Gulf Region - We thank Hugues Benoît who provided SAS code for extracting and standardizing the survey data, and calculating indices of abundance and geographic distribution.

Quebec Region - We wish to thank Hugo Bourdages and Philippe Schwab for helpful contribution to the analysis for this review.

All Regions – We wish to thank all the Fisheries and Oceans staff who participated in the research surveys and fishery observers on Commercial vessels who collected data and specimens over the years that allowed us to estimate trends and examine various biological aspects for the species

REFERENCES

Anon. 2003. Geomatica V. 9 Users Guide. PCI Geomatics, 50 West Wilmot St., Richmond Hill, ON.

Benoît, H.P., and Swain, D.P. 2003. Standardizing the southern Gulf of St. Lawrence bottom-trawl survey time series: adjusting for changes in research vessel, gear and survey protocol. Can. Tech. Rep. Fish. Aquat. Sci. No. 2505: iv + 95 pp.

Bigelow, H.B. and Schroeder, W.C. 1953. Fishes of the Gulf of Maine. U.S. Fish Wildl. Serv., Fish. Bull. 53. 577 p.

Bourdages, H., Archambault, D., Morin, B., Frechet, A., Savard, L., Gregoire, F., and Berube, M. 2003. Preliminary results from the groundfish and shrimp multidisciplinary survey from August 2003 in the northern Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec. Res. Doc. 2003/078.

2004. Preliminary results from the groundfish and shrimp multidisciplinary survey from August 2004 in the northern Gulf of St. Lawrence. DFO Can. Sci. Advis. Sec. Res. Doc. 2004/112.

Bowman, R.E., Stillwell, C.E., Michaels, W.L., and Grosslein, M.D. 2000. Food of Northwest Atlantic fishes and two common species of squid. NOAA Tech. Mem. NMFS-NE-155. 138 p.

Clay, D. 1991. Seasonal distribution of demersal fish (Osteichthyes) and skates (Chondrichthyes) in the southeastern Gulf of St. Lawrence. Can. Spec. Publ. Fish. Aquat. Sci. 113: 241-259.

Colbourne, E.B., Craig, J., Fitzpatrick, C., Senciall, D., Stead P., and Bailey W. 2006. An Assessment of the Physical Oceanographic Environment on the Newfoundland and Labrador Shelf in NAFO Subareas 2 and 3 during 2005. NAFO SCR Doc. 06/11 Ser. No. N5226.

Darbyson, E., and Benoît, H.P. 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. 1113: 294 p.

de Carvalho, M., Ulisses, R., Gomes, L., and Gadig, O.B.F. 2005. Description of a new species of skate of the genus Malacoraja Stehmann, 1970: the first species from the southwestern Atlantic Ocean, with notes on generic monophyly and composition (Chondrichthyes: Rajidae). Neotropical Ichthyology, 3(2): 239-258.

DFO 2006. Proceedings of the Maritimes Provinces Regional Advisory Process on the Recovery Potential Assessment of Winter Skate in 4T and 4VW, 21-23 November 2005. DFO Can. Sci. Advis. Sec. Proceed. Ser. 2006/012.

Doubleday, W.G. 1981. Manual on groundfish surveys in the Northwest Atlantic. NAFO Sci. Counc. Stud. No. 2.

Dulvy, N.K., Metcalfe, J.D., Glanville, J., Pawson, M.G., and Reynolds, J.D. 2000. Fishery stability, local extinctions, and shifts in community structure in skates. Conserv. Biol. 14: 283-293.

Dulvy, N. K., and Reynolds, J. D. 2002. Predicting extinction vulnerability in skates. Conserv. Biol., 16: 440-450.

Frisk, M.G., Miller, T.J., and Fogarty, M.J. 2001. Estimation and analysis of biological parameters in elasmobranch fishes: a comparative life history study. Can. J. Fish. Aquat. Sci. 58: 969-981.

Garrison, L.P. and Link, J.S. 2000. Dietary guild structure of the fish community in the Northeast United States continental shelf ecosystem. Mar. Ecol. Prog. Ser. 202: 231-240.

González C., Román, E., Paz, X., and Ceballos, E. 2006. Feeding Habits and Diet Overlap of Skates (*Amblyraja radiata*, *A. hyperborea*, *Bathyraja spinicauda*, *Malacoraja senta* and *Rajella fyllae*) in the North Atlantic. NAFO SCR Doc. 06/53 Ser. No. N5285, 17 p.

Hunter, E., Buckley, A.A., Stewart, C., and Metcalfe, J.D. 2005. Migratory behaviour of the thornback ray, *Raja clavata* in the southern North Sea. J. Mar. Biol. Assoc. UK 85, 1095-1105.

Kulka, D.W. 1986. Estimates of discarding by the Newfoundland offshore fleet in 1985, with reference to trends over the past 5 years. NAFO SCR Doc. 86/95, Ser. No. N1221. 20p.

1998. SPANdex - SPANS geographic information system process manual for creation of biomass indices and distributions using potential mapping. DFO Atl. Fish. Res. Doc. 98/60 28p.

Kulka, D.W., DeBlois, E.M., and Atkinson, D.B. 1996. Non-traditional groundfish species on Labrador Shelf and Grand Banks -- skate. DFO Atl. Fish. Res. Doc. 96/98. 29 p.

Kulka, D.W., and Pitcher, D.A. 2001. Spatial and Temporal Patterns in Trawling Activity in the Canadian Atlantic and Pacific. ICES CM 2001/R:02 57 p.

McEachran, J.D. 1973. Biology of seven species of skates (Pisces: Rajidae). Ph.D. dissertation, Coll. William and Mary, Williamsburg, VA. 127 p.

2002. Skates. Family Rajidae. *In* Bigelow and Schroeder's fishes of the Gulf of Maine. 3rd Edition. *Edited by* B.B. Collette and G. Klein- MacPhee. p. 60-75. Smithsonian Institution Press, Washington, DC. 748 p.

McEachran, J.D., Boesch, D.F., and Musick, J.A. 1976. Food division within two sympatric species-pairs of skates (Pisces: Rajidae). Mar. Biol. 35: 301-317.

McEachran, J.D. and Dunn, K.A. 1998. Phylogenetic analysis of skates, a morphologically conservative clade of elasmobranchs (Chondrichthyes: Rajidae). Copeia 1998 (2): 271-290.

McEachran, J.D. and. Musick, J.A. 1975. Distribution and relative abundance of seven species of skates (Pisces: Rajidae) which occur between Nova Scotia and Cape Hatteras. Fish. Bull. (U.S.) 73: 110-136.

Musick, J.A., Burgess, G., Cailliet, G., Camhi, M., and Fordham, S. 2000. Management of sharks and their relatives (Elasmobranchii). Fisheries 25: 9-13.

Musick, J.A. 2004. Introduction: management of sharks and their relatives (Elasmobranchii), In 'Elasmobranch Fisheries Management Techniques'. (Eds J.A. Musick and R. Bonfil), pp. 1-6. (Asia Pacific Economic Cooperation Publication. APEC#203-FS-03.2).

NOAA 2000a. Report of the 30th Northeast Regional Stock Assessment Workshop (30th SAW): Public Review Workshop. Northeast Fish. Sci. Cent. Ref. Doc. 00-04. 53 p.

2000b. Report of the 30th Northeast Regional Stock Assessment Workshop (30th SAW): Stock Assessment Review Committee (SARC) consensus summary of assessments. Northeast Fish. Sci. Cent. Ref. Doc. 00-03. 477 p.

2002. Annual report to Congress on the status of U.S. fisheries - 2001. U.S. Dep. Commerce, NOAA, NMFS, Silver Spring, MD. 142 p.

Packer, D.B., Zetlin, C.A. and Vitaliano, J.J. 2003. Smooth skate, *Malacoraja senta*, life history and habitat characteristics. NOAA Technical Memorandum NMFS-NE-177. 26 p.

Richards S.W., Merriman, D., and Calhoun, L.H. 1963. Studies in the marine resources of southern New England. IX. The biology of the little skate *Raja erinacea*, Mitchill. Bulletin of the Bingham Oceanographic Collection. 18, 311-407.

Roberts, C.M, and Hawkins, J.P. 1999. Extinction risk in the sea. Trends ecol. evol. 14: 66, 241-245, Elsevier.

Simon, J.E. and Comeau, P.A. 1994. Summer distribution and abundance trends of species caught on the Scotian Shelf 1970-92, by the research survey groundfish survey. Can. Tech. Rep.Fish. Aquat. Sci. 1953:x+145 p.

Simon, J.E., Harris, L.E. and Johnston, T.L. 2003. Distribution and abundance of winter skate, *Leucoraja ocellata*, in the Canadian Atlantic DFO Sci. Advis. Sec. Res. Doc. 2003/028, 70 p.

Simpson, M.R., and Kulka, D.W. 2005. Development of Canadian research trawl gear conversion factors for Thorny skate on the Grand Banks based on comparative tows. NAFO Res. Doc. 05/49 21 p.

Smith, S.J., and Somerton, G.D. 1981. STRAP: A user-oriented computer analysis system for groundfish research vessel survey data. Can. Tech. Rep. Fish. Aquat. Sci. 1030: iv + 66 p.

Smith, S.E., Au, D.W., and Show, C. 1998. Intrinsic rebound potentials of 26 species of Pacific sharks. Mar. Freshw. Res. 41: 663-678.

Sosebee K.A. 2005. Maturity of Skates in Northeast United States Waters e-Journal of Northwest Atlantic Fishery Science, 35: art. 9.

Stehmann, M. 1977. Ein neuer archibenthaler Roche aus dem Nordostatlantik, *Raja kreffti* spec. nov. (Elasmobranchii, Batoidea, Rajidae), die zweite Spezies im Subgenus Malacoraja Stehmann, 1970. Archiv für Fischereiwissenschaft, 28(2/3):77-93.

Stehmann, M., and Burkel, D.L. 1984. Rajidae. *In* Fishes of the North-eastern Atlantic and Mediterranean. *Edited by* P.J.P. Whitehead, M.-L. Bauchot, J.-C. Hureau, J. Nielsen, E. Tortonese. Volume 1. UNESCO, Paris. pp. 163–196

Sulikowski J.A., Tsang, P.C.W, and Howell, W.H. 2004. An annual cycle of steroid hormone concentrations and gonad development in the winter skate, *Leucoraja ocellata*, from the western Gulf of Maine. Mar. Biol. 144: 845-853.

Sulikowski, J.A., Elzey, S., Kneebone, J., Jurek, A.J., Danley, P.D., Howell, W.H., Tsang, P.C.W. 2005a. The reproductive cycle of the smooth skate, *Malacoraja senta*, in the Gulf of Maine. Marine and Freshwater Research. Fish. Bull. 103, 536-543.

2005b. Age and growth estimates of the thorny skate, *Amblyraja radiata*, in the Gulf of Maine. Fish. Bull. 3(1), 161-168.

Swain, D.P., and Sinclair, A.F. 1994. Fish distribution and catchability: what is the appropriate measure of distribution? Can. J. Fish. Aquat. Sci. 51: 1046-1054.

Swain, D.P., and Benoît, H.P. 2006. Change in habitat associations and geographic distribution of thorny skate (Amblyraja radiata) in the southern Gulf of St. Lawrence: density-dependent habitat selection or response to environmental change? Fish. Oceanogr. 15: 166-182.

Swain, D. P., Hurlbut, T., and Benoît, H.P. 2006. Changes in the Abundance and Size of Skates in the Southern Gulf of St. Lawrence, 1971–2002. J. Northw. Atl. Fish. Sci. 36: 15 p.

Templeman, W. 1965. Rare skates of the Newfoundland and neighbouring areas. J. Fish. Res. Bd. Can., 22(2):259-279.

1984a. Migrations of thorny skate, *Raja radiata*, tagged in the Newfoundland area. J. Northw. Atl. Fish. Sci. 5 (1): 55-64.

Walker, P.A., Howlett, G. and Millner, R. 1997. Distribution, movement and stock structure of three ray species in the North Sea and eastern English Channel. ICES J. Mar. Sci. 54: 797-808.

Winemiller, K.O., and Rose, K.A. (1992). Patterns of life history diversification in North American fishes: implication for population regulation. Can. J. Fish. Aquat. Sci. 49: 2196-2218.

Table 1. DFO-NL research trawl surveys were conducted in Spring on the Grand Banks (NAFO Division 3LNO and Subdivision 3Ps; refer to Fig. 1 and 2) and Fall/Winter on the Labrador Shelf to Grand Bank (NAFO Division 2GHJ3KLMNO). Various gears have been employed (Yankee-41.5 otter trawl, depicted in brown; Engel-145 otter trawl, blue area; Campelen-1800 shrimp trawl, yellow area) on various vessels (*A.T. Cameron; Gadus Atlantica; Wilfred Templeman; Alfred Needler; Teleost)*.These areas completely encompass the Hopedale, Funk and Flemish Cap DU's and a portion of the Laurentian DU (Fig. 11b).

	NAFO										
	2H	2J	3K	3L	3N	3O	3M	3L	3N	3O	3Ps
YEAR	Fall	Fall	Fall	Fall	Fall	Fall	Fall/winter	Spring	Spring	Spring	Spring
1971								Brown	Brown	Brown	
1972								Brown	Brown		Brown
1973								Brown	Brown	Brown	Brown
1974								Brown	Brown		Brown
1975								Brown	Brown	Brown	Brown
1976								Brown	Brown	Brown	Brown
1977		Blue	Blue				Blue	Brown	Brown	Brown	Brown
1978	Blue	Blue	Blue				Blue	Brown	Brown	Brown	Brown
1979	Blue	Blue	Blue				Blue	Brown	Brown	Brown	Brown
1980		Blue	Blue				Blue	Brown	Brown	Brown	Brown
1981	Blue	Blue	Blue	Blue			Blue	Brown	Brown	Brown	Brown
1982		Blue	Blue	Blue			Blue	Brown	Brown	Brown	Brown
1983		Blue	Blue	Blue			Blue				Blue
1984		Blue	Blue	Blue			Blue	Blue	Blue	Blue	Blue
1985		Blue	Blue	Blue			Blue	Blue	Blue	Blue	Blue
1986		Blue	Blue	Blue				Blue	Blue	Blue	Blue
1987	Blue	Blue	Blue	Blue				Blue	Blue	Blue	Blue
1988	Blue	Blue	Blue	Blue				Blue	Blue	Blue	Blue
1989		Blue	Blue	Blue	Blue	Blue		Blue	Blue	Blue	Blue
1990		Blue	Blue	Blue	Blue	Blue		Blue	Blue	Blue	Blue
1991	Blue	Blue	Blue	Blue	Blue	Blue		Blue	Blue	Blue	Blue
1992		Blue	Blue	Blue	Blue	Blue		Blue	Blue	Blue	Blue
1993		Blue	Blue	Blue	Blue	Blue		Blue	Blue	Blue	Blue
1994		Blue	Blue	Blue	Blue	Blue		Blue	Blue	Blue	Blue
1995		Yellow	Yellow	Yellow	Yellow	Yellow		Blue	Blue	Blue	Blue
1996	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
1997	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
1998	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
1999	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
2000		Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
2001	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
2002		Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
2003		Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow
2004	Yellow	Yellow	Yellow	Yellow	Yellow	Yellow		Yellow	Yellow	Yellow	Yellow
2005		Yellow	Yellow	Yellow	Yellow	Yellow		Yellow	Yellow	Yellow	Yellow
2006								Yellow	Yellow	Yellow	

Table 2. Description of research surveys in the northern Gulf of St. Lawrence (part of the Laurentian DU).

Vessel	Length	Year	Month	Gear	NAFO	Coverage	Tow duration (min.)	Tow Speed	Standard tow (nm)	Wing spread (ft)
Gadus Atlantica	73,8 m	1978 - 1994 No survey in 1982	January	Engels 145	3Pn, 4RST	Strata > 50 fathoms Estuary not covered Average surveyed area 62,550 km2 range 31,700 to 100,400 km^2 3Pn and 4R strata were well covered	30	3.5 knots	1.8	45
Lady Hammond	58 m	1984 - 1990	August	Western IIA	4RST	Strata > 50 fathoms 3Pn was not covered, Estuary sparsely covered Average surveyed area 85,300 km^2	30	3.5 knots	1.8	41
Alfred Needler	50,3 m	1990 - 2005 No survey in 2004	August	Uri Shrimp Trawl 81'/114'	3Pn, 4RST	Addition of shallow strata 20-50 fathoms 3Pn covered from 1993 to 2003 Average surveyed area 111,300 km^2 Range 95,070 - 119,000 km^2	24	3 knots	0.8	44
Teleost	63 m	2004-2006	August	Campelen 1800 Rock Hopper foot gear	4RST	3Pn was not coverd Average surveyed area 103,700 km^2 Range 91,600 - 116,100 km^2	15	3 knots	0.75	55.6

Table 3. Summary of spatial statistics for *M, senta* over its global range (Fig. 11b). Names in brackets are the designatable unit (DU) short forms used within the body of the text.

Designatable Unit	**Area (km^2 /000s)**	**Percent of Area**
(Hopedale) Channel	11.6	2.0%
Northeast Newfoundland Shelf (Funk)	106.4	18.2%
Flemish Cap/ NE Grand Bank (Cap)	40.6	7.0%
(Laurentian) Ch/surrounds	283.0	48.4%
Gulf of Maine (GoM)	142.8	24.4%
Total Area Occupied (*M. senta*)	584.5	46.85%
Total Shelf area (0-800 m, Lat 40 to 56.5^0)	1247.5	
Range Limits		
Latitudinal Range	Lat. 40 to 56.5°	
Northerly/Southerly records	Lat. 30 to Lat. 60°	
	Highest Densities	**Extreme records**
Depth (highest densities over entire range	150-550 m	25-1436 m
Bottom Temperature (highest densities over entire range)	2.7-10°	-1.3-15.7

Table 4. Summary of microsatellite locus results and RajaCOI (species identification locus) for NF samples. Samples that amplified are indicated with “y” samples with only weak amplification are indicated with “w”.

ID1	SkateTag	Sex	YEAR	Conc (ng/uL)	Loc05	Loc09	Loc15	Loc19	RajaCOI
70	3207	M	2005	4.28					
110	3271	M	2005	5.322					
69	3272	M	2005	6.678					
114	3279	F	2005	32.68					
63	3282	F	2005	22.311					y
120	3284	M	2005	37.589					y
251	4229	M	2003	21.035					y
136	4262	M	2003	4.249					y
3	5822	M	2004	0					
4	5944	F	2004	1.867					y
65	8806	M	2005	3.954					y
118	8810	F	2005	9.7	y	y		y	y
266	8811	M	2005	39.77	y	y	y	y	w
97	10409	F	2005	89.483	y	y	w	y	y
64	10423	M	2005	45.107	y	y	w	y	w
172	24WT476A	M	2003	1.609					
191	24WT476B	F	2003	6.786					
171	24WT476C	M	2003	1.048					y
2	27WT476	F	2003	0					
541	33WT688	M	2006	3.997					y
67	60aWT547	F	2004	43.299					y
68	60bWT547	M	2004	0					y
103	A-4345	F	2005	68.664	y	y	y	y	w
105	A4348	M	2005	39.203	y	y	y	y	w
119	E1468	F	2005	21.772					y
540	F35113	F	2006	0.117					
414	OBS 74	F	2006	3.671					
413	OBS 75	M	2006	0					y
158	W1717	M	2005	0.542					y
108	W1737	F	2005	38.936					
249	W1748	F	2005	10.48					
115	W1795	F	2005	9.986					
138	W2053	F	2005	5.323					y
107	W525	M	2005	23.016	y	w	w	y	y
556	W5702	F	2006	1.976					w
561	W5707	M	2006	0.06887					w
554	W5710	M	2006	5.91					
549	W5716	F	2006	10.368					
545	W5718	M	2006	4.685					w
550	W5719	M	2006	4.25	?				w
564	W5724	F	2006	7.875	?				w
559	W5726	M	2006	5.028	w				w
565	W5729	F	2006	2.154	?				
551	W5731	F	2006	4.239	?				
555	W5732	F	2006	3.122	?				
566	W5734	F	2006	0	?				w
567	W5738	F	2006	4.362	?				
235	W5743	F	2006	7.725	?				y
552	W5747	F	2006	3.295					w

Table 4 (Cont'd.)

546	W5748	F	2006	8.71					
562	W5752	F	2006	5.777					
542	W5754	M	2006	0.192					
560	W5756	M	2006	4.55					
547	W5760	F	2006	1.735					
543	W5762	M	2006	1.287					y
548	W5766	M	2006	2.075					y
558	W5768	F	2006	13.699					
563	W5769	F	2006	0.538					
557	W5774	M	2006	12.68					w
553	W5780	M	2006	0.727					
516	W5791	M	2006	6.88					y
678	W5793	M	2006	1.724					
515	W5797	F	2006	0					
130	W589	M	2005	87.321	y	y	y	y	y

Table 5a. Rates of decline of *M. senta* in the Funk Island Deep/NE NF Shelf (Funk DU) and Laurentian Channel/Southwestern Grand Banks (NL Region portion of the Laurentian DU). "INDEX" only contains strata sampled throughout the research survey time series. "ALL" encompasses every stratum sampled. Negative rate values indicate a population increase.

Area	Relationship	years	slope	calc	rate
Funk adult - all	**y=-0.086x+169.30**	**29**	**-0.086**	**-2.494**	**91.7**
Funk adult -index	y=-0.097x+192.45	25	-0.097	-2.425	91.2
Laurentian adult -all	**y=-0.008x+17.0317**	**31**	**0.008**	**0.248**	**-28.1**
Laurentian adult -index	y=0.004x-9.56	30	0.004	0.120	-12.7

Table 5b. Percent rates of change for juveniles (<48 cm TL) and adults (≥ 48 cm TL) smooth skate in the northern Gulf of St. Lawrence based on the 1991–2005 period.

	Log model Linear regression	Years	Slope	Calc	Increase Rate (%)
Juveniles	y=0.066x - 132.79	14	0.066	0.924	152
Adults	y=0.083x - 169.55	14	0.083	1.162	220

Table 6. Decline rates of adult (≥48 cm TL) *M. senta* in the southern Gulf of St. Lawrence (Gulf Region portion of the Laurentian DU) since 1971 as calculated by the log and nonlinear models. The decline rate is given by the slope of the regression of survey catch rates over time (yr).

Statistic	Log Model	Nonlinear model
Slope	-0.0478	-0.0506
SE	0.0151	0.0152
Upper 95% CI limit	-0.0175	-0.0197
Lower 95% CI limit	-0.0780	-0.0815
P	0.0034	<0.0001
% decline in 34 yr	80.3	82.1

Table 7. Decline rates of adult (≥48 cm TL) *M. senta* in the Laurentian DU based on a model fit to all available survey indices. The decline rate is given by the slope of the regression of survey catch rates over time (yr).

Statistic	1971-2005	1976-2005
Slope	-0.0466	-0.0447
SE	0.0069	0.0084
P	<0.0001	<0.0001
% decline over time period	79.5	72.6

Table 8. Weighted average rates of change in the abundance of adult (≥48 cm TL) *M. senta* in the Laurentian DU based on models fit separately to each available survey index. The decline rate is given by the slope of the regression of survey catch rates over time (yr).

Period	Survey	slope	SE	Weight	% change
1971-2005	4VW	-0.0712	0.0089	0.60555	-91.1
	4T	-0.0490	0.0120	0.39445	-81.1
	average	-0.0624			-88.0
1976-2005	4VW	-0.0779	0.0122	0.32363	-89.5
	4T	-0.0499	0.0155	0.21081	-76.5
	3NOPs	-0.0253	0.0119	0.46556	-52.0
	average	-0.0475			-74.8
1991-2005	4VW	-0.0411	0.0317	0.24183	-43.8
	4T	-0.0194	0.0410	0.15753	-23.8
	3NOPs	-0.0062	0.0405	0.34788	-8.3
	4RS	0.0964	0.0444	0.25276	285.5
	average	0.0092			13.8

Table 9. Bycatch of *M. senta* in the commercial fisheries in the NL Region - Grand Banks to Labrador, 1998-2005. Values are in metric tones. Numbers in the fishery description refer to vessel's class.

Fishery (Laurentian)	1998	1999	2000	2001	2002	2003	2004	2005	Average	Sum
Skate Longline 4-7 3LNOPs	5.435	9.892	0.324	5.885	5.237	7.260	0.000	0.000	4.254	34.034
Crab Pot 1-3 3LNOPs	4.667	0.000	0.303	6.004	5.307	1.842	2.419	0.000	2.568	20.543
Skate Longline 1-3 3LNOPs	0.057	0.708	1.530	3.249	9.236	1.215	0.000	0.000	1.999	15.995
Cod Otter Trawl 4-7 3Ps	14.879	0.000	0.000	0.000	0.050	0.000	0.000	0.000	1.866	14.929
Scallop Dredge 1-3 3LNOPs	0.000	0.000	11.567	0.623	0.000	0.000	0.000	0.000	1.524	12.190
Redfish Otter Trawl 4-7 3LNOPs	1.334	0.155	0.745	0.000	0.516	0.094	0.859	0.138	0.480	3.841
Monkfish Gillnet 1-3 3LNOPs	0.000	0.000	0.000	0.166	0.559	1.361	0.062	0.044	0.274	2.192
Witch Dan Seine 1-3 3LNOPs	0.041	0.035	0.117	0.460	0.417	0.346	0.427	0.335	0.272	2.177
Cod Longline 1-3 3Ps	0.000	0.000	0.000	0.000	0.000	0.000	1.892	0.000	0.237	1.892
Monkfish Gillnet 4-7 3LNOPs	0.000	0.000	0.000	0.000	0.008	0.700	0.743	0.005	0.182	1.456
Redfish Trawl 1-3 3LNOPs	0.000	0.000	0.000	0.000	0.788	0.000	0.000	0.014	0.100	0.802
Skate Otter_Trawl 4-7 3LNOPs	0.000	0.000	0.001	0.004	0.000	0.000	0.000	0.641	0.081	0.646
Witch Otter_Trawl 4-7 3LNOPs	0.019	0.000	0.240	0.004	0.012	0.001	0.100	0.165	0.068	0.542
Cod Gillnet 1-3 3Ps	0.000	0.000	0.269	0.000	0.027	0.148	0.000	0.018	0.058	0.461
Skate Gillnet 1-3 3LNOPs	0.000	0.000	0.074	0.016	0.012	0.248	0.000	0.000	0.044	0.349
Grdld Halibut Gillnet 1-3 3LNOPs	0.000	0.000	0.000	0.053	0.000	0.000	0.025	0.145	0.028	0.223
GrdldHalibut Gillnet 4-7 3LNOPs	0.000	0.000	0.019	0.126	0.028	0.000	0.001	0.005	0.022	0.179
Skate Otter_Trawl 1-3 3LNOPs	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.078	0.010	0.078
Am Plaice Otter_Trawl 4-7 3LNOPs	0.007	0.000	0.000	0.055	0.012	0.000	0.000	0.000	0.009	0.074
Shrimp Trawl 1-3 3LNOPs	0.000	0.000	0.000	0.000	0.000	0.000	0.070	0.000	0.009	0.070
Grdld Halibut Otter_Trawl 4-7 3LNOPs	0.000	0.000	0.000	0.000	0.000	0.000	0.056	0.000	0.007	0.056
White_Hake Gillnet 1-3 3LNOPs	0.000	0.000	0.000	0.000	0.007	0.000	0.040	0.000	0.006	0.047
Redfish Gillnet 1-3 3LNOPs	0.000	0.000	0.000	0.000	0.000	0.041	0.000	0.000	0.005	0.041
Skate Gillnet 4-7 3LNOPs	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.033	0.004	0.033
Lumpfish Gillnet 1-3 3LNOPs	0.000	0.000	0.032	0.000	0.000	0.000	0.000	0.000	0.004	0.032
Skate Danish_Seine 1-3 3LNOPs	0.000	0.000	0.012	0.000	0.000	0.000	0.000	0.000	0.002	0.012
Crab Pot 4-7 3LNOPs	0.000	0.000	0.005	0.000	0.000	0.007	0.000	0.000	0.002	0.012
Lobster Pot 1-3 3LNOPs	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.000	0.001	0.010
Lumpfish Gillnet 1-3 3Pn	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.003
Shrimp Shrimp_Trawl 4-7 3LNOPs	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.001
Cod Otter_Trawl 1-3 3NO	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001
Total	**26.440**	**10.790**	**15.249**	**16.645**	**22.216**	**13.265**	**6.696**	**1.621**	**14.115**	**112.922**

Fishery (NE NI Shelf)	1998	1999	2000	2001	2002	2003	2004	2005	Average	Sum
Crab Pot 1-3 2J3K	3.399	0.216	3.079	0.730	0.712	0.067	2.972	0.000	1.397	11.176
GrldHalibut Gillnet 1-3 2J3K	2.306	2.680	0.000	0.210	0.000	0.000	0.000	0.000	0.649	5.196
Shrimp Trawl 1-3 2J3K	0.453	0.000	1.842	1.567	0.027	0.027	0.000	0.000	0.490	3.917
Shrimp Shrimp_Trawl 4-7 2J3K	0.147	0.042	0.165	0.003	0.002	0.201	0.014	0.004	0.072	0.578
GrdldHalibut Otter_Trawl 4-7 2J3K	0.234	0.004	0.000	0.000	0.009	0.000	0.007	0.113	0.046	0.367
Crab Pot 4-7 2J3K	0.043	0.000	0.000	0.017	0.000	0.000	0.000	0.000	0.008	0.060
GrdldHalibut Otter_Trawl 1-3 2J3K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.002
GrdldHalibut Pot 1-3 2J3K	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.001
Crab Gillnet 1-3 2J3K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lobster Pot 1-3 2J3K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	**6.582**	**2.942**	**5.088**	**2.528**	**0.750**	**0.295**	**2.994**	**0.120**	**2.662**	**21.298**

Fishery (Hopedale)	1998	1999	2000	2001	2002	2003	2004	2005	Average	Sum
Greenland_Halibut Gillnet 1-3 2GH	0.489	0.097	0.107	0.222	0.023	0.008	0.007	0.003	0.120	0.956
Shrimp Shrimp_Trawl 4-7 2GH	0.123	0.107	0.048	0.021	0.002	0.480	0.044	0.001	0.103	0.826
GrdldHalibut Gillnet 4-7 2GH	0.321	0.064	0.036	0.031	0.000	0.000	0.005	0.027	0.061	0.484
Grdld Halibut Otter_Trawl 4-7 2GH	0.000	0.000	0.000	0.000	0.000	0.007	0.004	0.000	0.001	0.011
Grdld Halibut Otter_Trawl 1-3 2GH	0.000	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.001	0.007
Shrimp Shrimp_Trawl 1-3 2GH	0.000	0.000	0.001	0.003	0.000	0.000	0.001	0.000	0.001	0.004
Total	**0.933**	**0.268**	**0.191**	**0.277**	**0.025**	**0.503**	**0.060**	**0.031**	**0.286**	**2.288**

Fishery (Flemish Cap)	1998	1999	2000	2001	2002	2003	2004	2005	Average	Sum
Shrimp Trawl 4-7 3M	0.366	0.083	0.027	0.100	0.144	0.262	0.159	0.000	0.143	1.141
Shrimp Trawl 1-3 3M	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Total	**0.366**	**0.083**	**0.027**	**0.100**	**0.144**	**0.262**	**0.159**	**0.000**	**0.143**	**1.141**

Table 10. Reported landings of unspecified skate in the commercial fishery on the west coast of NL (Division 4R), 1994-2005. Values are in metric tonnes.

Directed Species	Gear	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	SUM	AVERAGE
American plaice	Gill Net	16.51	3.86	2.48	0.83	8.98	5.40	7.67	3.41	1.14	3.67	0.84	0.70	55.50	4.62
	Longline	0.02	0.08		0.06	0.10	0.04		0.12		0.04			0.45	0.06
Catfish	Gill Net	0.08	0.38	0.03	0.07	0.00								0.56	0.11
	Longline	0.03		0.11	0.63	0.02			0.01	0.02				0.82	0.14
Cod, Atlantic	Bottom Otter Trawl				0.12				0.05					0.17	0.08
	Danish Seine								0.05		0.02			0.07	0.03
	Gill Net	0.01	0.09	0.22	8.99	0.20	3.29	5.07	0.39	0.80	0.04	0.02		19.11	1.74
	Hand Line		0.00		0.02	0.88	1.05	0.04	0.13	0.03				2.15	0.31
	Longline	0.02	0.12	0.77	12.55	18.53	17.97	22.17	11.21	11.62	0.02	1.63	0.56	97.17	8.10
Crab, Queen/Snow	Gill Net			0.01										0.01	0.01
	Pot								0.00					0.00	0.00
Crab, spider/toad	Gill Net		0.02											0.02	0.02
Cusk	Gill Net				0.02									0.02	0.02
Dogfish	Gill Net	0.23												0.23	0.23
Greysole/witch	Danish Seine	2.95	2.18	0.05		0.71	0.08	0.54	1.63	1.79	0.49		1.60	12.00	1.20
	Gill Net							0.16						0.16	0.16
Groundfish	Gill Net			0.05										0.05	0.05
Haddock	Longline								0.06	0.02				0.08	0.04
Hake, white	Longline					0.01								0.01	0.01
Halibut	Gill Net	0.00	1.00	0.43	0.32		0.01	0.03		0.03	0.04		0.01	1.87	0.21
	Hand Line								0.12					0.12	0.12
	Longline	0.30	0.04	0.40	0.41	0.32	3.99	2.85	0.73	4.99	2.87	2.19	0.49	19.58	1.63
Herring, Atlantic	Gill Net		0.52	0.37	1.17									2.05	0.68
Lobster	Gill Net		0.84	1.34										2.18	1.09
Lumpfish	Gill Net			0.48	6.98	29.54	66.04	16.81	5.27	0.03	30.79	16.05	6.55	178.56	17.86
	Trap											0.09		0.09	0.09
Mackerel	Gill Net	0.05		0.54		0.02								0.60	0.20
	Hand Line					0.36								0.36	0.36
	Longline					0.01								0.01	0.01
Monkfish	Gill Net				0.43						0.29	0.01		0.74	0.25
Ocean/eel pout	Gill Net		0.02											0.02	0.02
Redfish	Bottom Otter Trawl	0.18							0.07	0.26	0.01	0.00		0.52	0.10
	Gill Net	0.05	1.24	0.48	0.17				0.01					1.95	0.39
	Midwater Trawl	0.05												0.05	0.05
Roe, lumpfish	Gill Net		0.08											0.08	0.08
Scallop, Iceland	Gill Net		0.18											0.18	0.18
Seal meat	Gill Net				0.06									0.06	0.06
Shrimp, *P. Borealis*	Bottom Otter Trawl				0.02									0.02	0.02
	Shrimp Trawl	0.34												0.34	0.34
Skate	**Gill Net**	**53**	**126**	**97**	**104**	**75**	**117**	**65**	**48**	**50**	**22**	**1**	**3**	**761**	**63**
	Hand Line					0.24	0.14							0.38	0.19
	Longline	0.42	0.01	0.60	3.00	8.66	0.07	0.05		0.02	0.98			13.82	1.54
	Midwater Trawl	0.24												0.24	0.24
	Pot								0.09					0.09	0.09
	Trap								0.02					0.02	0.02
Sturgeon	Gill Net							0.00						0.00	0.00
Greenland halibut	Gill Net	12.32	5.77	0.37	4.22	16.06	15.02	9.10	1.78	0.20	1.11	0.23	0.33	66.51	5.54
	Longline					0.08	0.07					0.07		0.23	0.08
Winter flounder	Danish Seine	1.42												1.42	1.42
	Gill Net	10.29	3.56	0.34	0.12	0.66		0.58				0.18	0.00	15.73	1.97
	Longline		0.15											0.15	0.15
	Trap				0.05									0.05	0.05
Yellowtail flounder	Gill Net		0.01											0.01	0.01
TOTAL		**98**	**146**	**106**	**144**	**161**	**230**	**130**	**73**	**71**	**63**	**22**	**14**	**1257**	**105**

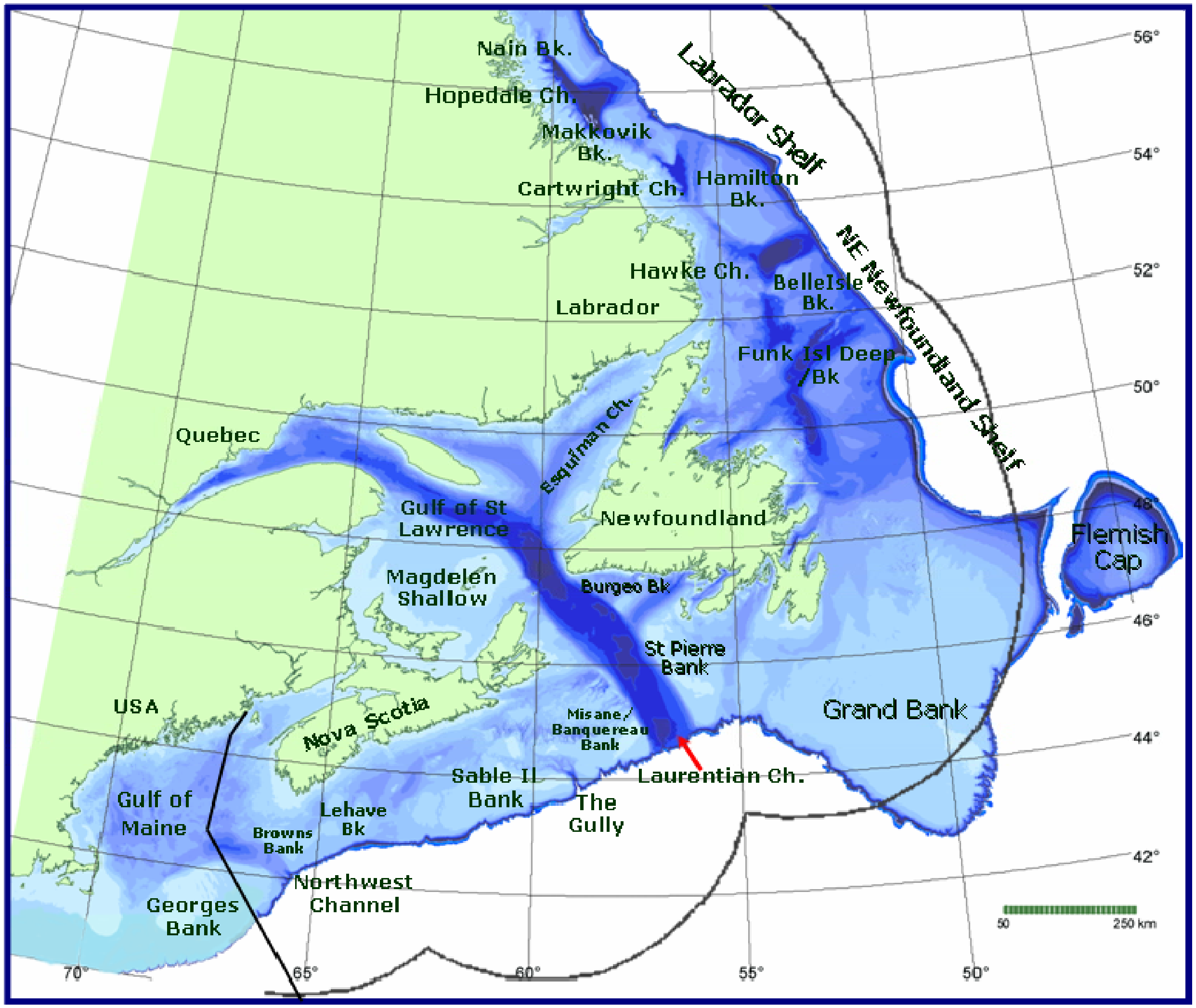


Figure 1. Bathymetry to 1000 m (darker=deeper) and geographic features corresponding to the global distribution of *M. senta.* Black line indicates Canada's 200-mile-limit.

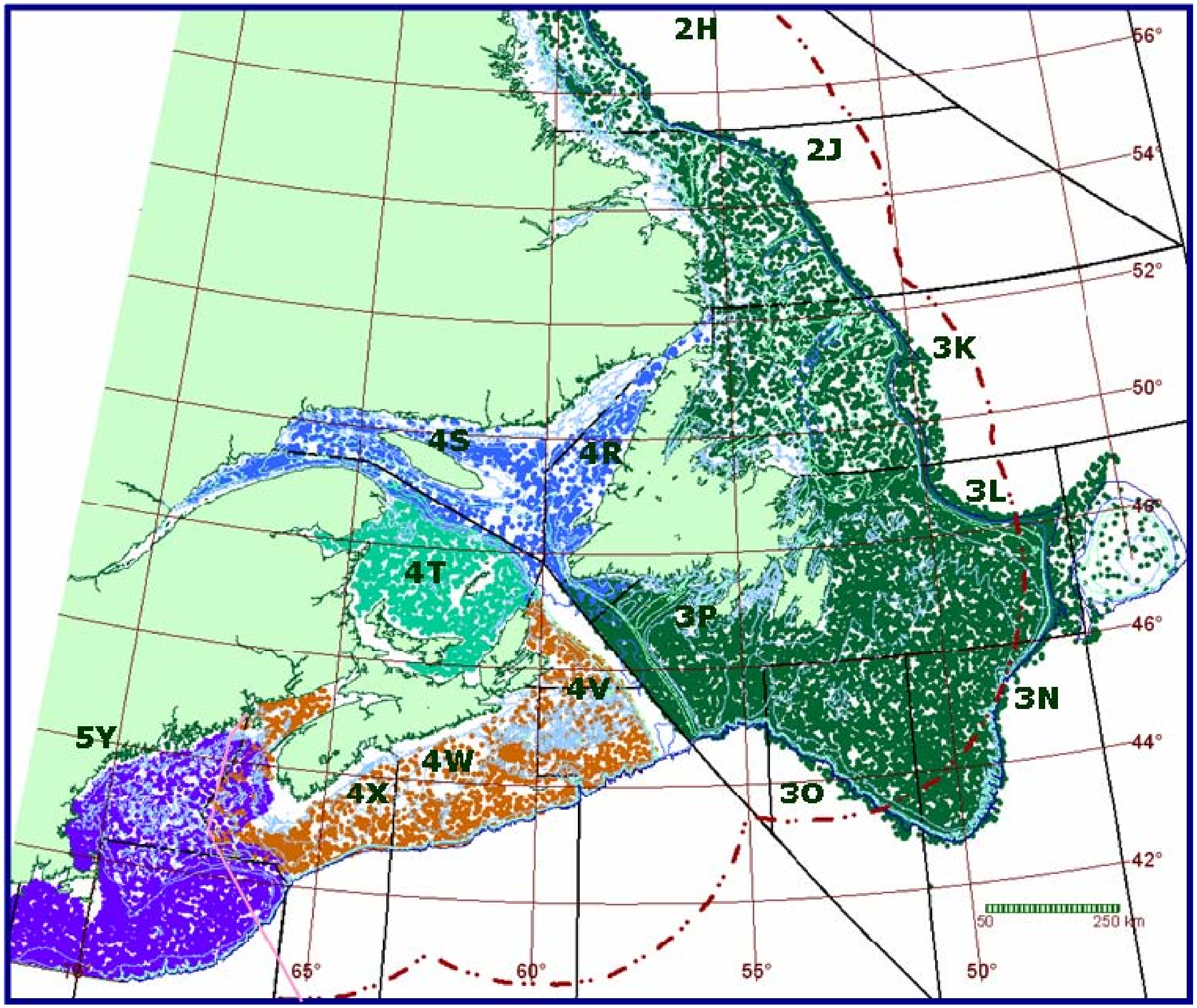


Figure 2. Distribution of research survey sets. Different colours represent different regional surveys: NL – Green; Quebec – Blue; Gulf – Teal; Maritimes – Red; USA – Purple. Solid lines delineate NAFO Divisions; dotted line represents Canada's 200-mile-limit.

