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 2011/116 / **Document de recherche 2011/116**

Newfoundland & Labrador Region / **Région de Terre-Neuve et Labrador**

Distribution, abundance, and life history of smooth skate (*Malacoraja senta* Garman 1885) in Northwest Atlantic waters

Répartition, abondance et cycle biologique de la raie à queue de velours (*Malacoraja senta* Garman 1885) dans les eaux du nord-ouest de l'Atlantique

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ISSN 1499-3848 (Printed / Imprimé)
ISSN 1919-5044 (Online / En ligne)

Correct citation for this publication:
La présente publication doit être citée comme suit :

Simpson, M.R., Mello, L.G.S., Miri, C.M., Treble, M., and Siferd, T. 2012. Distribution, abundance, and life history of smooth skate (*Malacoraja senta* Garman 1885) in Northwest Atlantic waters. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/116. iv + 40 p.

ABSTRACT

Decline in abundance and reduction in the extent of distribution have been observed in several Smooth Skate (*Malacoraja senta* Garman 1885) populations inhabiting Canadian waters, despite no directed commercial fisheries for this species. This paper presents the most recent information regarding the distribution and abundance of *M. senta* in Newfoundland and Labrador waters, and includes available data from adjacent and Arctic waters. The primary purpose of this paper is to provide this information to the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) for use in formulating and evaluating conservation and management strategies for this species in terms of risk of extinction.

Independent data series based on spring and fall bottom trawl survey catches and commercial fisheries statistics covering the distribution of *M. senta* in NAFO Div. 2HJ3KLMNOPs indicate that this species is comprised of several geographically distinct and persistent concentrations (each referred to here as a designatable unit or DU). These concentrations have experienced different trajectories in terms of abundance and distribution trends, but also have displayed common features such as thermal preferences and size-dependent distributions. The main concentration was centered in Div. 2J3K (Funk Island Deep DU) until the 1980s, but experienced substantial declines in abundance (juveniles and adults) and area of occupancy thereafter; although some population recovery has been detected since the mid-2000s. Two other smaller skate concentrations located in Div. 2H (Hopedale Channel DU) and Div. 3M (Flemish Cap DU) displayed spatio-temporal trends similar to those observed in the Funk Island Deep DU. In contrast, *M. senta* located in Div. 3OPs (Laurentian Channel DU) displayed relatively stable trends in abundance and distribution, and increasing trends have been detected during the last decade.

Several aspects of *M. senta* status in Newfoundland and Labrador waters remain uncertain; largely due to partial knowledge of population structure and biology, as well as the impacts of commercial fisheries and environmental variability.

RÉSUMÉ

L'abondance et l'étendue de la répartition de plusieurs populations de raie à queue de velours (*Malacoraja senta* Garman 1885) des eaux canadiennes ont diminué, bien que cette espèce ne soit pas menacée par la pêche commerciale. Ce document présente les dernières données sur la répartition et l'abondance de *M. senta* dans les eaux de Terre-Neuve et Labrador, ainsi que dans les eaux adjacentes et arctiques. Il a surtout pour but de communiquer cette information au Comité sur la situation des espèces en péril au Canada (COSEPAC), qui s'en servira pour définir et évaluer des stratégies de conservation et de gestion face au risque de disparition de cette espèce.

Des séries de données indépendantes sur les prises de relevé au chalut de fond au printemps et à l'automne et les statistiques de pêche commerciale, couvrant la répartition de *M. senta* dans les divisions 2HJ3KLMNOPs de l'OPANO, indiquent que cette espèce est répartie en plusieurs concentrations dans des lieux géographiques distincts et constants (chaque concentration portant ici le terme d'unité désignable). Ces concentrations ont présenté diverses tendances quant à l'abondance et à la répartition, mais aussi des caractéristiques semblables, telles que les préférences thermiques et la répartition par taille. La concentration principale se trouvait dans la division 2J3K (unité désignable de la fosse de l'île Funk) jusqu'aux années 1980, mais a ensuite grandement décliné quant aux facteurs d'abondance (tant pour les jeunes que pour les adultes) et d'aire d'occurrence; une légère augmentation de la population a cependant été décelée à partir du milieu des années 2000. Deux autres plus petites concentrations de raies situées dans les divisions 2H (unité désignable de Hopedale Channel) et 3M (unité désignable du Bonnet Flamand) ont montré des tendances spatio-temporelles semblables à celles signalées dans l'unité désignable de la fosse de l'île Funk. Par contre, les concentrations de *M. senta* situées dans les divisions 3OPs (unité désignable du chenal Laurentien) étaient relativement stables pour les facteurs d'abondance et de répartition, une augmentation progressive ayant été signalée au cours de la dernière décennie.

On ignore encore en grande partie le statut de *M. senta* dans les eaux de Terre-Neuve et Labrador, surtout à cause du manque de données sur la structure et la biologie de la population, ainsi que des répercussions de la pêche commerciale et des changements environnementaux.

INTRODUCTION

Declines in abundance and reduction in extent of distribution of smooth skate (*Malacoraja senta* Garman 1885, Family Rajidae) in the Northwest Atlantic Ocean have recently been reported in Canadian waters; including populations from the southern Gulf of St. Lawrence, Scotian Shelf, and in Newfoundland and Labrador waters (Simon and Comeau 1994; Kulka et al. 2006; Swain et al. 2006; McPhie and Campana 2009*a*). These declines have been observed despite no directed commercial fisheries for this species, and with removals limited to bycatch in fisheries targeting other species (Kulka 1986; Kulka et al. 2006; NOAA/NMFS 2000, 2009).

Vulnerability to exploitation, even when incidentally captured at low levels, has been documented for various elasmobranch species by Frisk et al. (2001); although not for *M. senta*. Notwithstanding, the International Union for the Conservation of Nature (IUCN) has listed *M. senta* as Endangered on their Redlist: a global assessment of risk of extinction (Sulikowski et al. 2004). Low reproductive potential resulting from slow growth, late sexual maturation, low fecundity, and long reproductive cycles is thought to lead to low resilience to fishing mortality (Hoenig and Gruber 1990; Smith et al. 1998; Musick et al. 2000; Musick 2004); probably rendering *M. senta* highly vulnerable to exploitation.

Recently, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) chose to evaluate the status of this species in terms of risk of extinction under Canada's *Species At Risk Act* (SARA). Accordingly, COSEWIC is responsible for assessing extinction risk of species that occur in Canada; including in surrounding oceans within jurisdictional limits. As part of this process for aquatic species, the Department of Fisheries and Oceans Canada examines data for which they are custodians.

This paper extends the review of *M. senta* by Kulka et al. (2006); providing updates on life history traits, trends in abundance and distribution, and other information for use in formulating appropriate conservation and management actions in terms of extinction risk. The primary purpose of this paper is to provide this information to COSEWIC for its evaluation of risk of extinction for this species; focussing on Canadian waters of the Northwest Atlantic Ocean.

LIFE HISTORY CHARACTERISTICS

With the exception of work by McPhie and Campana (2009*a*, 2009*b*) on the eastern Scotian Shelf, no additional research has been conducted in Canadian waters on the life history of *M. senta* since a review by Kulka et al. (2006). McPhie and Campana (2009*a*, 2009*b*) determined that length at 50% maturity for Smooth Skate was 47 cm and 50 cm for females and males, respectively. Age at 50% maturity for this species was found to be 10 years and 12 years for females and males, respectively.

In another study, Sulikowski et al. (2009) determined for *M. senta* in the Gulf of Maine that length at 50% maturity was 54-56 cm; with an age at 50% maturity of 9-10 years old.

MATERIALS AND METHODS

SURVEYS

NL Region

Bottom trawl surveys have been conducted throughout the continental shelves of Newfoundland and Labrador (NAFO Div. 2GHJ3KLMNOPs) in spring (1971-2010) and fall (1977-2010; Fig. 1). The surveys were originally designed to provide estimates of abundance for the major groundfish species such as Atlantic Cod (*Gadus morhua*) and Redfish (*Sebastes sp.*). However, *M. senta* distributes in similar depth and latitude ranges and thus, the survey footprint adequately covers the distribution range of this species in the NL Region.

Demersal trawl surveys in the NL Region employ a random stratified design, with fishing tow allocation based on depth intervals and location (latitude and longitude). A summary of the survey design employed in the NL Region since 1970 can be found in Doubleday (1981).

Fall surveys in NAFO Div. 2J3K were conducted by RV *Gadus Atlantica* until 1994. In 1995-2000 they were conducted mainly by RV *Teleost*; although RV *Wilfred Templeman* surveyed part of Div. 3K. NAFO Div. 3L surveys were conducted by RV *A.T. Cameron* (1971-82) and RV *Wilfred Templeman* or its sister ship RV *Alfred Needler* (1985-2000 in spring and 1983-2000 in fall). In recent years, RV *Teleost* surveyed a portion of Div. 3L. The fall survey was also extended into Div. 3NO in 1990, using the RV *Wilfred Templeman.* Several demersal fishing gears have also been deployed over the lifetime of the surveys (Table 1): Yankee 41.5 bottom trawl for spring surveys until 1982; Engel 145 Hi-lift for fall surveys in 1977-94 and spring surveys in 1983-95; and Campelen 1800 shrimp trawl for fall of 1995 and spring 1996 to present. 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 significant change in the surveys was the addition of shallower (<50 m) and deeper strata (>700 m) after 1993; although tows at depths <50 m were occasionally recorded in earlier years. It should be noted that no conversion factors exist between gears for *M. senta;* therefore, each time series should be considered independently.

Central and Arctic Region

Depth-stratified random surveys covering depths from 400 m to 1500 m were conducted by DFO with an Alfredo-III bottom trawl in NAFO Subarea 0A (1999, 2001, 2004, 2006, 2008), Subarea 0B (2000, 2001), Shrimp Fishing Area (SFA) 1 (2007, 2009), and SFA 2 and 3 (2005-09). The 2006 and 2008 surveys included tows in shallower strata (100 m-800 m) using a Cosmos shrimp trawl. These surveys were conducted by DFO in collaboration with Nunavut partners and the Greenland Institute of Natural Resources. Surveys were carried out on the Greenlandic RV *Paamiut*.

Other Surveys of Interest

Additional independent scientific surveys were conducted by other countries within or adjacent to the study area; often using the same stratification scheme as applied by Canada. Waters adjacent to the Canadian EEZ were surveyed by Spain (Instituto Español de Oceanografía, Far Fishery Program Communication), covering the “Nose” and “Tail” of the Grand Banks in Div. 3LNO (González-Troncoso et al. 2010; Roman et al. 2010), and the Flemish Cap in Div. 3M (Pérez-Rodriguez and Koen-Alonso 2010). Russia and France have also conducted surveys in the study area; thereby providing corroborative data on trends in Smooth Skate populations.

Spatial distribution and habitat associations

Geo-referenced catch and hydrographic data for the spring and fall bottom trawl surveys were used to assess the spatial distribution and habitat associations of *M. senta* throughout the study area. First, maps of the geographic distribution of catch rate (kg/tow) were plotted using data from all surveys. The plots were grouped by season and into two 5-year periods; except for the spring survey series during the 1990s, which were grouped for the periods 1990-95 and 1996-99. The periods were chosen to correspond to changes in fishing gear types; in particular from Engel to Campelen trawl in 1995-1996. The cumulative distribution of catch rate was also plotted for juveniles and adults (number of fish per tow). McPhie and Campana (2009*a*, 2009*b*) indicated that, for the Maritimes Region, *M. senta* <48 cm and ≥48 cm Total Length (TL) roughly corresponded to the juvenile and mature components of those populations, respectively.

The distribution of catch in relation to depth and temperature was also investigated. At each tow location, depth and bottom temperature were recorded using trawl-mounted sensors (SIMRAD depth sounder; Seabird 19 CTD). Plots of mean catch rate in relation to depth and temperature were produced for each NAFO Division, year, and season.

Area of occupancy

The area of occupancy (A_t) was calculated in each year t as follows:

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

where Y_{ijkl} is the number of fish in length interval l caught in tow i at site j in stratum k, a_k is the area of the stratum k (km^2), 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. A_t was calculated based on the *Index Strata* (i.e. those sampled throughout the time series), and sufficient data were available to conduct the analysis for three different regions: Div. 2J3K (fall), Div. 3LNO (spring and fall), and Div. 3Ps (spring).

Abundance indices and size composition

Abundance and biomass have been estimated by areal expansion of the stratified arithmetic mean catch per tow (Smith and Somerton 1981). Survey indices were expressed as the mean fish number and weight (kg) per standard tow and reported for spring (Div. 3LNOPs) and fall (Div. 2HJ3KLMNO); as well as for subsets of these areas referred to as Designatable Units or DUs (Kulka et al. 2006). Spring and fall survey footprints do not conform to *M. senta* DU boundaries. Thus, survey areas were segmented to conform to DU locations: Div. 2H for Hopedale DU, Div. 2J3K and a small portion of Div. 3L for Funk Island Deep DU, and all of Div. 3NOPs for the Laurentian DU. Total abundance at length was calculated as the sum of the strata estimates for each length group over the survey area. Estimation was also done separately for juveniles (<48 cm) and adults (≥48 cm), and indices were expressed as number per tow. To estimate abundance in number and biomass over a constant sampling area, only strata sampled throughout the time series were included. In addition, each stratum had to be sampled at least twice a year.

COMMERCIAL FISHERIES REMOVALS

Commercial fisheries data were obtained from three sources. The first source was the DFO Zonal Interchange Format (ZIF) database, which was created in 1985 to record data on Canadian landings (recorded in fishers' logbooks and on fish plants' purchase slips) in a standardized electronic format. The second source was the DFO Observer Program - Science database, which contains tow-by-tow information collected at sea in a standardized format by trained Canadian Fisheries Observers. This database was used here to investigate commercial discards of *M. senta* at sea during 1985-2010. The third source was the STATLANT-21A database maintained by the Northwest Atlantic Fisheries Organization. This database contains commercial catches from outside Canada's 200-mile limit, as reported by member countries. The latter was used here to estimate non-Canadian removals of *M. senta* in 1960-2009, and Canadian catches for 1960-84.

The Fisheries Observers database was used to generate maps of the geographic distribution of *M. senta* standardised catch rates [catch (kept+discard in kg) / tow duration in hours] for bottom trawl fisheries directing for skates, Atlantic Cod (*Gadus morhua*), Redfish (*Sebastes sp.*), American Plaice (*Hippoglossoides platessoides*), Witch Flounder (*Glyptocephalus cynoglossus*), and Yellowtail Flounder (*Limanda ferruginea*); using the same approach as for research survey data. Resultant distributions were then compared.

An index of exploitation or relative F was calculated using a ratio of reported commercial catch to the fall (for Funk Island Deep DU) and spring (for Laurentian DU - NL sector) research survey biomass index in 1998-2010. Commercial catch was estimated from Canadian Fisheries Observer data adjusted to total landings, and total lengths of *M. senta* in commercial catches from various gear types were measured only sporadically (2003-06).

RESULTS AND DISCUSSION

DISTRIBUTION AND HABITAT ASSOCIATIONS

Survey catch distribution

Distribution of catch from Canadian spring and fall surveys supported the view that several discrete concentrations of *M. senta* exist in the study area; as previously suggested by Kulka et al. (2006). Catch data from fall surveys indicated that the main concentration had its center of distribution located on the northeast Newfoundland Shelf (Div. 3K) during the mid-1970s and 1980s (Fig. 2). However, a substantial decline in skate density and extent of distribution occurred; starting in the mid to late 1980s. These changes were not related to a change in survey gear type in 1995 (Engel to Campelen), because observed catch and distribution patterns persisted over the duration of both time series. Similarly, two other concentrations with the center of distribution located in the Hopedale Channel (NAFO Div. 2H) and the Flemish Cap (Div. 3M) displayed spatio-temporal trends similar to those observed in Div. 3K. In contrast, *M. senta* in Div. 3OPs, with its center of distribution located on the southwest slope of the Grand Bank and along the Laurentian Channel (respectively), displayed relatively stable catch rates and extent of distribution (spring surveys), and increases in relative abundance were observed during the last decade. However, *M. senta* were not captured in research surveys in Subareas 0A and 0B.

Cumulative distributions of spring (1999-2010) and fall (1981-2010) bottom trawl survey catch rates for juvenile (<48 cm) and adult (≥48 cm) *M. senta* indicated that skates of all sizes overlapped in Newfoundland and Labrador waters (Fig. 3). However, size-dependent distributions were also found in some areas; notably a predominance of juveniles in Subdiv. 3Ps (spring) and Div. 2H (fall), and that of adults at the southern limit of the Laurentian Channel (spring) near the boundary between Div. 3O and Subdiv. 3Ps.

Distribution of spring and fall survey catch rates in relation to depth (Fig. 4) indicated that *M. senta* tended to be found in deeper and broader water layers (200-600 m) in the northern boundary of its distribution range (Div. 2HJ3K), and in shallower and broader layers (50-500 m) in the southern boundary (Div. 3NOPs); whereas in the intermediate regions (Div. 3LM), *M. senta* were caught in deeper but narrower depths (200-300 m). This species was infrequently recorded in tows below 800 m anywhere. These patterns varied in some areas over the years; along with changes in survey design, fishing gears, skate density, and distribution range. In other areas, few changes were detected.

Mean catch rates (fall survey) peaked at depths ranging between 400-600 m (0.3-0.7 kg/tow) in Div. 2H and varied little throughout the time series, and between 400-500 m in Div. 2J (0.1-0.2 kg/tow), Div. 3K (1-2.5 kg/tow), and Div. 3L (0.22-0.75 kg/tow) during a period when *M. senta* concentration in Div. 3K was abundant (1977-1989). Mean catch rates were subsequently found at depths > 600 m when catch rates in Div. 2J3KL declined to very low values (Fig. 5). However, the latter change can be partially explained by an inclusion of deeper survey strata after 1993. In Div. 3M, catch rates peaked in shallower depths (300 m) in 1980-1999 (0.2-0.4 kg/tow; except at 500 m in the late 1980s), and from 2000 onwards at depths > 900 m. In Div. 3N, catch rates were consistently low (<0.06 kg/tow), and no patterns were detected in relation to depth. In Div. 3O, catch rates were highest (0.4-0.6 kg/tow) at depths of 200-300 m, and remained consistent through time. In Div. 3LO, trends were largely similar between spring and fall time series; but in Div. 3N catch rates were higher in spring (up to 0.2 kg/tow), and peaked at 200-400 m (except at 600 m in 1990-1995). In Subdiv. 3Ps, catch rates varied little between the 1970s and 1990s (0.3-0.5 kg/tow); then increased consistently through the last decade to 1.8 kg/tow by 2010: the highest mean estimate for both spring and fall series. The depths of peak catch rates increased from 300 m in the 1970s to 400-500 m from 1980 onwards. Distribution by depth was different from that observed for this species in other areas to the south. For example, depth distribution described by Packer *et al*. (2003) in US waters (Georges Bank, Gulf of Maine) showed that *M. senta* inhabited considerably shallower depths (generally <400 m), and peaking at 200-300 m. This same depth range was also observed in the Gulf of St. Lawrence by Kulka *et al*. (2006).

