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Atlantic Halibut on the Scotian Shelf and Southern Grand Banks (NAFO Divisions 3NOPs4VWX5Zc) – Industry/DFO Longline Survey and Tagging Results to 2008

Flétan de l'Atlantique dans le plateau néo-écossais et au sud des Grands Bancs (divisions 3NOPs4VWX5Zc de l'OPANO) – Résultats de 2008 du relevé à la palangre réalisé par l'industrie et le MPO et du marquage

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ABSTRACT

The Industry/DFO (Department of Fisheries and Oceans) Atlantic halibut longline survey (halibut survey) has been in operation for 11 years. During this time, there has been no indication of a change in the distribution of halibut within the management unit area, NAFO (Northwest Atlantic Fisheries Organization) divisions 3NOPs4VWX5Zc. Overall, the halibut survey indicates that catch rates of halibut ≥81cm is either stable or possibly increasing and that there has been no depletion of large fish from the population since 1998. The number of pre-recruits (fish < 81cm) caught in the halibut survey declined from 2001 to 2004, but pre-recruits increased in 2005 and have remained high over the past 3 years in both the DFO research vessel (RV) survey and the halibut survey. The halibut survey uses a fixed station design, and the coverage of these stations has been erratic over the Scotian Shelf and on the southern Grand Banks in particular. Catch rates in 4VWX have been stable with a slight increase in 2007 and 2008. When the entire stock unit is considered and the survey standardized by estimating station effects, catch rates have been increasing since 2003. The commercial index catch rate shows a decline since 1998. However, this index is less standardized than the halibut survey, and not all sources of variability have been considered at this time. A tagging study was initiated in 2006: 526 tags and 848 tags were released in 2006 and 2007, respectively, on all sizes of fish caught by longline gear (50–200cm). Exploitation rate on the exploitable biomass (≥81cm) was estimated to be 17.7% (90% CI: 15.7-19.8%) in 2006, and 20.1% (90% CI: 17.7-22.7%) in 2007. An attempt has been made to calculate a simple reference point to determine the catch that would result in a zero change in the RV and halibut survey abundance indices. These measures, however, did not respond to changes in landings. The biomass and productivity of Atlantic halibut were estimated for the Scotian Shelf and Southern Grand Banks stock using halibut survey and tagging data. Over the last decade, 76% of the production has been taken in the catch, which for most stocks would be considered high. The current exploitation rate from tagging is about double natural mortality and $F_{0.1}$, which would be considered high for most stocks. Without biological reference points, it is impossible to know when the stock is recovered or what level of precaution is necessary. Although the exploitation rate is double natural mortality and $F_{0.1}$, given that the abundance indices from the halibut survey have been increasing recently and that there are good signs of recruitment, a 15% increase in the Total Allowable Catch (TAC) for the 2009/2010 fishing season is not expected to increase the risk to the stock as compared to the previous 4 years. However, the longer-term consequences of utilizing the relatively high catch to surplus production ratio (3.2:1) should be evaluated in the context of stock management objectives, reference points, and a risk management framework.

RÉSUMÉ

Le relevé à la palangre sur le flétan de l'Atlantique (étude sur le flétan) réalisé par l'industrie et le MPO (ministère des Pêches et Océans) est en cours depuis 11 ans. Pendant cette période, il n'y a eu aucun signe de changement dans la distribution du flétan dans la zone de l'unité de gestion, divisions 3NOPs4VWX5Zc de l'OPANO (Organisation des pêches de l'Atlantique Nord-Ouest). De façon générale, le relevé sur le flétan indique que les taux de prise de flétan de ≥ 81 cm sont stables ou croissants et qu'il n'y a pas eu de diminution de la population de poissons de grande taille depuis 1998. Le nombre de prérecrues (poisson de taille < 81 cm) prises dans le relevé sur le flétan a baissé de 2001 à 2004, mais le nombre de prérecrues a augmenté en 2005 et il est resté élevé pendant les trois dernières années du relevé réalisé par le navire de recherche du MPO et le relevé sur le flétan. Le relevé sur le flétan utilise un modèle de station fixe et la couverture de ces stations s'est révélée inégale sur le plateau néo-écossais et notamment au sud des Grands Bancs. Les taux de prise à 4VWX ont été stables et une légère augmentation a été observée en 2007 et 2008. Lorsque l'on tient compte de l'ensemble de la population et que le relevé est normalisé en estimant les effets liés à la station, on remarque que les taux de prise ont augmenté depuis 2003. L'indice commercial du taux de prise montre une baisse depuis 1998. Cependant, cet indice est moins normalisé que le relevé sur le flétan, et les sources de variabilité n'ont pas encore toutes été étudiées. Une étude de marquage a été amorcée en 2006 : 526 et 848 étiquettes ont été placées en 2006 et 2007, respectivement, sur les poissons de toutes tailles attrapés à la palangre (50 à 200 cm). Le taux d'exploitation de la biomasse exploitable (≥ 81 cm) a été estimé à 17,7 % (IC de 90 % : 15,7 à 19,8 %) en 2006, et 20,1 % (IC de 90 % : 17,7 à 22,7 %) en 2007. Une tentative a été faite pour calculer un simple point de référence afin d'identifier le taux de prise qui se traduirait par un changement nul des indices d'abondance de l'étude du navire de recherche et de l'étude sur le flétan. Ces mesures n'ont toutefois pas répondu aux changements de débarquements. La biomasse et la productivité du flétan de l'Atlantique ont été estimées pour la population du plateau néo-écossais et du sud des Grands Bancs à l'aide du relevé à la palangre sur le flétan et des données de marquage. Au cours de la dernière décennie, 76 % de la production est exploité par la pêche, ce qui représente un pourcentage élevé pour la majorité des populations. Le taux d'exploitation actuel estimé par le marquage correspond environ au double de la mortalité naturelle et $F_{0.1}$, ce qui est élevé pour la majorité des populations. Sans points de référence biologiques, il est impossible de determiner le niveau de population qui correspond au rétablissement ou quel est le niveau de précaution nécessaire. Étant donné que les indices d'abondance calculés grâce au relevé sur le flétan ont augmenté récemment et qu'il y a de bons indicateurs de recrutement, et cela bien que le taux d'exploitation soit le double de la mortalité naturelle et $F_{0.1}$, on ne craint pas qu'une augmentation de 15 % du total autorisé de captures (TAC) pour la saison de pêche 2009-2010 augmente le risque pour la population comparativement aux quatre années précédentes. Cependant, les conséquences à long terme de l'utilisation d'un rapport de production relativement élevé de prise par rapport au surplus (3,2:1) devraient être évaluées en fonction des objectifs de gestion du stock, des points de référence et d'un cadre de gestion du risque.

INTRODUCTION

Atlantic halibut (*Hippoglossus hippoglossus*) is the largest of all flatfish and ranges widely over Canada's East Coast (Bigelow and Schroeder, 1953). They are demersal, living on or near the bottom, at temperatures within a few degrees of 5°C (Bowering, 1986; Neilson *et al*., 1993). Atlantic halibut are frequently caught at depths of 200-500m in the deep-water channels running between the banks and along the edge of the continental shelf, with larger individuals moving into deeper water in winter (Bowering, 1986). The management unit definition (NAFO divisions 3NOPs4VWX5Zc) (Figure 1) was based largely on tagging results that indicated that Atlantic halibut move extensively throughout the Canadian North Atlantic (Stobo *et al*., 1988). Stobo *et al*., (1988) speculated that the Browns Bank area may be an important rearing area for juvenile halibut and that there is a north-eastward movement of fish as they grow. The geographic range of Atlantic halibut in the Northwest Atlantic once extended from the coast of Virginia in the south to the waters off Disko Bay, Greenland in the north (Scott and Scott, 1988; Bowering, 1986). Since the early 1990s, there appears to have been a significant reduction in the numbers of halibut in the northern and southern extent of its range, in US waters (Kanwit, 2007), and along the Labrador Shelf.

Although the growth and maturity cycles of Atlantic halibut require further study, it is known that females grow faster than males, and attain a much larger maximum size (Trumble *et al*., 1993). Females reach 50% maturity at about 115cm fork length, while males reach 50% maturity at about 75cm. In the absence of reliable growth information, age at maturity remains uncertain. Halibut are voracious feeders. The diet of small halibut (<30cm) consists almost exclusively of invertebrates (Kohler, 1967). Between 30cm and 66cm, halibut consume both invertebrates and fish, while halibut over this size eat almost exclusively fish.

Landings of Atlantic halibut have been recorded for the east coast of Canada since 1883 (Zwanenberg *et al*., 1997). Within the management unit (3NOPs4VWX5Zc), landings have averaged 1813 metric tons (t) annually from 1960 to 2008. Prior to 1988, the fishery was unregulated. A total allowable catch (TAC) of 3200t was implemented in 1988, was reduced to 1500t in 1994, and further reduced in 1996 to 850t (Figure 2). Reductions in the TAC were implemented in response to an 8 year decline in landings, a decision that continues to be a topic of significant debate among stakeholders. In 1999, recommendations made by the Fisheries Resource Conservation Council (FRCC) resulted in increases to the TAC for this stock from 850 to 1000t; 2 further increases were implemented to reach the present TAC level of 1475t. Landings for the 2005-2006 fishing season were 1253t (Table 1). Within the management unit, halibut is fished nearshore and offshore mainly by longliners using bottom hook-and-line gear. Since 1994, management plans and license conditions require the release of halibut less than 81cm.

Information on Atlantic halibut has been gathered by the DFO research vessel (RV) survey since 1970. The RV survey tends to catch 40 to 70 small (30 to 70cm) halibut per year. Since halibut ≥81cm are rarely caught in the RV survey, it is considered to be an unreliable estimate of adult biomass. In response to this lack of data, the TAC reduction, and a general lack of knowledge on the species status, an Industry/DFO longline halibut survey (halibut survey) on the Scotian Shelf and Southern Grand Banks (3NOPs4VWX5Zc) was initiated in 1998. The halibut survey provides an index of abundance and generates estimates of population size structure, including estimates of incoming recruits.