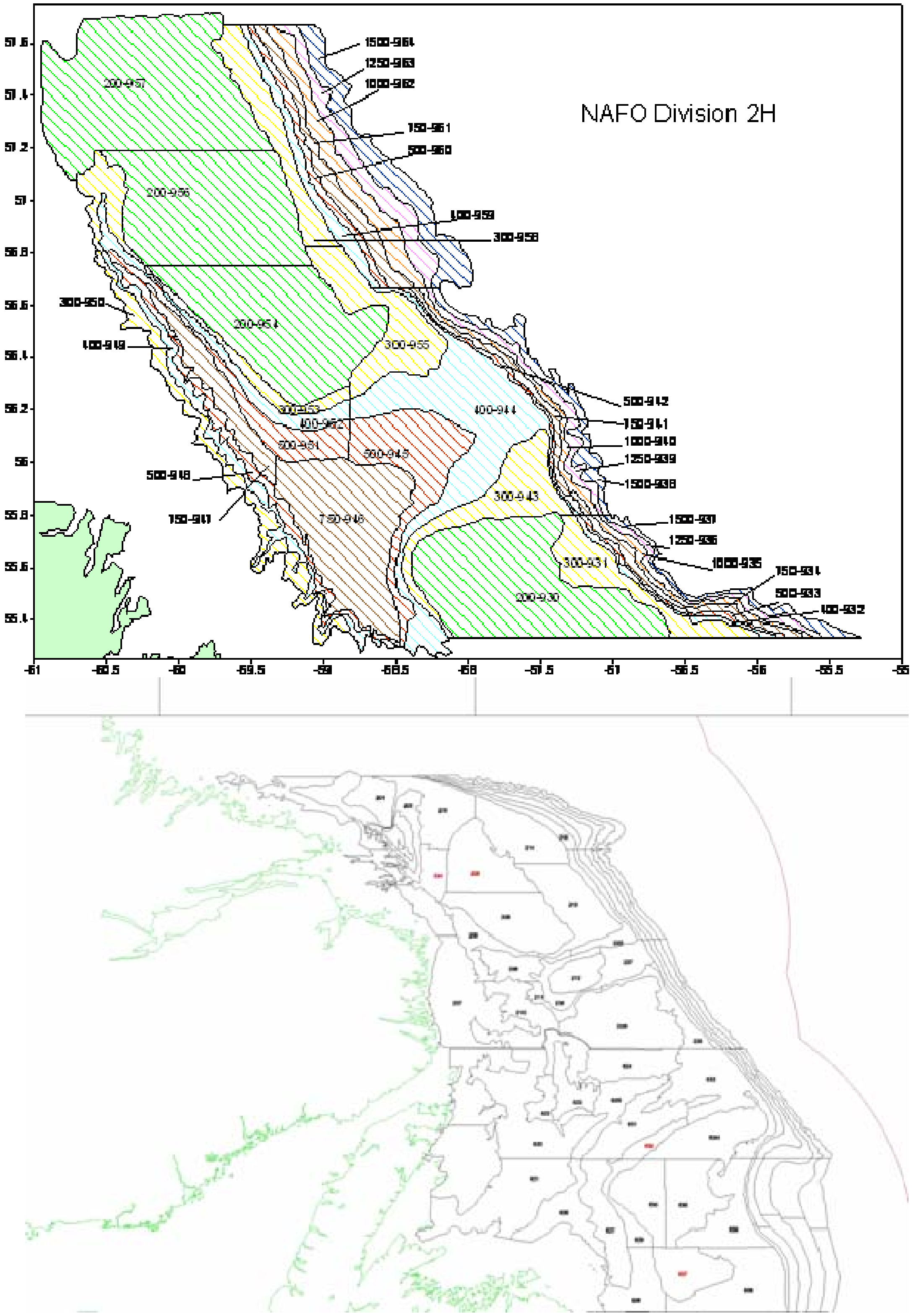


Figure 3. DFO-NL research survey stratification scheme used for the Labrador Shelf/Northeast Newfoundland Shelf (NAFO Division 2HJ3K).

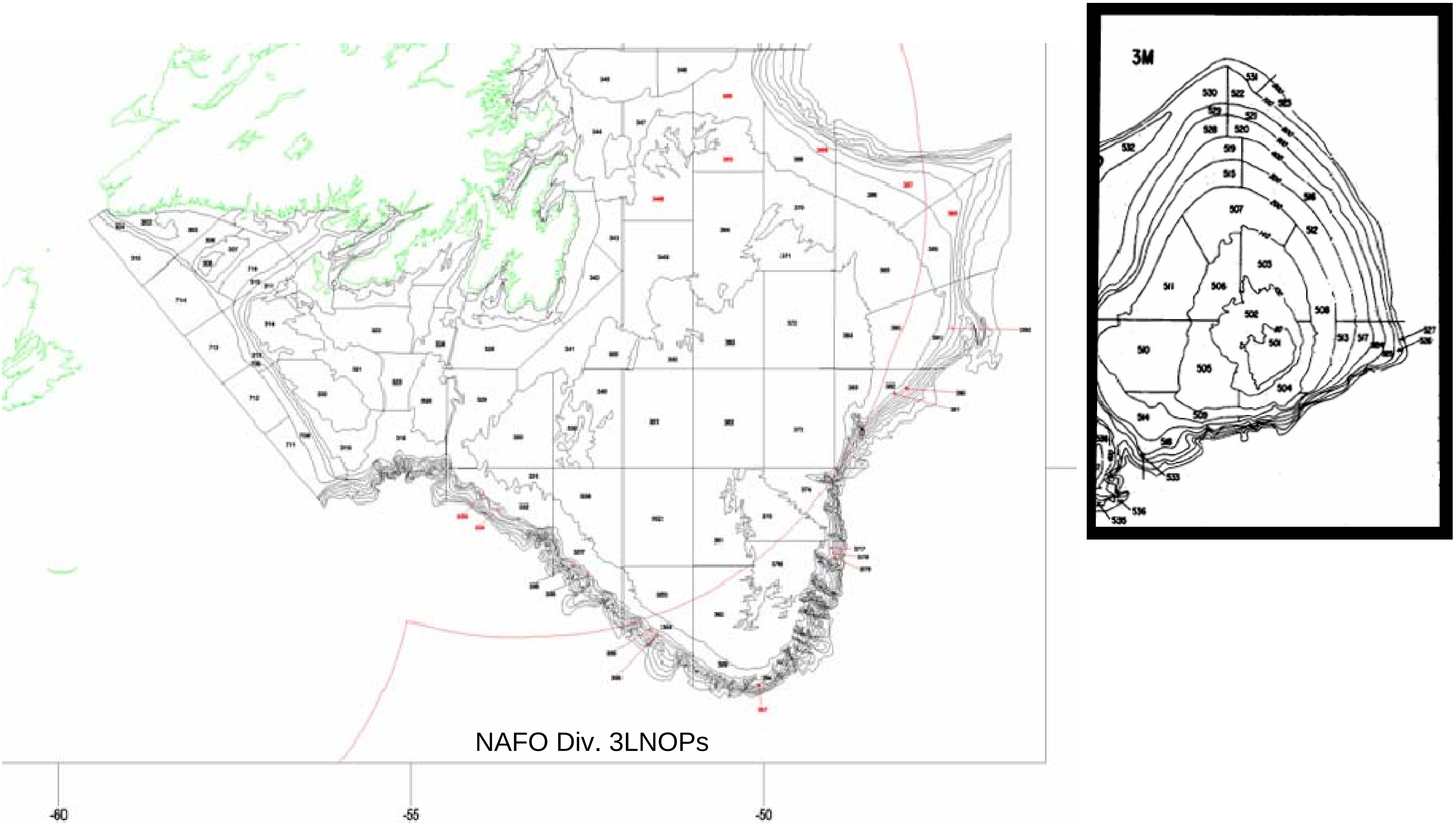


Figure 4. DFO-NL research survey stratification scheme used for the Grand Banks (NAFO Division 3LMNO and Subdivision 3Ps).

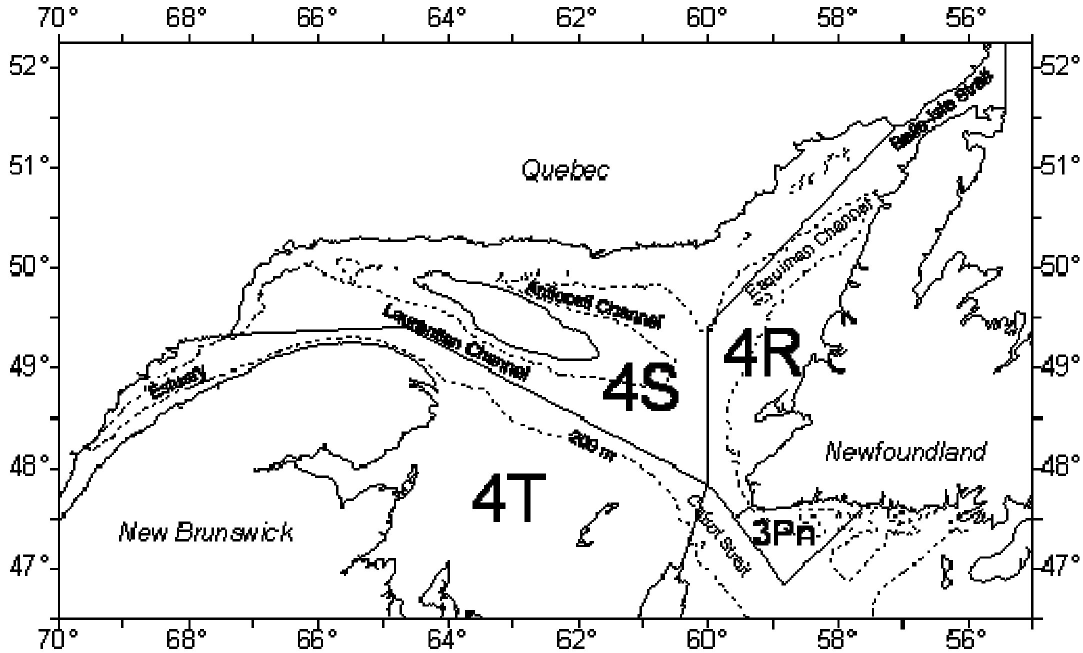


Figure 5. NAFO Divisions of the Gulf of St Lawrence, locations, and areas cited in the text.

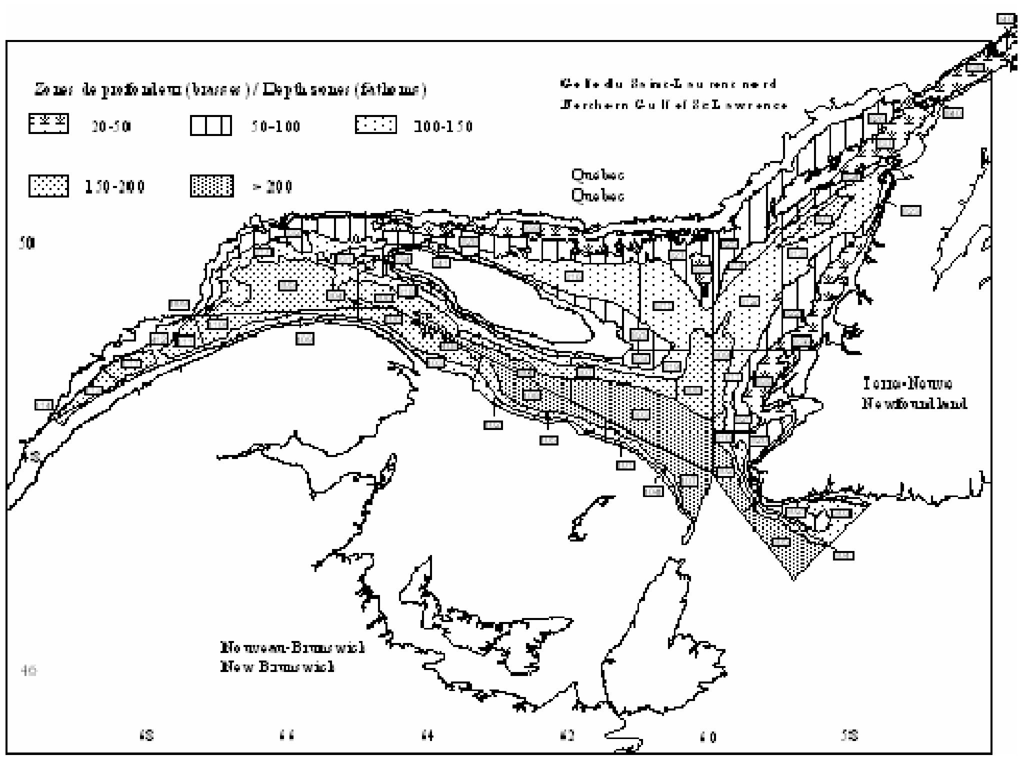


Figure 6. The northern Gulf of St. Lawrence stratification scheme used during groundfish trawl surveys.

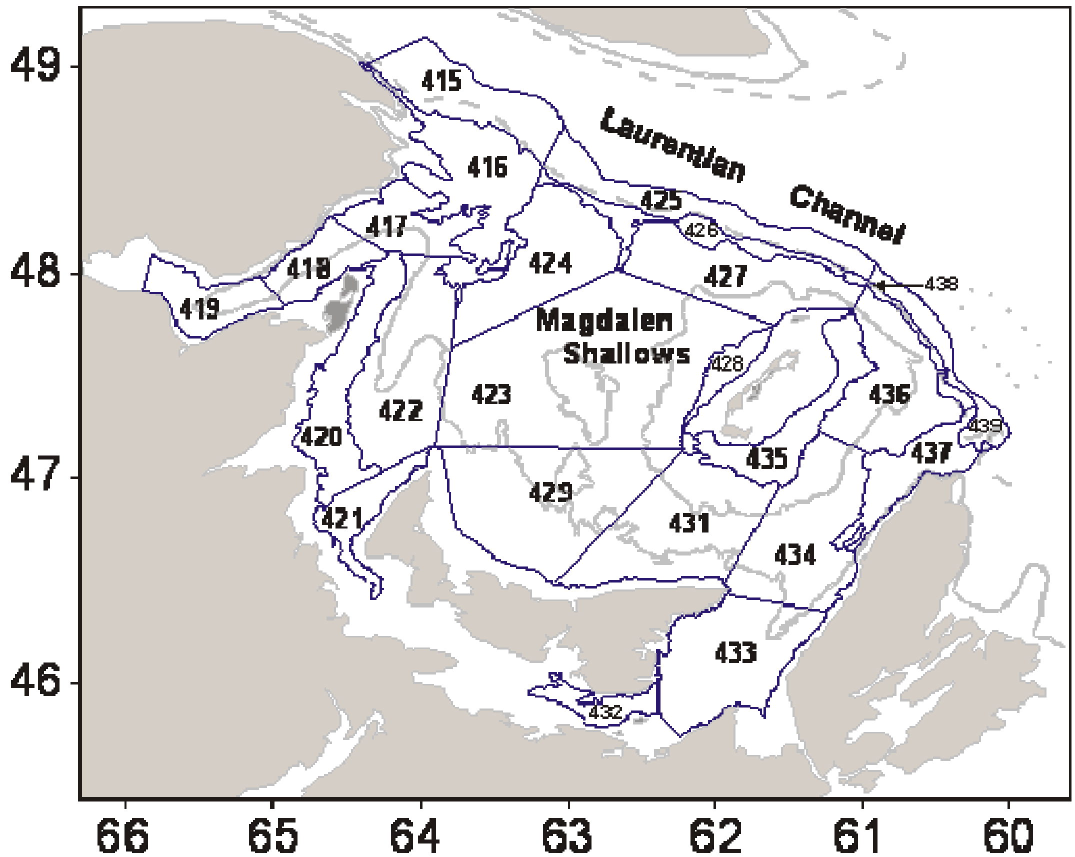


Figure 7. The southern Gulf of St. Lawrence, showing strata used since 1971 in annual September bottom-trawl surveys. Depth contours: solid grey line=60 m; dashed grey line=200 m; dotted grey line=500 m.

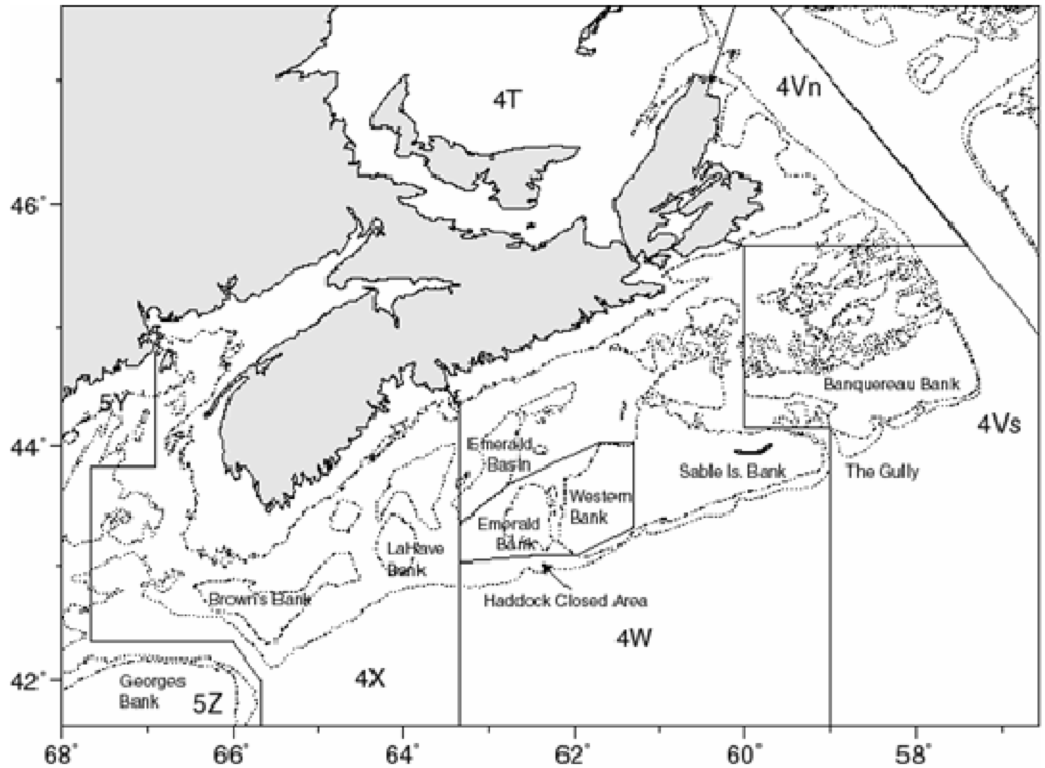
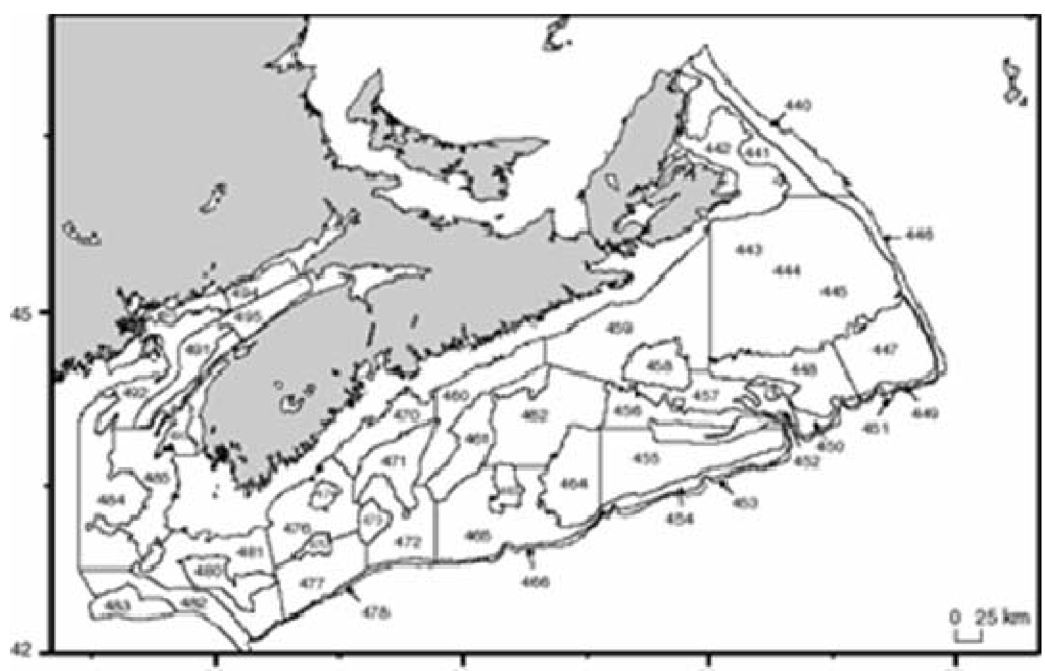


Figure 8. Geographic display of NAFO Divisions for the Maritimes Region encompassing the Scotian Shelf, Bay of Fundy, and northern Gulf of Maine.



.

Figure 9. Stratification scheme used during the Maritimes Region summer research trawl surveys for the area described in Fig. 8.

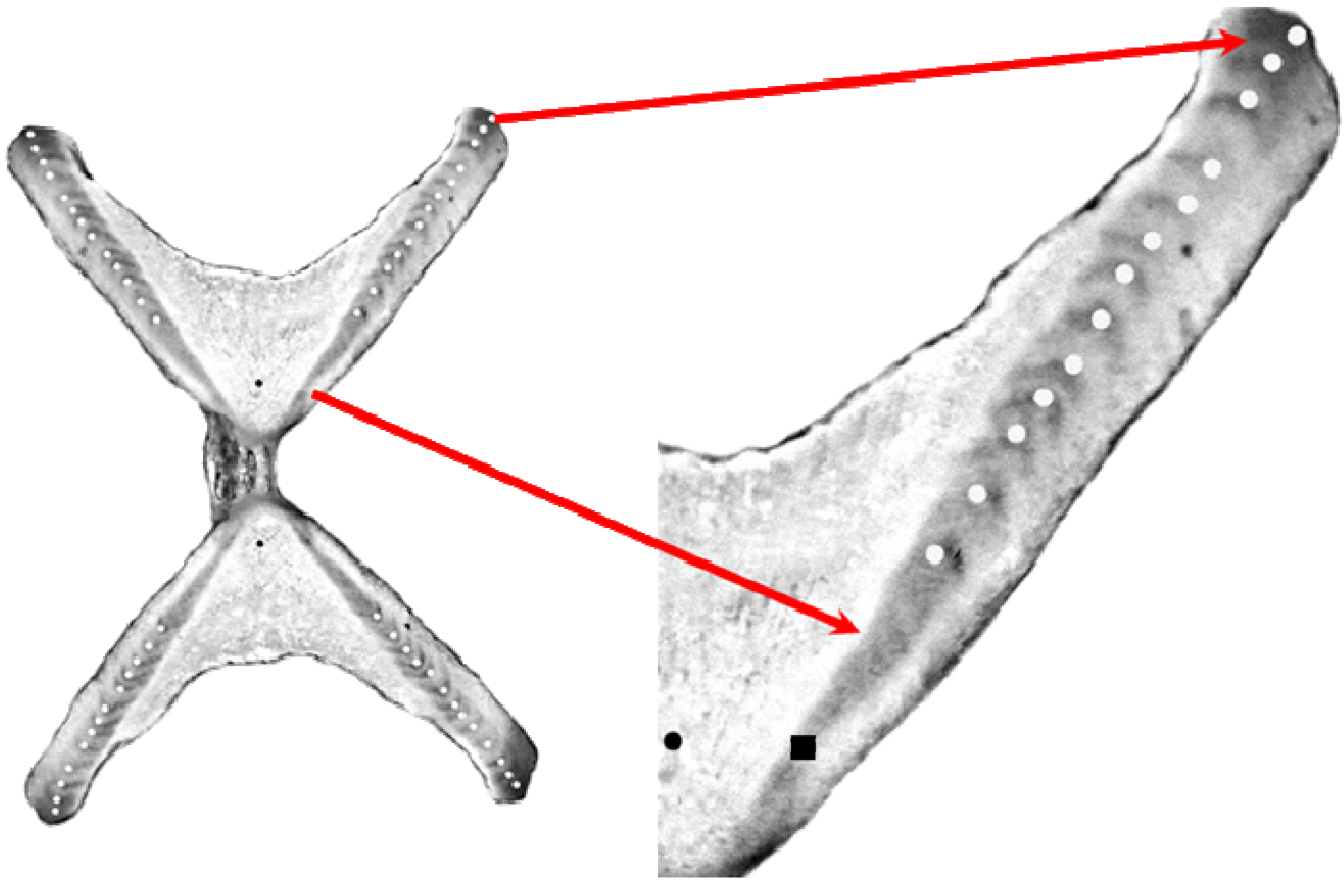


Figure 10. Example of a vertebral cross-section of an *M. senta* prepared for aging. The dots represent annual increments. The square marks the approximate location of the vertebral “birthmark”; the white dots illustrate where winter deposition was assumed to cease for that year prior to commencement of spring/summer growth.

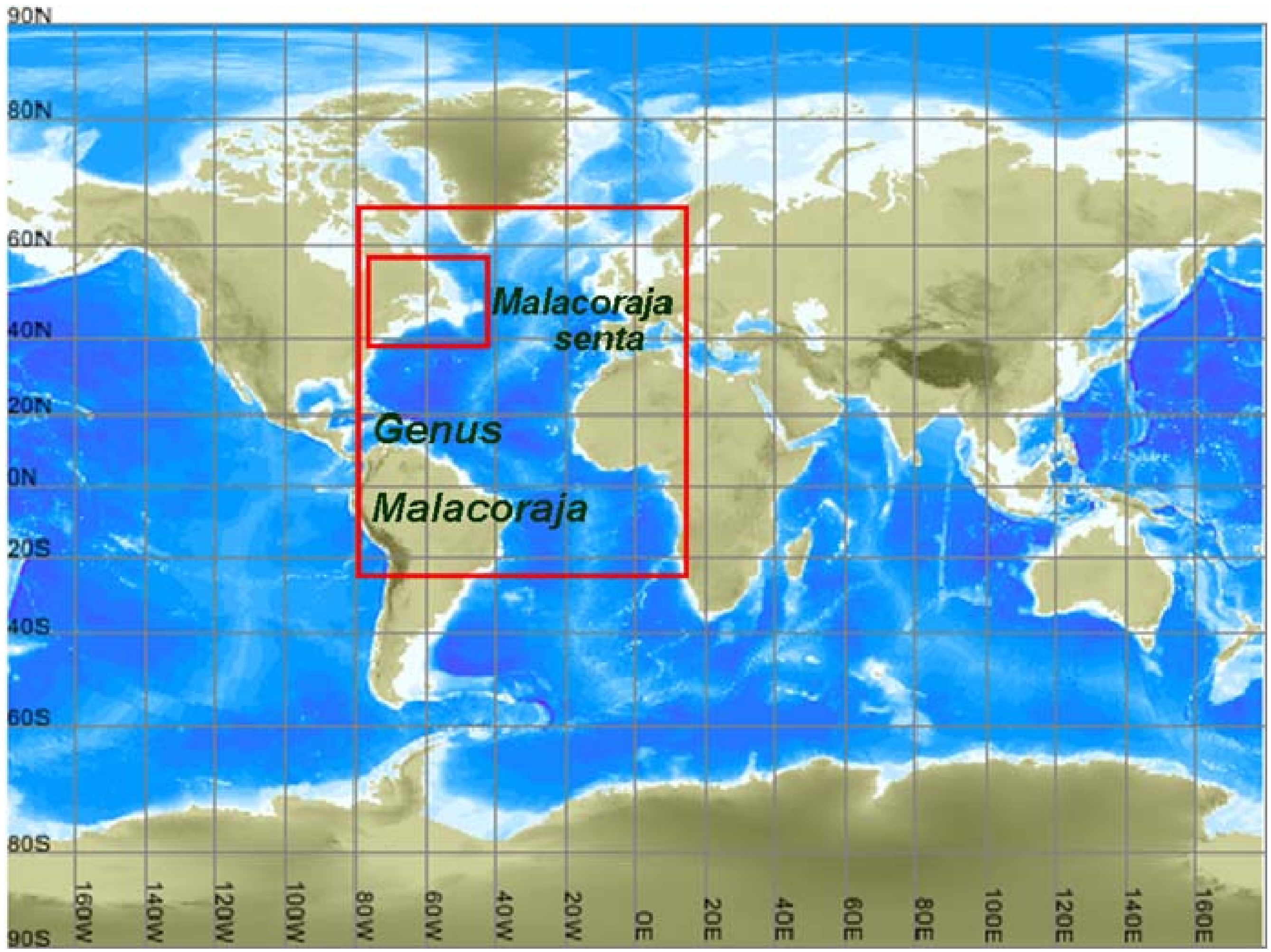


Figure 11a. World map delineating the extent of the global distribution of the Genus Malacoraja and *M. senta.* Within these squares, the species are restricted to portions of the continual shelf (see Fig. 11b for a detailed description of the distribution of *M. senta*)..

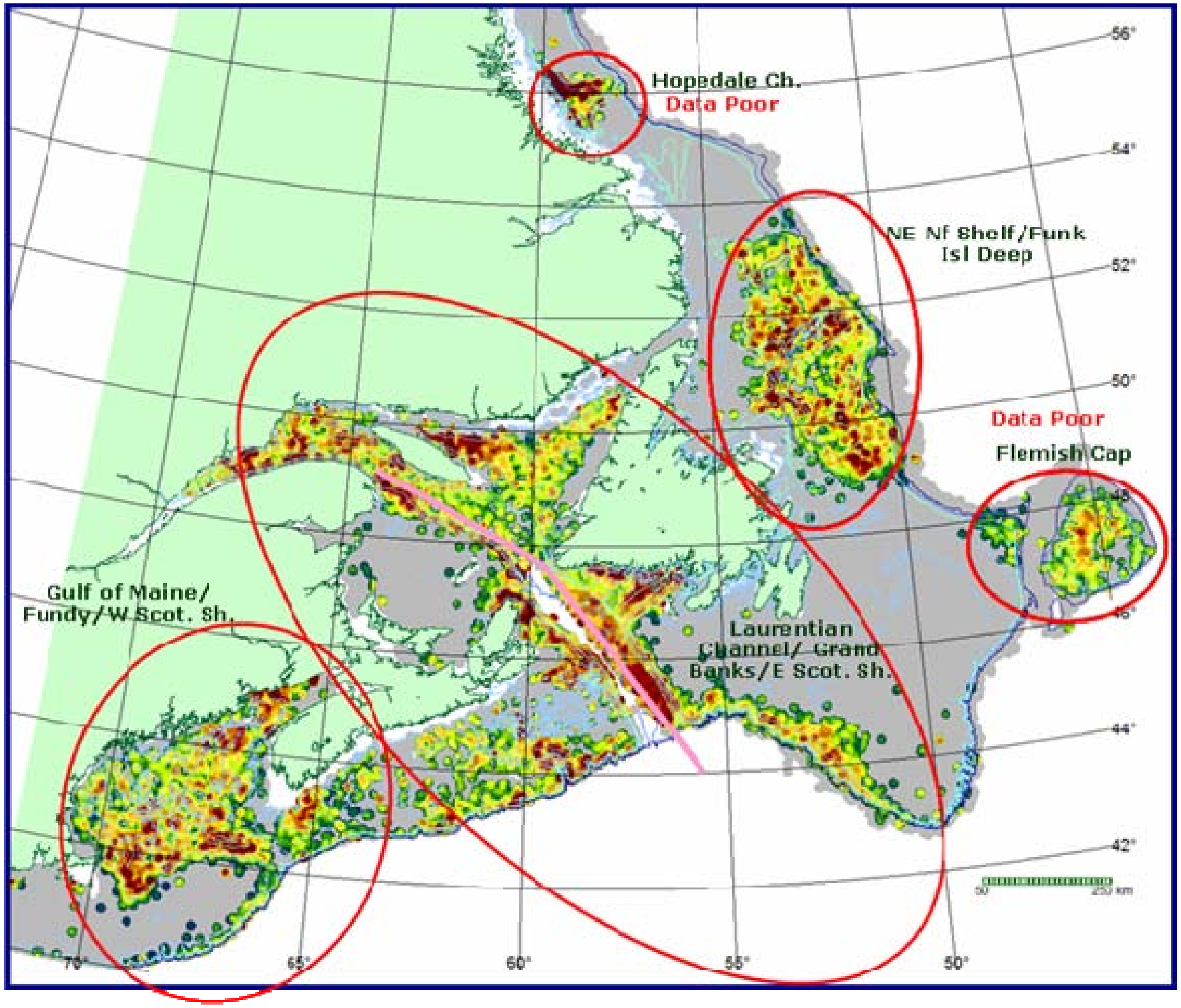


Figure 11b. Distribution of *M. senta* over its global range; as derived from various Canadian and US trawl surveys, 1970-2005. The red circles delineate DU's as defined in this paper

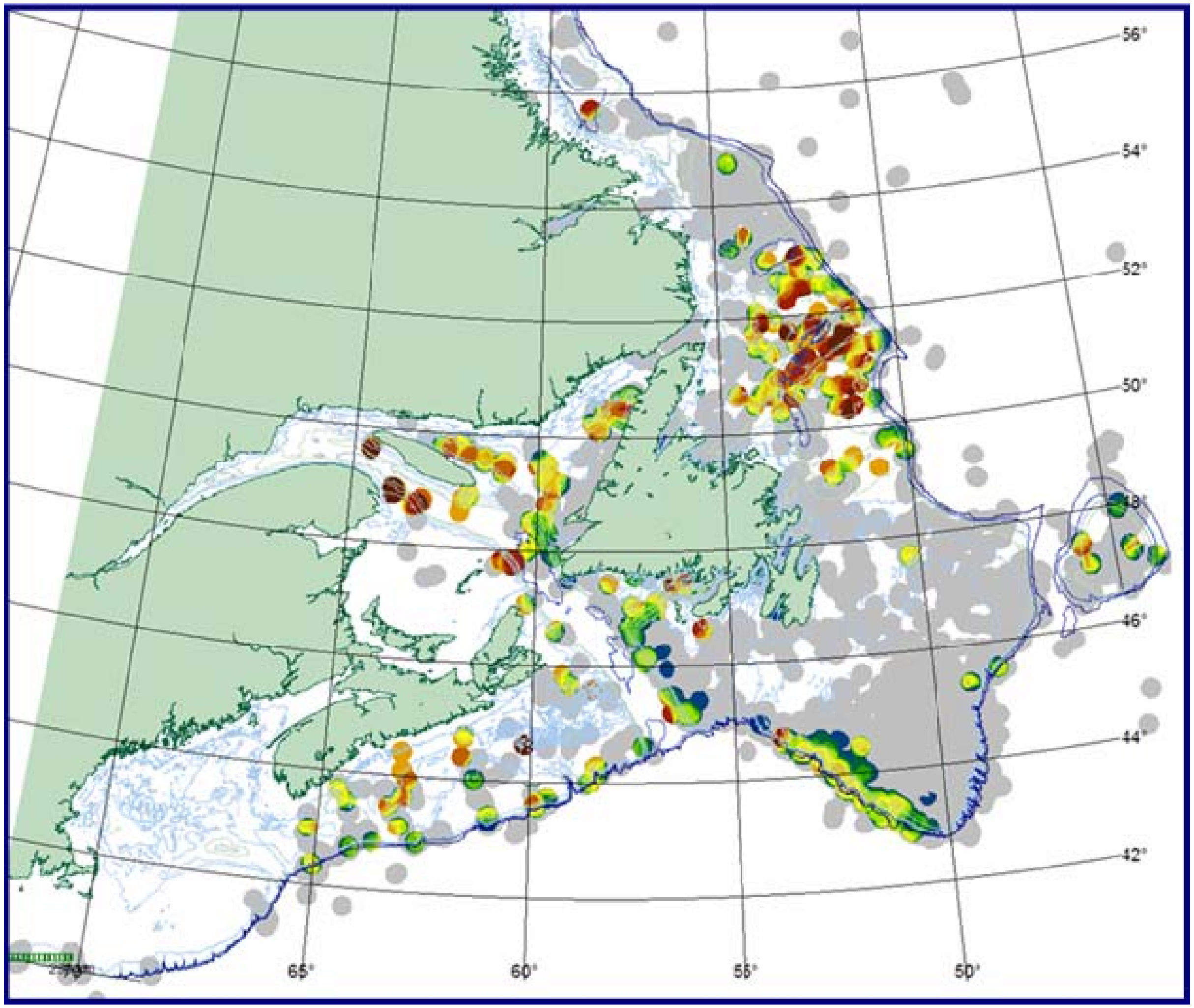


Figure 11c.Distribution of *M. senta* based on NL Region surveys from 1947 to 1970. Grey represents sampling but no catches. Red represents high concentrations

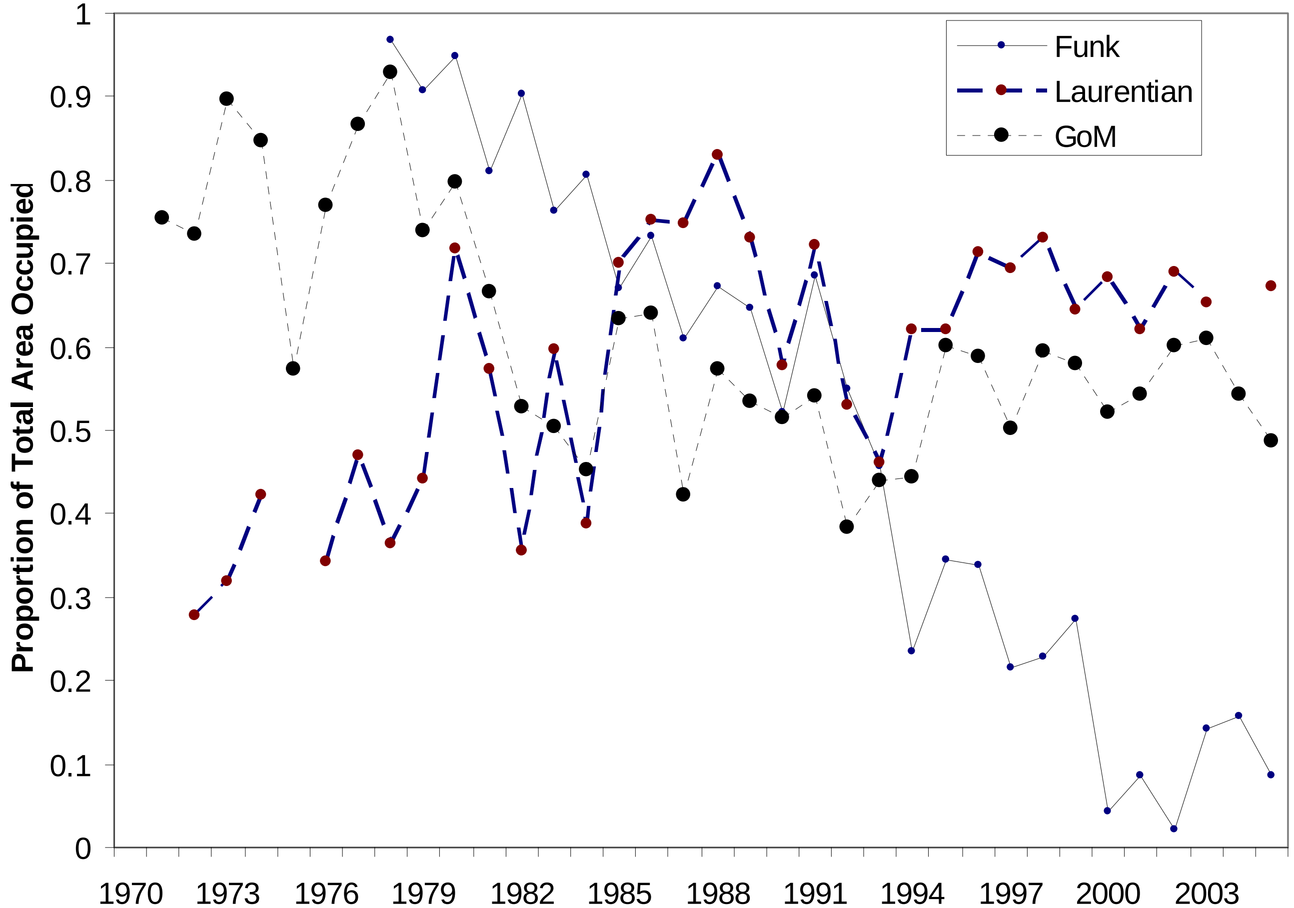


Figure 12. Proportion of total area occupied (all locations where *M. senta* occurred between 1971 and 2005) for DU's where sufficient data series exist: Funk, Laurentian and GoM. Area was calculated by transforming point data to surfaces with potential mapping and estimates of surface area were calculated by the GIS SPANS in km^2. Data from all Regions were integrated for this analysis.

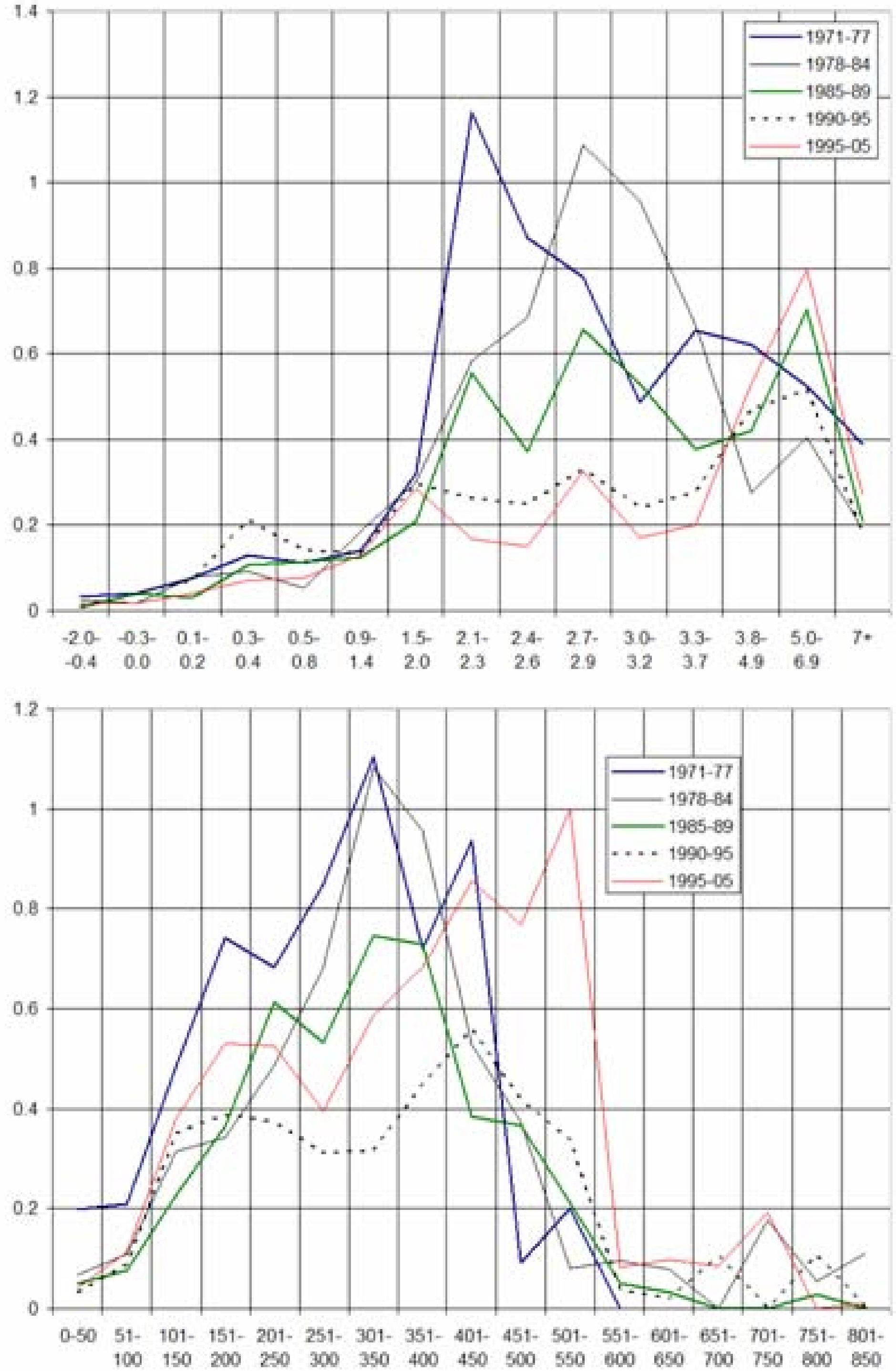
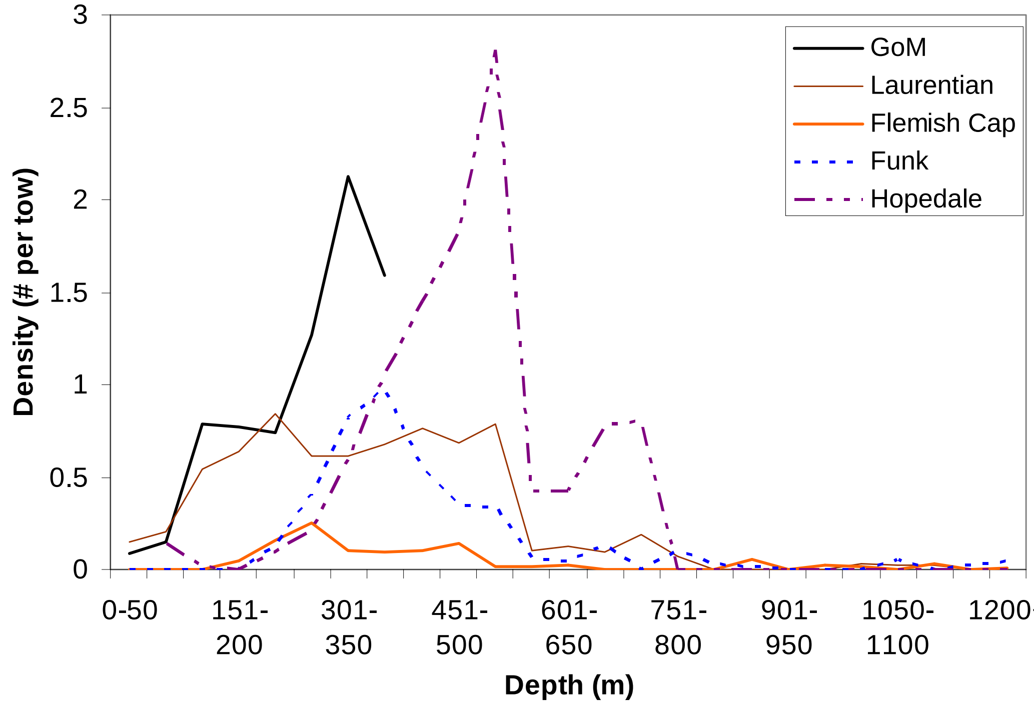


Figure 13a.Distribution of *M. senta* averaged over its global range with respect to temperature and depth during five time periods.