Distribution of mean catch rate (kg/tow) in relation to mean temperature at tow depth indicated that *M. senta* were distributed in waters varying from 0.1 to 7.1^{o}C; but tended to be found in preferential temperature ranges that changed according to latitudinal and longitudinal clines (Fig. 6). In northern areas, fall survey catch rates tended to peak within a narrow temperature band: 3-4^{o}C in Div. 2H; 2.5-3.2^{o}C in Div. 3K; 2.3-3.5^{o}C in Div. 3L; 3-4^{o}C in Div. 3M; except in Div. 2J (1.3-3.5^{o}C). In more southern regions (spring and fall), catch rates peaked over a broader range of temperatures (0.8-6.5^{o}C / 1.1-3.7^{o}C in Div. 3N; 1.8-3.7^{o}C / 2-7.1^{o}C in Div. 3O; and 4.1-5.6^{o}C in Subdiv. 3Ps). These distribution patterns were consistent over the time series in Div. 2H3MNOPs (regardless of gear type employed, skate density levels, and extent of distribution), and in Div. 2J3KL when an *M. senta* concentration on the northeast Newfoundland Shelf was evident (pre-1990s).

Geographic variability of juvenile and adult *M. senta* was investigated by mapping mean size distribution of survey catch (i.e., catch weight/ catch number) on a tow-by-tow basis. Analysis of cumulative distribution (1971-2009; Fig. 7), as well as distribution by five year intervals (Fig. 8) indicated spatial variation in size of skate caught in all areas. In the Hopedale DU, the smallest skates (<0.5 kg) were concentrated along the periphery of this distribution.

There was also a degree of separation observed for the Funk DU, but a pattern was less clear because larger fish occured in several locations. In the Laurentian DU, a pattern of size separation was distinct: *M. senta* on average were larger on the southwest slope and shelf edge of the Grand Bank; while being smaller in the Laurentian Channel and along the south coast of Newfoundland.

Considering the surveyed area as a whole, these results indicated that several recognizable concentrations of *M. senta* exist in Newfoundland and Labrador waters. The main concentration is centered on the northeast Newfoundland Shelf (Div. 2J3K), and experienced a decline in its extent of distribution. Another main skate concentration is located on the southwestern Grand Bank and St. Pierre Bank in Div. 3OPs. Two additional smaller concentrations exist near Hopedale Channel (Div. 2H) and the Flemish Cap (Div. 3M); although those time series were more limited in scope. In addition, habitat associations for *M. senta* were apparently partially driven by (warmer) temperature preferences.

In summary, *M. senta* were found over a similar range of water temperatures throughout Newfoundland and Labrador waters and over the survey time series; but occupied a different range of depths that varied according to area and time period. *M. senta* appeared to be temperature seekers, and at its northern extent were constrained geographically by availability of suitable temperatures. In all areas, densest concentrations of *M. senta* occurred in troughs surrounding the banks where temperatures were warmer.

Area of occupancy

In Div. 2J3K in the fall, area of occupancy peaked in 1979-1980 when *M. senta* were found over 42% of the strata, but subsequently declined steadily to <2% by the year 2000; then increasing over the last decade to 8-10% (Fig. 9). In Div. 3LNO, area occupied by *M. senta* in spring varied without trend between 1-5% through the time series; despite changes in fishing gears. In Subdiv. 3Ps, area of occupancy peaked at 49% in 1974, then varied without trend between 3-36% during the 1980s until mid-1990s (Engel series), and expanded to 23-35% once spring surveys changed to Campelen gear in 1996.

ABUNDANCE INDICES AND SIZE COMPOSITION

Gear Catchability

Catchability of skate species (including *M. senta*) by research bottom trawls has been considered low; given the bottom-dwelling nature of this group. Skates of all sizes have been observed to flatten into the substrate when fishing gear approaches and escape under the trawl's footrope. Consequently, abundance estimates from bottom trawl surveys likely underestimated the presence of *M. senta* to a large extent. Moreover, changes in fishing gears have substantially impacted catchability for this species. A comparison of mean number at length caught by Engel and Campelen trawls in spring over three years prior to and immediately after the gear change in 1996 suggested that catchability was higher for all size classes with the Campelen trawl, and that the Engel trawl captured almost no skates <26 cm; while Campelen captures in the latter size range were frequent (Fig. 10). For mature *M. senta* (≥48 cm), 4.9 times more fish were captured by Campelen in 1996-1998, as compared to Engel captures in 1993-1995. However, catchability of small *M. senta* (<26 cm) cannot be compared with survey data. While size-based conversion factors were derived for major commercial groundfish species (e.g., Atlantic Cod; flatfish) from comparative trawling, this was not done for *M. senta*. Hence, estimates of biomass and abundance presented in this paper must be viewed as minimum values. In addition, estimates of survey catch rate and abundance for this species over the periods prior and post-gear change are on different scales.

Catch rates and abundance estimation by NAFO Division

Standardized catch rates from spring surveys indicated that highest densities of *M. senta* were consistently observed in Div. 3OPs (Fig. 11). Mean catch weight per tow and mean catch number per tow in both areas displayed mostly stable trends throughout the time series (0.1-0.3 kg/tow; 0.2-0.8 fish/tow); regardless of changes in fishing gear type (i.e., Yankee to Engel in 1983; Engel to Campelen in 1996) Increases in relative abundance were detected in both areas during the last two decades; especially in Subdiv. 3Ps (Campelen time series). Catch rates in Div. 3LN were much lower and irregular (<0.07 kg/tow; <0.03 fish/tow); except in 1978 when catch rates reached 0.6 kg/tow and 0.25 fish/tow (respectively), although in most years *M. senta* was not caught in both areas.

Mean catch rates from fall surveys indicated that highest densities of *M. senta* were found in Div. 3K during the mid-1970s and 1980s (Fig. 12). However, a sharp decline in catch rates was observed during the mid to late 1980s. Mean catch per tow declined by up to two orders of magnitude between 1979 and 1995 (2.0-0.05 kg/tow; 3.0-0.2 fish/tow); remaining unchanged until the most recent assessment. Temporal trends in catch rate were similar in Div. 2J and Div. 3L, where catch rates started declining in early to mid-1980s to minimum values by 1993-1994 (0.15-0.3 to 0.01 kg/tow; 0.2-0.5 to 0.01 fish/tow). Since changing to Campelen gear, *M. senta* catch rates increased in Div. 2J until 2009; especially for number of fish per tow (0.2 fish/tow). In Div. 3L, no Smooth Skates have been caught since 1993; except in 2009 (<0.02 kg/tow; <0.02 fish/tow). Trends in Div. 3N were similar to those observed in Div. 3L, displaying very low and irregular catch rates (<0.03 kg/tow, <0.03 fish/tow). In Div. 3O, catch rates for the Campelen series exhibited low variability like those observed during spring surveys (0.2-0.3 kg/tow; 0.2-0.8 fish/tow). In Div. 2H, mean catch weight per tow was consistently low (<0.2 kg/tow); although mean numbers per tow were among the highest (up to 2.3 fish/tow) since the Campelen trawl was introduced; indicating that *M. senta* in this area were mostly small/ young fish.

Spring survey biomass estimates fluctuated without trend until 1995, ranging between 39-500 t (0.13-1 million fish); except in 1978 when biomass peaked at 900 t. From 1996 onwards, biomass estimates were between 200-1,000 t (0.3-2.7 million fish); with an increasing trend in abundance observed in Subdiv. 3Ps during the late 2000s (Fig. 13). *M. senta* in Subdiv. 3Ps (primarily) and Div. 3O comprised > 90% of estimates (biomass and abundance) in all years. Furthermore, <10% of survey estimates was from Div. 3L and Div. 3N; except in 1977 and 1978, when 30% and 70% of the biomass were from these areas, respectively.

Fall survey abundance trends declined in both biomass and number of *M. senta* in Div. 2J, Div. 3K, and Div. 3L during the period when an Engel trawl was used (1977-1994). Survey estimates fluctuated without trend during most of the Campelen surveys until the mid-2000s, and an increasing trend was observed since then (Fig. 14). *M. senta* biomass estimates peaked at 3,700 t (5.5 million fish) in 1979; of which > 95% was from Div. 3K and the remainder were from Div. 2HJ and Div. 3L; then declined to a minimum of 110 t (249,000 fish) by 1994. Biomass estimates ranged between 500-1,600 t (0.9-3.4 million fish) in 1995-2002, then increased through the mid to late 2000s, and peaked at 1,300 t by 2009 (5.7 million fish in 2008). In this case, most *M. senta* biomass (51-94%) were in Div. 3O, with the remainder in Div. 2HJ and Div. 3KLN. However, the observed pattern reflects additional sampling strata in the fall survey of Div. 3O starting in 1990; rather than an actual increase in abundance. However, the pattern observed in the late 2000s may reflect a real increase in abundance estimates. No *M. senta* were caught in Div. 2G over all the survey years; whereas Div. 2H was surveyed at irregular intervals, but the extent of *M. senta* distribution there is minimal. Kulka et al. (2006) reported that abundance estimation in this area is confounded by a lack of annual sampling, and a change in survey gear in 1995 that resulted in different catchability of this species. Similarly, Div. 3M (outside of Canada's 200-mile limit) has not been surveyed since 2003, and only irregularly in earlier years. Abundance estimates for Div. 3M were also presented by Kulka et al. (2006) for survey years, and averaged 3.6 million fish. Juveniles and adults were observed to be in similar proportions, and survey indices were lower in the late 1990s and early 2000s relative to the 1980s.

Catch rates and abundance estimation by DU

In the Laurentian Channel DU (spring) and Funk Island Deep DU (fall), Yankee and Engel catch rates displayed similar temporal patterns for juvenile and adult *M. senta*, as well as relative abundance, but Campelen catch rates were higher for juvenile skates (Figs. 15-16). Mean catch rates in the Laurentian DU fluctuated without trend, ranging mostly between 0.07-0.2 fish/tow until 1995 (Yankee and Engel surveys); then 0.1-0.3 fish/tow from 1996 onward (Campelen surveys). During the latter, both juvenile and adult catch rates increased until 2005, then declined in subsequent years. Mean catch rates in the Funk DU (Engel surveys) peaked in 1978 for juveniles (0.8 fish/tow) and in 1979 for adults (0.7 fish/tow); then declined in both cases to relatively low values until 1994 (<0.03 fish/tow). Catch rates remained at similar levels through the Campelen surveys (1995 onwards), but increased since 2005; particularly for juvenile *M. senta*. When compared to catch rates by NAFO Division, it appears that *M. senta* in Subdiv. 3Ps and Div. 3K were primary drivers of trends in relative abundance for the Laurentian and Funk DUs, respectively.

Abundance estimates of juvenile and adult *M. senta* for the Newfoundland and Labrador portion of the Laurentian Channel DU fluctuated in a similar way from the early 1970s until 2005; except in 2007-2010 when juvenile abundance declined, and the opposite was observed for adult fish (Fig. 15). Juvenile and adult abundance ranged between 0.1-0.6 million fish during Yankee and Engel surveys; declining to minimum values (<0.1 million fish) in 1993. Abundance estimates increased substantially for both groups during Campelen surveys; peaking at 2.6 million juveniles in 2002, and at 1.8 million adults in 2003, before declining in recent years to levels similar to those observed prior to 1996 (<0.8 million fish). Rates of decline in *M. senta* abundance since 1996 were 44% for juveniles and 9.5% for adults; according to a log model of catch rates (Fig. 17), although model fit was poor. Without knowledge of whether gear changes affected catchability of this particular species (especially at younger life stages/ smaller sizes), past and present abundance estimates are not directly comparable. In addition, these survey indices included a small area outside Canada's 200-mile limit (on the tail of the Grand Bank) that contained approximately 0.2% of total abundance in the southwestern Grand Bank component of this DU (i.e., Div. 3N in total contains only 3% of *M. senta* abundance).

Contrasting with patterns observed in the Laurentian Channel DU, abundance estimates of juvenile and adult *M. senta* in the Funk Island Deep DU declined through the 1980s and early 1990s (Engel surveys), remained relatively low and stable since the mid 1990s to early 2000s (Campelen surveys), and then the abundance of juvenile *M. senta* began to increase in recent surveys. Abundance peaked at approximately 3.5 million juveniles (1978) and 2.9 million adults (1979), declining to 0.14 million juveniles and 0.04 million adults (1994) just prior to the gear change (Fig. 16). Estimated rate of decline for both juvenile and adult abundance in 1978-1994 was 70%; whereas in 1995-2009, rates of increase for juvenile and adult *M. senta* were 11% and 27%, respectively (Fig. 18). In this case, model fit improved during the Engel time series ($0.51 < R^2 < 0.88$); but for the Campelen time series, model fit remained poor ($R^2 < 0.25$). This decline corresponds to the coldest water temperatures in that area (see Figs. 16-17 in Kulka *et al*. 2006).

Surveys of the Hopedale DU (Div. 2H) are conducted in the fall, but this time series is incomplete (Table 1). No *M. senta* were caught in some years, and in other years, the number of juvenile skates was lower prior to a change from Engel to Campelen gear; although abundance was higher thereafter (see Fig. 49 in Kulka et al. 2006). However, most of this difference can be attributed to the gear, due to a higher efficiency of the Campelen trawl in capturing smaller fish. The largest *M. senta* captured in the Hopedale DU was 52 cm and, unlike other areas, fish >30 cm are uncommon. Abundance estimates for juvenile *M. senta* reached 1.3 million fish after 1995 (10-fold increase since the late 1980s and early 1990s); whereas adult abundance approximated 0.03 million fish during both periods (Kulka et al. 2006). However, size-dependent differences in gear catchability and irregular sampling during different periods prevent long term comparison of survey catch rates. Therefore, trends in *M. senta* abundance for the Hopedale DU cannot be determined.

The Flemish Cap DU lies almost completely outside of Canada's 200-mile limit, but occasional small catches in Div. 3L occurred until the early 2000s; although survey sampling in that area was inconsistent. Survey indices were higher in the early 1980s (0.05-0.10 fish/tow) as compared to the late 1990s (<0.06 fish/tow; see Fig. 49 in Kulka et al. 2006). This indicated that abundance was lower in the latter period, but the degree of decrease is unknown; given a change in survey gear. Research surveys conducted by EU-Spain would document changes in *M. senta* abundance and distribution in this particular DU with greater coverage than Canadian surveys.

In NAFO Subarea 0 and Hudson Strait/ Ungava Bay, no *M. senta* have been identified in any Canadian research surveys. EU-Spain, Russia, and France have also conducted research surveys in these areas, but their results are not presented in this paper.

Size Distribution

Length frequency distributions (TL) for *M. senta* caught during Canadian spring surveys in Div. 3LNOPs (1999-2010) ranged from 5 cm to 82 cm (Fig. 19). In fall surveys, *M. senta* total lengths were 5 cm-70 cm in Div. 2J3K (1978-2009), and 9 cm-76 cm in Div. 3LNO (1981-2009); although primarily 10-60 cm for all areas (Figs. 20-21). Mean length varied between 27-42 cm in Div. 3LNOPs, 15-56 cm in Div. 2J3K, and 34-56 cm in Div. 3LNO (Table 2). In addition, length frequencies from spring surveys in Div. 3LNOPs (Campelen series) were typically bi-modal, with modal lengths representing juveniles (11-18 cm) and adults (48-57 cm); but also reflecting a higher efficiency of the Campelen trawl in capturing smaller fish (<25 cm; in spring and fall surveys).

In fall surveys, length frequency distributions in Div. 2J3K were bi-modal when a Yankee trawl was used (i.e., prior to 1983), with modal lengths ranging between 39-55 cm; indicating that catches contained mostly immature (40-47 cm) and adult sizes (≥48 cm). Length frequency distributions were mostly uni-modal while the Engel trawl (1983-1994) and Campelen trawl (1995 onwards) were employed. Modal lengths for Engel surveys were 19-56 cm, and 11-46 cm for Campelen surveys. In Div. 3LNO, length frequency distributions were predominantly uni-modal; ranging between 47-62 cm for Engel surveys, and 10-56 cm for Campelen surveys. Overall, most adult *M. senta* were found in Div. 2J3K (Funk Island Deep DU) prior to an abundance decline in that area during the mid 1980s. However, since Campelen surveys began, most juveniles and adults were consistently found in Div. 3NOPs (i.e., Laurentian Channel DU).

COMMERCIAL FISHERIES REMOVALS

NL Region

No directed fishery for *M. senta* has occurred in Newfoundland and Labrador waters to date. However, data on this species as bycatch in other fisheries are available as Canadian Fisheries Observers' at-sea skates speciated catches prorated to total reported groundfish landings (ZIF) from Div. 3KLNOP inside Canada's 200-mile limit (1985-2009). Estimated Canadian annual catches of *M. senta* averaged 54 t in 1993-2000; with a peak of 146 t in 2000 (Fig. 22). Subsequently, average catch estimates declined to 9 t in 2001-03; becoming negligible in all Divisions after 2003. Catch estimates were also insignificant in Subarea 2 and Div. 3KL in Canada's EEZ in 1985-2009. In Div. 3N, a 17-ton average was estimated for 1992-2001; with a 129 t peak in 2000. In Div. 3O, a 17-ton average was estimated for 1993-1998 (peak of 65 t in 1993), and a 3-t average for 1999-2003. In Div. 3P, a 16-ton average was estimated for 1990-99 (peak of 88-t in 1998), and a 1-t average in 2001-06.

With respect to fishing gear used by Canadian fishers in Canada's EEZ, Fisheries Observers' data indicated that longline in a Thorny Skate-directed (*A. radiata*) fishery in Div. 3O caught *M. senta* ranging between 49-91 cm (TL), with the highest numbers observed between 76-84 cm (Fig. 23). Gillnets with a 305 mm mesh in the Div. 3O Monkfish (*Lophius americanus*) fishery were observed to catch *M. senta* ranging between 54-89 cm, with the highest numbers observed between 80-82 cm. Bottom trawls with 100 mm codend mesh directing for Redfish (*Sebastes* sp.) in Div. 3O caught *M. senta* between 43-57 cm, but mostly between 46-54 cm, and between 20-61 cm in Div. 3Ps, with a 15% peak in numbers observed at 51 cm.