In 2009, DFO Fisheries and Aquaculture Management branch requested advice on the stock status of 3NOPs4VWX5Zc halibut to determine a TAC consistent with the management plan. The remit was as follows:

- What are the current removals, including surveys and bycatch of Atlantic halibut?
- What are the recent catch rate and distribution trends from the Atlantic halibut Industry/DFO survey?
- Evaluate what the impact of a 15% increase to the TAC (i.e., an increase from 1475mt to 1700mt) would have on Atlantic halibut in 2009/2010. Report on these impacts for the exploitable population.

METHODS AND MATERIALS

DFO Research Vessel (RV) Trawl Surveys

The DFO Scotian Shelf groundfish RV survey has been conducted every year during the month of July since 1970. Each year, about 231 fishing stations are sampled from the Upper Bay of Fundy to the northern tip of Cape Breton and offshore to the 400 fathom contour (approximately 700m) (Branton and Black, 2004). Because the catchability of the RV trawl survey is low for halibut >81cm, the catch rate is highly variable from year to year, and it is considered to be an unreliable index of adult abundance. Recruitment to the fishery can, however, be estimated since the median size of halibut caught in the trawl survey is between 40 and 50cm. The number of fish <81cm caught annually provides an estimate of pre-recruits entering the fishable population. Growth data indicate that these fish will enter the fishery (grow to ≥81cm) in 2 to 3 years.

The Industry/DFO Longline Halibut Survey and Commercial Index

The halibut survey was designed to generate an index of abundance for the exploitable population (≥81cm), as well as data on changes in distribution to inform an annual stock assessment. The survey also produces estimates of population size structure, including indications of incoming recruits. The halibut survey uses a fixed station design. In 1998, 222 stations were selected based on the previous 2 years of commercial catch and the goal of wide spatial coverage. A total of 73 stations have been added from 2005 to 2008. The number of stations fished has varied from year to year and has averaged 200 stations/year. Fishers are asked to follow fishing protocols (maximum distance from a station, hook size, number of hooks, and minimum soak times) (Zwanenburg and Wilson, 2000a, 2000b; Zwanenburg *et al*., 2003); however, there is still some variation in survey protocol, which could affect catch rates. During the same period, fishers also participate in a commercial index where participants fish at locations of their choosing. Participants tend to use the same protocol as the survey, but there are some important variations (putting out more hooks, soaking longer, etc.).

Halibut Survey and Commercial Index Catch Rates

Halibut survey catch rates are standardized to 1000 hooks and 10 hours soak time. The halibut survey uses a stratification scheme that is based on the distribution of observed landings for the period 1993 – 1997. Three strata were defined using high (>250kg), medium (50–249kg), and low (<49kg) landings (Zwanenburg *et al*., 2003). The area of each stratum was estimated using potential mapping with a radius of influence for each observation sufficient to define a stratum for most of the survey area. In the past, weighted catch rate estimates were calculated. However, the weighted catch rate estimates are no longer used in the assessment, and only the catch rates separated by strata are presented (Armsworthy *et al*., 2006). Three separate catch rate analyses were compared to determine whether irregular station sampling over the course of the survey affected the catch rate estimate: 1) data for all stations covered in 4VWX (n = 126 to 225), 2) data for stations completed since 1999 (n = 54), and 3) data for all stations covered in 5 or more years and standardized using a generalized linear model (GLM). The GLM used a negative binomial error distribution where year and station effects were estimated and the response variable (weight in kg) was offset by the log number of hooks. Other effects, such as area and vessel, were not considered.

The commercial index catch rate was calculated for 4VWX only and was standardized to 1000 hooks and 10 hours soak time. No stratification scheme was used.

For both the halibut survey and the commercial index, an index of pre-recruits (50-80cm halibut expected to enter the fishery in 1 or 2 years), and an index of exploitable biomass (≥81cm) were estimated.

Size Composition

The size composition of adult halibut caught in the halibut survey and commercial index was described by the 50th (median) and 95th percentiles of fish lengths. The 95th percentile is the largest 5% of halibut caught, while the 50th percentile is the length of halibut that falls in the middle of the size distribution. These values were tracked over the course of the survey as an indication of changes in size composition.

Tagging

There were several goals of the halibut tagging study. The first was to estimate exploitation, the second was to estimate relative abundance, and the third was to evaluate the distribution of halibut within the management unit. The tagging study was a joint collaboration between DFO Science Branch and the Atlantic Halibut Council (AHC), which includes members from the halibut fishing industry. Fish were tagged by observers from 2006-2008 during the halibut survey (May - July). The tags were applied 15cm apart at the widest point near the dorsal fin on the dark side of the body. A $100 reward was given for every pair of tags (or single tag should one be lost), and participants were entered into a lottery for $1000 to be drawn every quarter. Tags were returned to the Halibut Assessment Team at the Bedford Institute of Oceanography (Dartmouth, NS) for analysis. A full analysis of these tags will be reported in future publications. A map of release and recovery locations, and an estimate of exploitation rate (*F*) using the Peterson equation are presented.

$$F_t = R_t /((N_t - N_{\Delta w}) * (1-\phi) * \exp(M * (0.5 + \Delta w)) - \sum_{1}^{t-1} R_t) * \exp(-(L^2) * \Delta t) * \lambda$$

where, R_t is the number of recaptures, N_t is the number of fish marked, $N_{\Delta w}$ is the number of fish recovered during the wait period (w), (w = two months), ϕ is the release mortality, M is natural mortality, which occurs up until fish are recovered (assumed to be half-way through the recovery period), $\sum_{1}^{t-1} R_t$ is the number of previous recaptures, L is the rate of tag loss calculated from the proportion of single tags returned, Δt is the time interval (1 year), and λ is the reporting rate (assumed to be 0.90 because of the high reward). Tags were released in proportion to abundance estimated from previous halibut survey results (1999–2005).

One of the assumptions of a Petersen tag-recapture analysis is that the tagged fish mix randomly in the stock area before recapture. The effect of mixing periods ranging between 1 and 6 months after tagging (during which tag recaptures were not included) were tested on the resulting Petersen estimates. For both tagging years, the exploitation rates remained quite stable over the different recapture periods, at most, varying by less than 10%. Estimates of exploitation rate were especially stable for the 2007 tagging year for periods starting over 2 months post-release, varying by less than 1%. Therefore, 2 months post-tagging was considered to be an optimal waiting or mixing time, with annual exploitation rates being estimated from recoveries made during the 12-month period beginning in the third month post-release.

To estimate the uncertainty in the estimate of exploitation rate, exploitation rate was recalculated taking 1000 random samples from distributions around release mortality, natural mortality, tag loss, and reporting rate. Release mortality was estimated to be 23% by Neilson *et al*. (1989). To estimate uncertainty around the release mortality estimate, a binomial distribution with n = 47 was assumed, the number of individuals examined in the study. Natural mortality was assumed to be 0.1, a value which is based on halibut longevity of 40 years. The uncertainty in natural mortality was assumed to have a lognormal distribution and a sigma = 0.3. Since all fish were double tagged, it was possible to estimate tag loss. Of the fish ≥81cm released in 2006 and 2007, 50 out of 198 tags recovered in a 12-month period were returned as a single tag for a loss rate of 25%. Tag loss was assumed to have a binomial distribution. Reporting rate was assumed to be 90% because of the high reward for returned tags. A binomial distribution was used and a sample size was chosen that would allow the reporting rate to vary from 80 to 100% (n=70). The parameters, their mean, distribution standard deviation, and sample sizes are shown in Table 2.

Bycatch

Observer data was used to estimate bycatch in the commercial halibut longline fishery. This fishery is a multi-species fishery making it difficult to define a directed halibut fishing set. Consequently, analysis focused on vessels which are known to direct for halibut (15 vessels). Furthermore, only the sets where the species targeted was identified by the observer as halibut were selected. Outside of the halibut survey, there was little to no observer coverage in 4X and low and sporadic coverage in 3N, 4W, and 5Z, so it was not possible to estimate bycatch in these areas. This data selection gave a total of 3346 sets. After plotting catches against different explanatory variables (NAFO division, year, duration, hooks, depth, and vessel), extreme values which could potentially bias the results were eliminated. The number of hooks was limited to greater than 200 and less than 2000. Rare species (less than 10kg caught per set) were excluded from the analyses. Depth was limited to sets fished above 1200m. The vast majority of sets were fished in waters less than 1000m. Duration was limited to sets under 2000 minutes (33 hours), after exploring the effects of having 3000 or 4000 minutes as upper limits. This left 2866 sets in the data set. Each area (3N, 3O, 3Ps, 4V) was examined by quarter.

Reference Points

A simple reference point can be calculated by plotting the annual change in an abundance index versus exploitation rate or the total catch (e.g., Smith *et al*. 2008). If catch affects the abundance index, then a negative relationship is expected. The catch that produces a zero change in abundance could be viewed as a reference point. This strategy, however, might not always be desirable, and sometimes it may be advisable to exceed or remain below the reference point depending on recruitment, the population trajectory, and current circumstances.

To estimate this reference point, the annual change in abundance in the RV and halibut survey was plotted against the total catch.

RESULTS AND DISCUSSION

Survey Coverage

Participation in the halibut longline survey has waxed and waned since 1998. In 2005, there were concerns over a reduction in the number of sets completed when compared to previous years. Eleven vessels participated from 2004 to 2006, and 2006 was the lowest level of coverage since the inception of the survey with 157 stations covered. Participation increased to 17 vessels in 2007 and they covered a record number of stations. In 2008, coverage increased again and 272 stations were covered (Figure 3).

Over the course of the halibut survey, station coverage has been irregular. Of the 275 fixed station locations (Figure 4), only 54 have been consistently completed since 1999. To expand the sampling range, 4, 51, 8 and 10 new fixed stations were added to the survey area in 2005, 2006, 2007, and 2008, respectively (see Figure 4). Stations created in 2008 were located on the northeast edge of Georges Bank, the first time this area has been sampled.

In keeping with past assessments and as a basis for comparison, one of the catch rate analyses used only data from the most consistently occupied survey area, 4VWX. The erratic coverage of stations in the halibut survey is most notable in the Southern Grand Banks (3NOPs) (Figure 5). This is largely due to the high cost of getting to these areas by Nova Scotia-based participants, and to cod bycatch limits in 3Ps, which limits the number of fixed stations and precludes fishing to produce a commercial index. Consequently, it is necessary to standardize the halibut survey catch rates with a generalized linear model which estimates station effects.