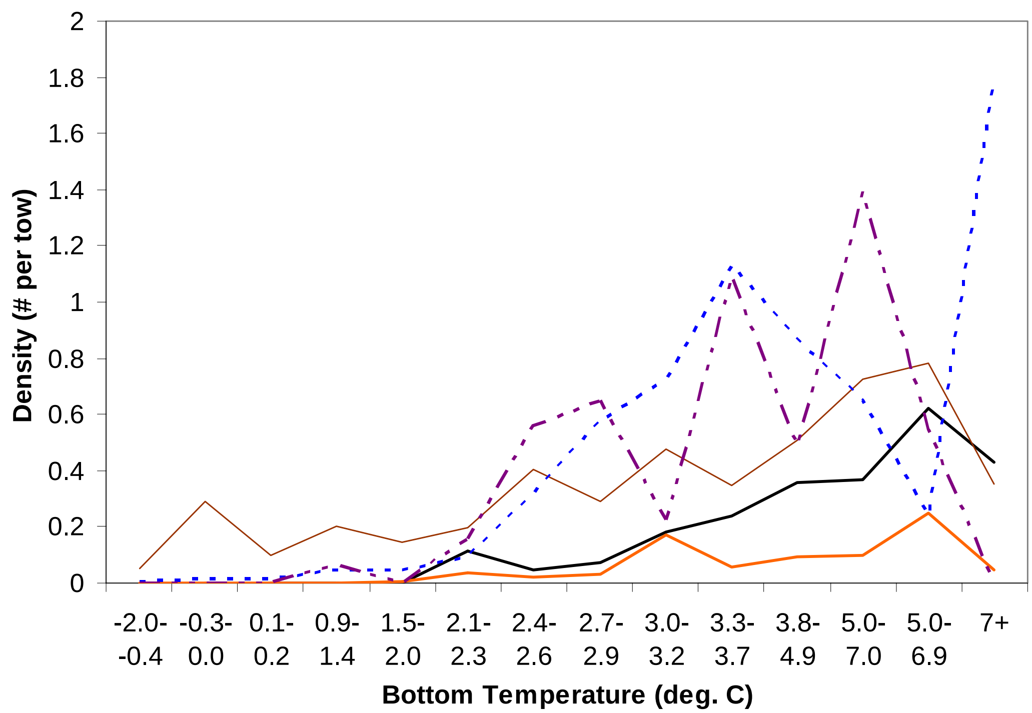


Figure 13b. Distribution of *M. senta* for the various DUs over its range with respect to temperature and depth during 1971-2005.

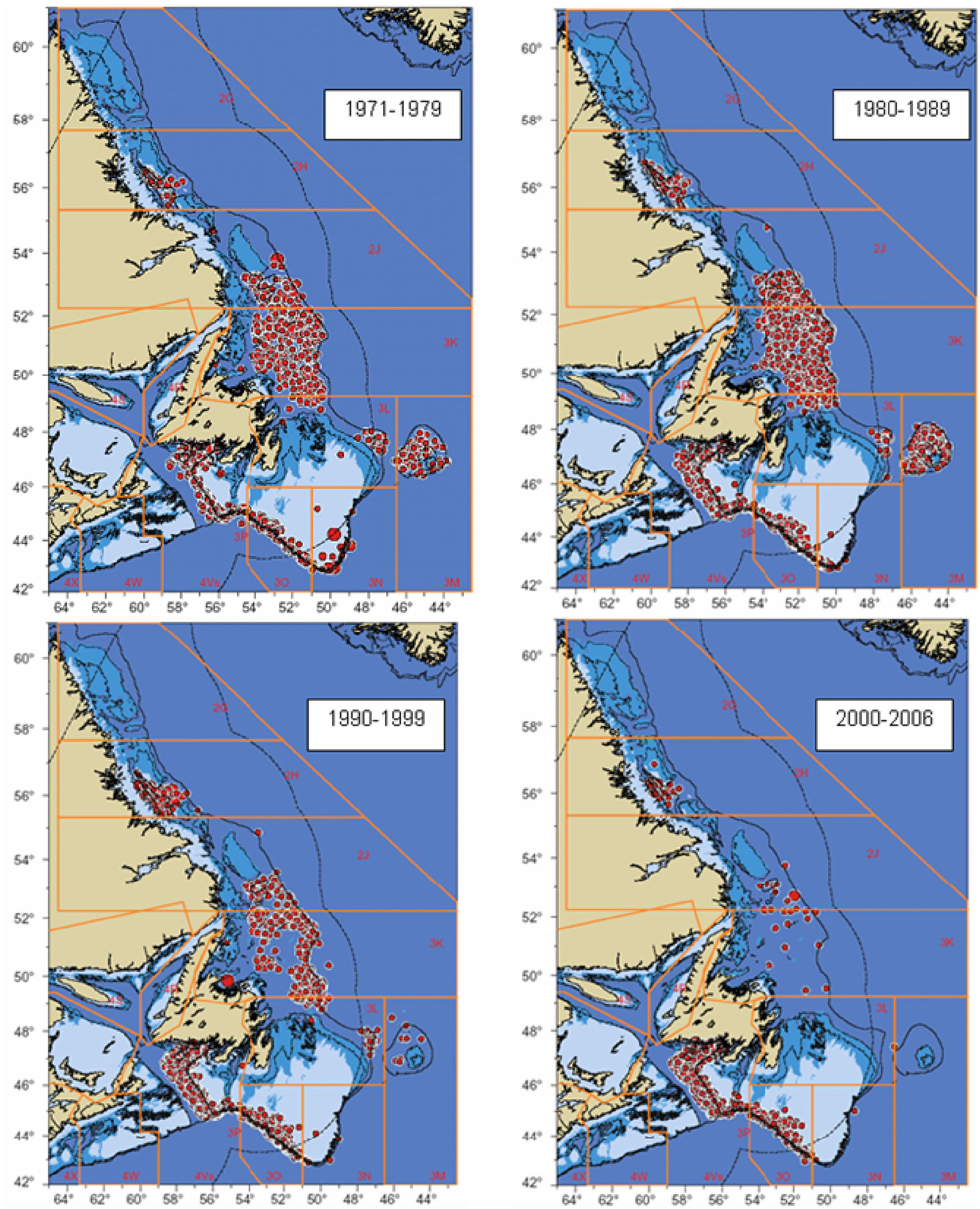


Figure 14. Expanding symbol plots of *M. senta* by decadal period: 1971-79.; 1980-89;1990-99; 2000-06. Only survey sets containing *M. senta* are included.

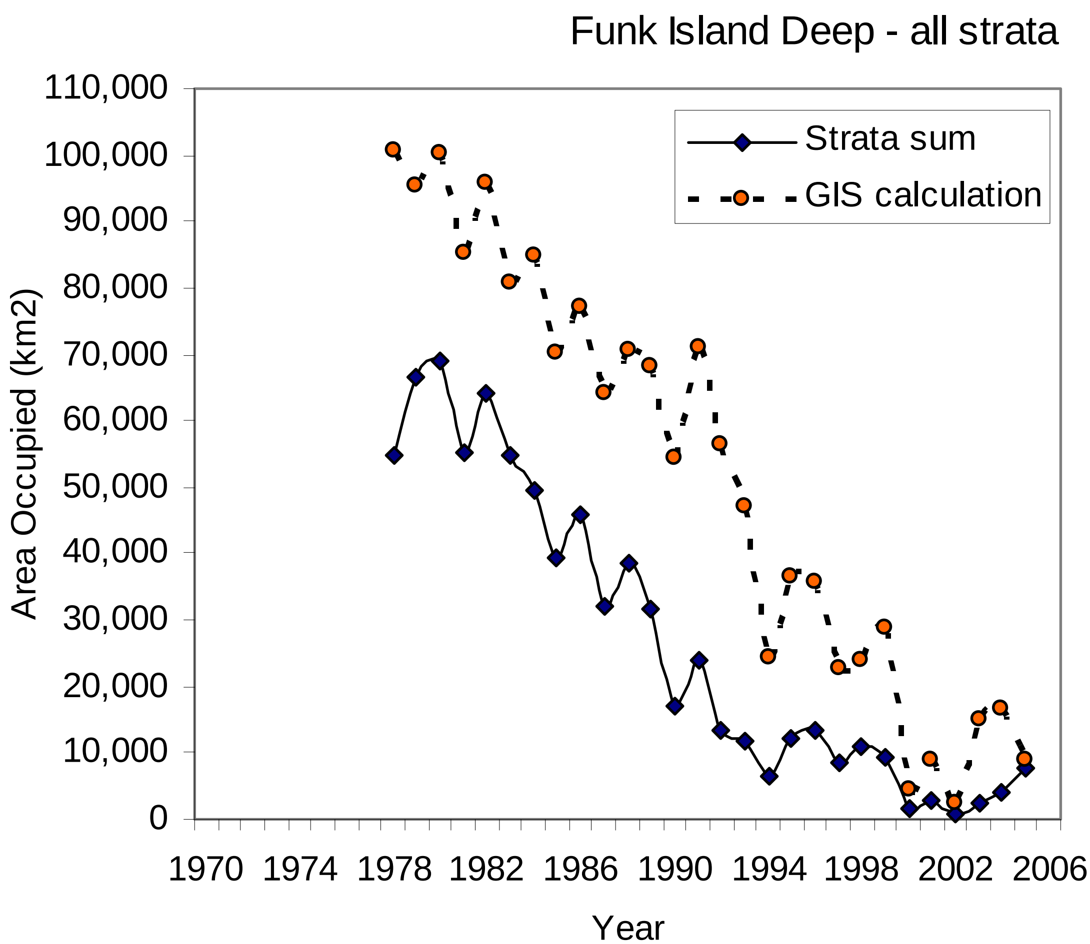


Figure 15. Area occupied by *M. senta* in the Funk DU (Funk Island Deep/NE NF Shelf), 1978-2005. "All strata" encompass every stratum sampled in the research survey time series. Note that the GIS calculation of area occupied encompasses the entire DU while the Strata Sum was done for the NL Region segment of the DU.

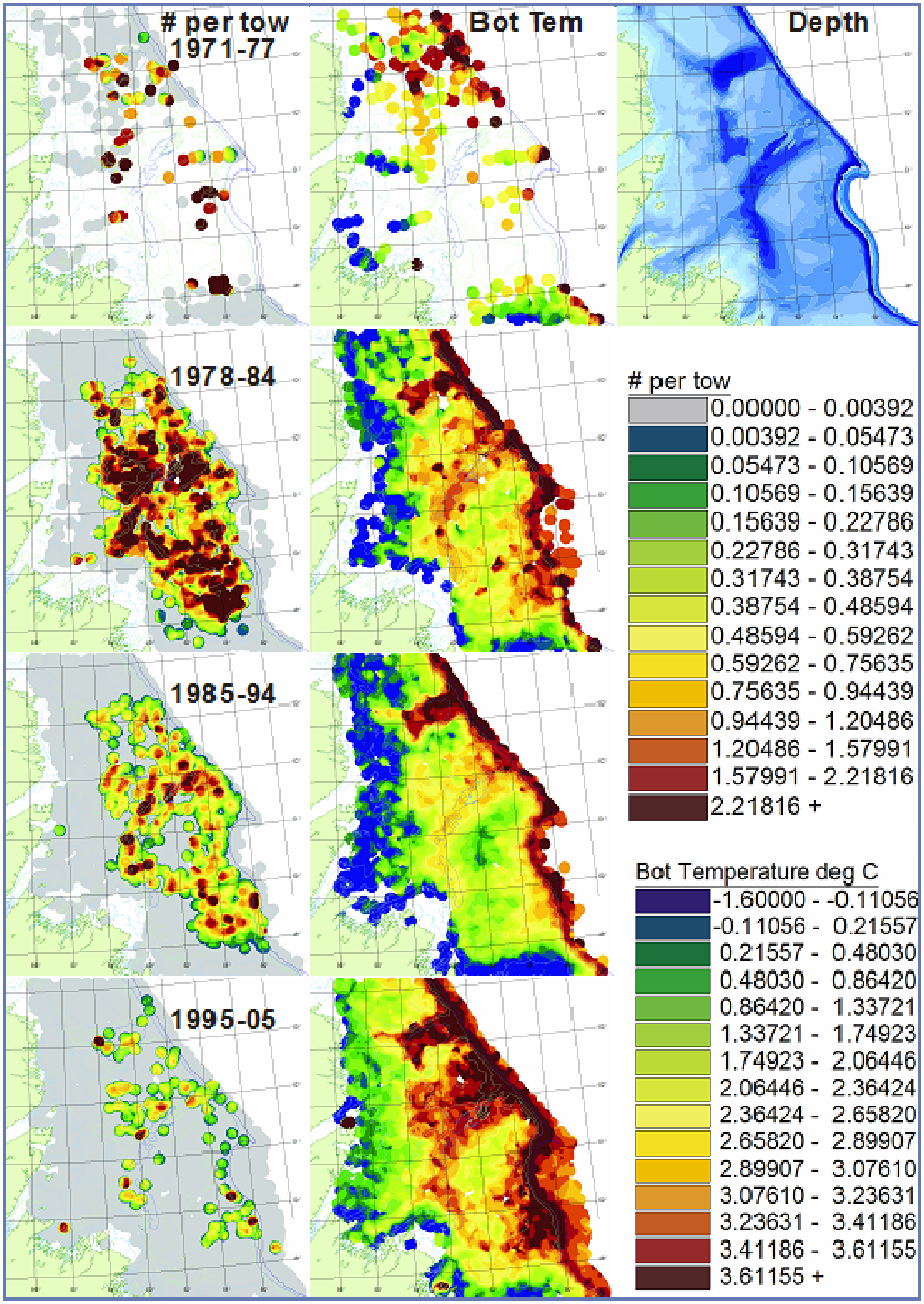


Figure 16. Left Column: Distribution of *M. senta* in the Funk DU (Funk Island Deep/NE NF Shelf). Red depicts high density concentrations; scaling to low density (blue). Grey depicts areas surveyed; but with no catches of *M. senta*. Middle Column: Bottom temperature in degrees C. Right Column: Depth (0-1000 m) and legends for the left and middle columns.

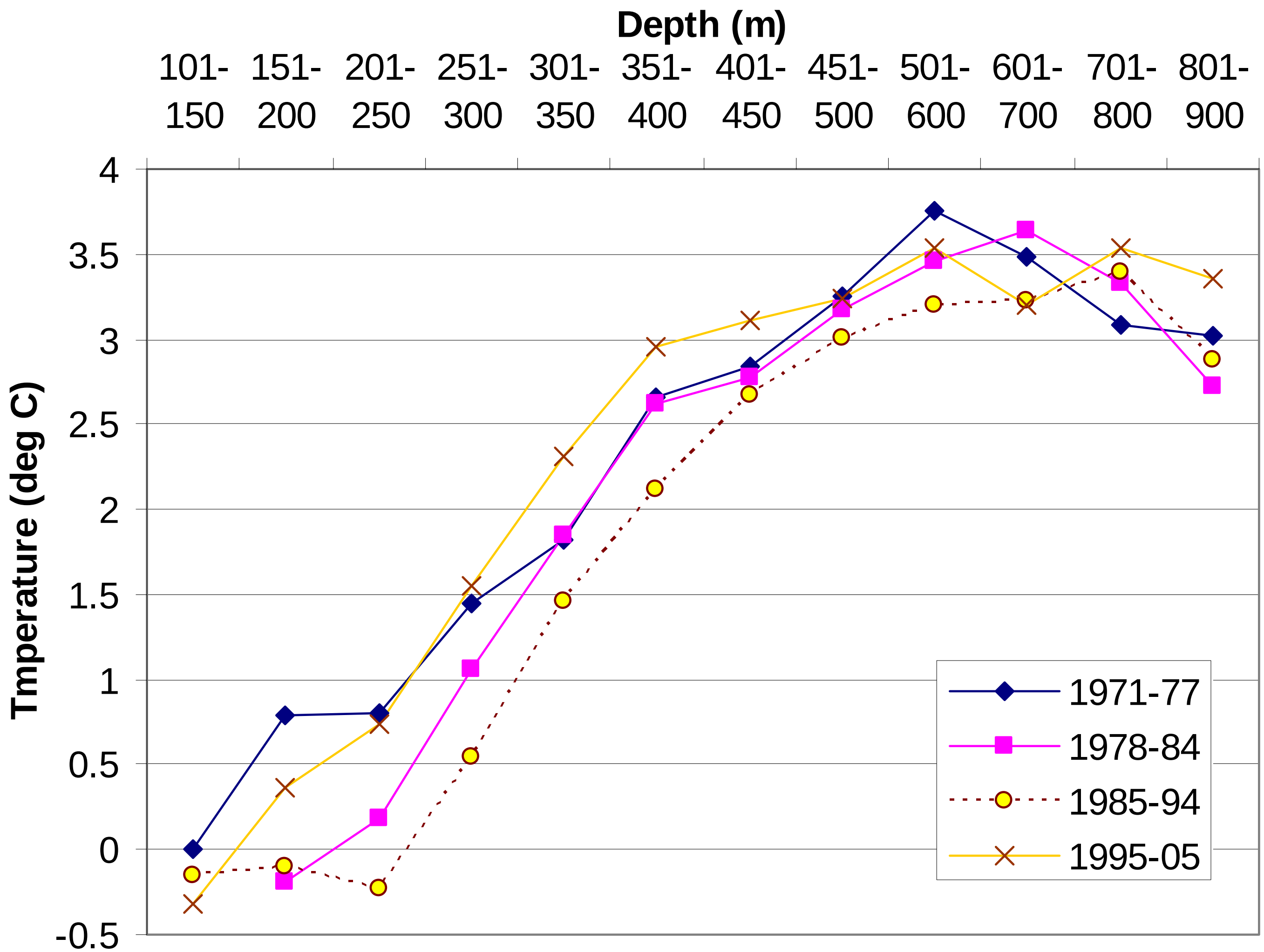


Figure 17. The relationship between depth and bottom temperature in the Funk DU (Funk Island Deep/NE NF Shelf) during five time periods.

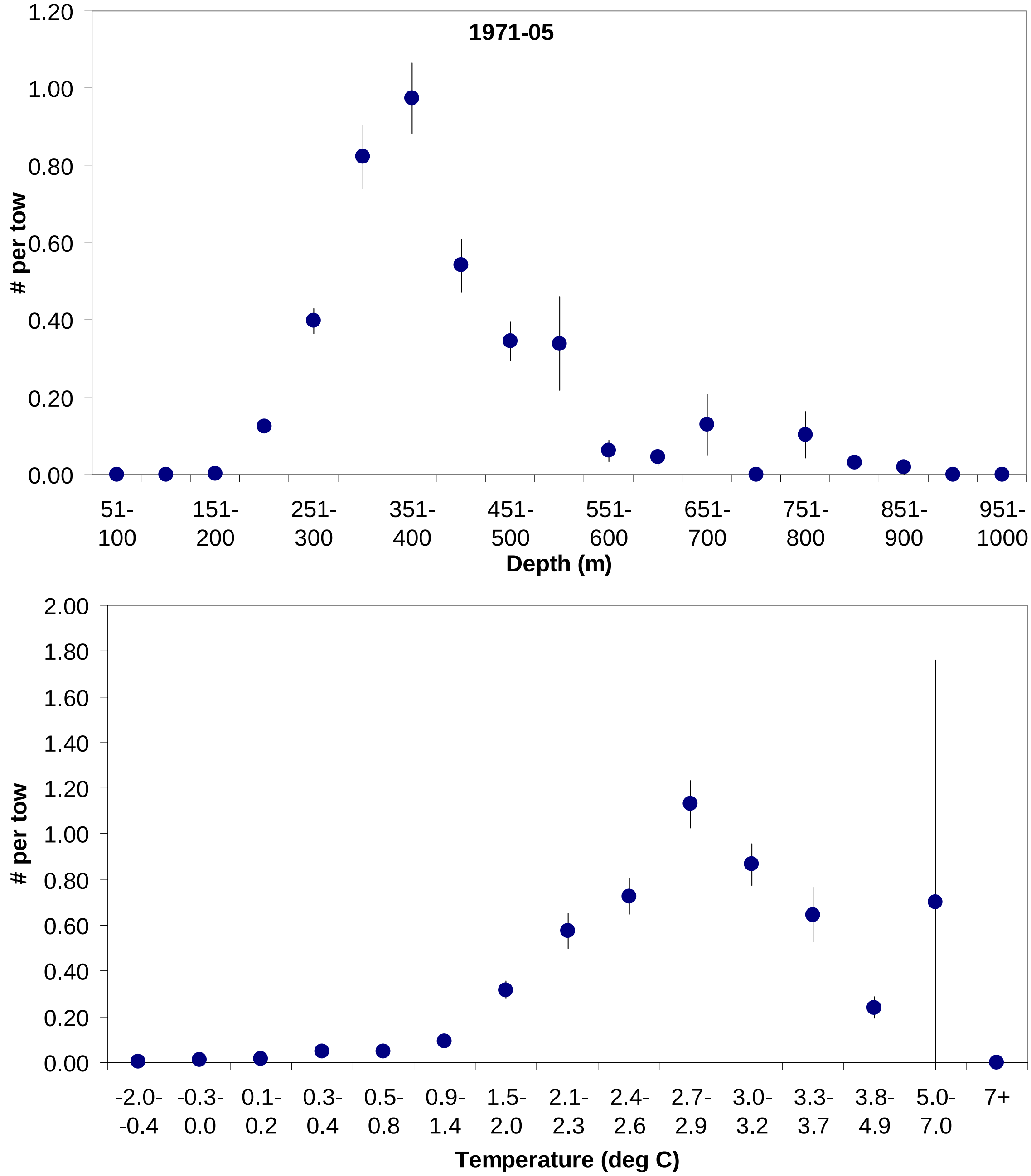


Figure 18. Distribution of *M. senta* in the Funk DU (Funk Island Deep/NE NL Shelf) with respect to depth and temperature, 1971-2005.

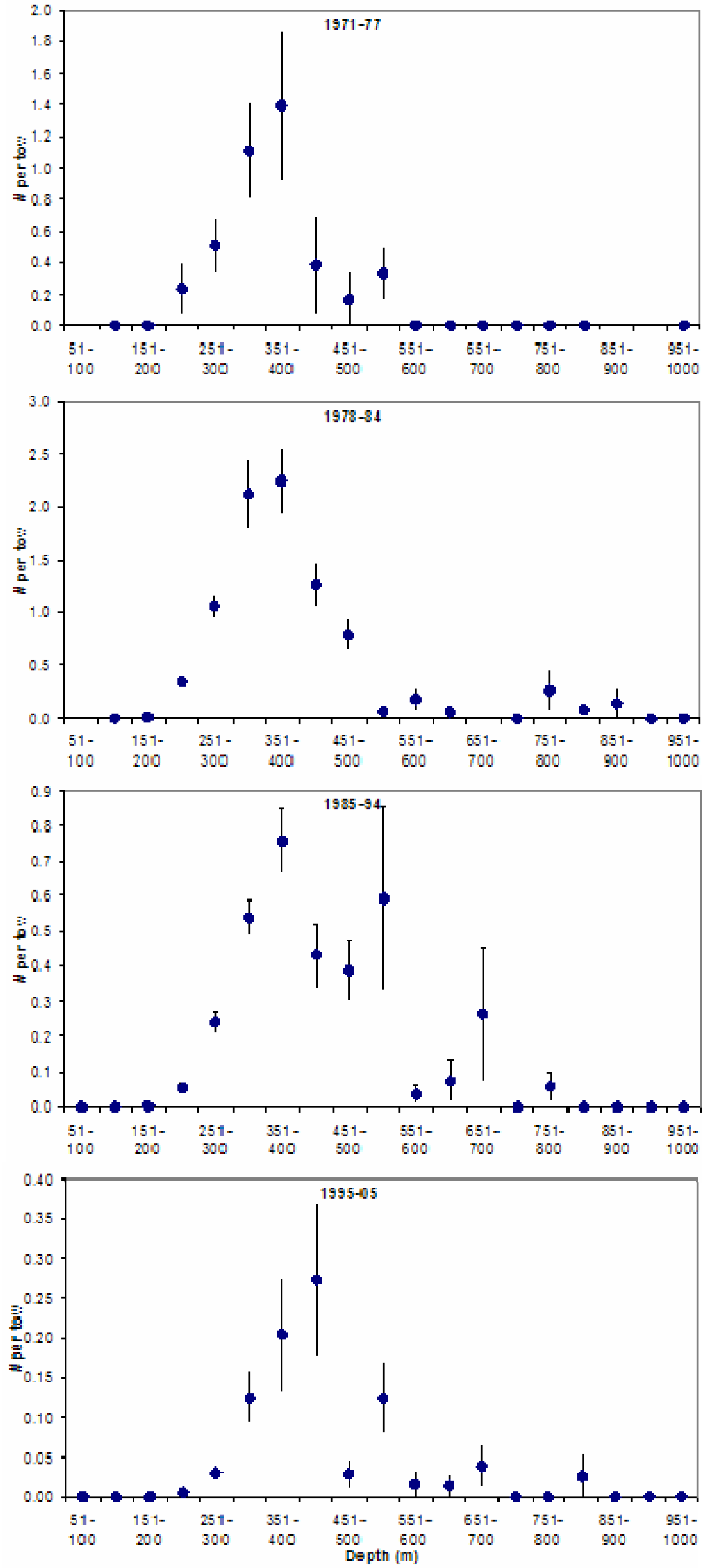


Figure 19. Distribution of *M. senta* in the Funk DU (Funk Island Deep/NE NF Shelf) with respect to depth during four different time periods.

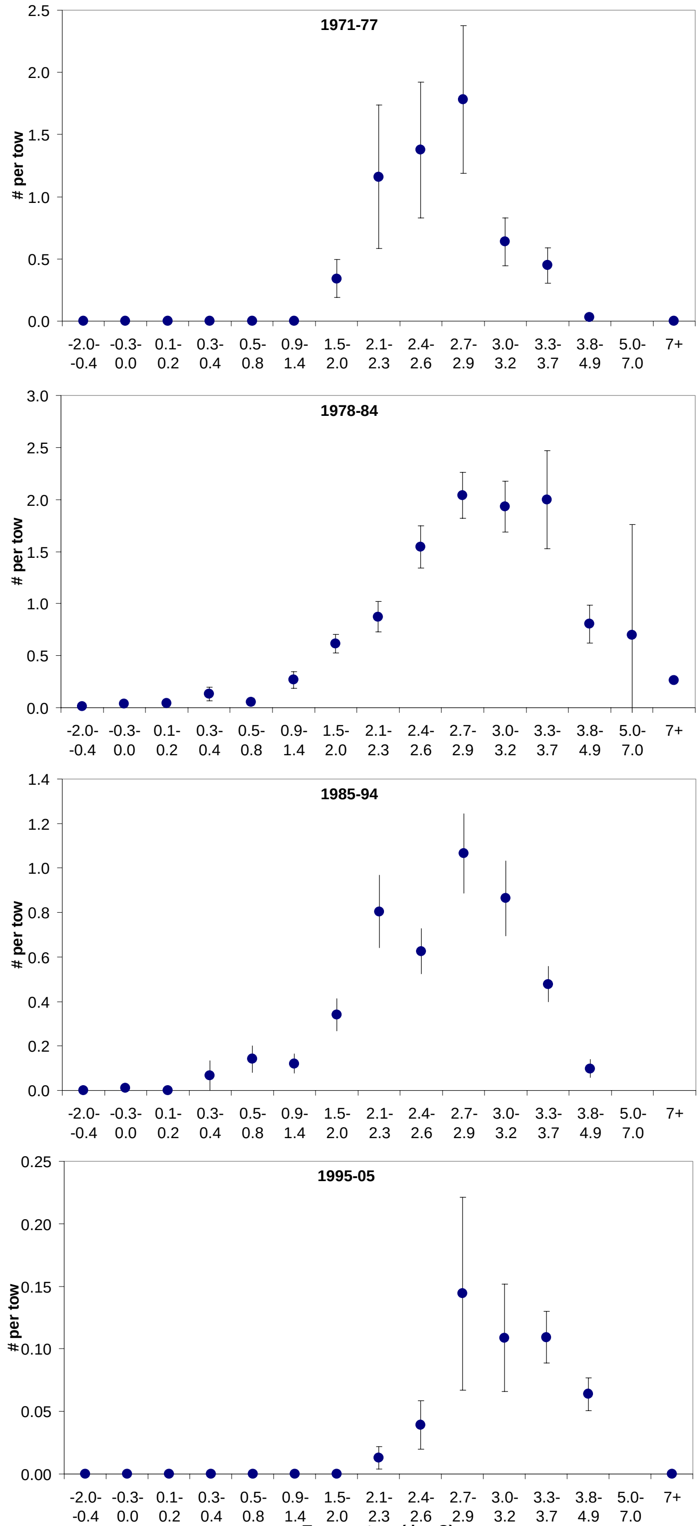


Figure 20. Distribution of *M. senta* in the Funk DU (Funk Island Deep/NE NF Shelf) with respect to bottom temperature during four different time periods.

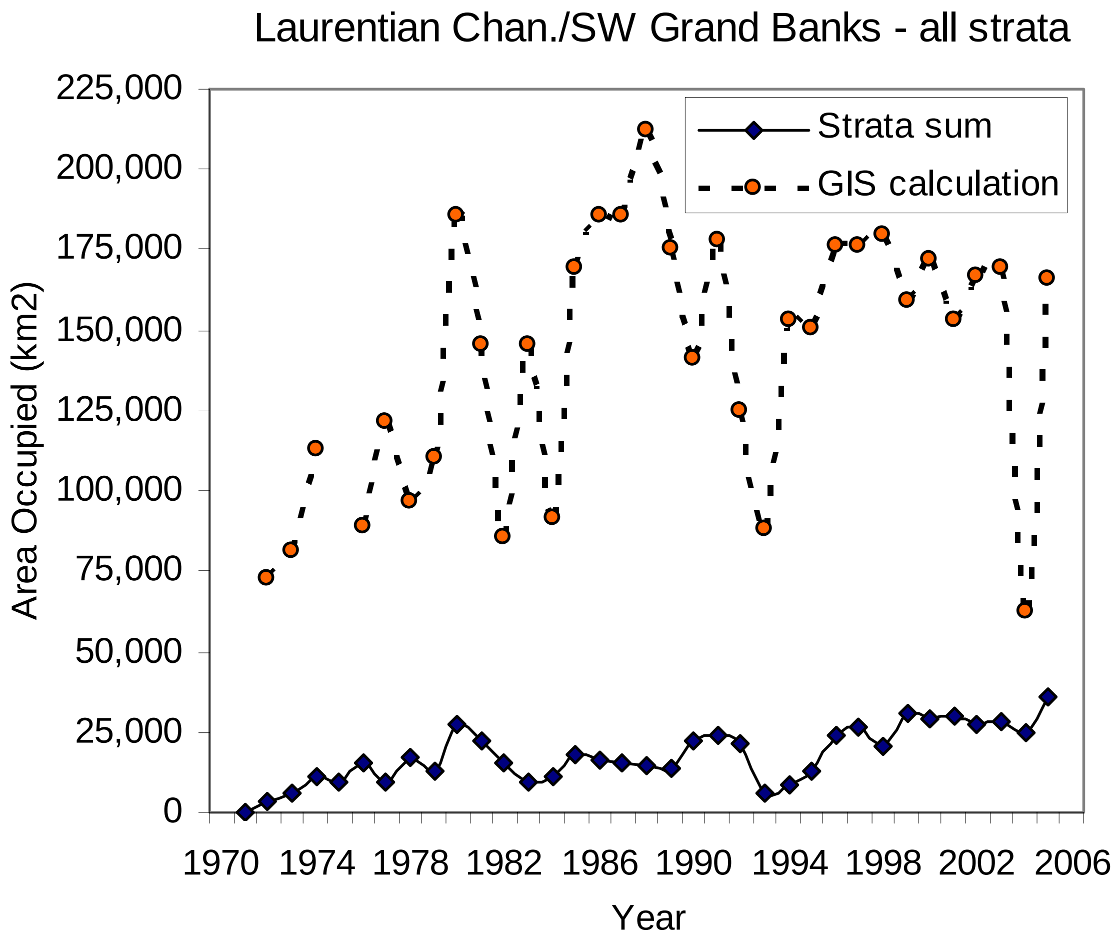


Figure 21. Area occupied by *M. senta* in the Laurentian Channel/Southwestern Grand Banks, 1972-2005. All strata encompass every stratum sampled in the research survey time series.

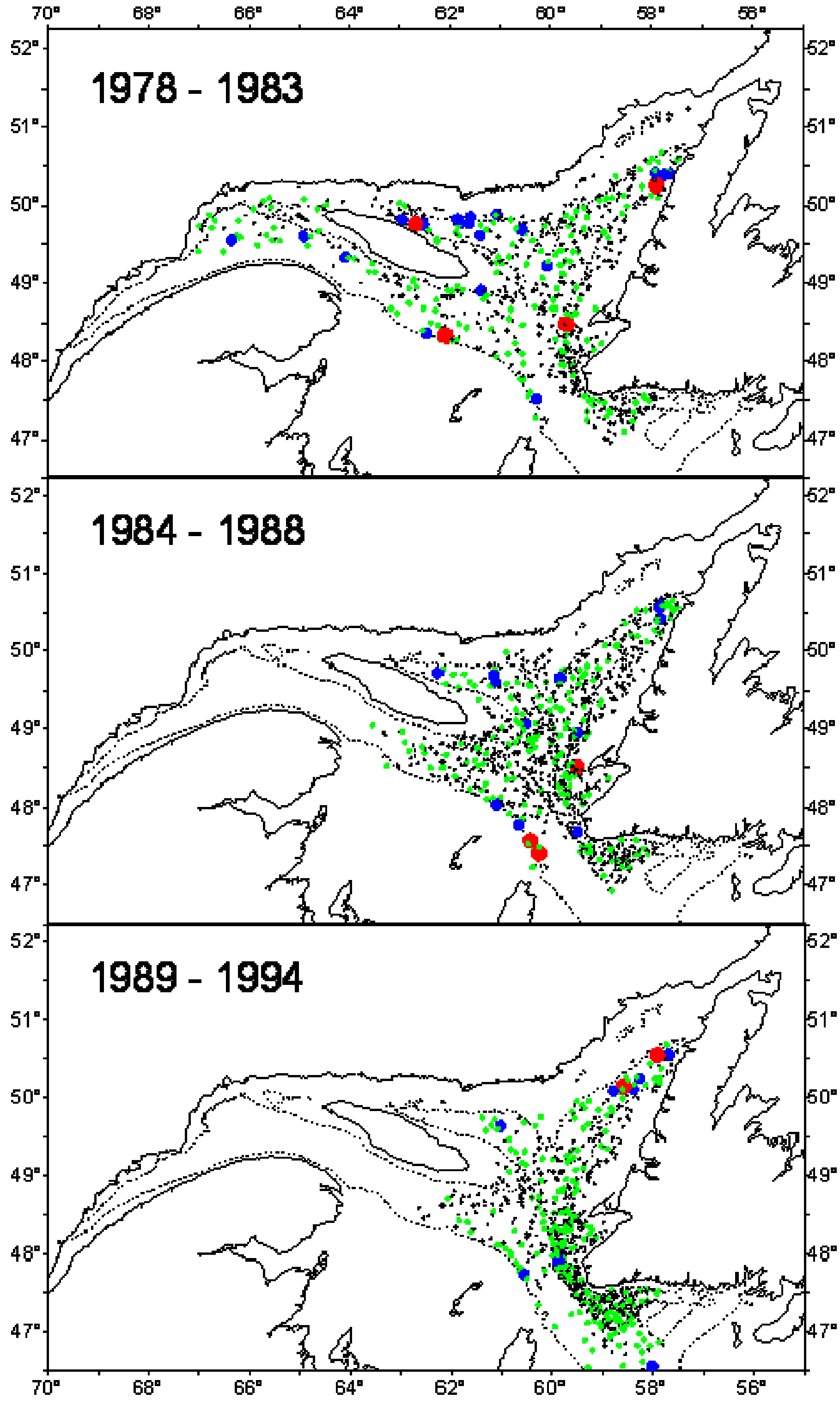


Figure 22. Geographic distribution of *M. senta* catches (standardized number per tow) in the *Gadus Atlantica* January survey of the northern Gulf of St. Lawrence. Catch symbols: +=0; 0 <green <5; 5 ≤ blue <10; red ≥ 10. Depth contours: dotted line=200 m.

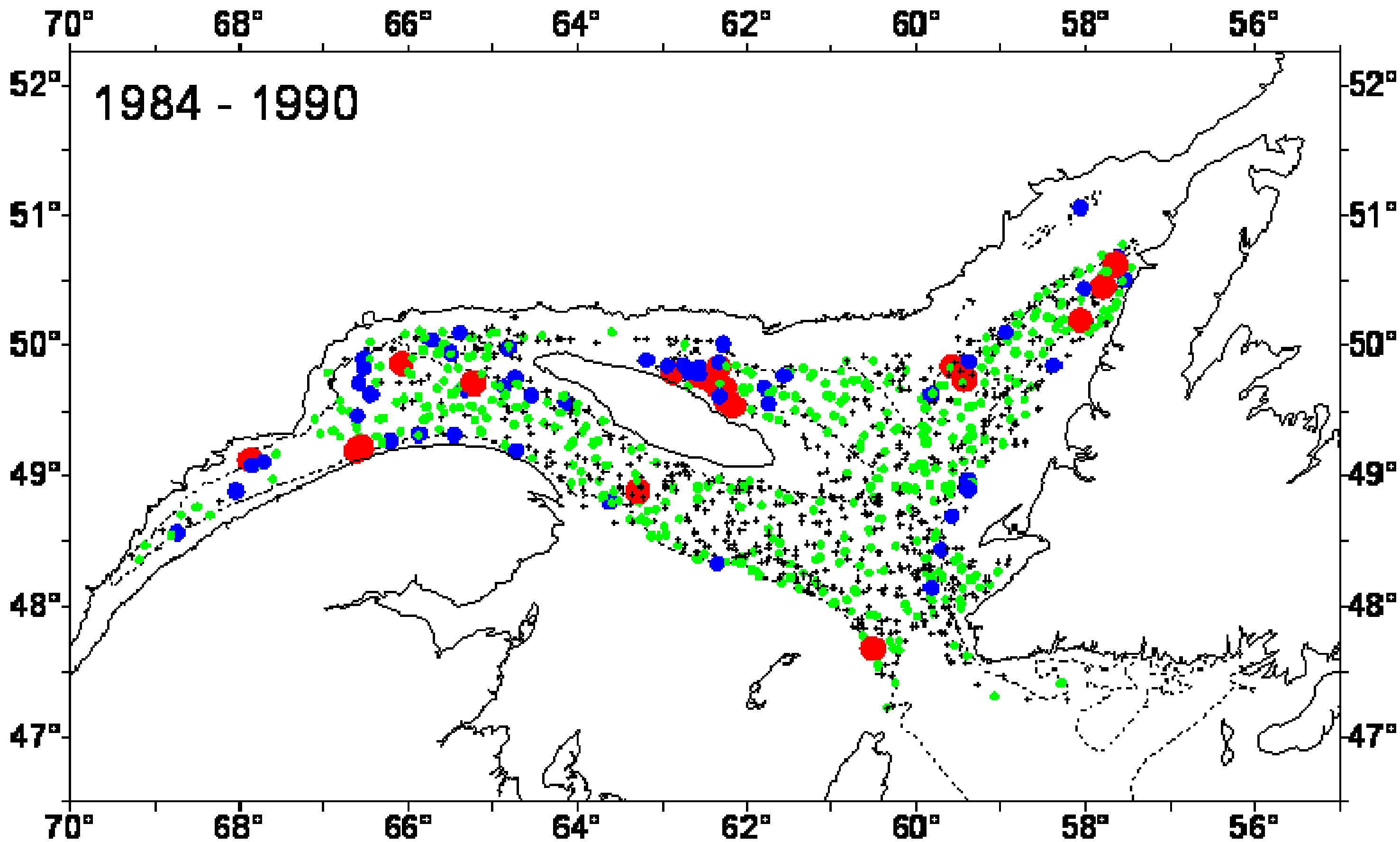


Figure 23. Geographic distribution of *M. senta* catches (standardized number per tow) in the *Lady Hammond* August survey of the northern Gulf of St. Lawrence. Catch symbols: +=0; 0 <green <5; 5 ≤ blue <10; red ≥ 10. Depth contours: dotted line=200 m.

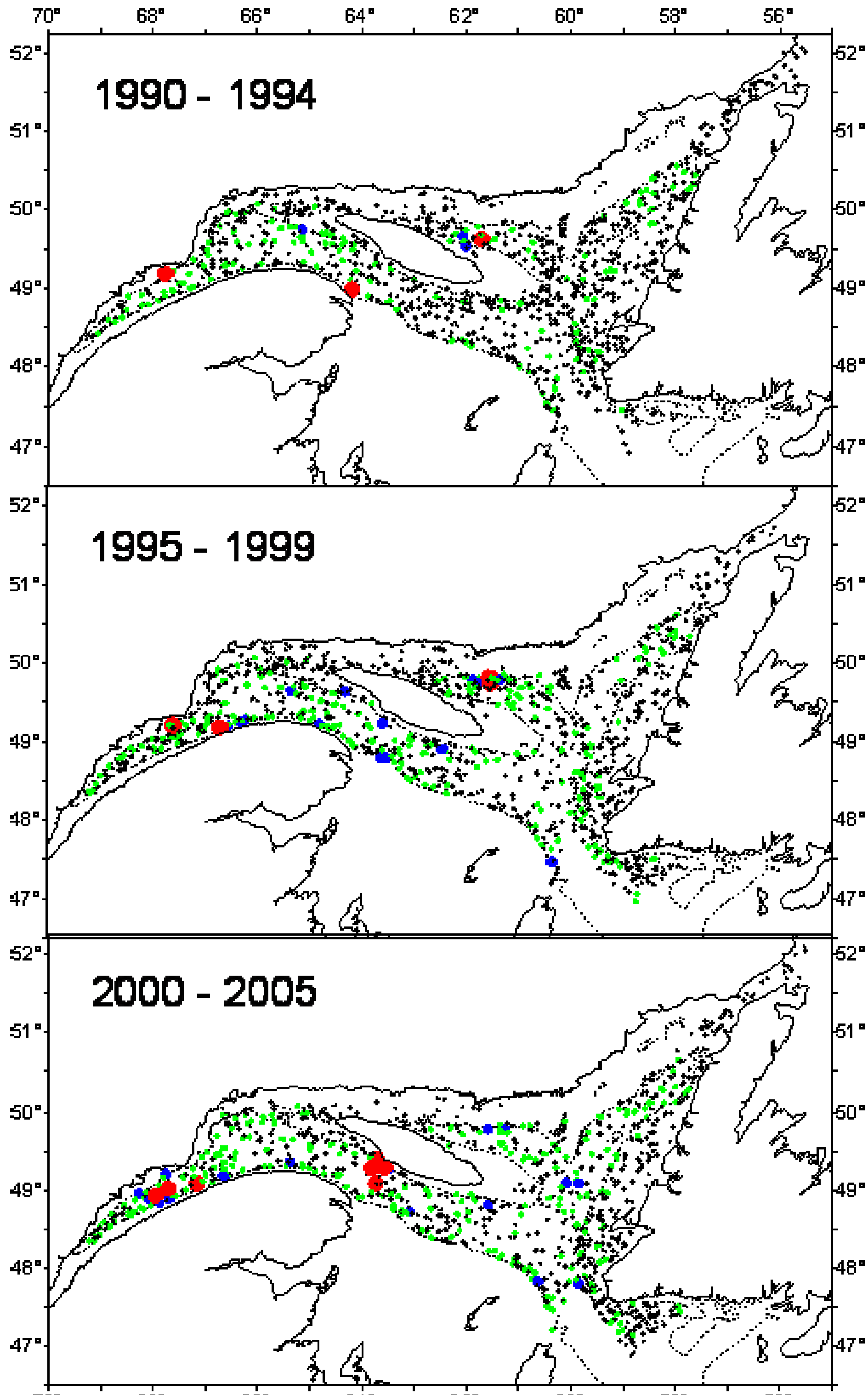


Figure 24. Geographic distribution of *M. senta* catches (standardised number per tow) in the *Alfred Needler* August survey of the northern Gulf of St. Lawrence. Catch symbols: +=0; 0 <green <5; 5 ≤ blue <10; red ≥ 10. Depth contours: dotted line =200 m.