Fisheries Observers' data from bottom trawl fisheries directing for unspeciated skates and other demersal fishes (e.g., Atlantic Cod, Redfish, American Plaice, Witch Flounder, Yellowtail Flounder) indicated that *M. senta* catch rates were highest in the Funk Island Deep DU (Div. 3K) during the late 1970s; while low catch rates were observed elsewhere (Fig. 24). In the 1980s, low catch rates were found throughout Newfoundland and Labrador waters (Div. 2J3KLNOPs); notably along the shelf edge. In the 1990s, most *M. senta* were caught in the Laurentian Channel DU along the shelf edge (Div. 3OPs), as well as in shallower waters over the Grand Bank (Div. 3NO). In the last decade, highest catch rates were again found in the Laurentian DU, but mostly in shallow waters of the Grand Bank (Div. 3NO); while low values were observed along the shelf edge (Div. 3OPs).

Relative fishing mortality (F = commercial catch weight for all fishing gears combined / research survey biomass index) was available for 1998-2005, and averaged 1.4% for both the Funk and Laurentian DUs (Fig. 25). However, F ranged from 0.12% to 2.3% for the Funk DU (except at 5% in 2000), and from 0.1% to 1.6% for the Laurentian DU (except at 3.8% in 1998).

Central and Arctic Region

M. senta have been reported as bycatch in fisheries targeting Greenland Halibut (*Reinhardtius hippoglossoides*) and Northern Shrimp (*Pandalus borealis*). Fisheries have variable coverage levels by Canadian Fisheries Observers: 100% for the Greenland Halibut fishery (Subarea 0A) and shrimp fisheries (SFA 2 and 3), and 0-20% for fixed gear fisheries. In SA 0, *M. senta* have been caught close to the boundary with SFA 1 (i.e., Greenland waters) and Div. 2G (i.e., Newfoundland waters); possibly representing an extension of stocks from one or both of these areas. However, no *M. senta* have been identified during Canadian research surveys; suggesting that northern specimens identified by Fisheries Observers may have been misidentified.

CONCLUSION

The present study extends the work of Kulka *et al*. (2006), with the aim of determining the current status of *M. senta* in Newfoundland and Labrador waters. This species, although extensively distributed in Canadian and northern US waters, forms several distinct and persistent concentrations that are separated by widespread disjunctions (i.e., where *M. senta* was rarely recorded).

Trends in *M. senta* abundance and distribution varied between areas delimited as DUs. Extensive declines in abundance and area of occupancy were observed for both juveniles and adults in the Funk Island Deep DU during the 1980s and 1990s; whereas in the Laurentian Channel DU (Grand Bank-Laurentian Channel portion), *M. senta* experienced few changes in abundance and distribution during that period. However, both areas have shown population increases since the mid-2000s; recently reaching high levels over a very short time in the Laurentian DU. In the Hopedale Channel and Flemish Cap DUs, no adequate data time series exists to quantify changes in abundance and distribution. Similarly, recent assessments in the Gulf of Maine indicated that biomass of *M. senta* increased above threshold levels mandated by the Sustainable Fisheries Act; therefore, this species is no longer considered to be overfished (NOAA/ NMFS 2009).

The period of decline in the Funk DU corresponds to the coldest water temperatures in this area (Colbourne et al. 2006). In addition, a comparison of rates of decline in areas of intense commercial trawling with those in areas of no trawling indicated no difference in decline rates of relative abundance of *M. senta* (Kulka et al. 2006). Although commercial fishing removals contributed to population decline for this species, the lack of recovery during the 1990s following a warming period, plus apparently low fishing pressures observed since the late 1990s, suggests that factors other than fishing and environmental conditions are driving the dynamics of *M. senta* populations in Newfoundland and Labrador waters.

SOURCES OF UNCERTAINTY

Several aspects of the current assessment of *M. senta* in Newfoundland and Labrador waters remain uncertain; largely due to partial knowledge about population structure, dynamics, and biology. Hence, caution should be invoked when interpreting results in this paper. Partitioning of *M. senta* populations into five distinct groups was based solely on geographic distribution. Further analyses based on genetic, morphometric and meristic characteristics, and mark and recapture experiments are necessary in order to clearly delineate reproductive or population units. Inclusion of new sampling strata and changes in gear type (and selectivity by fish size) in different survey periods make it difficult to assess spatial and temporal trends in abundance and distribution, the relationship between spawning population and recruits, and changes in survival, growth rate, and age structure over more than a few generations.

In addition, information on threats related to commercial fisheries was limited to recent years, and only available for a few areas; making it difficult to estimate the impact of bycatch mortality on abundance trends and population structure. Furthermore, it remains unclear how *M. senta* in the Laurentian Channel DU (i.e., where most of the biomass in NL waters was found), relates to other recognized populations (e.g., Gulf of St. Lawrence; Scotian Shelf; Gulf of Maine). In all cases, stock discrimination techniques, such as those mentioned above, should provide data necessary for delineating population structure and reducing other sources of uncertainties.

ACKNOWLEDGEMENTS

We thank Fisheries and Oceans staff who participated in Canadian research surveys, and Canadian Fisheries Observers who collected data and specimens aboard commercial vessels over many years; thereby allowing us to estimate trends and examine various biological aspects of *M. senta*.

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Table 1. List of bottom trawl research surveys conducted in the Newfoundland and Labrador Region (NAFO Division 2HJ3KLMNOPs) during the period 1971-2010. Various vessels and fishing gears were used over the years. Vessels: A.T. Cameron, Gadus Atlantica, Wilfred Templeman, Alfred Needler, Teleost. Gears: Yankee-41.5 otter trawl (brown), Engel-145 otter trawl (blue) and Campelen-1800 shrimp trawl (yellow). White cell: no survey was conducted in the area/season/year. Winter/fall surveys (*).

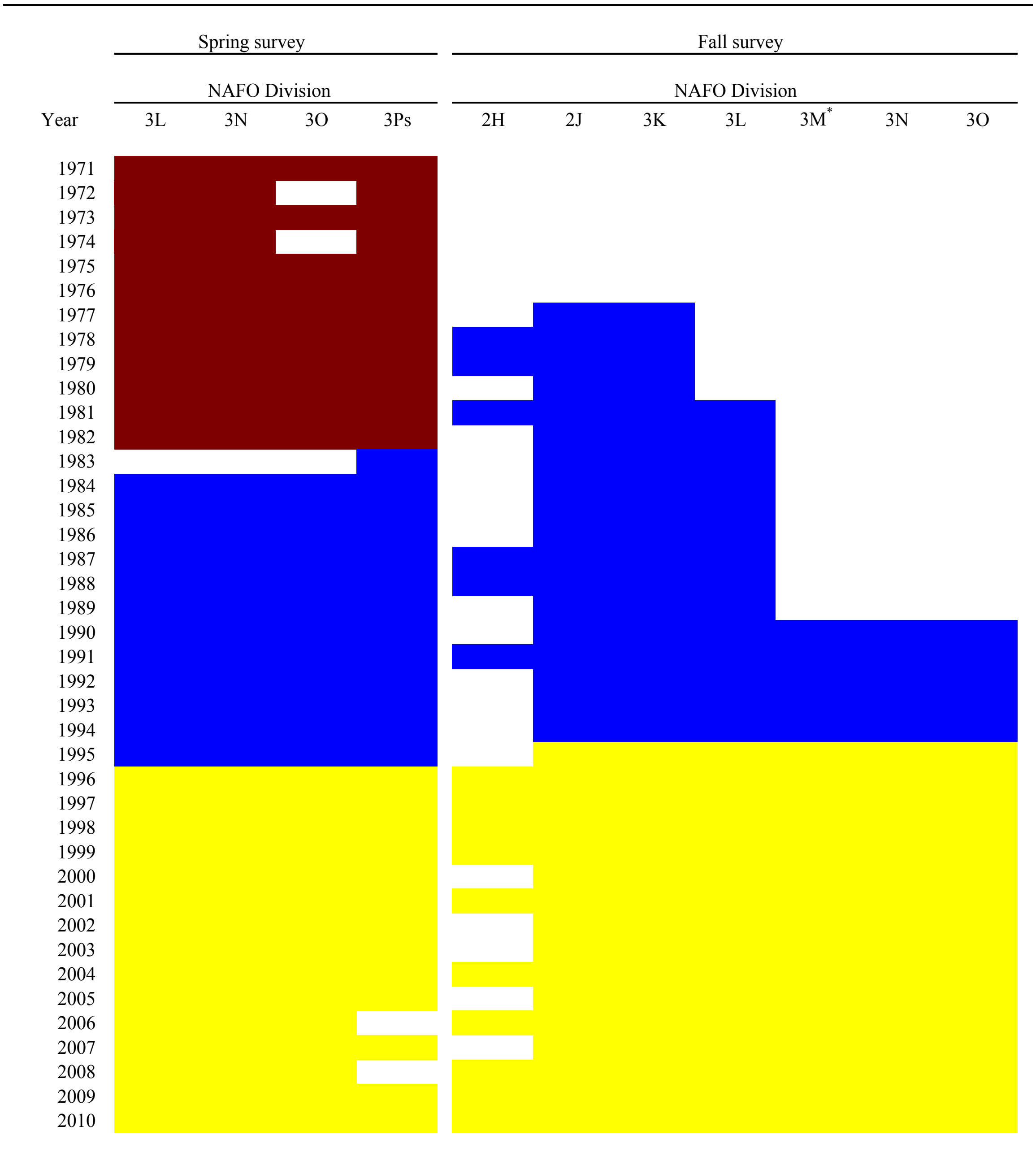

Table 2. Mean and mode estimation from available length frequency distributions (TL) for M. senta caught during the spring (1999-2010) and fall (1978-2009) bottom trawl surveys in NAFO Division 2J3KLNOPs.

	Spring Survey			Fall Survey					
	Div 3LNOPs (cm)			Div. 2J3K (cm)			Div 3LNO (cm)		
Year	Mean	Mode 1	Mode 2	Mean	Mode 1	Mode 2	Mean	Mode 1	Mode 2
1978				42	41	55			
1979				45	55	39			
1980				47	53	46			
1981				47	54	43	50	55	
1982							49	62	
1983				48	51	41	51	53	
1984				48	49		51	56	
1985				48	56		44	57	
1986				48	56	42	56	55	
1987				46	49	25	56	52	
1988				49	49		55	60	
1989				43	55		54	58	
1990				44	51	38	50	53	40
1991				38	19		53	56	
1992				29	30		53	47	
1993				39	29		50	55	
1994				34	30		48	53	
1995				31	20		48	52	
1996				29	16		50	52	
1997				31	36		42	55	
1998				35	46		53	54	
1999	41	48	18	36	46		34	10	57
2000	36	57	15	47			45	58	34
2001	42	53		48			52	53	
2002	36	52	14	15			50	50	
2003	40	51	15	43			50	56	
2004	34	52	16	31			38	41	27
2005	38	54	17	23	11		46	52	
2006	27	11	55	32	13		47	50	
2007	36	52	11	27	11		45		
2008	33	10	51	30	30		49		
2009	36	56	11	56			52		
2010	33	14	55						

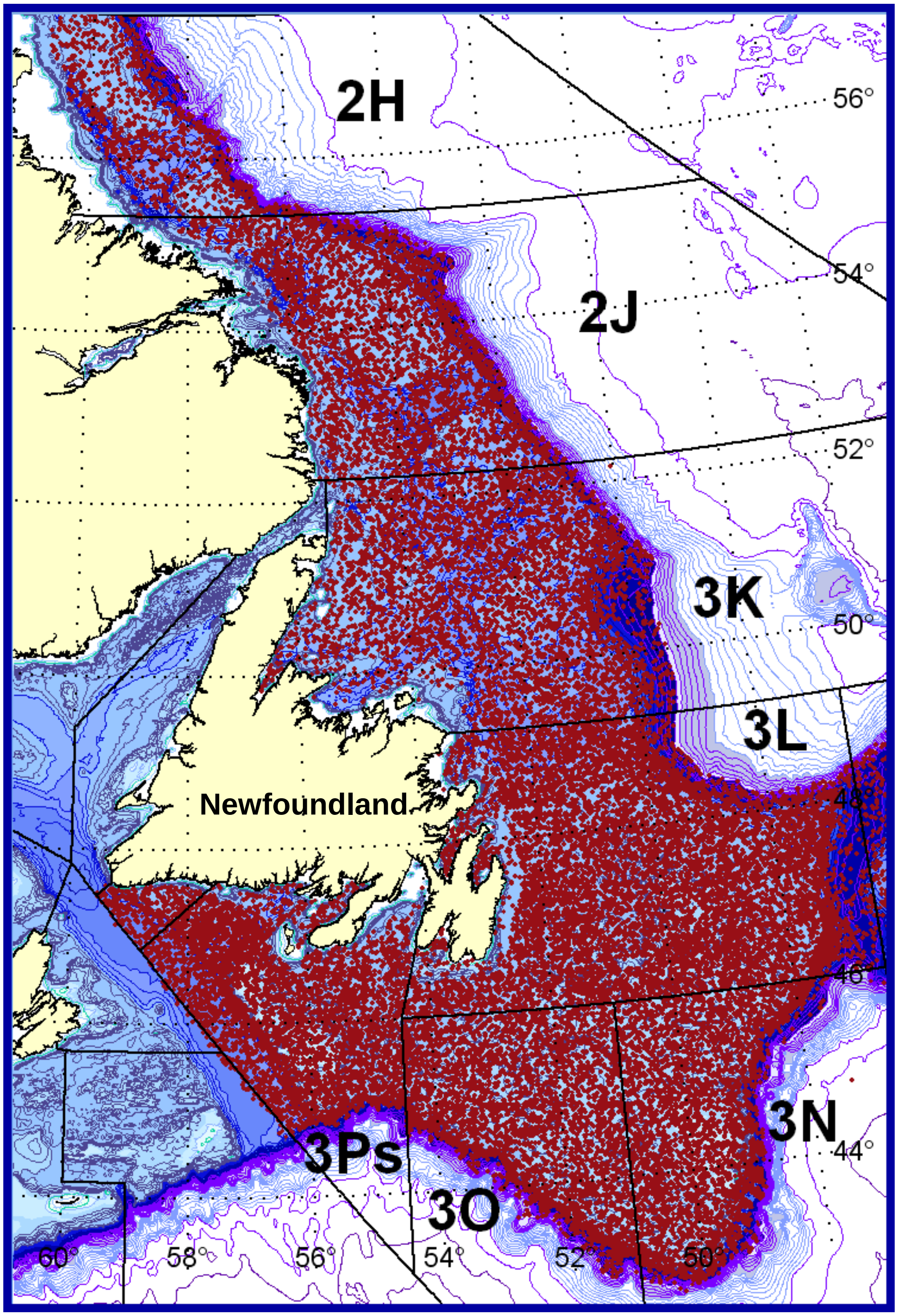

Figure 1. Distribution of fishing tows (red dots) conducted during spring and fall bottom trawl research surveys in NAFO Division 2HJ3KLMNOPs during the period 1971-2010 (all data combined). Solid black lines delineate NAFO Divisions. Fishing gear changed from Yankee to Engel in 1983 (spring survey) and from Engel to Campelen in 1995 (fall survey) and 1996 (spring survey).

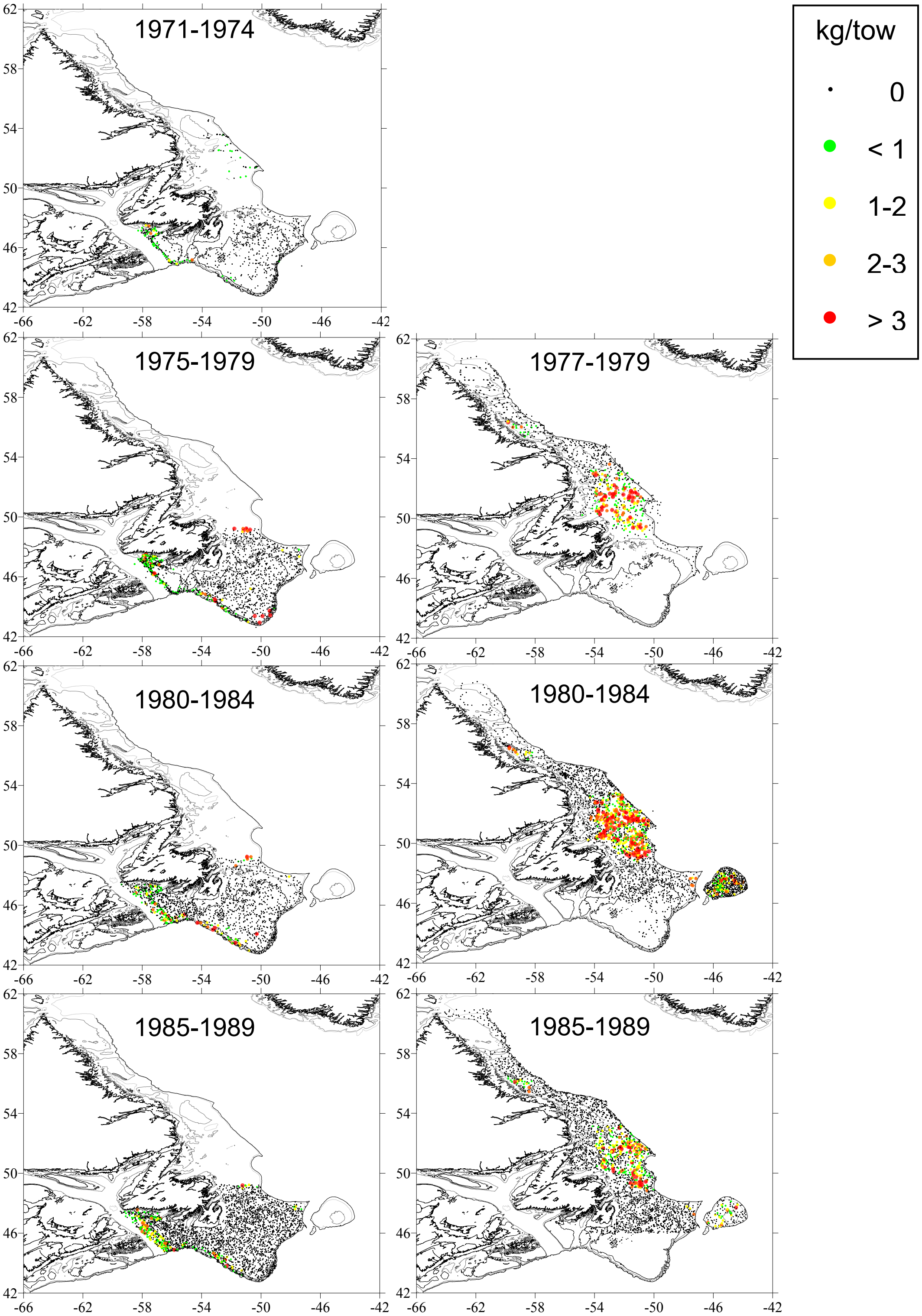

Figure 2. Geographic distribution of spring (left panels) and fall (right panels) bottom trawl research survey catch rate (kg/tow) for M. senta in the NL Region.