The number of commercial index sets is approximately 3 times that of the halibut survey. The greatest number of commercial index sets were done in 2004 (820 sets). The number fell 3 years in a row to an all-time low of 453 sets in 2007. In 2008, the number of sets fished increased dramatically to the second-highest level since the start of the halibut survey (733 sets, Figure 3). This data set also requires standardization with a generalized linear model; however, this analysis has not yet been completed.

Catches for the halibut survey and commercial index are shown in Table 3. Standardized catch was plotted by year and location to show the distribution of halibut for the halibut survey and commercial index (figures 5 and 6). Despite variability in coverage, there was no obvious indication of a change in the distribution of Atlantic halibut in the survey (Figure 5) or commercial index (Figure 6).

Halibut Survey Catch Rates

Three different analyses of catch rates during the halibut survey were compared: 1) only stations covered in 4VWX, 2) 54 stations occupied every year since 1999, and 3) a generalized linear model of stations covered in 5 years or more (Figure 7). When only stations covered in 4VWX were included, catch rates were generally flat with a slight increase since 2007. The 54 stations that have been covered since 1999 showed sharp increases in catch rates in 2006 and 2007. The GLM standardized catch rates showed a slower more steady increase from 2003 to 2008 (Table 4). When year is treated as a factor, which is necessary for standardizing the data, it is not significant. When year is treated as a continuous variable in a linear regression inversely weighted by the variance in the annual catch rate, catch rates increased significantly at a rate of 1.4 kg/1000 hooks/10 hours soak time ($p = 0.04$). However, some of this increase could be due to vessel effects. When the data was further restricted to only include vessels that have participated in the survey for 2 or more years, the positive trend in catch rates is lower (0.1 kg/1000 hooks/10 hours soak time), although still statistically significant ($p = 0.01$) . This result indicates that either vessel effects or captain effects need to be examined further.

Fixed station catch rates in the halibut survey estimated for each of the 3 strata have shown some variability from year to year, but they appear to be stable overall (Figure 8).

Commercial Index Catch Rates

The catch rate in the commercial index in 4VWX shows a significant decline at a rate of 3kg/1000hooks/10hours soak time ($p = 0.02$) since 1998, albeit with considerable inter-annual variation (Figure 7). This index is less standardized than the halibut survey, and not all sources of variability have been considered at this time.

Pre-Recruitment

The number of pre-recruit halibut (<81cm) caught on the DFO RV trawl surveys indicates that recruitment was below average from 1993 to 2003, but has been above average since 2004 (mean = 0.192 halibut per standard tow) (Figure 10).

The halibut survey has a much higher catchability of pre-recruit halibut than the RV survey (Figure 10). The number of pre-recruit halibut caught on the halibut survey declined from 2001 to 2004 and increased from 2005 to 2008. From 2005 to 2008, the majority of pre-recruits were caught in 4X; 4X consistently represented the area of the stock with the greatest proportion of pre-recruits caught during the survey period.

Size Composition

The size composition of both the 50^{th} and 95^{th} percentiles of fish caught in the halibut survey and the commercial index had been stable. This indicates that large fish have not been depleted, and/or that the proportion of small fish is not increasing. There was some variation in the last 2 years, but these values might be year effects, and more data is needed to determine if size composition is changing (figures 12 and 13).

Tagging

Over 3 years, 2076 halibut ranging in size from 50 to 207cm were tagged with 2 pink spaghetti tags. By February 2009, 224 had been recaptured (Figure 14). The greatest number of tagged halibut were caught during times of intensive halibut fishing, such as during the halibut survey and during the spring fishery. The distance between tag and recapture location was anywhere between 0km and 2698km from their release site. Notably, 2 halibut traveled approximately 2600km from the Grand Banks to Icelandic waters in about 2 years. The exact route they traveled can not be determined using conventional tagging; however, commercial fishing data indicates that most halibut seem to prefer the edge of the continental shelf.

Halibut caught near the borders of the 3NOPs4VWX5Zc management unit may belong to other management units (i.e., 4RST). A tagging study in the Gulf of Maine found that 28% of juvenile tagged fished were recovered in Canadian waters (Kanwit, 2007). Of 2076 fish tagged in 3NOPs4VWX between 2006 and 2008, none have been recovered in Maine, 6 have been recovered in 4RST, 22 have been recovered outside the Exclusive Economic Zone (EEZ) on the Southern Grand Banks, and 2 have been recovered in coastal Icelandic waters.

Exploitation rate was calculated for the exploitable biomass (≥81cm). In 2006, 420 fish ≥81cm were tagged, of which 44 were returned and 5 tags were excluded because they were caught within the 2 month waiting period. In 2007, 653 fish ≥81cm were tagged, of which 78 returned and 6 tags were excluded because they were caught within the 2 month waiting period. From these values, exploitation rate were estimated to be 17.7% (90% CI: 15.7-19.8%) in 2006, and 20.1% (90% CI: 17.7-22.7%) in 2007 (Figure 15).

Bycatch

Bycatch in the halibut fishery was highly variable in time and space. When halibut was directed for, typically 40 to 60% of the catch weight were species caught incidentally (Figure 16). Sixteen species showed up regularly in the bycatch but most were in small proportions. White hake was the most frequently caught bycatch species averaging approximately 30% of the catch and ranging from 5 to 75%. Cod averaged approximately 7% and cusk 5% of the catch.

Bycatch was estimated by area and season. There were 17 trips and 613 sets in 3N that were included in the analysis. Quarter 1 only had 1 year of data (2007), quarters 2 and 3 had 5 and 4 years of data, respectively. There was no data which met the criteria for analysis in the fourth quarter. Over quarters 1, 2 and 3, halibut ranged from approximately 20-65% of the total catch. Both the composition and proportion of bycatch species were quite variable (Figure 17). Depending on the year, cod, turbot (Greenland halibut), thorny skate, and striped Atlantic wolffish were the major bycatch species. Cod comprised a small portion (~10%) of the catch in the second quarter.

There were 34 trips and 980 sets in 3O that were included in the analysis. Quarters 1, 3, and 4, have 6 years of data, and quarter 2, 11 years. The proportion of halibut in the catch peaked in the first 2 quarters of the year (January – June, Figure 18). White hake consistently made up a large portion of the catch in all quarters, and in the fourth quarter represented greater than 80% of the catch.

There were 36 trips and 859 sets in 3Ps that were included in the analysis. Quarters 2, 3, and 4 have 5 years of data, whereas quarter 1 had 11 years of data (Figure 19). Halibut catches appear to be highest in quarter 4, but the number of observed sets was low. Quarter 1 had the highest amount of observer coverage. Over all quarters, white hake and hake (unidentified) represent a significant portion of the catch ranging from approximately 10-80%. Cod also represented a significant portion of the catch, especially in quarter 1 where it comprised between 10 and 50%.

There were 36 trips and 607 sets in 4V that were included in the analysis. Quarter 1 has 11 years of data, whereas quarters 2, 3, and 4 only had 4 years of data (Figure 20). Halibut catches were generally greater than 35% of the total catch in quarter 1, and greater than 40% in the other 3 quarters. White hake comprised a large percentage of the total catch, especially in quarter 1, where it was 40-50% of the total catch in 2006 and 2007. Cod was also caught in all quarters, but did not comprise more than 20% of the catch. Cusk was more frequently caught in 4V than in 3O or 3Ps, but still only comprised 5-15% of the catch in all quarters.

The percent halibut catch varied greatly by year, season, and area and did not show any consistent patterns. The highest cod bycatch was in 3Ps, where the population is known to be doing better than in surrounding regions (Bratty *et al*. 2008). Skates in general and thorny skate in particular were caught with some frequency in 3O and 4V, but less so in 3Ps. Five bycatch species are listed by Committee on the Status of Endangered Wildlife in Canada (COSEWIC) and / or the *Species at Risk Act* (SARA) (Table 5). Of these, cusk was the most commonly caught but typically only represented 5% of the catch. Small samples sizes (tonnage of observed sets) may lead to an inaccurate or biased representation of the catch.

Reference Points

The annual change in the catch rate of both the RV and the halibut survey are highly variable, and do not show a trend with total catch (Figure 21). The lack of a relationship could be for 2 reasons: the variability in the abundance indices is so high neither index tracks true changes in abundance, and/or the exploitation rates are not high enough to impact the population. The latter seems unlikely as the estimates of exploitation from tagging data are 17.7 and 20.1% for 2006 and 2007, respectively. This approach may be more fruitful when using annual changes in abundance from an assessment model which takes advantage of length frequency data. Given the current data and these reference points, it is not possible to predict the impact of a 15% increase in the TAC on population productivity. Consequently, it is necessary to be precautionary given the high variability in the abundance indices and the level of uncertainty in predicting impacts on the population.

Halibut Biomass and Productivity

Biomass and productivity of Atlantic halibut were estimated for the Scotian Shelf / Southern Grand Banks stock using halibut survey and tagging data. In particular, the halibut survey results from a generalized linear model were used (Table 4, Figure 7). Because of variable coverage on the Southern Grand Banks, 2 separate analyses were conducted: 1) data over the entire stock area including stations on the Southern Grand Banks (3NOPs), and 2) data for stations on the Scotian Shelf (4VWX) only. Indices were rescaled to absolute biomass based on the 2007 catch and an estimate of exploitation rate from tagging data.

The TAC in 3NOPs4VWX5Zc in 2007 was 1475t (Table 1), and the catch is expected to be close to this value when the landings in 3NOPs are incorporated. The estimated exploitation rate from tagging was about 20%. A simple estimate of exploitable biomass (B) can be generated by dividing the catch by the exploitation rate, B =1475/.20 = 7375t. The standardized catch rate for the halibut survey for the entire stock area and just the Scotian Shelf are shown in Table 6. There is considerable uncertainty in these estimates as the coefficients of variation for these estimates is ~0.53. The catch rate in a survey (I) is related to the biomass by the catchability as $I = qB$. Solving for q and putting in the 2007 values for I and B gives q_{all} = 0.005237, and q_{4VWX} = 0.006702, where *all* and *4VWX* indicates what proportion of the stock unit is used in the analysis. Biomass each year can then be estimated as $B = I/q$ (Table 6). Notice that the biomass estimate from the 4VWX data set tends to be about 1000t higher.

