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The status of Monkfish (Lophius americanus) in NAFO Divisions 2J, 3K, 3L, 3N, 3O and Subdivision 3Ps

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ABSTRACT

Monkfish (*Lophius americanus*) is described at the northern end of its distribution. It was found to be restricted primarily to the southwest slope of the Grand Banks, closely associated with the warmest available bottom waters. Survey data also indicate occasional records to the north on the Labrador Shelf in deeper, warmer trenches and on the slope edge. Biomass at depth was observed to change over time. A shift to deeper waters after the mid-1980's followed by a return to shallower depths in recent years may be related to a cooling trend during the mid-1980's. The highest densities (kg per tow) of monkfish on the Grand Banks were located where bottom temperatures exceeded 4^0 C. Nearly all of the biomass from spring surveys occurred in NAFO Div. 3Ps and 3O, with $2/3^{rds}$ in 3O. Biomass and abundance indices fluctuated at a low in 1979, peaking in 1988. Biomass then fluctuated downward until reaching a low in 1992-93. Since then, the index has fluctuated widely, particularly from the Campelen gear. 2000 represents a year of peak abundance, almost double the previous year. Such abrupt changes from year to year likely do not reflect dramatic fluctuations in the population. Rather, these changes suggest that there may be a catchability issue. Mean monkfish weight peaked in the late 1980's in conjunction with the peak in biomass. It has declined since 1996. A Canadian experimental trawl fishery for monkfish contributed to an increase in monkfish landed in 1991. A directed gillnet fishery began in 1993. In 1995-1997, a 200 metric tonne quota was instituted but was removed in 1998. Landings increased from 1993 to 1998 (except 1995). In 1998-2000, bycatch restrictions as per the conditions of licence is the primary limitation on effort in the monkfish fishery. Given the limited knowledge of most aspects of monkfish biology and relevant fisheries, it is difficult to determine stock health and whether the exploitation rate is appropriate. Even from a precautionary (conservative) point of view, the ratio of commercial removals and research survey biomass estimates seems to be small in recent years. Thus, there is no evidence presented here that would suggest that current levels of fishing are having a significant negative impact on monkfish. Closure due to excessive bycatch of restricted species has acted as a regulator for this stock.

Résumé

La présente étude porte sur la distribution de la baudroie (*Lophius americanus*) dans la partie nord de son aire de répartition. L'espèce fréquente principalement le talus sud-ouest de Grand Banks, privilégiant les eaux de fond les plus chaudes. Les données de relevé révèlent qu'elle est présente à l'occasion au nord du plateau continental du Labrador dans les fosses plus chaudes et sur le bord du talus. La biomasse selon la profondeur varie au fil du temps. Ainsi, après avoir migré vers les eaux profondes au milieu des années l980, la baudroie est revenue à des eaux moins profondes dans les dernières années, peut-être à cause d'une tendance à un refroidissement progressif des eaux durant cette période. Les plus fortes densités (kg/trait) de baudroies de Grand Banks ont été récoltées aux endroits où la température de l'eau au fond était supérieure à 4 ^{0}C. Presque toute la biomasse des relevés de printemps a été récoltée dans les divisions 3Ps et 3O de l'OPANO, dont 2/3 dans 3O. Les indices de biomasse et d'abondance fluctuaient à un faible niveau en 1979 et ont atteint un pic en 1988. L'indice de biomasse a alors chuté à un creux en 1992-1993; il fluctue beaucoup depuis, en particulier dans le cas du chalut Campelen. L'abondance a atteint un pic en 2000, se chiffrant à presque deux fois celle observée l'année précédente. De telles variations brusques d'une année à l'autre ne reflètent probablement pas des fluctuations marquées dans la population; elles semblent plutôt indiquer qu'il existe peut-être des problèmes de capturabilité. Le poids moyen de la baudroie a atteint un pic à la fin des années 80 correspondant au pic de la biomasse. Il a diminué depuis 1996. Une pêche canadienne expérimentale de la baudroie au chalut a contribué à une augmentation des débarquements en 1991. Une pêche dirigée aux filets maillants a commencé en 1993. Le quota de 200 tonnes métriques mis en vigueur en 1995-1997 a été éliminé en 1998. Les débarquements ont augmenté de 1993 à 1998 (sauf en 1995). Pour 1998-2000, des limites de prises accessoires établies comme conditions de permis sont le principal moyen pour limiter l'effort de pêche de la baudroie. Étant donné la carence de données sur la plupart des aspects de la biologie de la baudroie et des pêches pertinentes, il est difficile de déterminer l'état de santé du stock et si le taux d'exploitation est approprié. Même du point de vue de l'approche de précaution, le rapport des prises commerciales aux estimations de la biomasse issues des relevés de recherche semble être peu élevé dans les dernières années. Aucune donnée n'est présentée qui pourrait suggérer que les niveaux actuels de pêche ont d'importantes répercussions néfastes sur la baudroie. La fermeture de la pêche à cause de prises accessoires trop élevées d'espèces visées permet de réglementer la pêche de ce stock.

INTRODUCTION

Biology: The monkfish or goosefish (*Lophius americanus*) is a member of the Lophiidae, a family generally inhabiting warm slope regions. *L. americanus* is distributed from Florida to the Labrador Shelf. Most of the studies done on this species have been done in US waters where such aspects as reproduction, growth, distribution, migration and stock structure have been examined (reviewed by Steimle et al. 1999). A closely related European species *L. piscatorius*, the target of a directed fishery for many years is also well documented.

In Canadian waters, studies on this species are limited. Elsewhere, it has been found in depths from the tide line down to about 650 m. Armstrong et al. (1992) reported specimens as deep as 800 m in USA waters. It has been found in temperatures from 0-21^{0}C (Scott and Scott 1988), although the preferred temperature for the species is 6-10^{0}C (based on observations in US waters, Steimle et al. 1999). Although occasionally found as far north as the Labrador Shelf, it is distributed largely on the southwest slope of the Grand Banks, throughout the Gulf of St. Lawrence, on the Scotian Shelf and in the Bay of Fundy, and south to northern Florida.

The stock structure of monkfish is largely unknown. There is no evidence of distinct stocks in the western Atlantic. On the Grand Banks, the northern most part of where it is found in relatively dense concentrations, its distribution is restricted mainly to the southwest slope and adjacent Laurentian Channel (Kulka and Deblois 1996). Survey distributions do not indicate a discontinuity with fish to the south and west. Degree of mixing with monkfish on the Scotian Shelf is unknown. There appears to be no seasonal difference in the way monkfish are distributed based on Grand Banks spring and fall surveys although Hartley (1995) noted a winter-spring offshore migration in the Gulf of Maine to avoid cold waters.

Spawning has been reported over much of its range (Steimle et al. 1999). Off Nova Scotia, spawning was reported to occur from June to September (McKenzie 1936). Eggs are deposited at the surface in large mucous sheets, sometimes containing more than 1 million eggs. Upon hatching, larvae with enlarged dorsal head spines and pelvic fins float to the surface spending several months in a pelagic phase then settle to the bottom as post-larvae. Young stages have been found from Cape Hatteras to as far north as the northeastern edge of the Grand Banks.

Growth appears to be fairly rapid and similar between sexes. Information mainly from other areas suggests they reach a length of about 11 cm (3 inches) at age 1, 40 cm at age 3 and a lengths of about 76 cm (30 inches) and 102 cm (40 inches) at ages 7 and 10 respectively. Monkfish is thought to be a relatively short lived species with a maximum age of about 11 years. The largest specimens weigh about 27 kg. Studies exist on age, growth and reproduction for fish sampled from Cape Hatteras to Georges Bank (Armstrong *et al.* 1992, Hartley 1995). Monkfish reach maturity in their 4th to 7th year. Spawning occurs between March and September depending on area. Length/Weight relationships have been developed for northeastern US fish (Almeida *et al.* 1995). Most recently, Steinle *et al.* (1999) provided information on life history and habitat characteristics for the northeast USA. A description and status of monkfish was provided by Beanlands and Annand (1996) for the Scotian Shelf, and by Gregoire (1998) for the Gulf of St. Lawrence. Distribution and trends in relative abundance on the Grand Banks were reviewed by Kulka and Deblois (1996), as a preliminary assessment of the species in this area. The current document represents an update and expansion of that work.

The fishery: Directed fisheries for monkfish exist along much of the shelf and slope waters from the Carolinas north to the Grand Banks. At the 31st Northeast Regional Stock Assessment workshop, USA (Anon. 2000), concern was expressed that monkfish has been overfished in American waters. Catch and effort for that species has steadily increased since the 1980's leading to a truncation in the size distribution. Beanlands and Annand (1996) for the Scotian Shelf, and by Gregoire (1998) for the Gulf of St. Lawrence indicated the recent development of a directed fishery for monkfish in their respective area. Concern was expressed regarding potential over-exploitation in the respective areas as landings rose rapidly after 1995. As well, very large amounts of small monkfish were recorded as bycatch in the scallop dredge fishery on the Scotian Shelf.

The fishery in NAFO Div. 3LNOP is much smaller than the US and Scotian Shelf fisheries where monkfish are much more widely distributed. For the Grand Banks, prior to 1991, monkfish was not targeted in a directed commercial fishery, but was a common bycatch in some groundfish fisheries, primarily in NAFO Div. 3O and 3P (Kulka, 1982, 1984, 1986a and b). Most of the catch records during those years relate to bycatch in otter trawls. Since the early 1990s, however, following the decline of many major species, monkfish has become a target for commercial effort (Kulka and Deblois 1996). Canadian landings increased sharply in 1991, as markets were developed for this species. A closely related species *Lophius piscatorius*, (once thought to be the same species) that inhabits the northeast Atlantic is a delicacy in several European countries, and this is where a potential market for *L. americanus* products exists. Churchill (1994) reported on the experimental fishery on the Grand Banks in 1993 and 1994, which led to a limited directed fishery for monkfish prosecuted mainly by large mesh gillnet. A precautionary quota of 200 mt was imposed in 1995-1997. Since then, the fishery has been regulated only by bycatch restrictions.

This paper provides an examination of the trends in biomass and abundance for monkfish from 1995 to 2000, and data from 1971 to1994 is updated (see Kulka and Deblois 1996). The paper also examines the distribution of this species northeast of the Laurentian Channel, on the Grand Banks, Labrador Shelf, and as far north as Nain Bank (Fig. 1), back to 1951. These distributional analyses can serve industry by providing information on good fishing locations for developing fisheries. More importantly, it provides baseline biology for *L. americanus*, allowing comparisons with any subsequently observed patterns to determine population changes. Landings information are presented back to 1985 and fishing grounds are mapped back to 1985. Limited information on size of monkfish in the catch is also presented.

METHODS

Catch data on monkfish have routinely been collected during research surveys in waters around Newfoundland employing a random stratified survey design. A summary of the survey design, adopted after 1970 by the Newfoundland region can be found in Doubleday (1981). While survey design has since remained constant, strata have been added to the survey area in recent years, along with modifications to some of the original strata. These modifications are described in Bishop (1994). Also, there was a change in standard survey gear after the spring 1995 survey, from Engels 145 to Campelen 1800 bottom trawls that profoundly affected catchability for all species. Conversion factors to standardize between gears, the amounts and sizes of fish caught were subsequently derived for major commercial species, but not for monkfish. Thus, catch rate data and biomass and abundance indices are on a different scale that begins in the fall of 1995. This change also affected gear selectivity of fish by size for the major species. However, any effect on size selectivity of monkfish is unknown, since this species has not been measured for length in past surveys. In this paper, the gear change is delineated on tables by a vertical line, and on figures by a vertical bar. It is important to understand that the period prior to fall 1995 is not directly comparable to fall 1995 and afterwards. Either a CTD, BT, or XBT hydrographic sampling device was used to record bottom temperatures at all survey locations. These data were used to examine the relationship between monkfish distribution and temperature, as described below.

Trawl data from spring stratified random surveys in Divisions 3LNOPs were used to estimate biomass and abundance, and examine trends in average size (biomass/abundance) of monkfish from 1977 to 2000. Fall data were not used for this analysis because NAFO Div. 3P, an important area for monkfish is not surveyed in the fall. STRAP (Smith and Somerton 1981) was used to estimate biomass and numbers of monkfish by areal expansion within a series of predefined strata, partially related to depth. These strata estimates are then added over the survey area. Extra sets, which are not part of standard surveys, have recently been added to some strata for diurnal research. These represent a deviation from the proportional allocation of survey sets, but do not differ in sampling protocol. Diurnal sets are included in all STRAP estimates. The survey area also changed in extent over the years, primarily due to the addition of inshore and deepwater strata. An analysis of monkfish catch at depth (elaborated below) was performed to determine if the addition of shallow and deepwater sets could affect abundance and biomass indices among the years when the survey area was changing. The area surveyed in 1996-99 was 294,589 km^2, in 1994-96 was 283,321 km^2 and in 1986-93 was 255,542 km^2 (Bishop 1994).

For analysing monkfish distribution, the same data was used as for biomass and abundance estimations, plus additional Campelen sets from special August surveys in Div. 3Ps that primarily covered the Laurentian Channel. These extra sets were grouped with fall data. This provided a more complete picture, because monkfish is distributed continuously across the Laurentian Channel onto the shelf in NAFO Div. 4Vn. Grouping data from the two time periods is logical since monkfish tend to show little inter-annual movement (fall and spring distributions almost completely overlap).

SPANS GIS was used to investigate:

a) spatial distribution of monkfish (Engels sets, 1951-1994, summarized by 5 year intervals only for spatial distribution, in addition to more recent Campelen sets presented annually as well as combined);
b) monkfish distribution in relation to bottom temperature; and
c) distribution in relation to depth from research survey data (Campelen sets for the fall 1995-1999and 1996-2000 for spring, for spatial distribution and distribution in relation to temperature and depth).

Distribution plots (density surfaces showing where fish were more abundant by darkening grey shades) and bottom temperature contours were produced using potential mapping in SPANS, a GIS (Geographical Information System, Anon 1997). Catch rates (kg per standard tow) for individual survey sets (point data) were converted to surfaces (classified maps), depicting differing levels of fish density using potential mapping. The strata class bounds (catch per tow legend values) were held constant across years (a single legend for all years), so that different amounts of each grey shade (which represent a density level) would vary and reflect relative changes in density. In the resulting maps, darkest areas represent the highest density of monkfish (highest catch per tow), which fade to light grey, representing the lowest density. White areas depict no catch. Five year averaged distribution plots using fall and spring research data were done for 1951-1994. Multi-year averaged distributions were also plotted for fall (1995 to 1999, combined) and spring (1996 to 2000, combined). As well, annual plots were done for 1995-2000. For this recent period, black dots overlaying the map's surface show where the survey sets occurred.

Bottom temperature maps were created using potential mapping in SPANS for both spring and fall using 15 strata of equal size, varying from –1.3 to 5.2+ ^{0} C. These comprised the temperature strata. Details of the mapping method are elaborated in Kulka (1998). Distribution in relation to depth was determined by calculating average kg per standard tow within each of the depth strata (0-50, 51-100, 101-150, 151-200, 201-250, 251-300, 301-350, 351-400, 401-450, 451-500, 501-600, 601-700, 701-800, 801-900, 901-1000, 1001-2000 m). The survey catch rate (kg per tow) and point (survey set) data were overlaid on density/temperature/depth strata, then averaged within each stratum to yield a measure of density of monkfish by stratum.