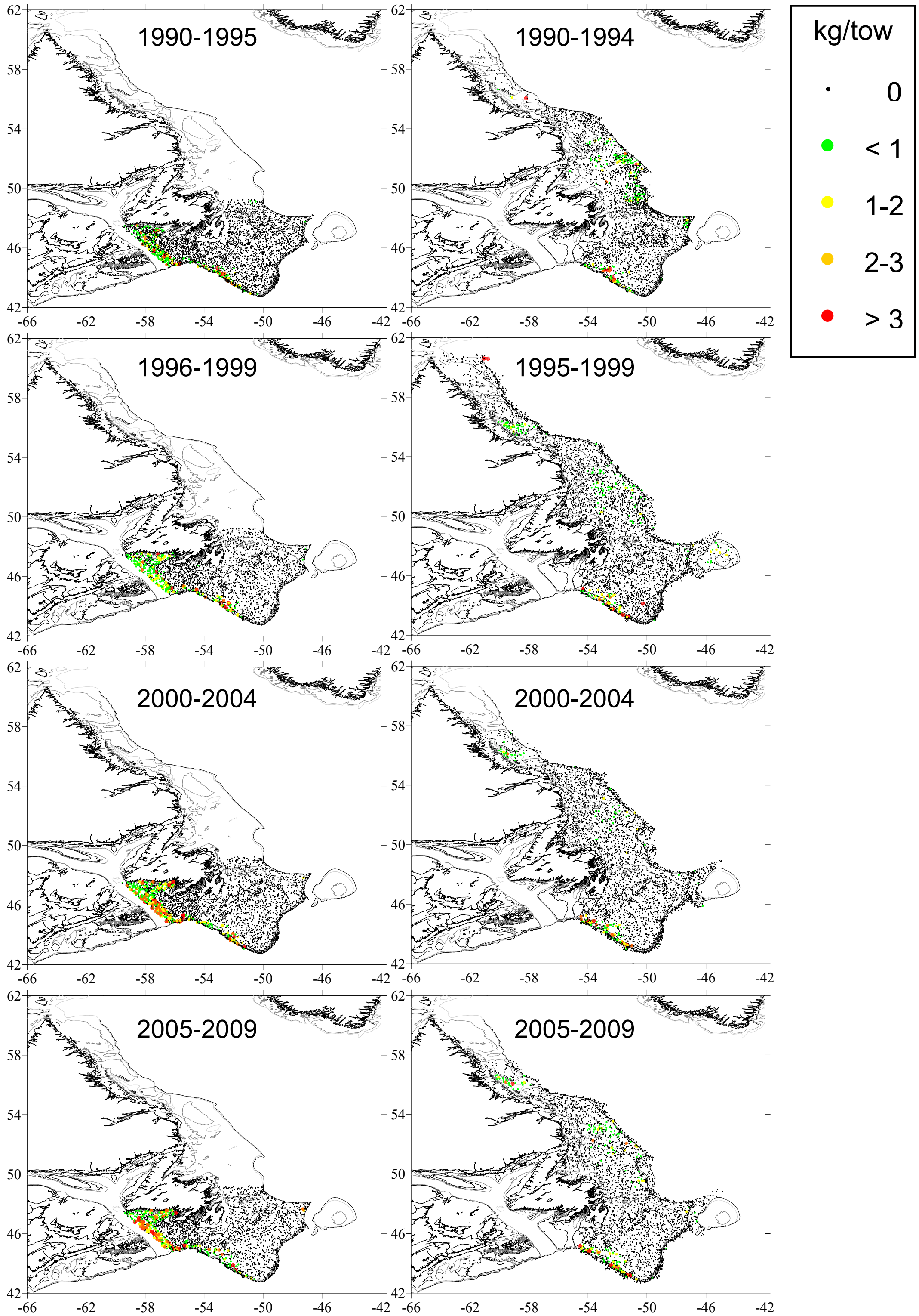

Figure 2. (cont'd.) Geographic distribution of spring (left panels) and fall (right panels) bottom trawl research survey catch rate (kg/tow) for M. senta in the NL Region.

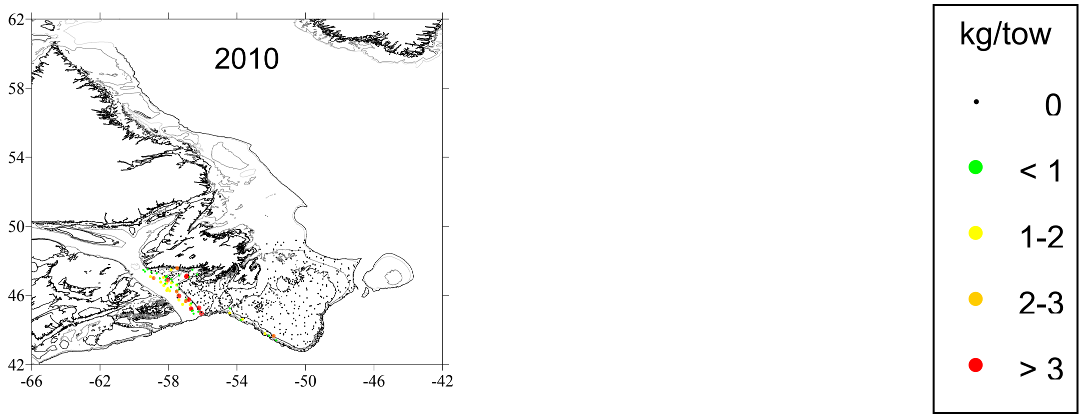

Figure 2. (cont'd.). Geographic distribution of spring (left panel) bottom trawl research survey catch rate (kg/tow) for M. senta in the NL Region.

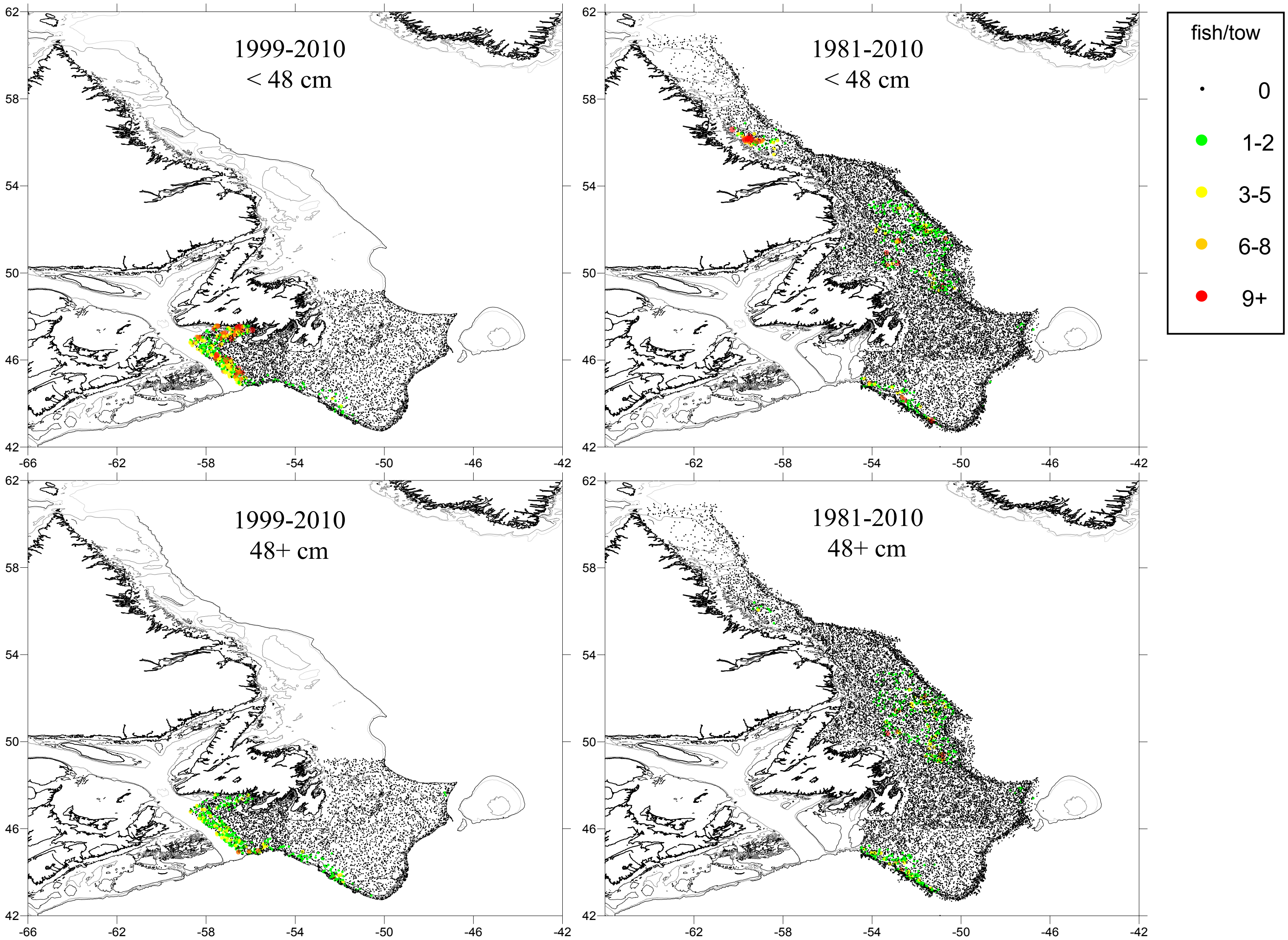

Figure 3. Geographic distribution of spring (left panels) and fall (right panels) bottom trawl research survey catch rate (no. fish/ tow) for juvenile (< 48 cm) and adult (≥48 cm) M. senta in the NL Region.

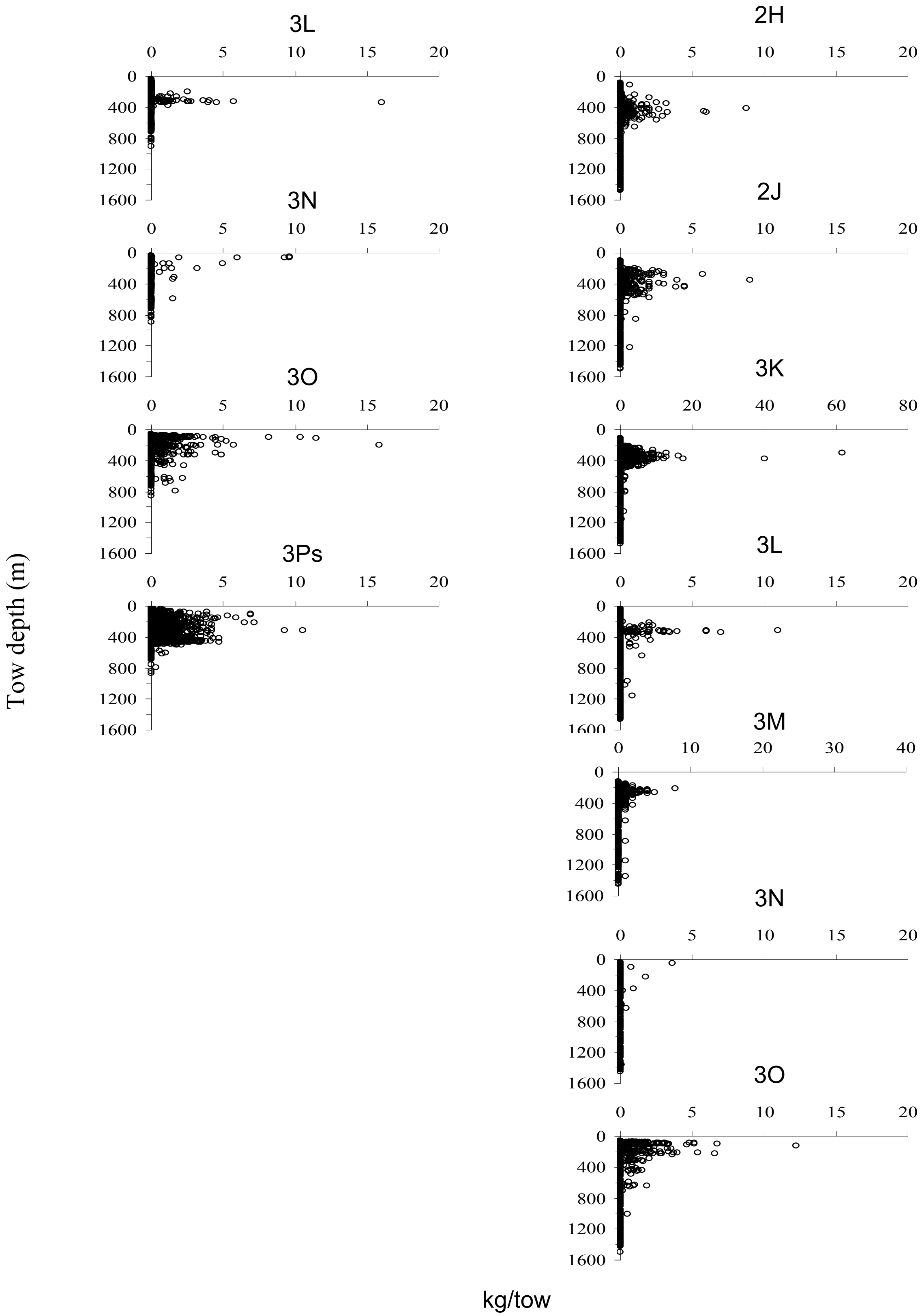

Figure 4. Distribution of spring (1971-2010, left column) and fall (1977-2009, right column) bottom trawl catch rate (kg/tow) for M. senta in relation to depth in the NL Region (Division 2HJ3KLMNOPs).

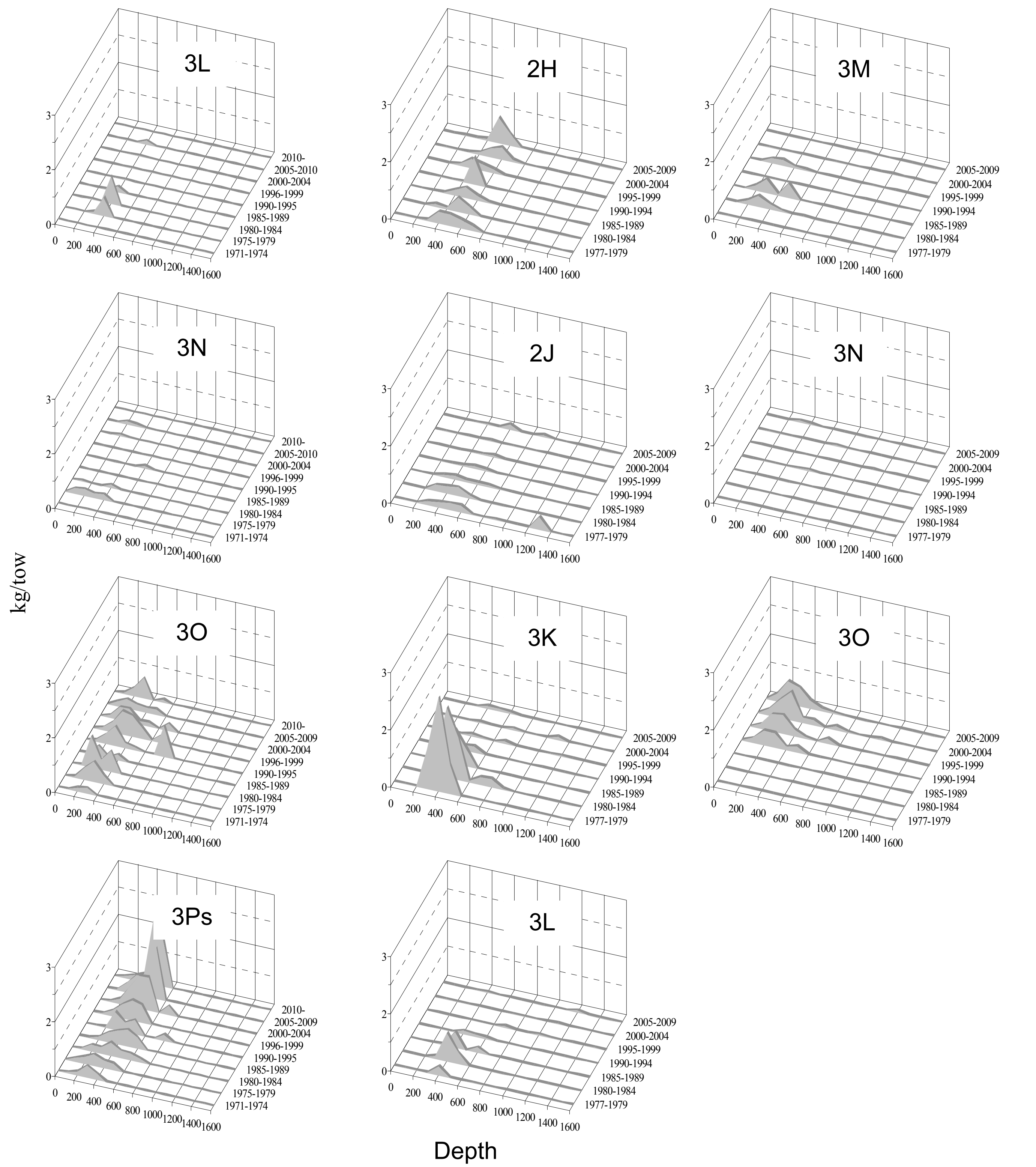

Figure 5. Distribution of M. senta mean catch rate in relation to depth during the spring (1971-2010, left column) and fall (1977-2009, centre and right columns) bottom trawl research survey in the NL Region (Division 2HJ3KLMNOPs).