In both analyses, the index is increasing since 2003. A linear regression was fit using the inverse of the variance of the standardized catch per unit effort (CPUE) as weights (survey $\sigma^2/q)^{-1}$, thereby accounting for some observation error. Using the entire time period (1998-2008), significant trends in abundance were observed, and it was estimated that the stock is increasing at a rate of 252t/year over the entire stock unit (Figure 22, Table 7a) and 315 t/year in 4VWX (Table 7b). A quadratic function more accurately represents the rate of increase since 2003; however, it is not statistically significant (Figure 22, Table 8).

There is considerable variability associated with the estimate of exploitation rate from the tagging data, and it is important to incorporate this source of uncertainty in the estimate of biomass. Table 9 represents the results for the 10th, mean (as above), and 90th confidence limit of the 2007 exploitation rate. The biomass estimate varies by 6498 to 8333t, and the annual change in biomass ranges from 243 to 312 tons/year depending on which exploitation rate is used.

Surplus production is the annual change in biomass plus the catch. On average, 76% of the production is taken as catch and 24% is left for future growth (Table 10). Yield per recruit was estimated using: 1) growth parameters from a Von Bertalanffy fit to ageing data (not presented), 2) length at age converted to weight at age using an allometric relationship (not presented), an assumed natural mortality of 0.1 and knife-edged selectivity at age 6 (~85cm). $F_{0.1}$ was found to be 0.09, which is about half the exploitation rate from current tagging data (Figure 23). Figure 24 shows the estimated exploitation rate (catch/biomass) since 1998, which has exceeded $F_{0.1}$ in all years and has averaged 26%.

In conclusion, a 15% increase in the TAC (215t) is close to the annual growth in biomass. Over the last decade, 76% of the production has been taken in the catch, which, for most stocks, would be considered high. The current exploitation rate from tagging is about double natural mortality and $F_{0.1}$, which would be considered high for most stocks. Without biological reference points, it is impossible to know when the stock is recovered or what level of precaution is necessary.

CONCLUSION

The halibut survey has been in place for 11 years and has been used as an indicator of population status. Its continued operation is essential to the management of the fishery.

Station coverage and NAFO division coverage has been erratic over the course of the survey. In the future, it is vital that the survey consistently cover as many stations as possible over the entire management unit, including 3NOPs.

Overall, there appears to be relative stability in the population of 3NOPs4VWX5c Atlantic halibut based on the halibut survey. The size composition from both the halibut survey and commercial index indicates there has been no depletion of large fish from the population over the survey time series. The commercial index catch rate in 4VWX shows a statistically significant decline. Numbers of pre-recruits and fishable size halibut from the DFO RV and halibut surveys have increased since 2004.

Exploitation rate of the exploitable biomass (>81cm) was estimated to be 17.7% (90% CI: 15.7–19.8%) in 2006, and 20.1% (90% CI: 17.7–22.7%) in 2007 based on the tagging results. This is approximately double natural mortality (10%) and $F_{0.1}$ (9%), and it is not known whether this rate is sustainable.

Surplus production for the period 1998 to 2007 was estimated to average approximately 1700t, 76% of which was taken as catch and 24% was left for future growth of the population. Utilizing 76% of the surplus production in more recent years (2183t) would result in a catch of 1700mt.

Although the exploitation rate is double natural mortality (M) and $F_{0.1}$, given that the abundance indices from the halibut survey have been increasing recently and there are good signs of recruitment, a 15% increase in the TAC for the 2009/2010 fishing season is not expected to increase the risk to the stock as compared to the previous 4 years. However, the longer-term consequences of utilizing the relatively high catch to surplus production ratio (3.2:1) should be evaluated in the context of stock management objectives, reference points, and a risk management framework.

Atlantic halibut can move large distances creating some uncertainty in stock structure. Other sources of uncertainty, including vessels, bait and temperature effects on the halibut survey and commercial index, have not been fully analyzed. A lack of a population model and biological reference points make it impossible to know whether the stock is rebuilt or what is precautionary.

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Table 1. Total reported Canadian and foreign landings (t) of Atlantic halibut from NAFO divisions 3NOPs4VWX5Zc[1]. Ten year annual average landings are presented for 1960 to 1999.

	Year(s)	3NOPs	4VWX	5Zc[5]	3NOPs4VWX5Zc Landings	TAC[6] (3NOPs4VWX5Zc)
Avg	1960-69	996	1464		2595	
Avg	1970-79	487	851		1352	
Avg	1980-89	955	1561	50	2536	
Avg[2]	1990-99	503	790	30	1323	1855
	2000[3]	397	541	6	944	1000
	2001	641	761	11	1413	1150
	2002	682	768	10	1460	1150
	2003	982	819	14	1815	1300
	2004	554	873	12	1439	1300
	2005	483	825	9	1317	1375
	2006	452	912	10	1374	1475
	2007[4]	396	935	35	1366	1475
	2008[4]	191	962	29	1182	1475

[1] Landings from NAFO Table 21A dated 26 November 2008.
[2] Landings in 1999 based on 15 months: January 1999 - March 2000.
[3] Landings from 2000 onwards are from NAFO, are based on calendar year, and do not correspond to the April-March fishing year.
[4] Landings for 2007 and 2008 are from MARFIS and are based on Scotia-Fundy landings.
[5] Landings for 5Zc were first listed in 1986.
[6] The Total Allowable Catch (TAC) is set for April through March.

Table 2. Parameters used in estimating exploitation rate from tagging data. Means, distributions and variances (sigma or sample size) are reported. B = binomial distribution, LN = lognormal, NA = not applicable.

Parameter	Symbol	Distribution	Mean	Variance
Number of recaptures	R_t	NA		
Number of fish marked	N_t	NA		
Release mortality	ϕ	B	0.23	47
Natural mortality	M	LN	0.1	0.3
Previous recaptures	$\sum_{1}^{t-1} R_t$	B	0	
Rate of tag loss	L	B	0.25	92
Waiting period	w	NA	2 months	
Time interval	Δt	NA	1 year	
Reporting rate	λ	B	0.90	70
Percent exploitation rate	F	NA		

Table 3. Industry / DFO Atlantic halibut longline survey catches (t).

Year	Halibut Survey	Comm. Index	Total
1998	11.8	72.6	84.5
1999	8.6	70.0	78.6
2000	10.6	89.6	100.2
2001	8.9	77.7	86.6
2002	9.3	79.4	88.7
2003	8.9	78.7	87.6
2004	10.7	85.8	96.5
2005	8.7	56.7	65.4
2006	2.9	62.5	65.4
2007	5.2	74.9	80.1
2008	8.8	125.7	134.5
Total	94.4	867.4	968.1

Table 4. Generalized linear model summary table; year has no significant effect on catch, but station has a significant effect. Stations had to be covered in 5 or more years to be included in the analysis. The response variable, BOTHWGT, was offset by the log number of hooks.

Negative Binomial Model
Analysis of Deviance Table
Response: BOTHWGT
Terms added sequentially (first to last)

	Df	Deviance	Resid. Df	Resid. Dev.	P(>|Chi|)
Null			1949	3274	
Year	10	10.5	1939	3264	0.4
Station	230	1289.2	1709	1975	< 0.0001

Call: glm.nb(formula = bothwgt ~ year + station + offset(log(hooks)), data = x, init.theta = 0.352536710979447, link = log).

Table 5. Species caught as bycatch in the halibut longline fishery and their COSEWIC and SARA status.

Species	Population	COSEWIC Status	SARA Status	Listing Decision Date
Cusk	Atlantic Ocean	threatened	no status	2009
Atlantic wolffish	Atlantic Ocean	special concern	special concern	
Northern wolffish	Arctic and Atlantic Ocean	threatened	threatened	
Spotted wolffish	Arctic and Atlantic Ocean	threatened	threatened	
Winter skate	Southern Gulf	endangered	no status	2009
	Eastern Scotian Shelf	threatened	no status	2009
	Georges Bank-Western Scotian Shelf and Bay of Fundy	special concern	no status	2009

Table 6. Standardized index of abundance, standard error (SE), and biomass estimate (t) from the halibut longline survey in the entire area of the stock unit (NAFO divisions 3NOPs4VWX5Zc) and on the Scotian Shelf (NAFO divisions 4VWX).

	Entire area			4VWX		
Year	Index of abundance	SE	B	Index of abundance	SE	B
1998	21.56	11.43	4117	21.83	11.57	3256
1999	20.01	10.57	3822	14.22	7.57	2122
2000	38.07	19.99	7269	37.24	19.63	5556
2001	25.94	13.65	4953	24.28	12.83	3623
2002	24.65	12.96	4708	23.52	12.39	3510
2003	20.38	10.74	3893	19.80	10.45	2954
2004	23.99	12.60	4580	25.23	13.32	3765
2005	27.98	14.79	5343	29.20	15.47	4357
2006	33.27	17.70	6353	34.03	18.10	5078
2007	38.62	20.37	7375	49.43	26.20	7375
2008	41.78	22.01	7979	45.24	23.93	6749

Table 7a. Analysis of variance table for stations covering the NAFO divisions 3NOPs4VWX5Zc stock for the entire period of the survey (1998-2008).

	Df	Sum Sq	Mean Sq	F-value	Pr(>F)
Year	1	159.7	159.7	5.47	0.044
Resid	9	262.8	29.2		

Table 7b. Analysis of variance table for stations in NAFO divisions 4VWX for the entire period of the survey (1998-2008).

	Df	Sum Sq	Mean Sq	F-value	Pr(>F)
Year	1	331.6	331.6	9.07	0.015
Resid	9	329.2	36.6		

Table 8. Analysis of variance table for stations covering the NAFO divisions 3NOPs4VWX5Zc stock for the entire period of the survey (1998-2008), estimating a quadratic increase over time.

	Df	Sum Sq	Mean Sq	F-value	Pr(>F)
Year	1	159.66	159.66	6.57	0.033
$Year^2$	1	68.42	68.42	2.82	0.132
Resid	9	329.2	36.6		

Table 9. Calculations of catchability (q) and biomass using the 10th, mean, and 90th confidence limit of the 2007 exploitation rate (F %), and annual change in biomass (∆B/year) from 1998-2008 for the entire area of the stock unit (NAFO divisions 3NOPs4VWX) and on the Scotian Shelf (4VWX).