To calculate biomass within temperature and depth intervals, the method used is very similar to the STRAP method (Smith and Somerton 1981), employing areal expansion. The technique overlays local density data (kg per standard tow) from survey sets on a surface depicting fish density/bottom temperature/depth intervals. Biomass analyses were not dependent on pre-specified strata, as required for STRAP calculations. Instead, set data were pooled into post-stratified categories or strata. The result was a larger number of sets per stratum (average 47 sets per depth interval per year; 40 per temperature stratum per year) for density and biomass calculations. Mean catch per tow in each stratum is adjusted to stratum area, then summed over all strata to estimate biomass.

Information on monkfish removals in Canadian waters was obtained from three sources:

a) Canadian landings were compiled from statistical records in Zonal Interchange Format (ZIF) files. Data were summarised by gear, area and month for 1985 to 1999, and information to date for 2000.
b) Non-Canadian catches are based on information reported to NAFO information.
c) Amounts discarded at sea were estimated from observer records (see description of observer coverage below).Observer data were also used to quantify non-Canadian catches within the 200 mile limit.

Since the start of the directed Canadian commercial monkfish fishery in 1993, observers have been deployed to cover approximately 8% of the effort. Observers collected set by set information on catches as per methods described in Kulka and Firth (1987; updated in annual unpublished versions of the Newfoundland Observer Program Training manual).

Observer data were used to examine discarding, distribution of fishing effort and catch rates. Discards from Canadian fisheries inside 200 miles were calculated by applying the proportion of monkfish catch to groundfish landings (kept fish, all species) in the observer database to the reported landings of groundfish in ZIF files. These were then summarised by division and year. Also, monkfish catch (kept plus discards) of non-Canadian vessels inside 200 miles were extracted from fishery observer reports. Observers have been placed on nearly all non-Canadian vessels fishing in Canadian waters. The potential mapping method described above was used to create distribution maps of observed fishing activity (catch rate over area by gear). Fishing grounds were compared to monkfish distribution as determined from research vessel surveys.

RESULTS AND DISCUSSION

Distribution: Fig, 2a-c, based on combined spring and fall research vessel survey data show the 5-year averaged distribution maps of monkfish for 1951 to 1994. Fig. 3a shows annual fall distribution for 1995 to 1999, plus a 5-year composite. Fall surveys do not cover the bank area of 3Ps but Campelen sets targeting redfish in the Laurentian Channel largely cover the distribution of monkfish in 3P. Fig. 3b shows annual spring distributions for 1996-2000, plus a 5-year composite.

The observed distributions are:

a) consistent over time;
b) consistent between surveyed seasons; and
c) largely restricted to the southwest slope of the Grand Banks, the western slope of 3P and the adjacent Laurentian Channel.

Monkfish is near its northern distributional limits on the Grand Banks and in the Gulf of St. Lawrence. It is found primarily along the southwest slope of the Grand Banks, the western slope of St. Pierre Bank, and in the Laurentian Channel, the western most extent of the surveyed area where monkfish are concentrated (see fall survey maps) is directly adjacent to concentrations on the eastern Scotian shelf as reported by Beanlands and Annand (1996). It is also caught sporadically along the lower southeast slope, on the bank area, and in the deeper (warmer) areas of the northeast Newfoundland and Labrador Shelf.

Monkfish do not form dense aggregations, so survey data tend to be somewhat patchy and variable. This pattern has been consistent since the 1950s. There is no evidence of a shift or a reduction in the extent of its distribution over the past 50 years, as was seen for many northerly distributed species. Comparisons of survey data in the spring and fall periods of 1995-2000 show very similar patterns, suggesting that there is little or no seasonal change in monkfish distribution on the Grand Banks. However, Hartley (1995) indicated that monkfish in the Gulf of Maine was observed to undergo a limited seasonal migration to shallower water in summer and deeper water in winter to avoid colder temperatures. Beanlands and Annand (1996) indicted that similar movements were not observed on the Scotian Shelf. Similarly for the Grand Banks, no seasonal movements were detected. A comparison of fall versus spring biomass indices in NAFO Div. 3O (an area where the surveys overlapped) did not indicate any differences in local biomass/abundance. In some years, the fall index was higher, in other years the spring index was higher. However, given the wide separation between survey sets (on average about 18 km), the relatively few sets where monkfish were captured and limited seasonal nature of surveys, data resolution may not be sufficient to identify small seasonal movements. If related to bottom temperature, it is unlikely that Grand Banks monkfish would undergo a migration because bottom waters are seasonally quite stable where monkfish are found (see description below).

Monkfish distribution at depth has changed over the years. Kulka and Deblois (1996) showed that the average depth at which monkfish were caught during research surveys was 200 m for 1976-85. They became distributed more deeply at 275 m during 1986-1990, and at 325 m for 1991-1994. During 1995-1999, monkfish were found at depths between 100 and 700 m, averaging 270 m. (Fig. 4). This change to deeper waters after the mid-1980's followed by a return to shallower depths may be related to a cooling trend during the mid-1980s, since bottom temperatures tend to be warmer in deeper waters.

Biomass was found to be bimodally distributed, peaking at 125 and 375 m. This bimodality suggests that the population may be segregated by size or sex. Data on lengths or sex of monkfish are not available from the surveys to determine if this bimodality is related to life stages such as adults vs. juveniles, or sex. However, mean size (weight of monkfish/numbers) at depth was used as a proxy to examine life stages at depth. Fig. 5a shows that fish at less than 250 m representing the 125 m mode were of similar mean weight compared to fish from the 375 m mode. On average, over all years, mean size of monkfish was very similar within the two depth ranges: 3.35 kg (58 cm, refer to Fig. 14) in less than 125 m and 3.02 kg (56 cm) in greater than 125 m. As well, monkfish sizes were also distributed evenly with respect to bottom temperatures. Fig. 5b shows no trend in mean size with respect to bottom temperature and was consistent among years. This suggests that monkfish do not segregate by size. Thus, all ages that are captured by the survey trawls are intermixed.

The depth distribution observed on the Grand Banks contrasts with observations in US waters. The 31st Northeast Regional Stock Assessment Workshop (Anon. 2000) showed that monkfish were distributed much more widely on the shelf, from the shoreline to about 200 m. the majority of the population was found in less than 200 m. This was also the case on the Scotian Shelf where Beanlands and Annand (1996) reported monkfish across much of the shelf. This significantly different pattern is related to warmer bottom temperatures found over a wider area in the more southerly waters (refer to the following section).

Very cold conditions typify the near bottom waters of a large proportion of the Grand Banks (Fig. 6, Fig. 7, upper panel). The exception is an area along the southwest slope and on the Southeast Shoal. Monkfish is a species that over its entire range typically occupies temperatures in the 3-10^0 C range (Beanlands and Annand 1996). Thus, monkfish would be expected to occupy only a small proportion of the Grand Banks i.e. where bottom waters were warmest along the southwest slope (Fig. 7). This was observed to be the case. Data from 1995-1999 shows that the highest densities (kg per tow) of monkfish were in bottom waters exceeded 4^0 C. Although a large proportion of the Grand Banks was covered by bottom waters less than 3^0 C (88% in spring and fall), the large majority of monkfish biomass (81% in spring, 70% in the fall) was found in waters warmer than 3^0 C. Fall surveys occasionally pick up monkfish north of the Grand Banks. These catches are invariably taken in the deeper trenches on the shelf or along the slope where bottom temperatures usually exceeds 3^0 C. Monkfish were also taken in some of the deepwater slope fisheries to the north: it was not an uncommon bycatch in the turbot and grenadier fisheries of the 1980's north of 49^0 Lat. and as far north as 55^0 Lat. where depths exceeded 800m and bottom temperatures exceeded 3^0 C (refer to Fig. 3 and 14). Thus, there is a component of the population that occupies deep waters over a much wider range of latitudes. What proportion of the total population that it comprises is uncertain but is likely small. The deep water northern biomass is not included in the biomass and abundance estimates described below.

Annual Survey Biomass and Abundance Estimates: There has been an expansion of the area surveyed in recent years by the addition of nearshore as well as offshore slope sets. However, effect of this expansion of surveyed area on the abundance and biomass indices of monkfish should be minimal. Fig. 4. shows that monkfish on the Grand Banks are largely restricted in their distribution to depths between 100 and 650 m and this distribution corresponds to the range of depths that have been surveyed over the longer term. Thus, expansion of survey extent in recent years would not significantly affect estimates of monkfish biomass and abundance given that most of the population is found within depths that were surveyed consistently over the long term. However, the change in survey gear in 1995 did create a discontinuity in the time series. As described in Methods, 1996-1999 biomass and abundance indices are not comparable to previous years, due to a change from Engels to Campelen trawl survey gear. Interannual variability in both indices is even more pronounced during Campelen years. As well, the smaller apparent change in biomass between Engels and Campelen years as compared to abundance, suggests that Campelen gear captures smaller monkfish on average. This would be expected because a Campelen trawl has a much smaller mesh size relative to Engels.

On average (1977-2000), 99.6% of biomass from spring surveys occurred in NAFO Div. 3Ps and 3O, with 66% in 3O. Monkfish biomass and abundance indices (Figure 8 and Table 1) were at a low in 1979, and increased steadily to a peak in 1988. Biomass then fluctuated downward until reaching a low in 1992-93. Since then, the index has fluctuated widely, particularly from the Campelen gear. 2000 represents a year of peak abundance, almost double that of the previous year. Such abrupt changes from year to year likely do not reflect dramatic fluctuations in the population. Rather, these changes suggest that there may be a catchability issue for this species. It does not seem reasonable that biomass could, for example, decrease by 4 times between two successive years (1991-1992) and double or halve its abundance between years. The answer may rest with the behaviour of the species. Monkfish spend much of their time motionless on the bottom (camouflaged by the substrate), waiting for prey to come within striking range. This lifestyle may result in low catchability for monkfish due to escapement under the trawl footrope. As well, the number of monkfish caught per survey set is low, and thus only a few fish can make a substantial difference to resultant indices. These factors could partially explain large inter-annual changes in the indices, and may also suggest a substantial underestimation of stock size. These factors further complicate using the survey indices to monitor the status of monkfish.

Fig. 9 shows recent trends in size of monkfish. Mean weight peaked in the late 1980's in conjunction with the peak in biomass. It has declined since 1996 in both NAFO Div. 3O and 3Ps to an average low of about 2 kg (48 cm). Monkfish caught in research vessel surveys were not measured for length, and thus changes in mean weight cannot be related to fish length composition in catches i.e. whether the recent decline in mean size is related to an increase in numbers of juveniles (recruitment) or an decrease in adults (reduction in spawner biomass). It should also be noted that post-1995 sizes cannot be compared to earlier year because of the change in selectivity of the survey gear.

Commercial Fisheries: Until 1991, monkfish were taken only as bycatch in gillnet and trawl fisheries and was largely retained by non-Canadian fleets but discarded by Canada. Substantial amounts of monkfish were reported from the NRA (non-regulatory area outside 200 miles) by non-Canadian fleets prior to 1994 but has been null since. This suggests under reporting in later years. Beginning in 1991, Canadian experimental trawl fisheries for monkfish contributed to an increase in monkfish that was landed (Fig. 10 and 11). A directed gillnet fishery (not regulated by quota) began in 1993. In 1995, a 200 metric tonne quota was instituted for the emerging fishery. The quota was kept in place for 1996 and 1997 but was removed in 1998. Effort has been unregulated although it is mandatory that all landings are recorded by dockside monitors. Landings increased from 1994 to 1998 (except 1995). In 2000, bycatch restrictions as per the conditions of licence are the primary limitation on effort in the monkfish fishery.

Originally exploited by trawl, the majority of effort shifted to gillnets following a successful experimental fishery in 1993-1994 (Churchill 1994) employing large mesh gear. In 1999, monkfish landings in both directed and non-directed gillnet fisheries decreased. In 2000, nine vessel operators were licensed to take part in the mixed monkfish/skate/hake fishery but as in past years, it was often closed due to the high bycatches of restricted species, namely cod and haddock.

As part of a mixed monkfish/skate fishery often with a substantial bycatch of white hake, cod, pollock and plaice, monkfish are landed from Div. 3O and 3Ps primarily from gillnets (Table 3). This reflects their southerly distribution and overlaps with skate. When directing for monkfish/skate, the daily bycatch restriction for plaice, yellowtail cod and witch is 5% and longer term closure rules apply if bycatch levels exceed 10 an 15%. Special restrictions also exist for pollock for NAFO Subdivision 3Ps. Monkfish is also taken as bycatch with directed trawl fisheries for skate and white hake.

Fig. 12 shows that trawls, predominantly used during the earlier years of the fishery (1991-1993) were employed mainly during the winter months. Gillnets predominated as the gear of choice after 1993 and effort occurred primarily during Apr.-Jul. due to season restrictions. In 2000, fishing outside 12 miles was restricted to May 15 and later. Thus, seasonality observed in the fishery related to regulatory restrictions rather than stock availability.

Length frequencies from commercial catches show that monkfish captured in gillnets ranged in size from 43 to 118 cm (130 in 1993) based on information from 1993-2000 (Fig. 13). There are no comparative data from earlier years in either directed or non-directed fisheries. The range of sizes in the commercial catch is quite similar to what was observed in the fisheries of the Scotian Shelf and in US waters (Beanlands and Annand 1996, Anon. 2000). The exception, 1993, the first year of the experimental fishery, there was a significant proportion of the catch that exceeded 110 cm. These larger fish were largely absent in subsequent years although gear used to prosecute the fishery was similar among years. Whether this was a result of the an increase in exploitation in the previous two years is uncertain.

Notable is a large pulse of fish in 2000 averaging about 60 cm, a mode not seen in previous years. These small fish are about 4-5 years old just reaching maturity (if their growth characteristics are similar to what has been observed in US waters, Steimle et al. 1999). Also, the sharp increase in abundance and decrease in mean size observed in the 2000 survey provides further evidence of recruitment. This information on size of fish in the catches is very limited and must be used with caution.

Current regulations for the monkfish/skate fishery specify that fishers are restricted to using gillnets with greater than 10 ½ in. (267 mm) inside 12 miles and 12 in. (300 mm) mesh outside 12 miles. The fishery was prosecuted outside 12 miles and thus minimum mesh observed was 300 mm. A 356 mm mesh was also employed on occasion. In 2000, the size frequency of commercial catches was bimodal, with a peak of large monkfish at 83 cm and of smaller fish at 65 cm. To determine whether this bi-modality was due to different mesh sizes used, the data from 2000 were plotted according to gillnet mesh size. The resultant frequency (Fig. 13b, upper panel) maintained a bimodal shape for each mesh size (356 mm for the directed monkfish fishery, 300-310 mm for the directed skate fishery), suggesting a similar size selectivity between meshes and a bimodal population distribution.

The 2000 fishery was observed to take place in three NAFO Divisions. Fig 13b (lower panel) shows that the size distribution of the catches was very similar among areas. This is expected because the effort was located in close proximity at or near the convergence of the three Divisions around Green Bank.

Although monkfish are not measured for length during surveys on the Grand Banks, 37 individuals were measured and weighed during the 1993-1994 experimental fishery. Fig. 14 shows the length/weight relationship for monkfish based on the information collected from commercial catches. Catch size at the low end of the spectrum, 43 cm were equivalent to 1.4 kg (aged 3) and at the upper end, 118 cm equivalent to about 26 kg or 10 years. This length-weight relationship is quite similar to what was observed in US waters (Almeida et. al 1995). They found a high degree of overlap in the relationship among different locations in US waters and also indicated that their work agreed closely with earlier studies in the same areas. This suggest a consistent weight at length relationship for the Atlantic.