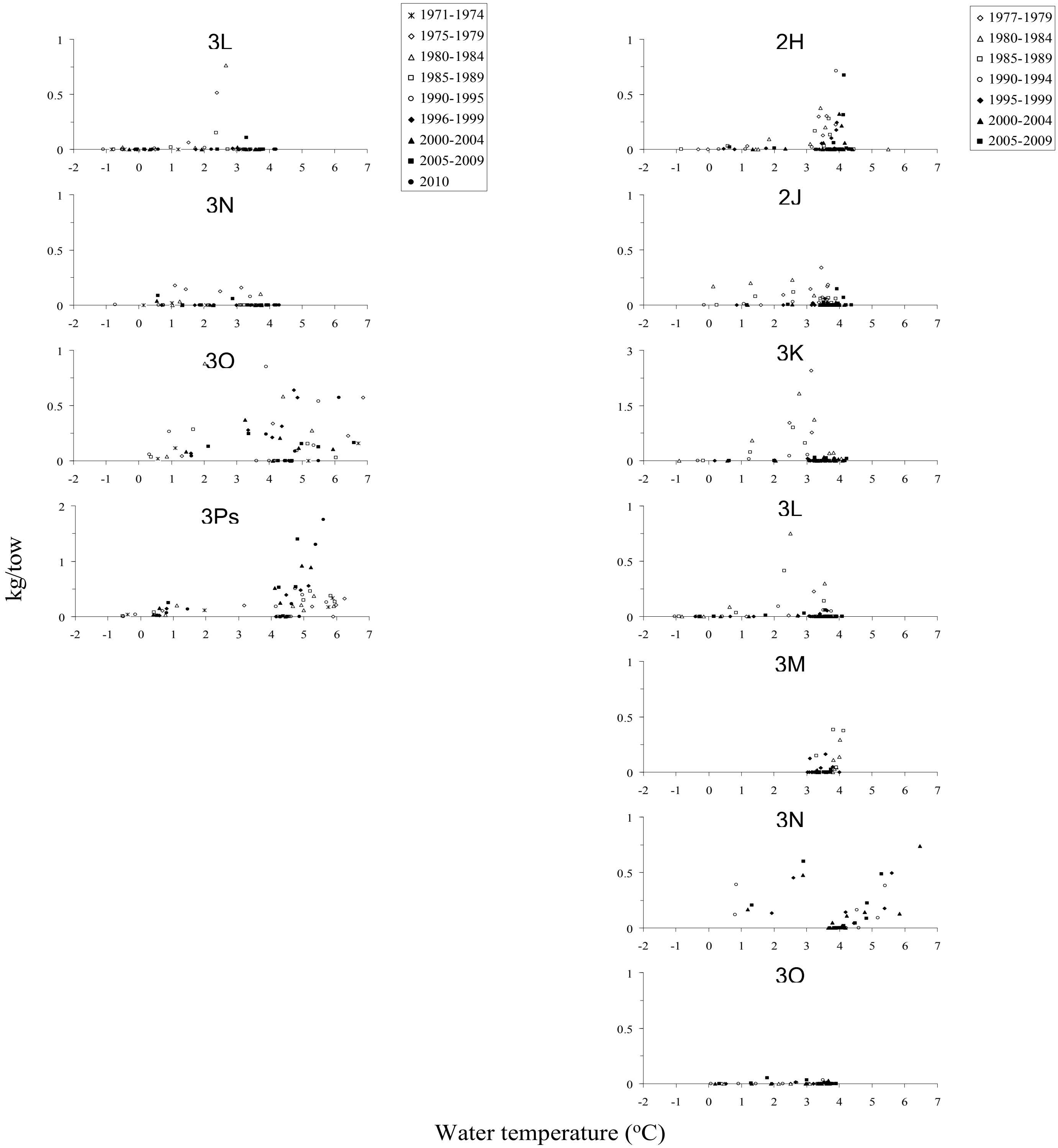

Figure 6. Distribution of M. senta mean catch rate in relation to water temperature at tow depth during the spring (1971-2010, left column) and fall (1977-2009, right column) bottom trawl research survey in the NL Region (Division 2HJ3KLMNOPs). Left column (spring), right column (fall).

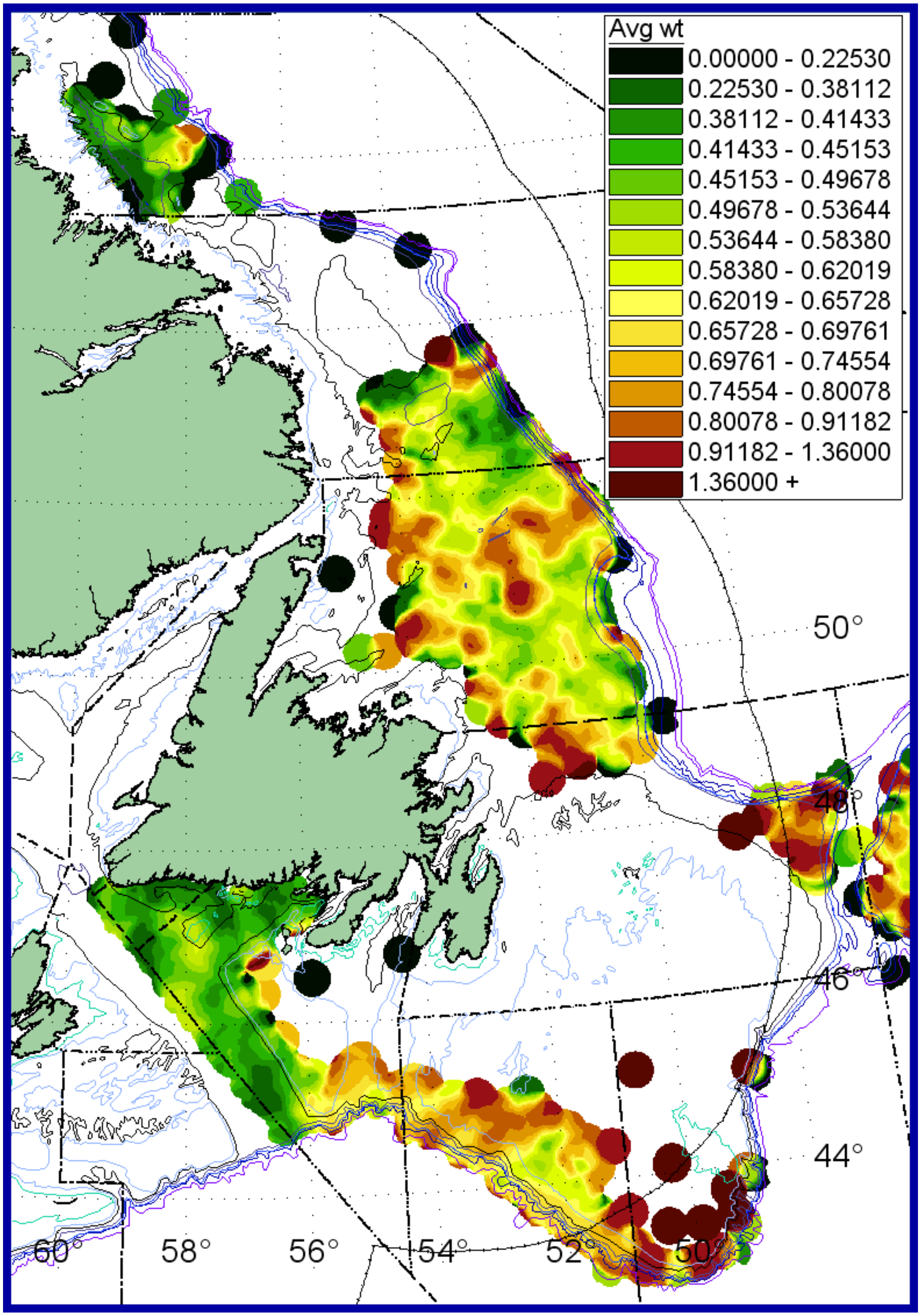

Figure 7. Mean size distribution (catch weight per tow/catch number per tow) of M. senta for combined spring and fall surveys (1971-2009) in the NL Region. White denotes areas sampled but with no catches. Maps were produced using a surface modelling technique described in Kulka (1998).

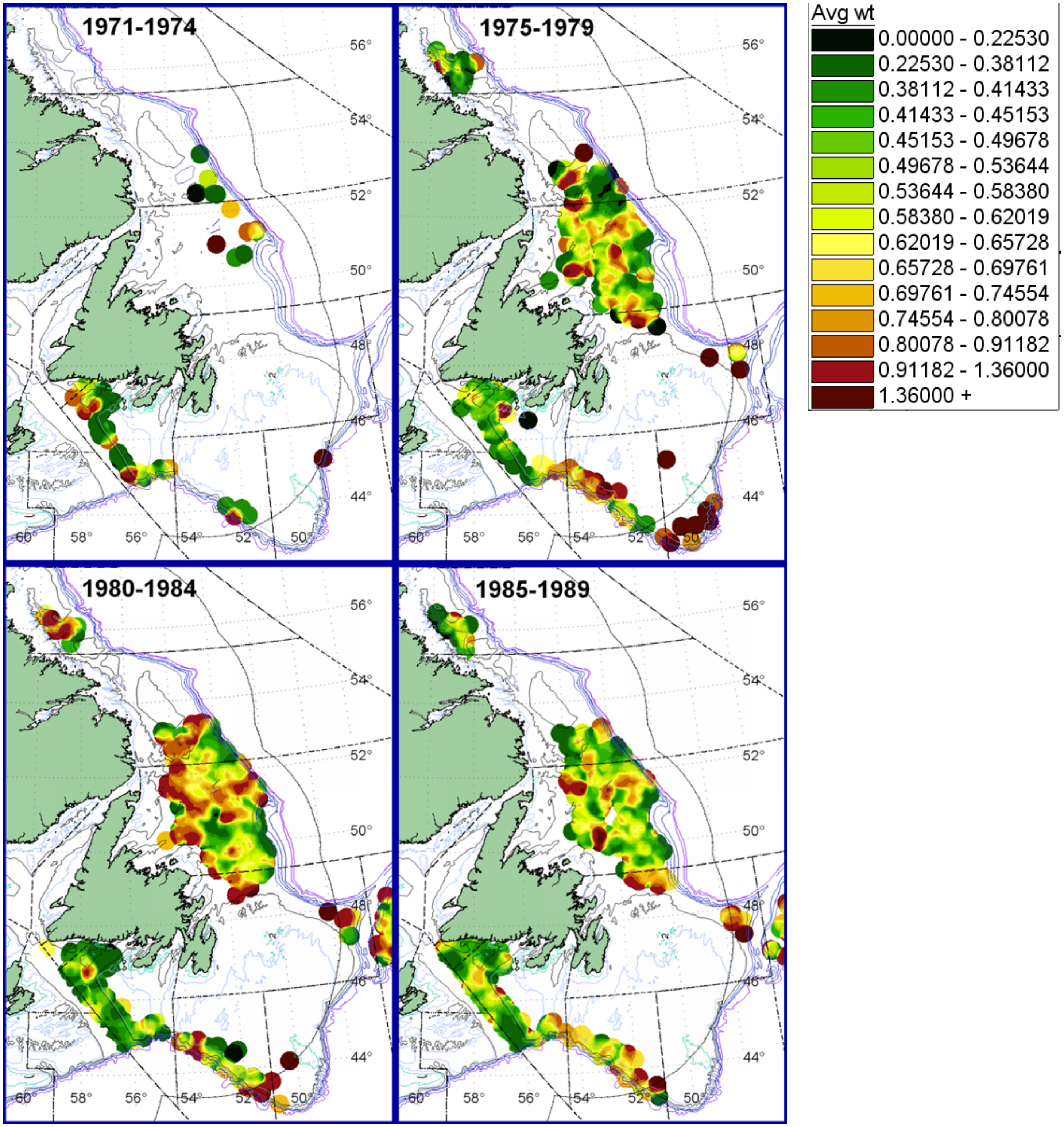

Figure 8. Mean size distribution (catch weight per tow/catch number per tow) of M. senta for spring and fall surveys (5-year intervals) in the NL Region. White denotes areas sampled but with no catches. Maps were produced using a surface modelling technique described in Kulka (1998).

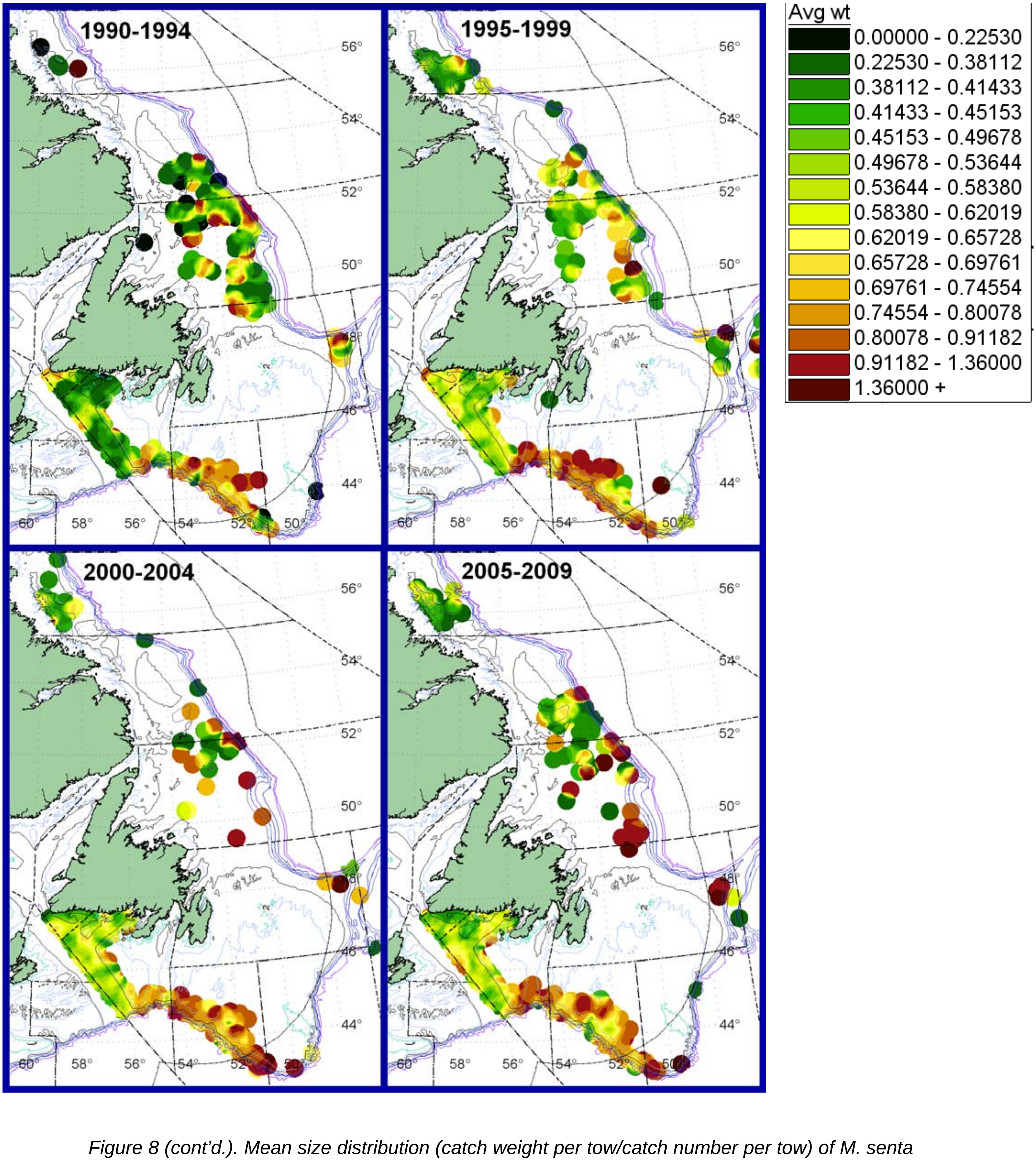

Figure 8 (cont'd.). Mean size distribution (catch weight per tow/catch number per tow) of M. senta for spring and fall surveys (5-year intervals) in the NL Region. White denotes areas sampled but with no catches. Maps were produced using a surface modelling technique described in Kulka (1998).

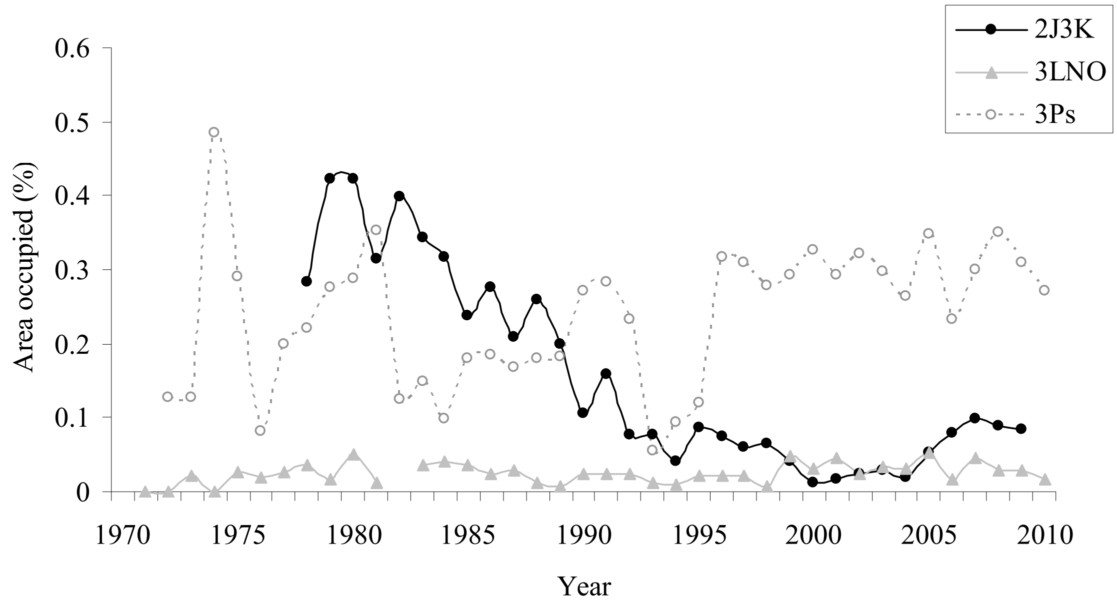

Figure 9. Area of occupancy for M. senta in Division 2J3K during the fall (1978-2009) and in Division 3LNO and Subdivision 3Ps during the spring (1971-2010).