F (%)	q_{all}	B_{all}	∆B/year	q_{4vwx}	B_{4vwx}	∆B/year
0.177	0.004634	8333	312	0.005931	8333	380
0.201	0.005237	7375	276	0.006702	7375	336
0.227	0.005943	6498	243	0.007607	6498	296

Table 10. Estimated population surplus production. On average 76% of the production is taken as catch and 24% left for future growth.

Year	Catch	∆B	Production
1998	1015	-295	720
1999	1009	3447	4456
2000	944	-2316	-1372
2001	1413	-245	1168
2002	1460	-815	645
2003	1815	688	2503
2004	1439	762	2201
2005	1317	1010	2327
2006	1374	1022	2396
2007	1366	604	1970
AVG	1315	386	1701

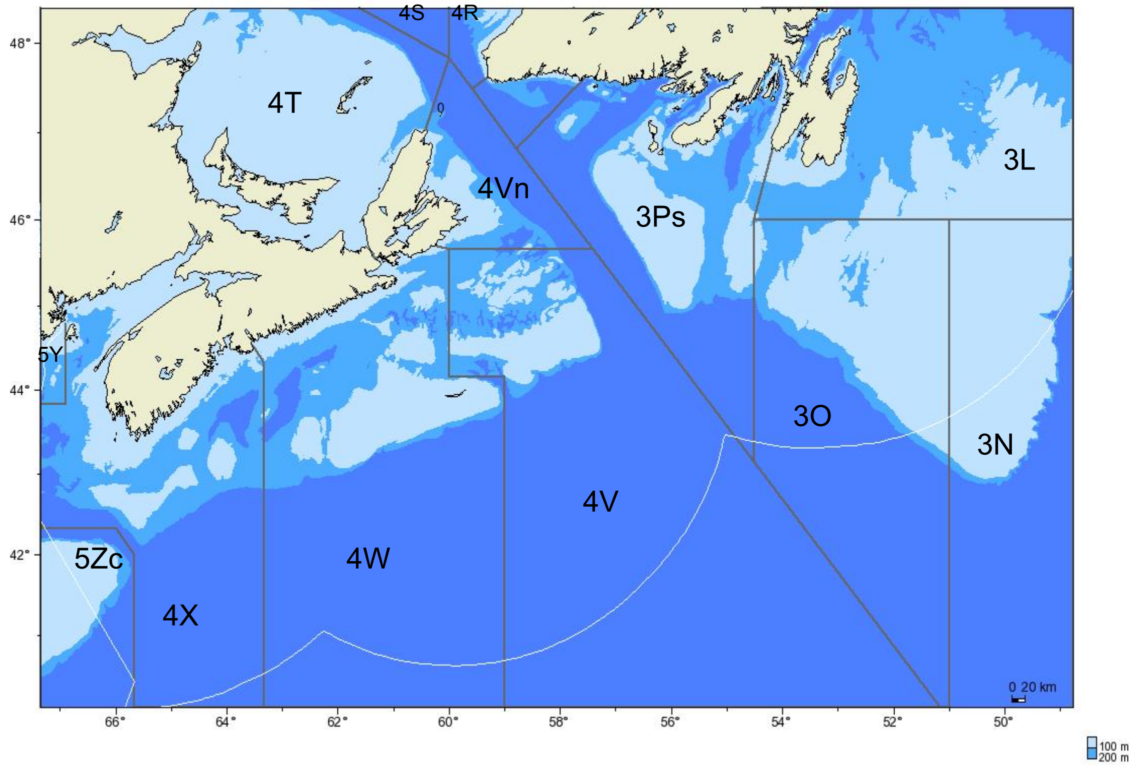


Figure 1. Map of the management unit (NAFO divisions 3NOPs4VWX5Zc) for Atlantic halibut. The Gulf of St. Lawrence (4RST), the northern Grand Banks (3L), and US waters are outside the management unit. The white line indicates the Exclusive Economic Zone (EEZ).

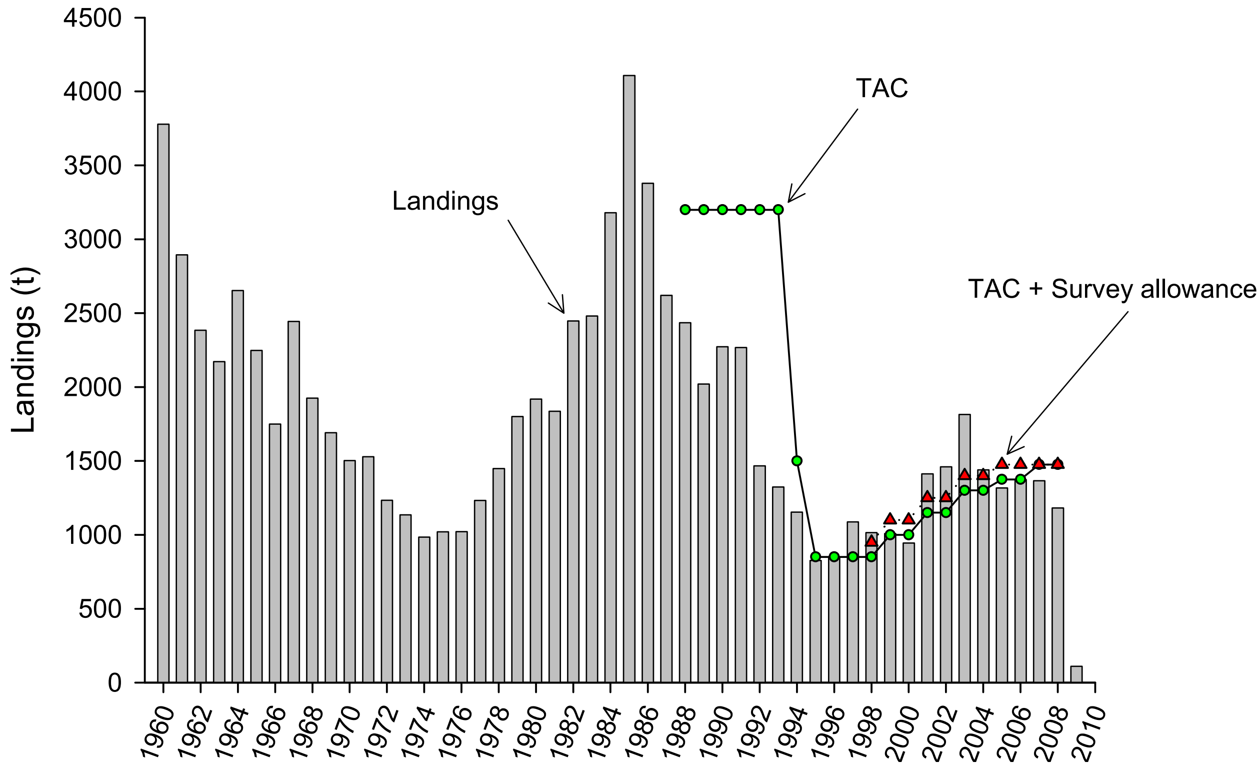


Figure 2. Landings, Total Allowable Catch (TAC), and survey catch limit for Atlantic halibut from the Scotian Shelf and Southern Grand Banks (NAFO divisions 3NOPs4VWX5Zc). A size limit of 81cm was imposed in 1994.

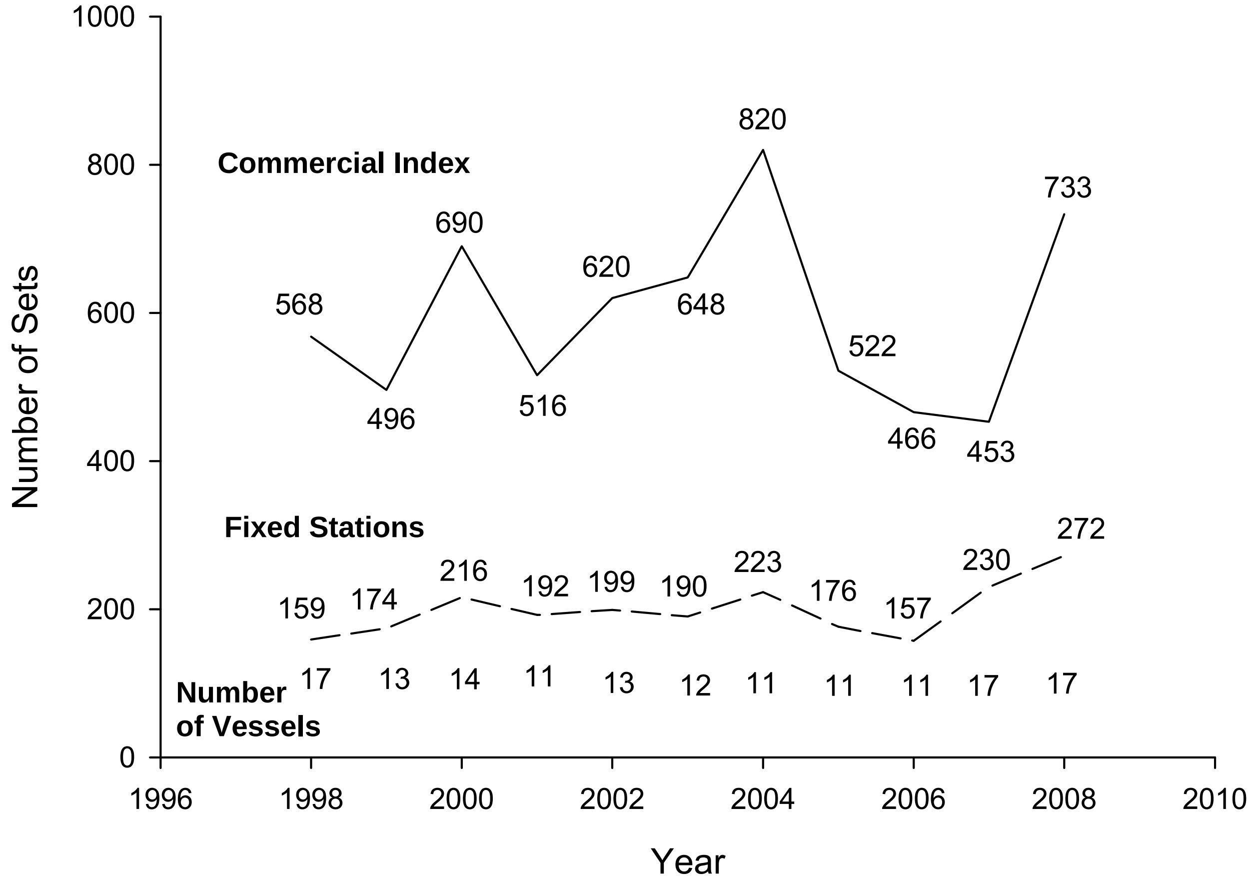


Figure 3. Number of vessels and number of sets completed per year in the halibut survey and the commercial index for NAFO divisions 3NOPs4VWX5Zc. The number of vessels is the same for both indices.