Distribution maps of bycatch from commercial otter trawl and gillnet fisheries for monkfish (Fig. 15a, gillnets, 15b otter trawls, based on observer data for 1981-2000) showed that this species is caught primarily from the southwestern edge of the Grand Banks, along the shelf break, and in the Laurentian Channel. Commercial catch distribution is similar to the distribution determined from research surveys, but is more extensive. It appears that commercial otter trawls are more efficient in capturing monkfish than survey gear. No monkfish directed trawling was observed. As noted above, gillnets have been the primary gear used to capture monkfish since 1994 but the effort distribution with this gear is much more restricted to the southwestern slope of the Grand Banks near the 3O/3Ps border.

On the Scotian Shelf, a large portion of the catch is comprised of small monkfish taken in dredges directing for scallops and clams (Beanlands and Annand 1996). On the Grand Banks, the distribution of the dredge and gillnet fisheries (and fish) do not overlap. Thus the problem of bycatch of juveniles in the dredges in this area is not significant. Very few juveniles are taken in the directed gillnet fishery either on the Grand Banks or the Scotian Shelf.

An index of exploitation (total catch/survey biomass) shows considerable variability among rates between 1985 and 1995, and a less variable but declining trend from 1996 to 2000 after the Campelen survey trawl change (Fig. 16). The two index peaks, in 1987 and 1992-1993 suggest very high rates of exploitation in those two periods. In all other years (even prior to 1985) the index ranged around 0.05-0.3. The actual exploitation rate was probably considerably lower since as previously mentioned, the sedentary habits of monkfish probably result in low catchability for survey trawls. In addition, the very large catch reported in 1987 is attributed mostly to Spain in NAFO Div. 3N, a Division where the distribution of monkfish is very limited. This suggests that the 1987 reported catch may represent primarily a case of misreporting. Correspondingly, the exploitation index in that year may be biased.

CONCLUSION

In managing a commercially exploited species, it is important to have some knowledge of the reproductive biology, spatial distribution (including how catches are taken relative to its distribution), stock structure, and composition of commercial catches (amounts, lengths, ages). For monkfish on the Grand Banks, information from both research vessel surveys and commercial catches is limited, and there are no earlier studies, aside from information on distribution to develop an historic perspective on this species. Information must be extrapolated from other areas while examining of the aspects of the biology of monkfish.

Monkfish is a relatively minor species in terms of amounts taken in research surveys, and fish lengths, ages, and maturities have not been measured during the history of these surveys. With respect to commercial catches, processing of monkfish at sea (e.g., tails kept as product) prevents land-based sampling. Sampling at sea has been very limited, due to it not being a targeted species before the 1990’s and very low observer coverage since. Thus, due to its relative unimportance historically and inadequate resources to study the emerging fishery, there is only limited information available to assess the status of monkfish.

Monkfish are largely concentrated in a narrow band on the southern Grand Banks (straddling 3O and 3Ps divisional borders), with no significant seasonal shifts. This pattern of distribution appears to be stable at least since the 1950s. The distributional dynamics suggest a single stock (or one that may be tied to monkfish on the Scotian Shelf across the Laurentian Channel) No information on stock structure has been presented in this paper or elsewhere, but the current work indicates that NAFO division boundaries are not appropriate for defining monkfish management units. Stock definition, including determination of spatial boundaries, remains to be done.

Analyses of biomass, abundance, and average size by NAFO Division suggest that survey trawl gear (Engels, and particularly Campelen) may not efficiently sample this relatively uncommon species, making it difficult to compare interannual trends in biomass. Based on survey data, the population appears to have fluctuated quite widely, the most recent peak in the late 1970’s. Change in survey gear in 1995 plus apparent changes in catchalbility from year causing large interannual fluctuations (in addition to the low priority accorded this species in terms of resources for data collection and analysis (noted above) limit deductions that can be reached about the status of the stock.

Although monkfish has always been a regular bycatch in offshore fisheries, catch numbers have been low and, prior to 1991, there was no directed fishing effort. Consistent with the distribution pattern determined from research surveys, the majority of bycatch originated from the southern Grand Banks. An analysis of the ratio of total commercial catch and survey biomass (index of exploitation) indicates that, as with some other species, what affect the "newly" directed effort has had on the stock remains uncertain.

DEFICIENCIES

There remain important limitations to our knowledge of monkfish in Newfoundland waters. It is important to understand how the species is being exploited in relation to its spatial distribution. In the absence of monkfish lengths from research surveys or adequate length sampling of commercial catches, a demonstration of size-dependent spatial distribution coupled with commercial fishery catch locations to identify what part of the stock and what sizes were being targeted by the fishery was not possible.

No length measurements nor ageing of monkfish have been done in research vessel surveys, thus precluding any age dis-aggregated analyses. Biological sampling of commercial catches continues to be greatly inadequate, with only information on removals by weight available. There are uncertainties in reported landings, although this study tried to present a better accounting of monkfish catches. For these reasons, available data are not suitable for analysis by traditional stock assessment methods. In addition, much of the previous biological work such as feeding behaviour and diet, stock structure, morphology and reproduction, were based on other populations located south of the Grand Banks. Studies of early life history could also lead to a better understanding of monkfish populations. Length measurements, ageing, maturity and stock structure research would enhance our knowledge of monkfish status in 3LNOPs. Tagging work could help determine the mechanism underlying stock structure, including its relationship to monkfish in other areas. A program of sampling commercial catches before processing should be strongly supported to define monkfish removals by length and possibly age.

PROGNOSIS

Given the limited knowledge of most aspects of monkfish biology and relevant fisheries, it is difficult to determine stock health and whether the exploitation rate is appropriate. Monkfish on the Grand Banks, although never historically abundant during the surveyed period, appear to have a relatively stable distribution even after a limited directed fishery began in the early 1990's. Except for 1987, when Spain reported catching a large amount of monkfish, catches have remained relatively low. Even from a precautionary (conservative) point of view, the ratio of commercial removals and research survey biomass estimates seems to be small in recent years. Thus, there is no evidence presented here that would suggest that current levels of fishing are having a significant negative impact on monkfish. Closure due to excessive bycatch of restricted species has acted as a regulator for this stock. Should this change, catch restrictions in place in 1995-1997 would need to be reconsidered.

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Table 1. Biomass, abundance, and mean weight of monkfish in NAFO Div. 3LNOPs, 1977-2000, based on Spring surveys.

Biomass (t)					
Year	Div. 3L	Div. 3N	Div. 3O	Div. 3P	All Divs.
1977	0	0	332	1,053	1,385
1978	0	0	506	597	1,103
1979	0	0	131	370	501
1980	0	0	535	223	758
1981	0	0	71	538	609
1982	0	0	1,231	218	1,449
1983	0	0	0	1,130	1,130
1984	0	0	246	1,387	1,633
1985	0	0	682	1,098	1,780
1986	0	0	535	2,580	3,115
1987	0	0	916	2,843	3,759
1988	0	179	2,191	1,430	3,800
1989	0	0	359	1,445	1,804
1990	0	0	452	2,220	2,672
1991	0	0	909	2,187	3,096
1992	0	0	93	710	803
1993	0	0	185	474	659
1994	0	1	1,224	1,218	2,442
1995	0	0	232	1,098	1,331
1996	0	0	590	1,136	1,726
1997	0	0	1,515	2,881	4,396
1998	0	0	274	1,187	1,461
1999	0	0	1,165	640	1,805
2000			1,266	1,324	2,590

Abundance (thousands)					
Year	Div. 3L	Div. 3N	Div. 3O	Div. 3P	All Divs.
1977	0	0	123	184	307
1978	0	0	70	157	227
1979	0	0	108	142	250
1980	0	0	161	208	369
1981	0	0	18	283	301
1982	0	0	313	94	407
1983	0	0	0	421	421
1984	0	0	128	234	361
1985	0	0	129	357	486
1986	0	0	64	419	483
1987	0	0	157	412	569
1988	0	20	186	360	566
1989	0	0	44	235	279
1990	0	0	34	341	375
1991	0	0	196	425	621
1992	0	0	34	187	222
1993	0	0	29	107	137
1994	0	4	426	143	573
1995	0	0	38	167	204
1996	0	0	92	296	388
1997	0	0	461	778	1,239
1998	0	0	51	452	503
1999	0	0	509	370	879
2000			883	596	1,479

Mean Weight (kg)					
Year	Div. 3L	Div. 3N	Div. 3O	Div. 3P	Average
1977			2.71	5.71	4.21
1978			7.20	3.80	5.50
1979			1.21	2.61	1.91
1980			3.32	1.07	2.20
1981			4.00	1.90	2.95
1982			3.94	2.31	3.12
1983				2.68	2.68
1984			1.92	5.94	3.93
1985			5.28	3.08	4.18
1986			8.37	6.16	7.27
1987			5.85	6.90	6.37
1988		9.00	11.79	3.97	8.25
1989			8.19	6.15	7.17
1990			13.34	6.51	9.92
1991			4.63	5.15	4.89
1992			2.70	3.79	3.24
1993			6.32	4.41	5.37
1994			2.87	8.54	5.70
1995			6.14	6.59	6.37
1996			6.43	3.84	5.13
1997			3.29	3.70	3.49
1998			5.37	2.63	4.00
1999			2.29	1.73	2.01
2000			1.43	2.22	1.83

Table 2. Canadian and non-Canadian landings of monkfish in 3LNOPs, 1985-2000. Canadian landings are compiled from Zonal Interchange Format files. Non-Canadian landings are based on NAFO statistics. Discards were estimated from observer records. Note that 1999 and 2000 do not include non-Canadian catches, and ZIF data for 2000 are incomplete.

	3L		3N		3O		3Ps		
Year	Can	Non-Can.	Can	Non-Can.	Can	Non-Can.	Can	Non-Can.	Total
1985	7	0	3	1	35	100	79	0	225
1986	9	68	0	34	69	53	45	1	278
1987	29	5	1	1,418	16	360	142	25	1,997
1988	1	79	1	352	40	3	35	45	556
1989	1	0	12	176	71	24	128	30	441
1990	2	46	5	138	66	1	72	0	331
1991	2	0	2	281	170	5	148	0	609
1992	3	0	1	7	275	31	113	4	434
1993	0	0	4	0	449	2	47	0	502
1994	0	0	0	0	445	0	390	0	836
1995	6	0	0	0	105	0	63	0	173
1996	22	0	0	0	190	0	188	0	400
1997	0	0	0	1	395	0	158	0	555
1998	0	0	0	1	301	1	166	1	469
1999	0		0		109		67		176
2000	48		0		41		37		126

Table 3. Canadian monkfish landings in 3LNOPs, 1985-2000, by directed and non-directed modes (upper table) and by gear type (lower table). Canadian landings are compiled from Zonal Interchange Format files and discards are estimated from observer records. Note that ZIF data for 2000 are incomplete.

	3L		3N		3O		3PS		Total
Year	**Bycatch**	**Directed**	**Bycatch**	**Directed**	**Bycatch**	**Directed**	**Bycatch**	**Directed**	
1985	7		0		4		17		28
1986	8		0		22		33		64
1987	29		0		9		26		64
1988	1		0	0	9		9	0	19
1989	1		0		19	0	6	0	27
1990			0		13	0	8	0	22
1991	2		2		130		42		176
1992	3		1		247	0	91	0	341
1993			4		419	13	41	0	477
1994			0	0	399	42	160	228	830
1995	6				68	35	46	14	168
1996	16	6			56	133	37	146	395
1997	0		0		286	100	66	90	542
1998	0				189	82	59	106	436
1999			0		83	18	36	31	168
2000	48				29	7	22	15	122

	Gillnet		Lines	Other		Trawl		Seine	Grand Total
Year	**Bycatch**	**Direct**	**Bycatch**	**Bycatch**	**Direct**	**Bycatch**	**Direct**	**Bycatch**	
1985	6		0	13		8			28
1986	8		0	24		31			64
1987	27		1	17		19			64
1988	4		2	5		9	0		19
1989	0		1	4		21	0		27
1990			0	4		17	0		22
1991	1		0	4		171			176
1992	35		0	7		298	0		341
1993	22	12	0	5	1	437	0		477
1994	492	270	0	0		67	0		830
1995	60	49	0	1		58			168
1996	83	285	0			27	0	0	395
1997	307	190	0			46	0	0	542
1998	211	188	0	0		37		0	436
1999	95	49	0			24		0	168
2000	95	23	0			3			122

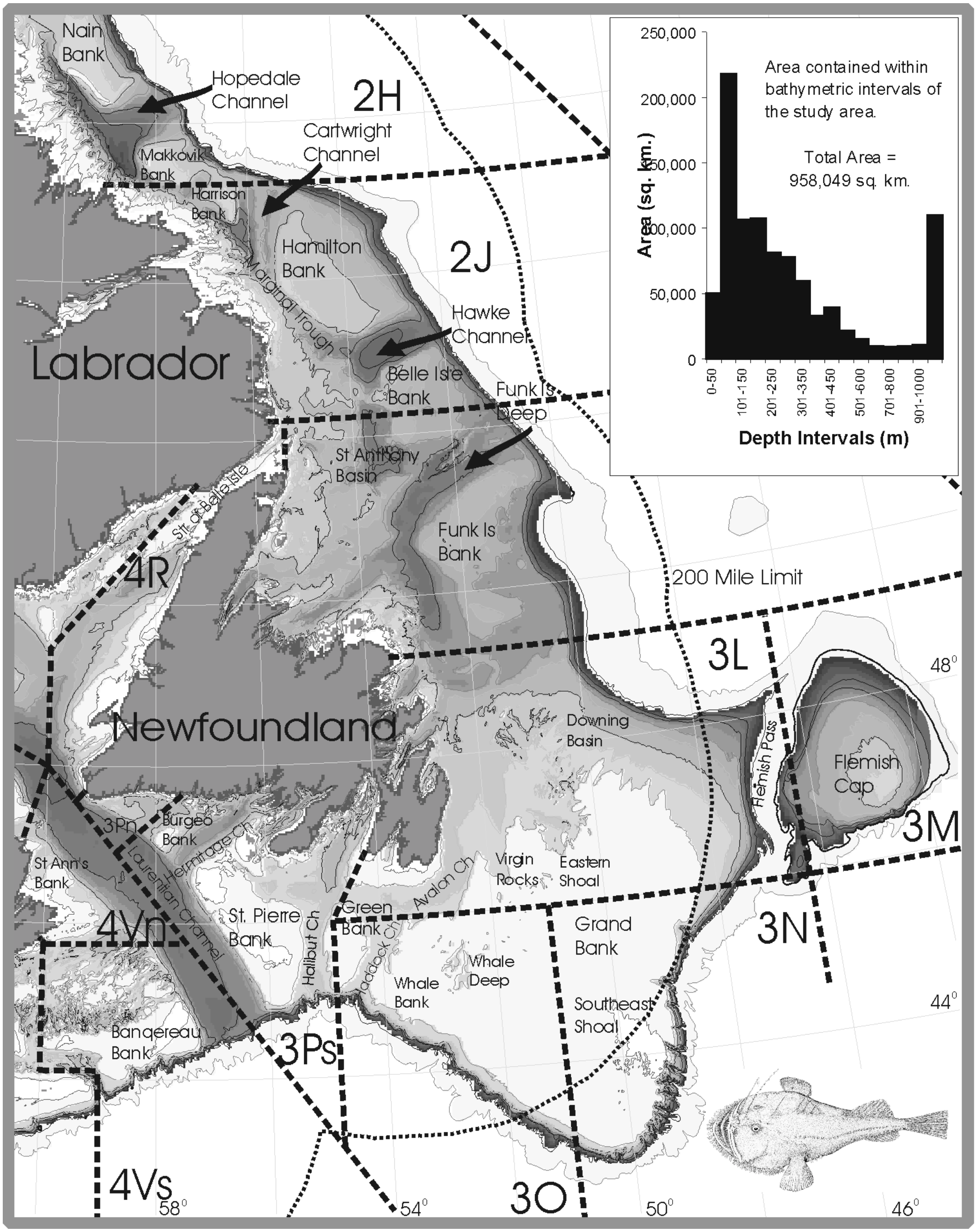


Figure 1. Study area for monkfish showing NAFO Divisions, Canada's 200-mile limit, specific locations and bathymetry.