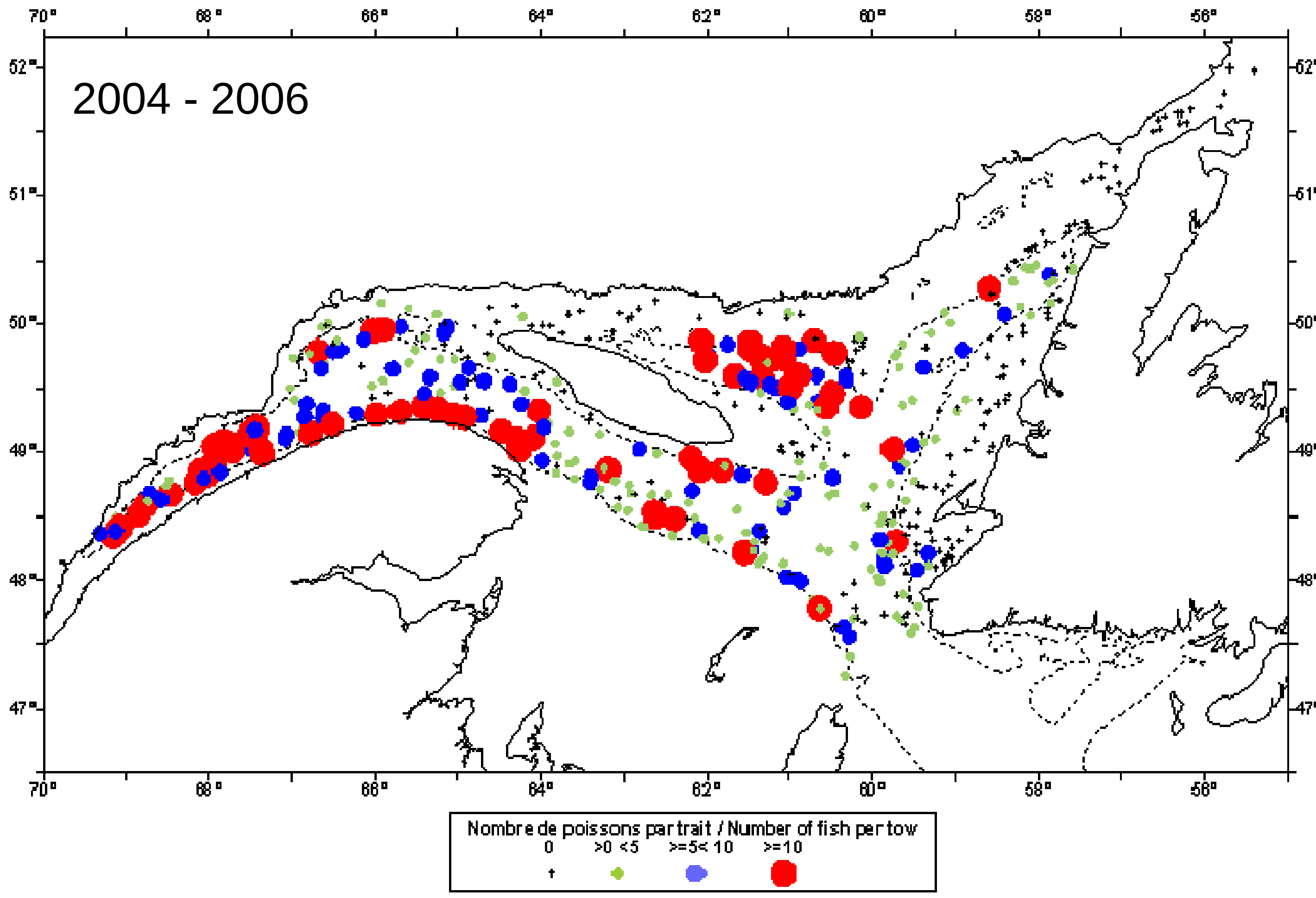


Figure 25. Geographic distribution of *M. senta* catches (standardised number per tow) in the *Teleost* August survey of the northern Gulf of St. Lawrence. Catch symbols: +=0; 0 <green <5; 5 ≤ blue <10; red ≥ 10. Depth contours: dotted line=200 m.

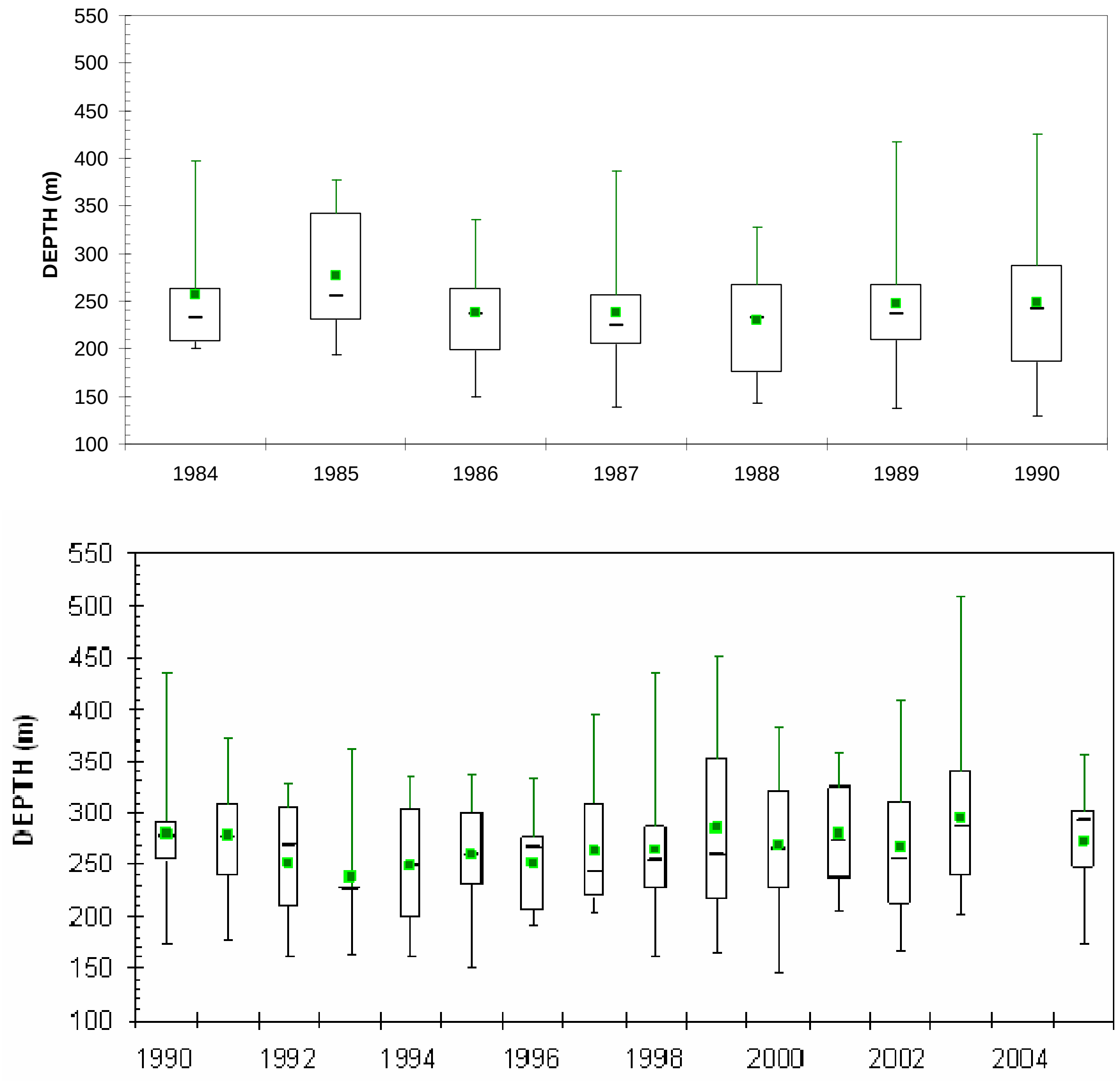


Figure 26. Ranges of depth where *M. sentas* are found in the northern Gulf of St. Lawrence surveys (segment of the Laurentian DU). Top panel: *Lady Hammond* (1984-1990). Bottom panel: *Alfred Needler* (1990-2005) surveys. Squares and horizontal lines show mean and 50th percentile; boxes show 25th and 75th range; bars show 5th to 95th range.

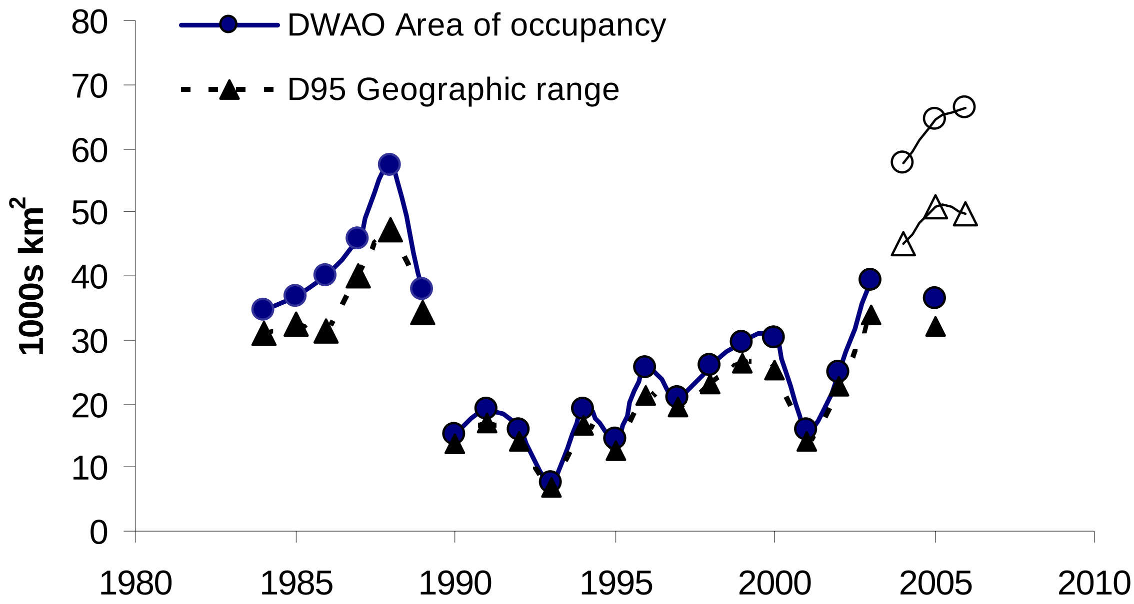


Figure 27. Area occupied (DWAO) and geographic range index (D_{95}) for the summer August surveys in the northern Gulf of St. Lawrence (open symbols represent *Teleost* surveys).

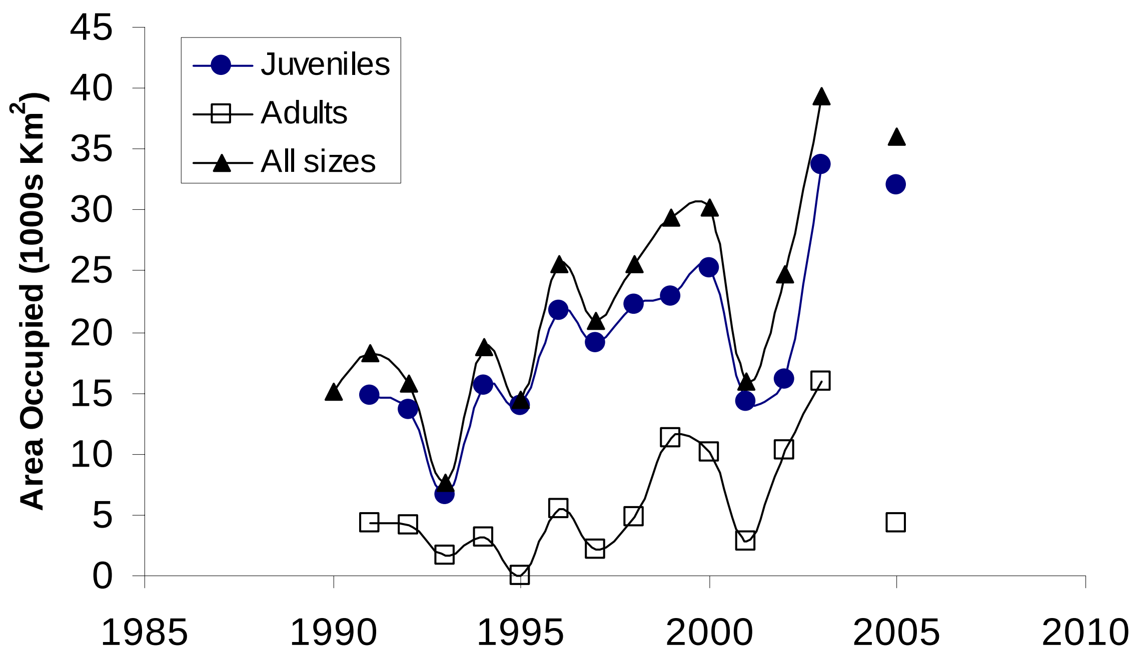


Figure 28. Area occupied by juvenile (<48cm), adult (≥48 cm), and total *M. senta* in August for the northern Gulf of St. Lawrence *Alfred Needler* survey.

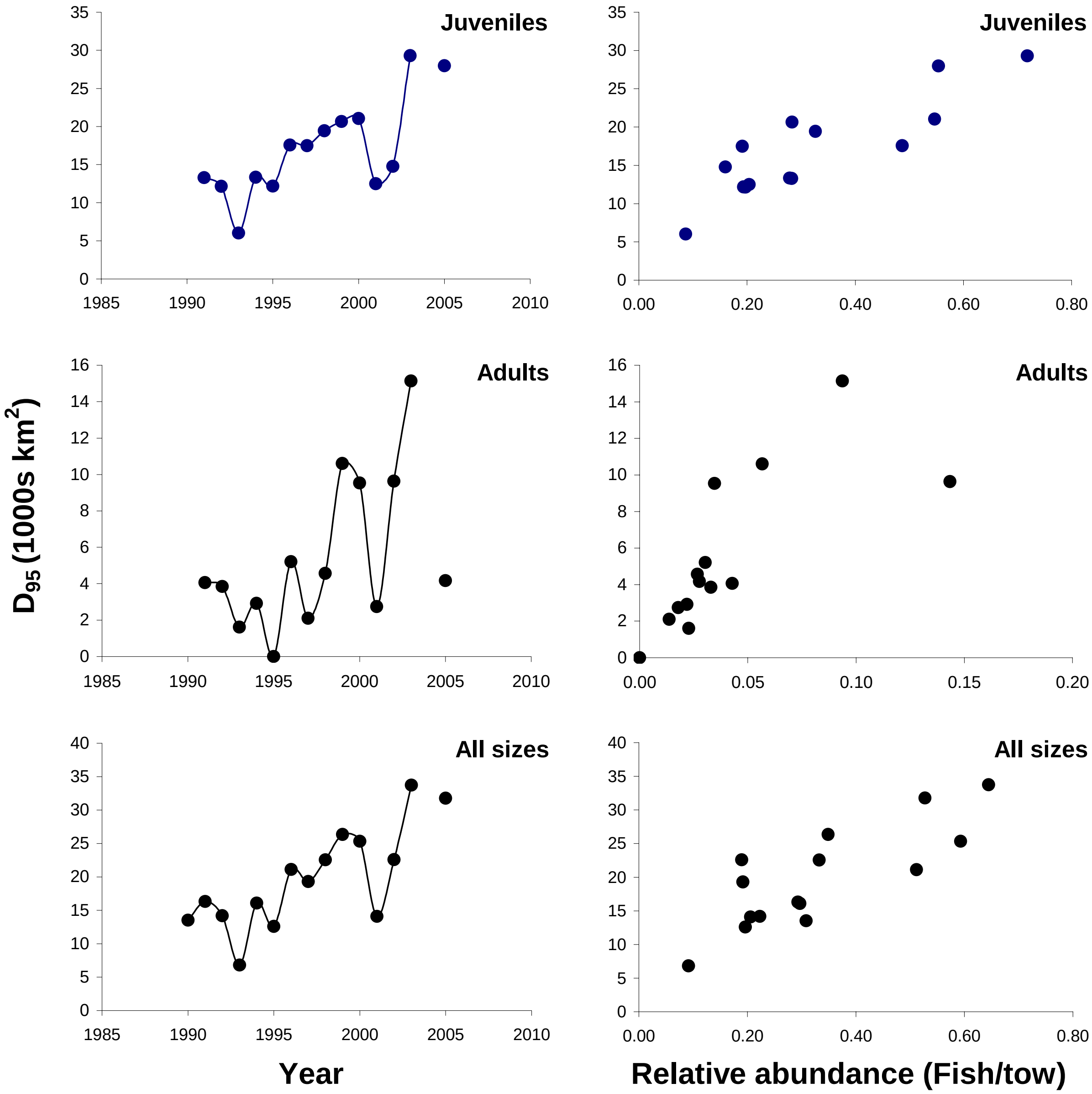


Figure 29. Time trend in an index of geographic range (D_{95}), and its relation with relative abundance for *M. senta* in the *Alfred Needler* surveys of the northern Gulf of St. Lawrence.

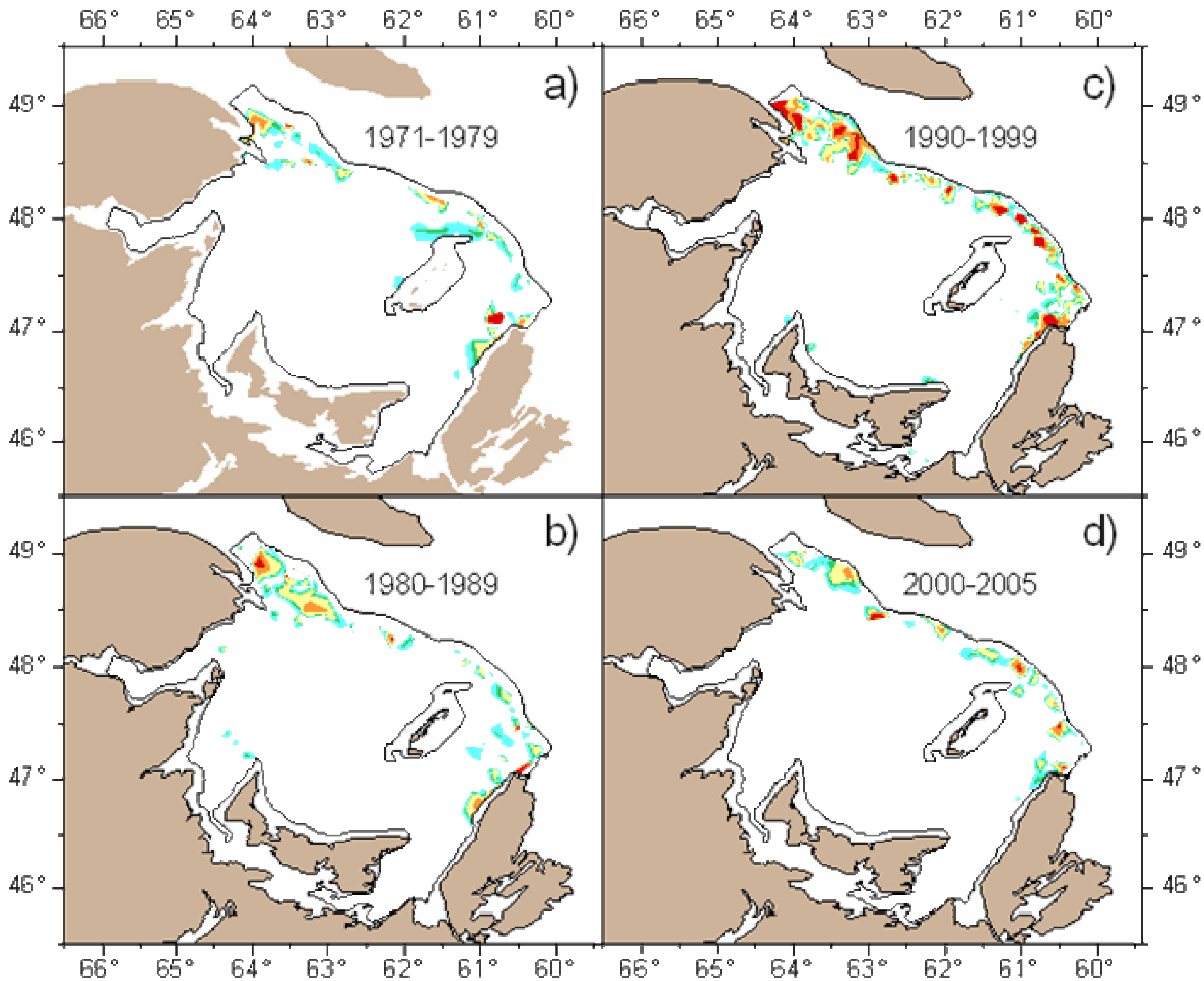


Figure 30. Geographic distribution of *M. senta* catches in the September survey of the southern Gulf of St. Lawrence. Contour intervals are the 10th (blue); 25th (green); 50th (yellow); 75th (orange); and 90th (red) percentiles of nonzero catches (fish/tow).

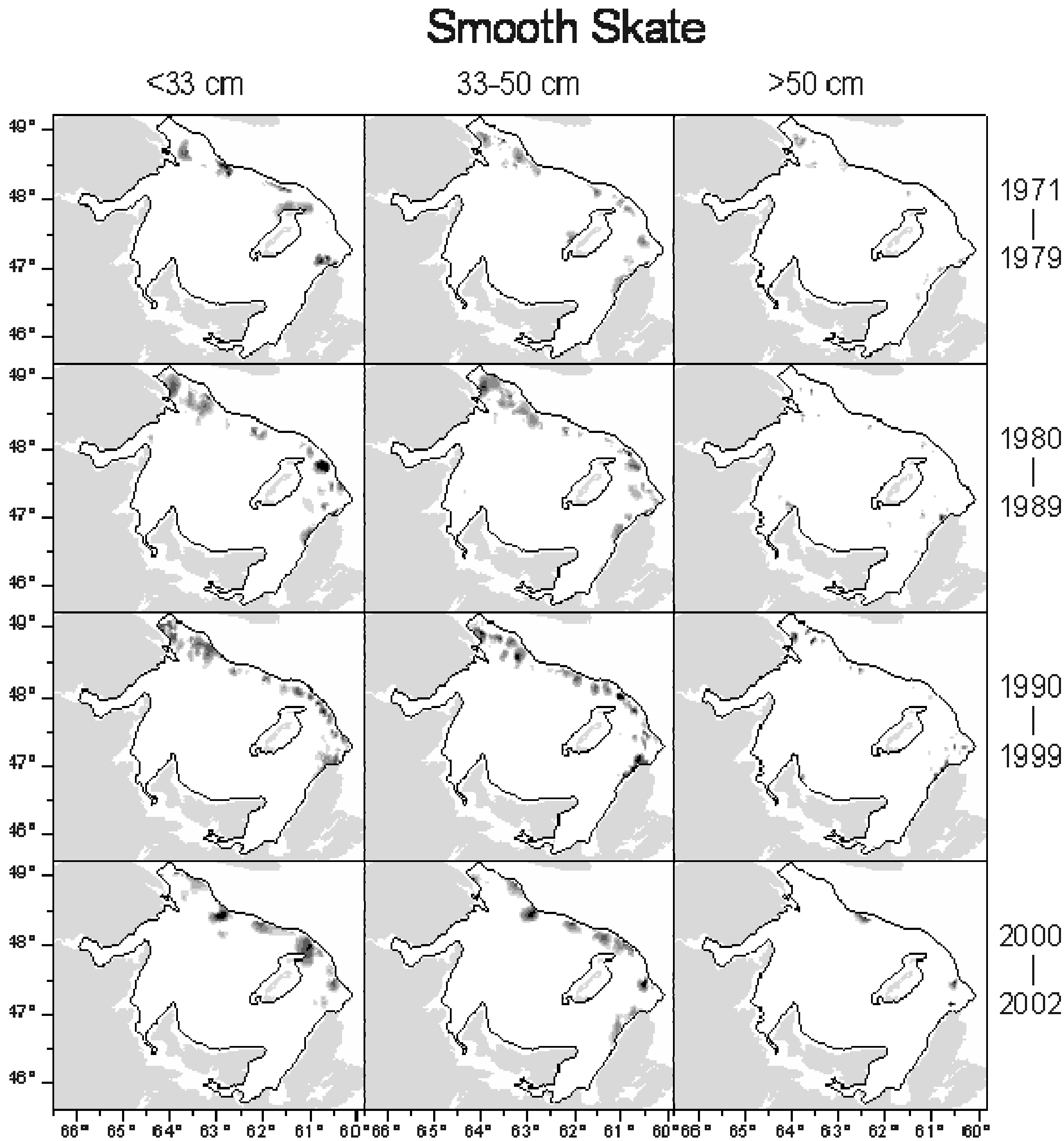


Figure 31. Geographic distribution of three size classes of *M. senta* in September in the southern Gulf of St. Lawrence. Contour intervals are the 10th (lightest); 25th; 50th; 75th; and 90th (darkest) percentiles of nonzero catches (fish/tow) of each size class.

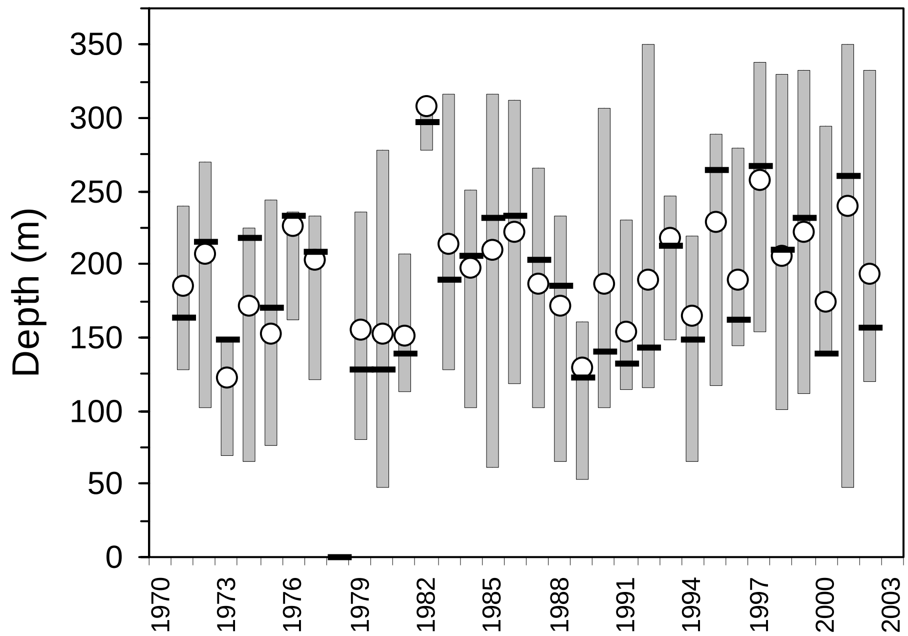


Figure 32. Associations of *M.senta* with depth in September for the southern Gulf of St. Lawrence. Circles and horizontal lines show the mean and median depths occupied by *M. senta*, respectively. Bars show the 10th to 80th percentiles of occupied depths.

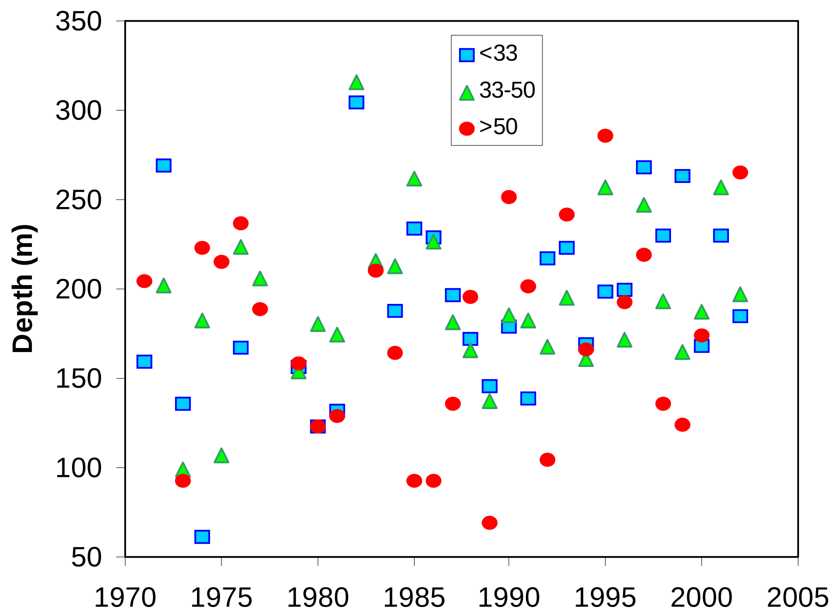


Figure 33. Mean depth occupied by length class of *M. senta* in September for the southern Gulf of St. Lawrence.

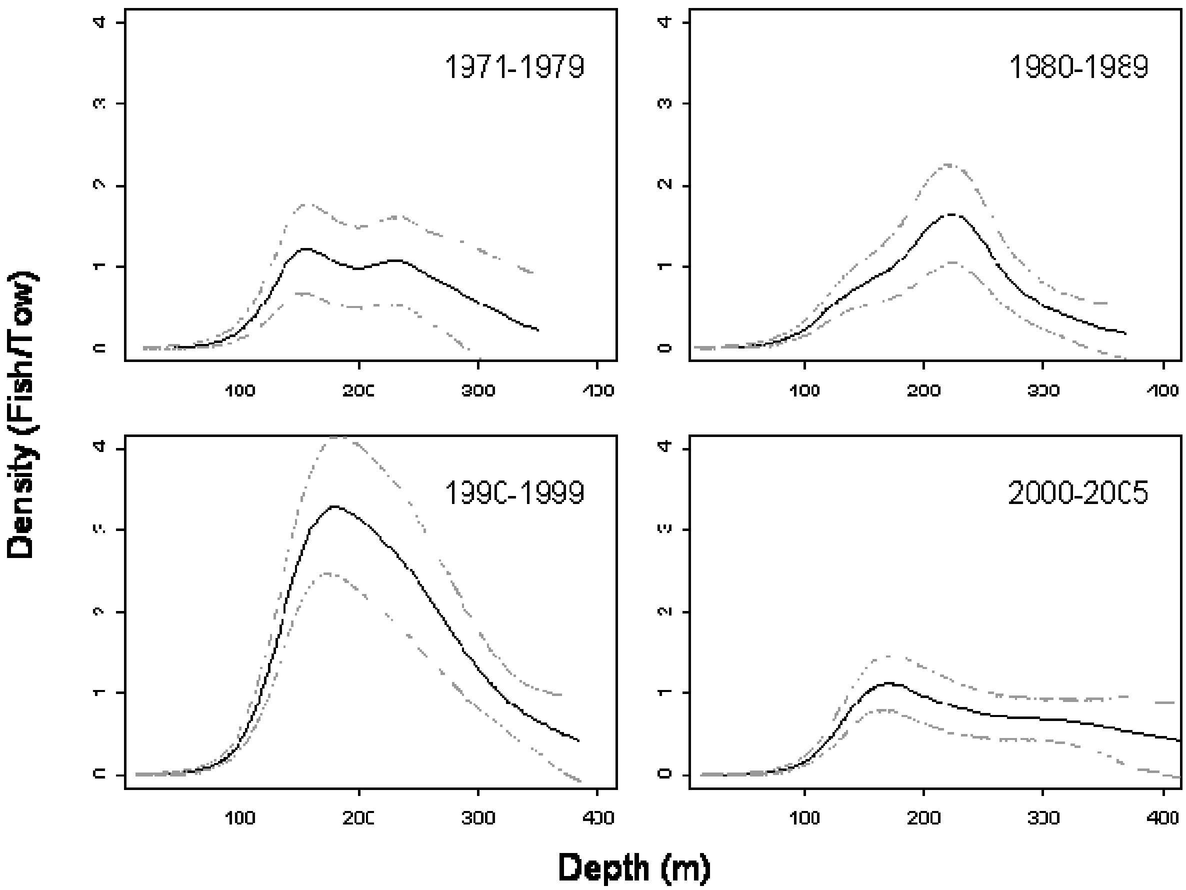


Figure 34. Effect of depth on the local density of *M. senta* in September for the southern Gulf of St. Lawrence in four time periods. Heavy lines show the fitted relationship; shaded bands are ±2SE.

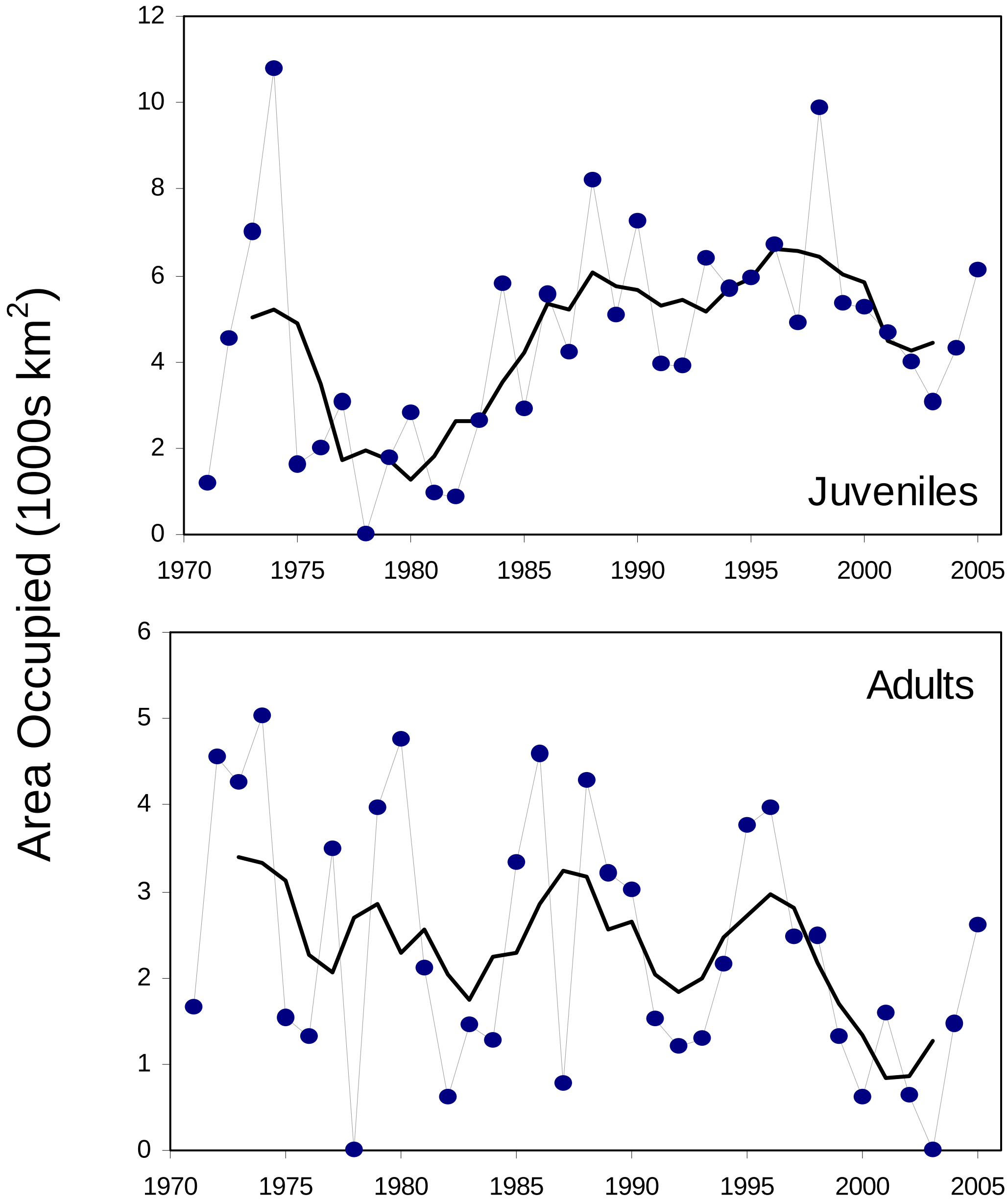


Figure 35. Area occupied by juvenile (<48 cm TL) and adult (≥48 cm TL) *M. senta* in September for the southern Gulf of St. Lawrence, 1971-2005. Heavy line is a 5-year moving average.

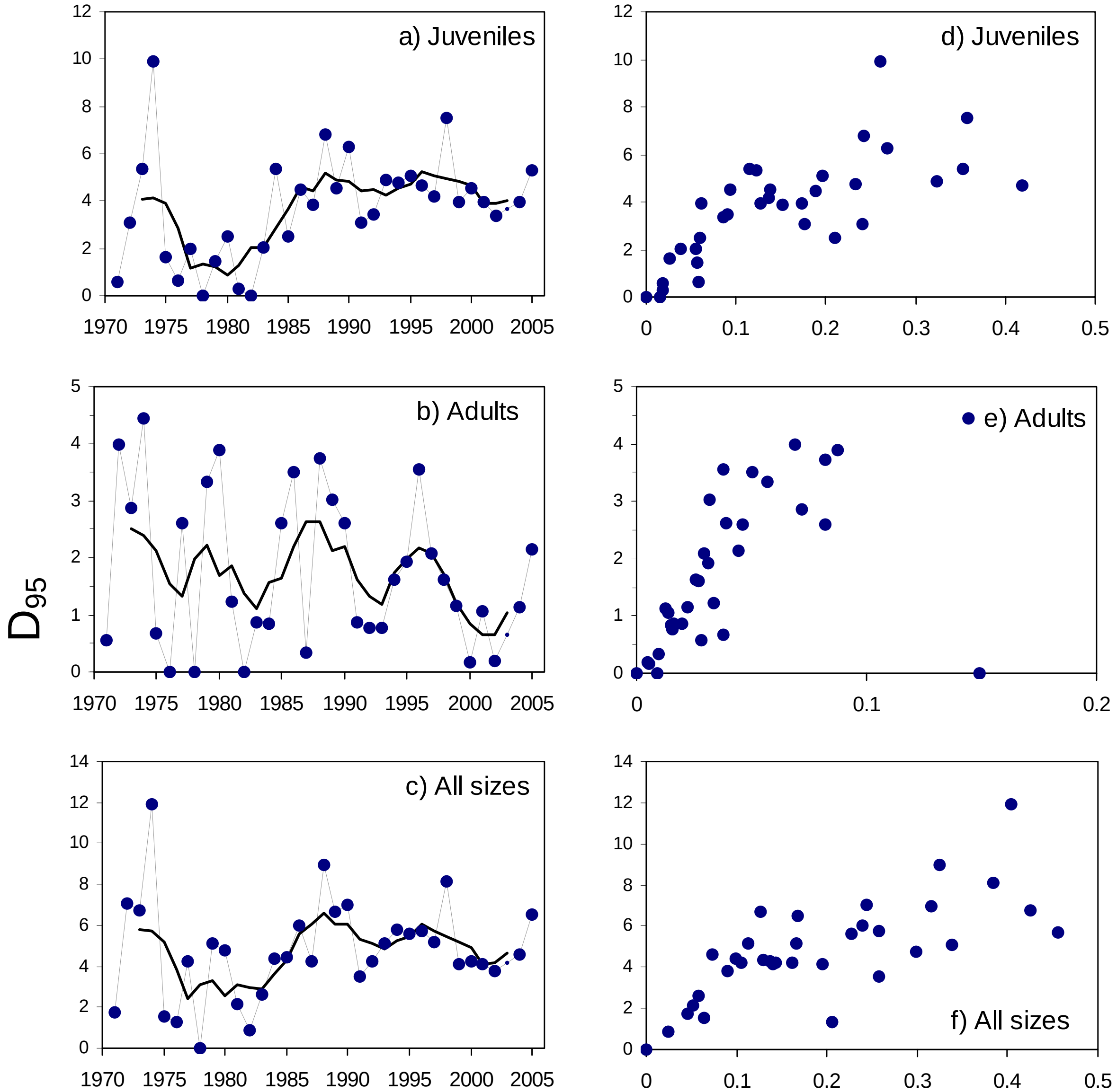


Figure 36. Time trend in an index of geographic range (D95: panels a-c), and its relation with relative abundance (panels d-f) for three size classes of *M. senta* in September for the southern Gulf of St. Laurence (juveniles: <48cm TL; adults: ≥48 cm TL).

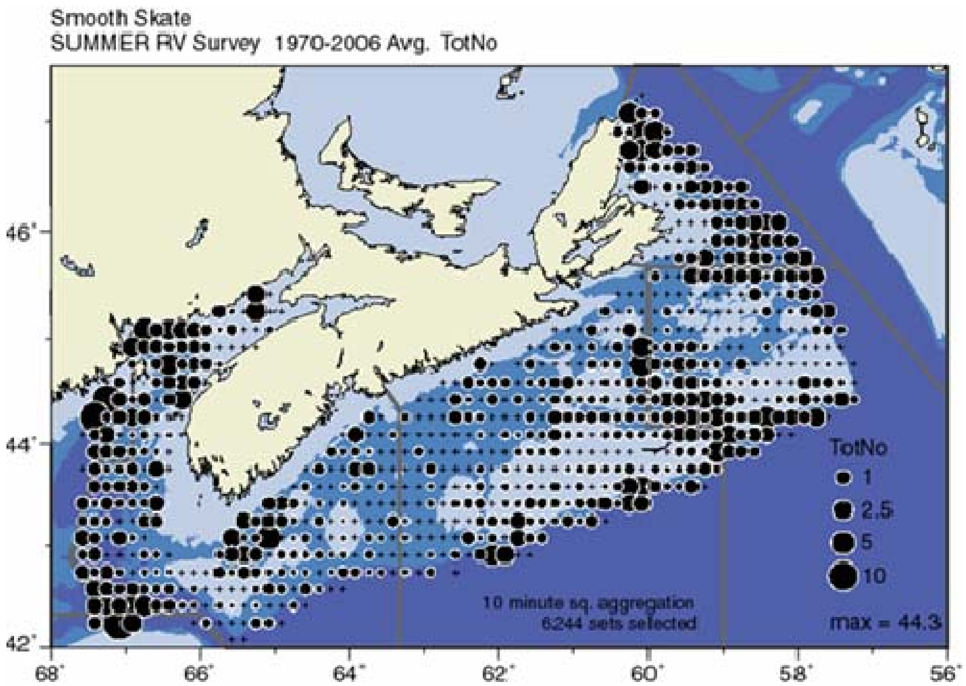


Figure 37. Distribution of *M. senta* in the summer RV surveys, 1970-2006.

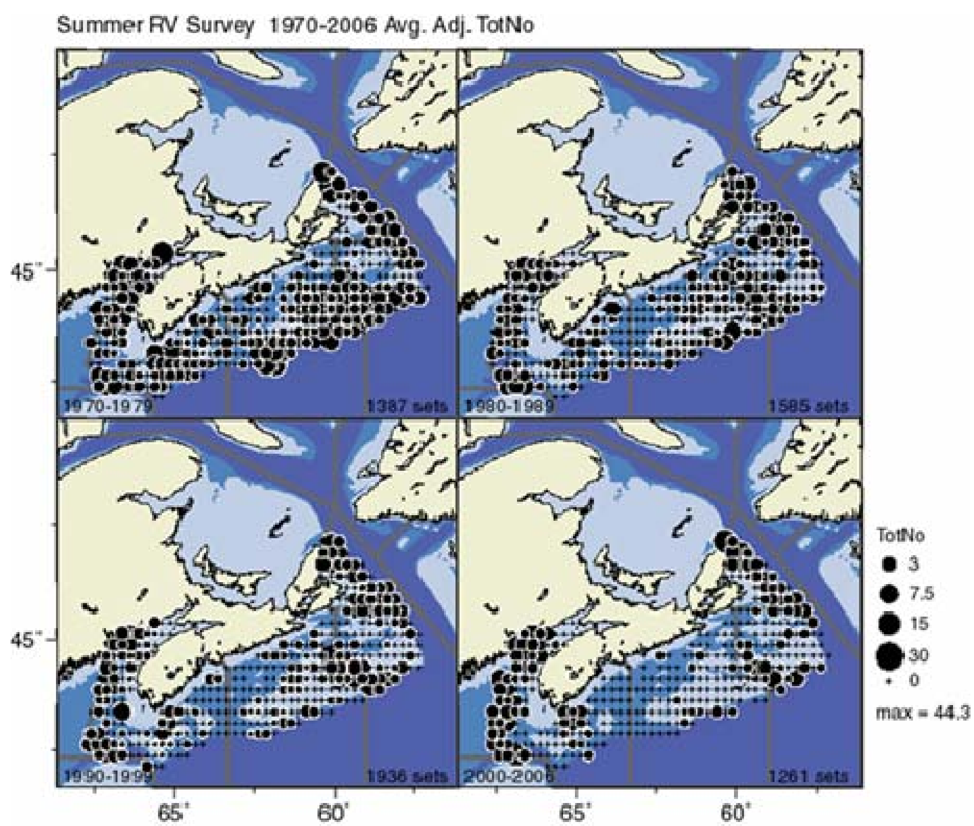


Figure 38. Distribution of *M. senta* aggregated into 10-year blocks, 1970-99. Note that 2000-06 does not include the 2004 survey.

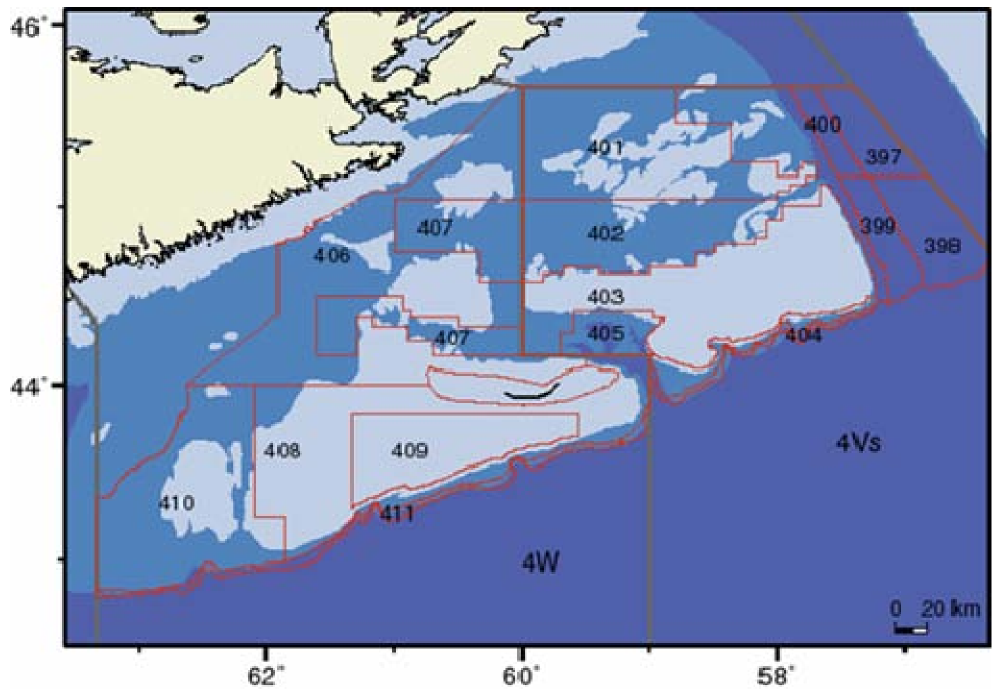


Figure 39a.Stratification scheme used in the 4VW cod surveys, 1986-2006. Note that deepwater strata in the Laurentian Channel were added later in the series.