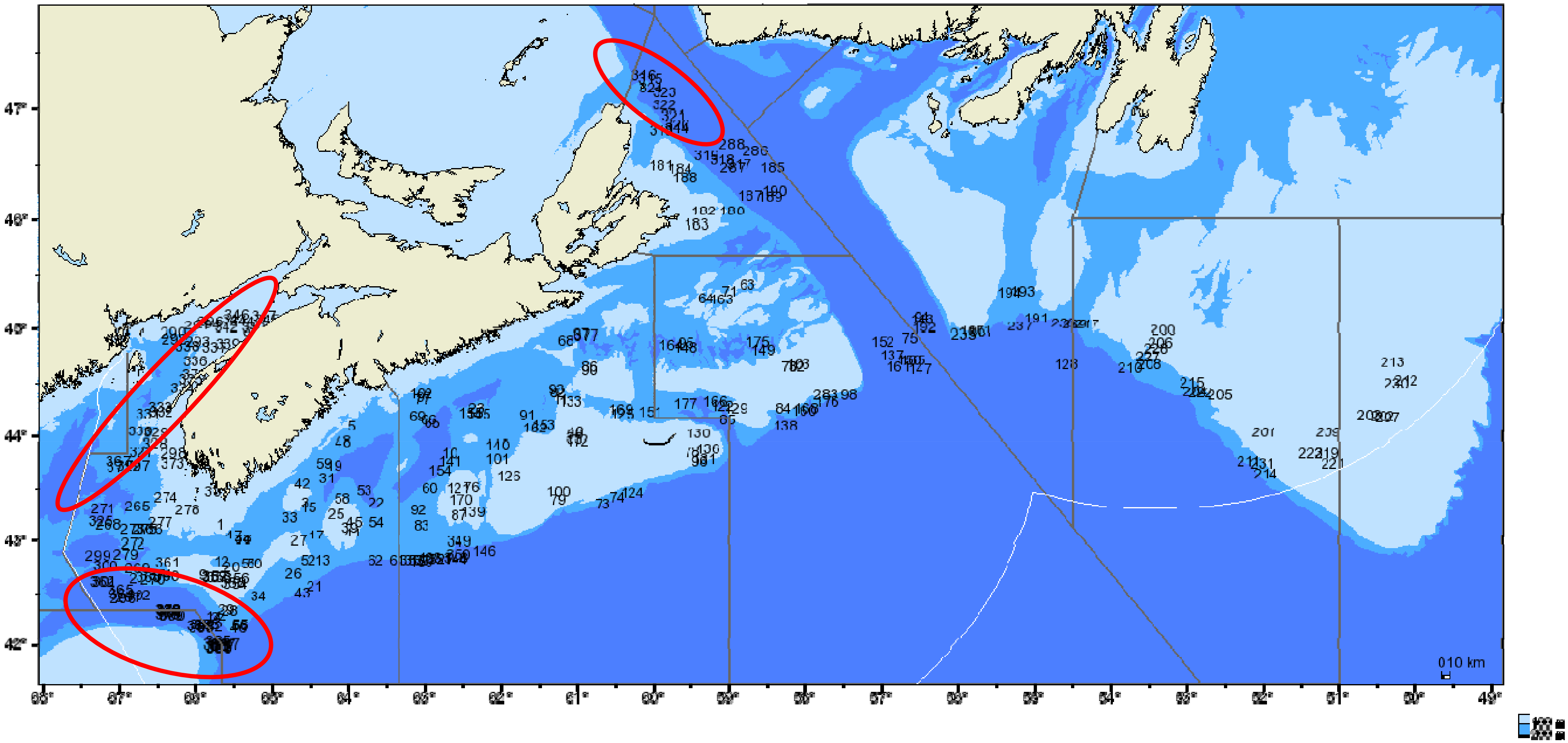


Figure 4. Halibut survey station locations sampled in 2008; including 73 new stations in NAFO divisions 4Vn, 4X, and 5Z indicated in the red ovals.

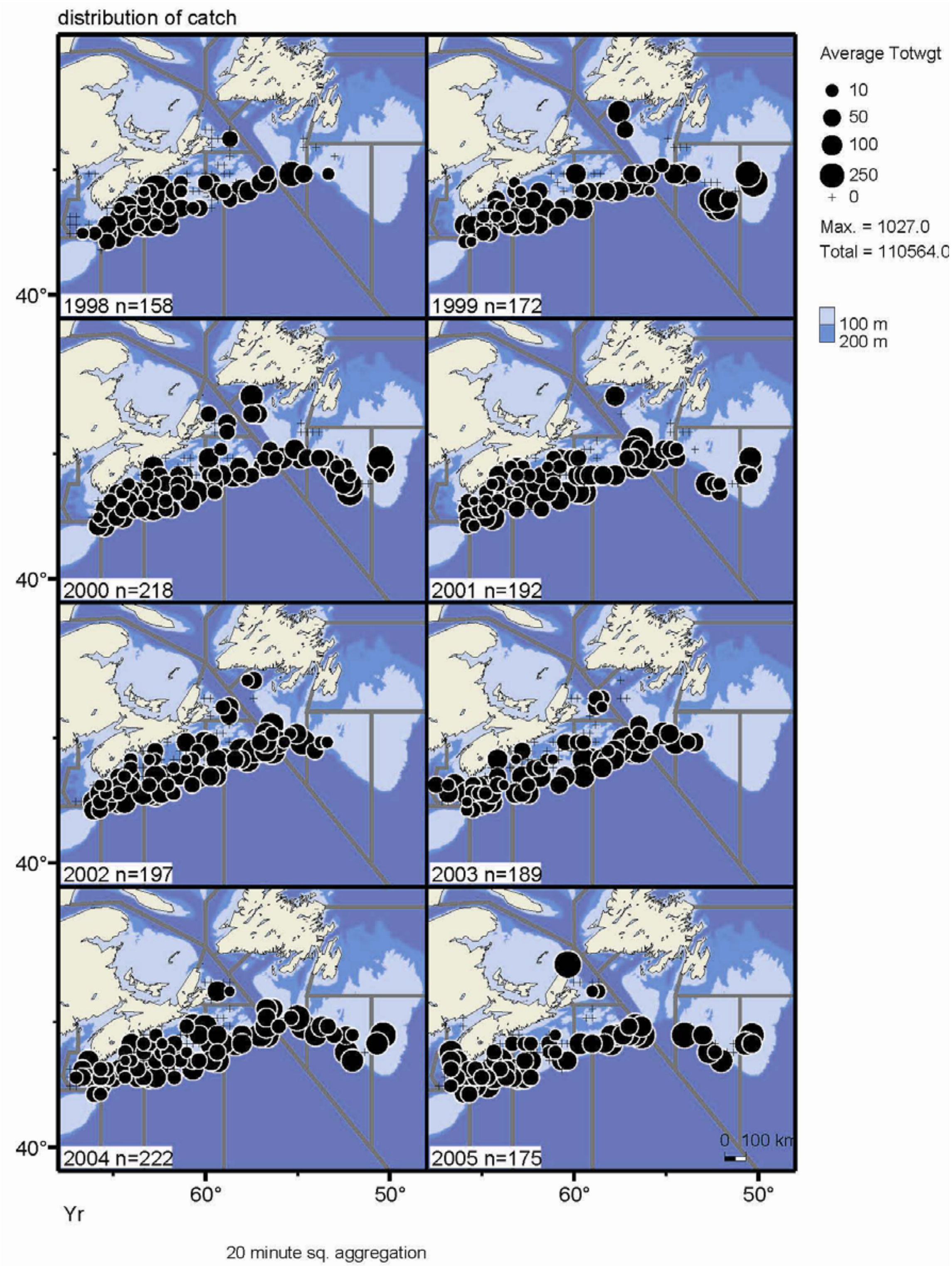


Figure 5. The distribution and average total weight of Atlantic halibut catch at halibut survey stations. Circles in legend indicate total average weight (kg). n = number of stations sampled. Year to year coverage in NAFO divisions 3NO was variable.