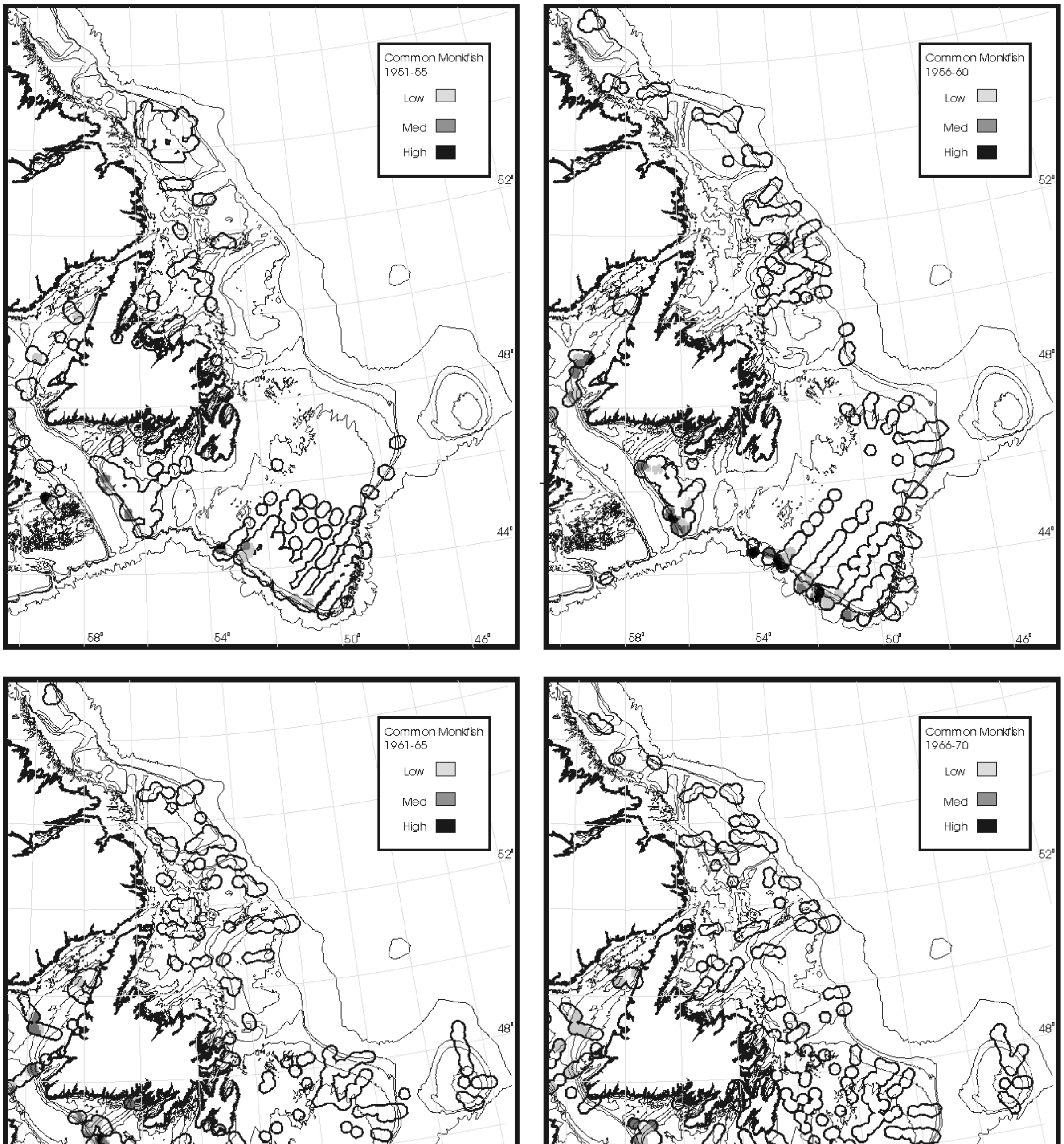


Figure 2a. Monkfish distribution from combined Spring and Fall research vessel surveys, 1951-1970, where high = > 13.5, med = 3.0 - 13.49 and low = < 2.99 kg. per tow. Catch rate categories are based on 35th and 75th percentile distribution. Thick lines enclose the surveyed areas.

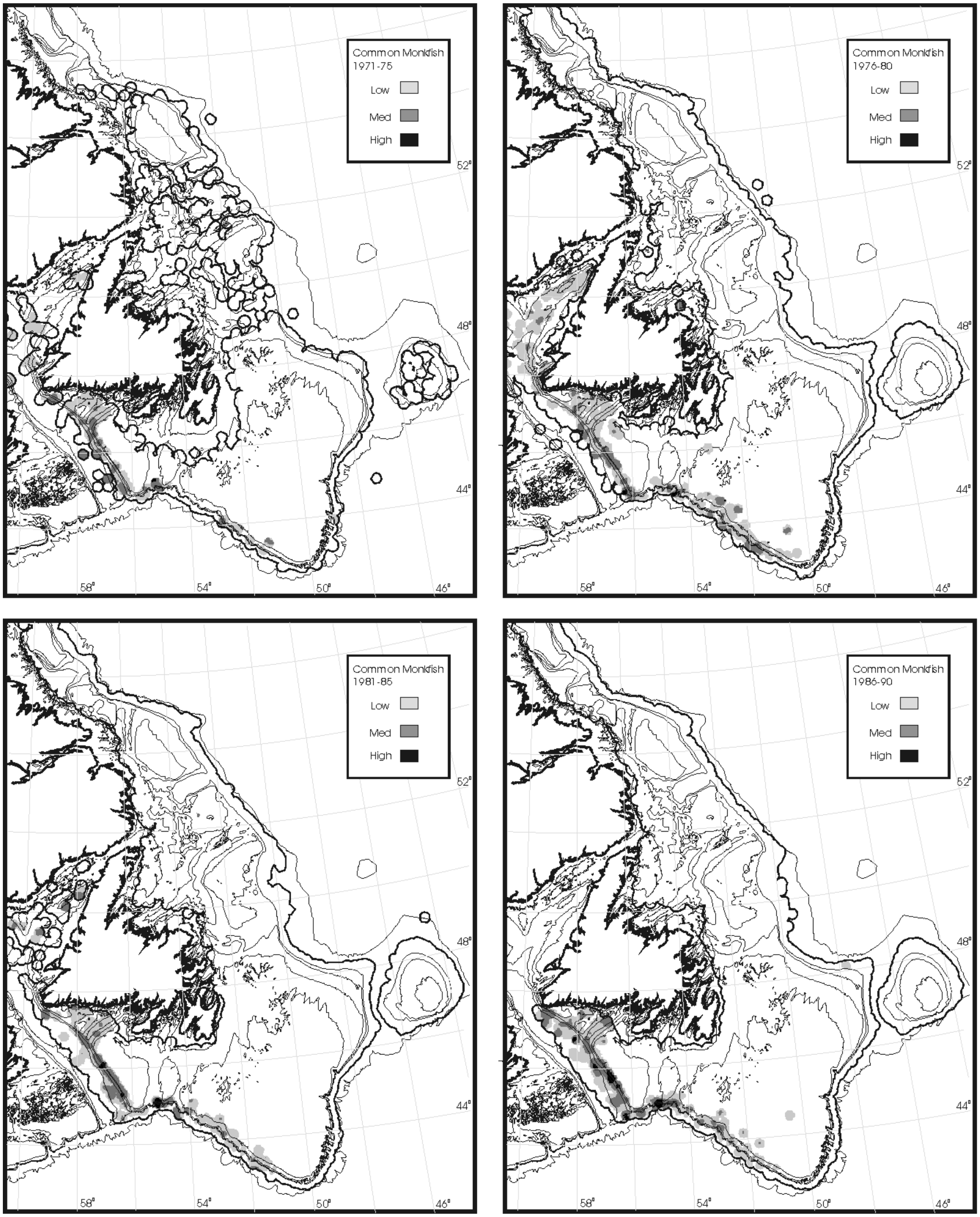


Figure 2b - Monkfish distribution from combined Spring and Fall research vessel surveys, 1971-1990, where high = > 13.5, med = 3.0 - 13.49 and low = < 2.99 kg. per tow. Catch rate categories are based on 35th and 75th percentile distribution. Thick lines enclose the surveyed areas.

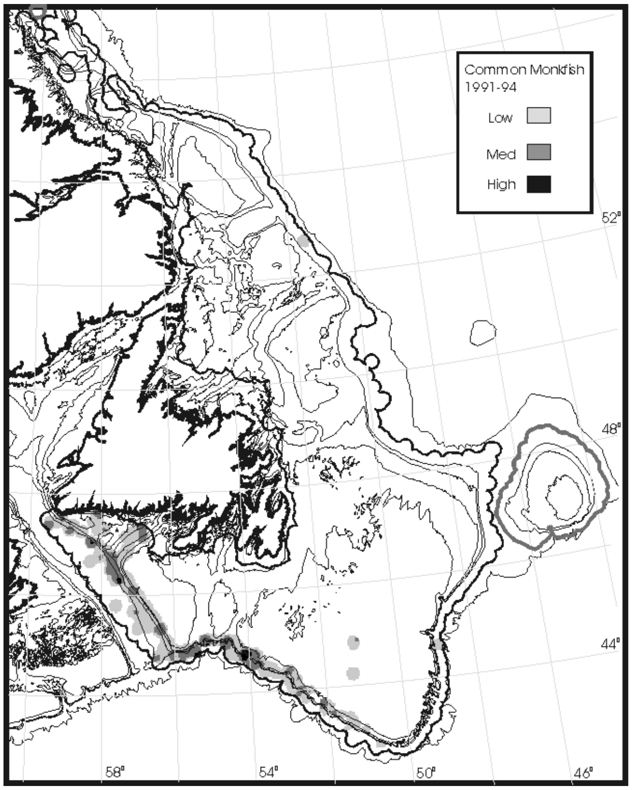


Figure 2c. Monkfish distribution from combined Spring and Fall research vessel surveys, 1991-1994, where high = > 13.5, med = 3.0 - 13.49 and low = < 2.99 kg. per tow. Catch rate categories are based on 35th and 75th percentile distribution. Thick lines enclose the surveyed areas.

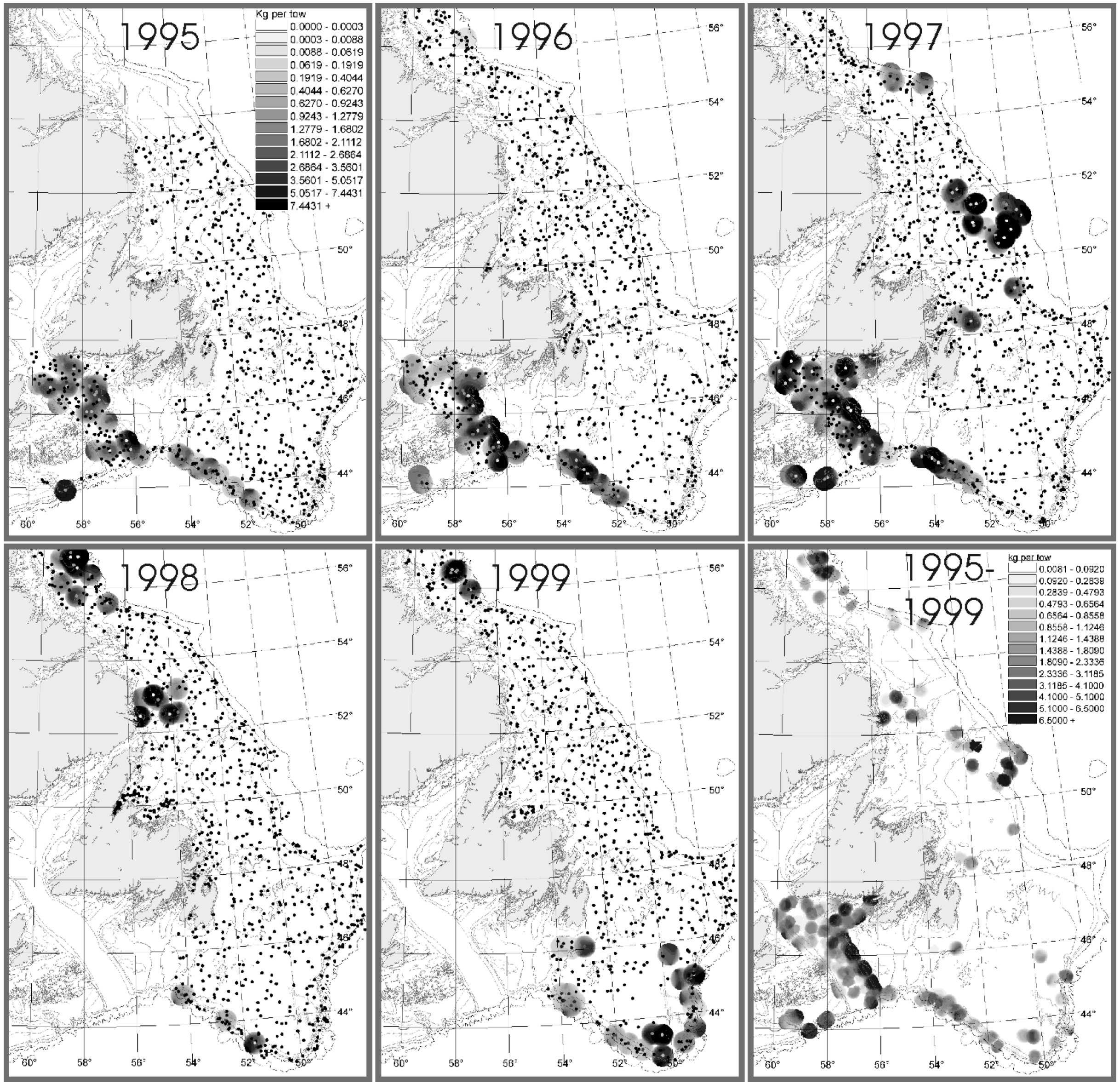


Figure 3a. Monkfish distribution from Fall research vessel surveys, 1995-1999. Denser concentrations (higher kg per tow) are depicted by darker shades as delineated by the legend. Black dots represent survey set locations.