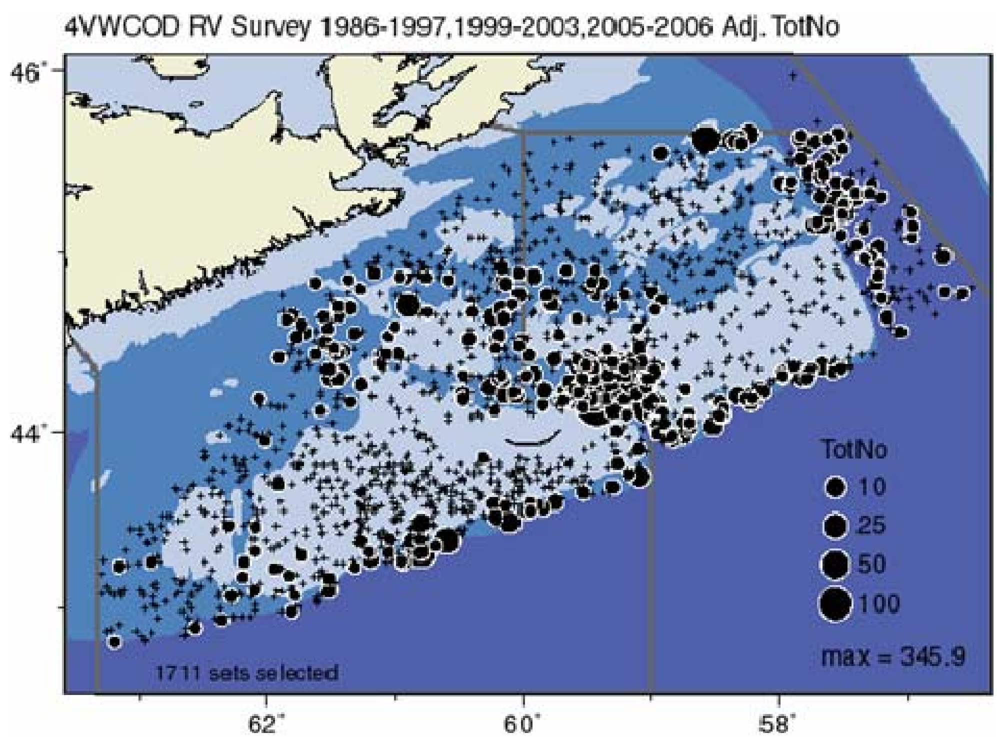


Figure 39b. Distribution of *M. senta* in the 4VW cod RV surveys, 1986-2006.

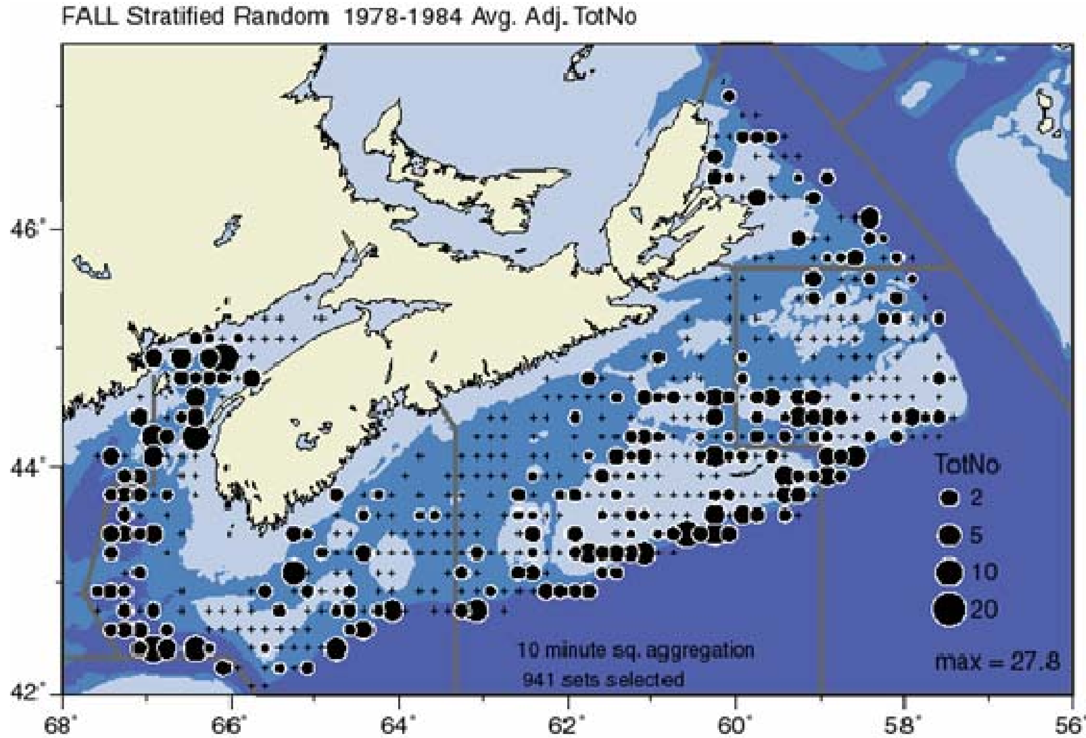


Figure 40. Distribution of *M. senta* in the Fall RV surveys, 1978-1984.

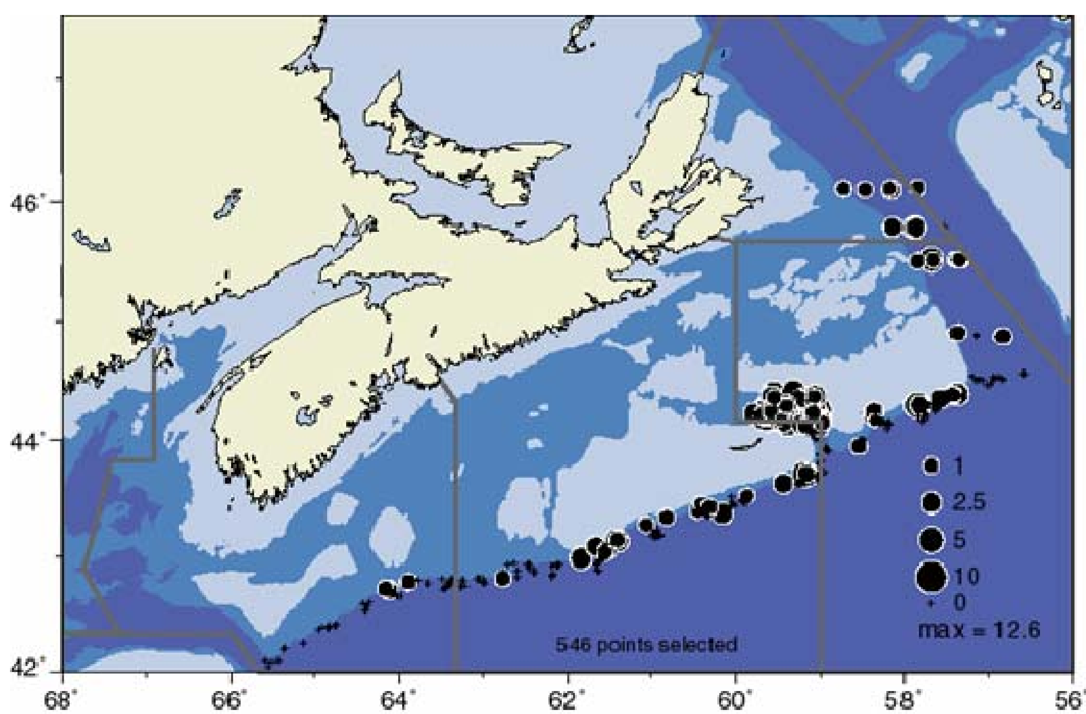


Figure 41. Distribution of *M. senta* in the deep sea redfish RV surveys, 1982-88.

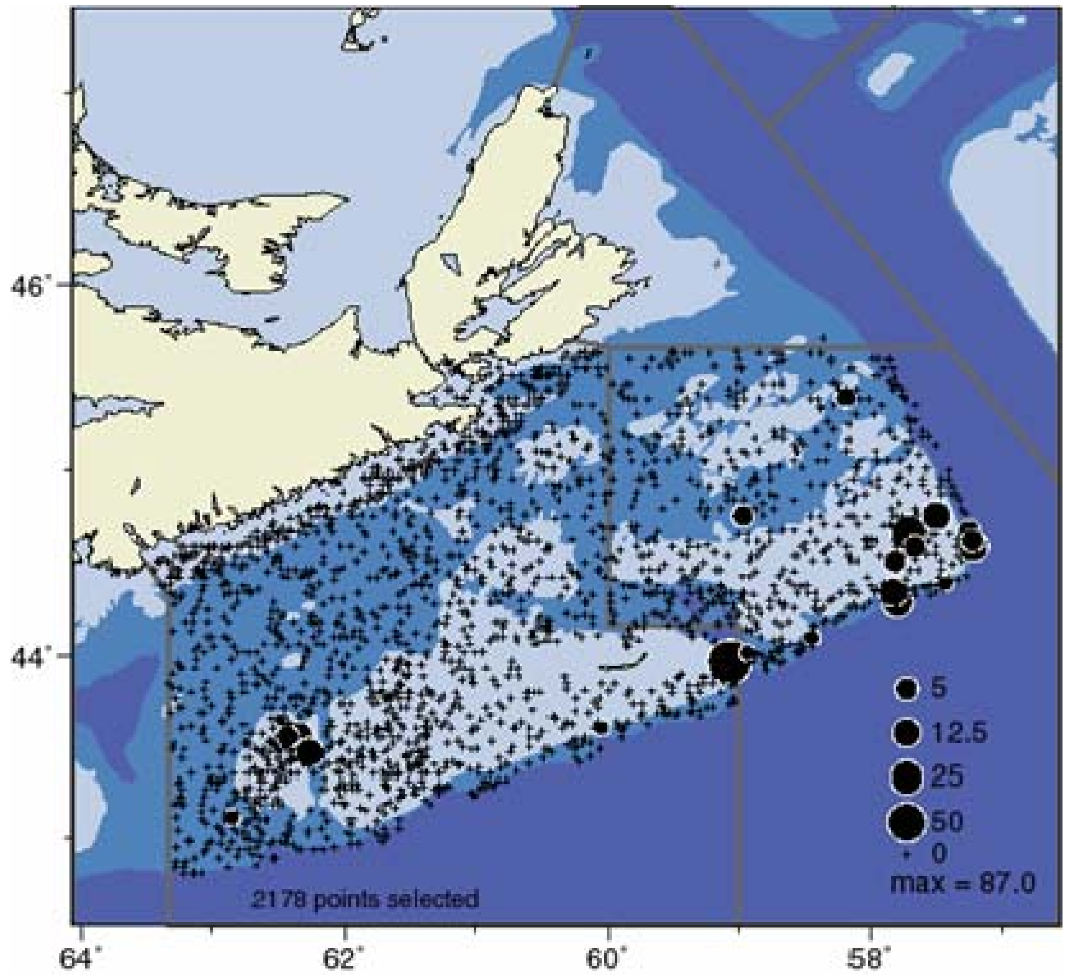


Figure 42. Distribution of *M. senta* in the 4VW Sentinel Surveys, 1995-2005.

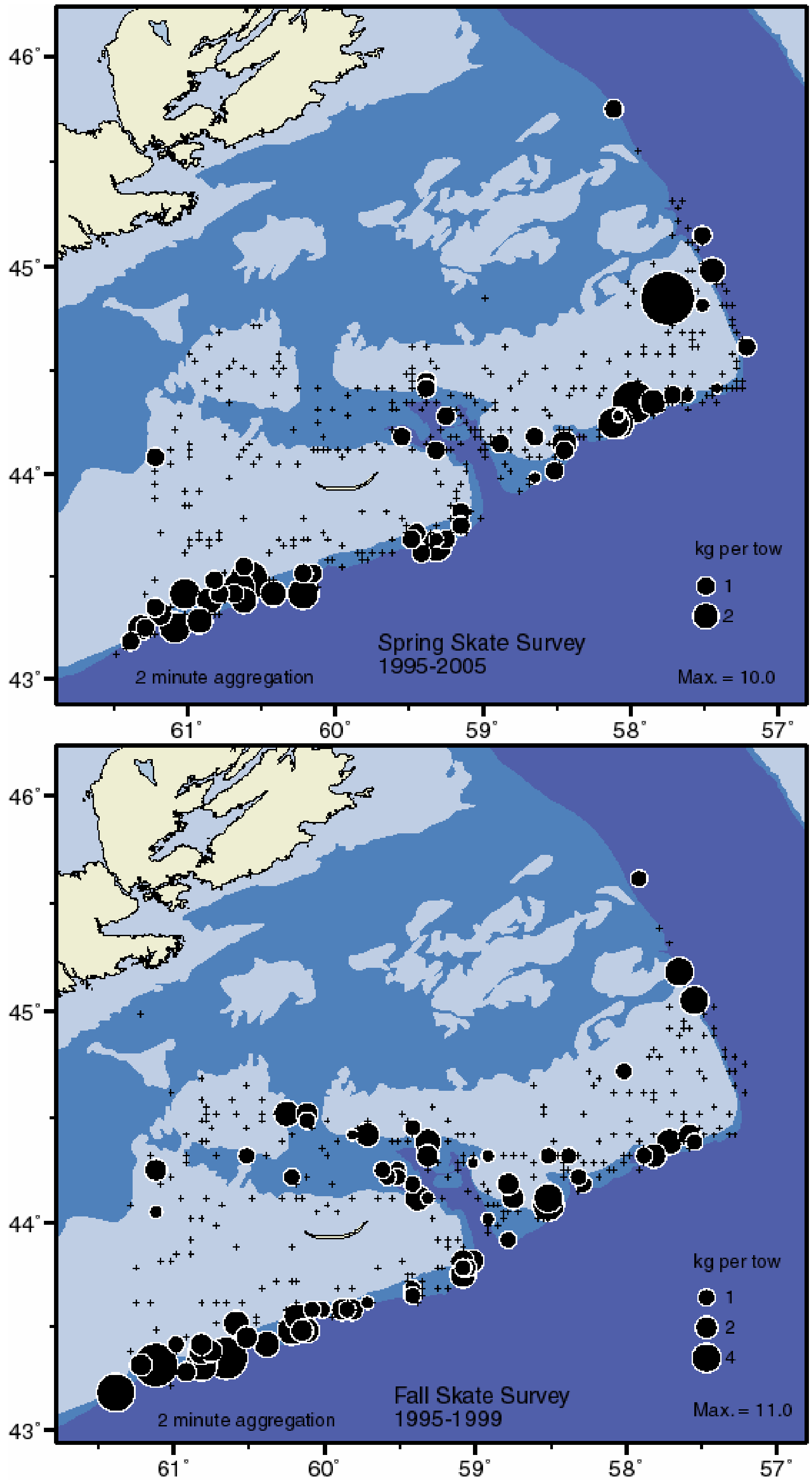


Figure 43. Distribution of *M. senta* in the Spring and Fall Industry Skate Surveys.

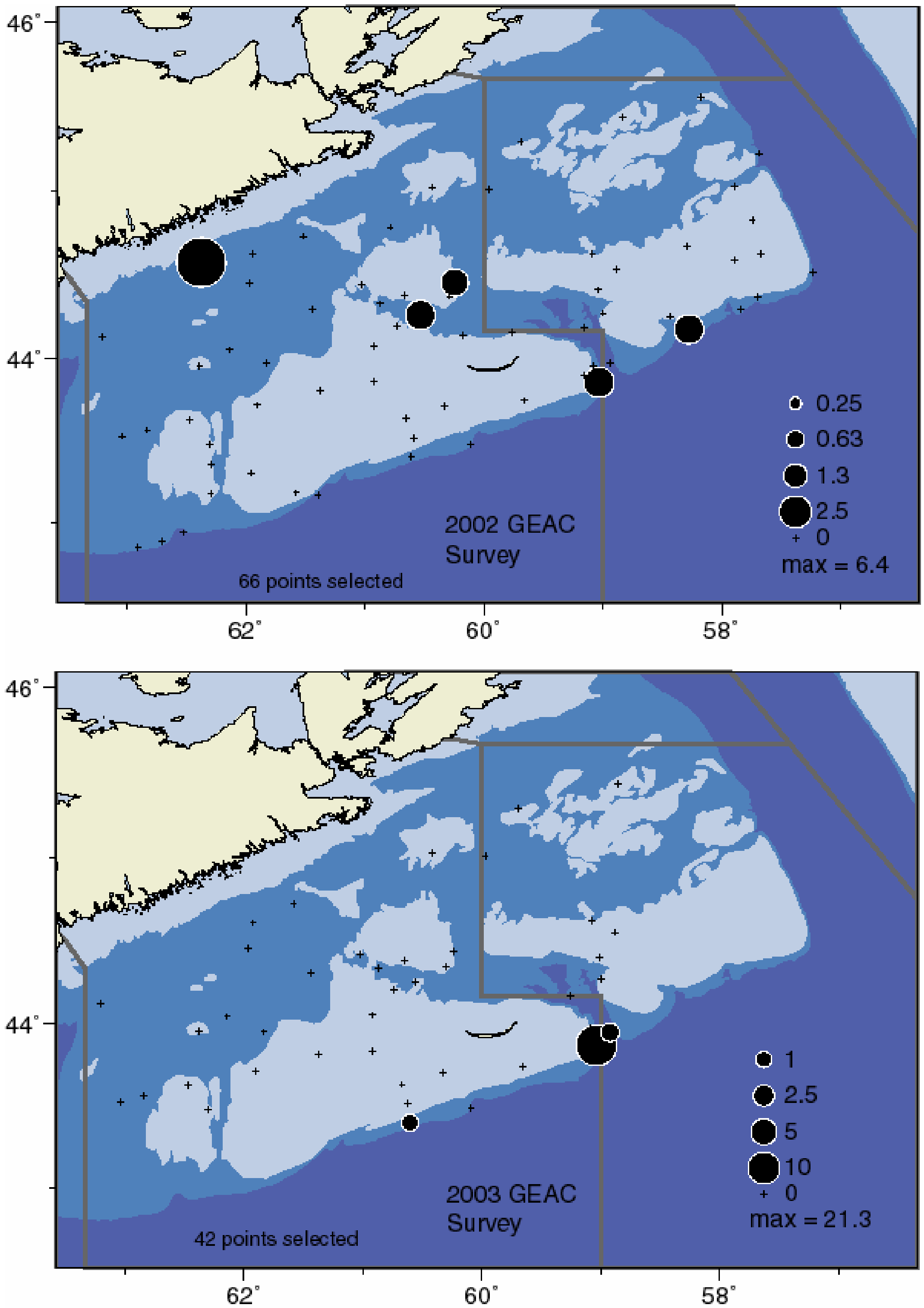


Figure 44. Distribution of *M. senta* from the 2002 and 2003 GEAC surveys using Campelen trawl gear.

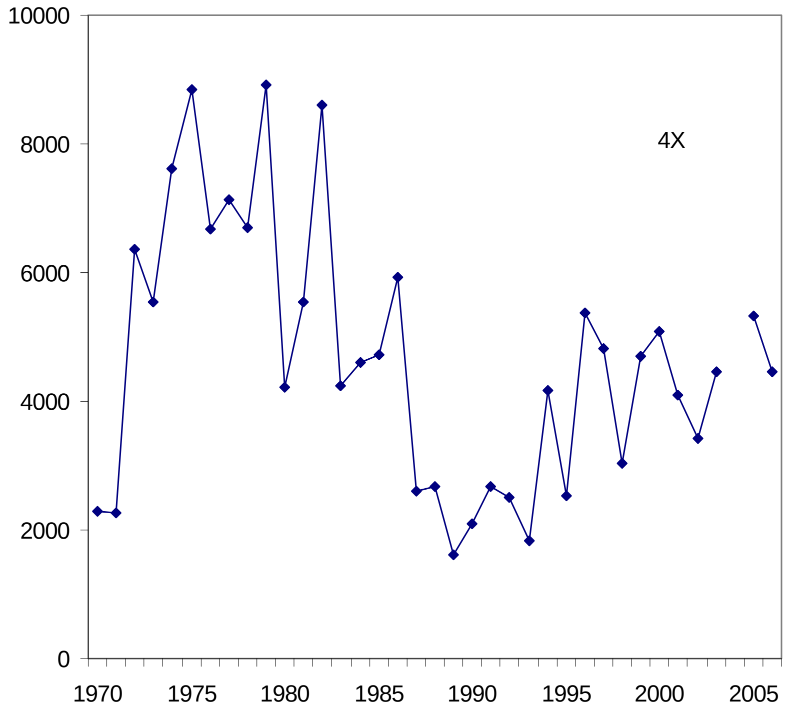


Figure 45. Stratified area occupied by *M. senta* in NAFO Division 4X.

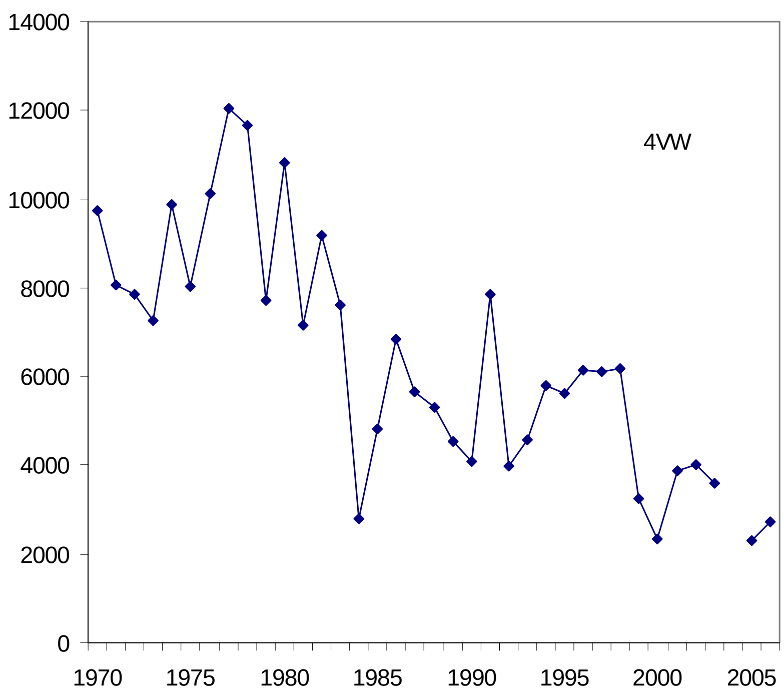


Figure 46. Stratified area occupied by *M. senta* in Division 4VW.

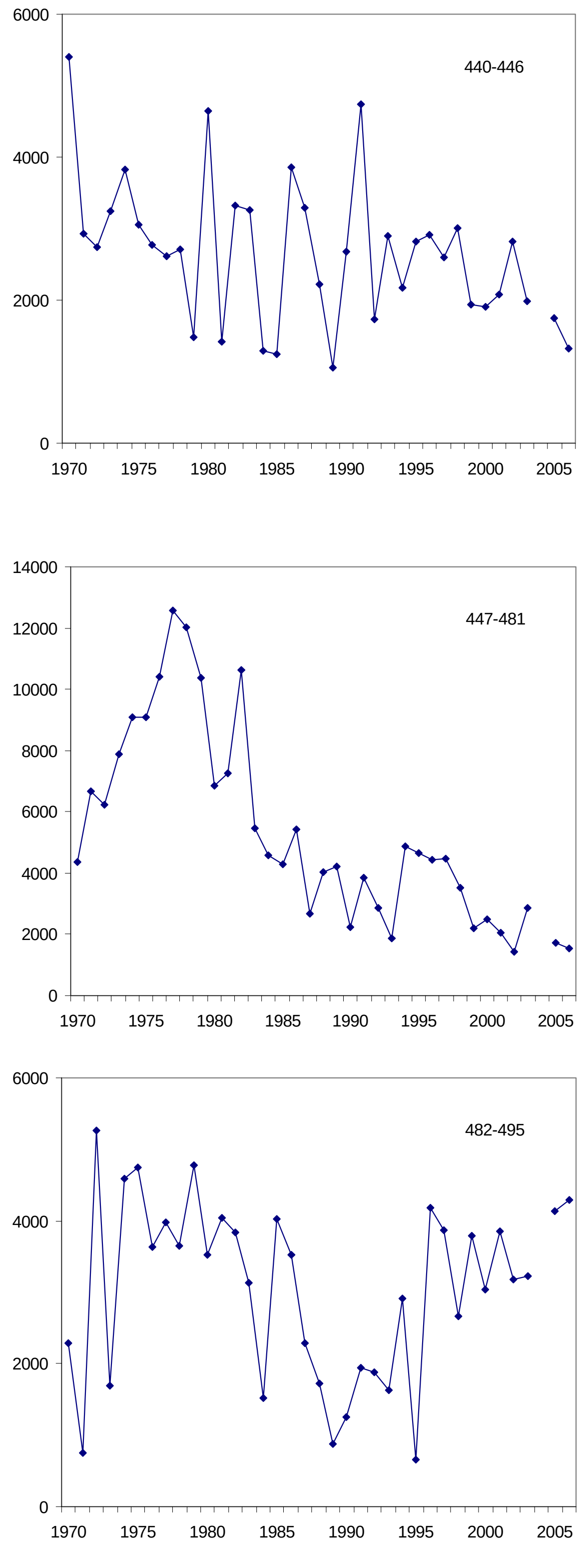


Figure 47. Stratified area occupied from the summer RV surveys in Sydney Bight, the central Scotian Shelf, and the Bay of Fundy.

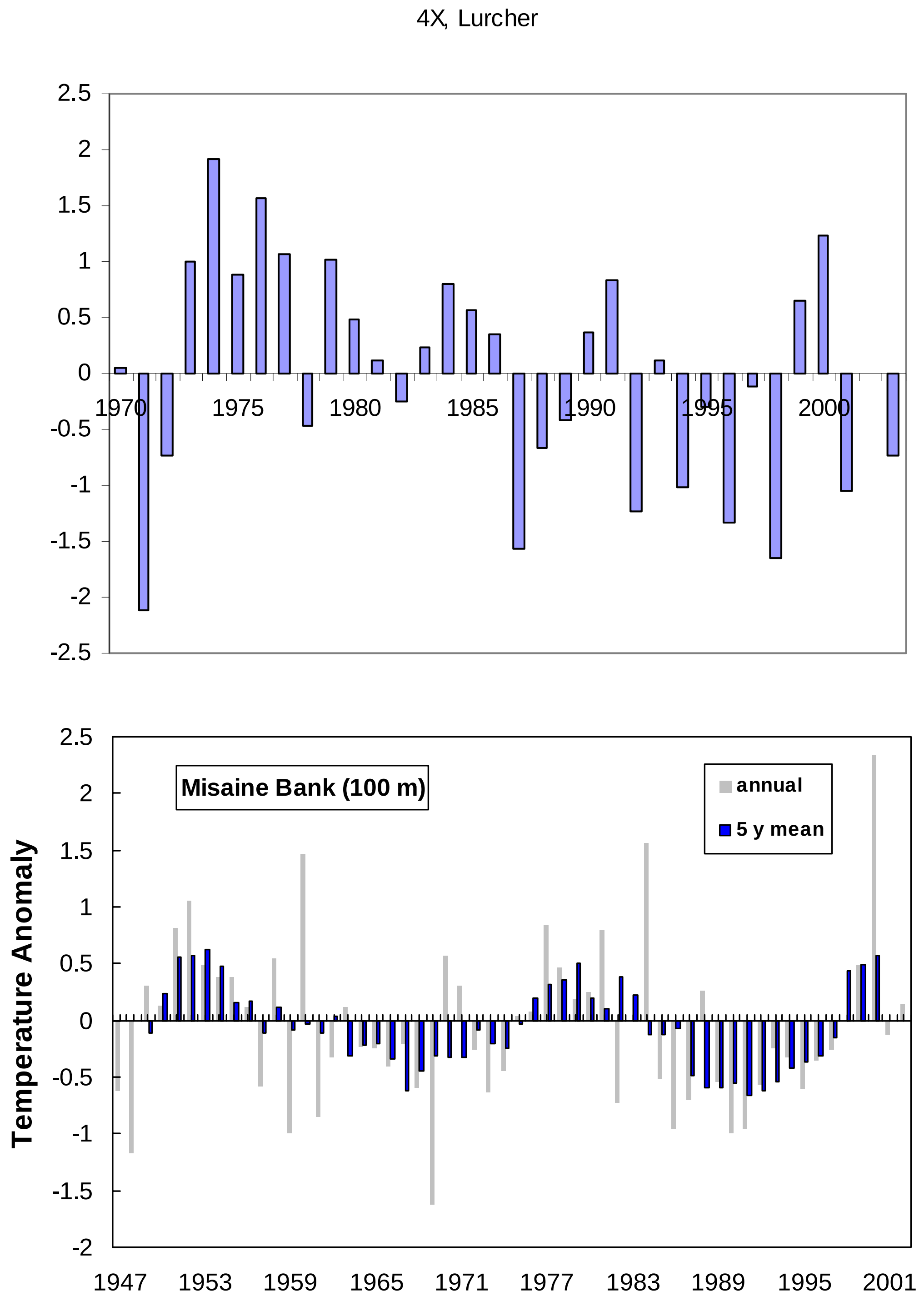


Figure 48. Temperature anomalies in NAFO Division 4X (Lurcher) and 4VW (Misaine) on the Scotian Shelf.

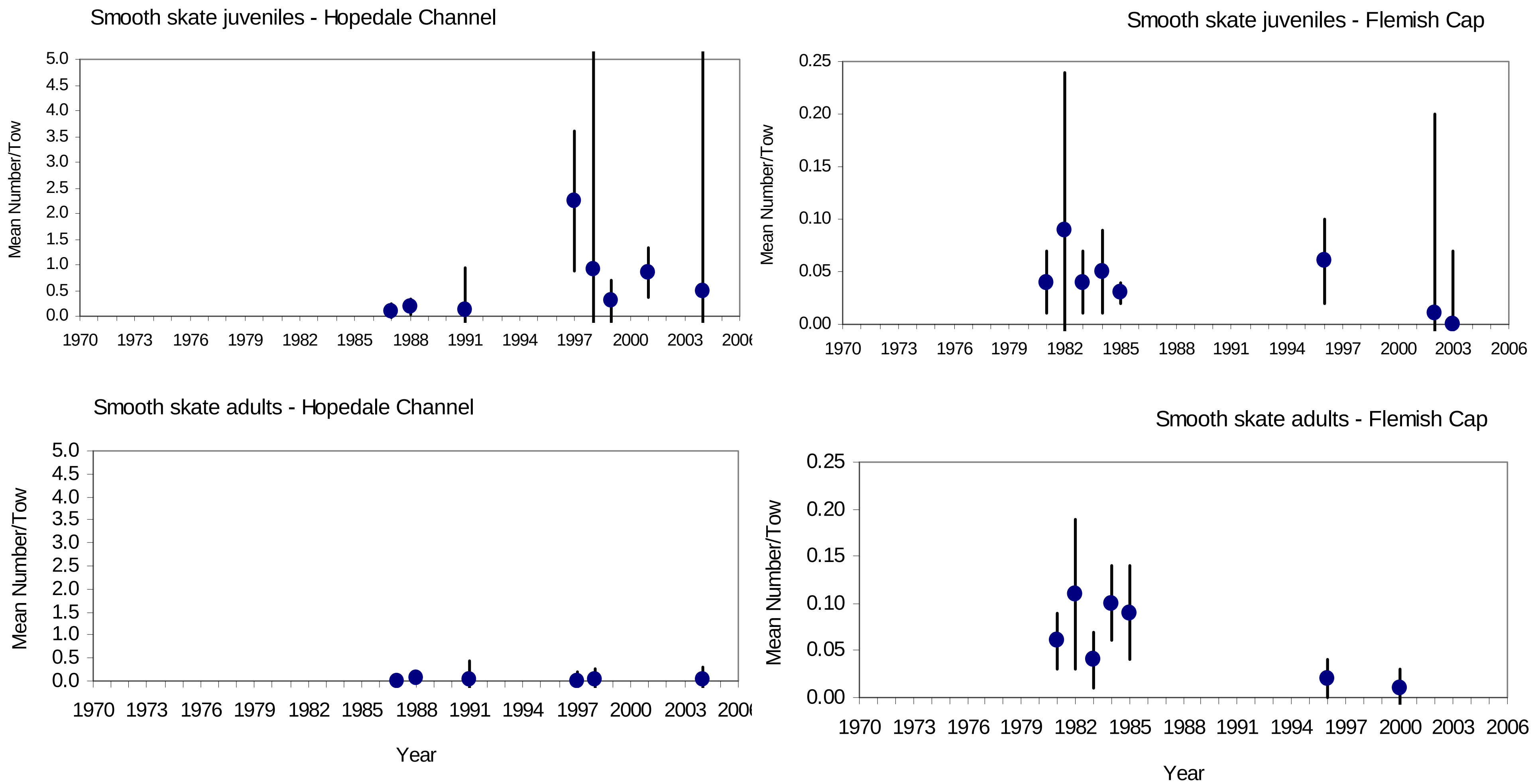


Figure 49. Survey catch rates of two size classes of *M. senta* in the Hopedale Channel and Flemish Cap. Skates under 48 cm in total length (TL) are assumed to be juveniles; those 48cm and longer are assumed to be adults. Vertical lines are ±95%CI.

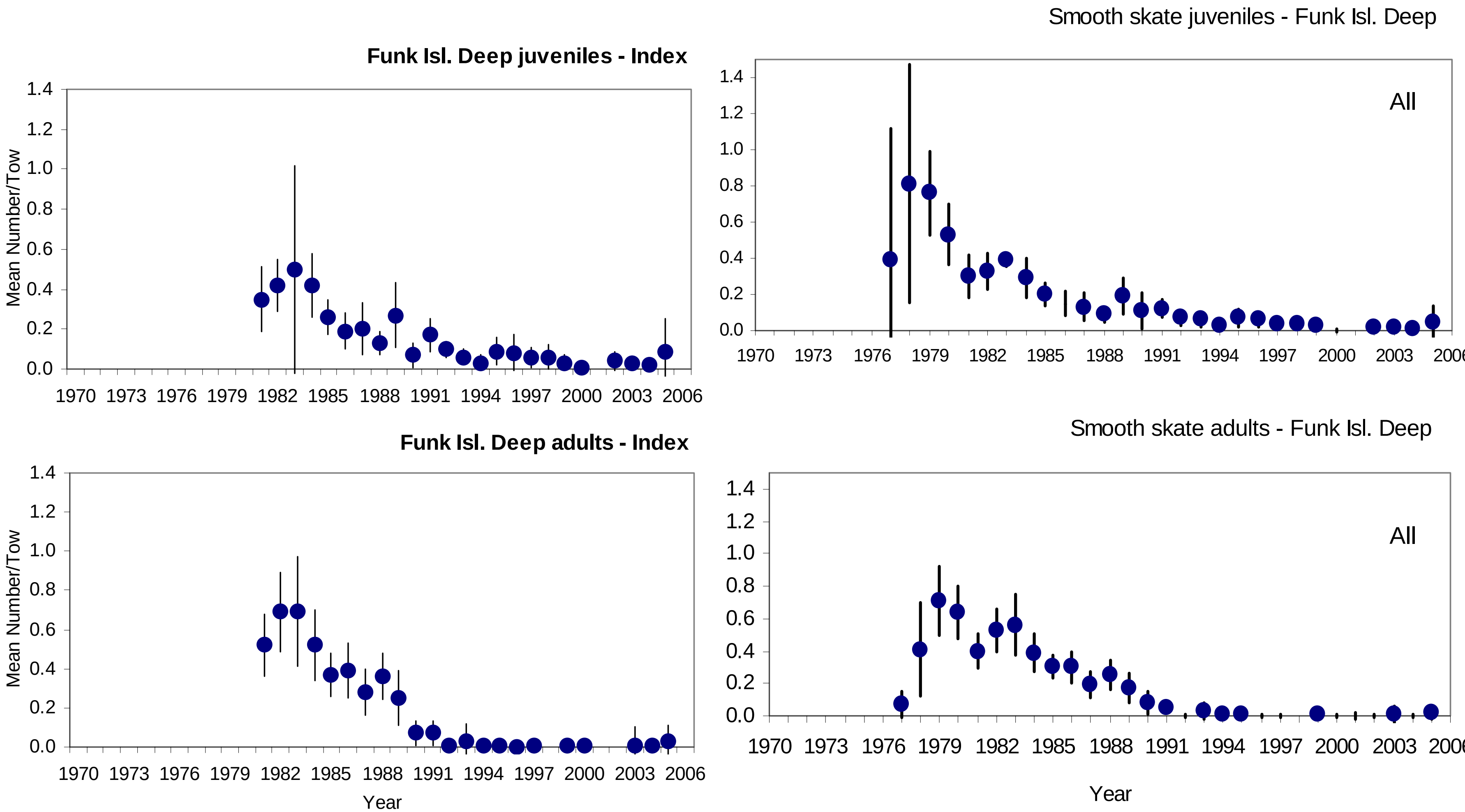


Figure 50. Catch rates of *M. senta* juveniles (<48cm TL) and adults (≥48cm) in the Funk Island Deep/NE NF Shelf, 1977-2005. INDEX only contains strata sampled throughout the research survey time series. ALL strata encompass every stratum sampled. Vertical lines are ±95%CI.

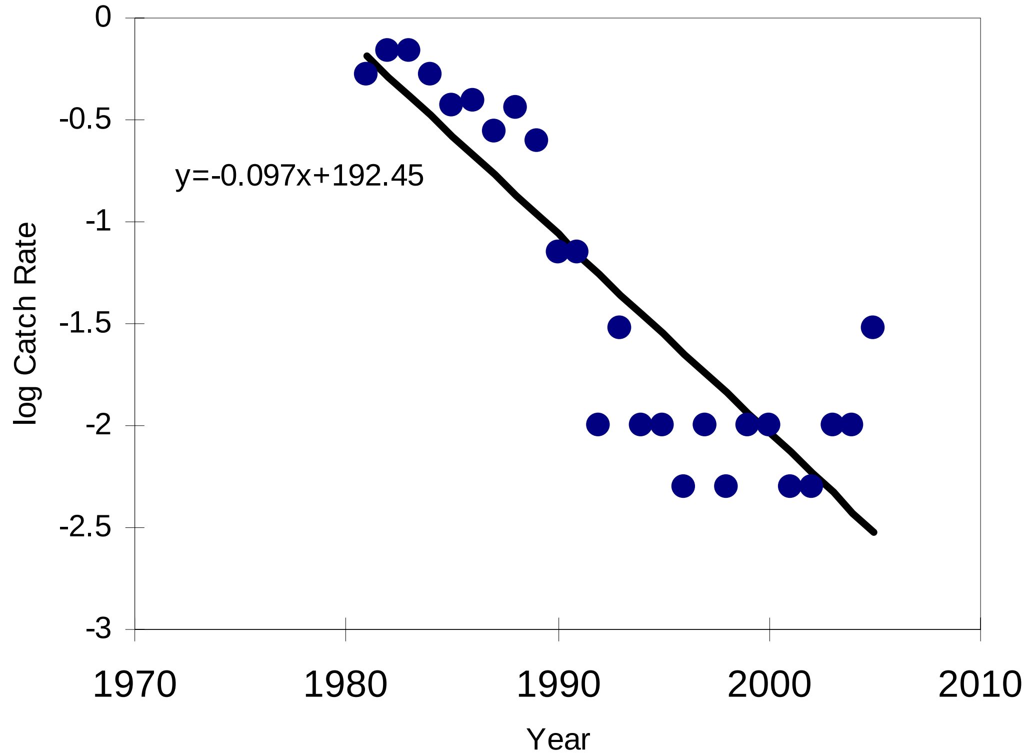


Figure 51. Log_e-transformed catch rates of adult ($\geq$48cm) *M. senta* in the Funk Island Deep/NE NF Shelf, and their linear trend.

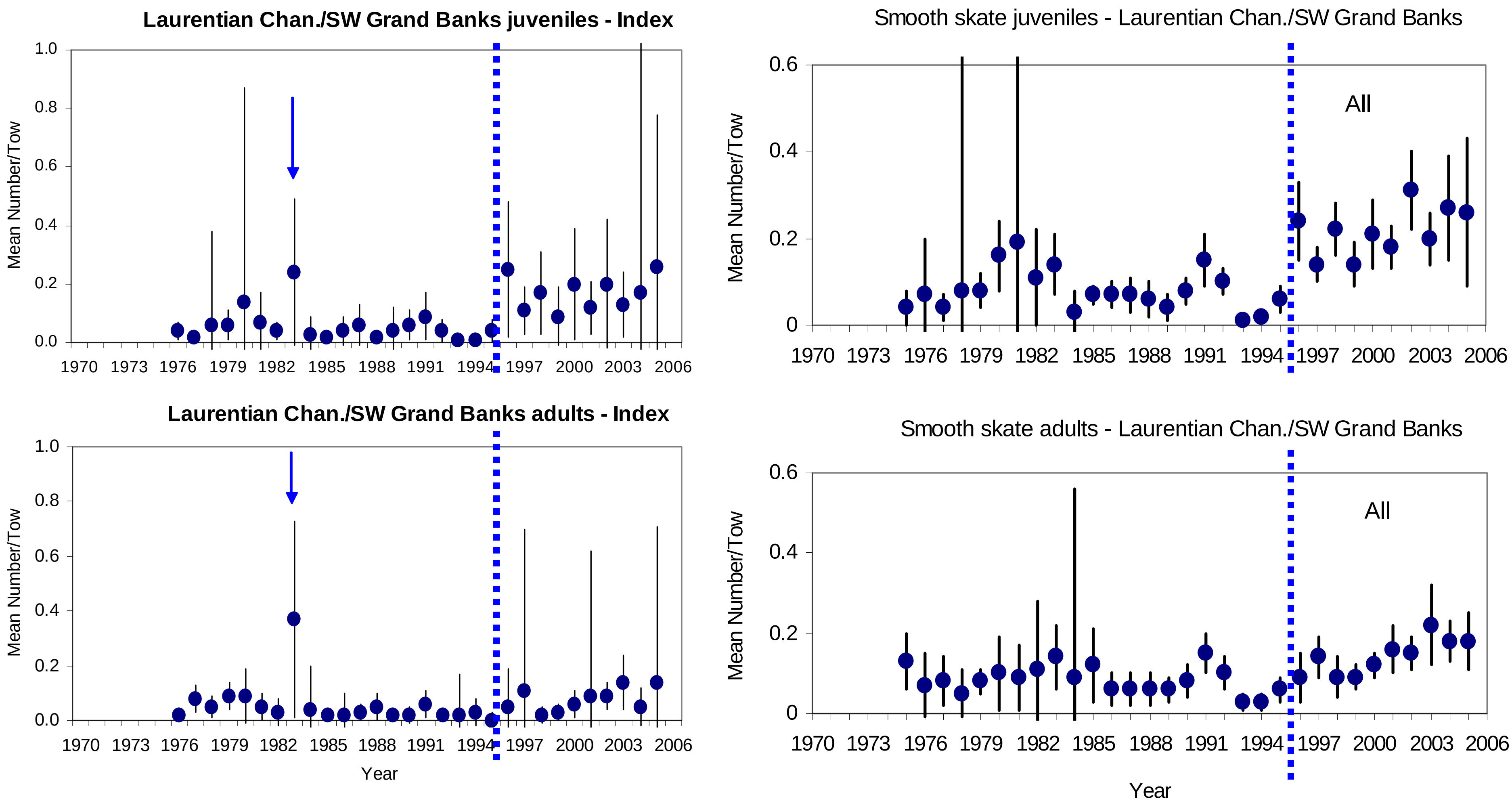


Figure 52. Catch rates of *M. senta* juveniles (<48cm TL) and adults ($\geq$48cm) in the Laurentian Channel/southwestern Grand Banks. INDEX only contains strata sampled throughout the research survey time series. ALL strata encompass every stratum sampled. Vertical lines are ±95%CI. Note that survey gear changed from Engel to Campelen in Spring 1996; denoted by dashed vertical blue line.