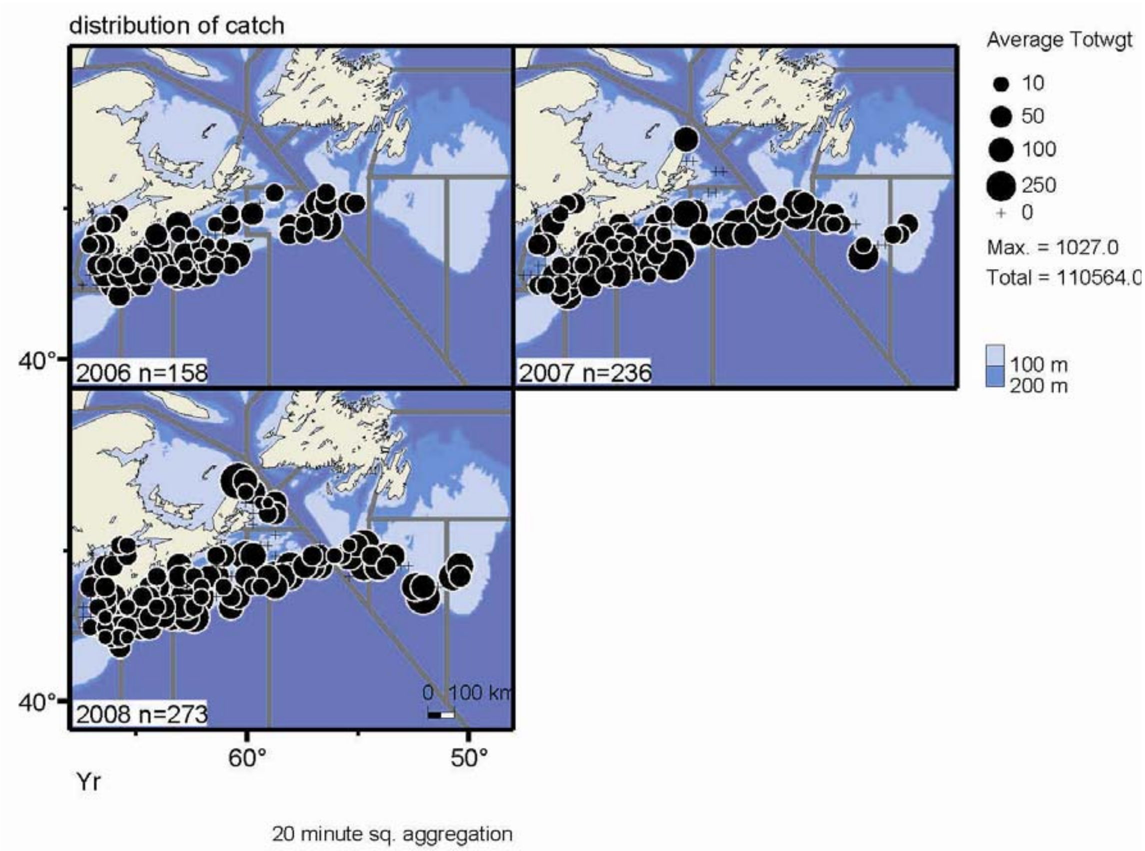


Figure 5 continued. The distribution and average total weight of Atlantic halibut catch at halibut survey stations. Circles in legend indicate total average weight (kg). n = number of stations sampled. Year to year coverage in NAFO divisions 3NO was variable.

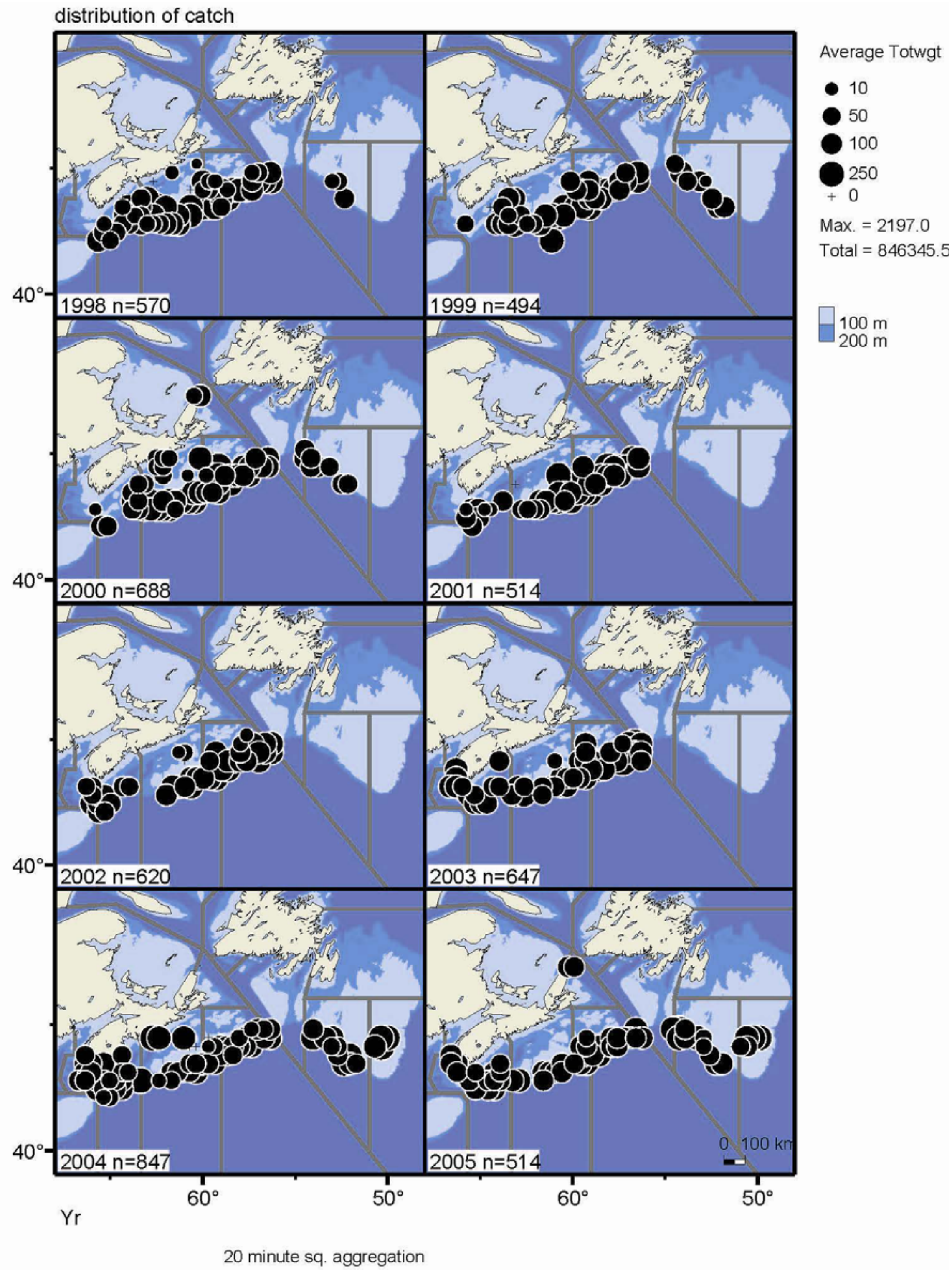


Figure 6. The distribution and average total weight of Atlantic halibut catch during the commercial index. Circles in legend indicate total average weight (kg). n = number of stations sampled. Year to year coverage in NAFO divisions 3NO was variable.

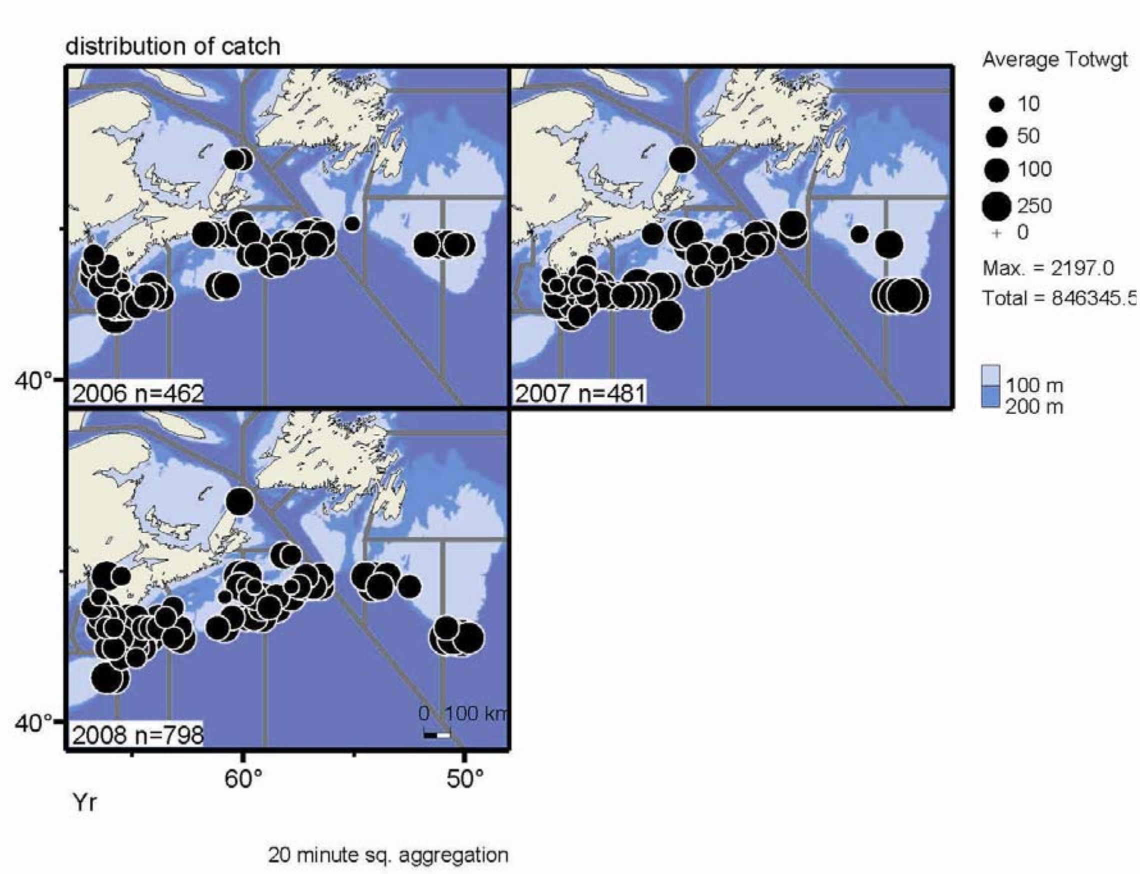


Figure 6 continued. The distribution and average total weight of Atlantic halibut catch during the commercial index. Circles in legend indicate total average weight (kg). n = number of stations sampled. Year to year coverage in NAFO divisions 3NO was variable.