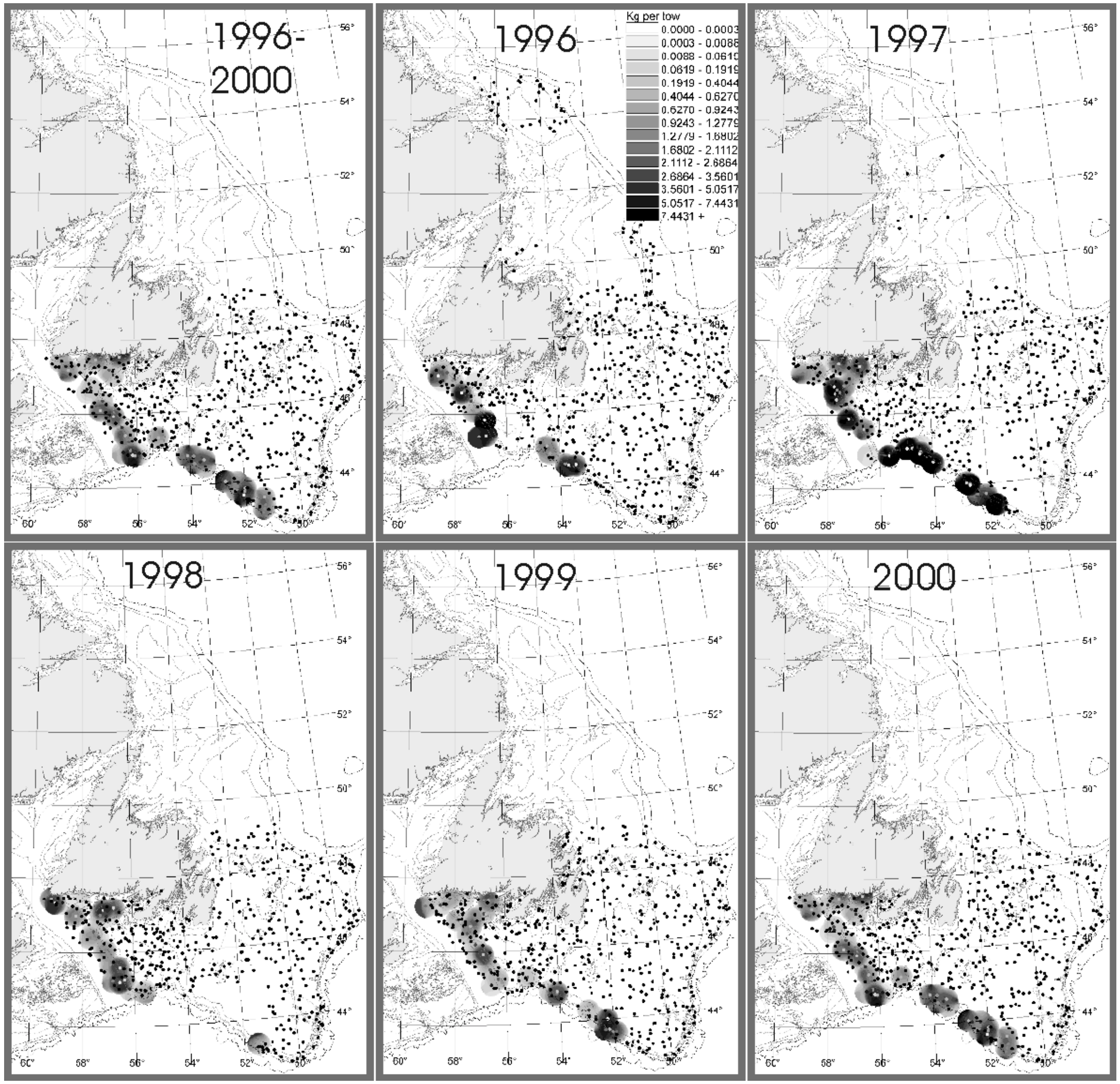


Figure 3b. Monkfish distribution from Spring research vessel surveys, 1995-1999. Denser concentrations (higher kg per tow) are depicted by darker shades as delineated by the legend. Black dots represent survey set locations.

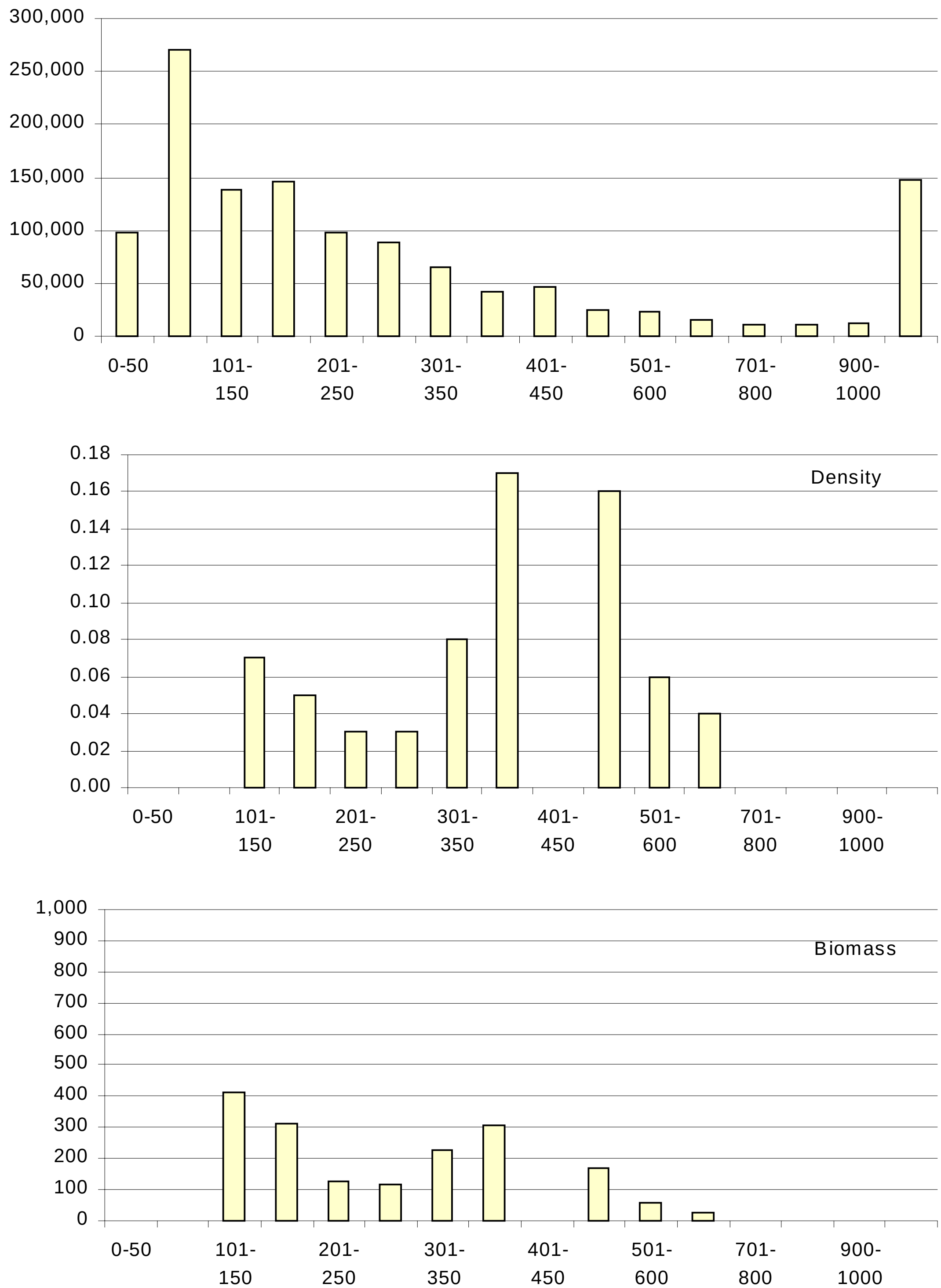
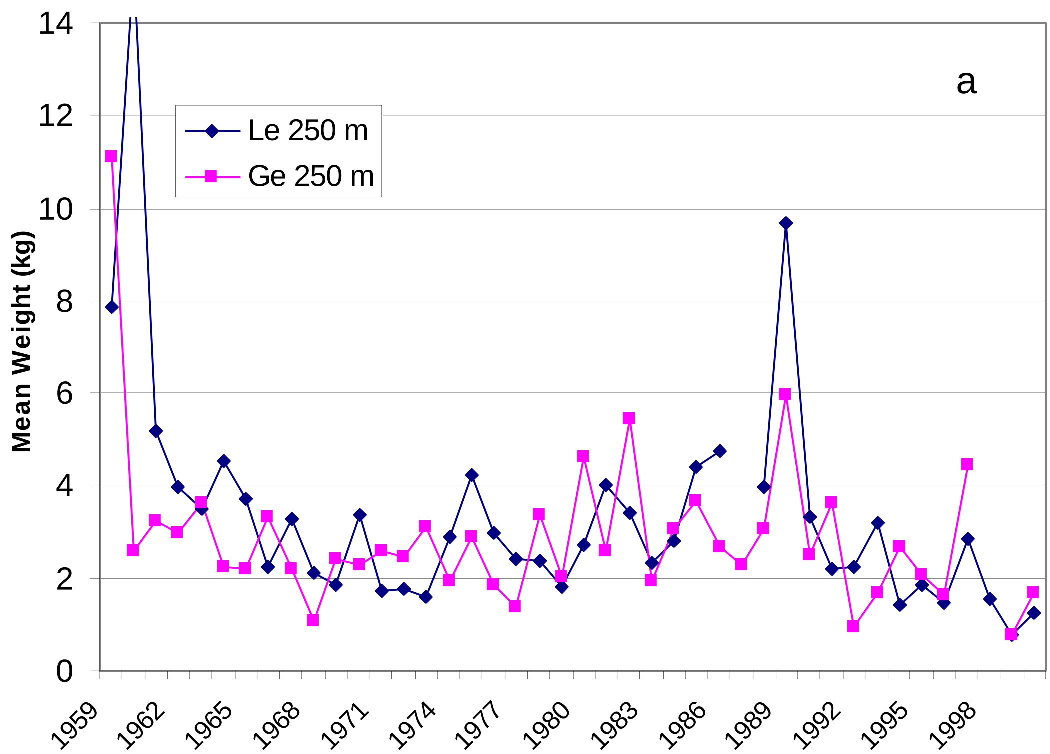


Figure 4. Distribution of monkfish in relation to depth (m), 1995-1999. Upper panel shows the available habitat (km^2 within each depth interval). Middle panel shows density (mean kg per tow at depth). Lower panel depicts biomass at depth.



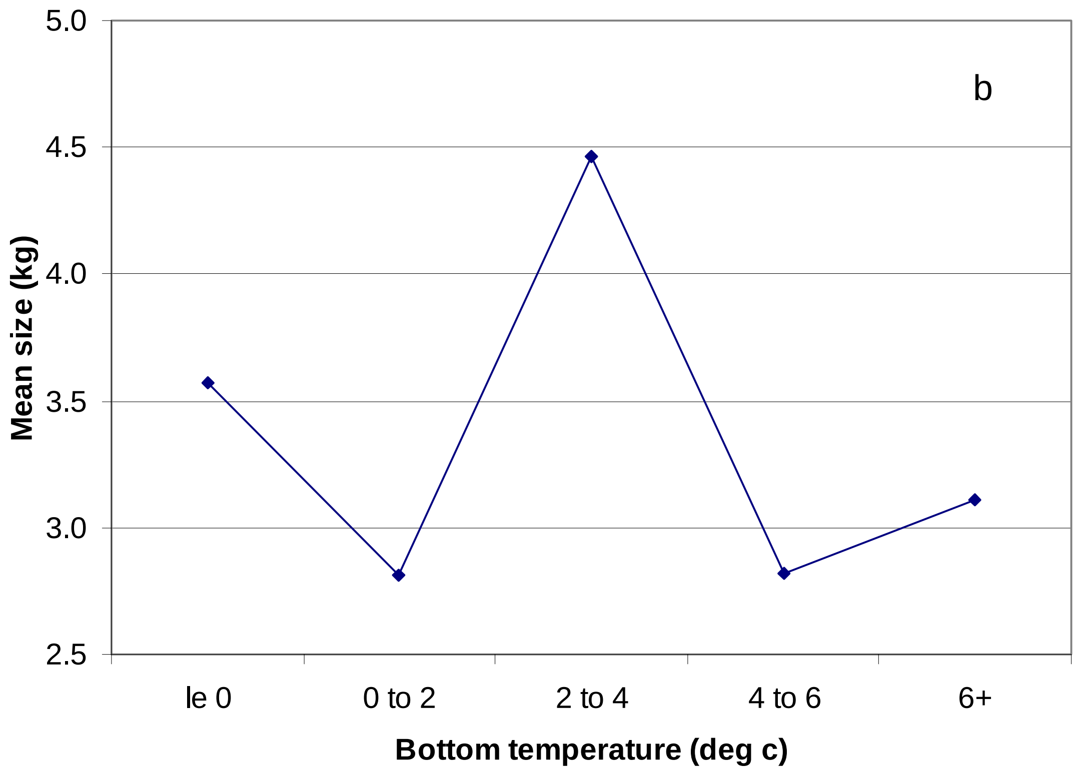


Figure 5. Mean weight of monkfish at a) depths less than 250 m (150 m mode seen in Fig. 4) and at greater than 250 m (450 m mode seen in Fig. 4) and b) by bottom temperature range.

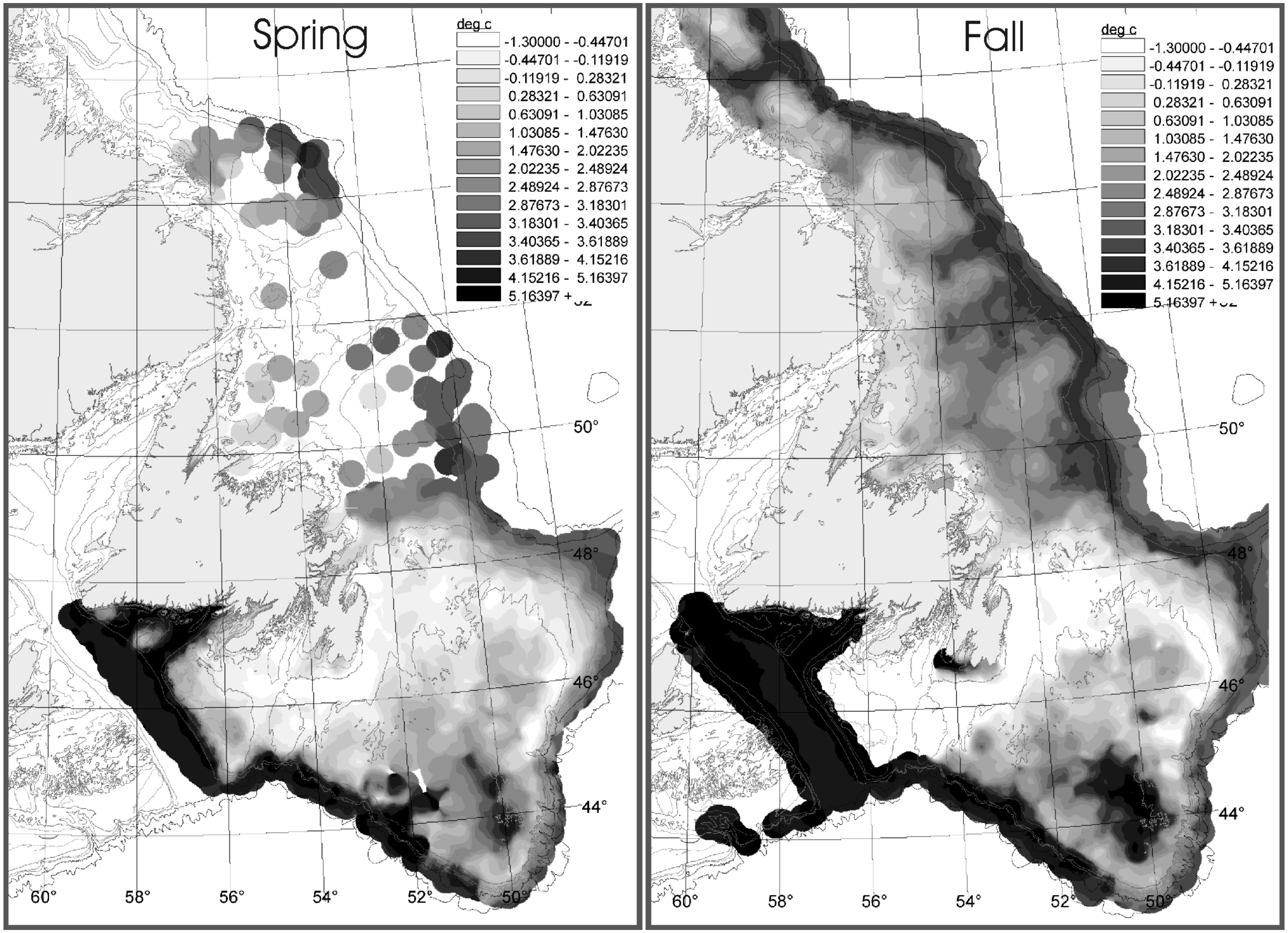


Figure 6. Bottom temperatures collected during research vessel surveys, averaged over 1995-1999 for Fall and 1996-2000 for Spring.