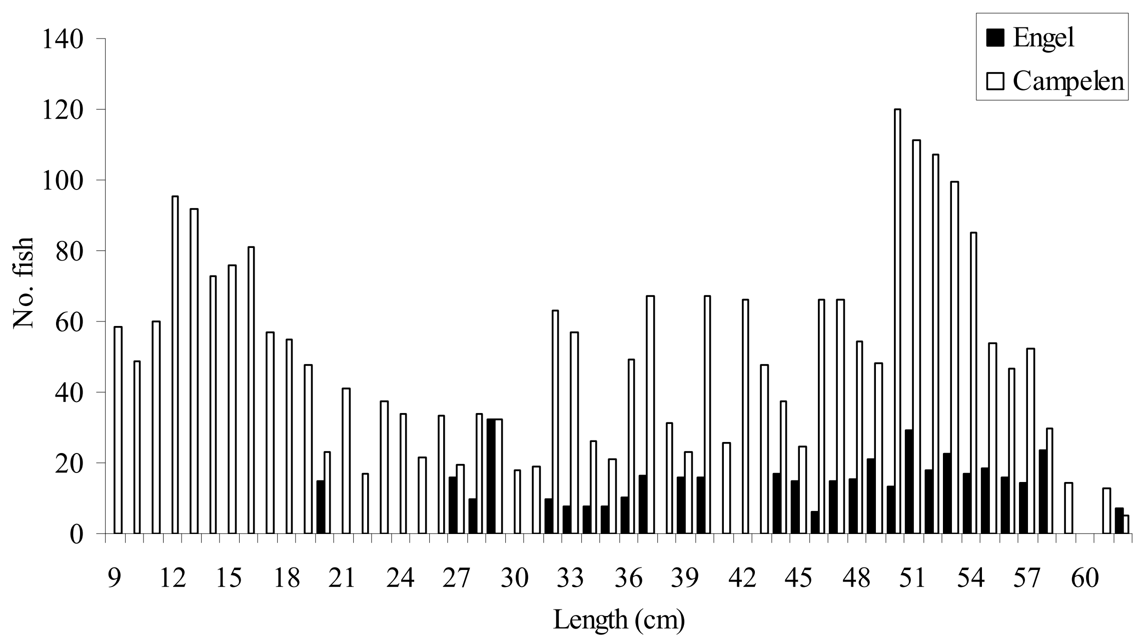

Figure 10 Length frequency distribution for M. senta captured during the spring surveys in Division 3NOPs. The distributions were calculated as the overall mean number at length caught by the Engel and the Campelen trawls in the three years prior to (1993-95) and following the gear change (1996-98).

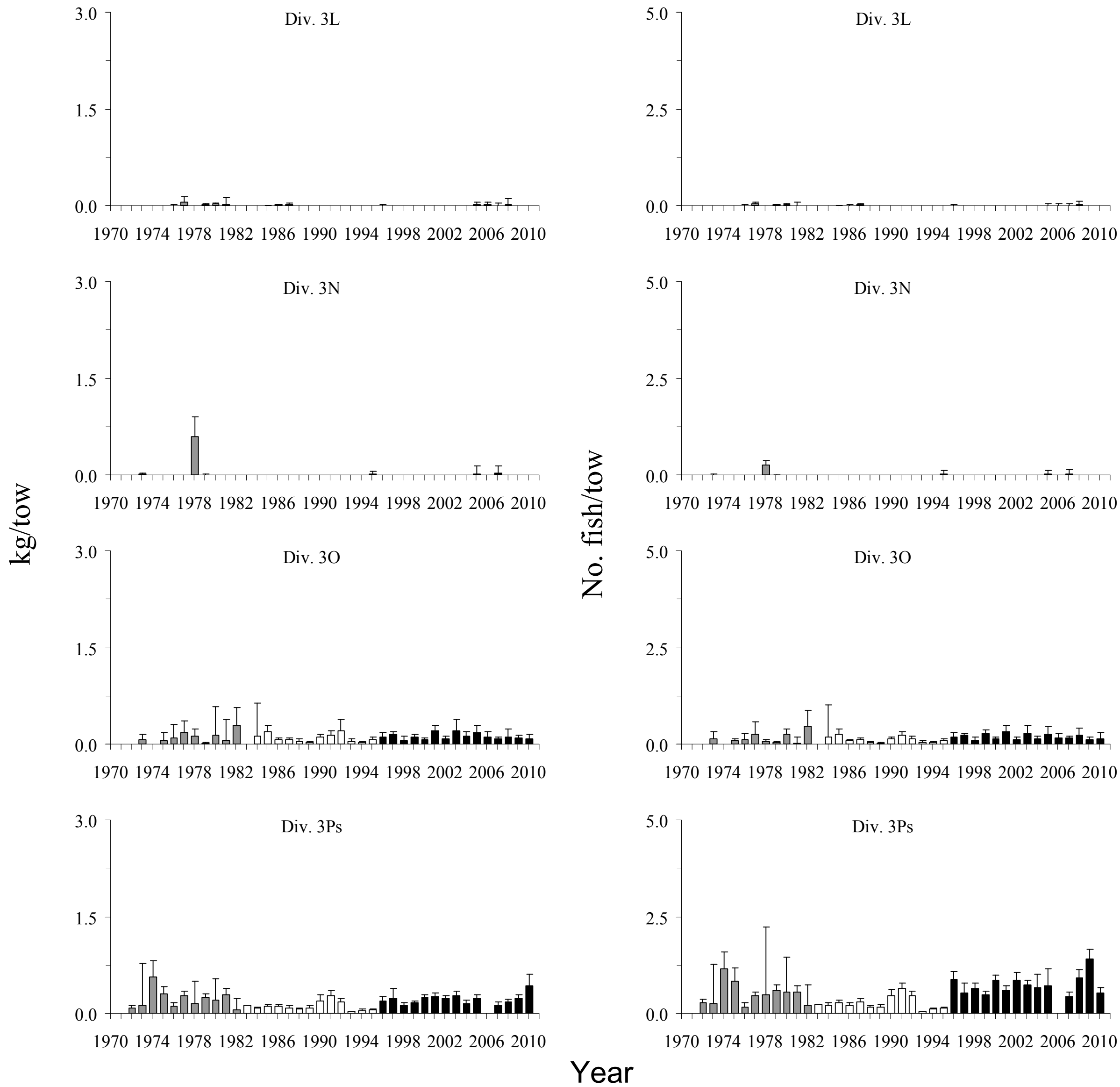

Figure 11. Spring bottom trawl survey standardised indices of relative abundance (1971-2010) for M. senta in Division 3LNOPs. Left column: mean catch weight per tow. Right column: mean catch number per tow. T-bar = 1 SE. Survey fishing gear changed from Yankee (grey bars) to Engel (white bars) in 1983, and from Engel to Campelen (black bars) in 1996.

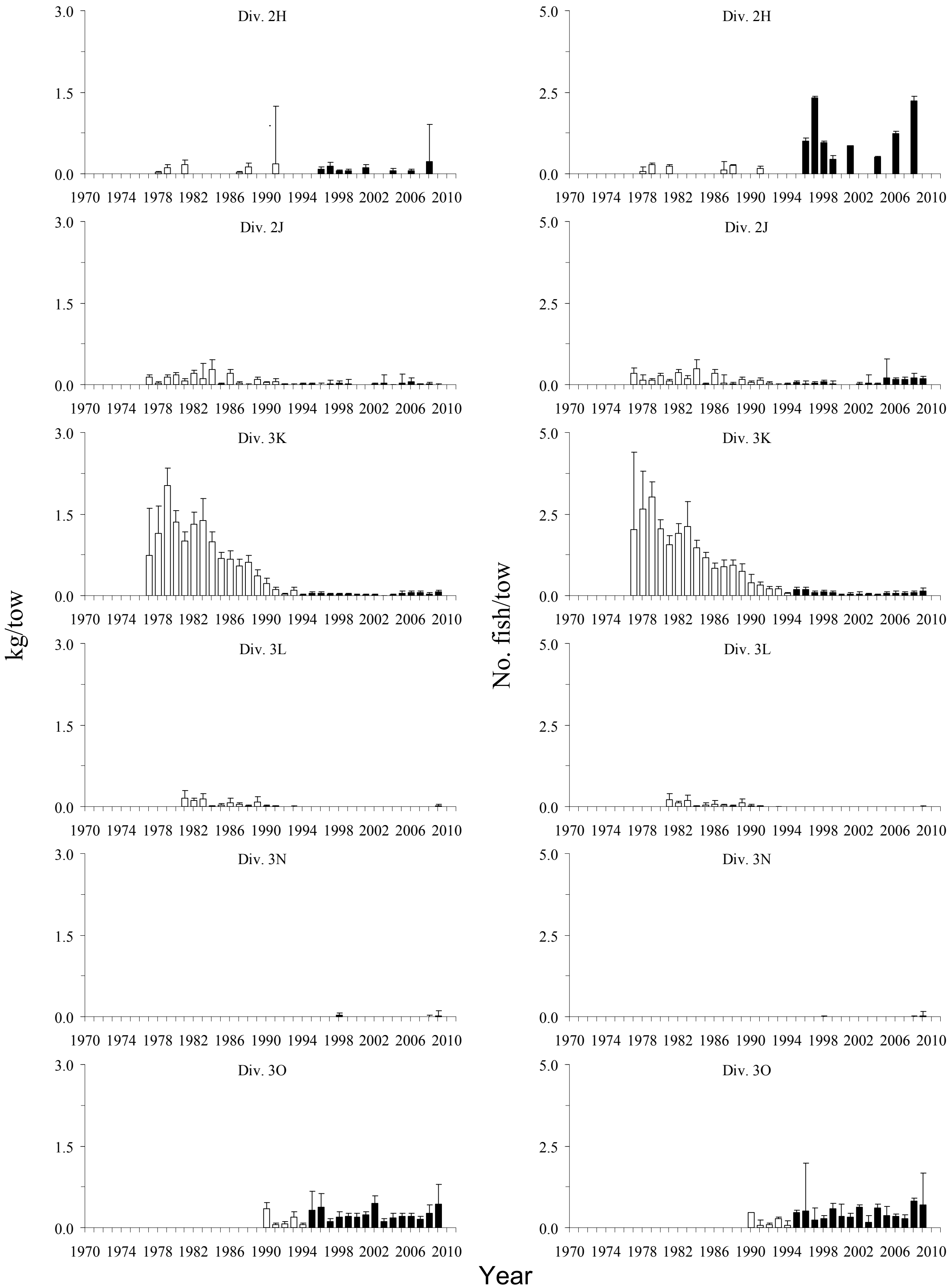

Figure 12. Fall bottom trawl survey standardised indices of relative abundance (1977-2009) for M. senta in Division 2HJ3KLMNO. Left column: mean catch weight per tow. Right column: mean catch number per tow. T-bar = 1 SE. Survey fishing gear changed from Engel (white bars) to Campelen (black bars) in 1995.

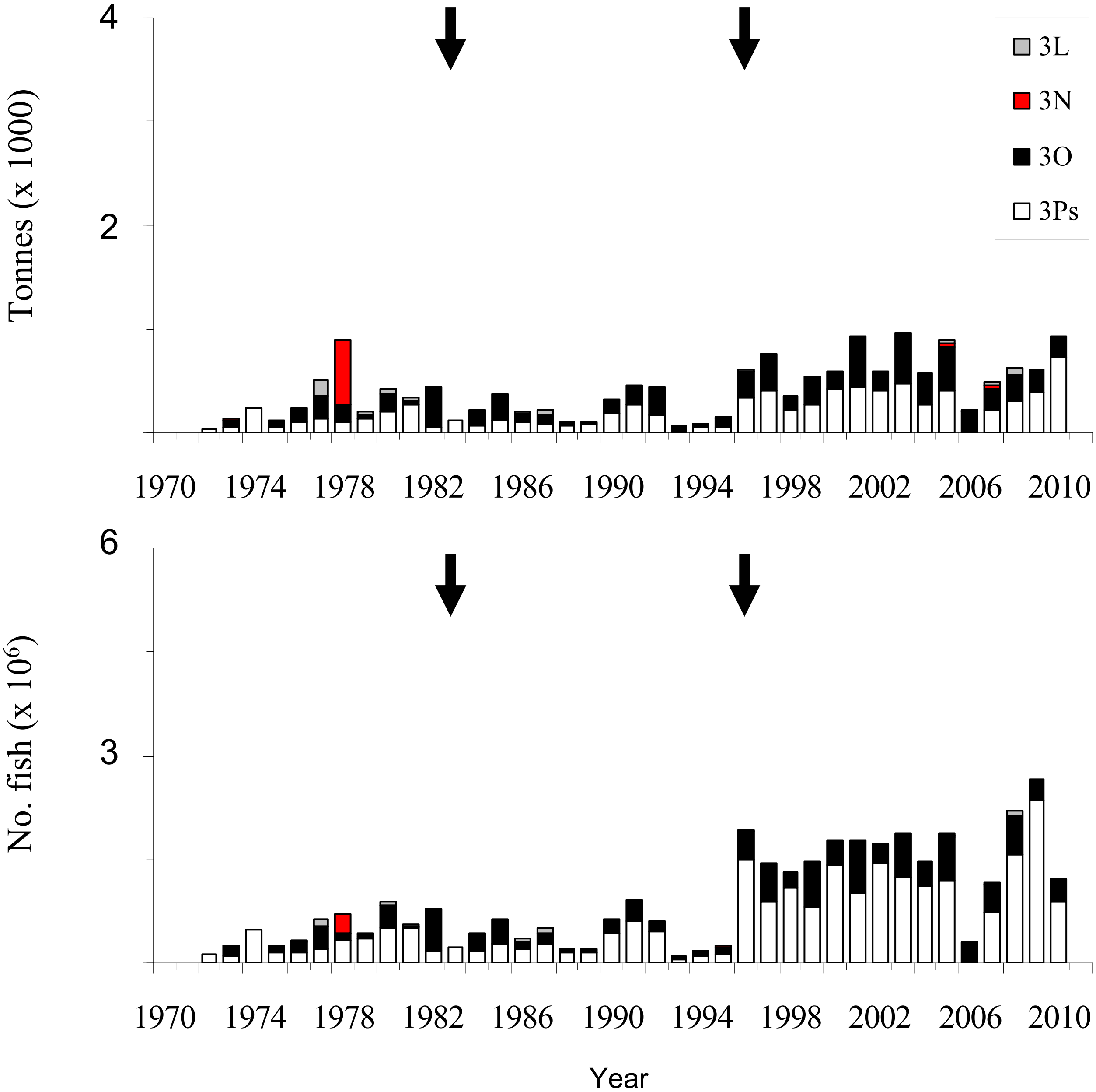

Figure 13. Spring survey abundance estimation for M. senta in Division 3LNOPs (1971-2010). Upper panel: biomass, lower panel: number of fish. Calculations are based on areal expansion projections of catch rates using the STRAP routine (see text for details). Black arrows denote change in fishing gear: Yankee to Engel (1983), and Engel to Campelen (1996).

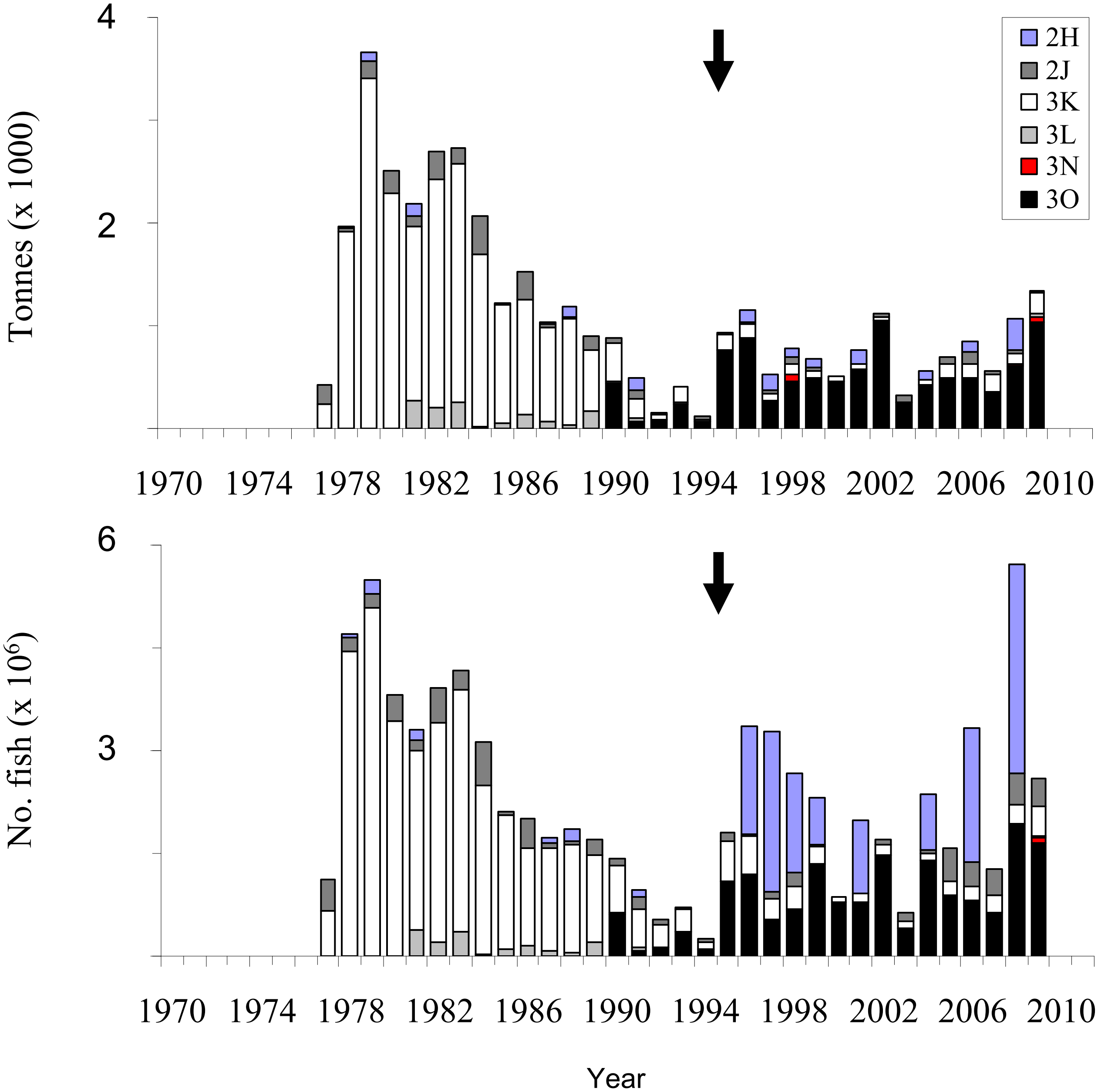

Figure 14. Fall survey abundance estimation for M. senta in Division 2HJ3KLNO (1977-2009). Upper panel: biomass, lower panel: number of fish. Calculations are based on areal expansion projections of catch rates using the STRAP routine (see text for details). Black arrow denotes change in fishing gear: Engel to Campelen (1995).