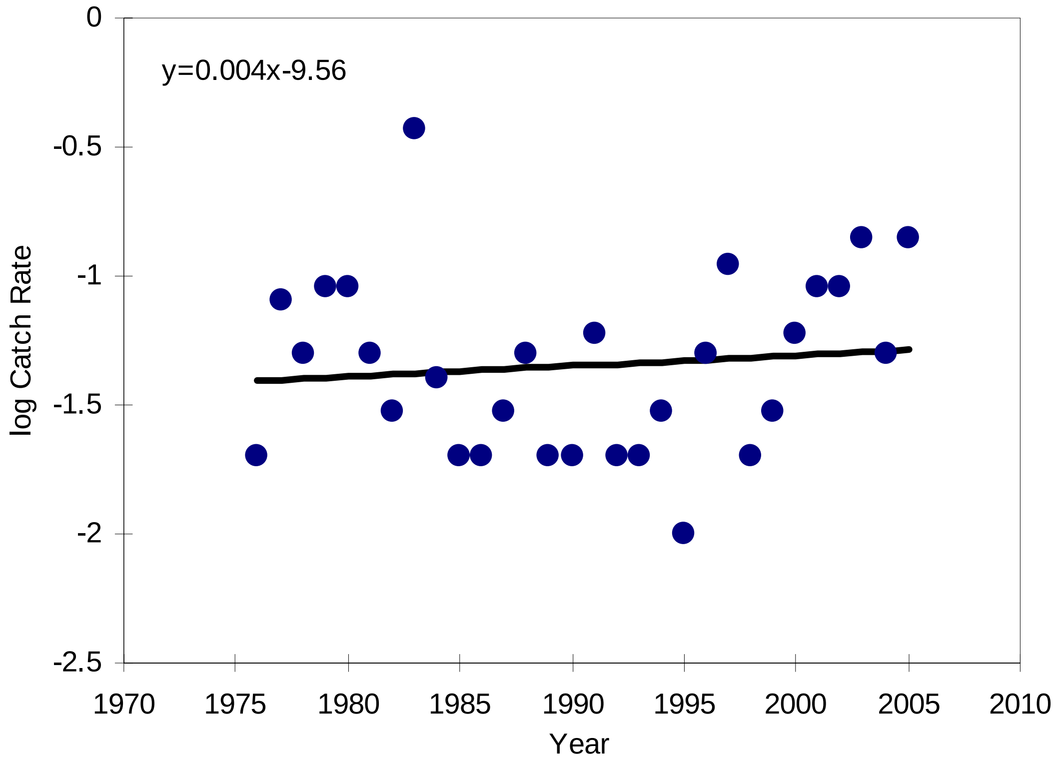


Figure 53. Log_e-transformed catch rates of adult (≥48cm) *M. senta* in the Laurentian Channel/southwestern Grand Banks, and their linear trend.

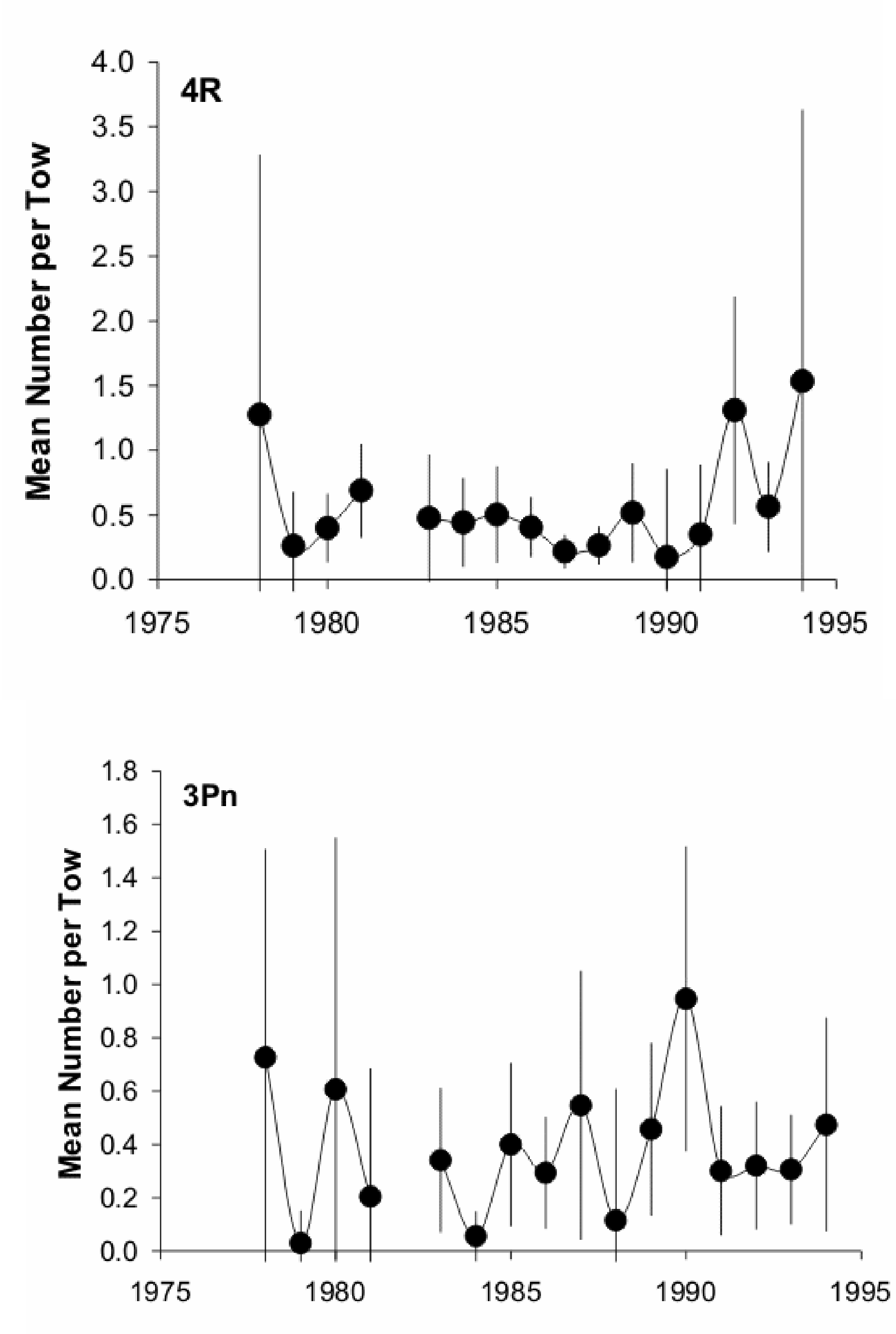


Figure 54. Catch rates in NAFO Division 4R and 3Pn for *M. senta* in the Winter *Gadus Atlantica* survey of the northern Gulf of St. Lawrence. Circles show the stratified mean catch rate. Vertical lines are ±95%CI.

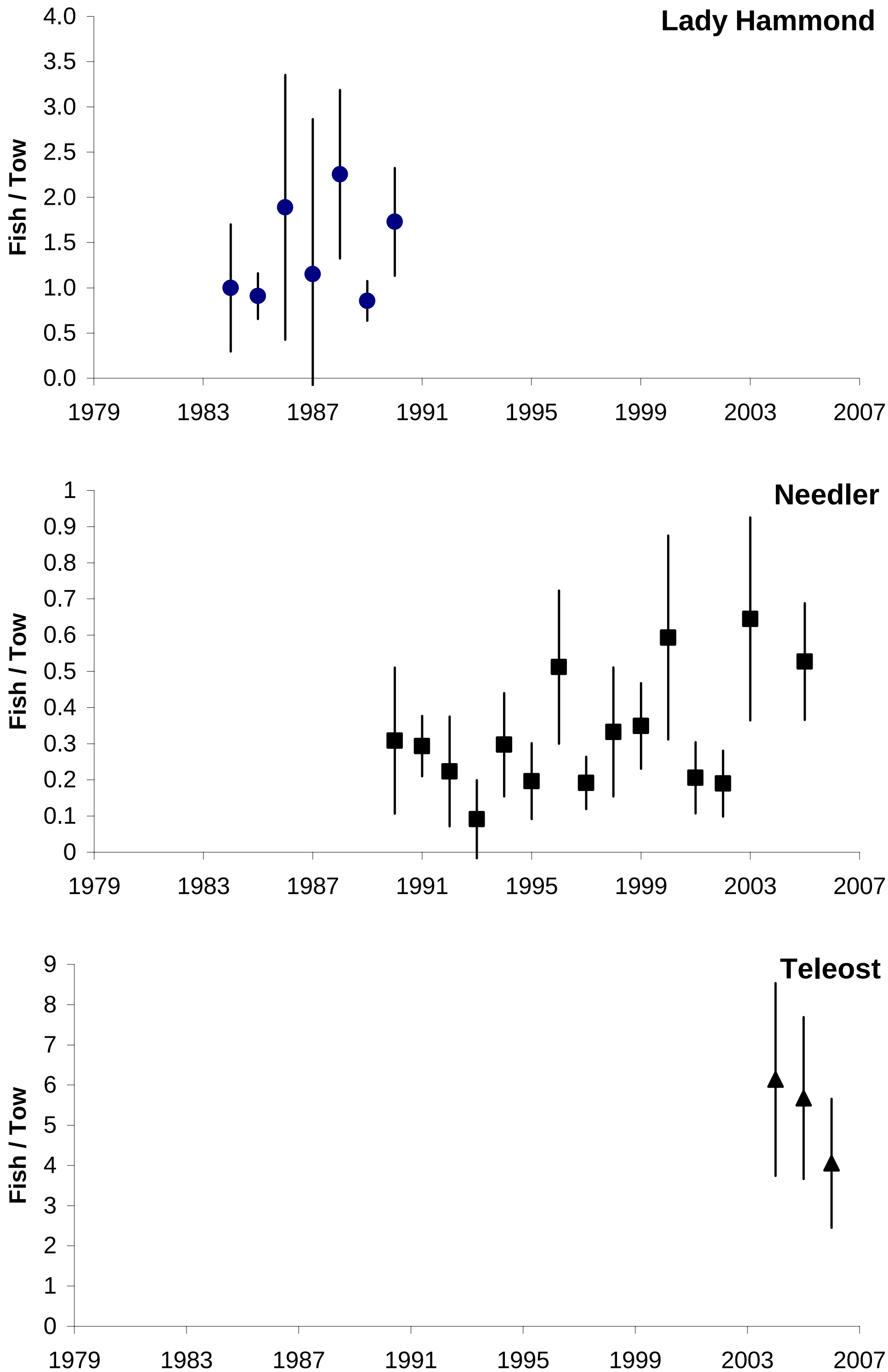


Figure 55a. Catch rates of *M. senta* in the August surveys of the northern Gulf of St. Lawrence. Circles show the stratified mean catch rate. Vertical lines are ±95% CI.

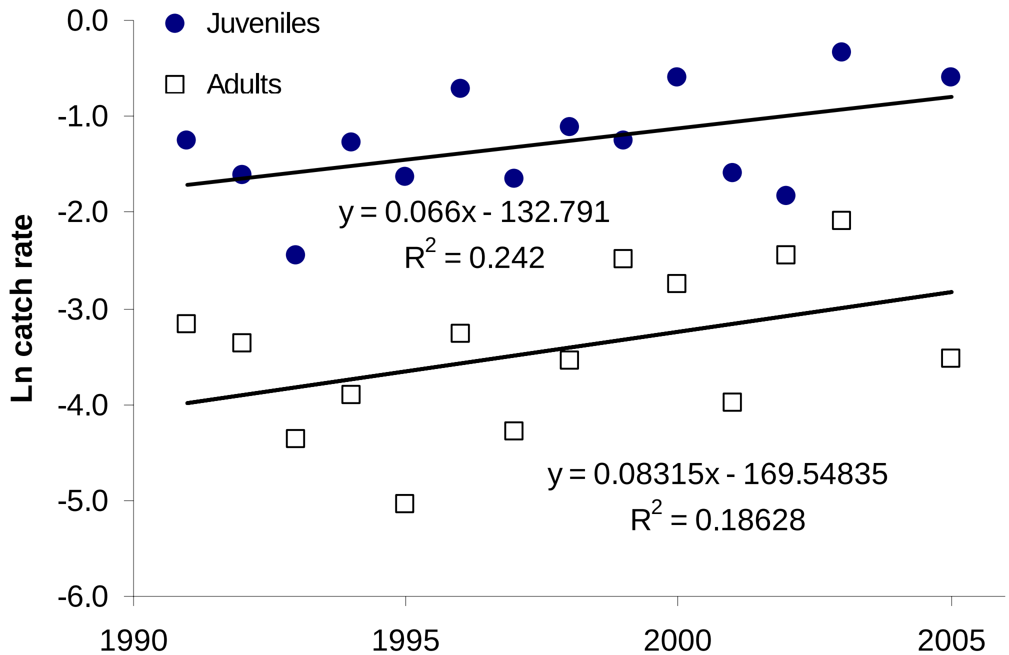


Figure 55b. Catch rates for two size classes of smooth skate in the Alfred Needler (1991–2005) for the northern Gulf of St. Lawrence. Juveniles are skate under 48 cm and adults are those of 48 cm and more. Symbols represent stratified mean catch rate, error bars show ± 95%. CI.

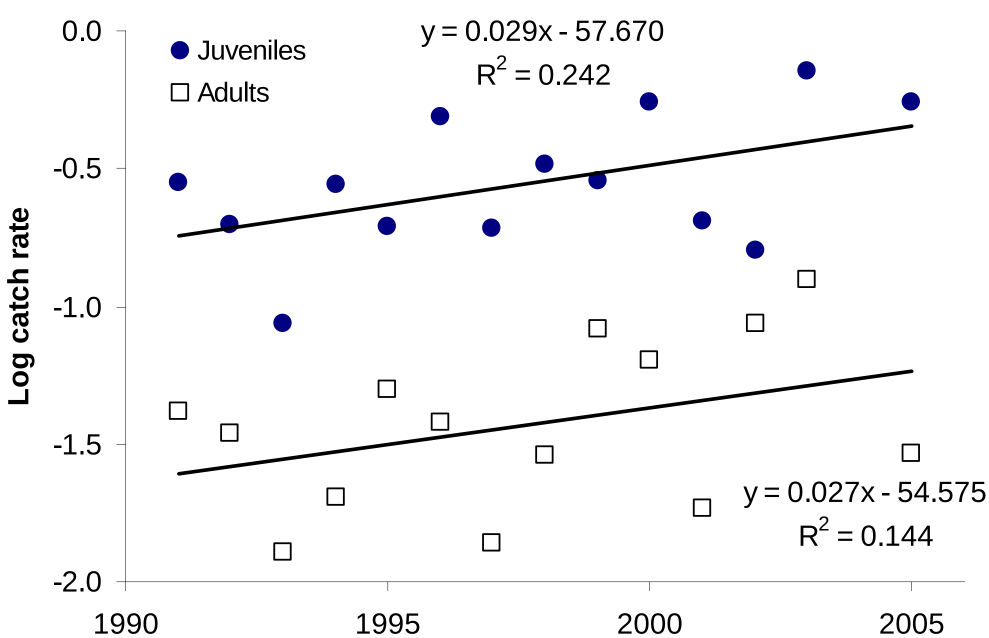


Figure 55c. Log_e-transformed and corresponding linear regression of catch rates of smooth skate (juveniles and adults) from the September *Alfred Needler* survey of the northern Gulf of St. Lawrence.

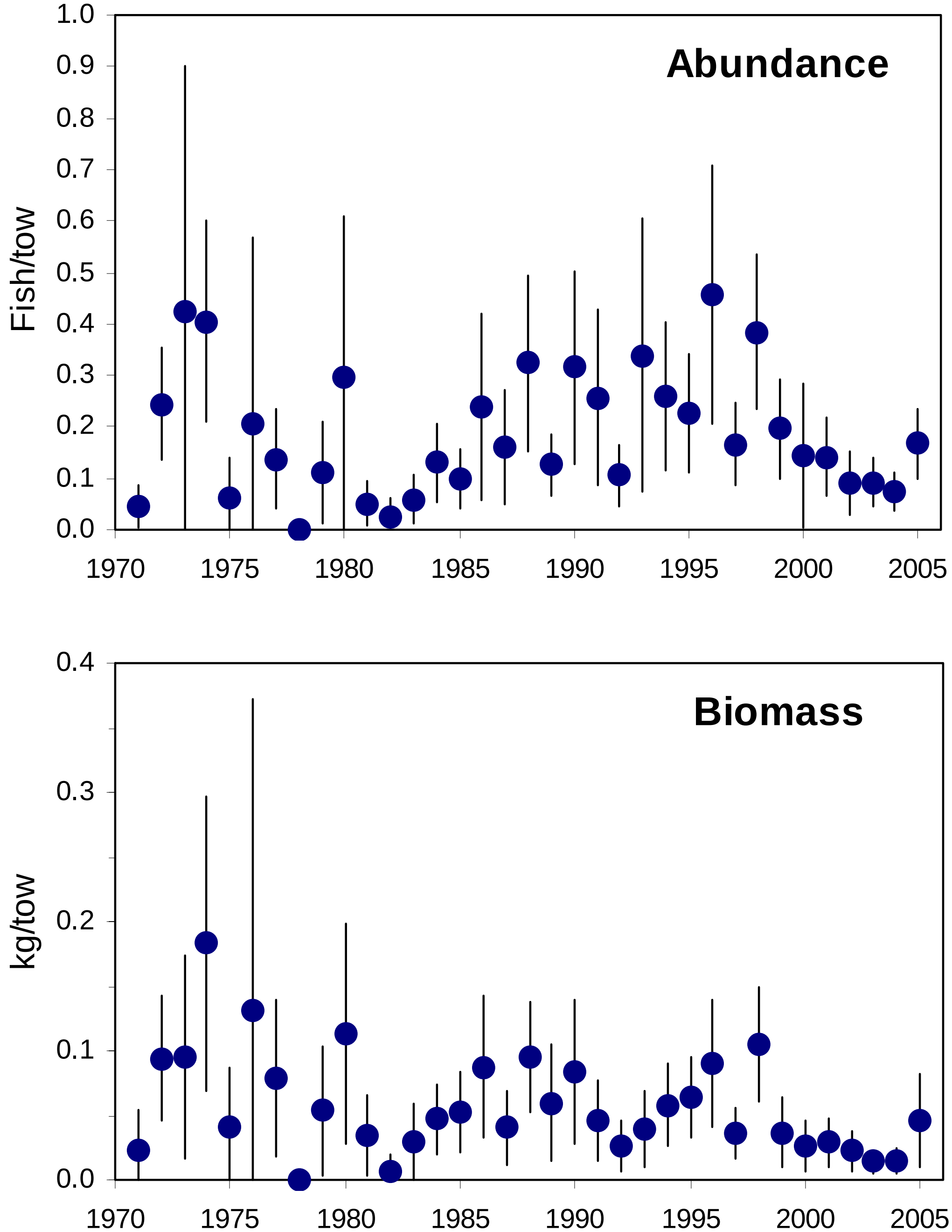
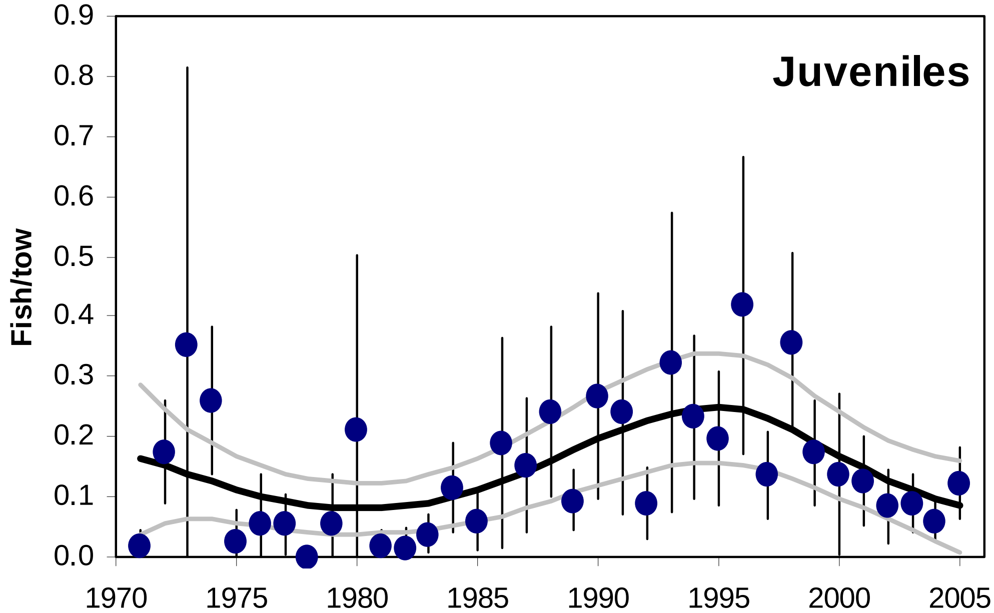


Figure 56. Catch rates of *M. senta* of all sizes in the September survey of the southern Gulf of St. Lawrence. Circles show the stratified mean catch rate. Vertical lines are ±2SE.



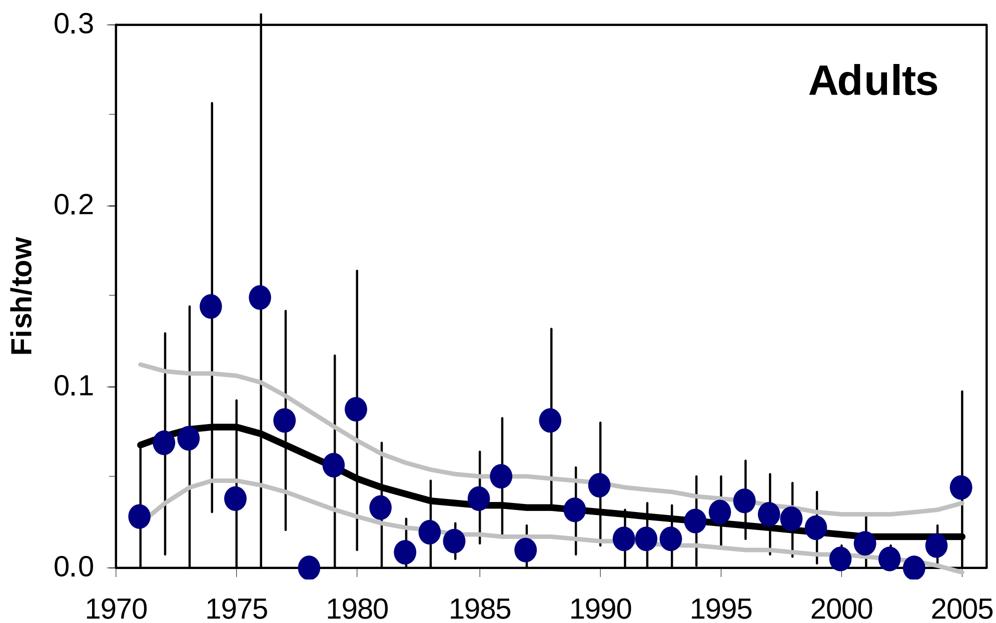


Figure 57. Catch rates of two size classes of *M. senta* in the September survey of the southern Gulf of St. Lawrence. Skates under 48 cm in total length (TL) are assumed to be juveniles; those 48 cm and longer are assumed to be adults. Circles show the stratified mean catch rate. Vertical lines are ±2SE. Heavy line is a GAM fit to the data; grey lines are approximate 95% Confidence Intervals.

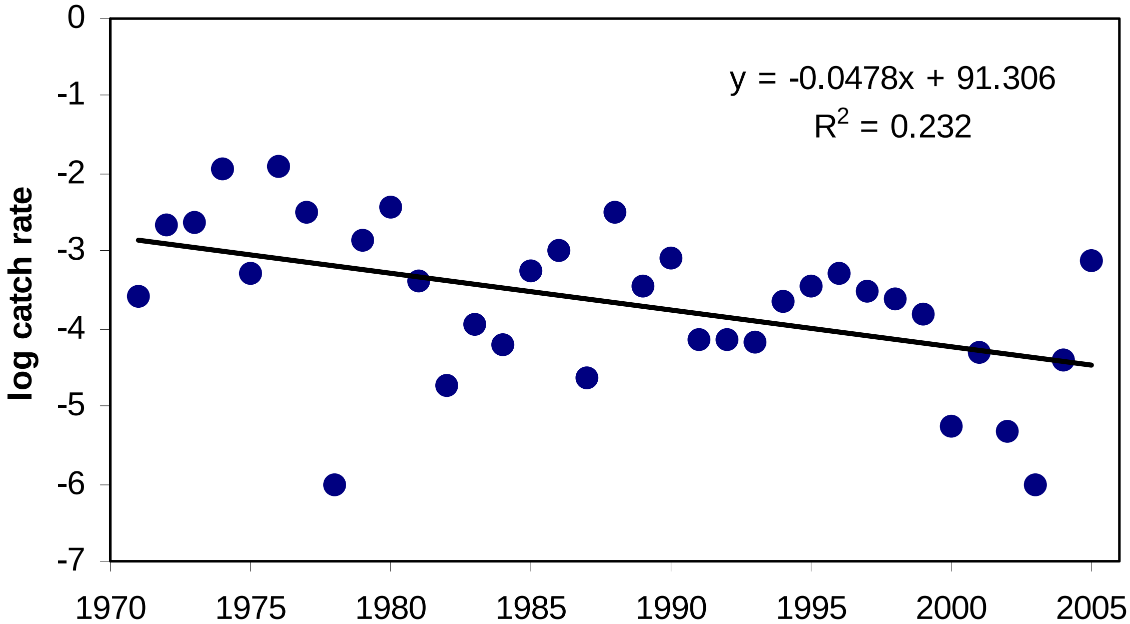


Figure 58. Log_e-transformed catch rates of adult (≥48cm) *M. senta* in the September survey of the southern Gulf of St. Lawrence, and their linear trend.

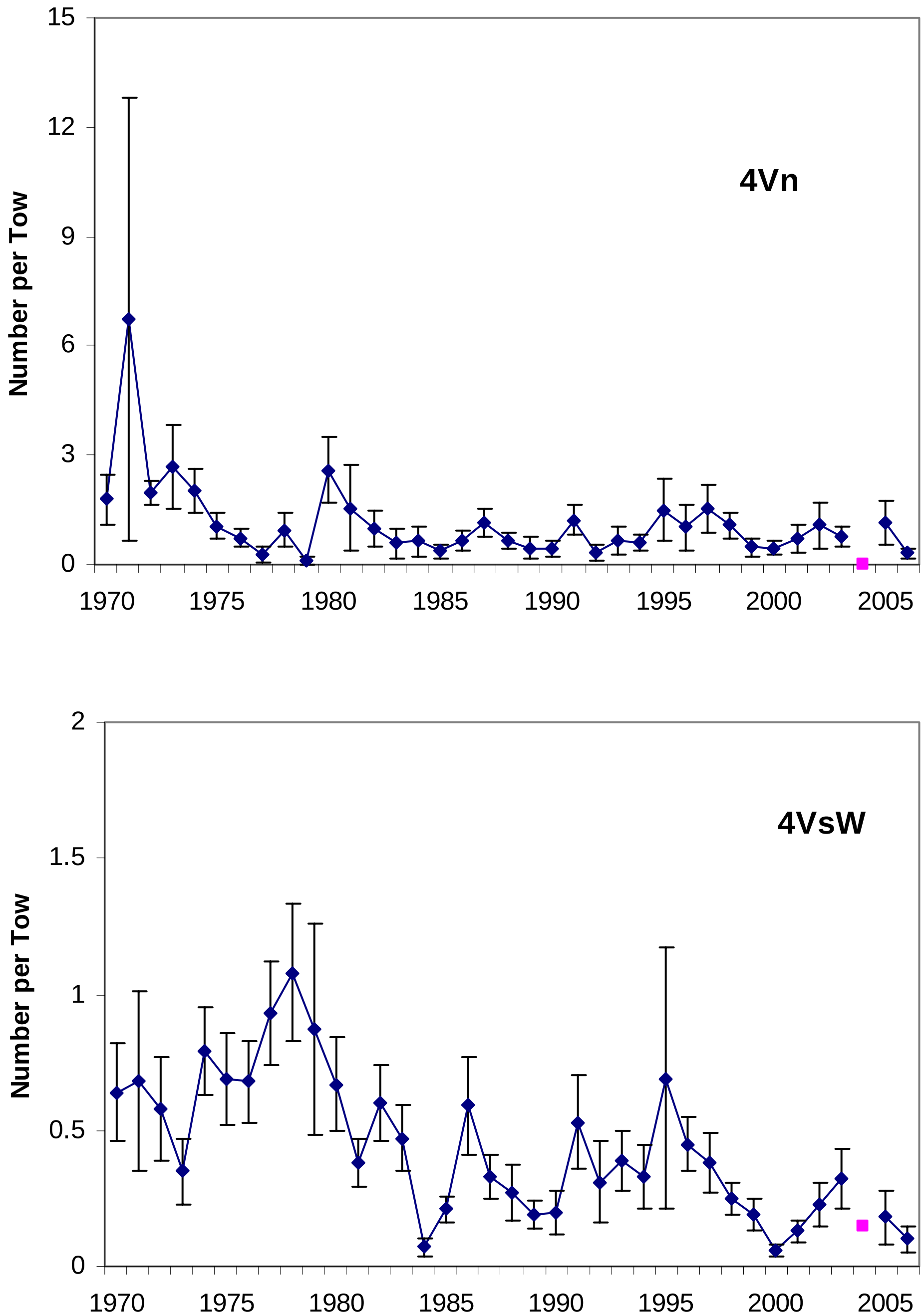


Figure 59. Stratified mean number per tow of *M. senta* from the summer RV survey in Division 4Vn (upper panel) and 4VsW (lower panel).

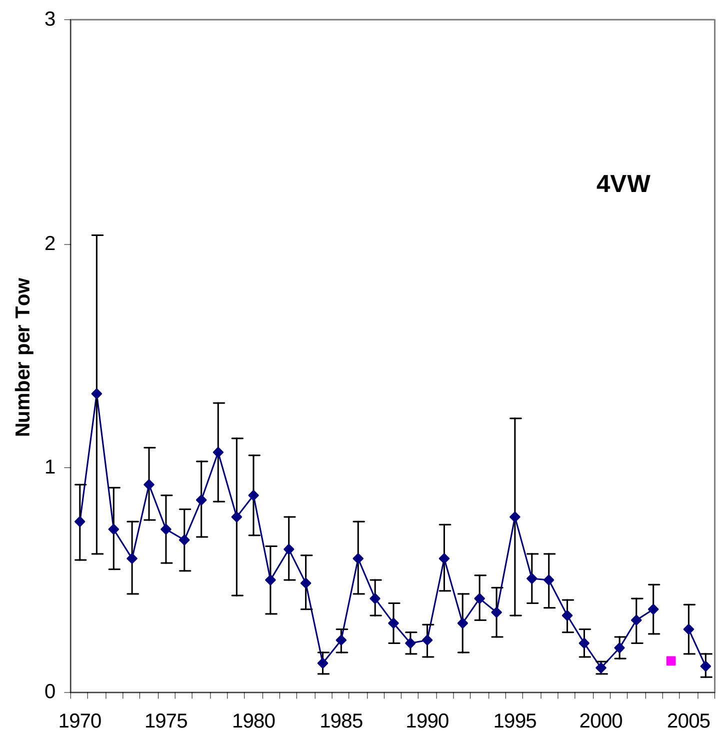


Figure 60. Stratified mean number per tow of *M. senta* from the summer RV survey in Division 4VW.

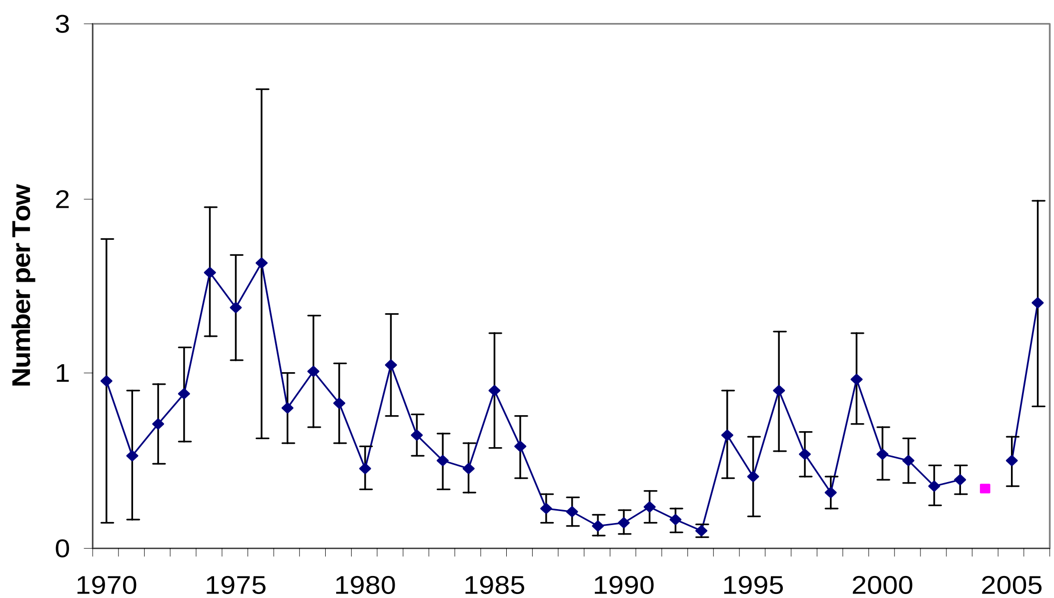


Figure 61. Stratified mean number per tow from the summer RV survey in Division 4X.

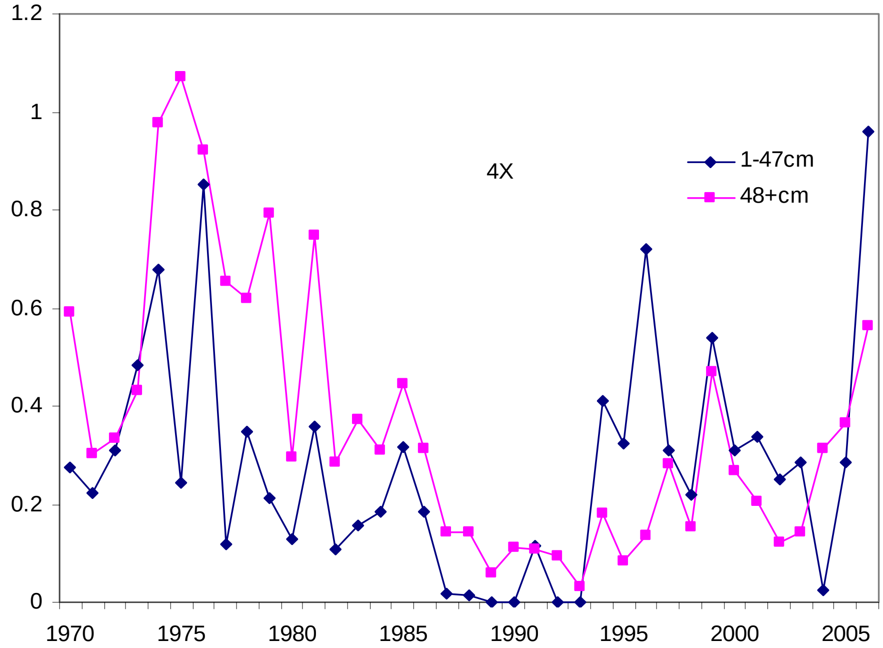


Figure 62. Stratified mean number per tow from the summer RV survey in Division 4X, aggregated by length: <48cm=immature; ≥48cm=mature.

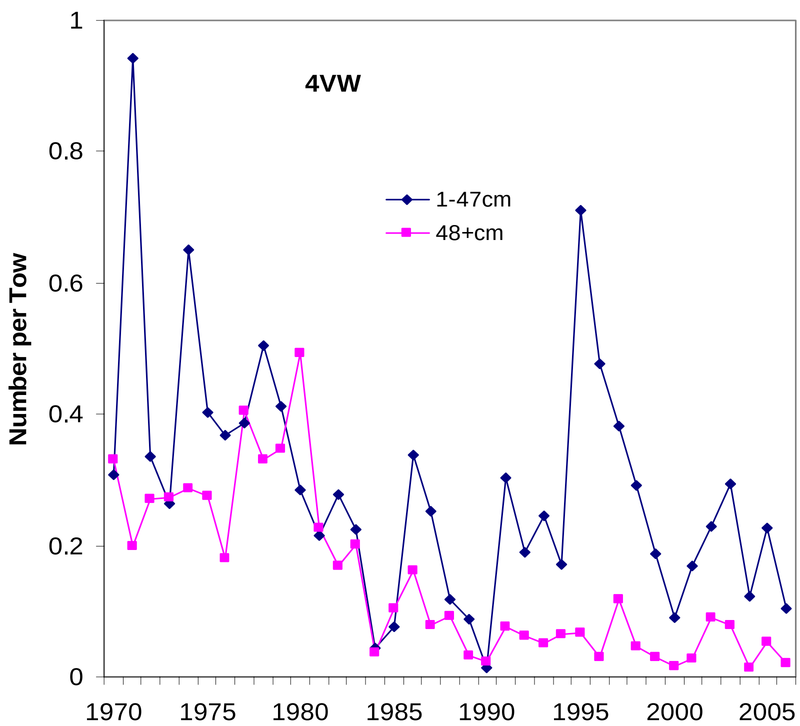


Figure 63. Stratified mean number per tow from the summer RV survey in Division 4VW, aggregated by length: <48cm=immature; ≥48cm=mature.

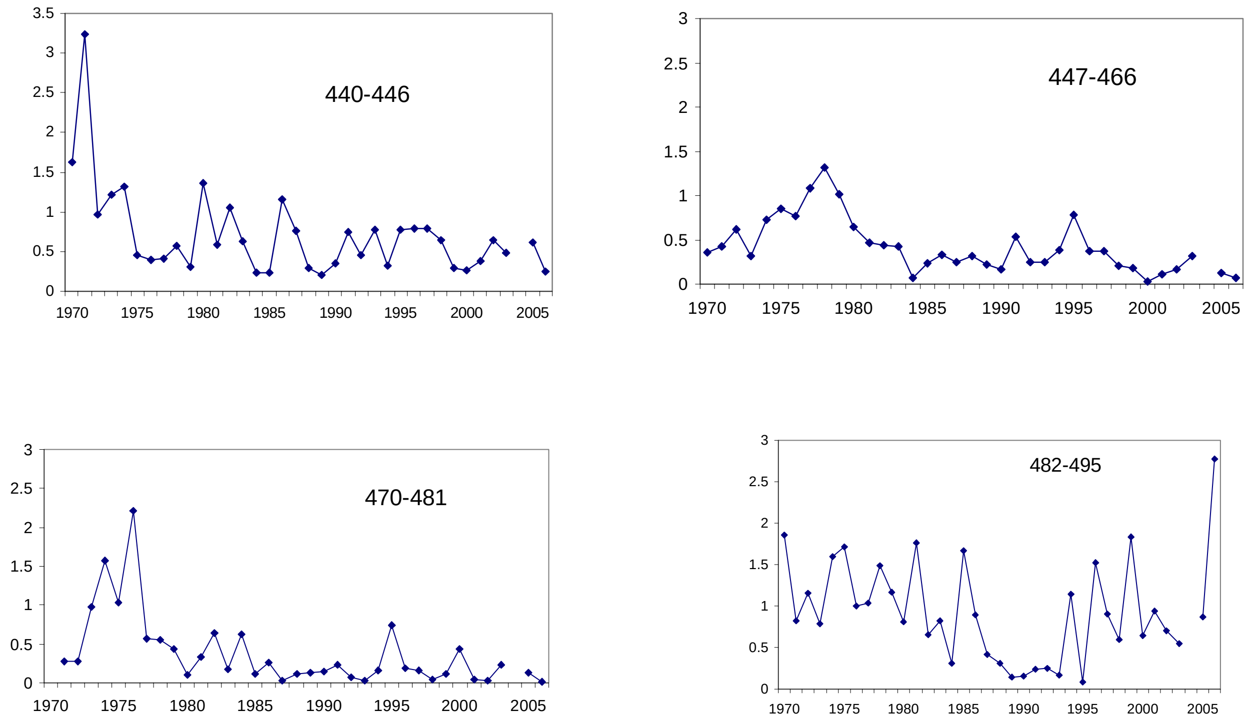


Figure 64. Stratified mean number per tow from summer RV survey strata groupings on the Scotian Shelf.

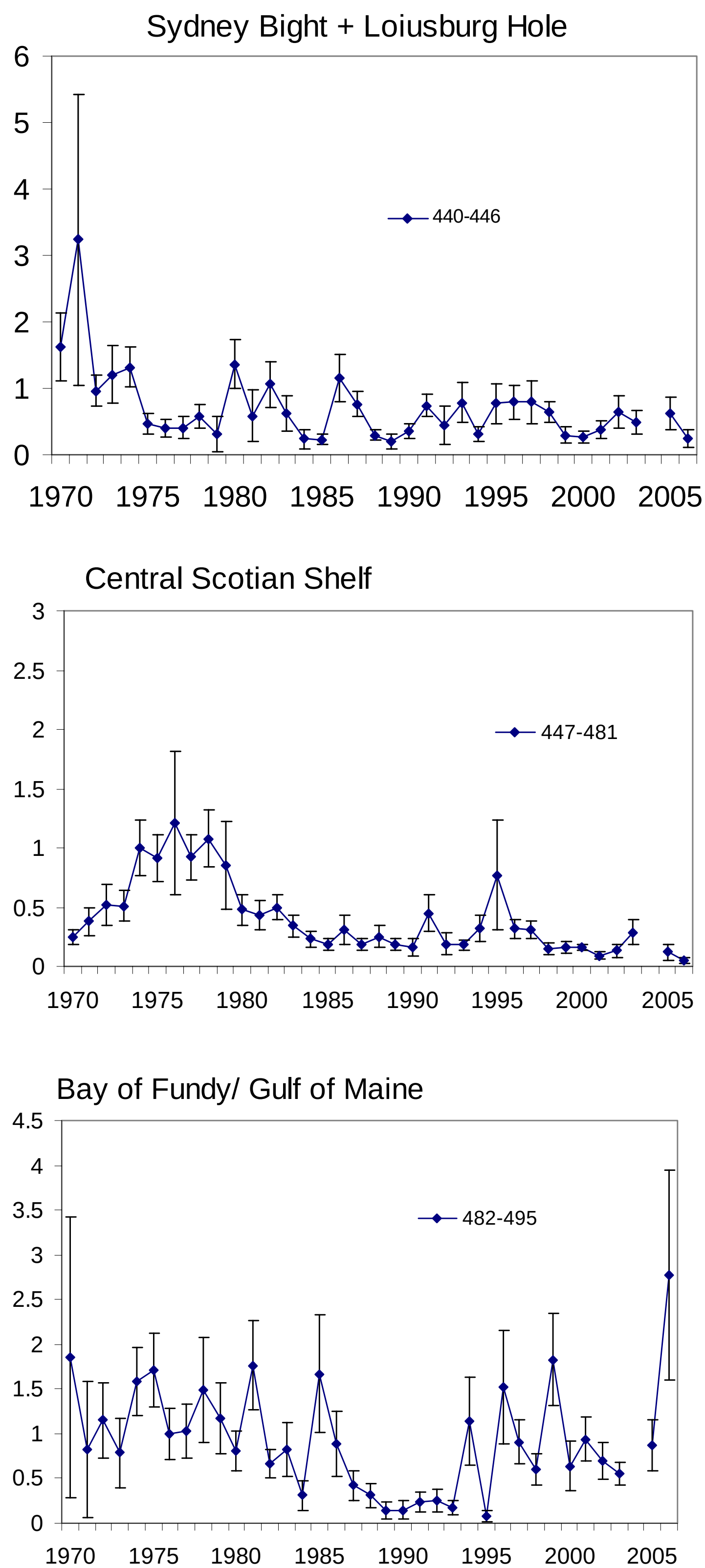
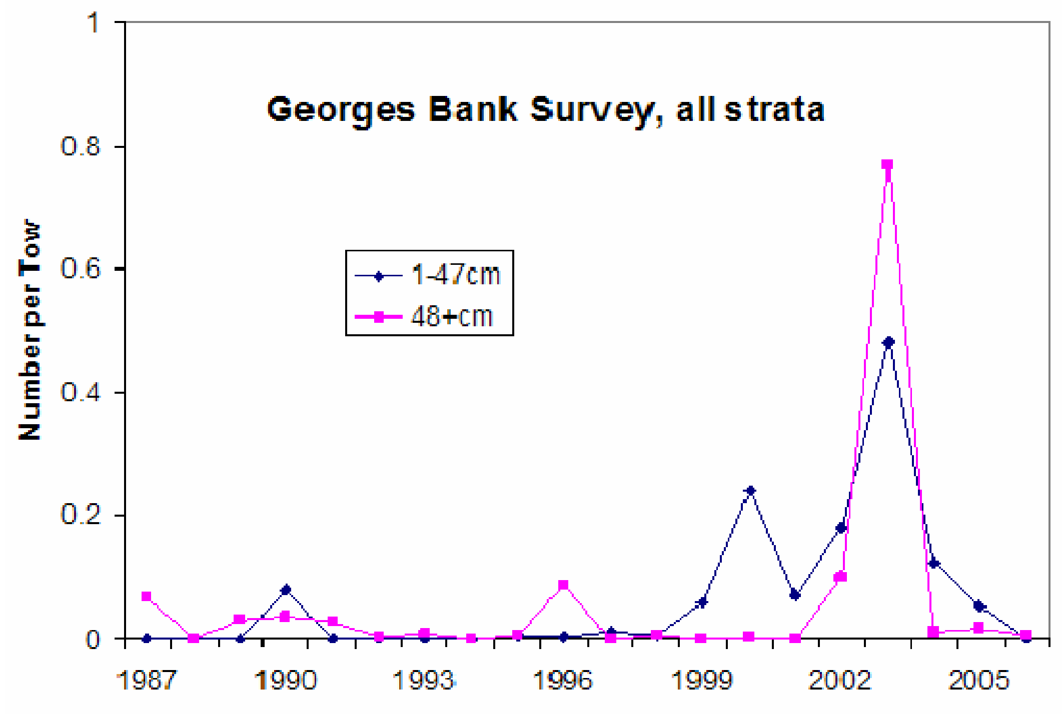


Figure 65. Stratified mean number per tow from Sydney Bight, the central Scotian Shelf, and the Bay of Fundy.