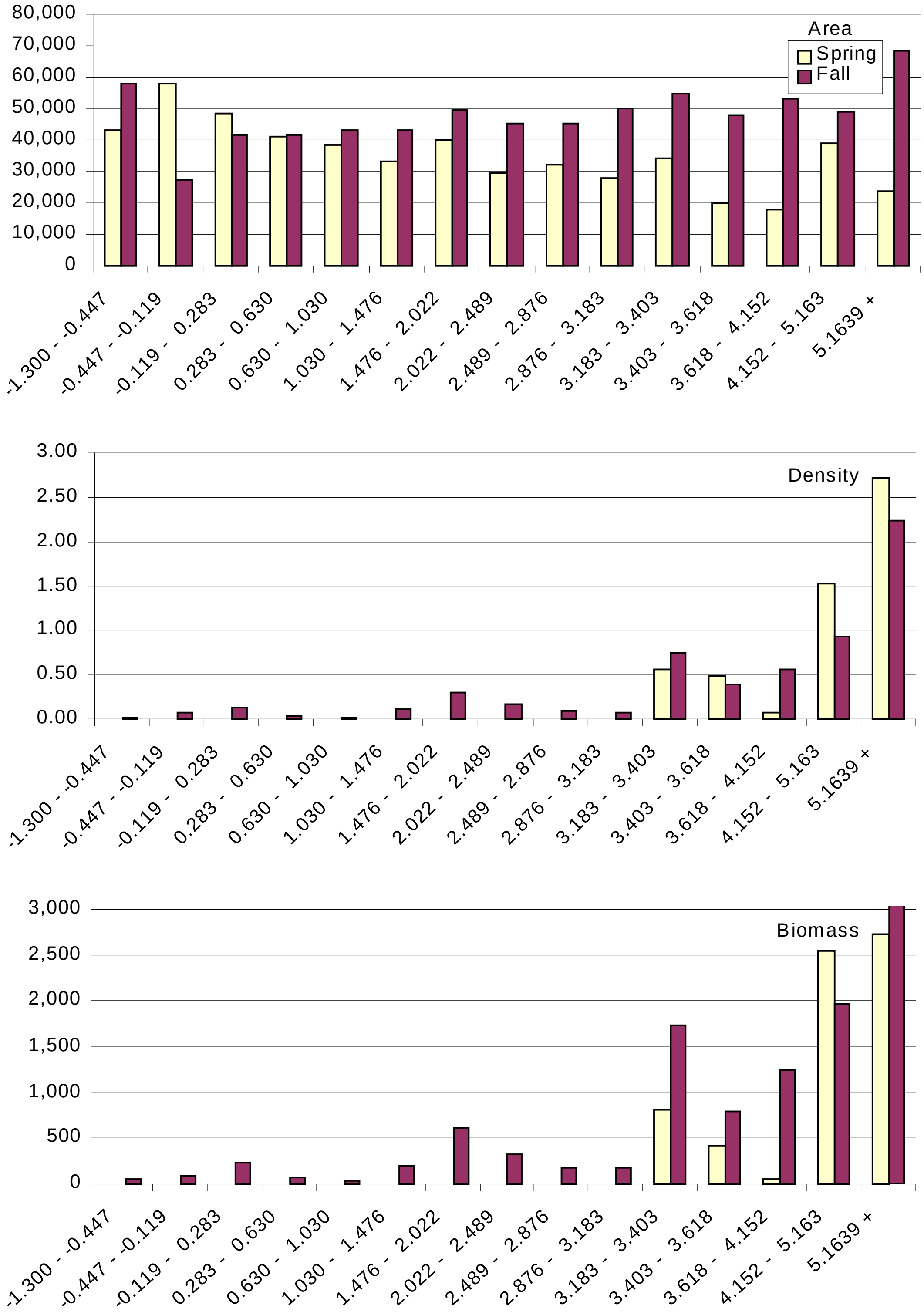


Figure 7. Distribution of monkfish in relation to temperature (deg C) for Fall 1995-1999, and Spring 1996-2000. Upper panel shows the available habitat (km^2 within each temperature interval). Middle panel shows density (mean kg per tow within each interval). Lower panel depicts biomass by temperature interval.

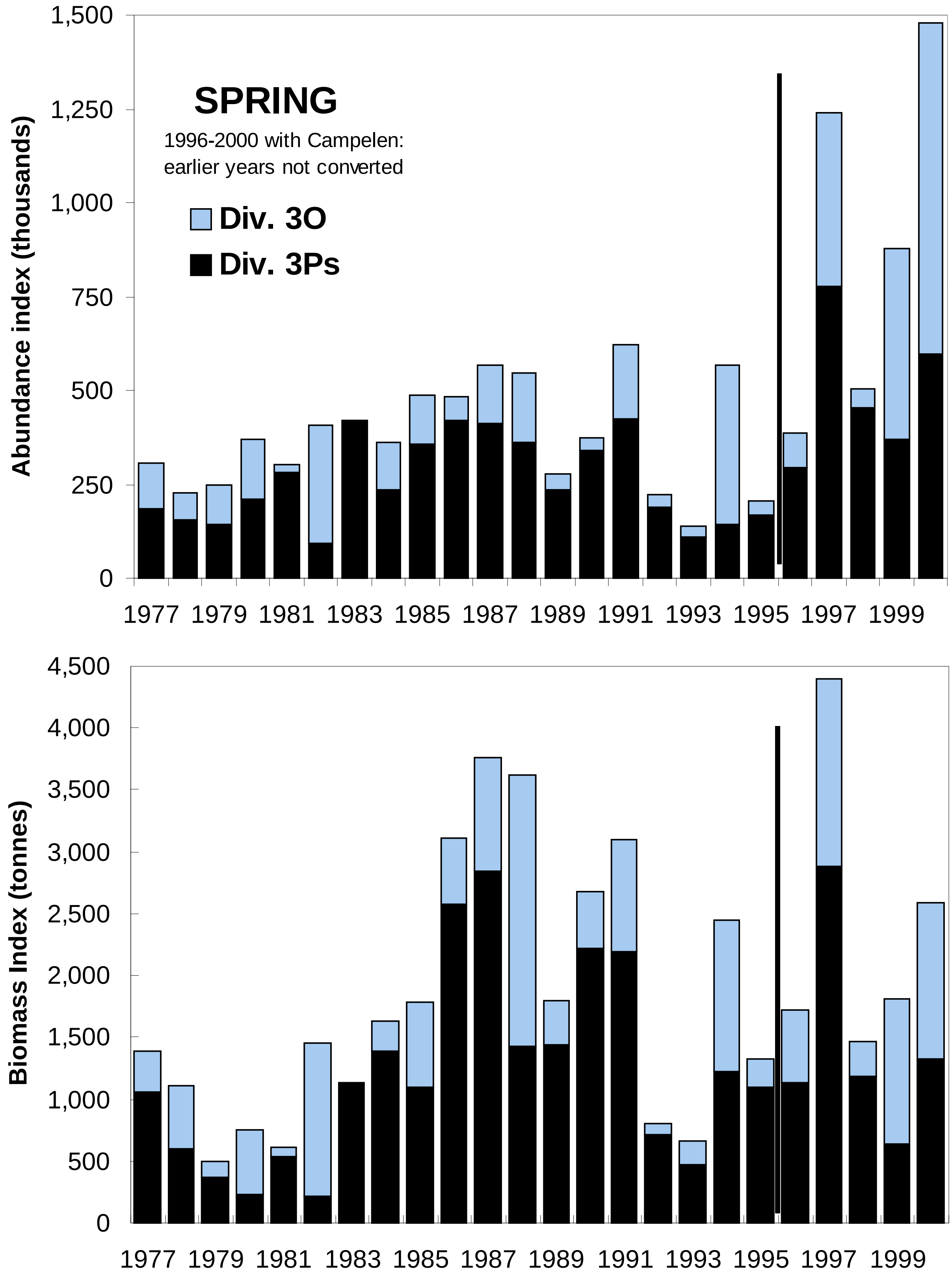


Figure 8. Abundance (upper panel) and biomass (lower panel) of monkfish in NAFO Div. 3OPs, 1977-2000. Indices are based on Spring survey data.

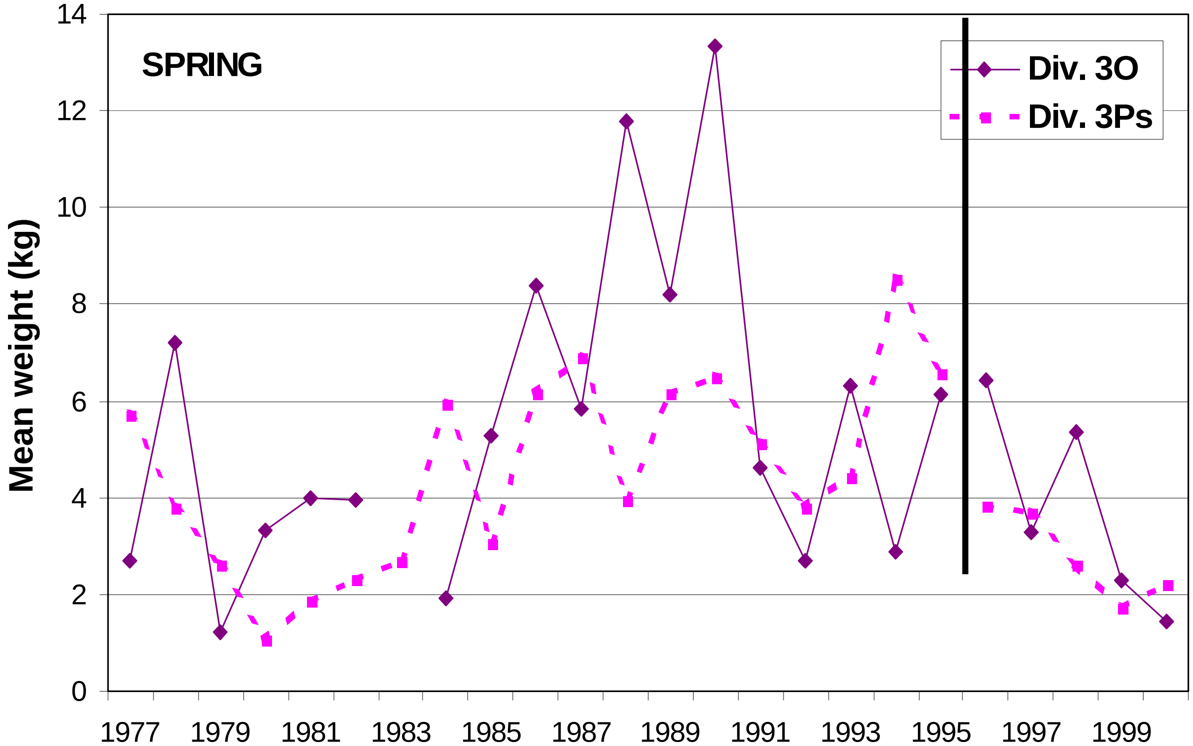


Figure 9. Mean weight of monkfish in Spring research surveys in NAFO Div. 3OPs, 1977-2000.

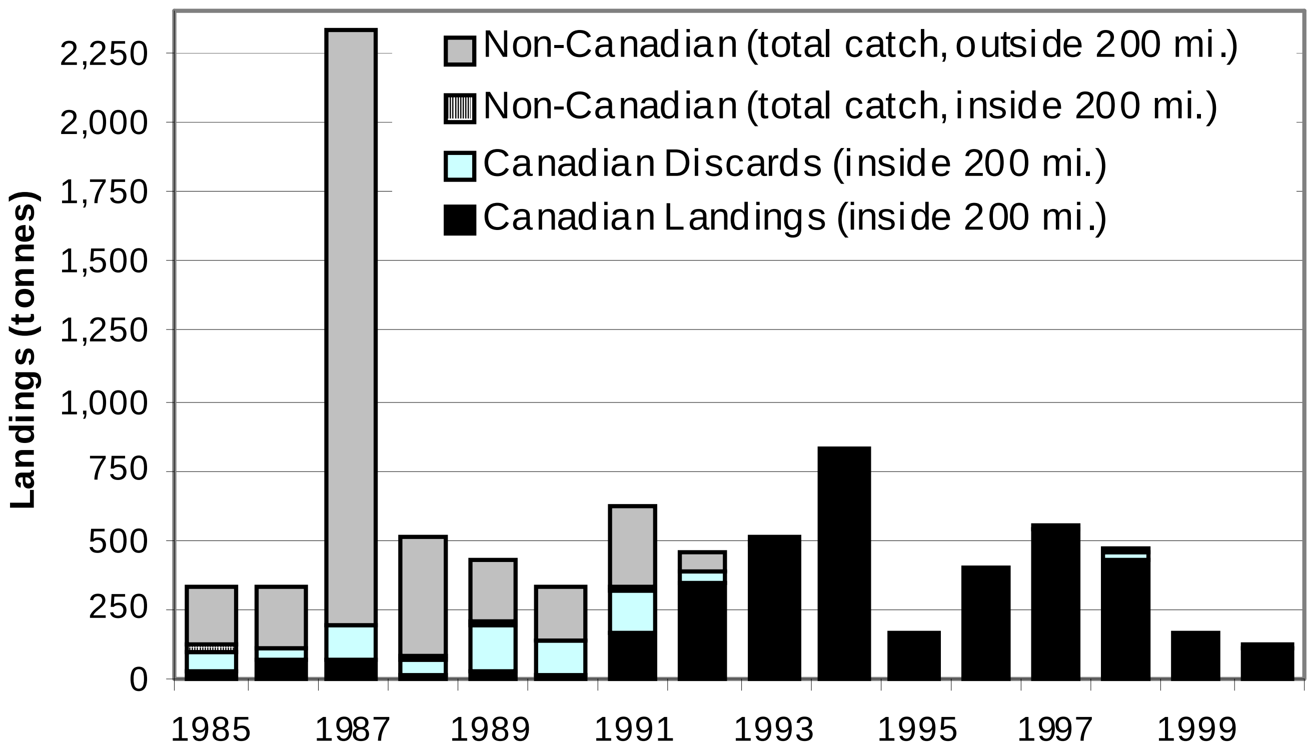


Figure 10. Canadian and non-Canadian landings of monkfish in 3LNOPs, 1985-2000. Canadian landings are compiled from Zonal Interchange Format files. Non-Canadian landings are based on NAFO statistics. Discrds are estimated from observer data. Note that 1999 and 2000 do not include non-Canadian landings, and ZIF data for 2000 are incomplete