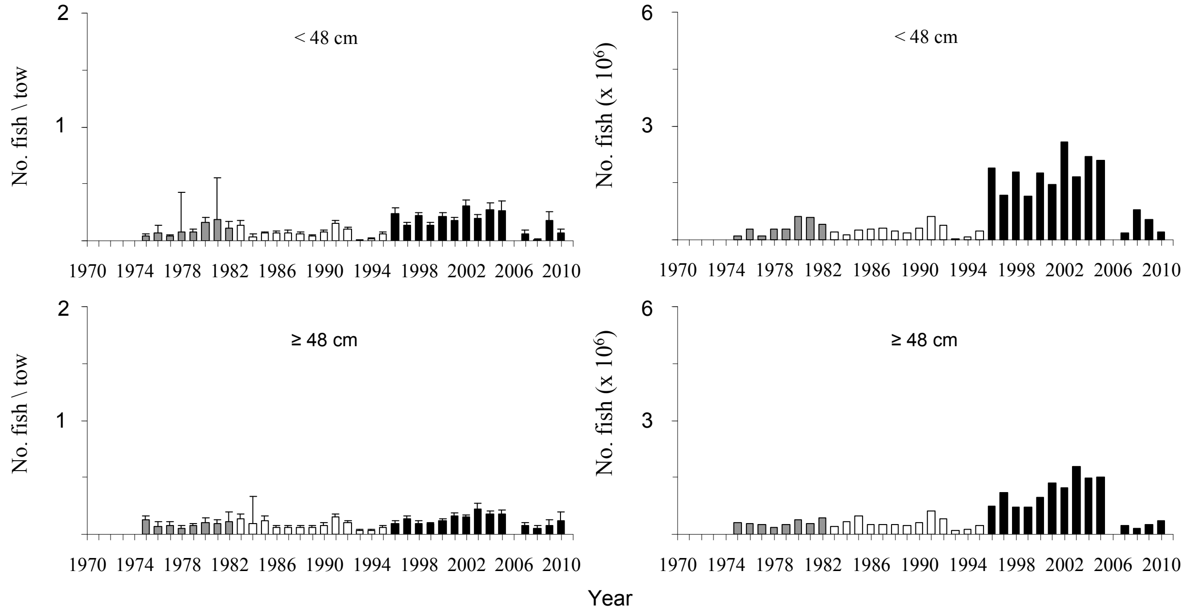

Figure 15. Spring survey catch rate and abundance estimation (1975-2010) for juvenile (<48 cm) and adult (≥48 cm) M. senta in the Laurentian Channel DU. Left panels: mean catch number per tow; right panels: number of fish. T-bar = 1 SE. Survey fishing gear changed from Yankee (grey bars) to Engel (white bars) in 1983, and from Engel to Campelen (black bars) in 1996.

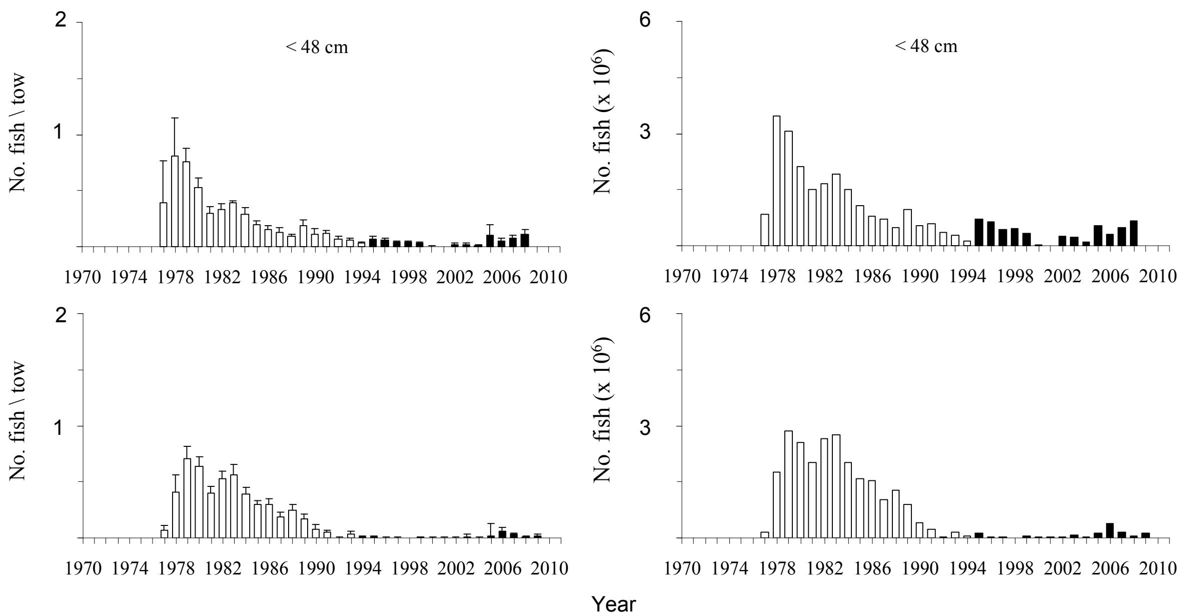

Figure 16. Fall survey catch rate and abundance estimation (1977-2009) for juvenile (<48 cm) and adult (≥48 cm) M. senta in the Funk Island Deep DU. Left panels: mean catch number per tow; right panels: number of fish. T-bar = 1 SE Survey fishing gear changed from Engel (white bars) to Campelen (black bars) in 1995.

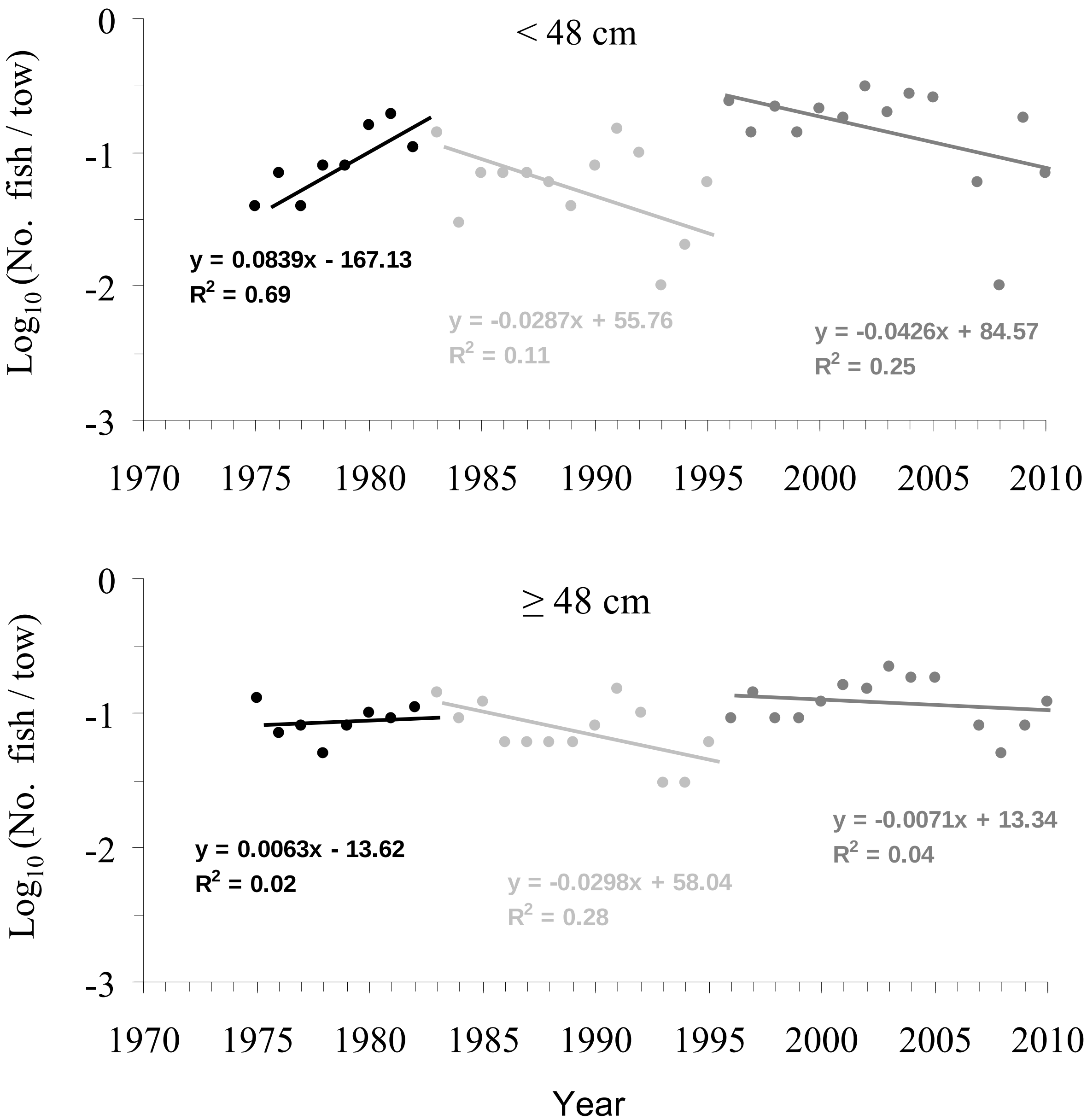

Figure 17. Log transformed spring survey catch rate for juvenile (<48 cm) and adult (≥48 cm) M. senta from the Laurentian DU (1975-2010), and regression lines showing trends in relative abundance over time. Survey fishing gear changed from Yankee (black) to Engel (light grey) in 1983, and from Engel to Campelen (dark grey) in 1996.

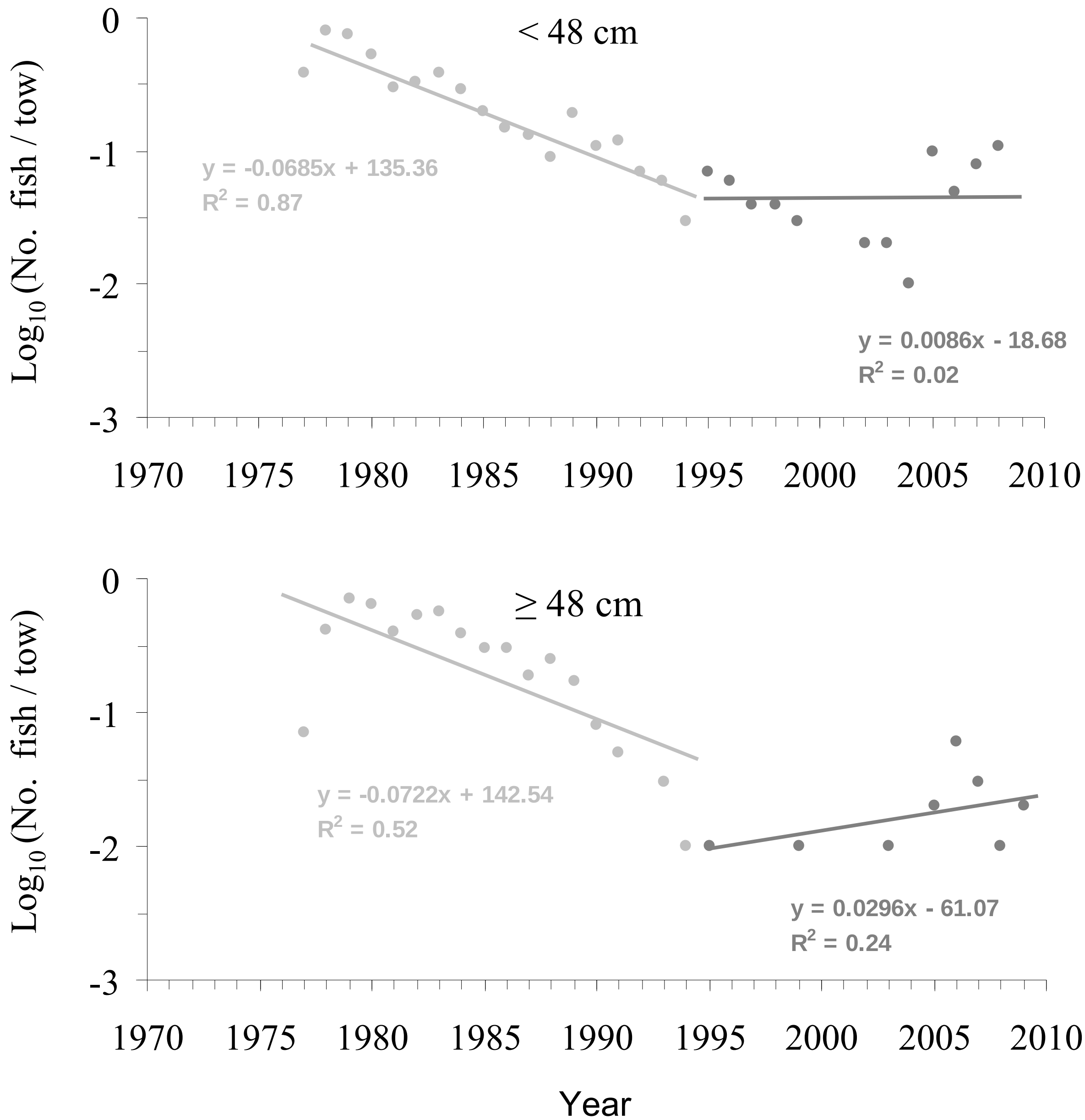

Figure 18. Log transformed fall survey catch rate for juvenile (<48 cm) and adult (≥48 cm) M. senta from the Funk DU (1977-2009), and regression lines showing trends in relative abundance over time. Survey fishing gear changed from Engel (light grey) to Campelen (dark grey) in 1995.

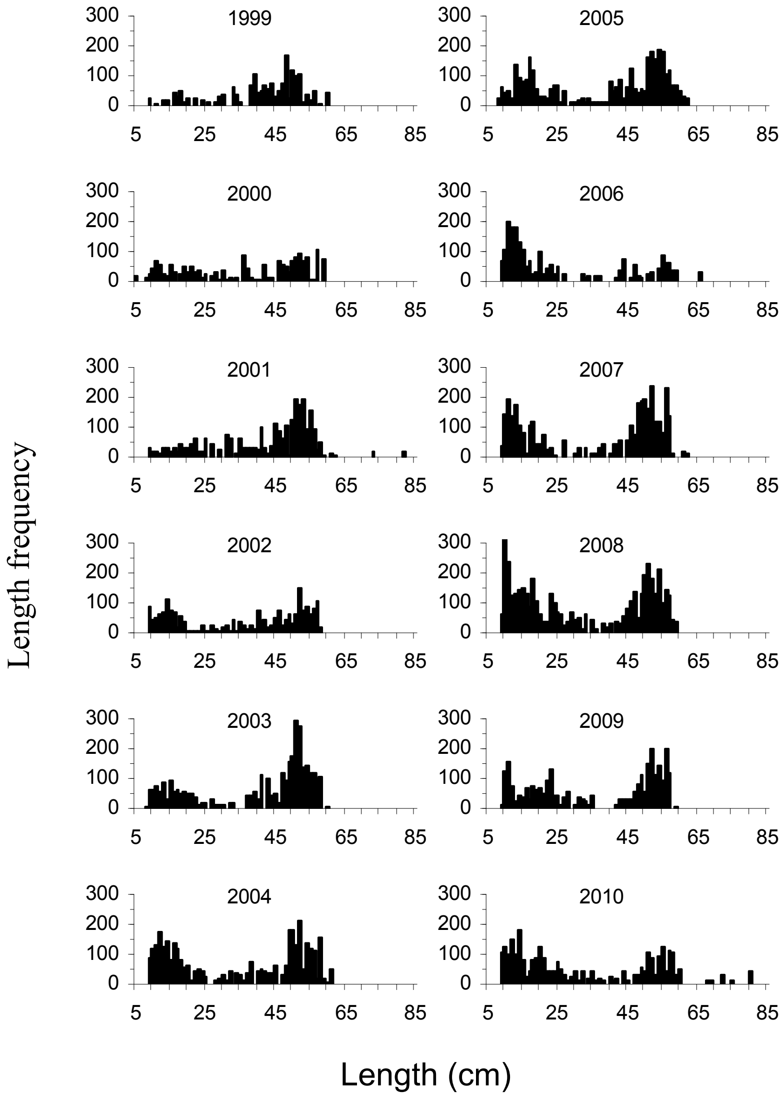

Figure 19. Length frequency distribution (TL) for M. senta caught during the spring bottom trawl survey (1999-2010) in Division 3LNOPs. All tows were conducted using a Campelen trawl.

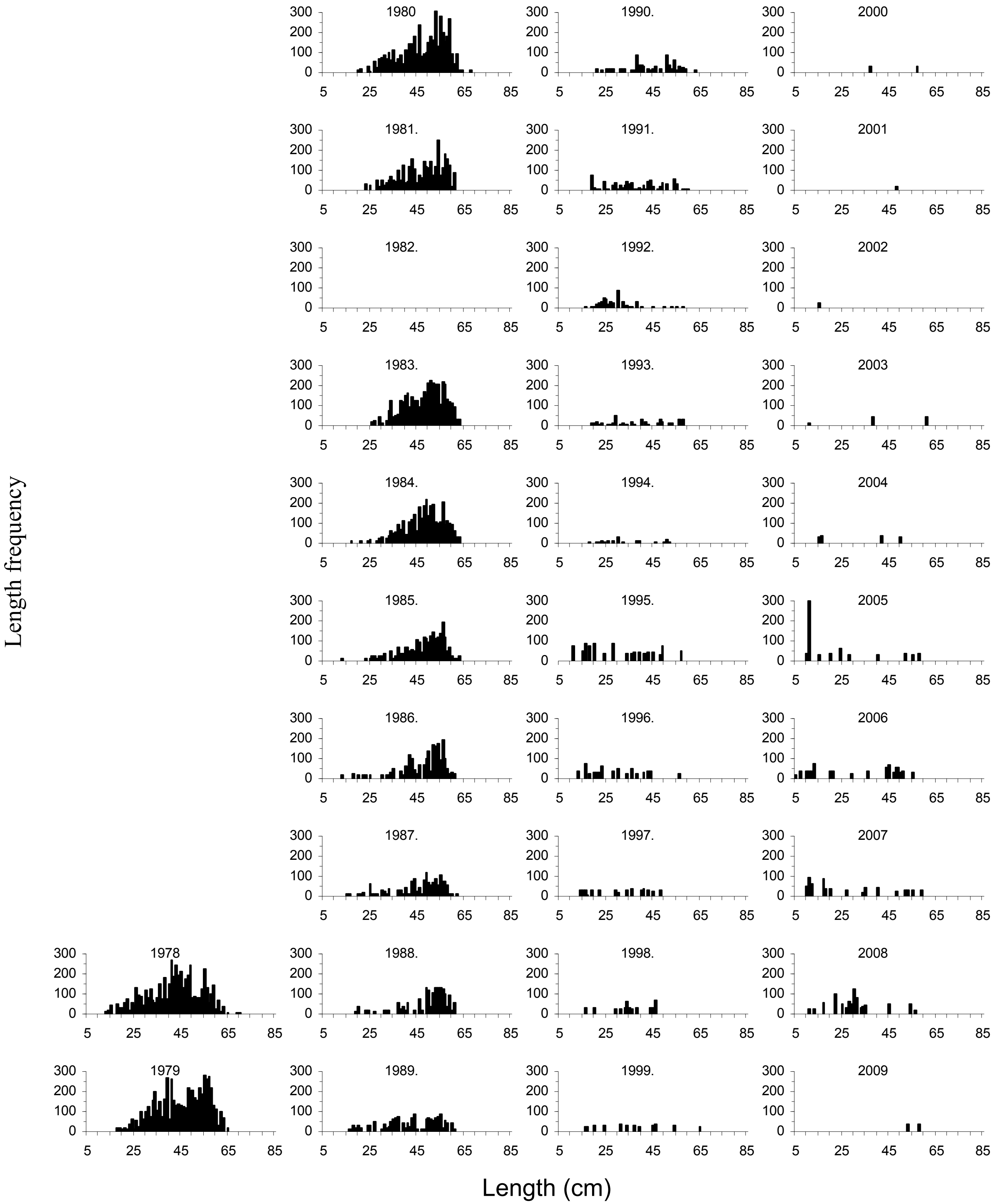

Figure 20. Length frequency distribution (TL) for M. senta caught during the fall bottom trawl survey (1978-2009) in Division 2J3K. Tows were conducted using either an Engel trawl (1978-94) or a Campelen trawl (1995-2009).