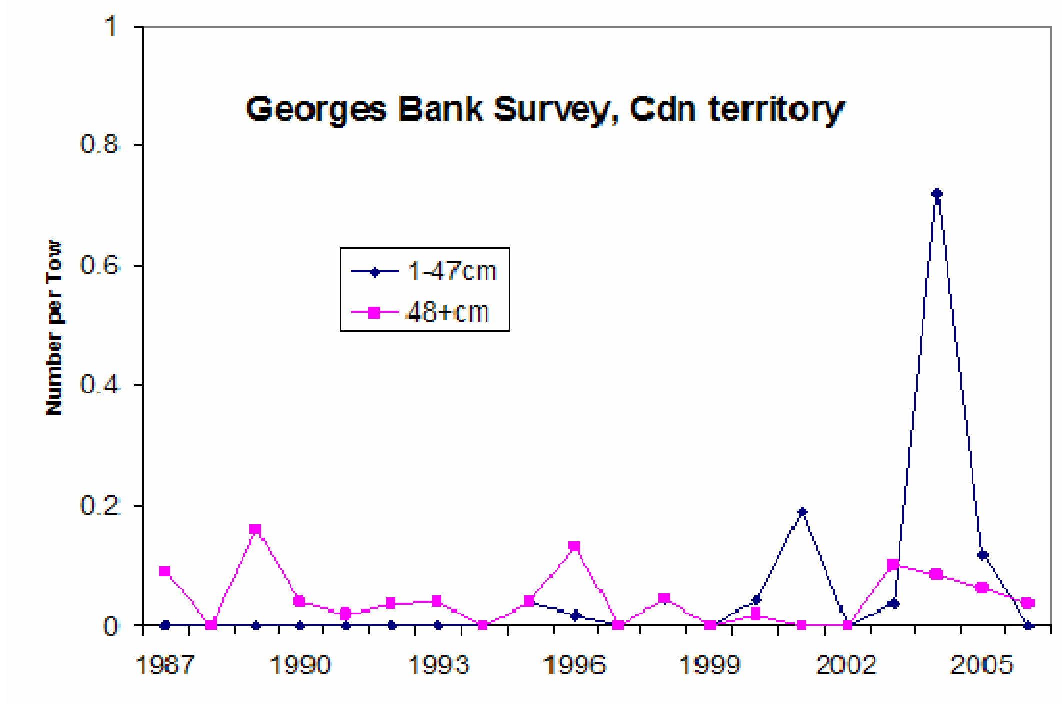
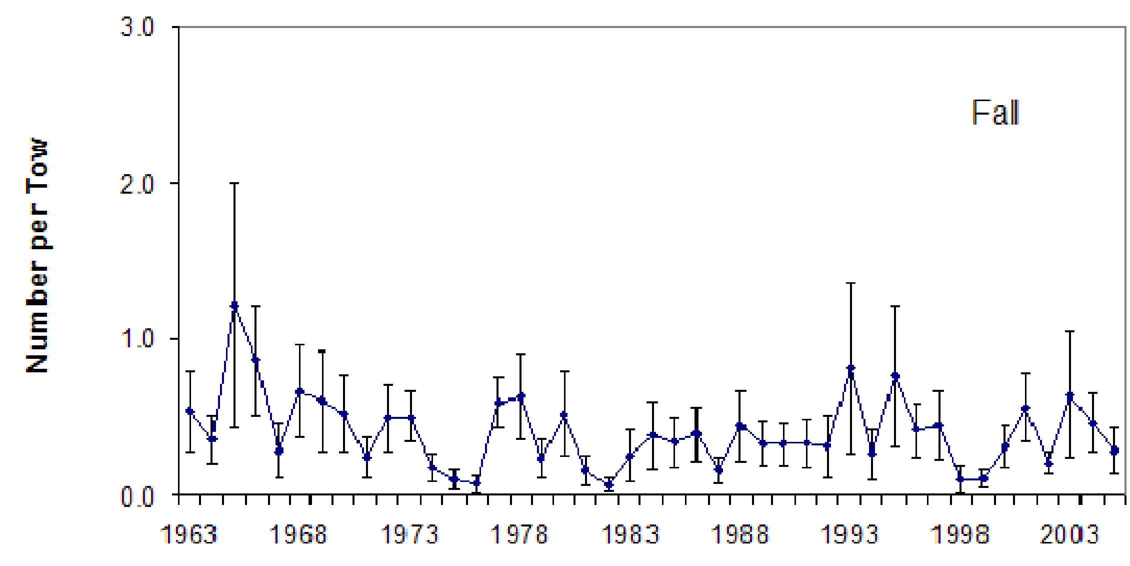


Figure 66. Stratified mean number per tow of *M. senta* from the all strata surveyed and only the strata on the Canadian side of the survey by length groups 1-47 cm (immature) and 48 +cm (mature).



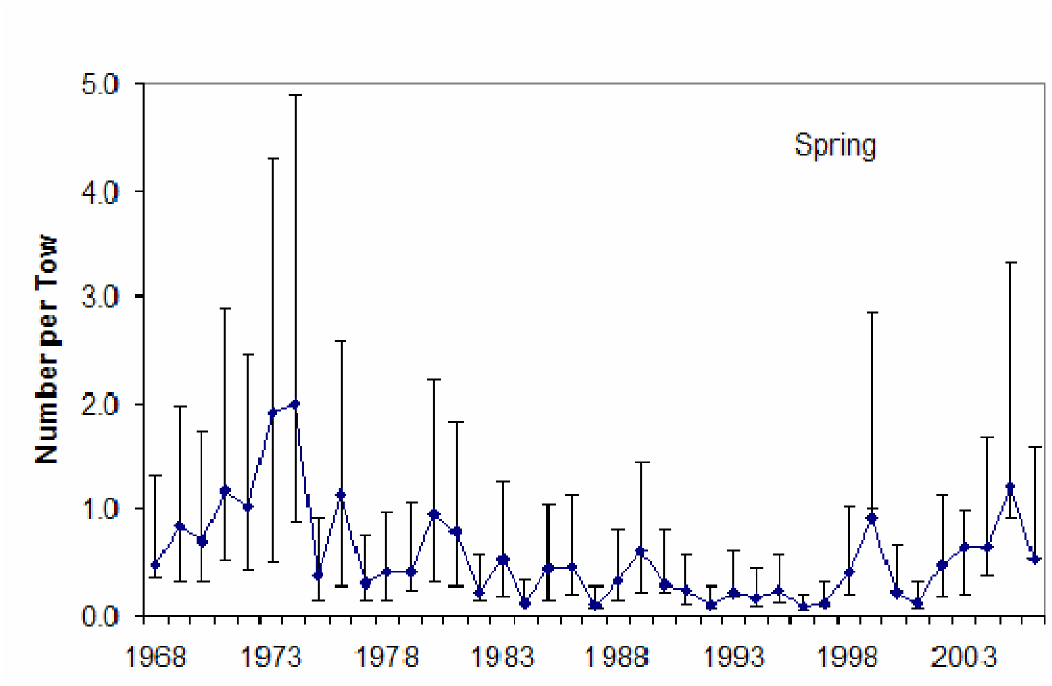


Figure 67. Stratified mean number per tow from the NMFS fall and spring surveys, strata 1-30, 33-40. This corresponds approximately to the area east of the Gulf of Maine and Georges Bank. Bars are 95% confidence limits.

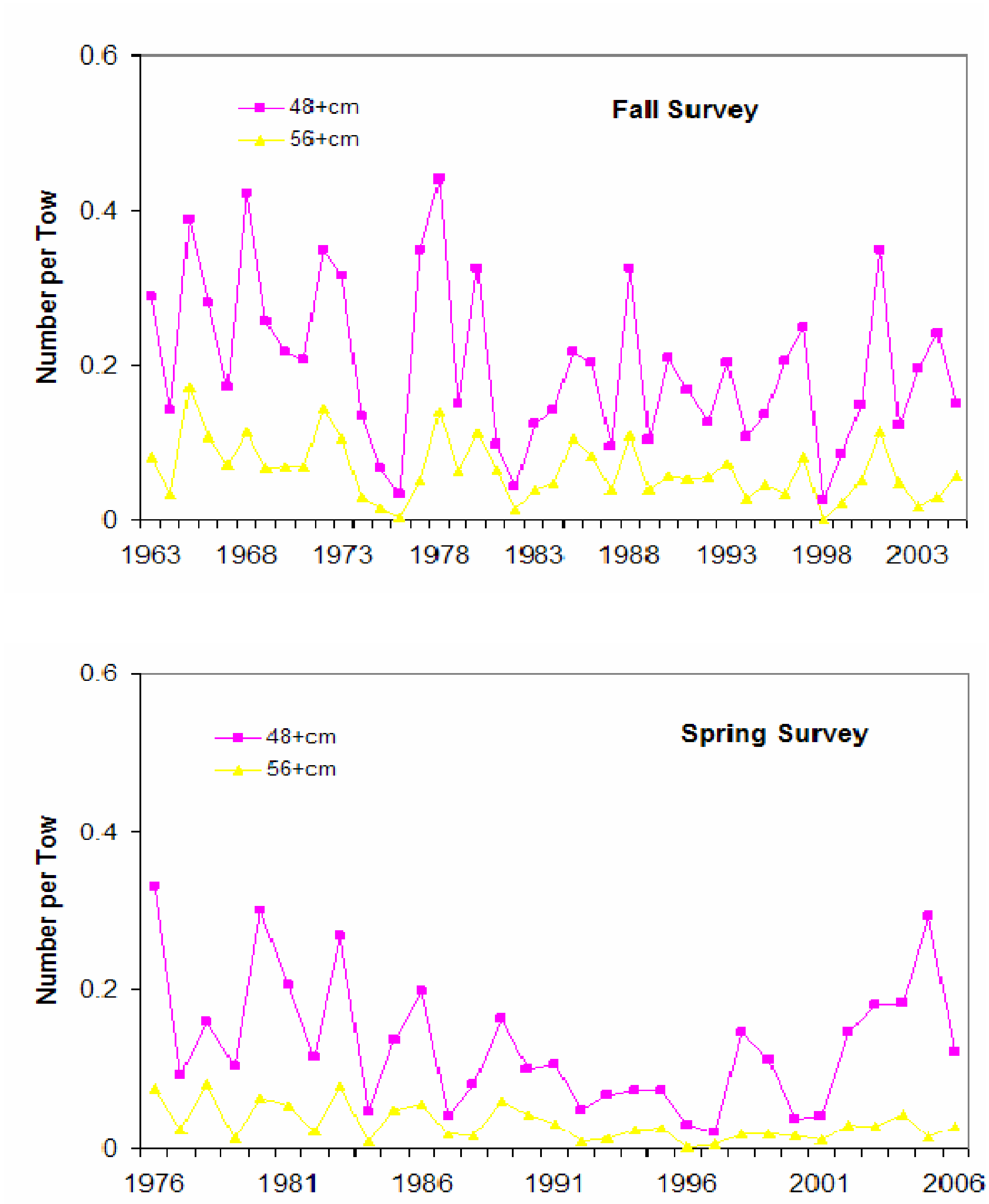


Figure 68. Stratified mean number per tow from the NMFS fall and spring surveys, strata 1-30, 33-40. This corresponds approximately to the area east of the Gulf of Maine and Georges Bank. Two 50% maturity estimates are presented.

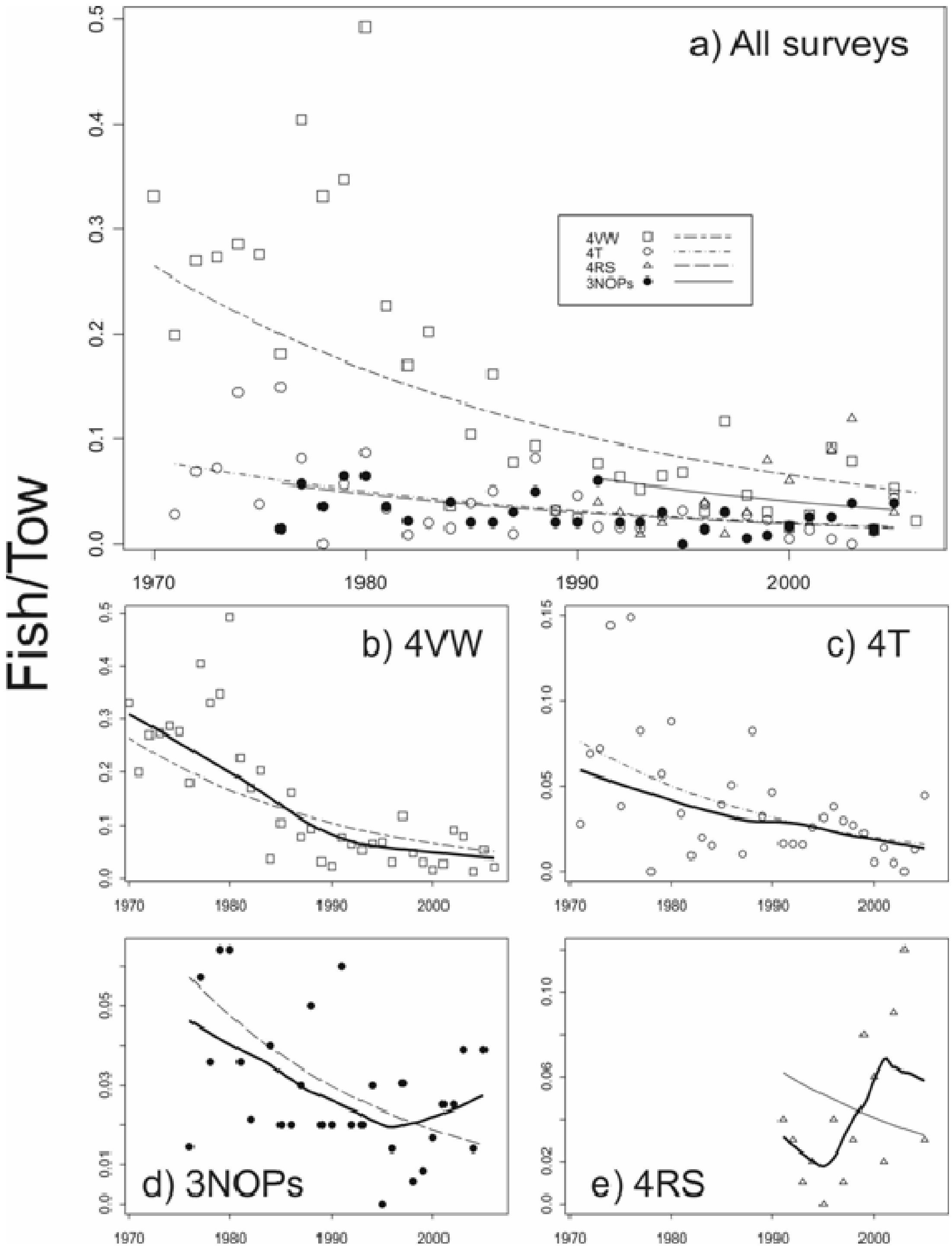


Figure 69. Relative abundance of adult *M. senta* in the Laurentian DU (analysis integrating data from all Regions). Symbols show the observed mean catch rate in each survey, light lines the predicted catch rate assuming a common slope for all surveys, and heavy lines a loess smooth fit separately to the catch rates in each survey.

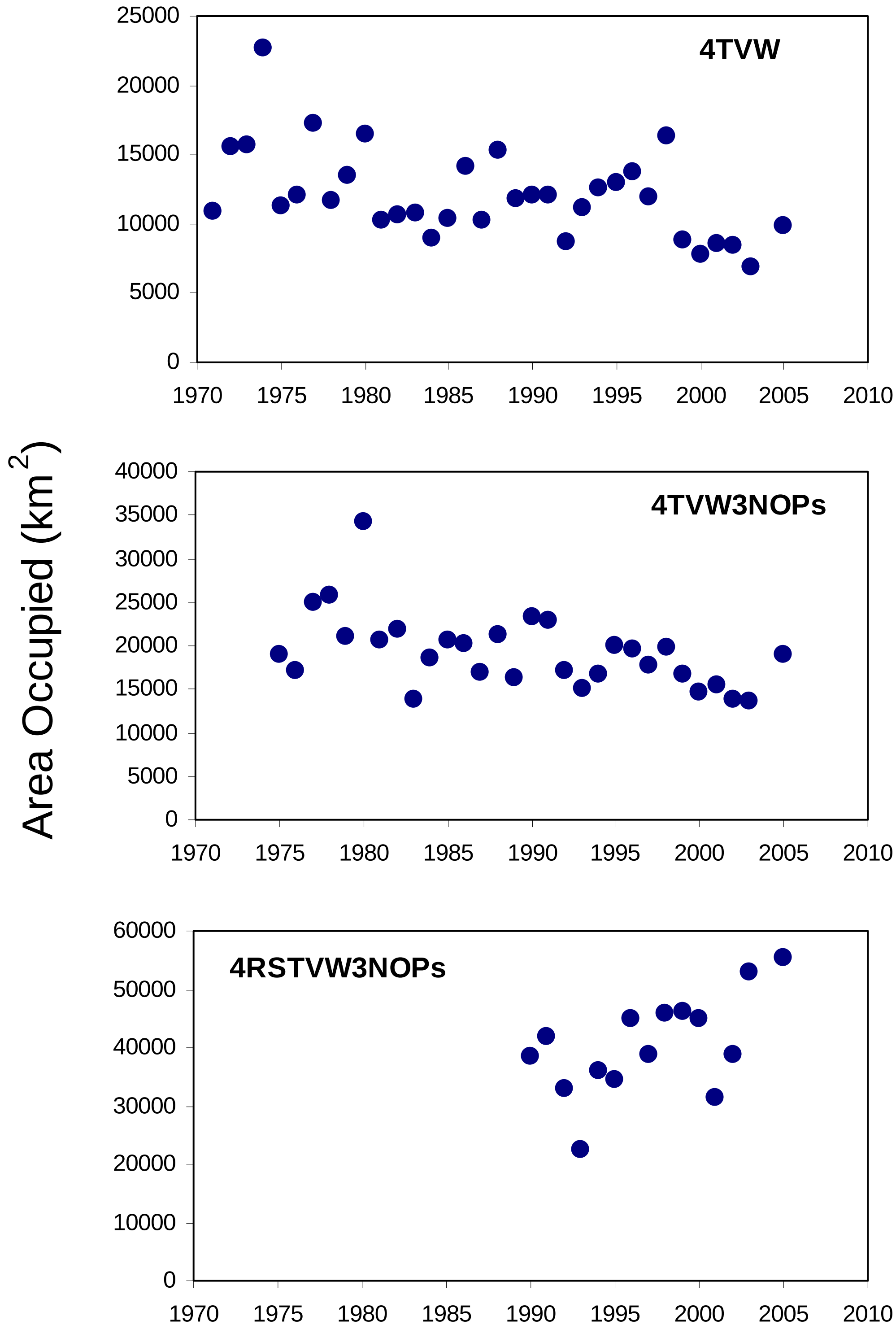


Figure 70. Area occupied by *M. senta* (all sizes) in the Laurentian DU (analysis integrating data from all Regions).

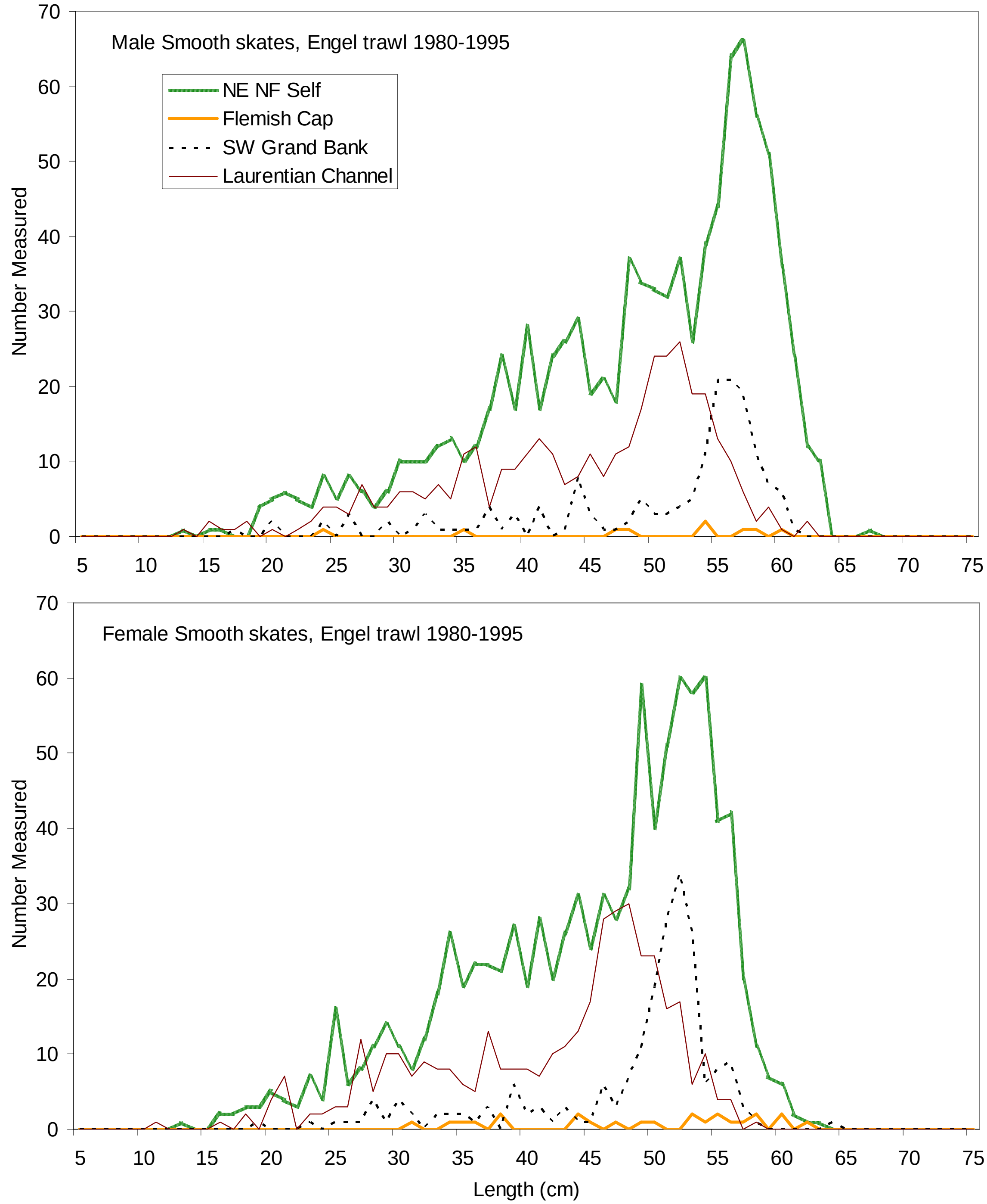
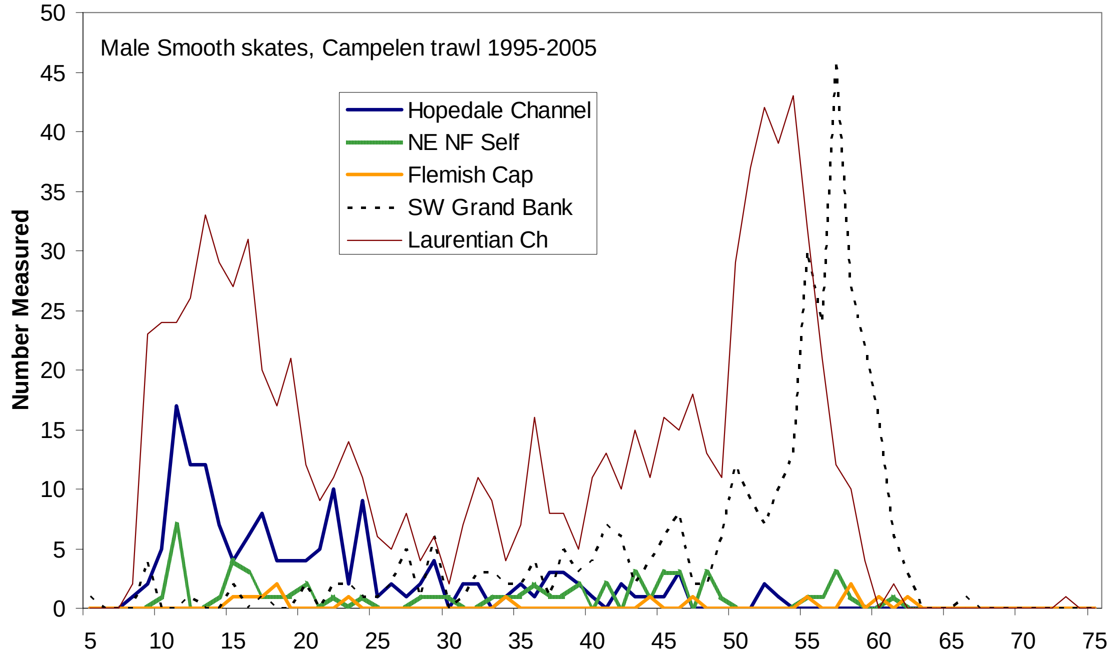


Figure 71a. Percent length frequencies of *M. senta* captured in Engel survey trawls from Hopedale Channel, Funk Island Deep, Flemish Cap, and Laurentian (NL Region, Channel/SW Grand Banks), 1980-95.



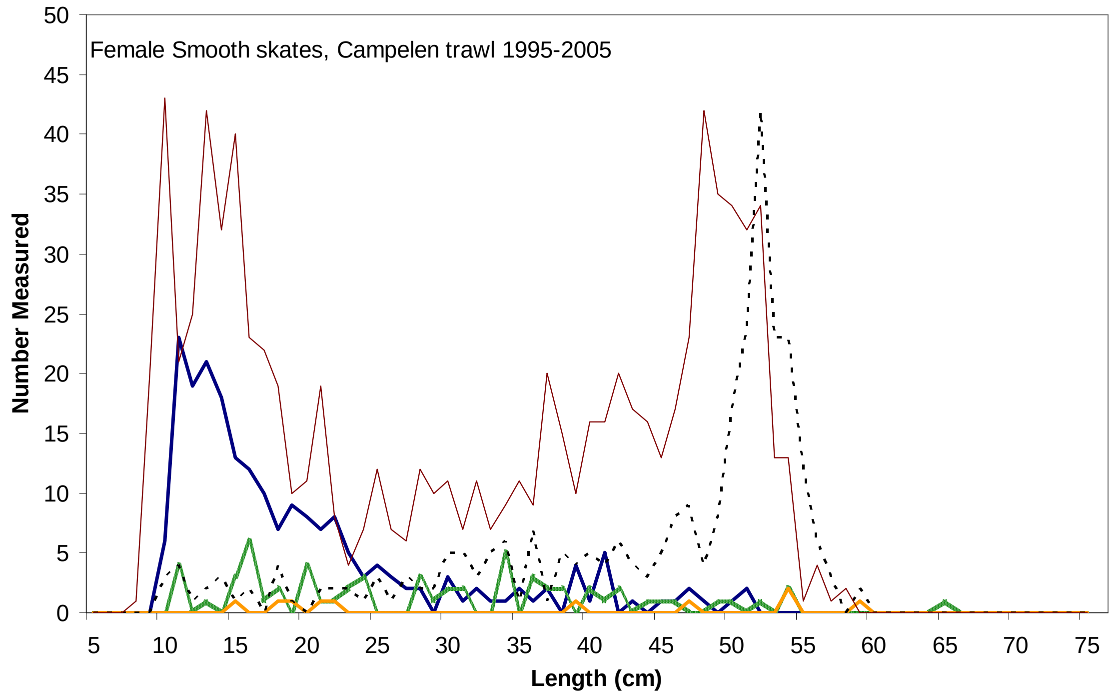


Figure 71b. Percent length frequencies of *M. senta* captured in Campelen survey trawls from Hopedale Channel, Funk Island Deep, Flemish Cap, and Laurentian (NL Region, Channel/SW Grand Banks), 1995-2005.

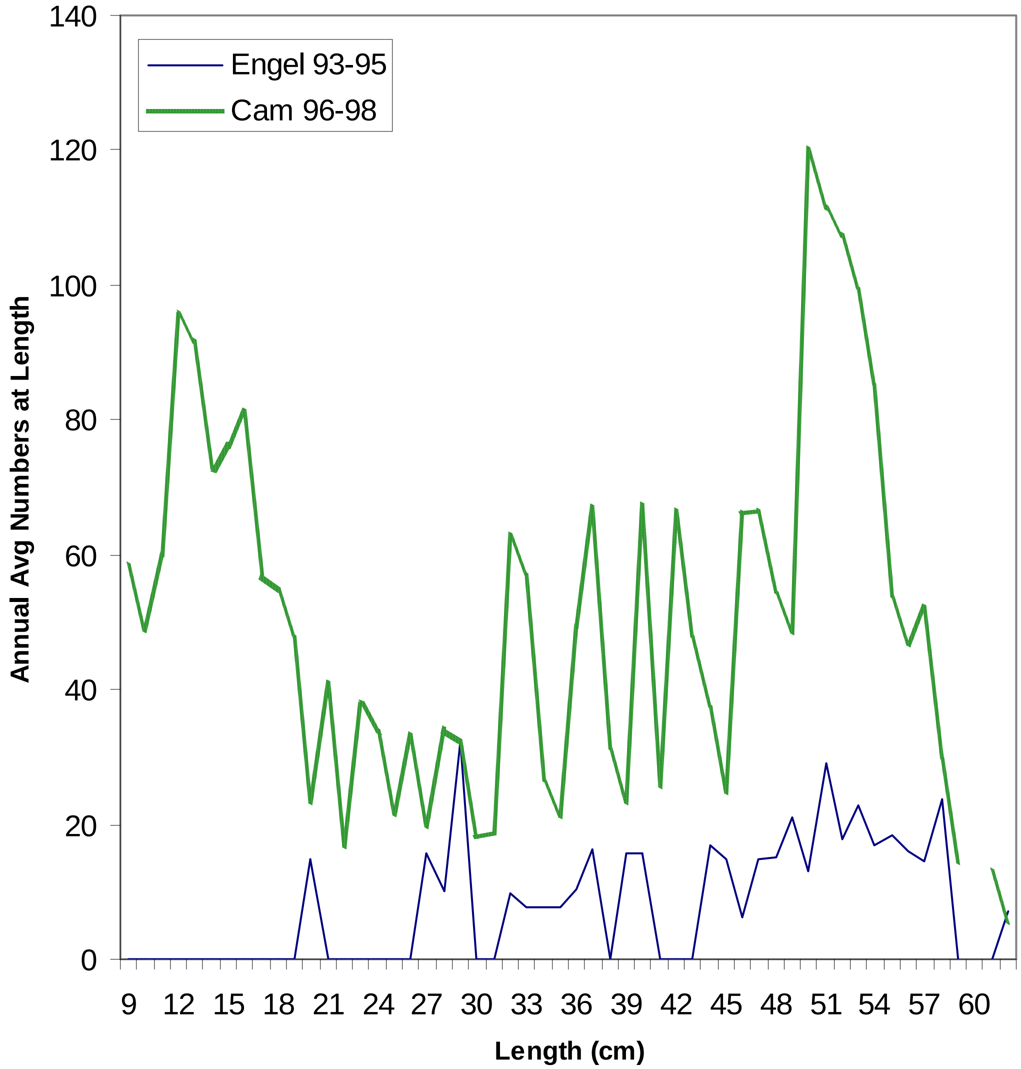
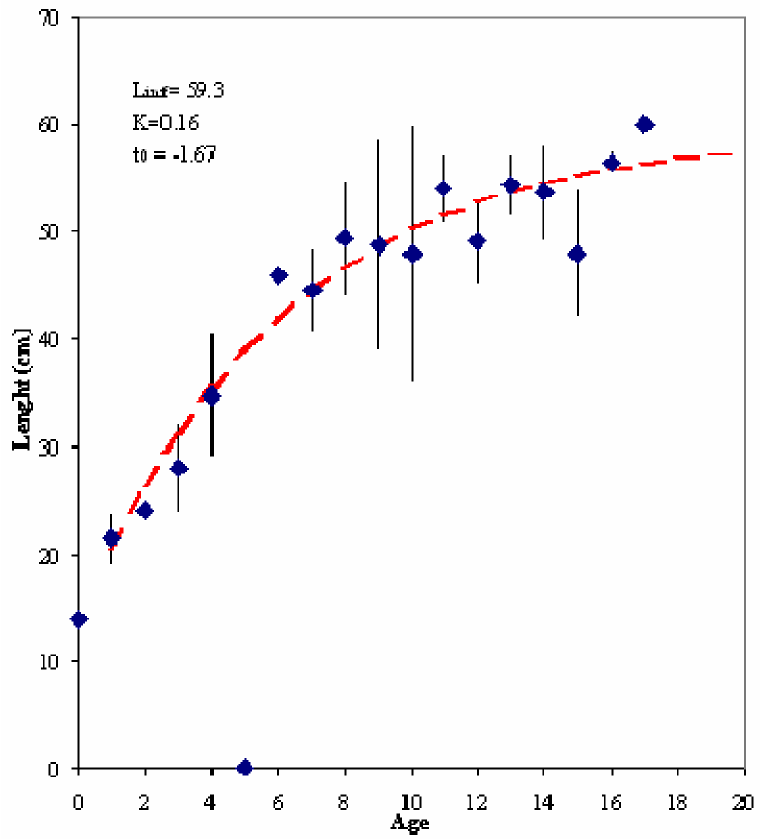


Figure 71c. Annual average numbers at length of *M. senta* captured in the last 3 years of the Engel survey (1993-95) compared to the first three years of the Campelen survey from Hopedale Channel, Funk Island Deep, Flemish Cap, and Laurentian (NL Region, Channel/SW Grand Banks).



von Bertalanffy parameters:

L_{inf}=59.3
K=0.16
$t_{o=}$-1.67

50% maturities:
TL50% male=49 cm
TL50% female=40.5 cm
Max. age observed 18 yrs
Min. age of maturity observed 8 yrs
Fecundity <100 per year

Generation Time:
If assumed m of.2 and age at maturity of 8 then G.T.=13 years

Figure 72. von Bertalanffy growth curve for *M. senta* taken primarily from the Laurentian DU (southwest Grand Banks segment) and to a lesser extent from the Funk DU, n=71.

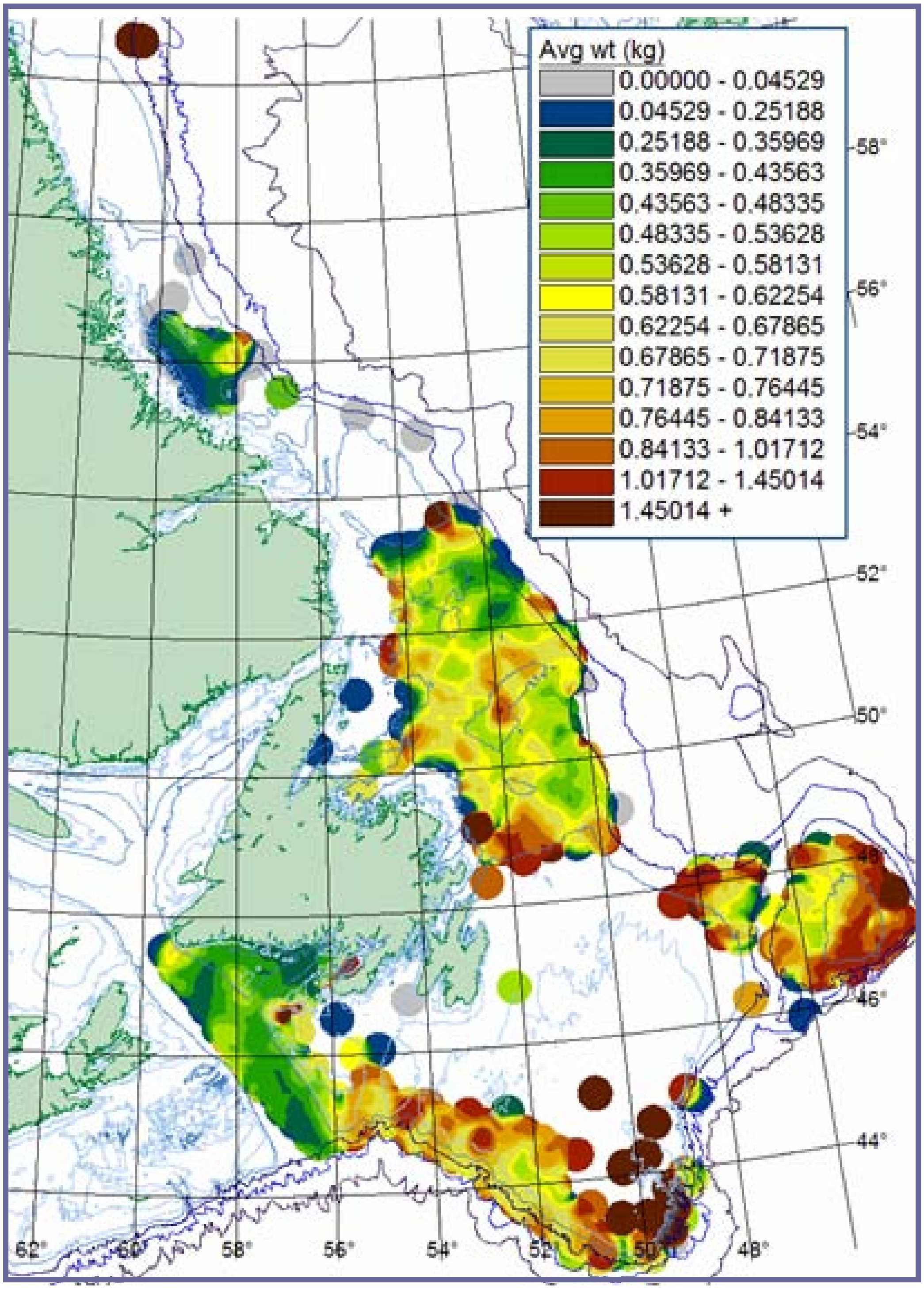


Figure 73a. Map of average weight (weight/number per tow) from NL Region surveys for 1995-2005, Campelen gear.

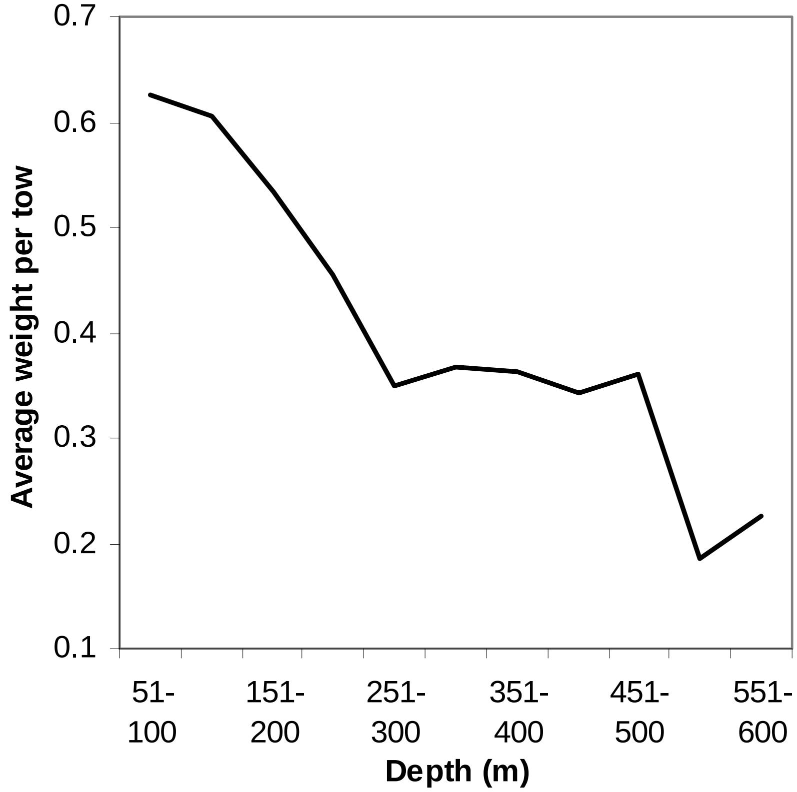


Figure 73b. Average weight (weight/number per tow) by depth from NL Region surveys for 1995-2005.

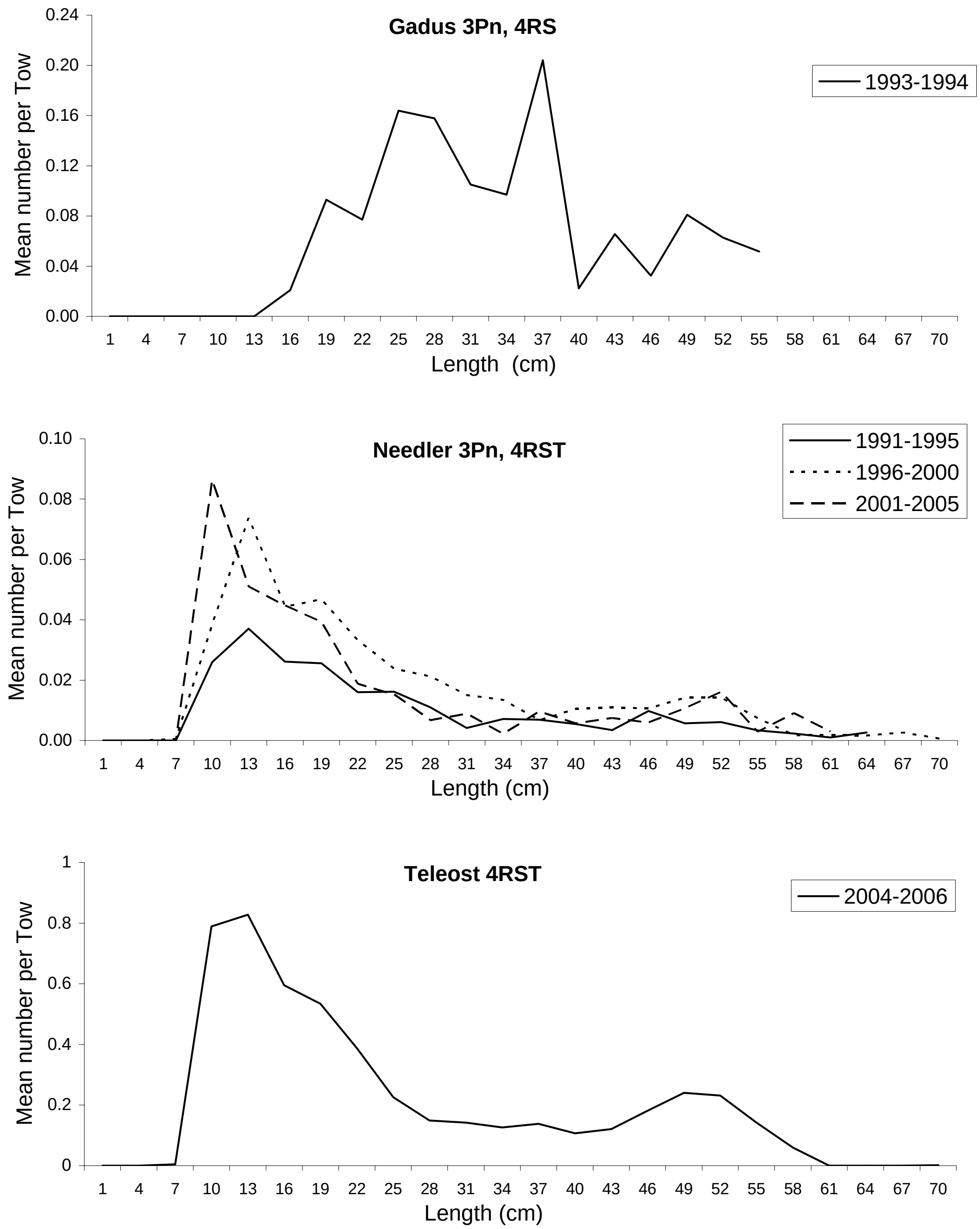


Figure 74. Size distribution of *M. senta* in research surveys of the northern Gulf of St. Lawrence (3cm length class). The *Gadus Atlantica* survey was conducted with an Engel-145, the Alfred Needler survey with a URI shrimp trawl and the Teleost with a Campelen trawl.