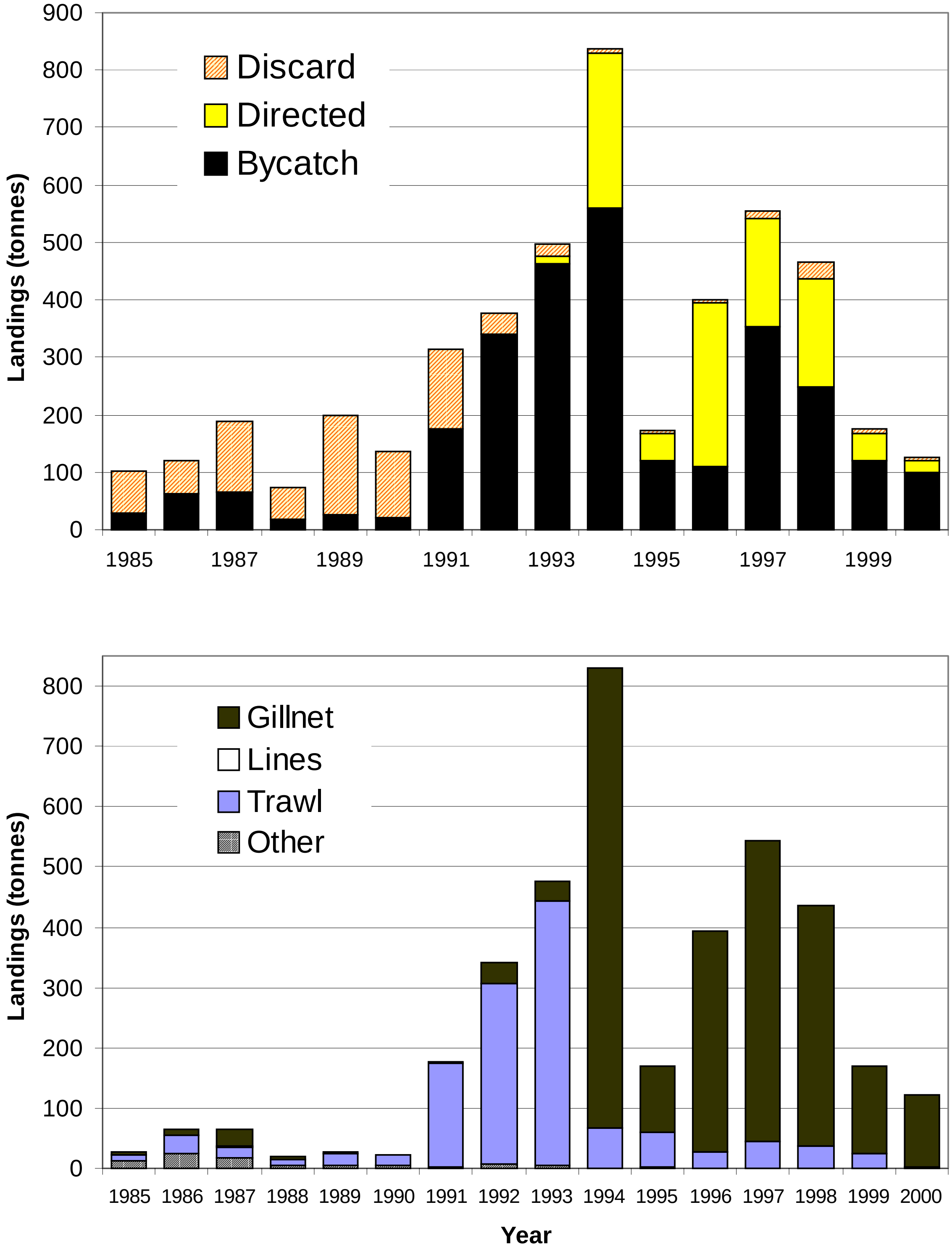


Figure 11. Canadian landings of monkfish in 3LNOPs, 1985-2000, by directed and non-directed modes (upper panel) and by gear type (lower panel). Canadian landings are compiled from the Zonal Interchange Format files and discards are estimated from observer records. Note that ZIF data for 2000 are incomplete.

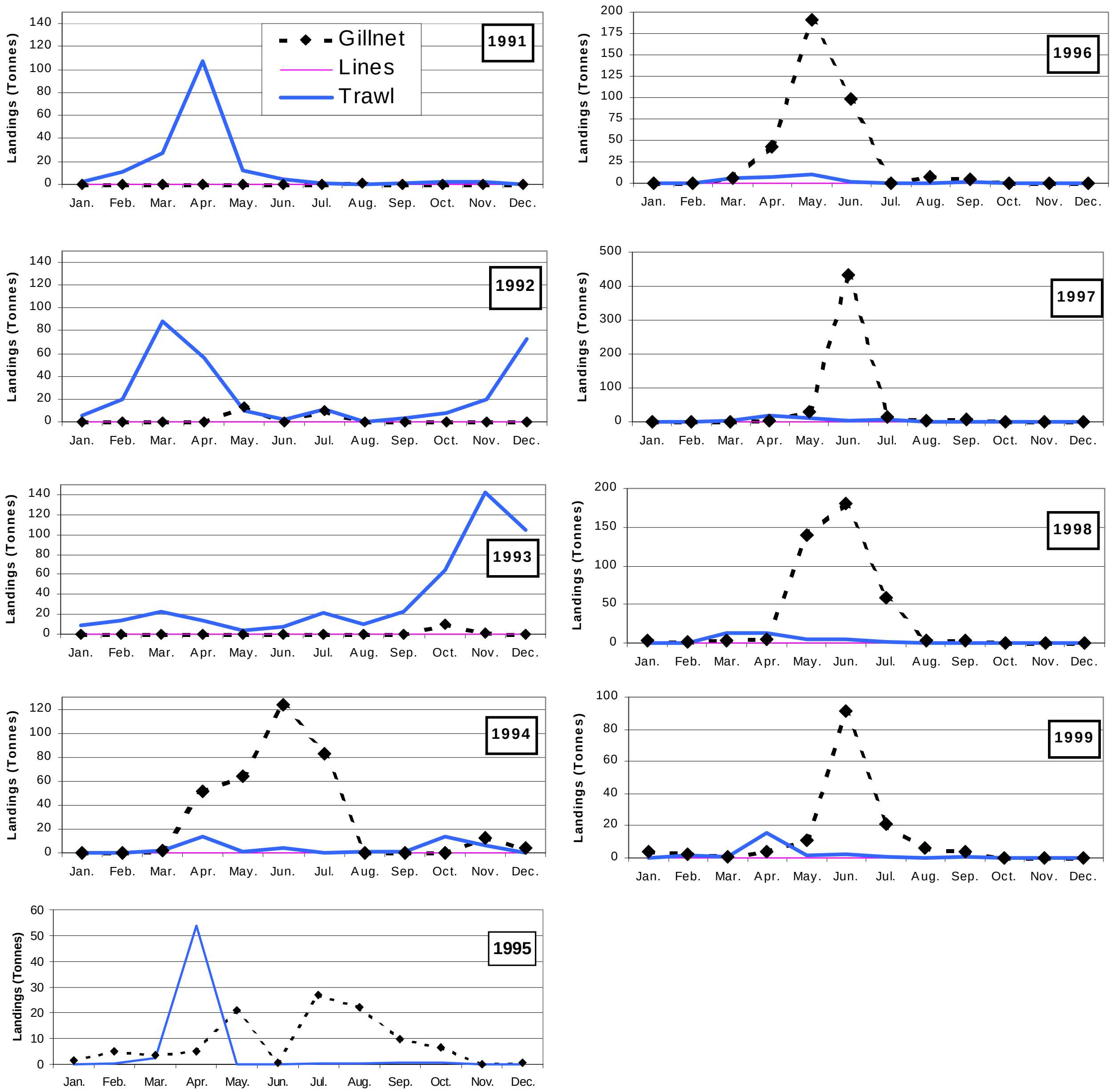


Figure 12. Canadian landings of monkfish by month and gear in NAFO Div. 3LNOPs, 1991-1999. Landing records for which no month was recorded are excluded.

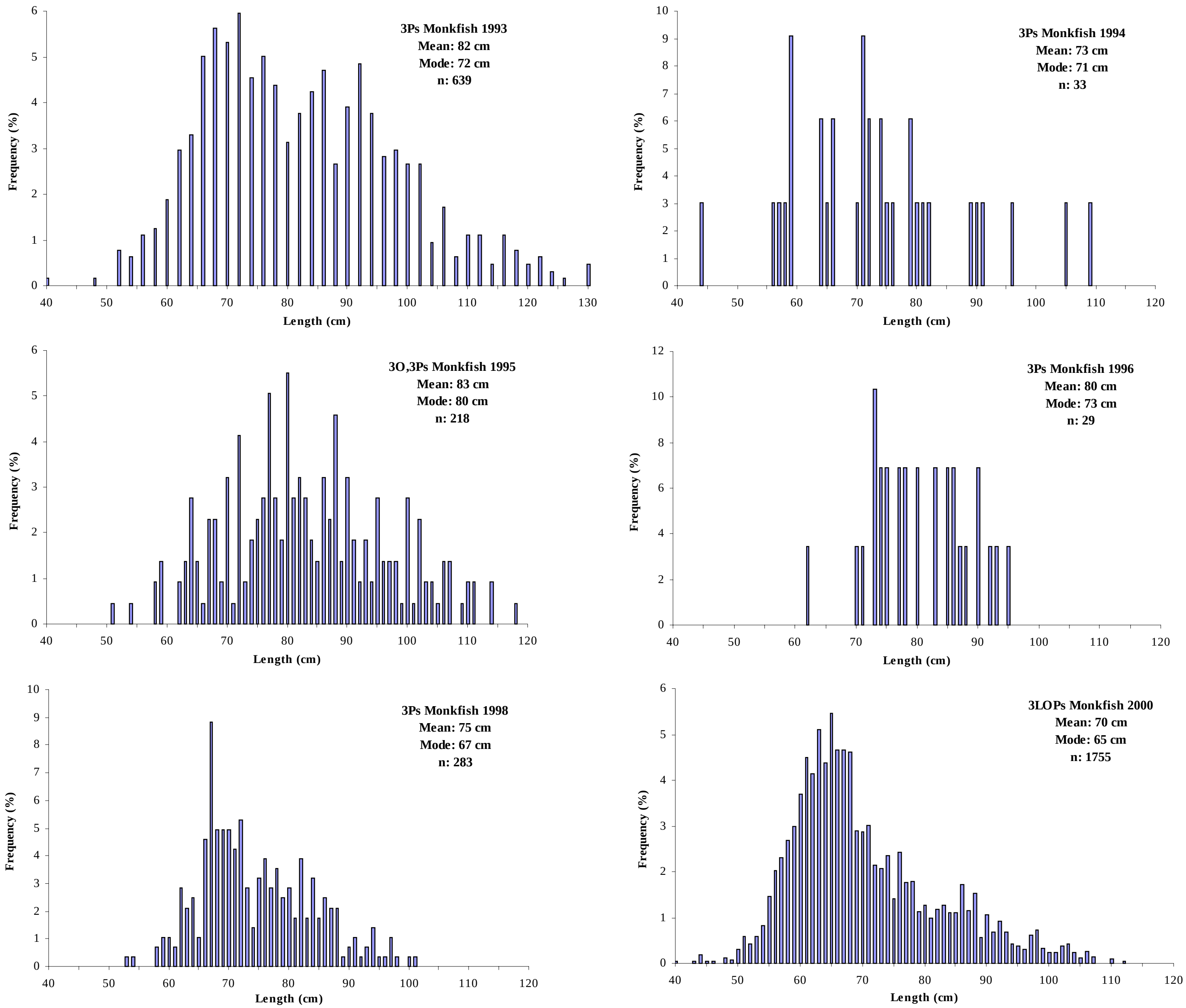
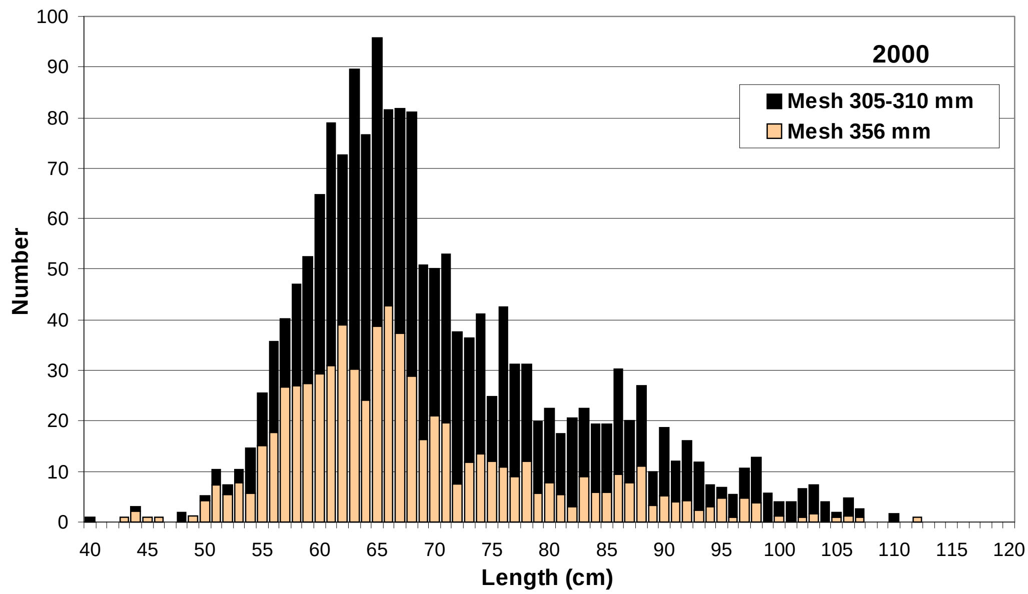


Figure 13a. Size of monkfish in commercial catches from gillnet gear in NAFO Div. 3OPs.



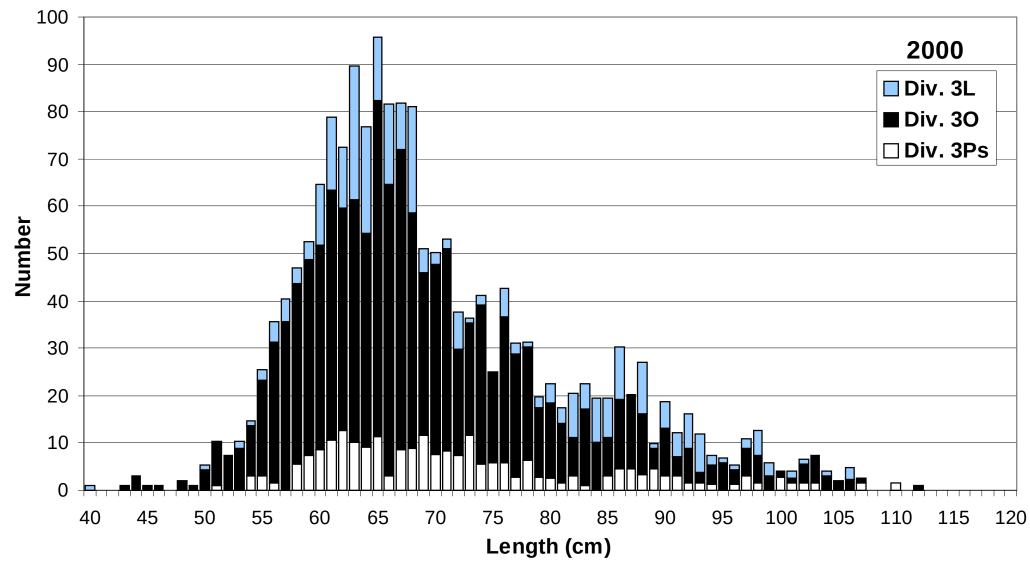


Fig. 13b. Size of monkfish by mesh size of commercial gillnets in Div. 3O, 2000.