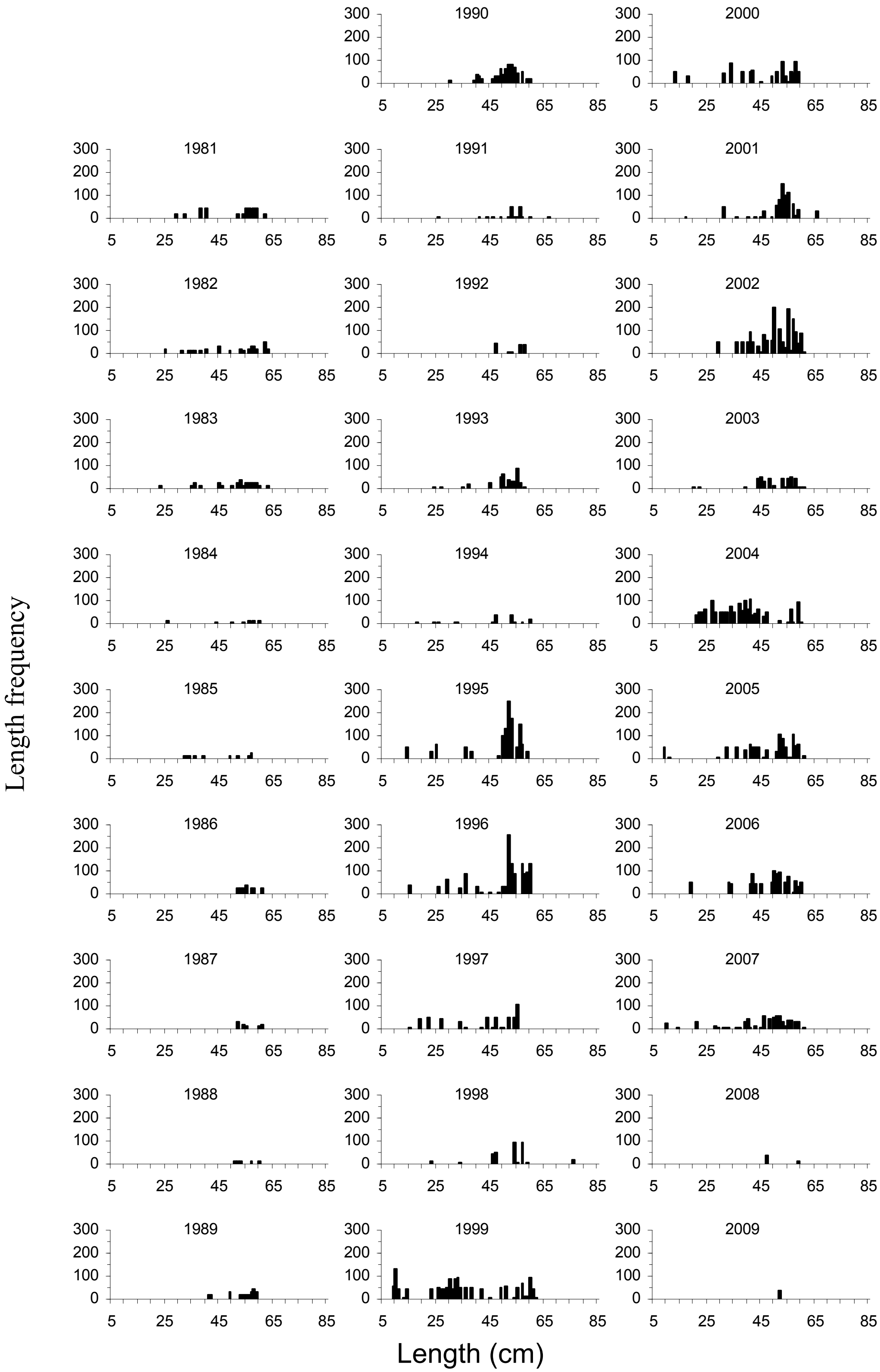

Figure 21. Length frequency distribution (TL) for M. senta caught during the fall bottom trawl survey (1981-2009) in Division 3LNO. Tows were conducted using either an Engel trawl (1981-94) or a Campelen trawl (1995-2009).

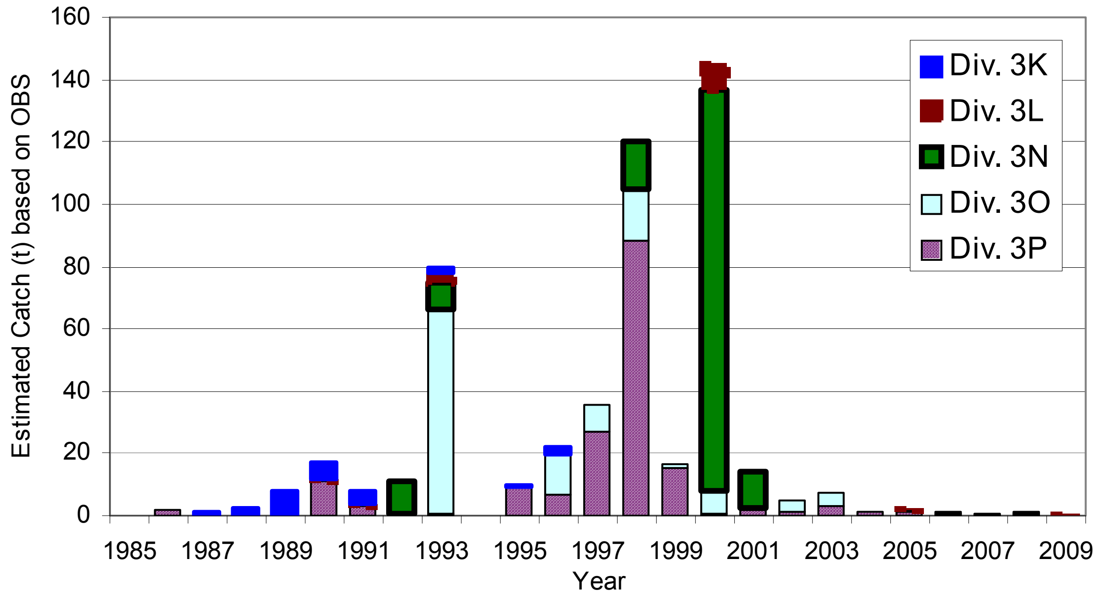

Figure 22. Canadian Fisheries Observers' at-sea M. senta catch data prorated to total reported groundfish landings (ZIF) from Division 3KLNOP in Canada's EEZ for 1985-2009.

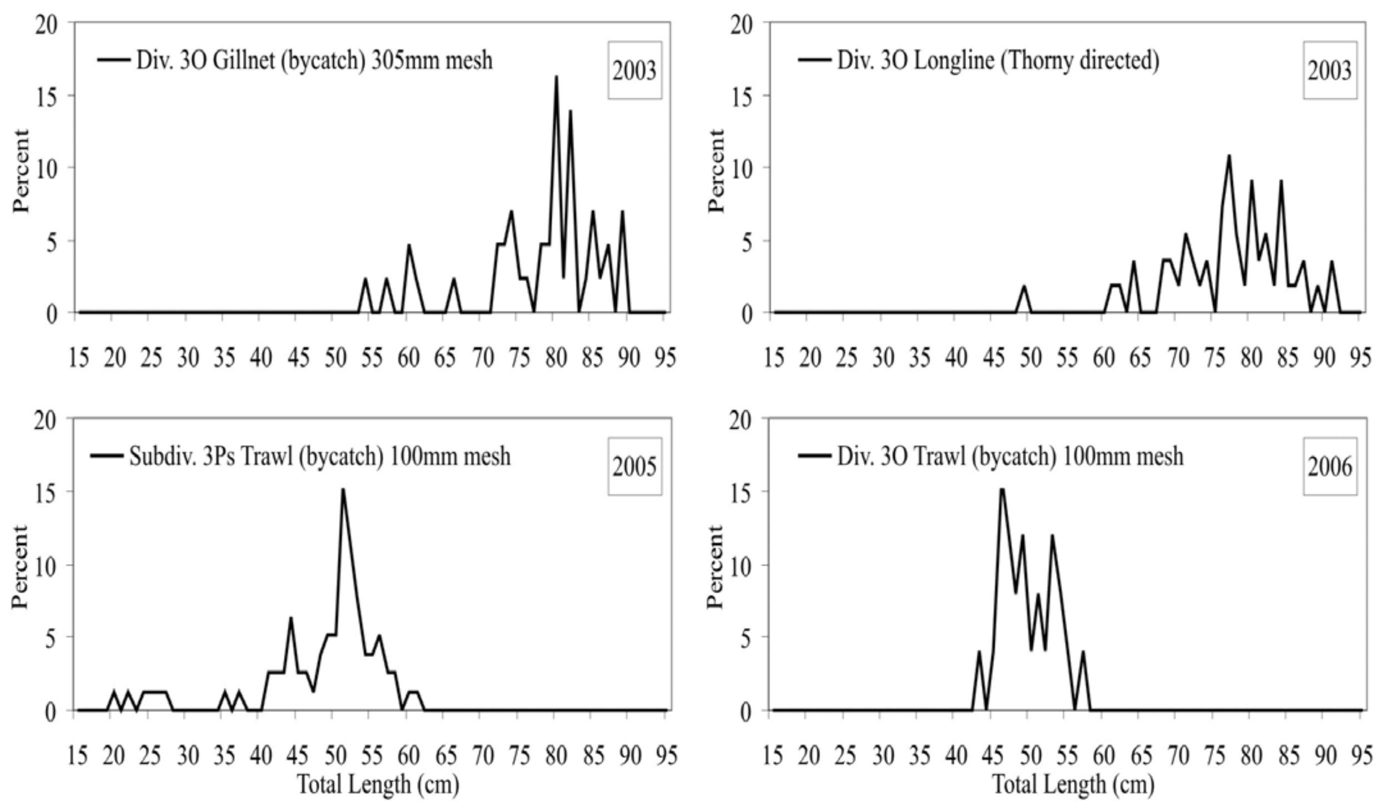

Figure 23. Canadian Fisheries Observers' at-sea length frequencies (TL) of M. senta bycatch in a Monkfish directed gillnet fishery in 2003 (Division 3O), Thorny Skate longline fishery in 2003 (Division 3O), and Redfish bottom trawl fishery in 2005-06 (Division 3OPs).

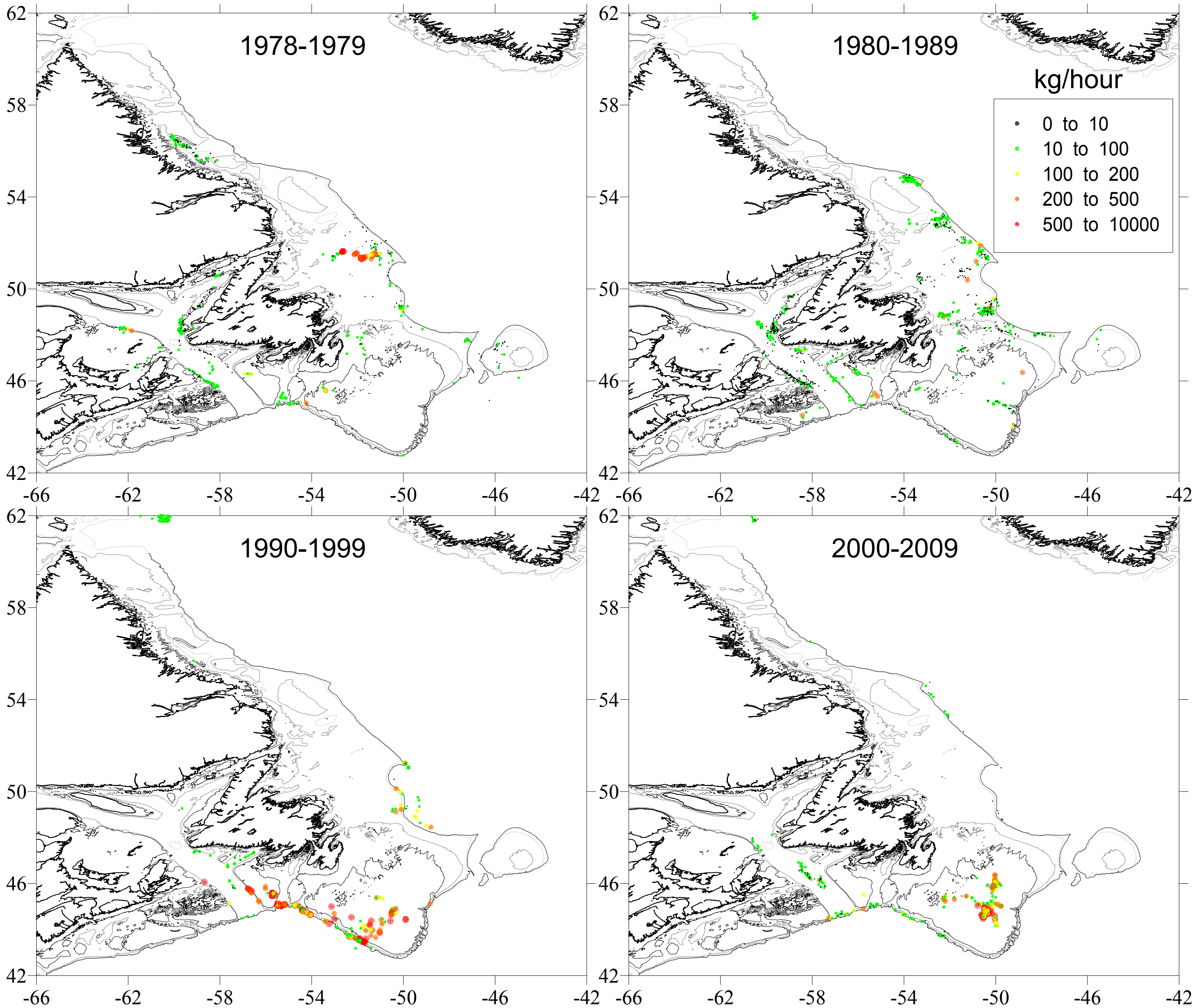

Figure 24. M. senta standardized catch rates [kept+discards (kg)/ tow duration (hours)] for bottom trawl fisheries directing for unspeciated skates and other demersal fish (e.g., Atlantic Cod, Redfish, American Plaice, Witch Flounder, Yellowtail Flounder); based on Canadian Fisheries Observers' at-sea data (1978-2009).

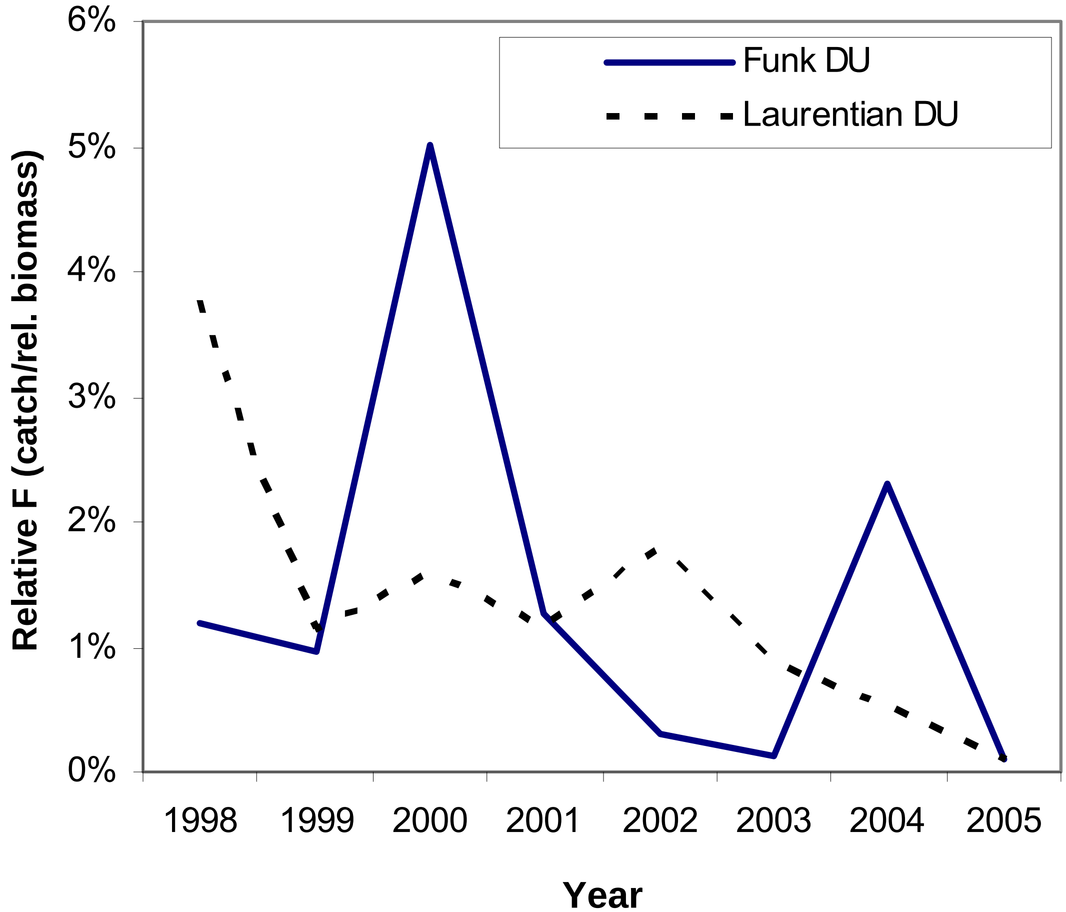

Figure 25. Relative fishing mortality (F = commercial catch/ survey relative biomass) for M. senta in the Laurentian Channel DU (spring survey) and Funk Island Deep DU (fall survey) in 1998-2005. F was estimated for all demersal gears combined.