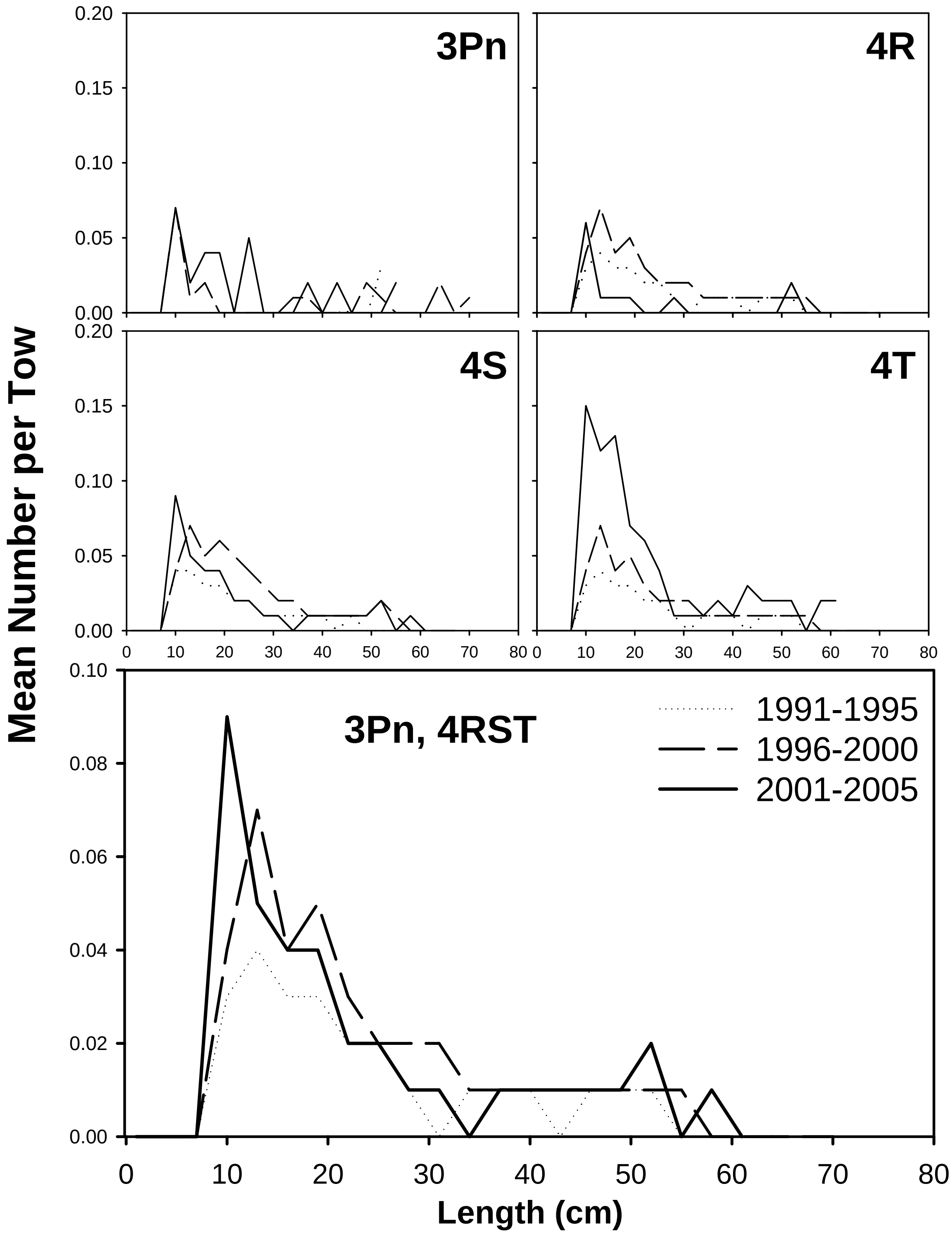


Figure 75. Size distribution of *M. senta* by NAFO Division from the *Alfred Needler* August survey of the northern Gulf of St. Lawrence in 5-year periods employing the URI shrimp trawl.

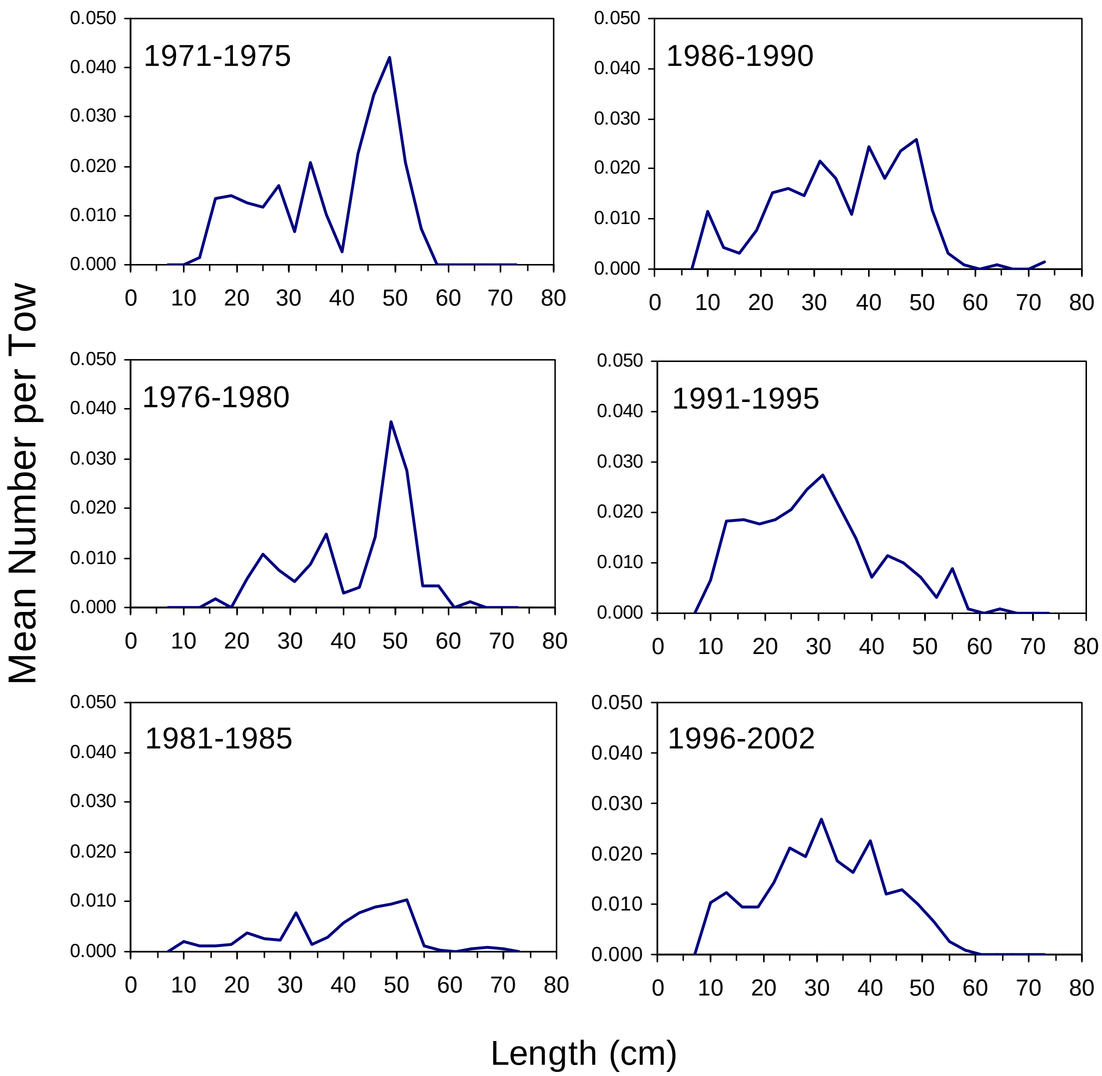


Figure 76. Size distribution of *M. senta* in September survey catches for the southern Gulf of St. Lawrence in 5-yr periods. Surveys were conducted using a Yankee-36 trawl from 1971 to 1985 and a Western-IIA trawl since 1985.

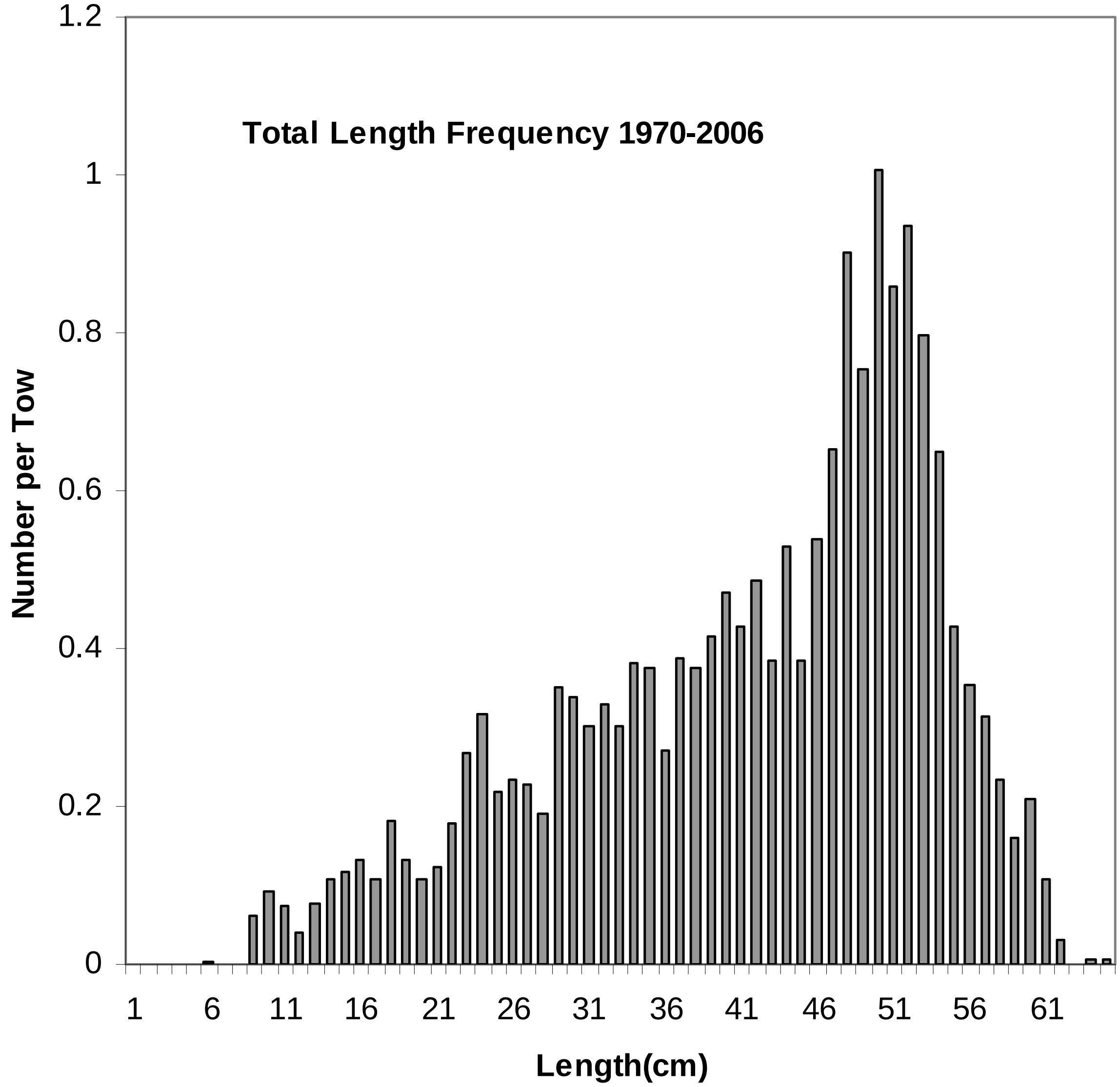
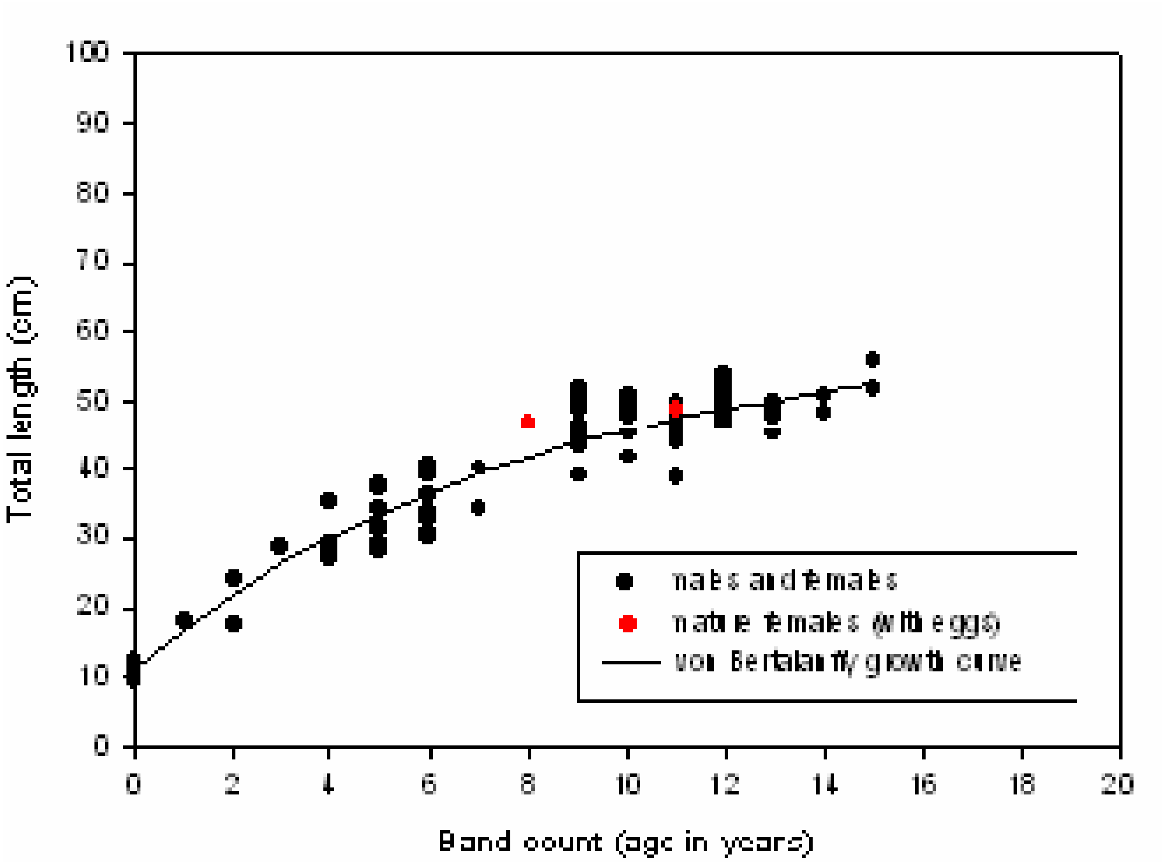


Figure 77. Cumulative length frequency of *M. senta* from the Maritimes summer RV surveys in 1970-2006; all strata on the Scotian Shelf. From 1970 to 1981, the survey was conducted using a Yankee-36 trawl and a Western-IIA since.



von Bertalanffy parameters:

L_{inf}=60.7
K=0.119
t_o=-1.736

50% maturities:
TL50% male=49.8cm
TL50% female=47.2cm
Max. age observed 15yrs
Min. age of maturity observed 8 yrs
Fecundity <100 per year

Generation Time:
If assumed m of.2 and age at maturity of 8 then G.T.=13 years

Figure 78. Growth curve and biological parameters of *M. senta* on the Scotian Shelf: NAFO Division 4VWX.

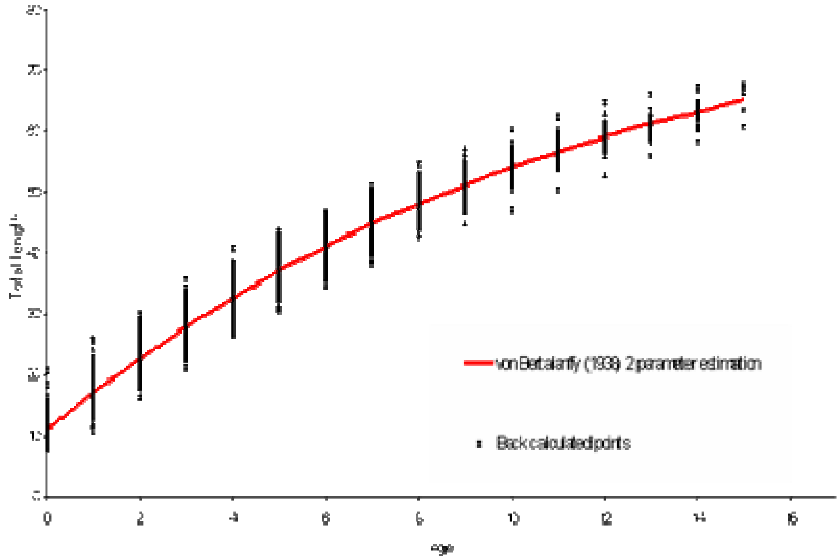


Figure 79a. Male growth curve and biological parameters of *M. senta* in the Gulf of Maine. Based on back calculated data. L_{inf}=75.4, K=0.12. t_o=11.

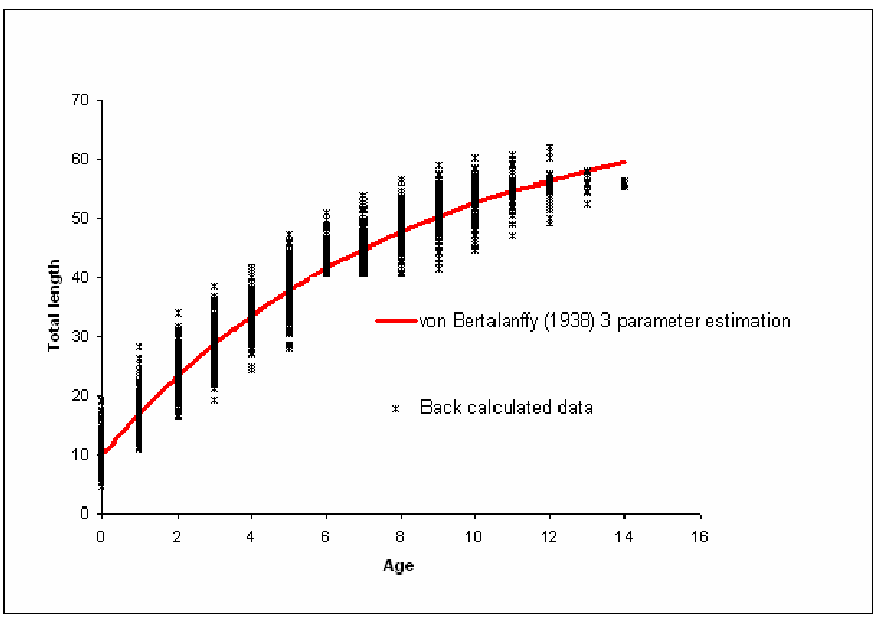


Figure 79b. Feale growth curve and biological parameters of *M. senta* in the Gulf of Maine. Based on back calculated data. L_{inf}=69.6, K=0.12. t_o=10.

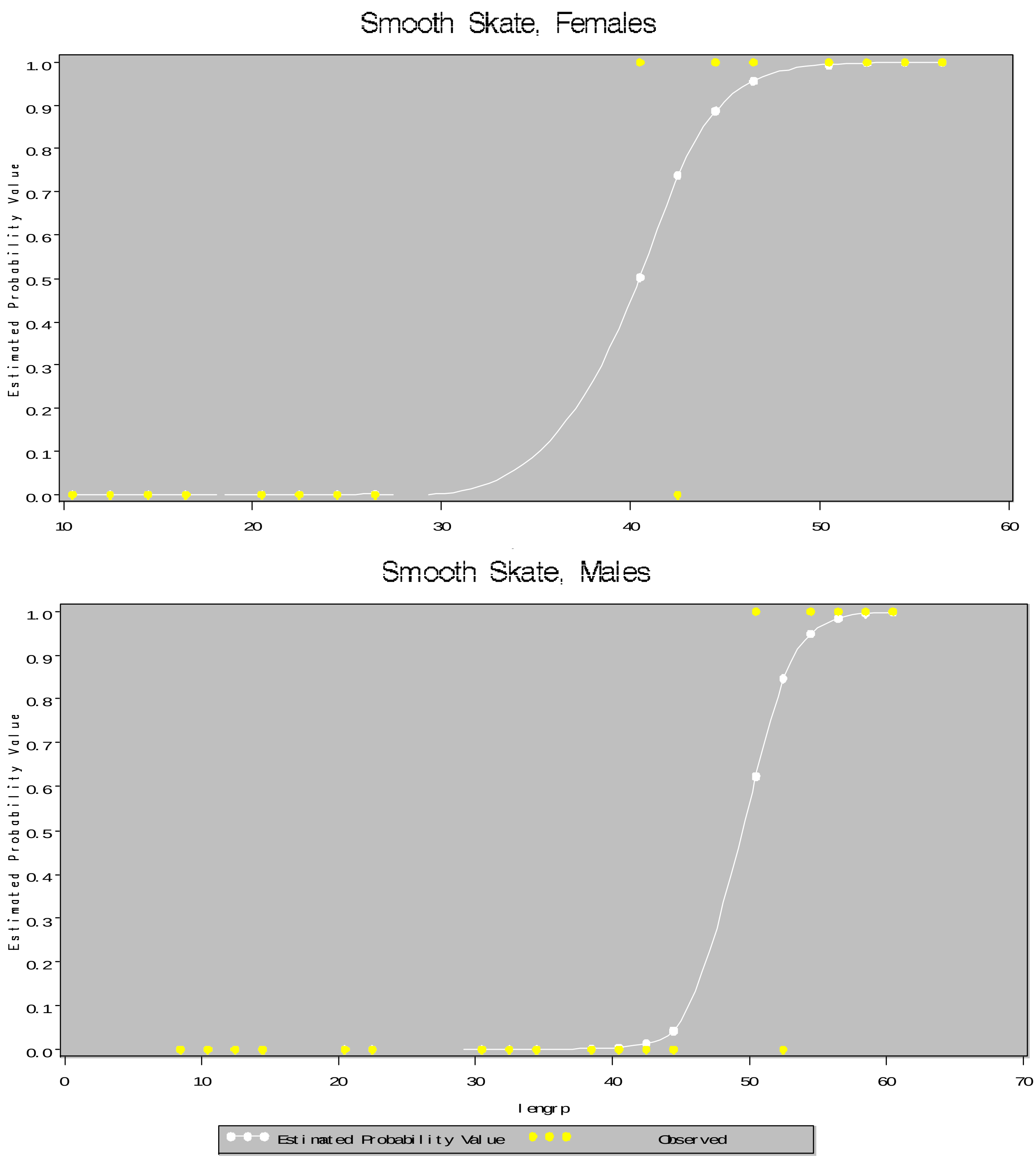
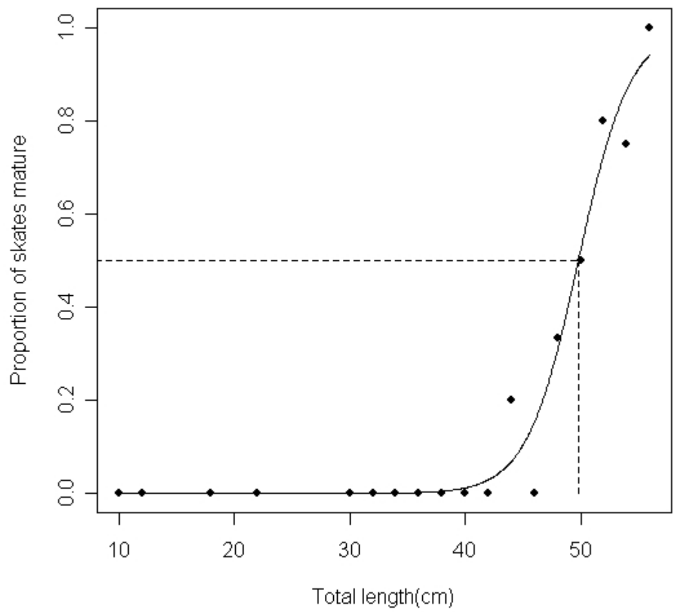
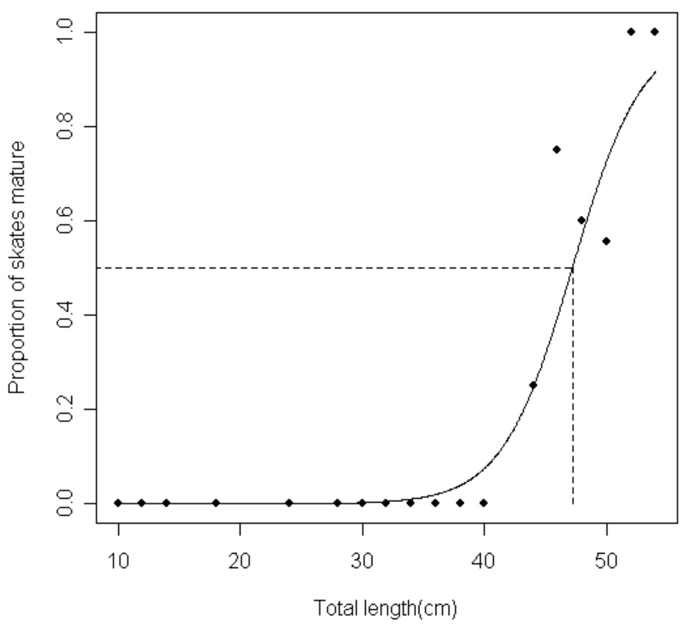


Figure 80. Maturity ogives for NL (Funk and Laurentian DU) *M. senta*. Length at 50% maturity for males was 49cm, and 40.5cm for females.





(B)

Figure 81. Maturity ogives for (A) male and (B) female smooth skate in 4VsW. Proportions within a size (total length (cm)) interval observed to be mature (based on a number of reproductive indices) are plotted along with fitted logistic curves and lengths-at-50% maturity (male: 49.81cm TL; female: 47.19cm TL). Size intervals are 2cm.

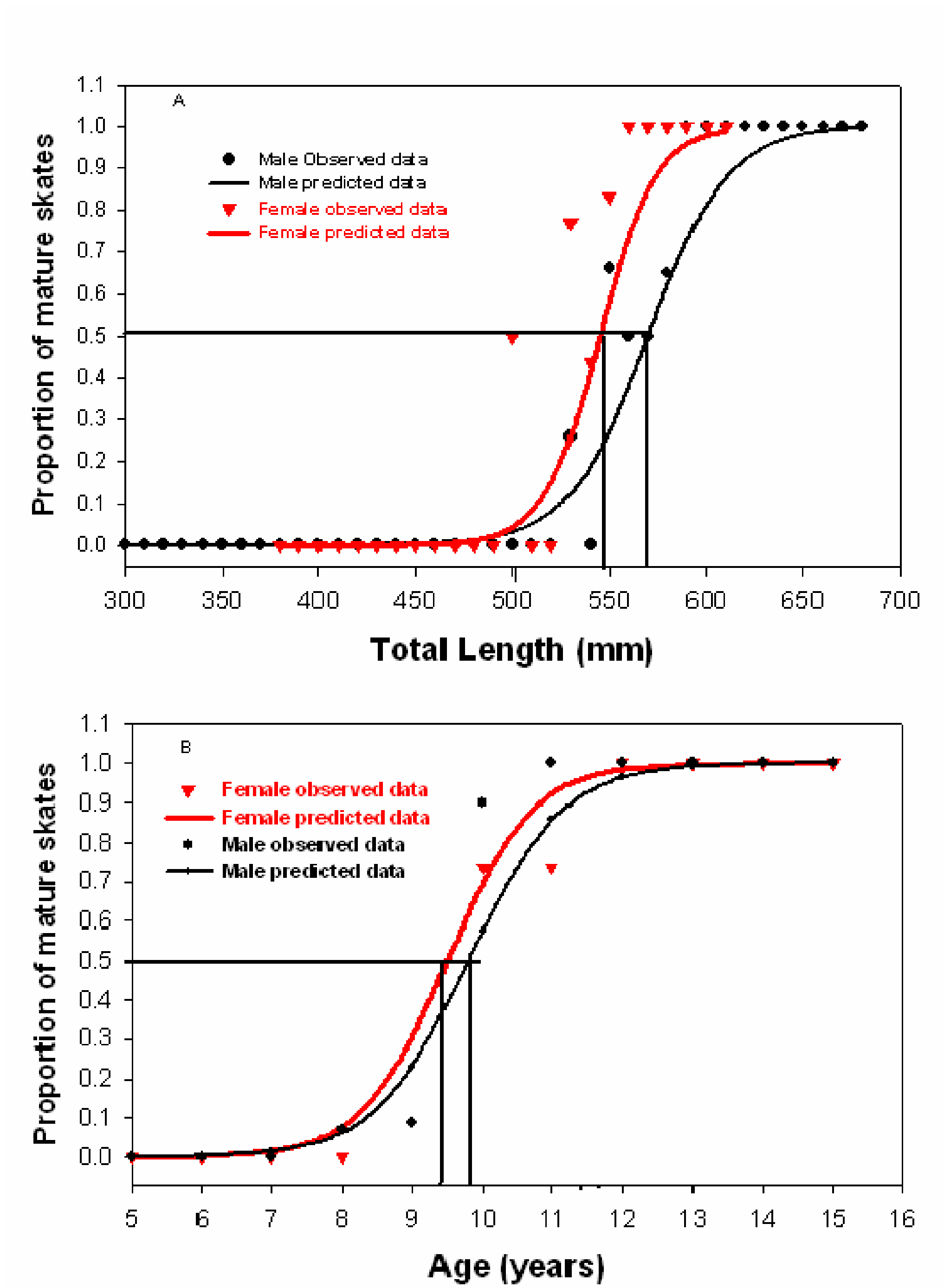


Figure 82. Maturity ogives based on morphological and histological analyses for male and female *M. senta* in the Gulf of Maine. (A) represents the total length of male and female *M. senta* given in 10 mm intervals, and (B) represents the age of male and female *M. senta* given in one year increments.

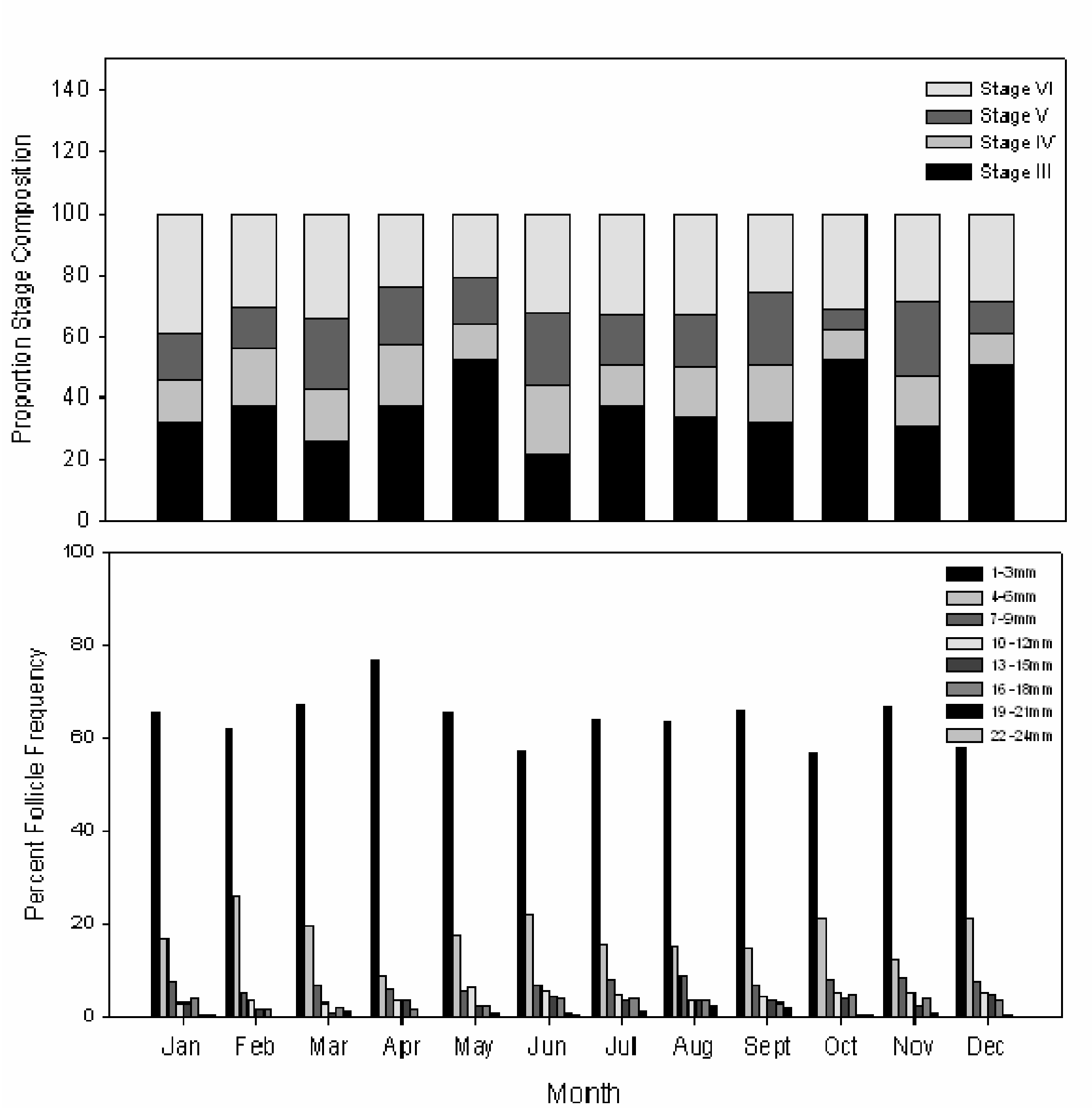


Figure 83. Comparisons between (A) the percentage of each stage of spermatogenesis (Stages III-VI) and (B) ovarian follicular dynamics, in *M. senta*s (*M. senta*) over the course of the sampling period. For (A), the values represent the mean percent of each stage of spermatogenesis (III-VI) occupied along a transect line across one representative full lobe cross section of testis. For (B), follicles were assigned to one of eight size classes and the number of follicles in each size class was expressed as the percent of the total number of follicles ≥ 1 mm in diameter (percent follicle frequency).

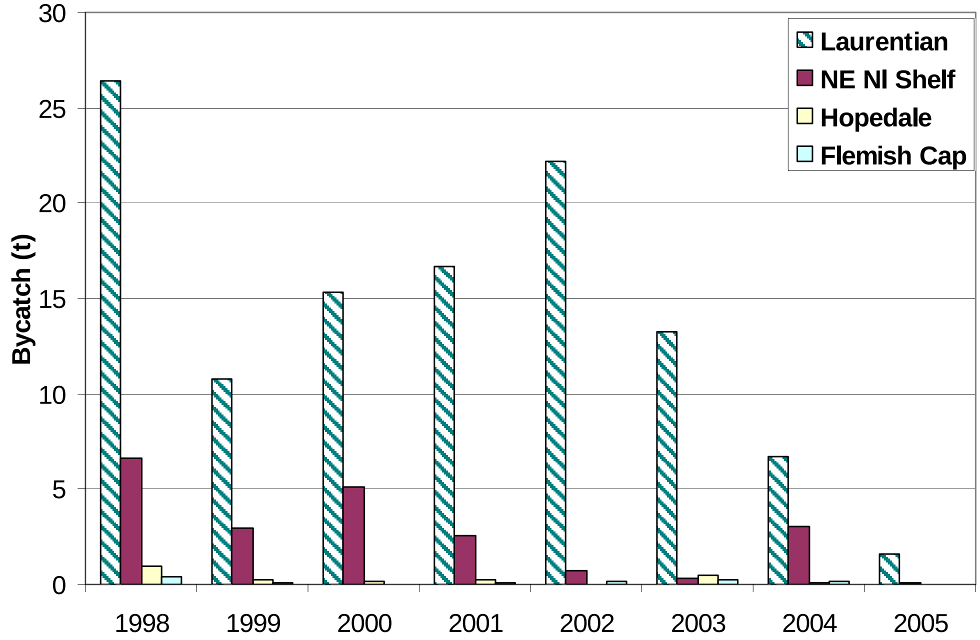


Figure 84a. Estimates of bycatch removals of *M. senta* in commercial fisheries that occur from the Grand Banks to the Labrador Shelf, calculated for each of the DU's that occur in the NL Region jurisdiction.

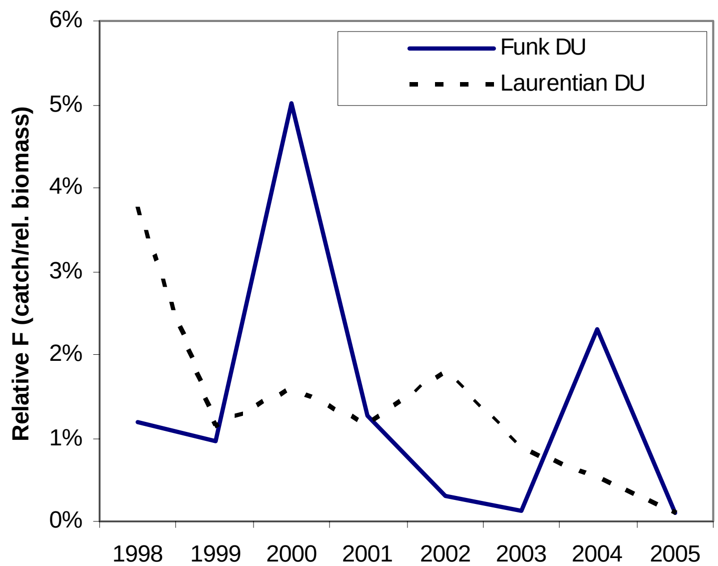


Figure 84b. Relative F (catch/ relative biomass) for all demersal gears from 1998-2005.

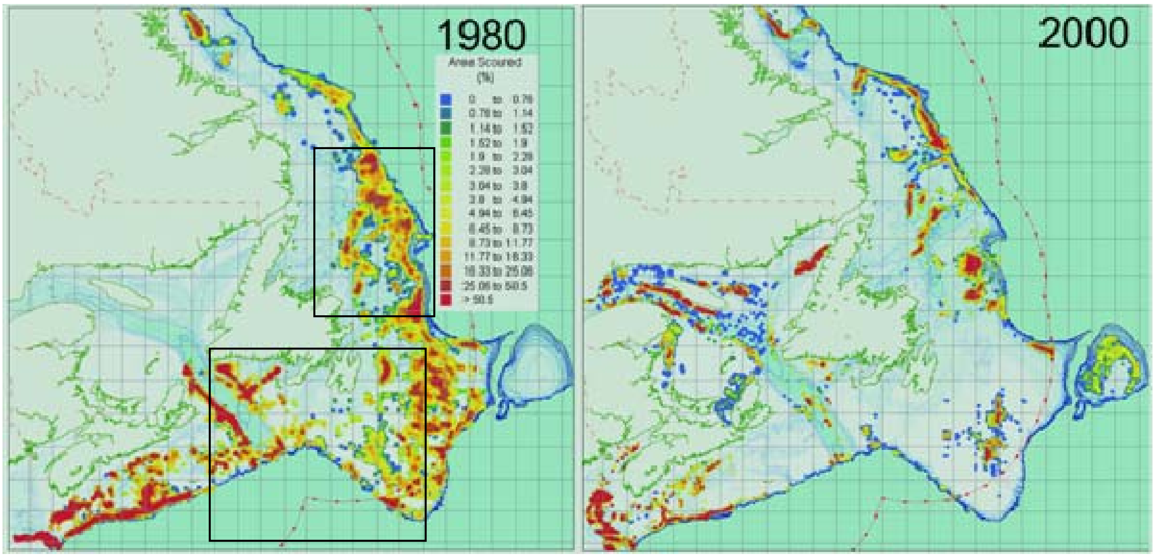


Figure 85. Distribution of trawl effort, 1980-2000. Note that the 1980 map does not include effort in the Gulf of St. Lawrence (after Kulka and Pitchers 2001). Boxes delineate DU regions.

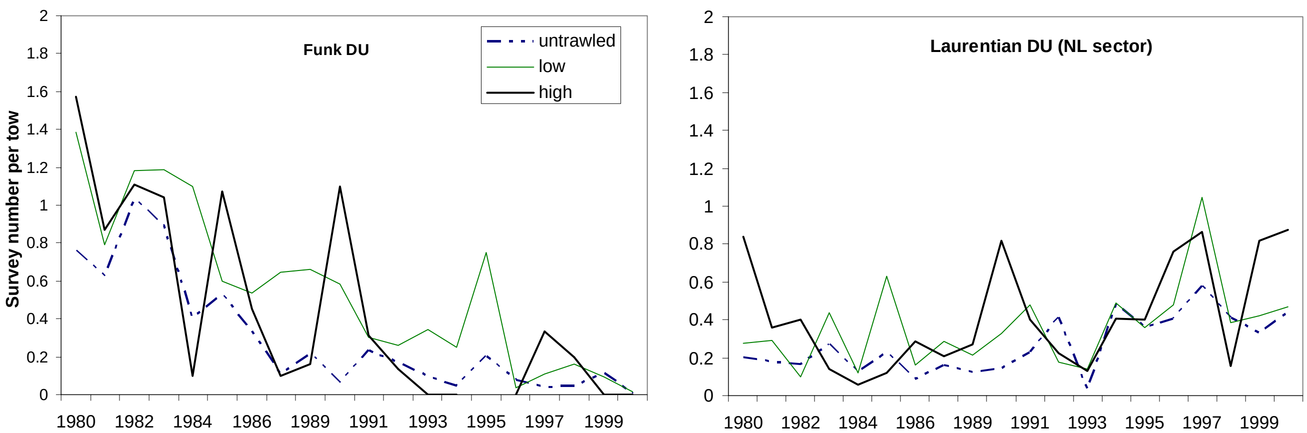


Figure 86. Change in abundance of *M. senta* in relations various levels of intensity of trawl effort In the Funk DU High refers to locations where >25% of the bottom was covered by trawling, low, where 0.01-25% was trawled and untrawled - where no trawl effort occurred in that year. (refer to Kulka and Pitchers 2001 for details).

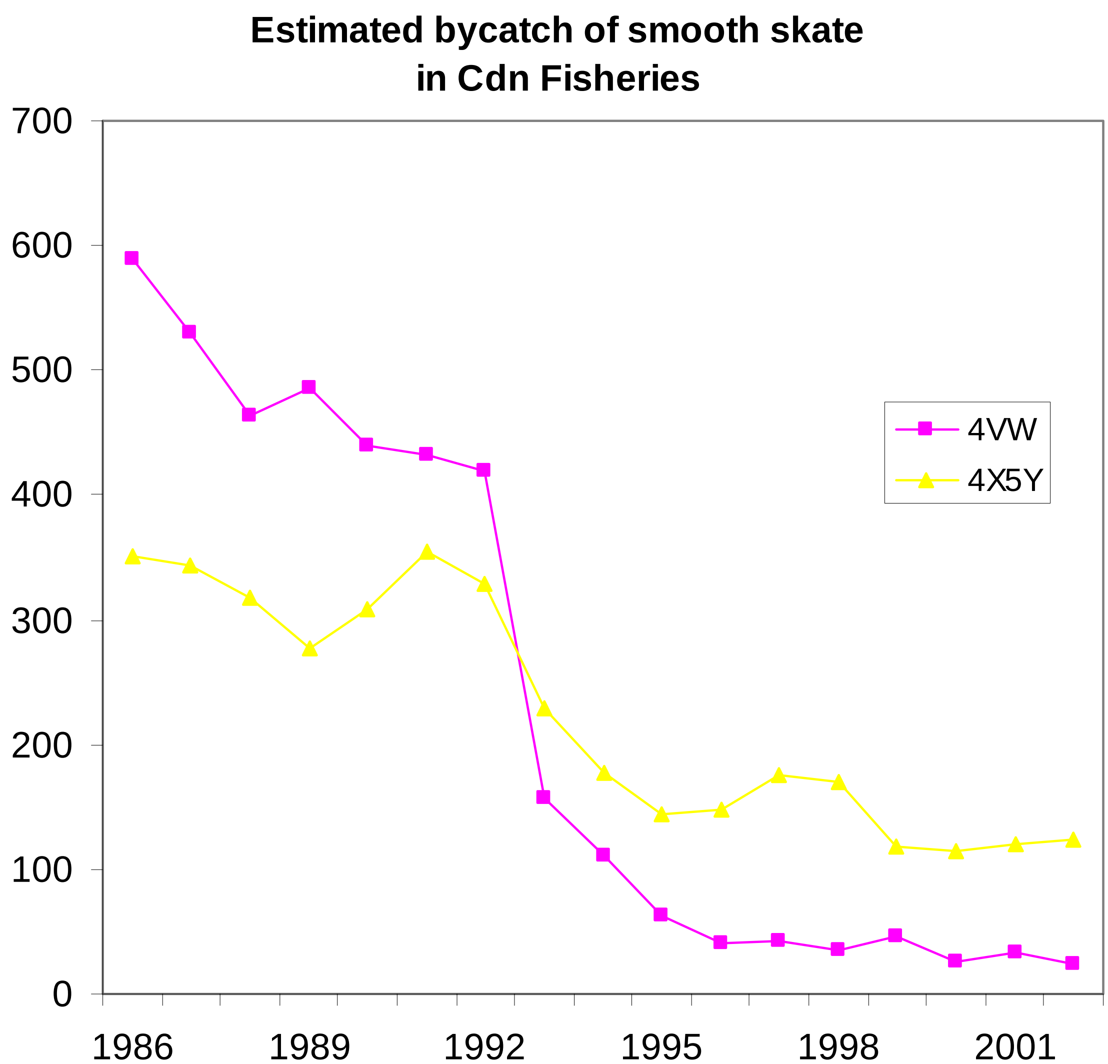


Figure 87. Estimated bycatch of *M. senta* from Canadian fisheries on the Scotian Shelf (Division 4X5Y and 4VW).