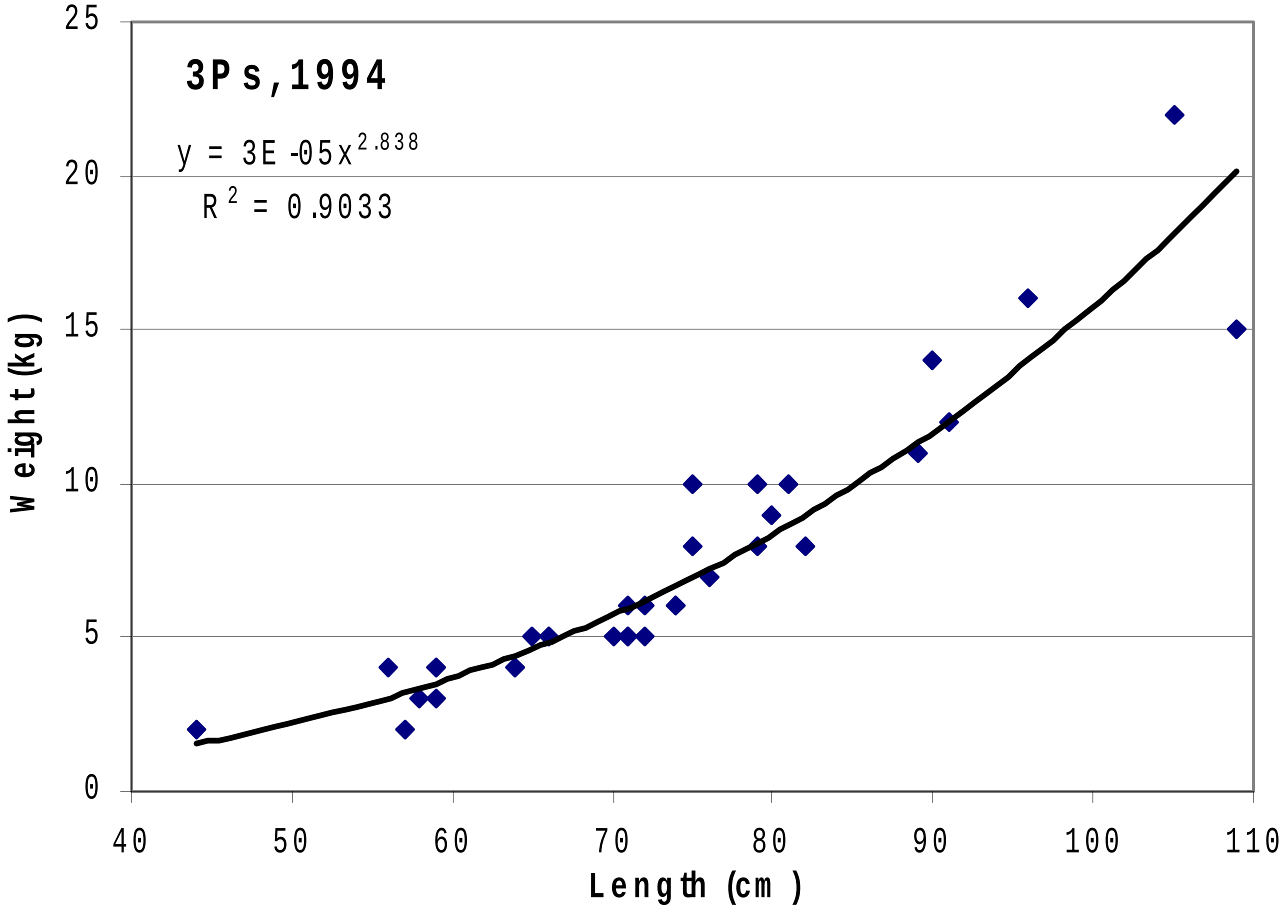


Figure 14. Length/weight relationship for monkfish based on data collected by observers from the 1994 experimental fishery for monkfish.

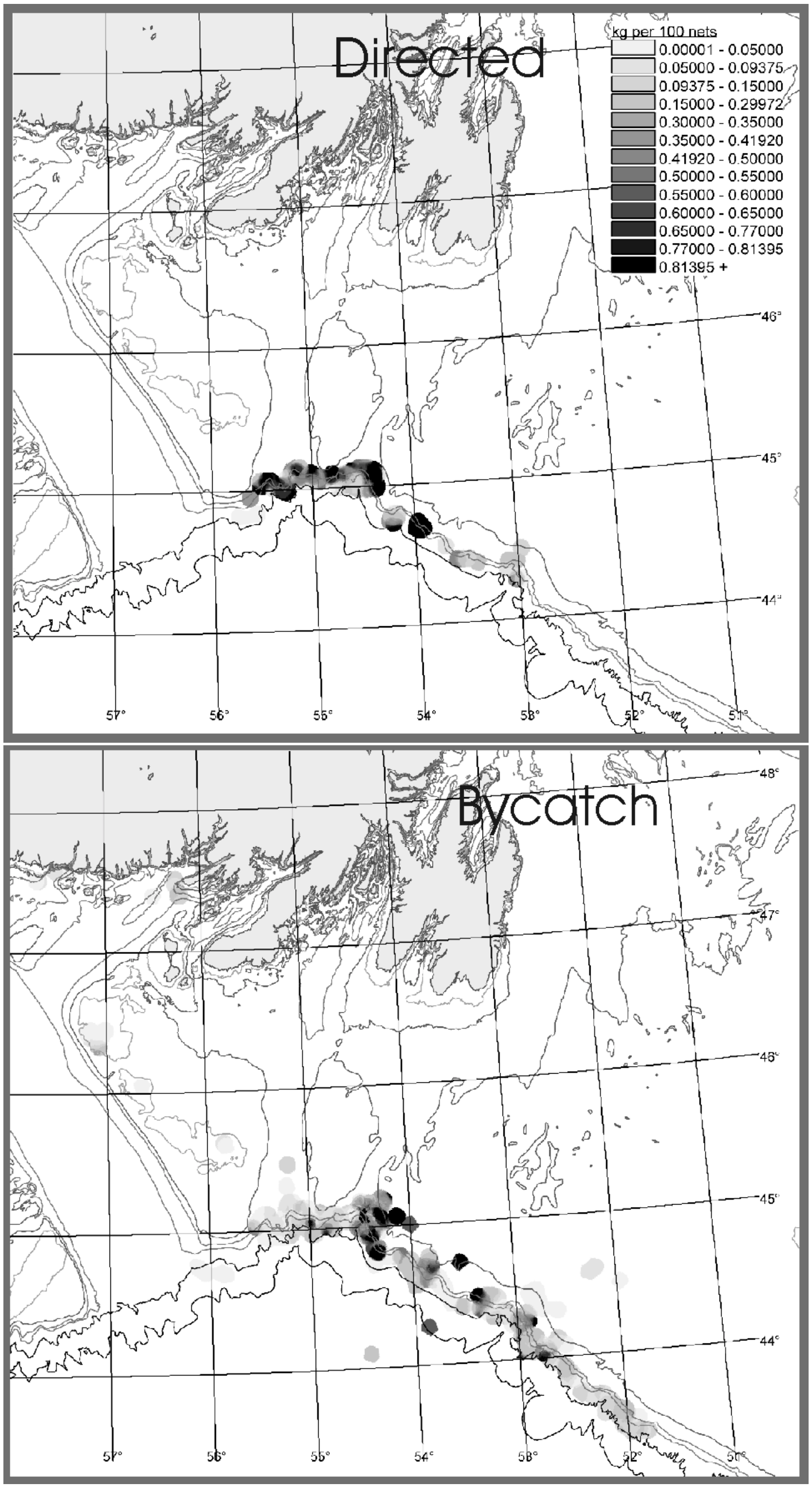


Figure 15a. Fishing grounds for directed and non-directed gillnets, 1991-2000. Darker shades depict areas of higher catch rates.

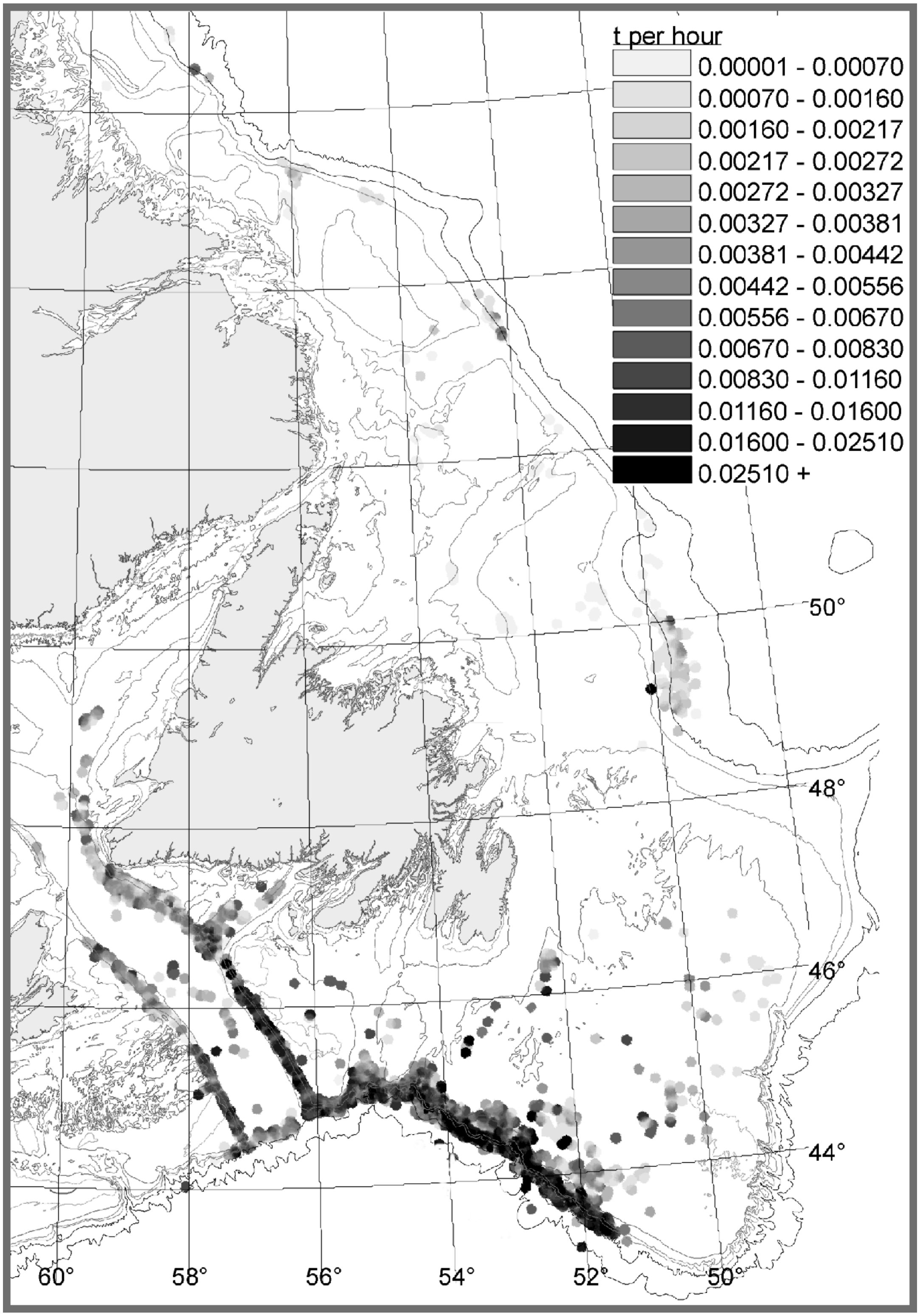


Figure 15b. Bycach of monkfish in otter trawl fisheries, 1991-2000. Darker shades depict higher catch rates.

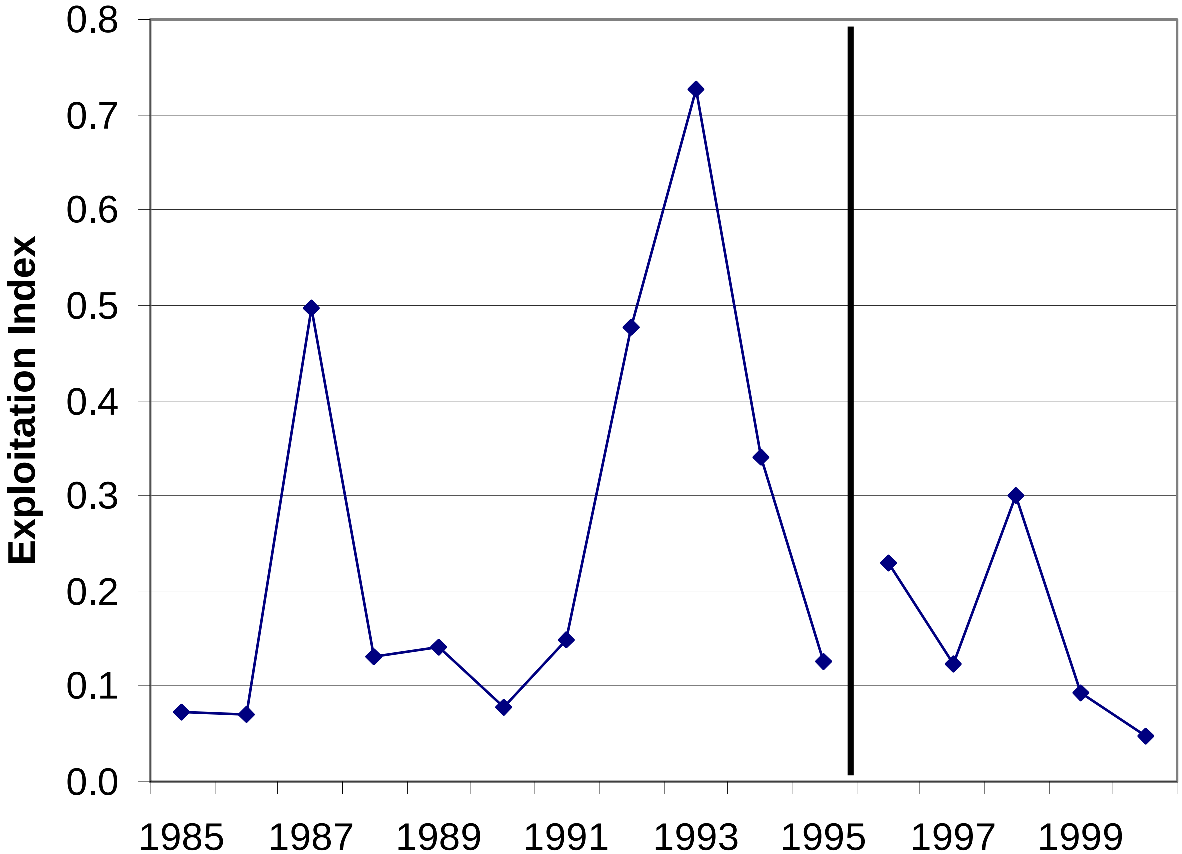


Figure 16. A monkfish exploitation index: Ratio of total commercial catch and survey biomass index.