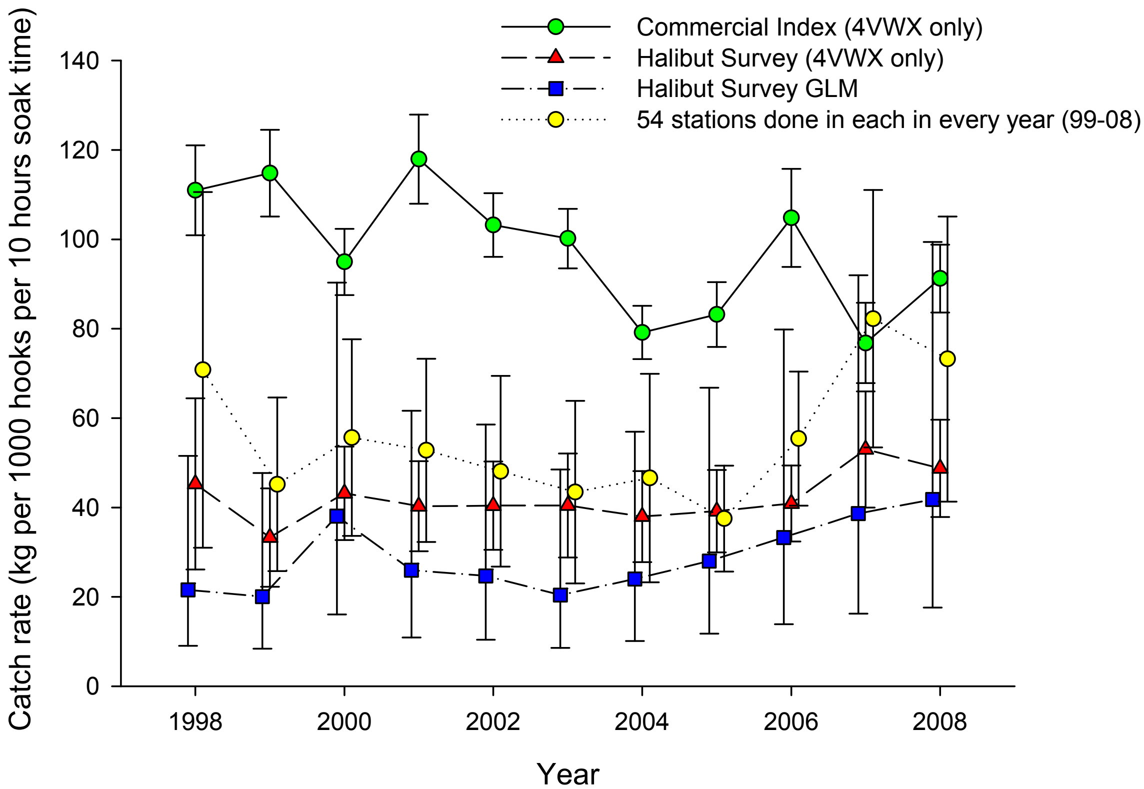


Figure 7. Trends in the halibut survey and commercial index catch rates (+/- 2SE). The survey was analyzed 3 different ways: all stations in NAFO divisions 4VWX; the 54 stations that have been covered each year since 1999; all stations covered 5 or more years and standardized with a Generalized linear model (GLM).

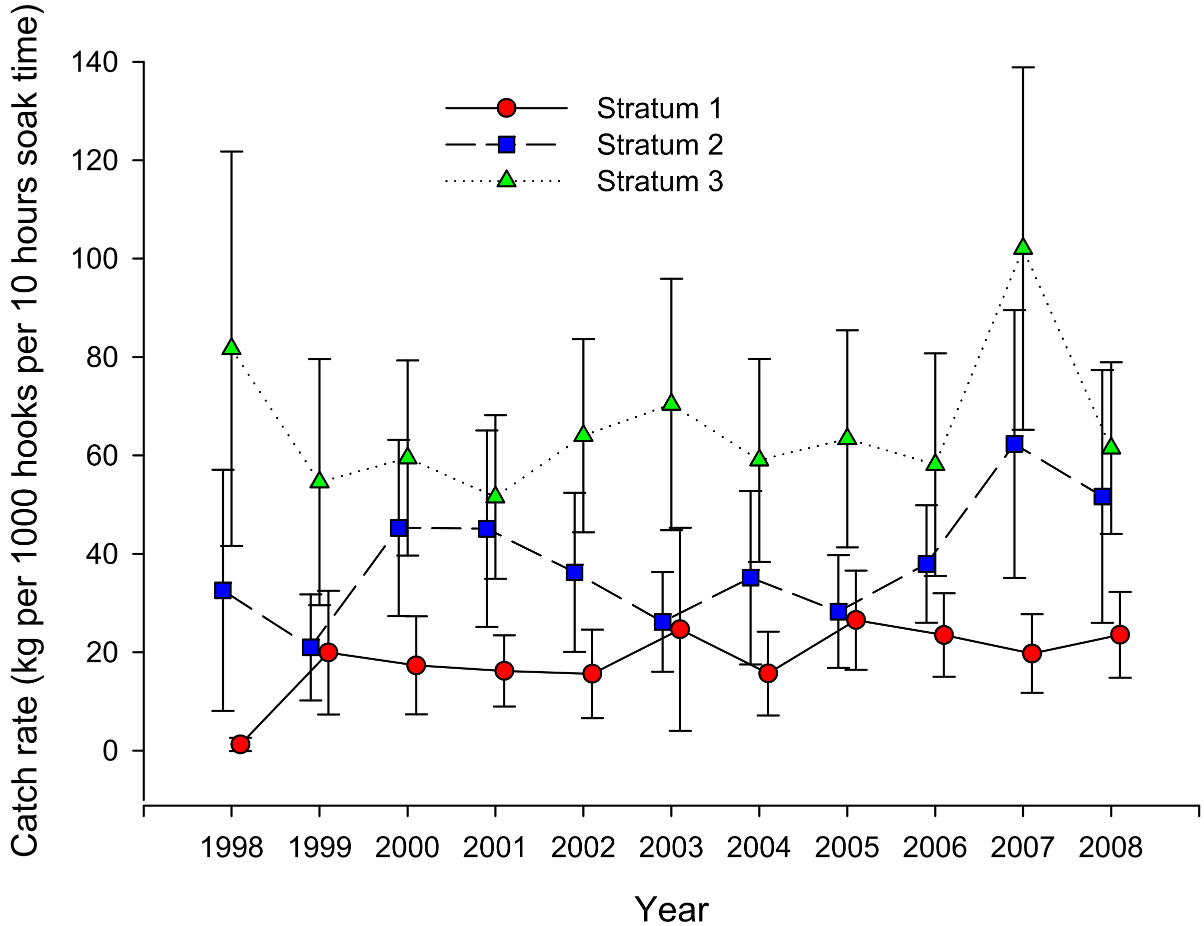


Figure 8. Mean halibut survey station catch rate (+/- 2SE) by stratum of Atlantic halibut, analysis includes all stations done in NAFO divisions 4VWX over the entire survey. Note that for stratum 1, a number of sets in the Bay of Fundy, used in 1998, were abandoned for subsequent years. Stratum 1, 2, and 3 were defined as areas with low, medium, and high catch from 1993 to 1997.

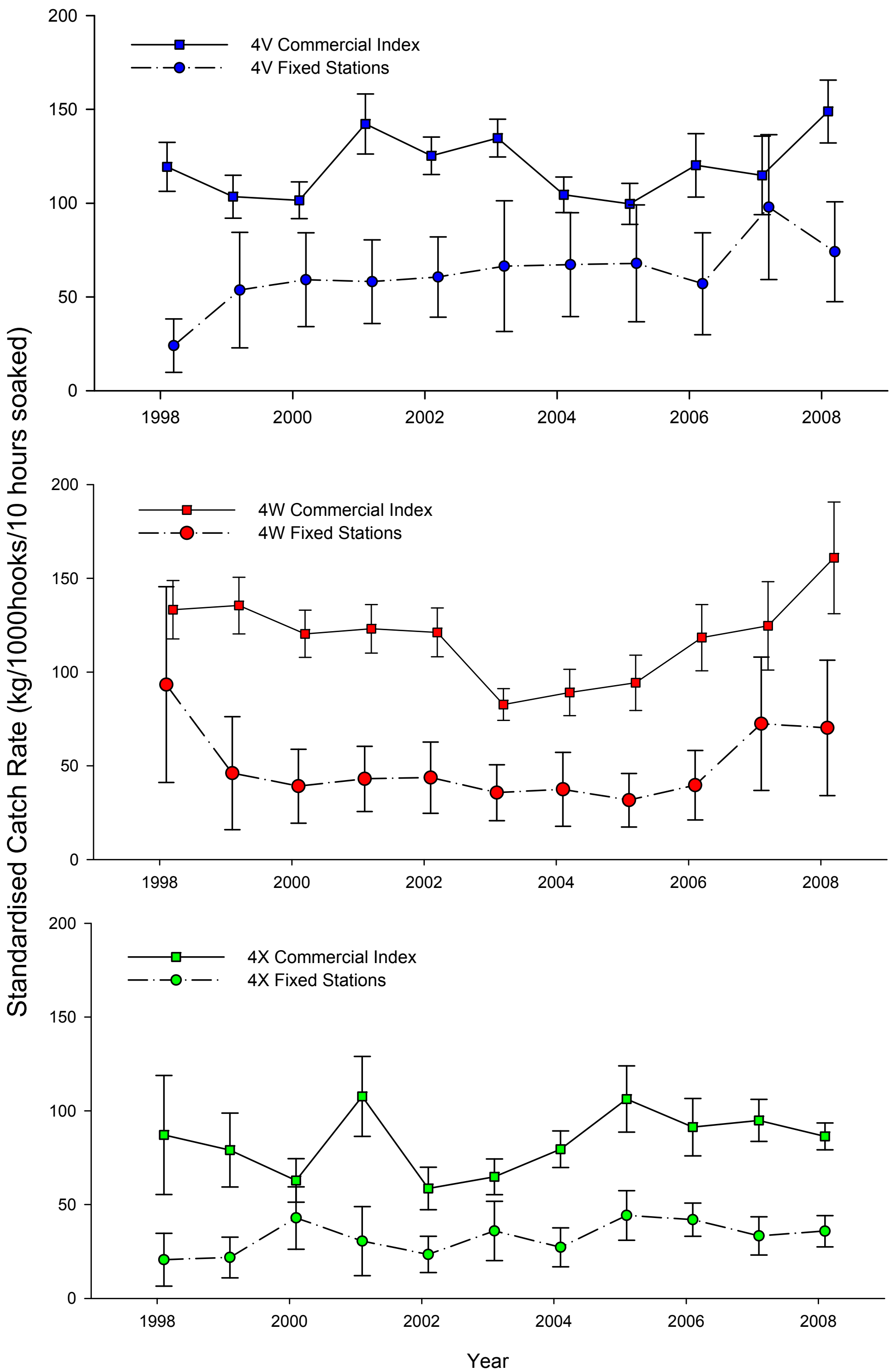


Figure 9. Mean commercial index and halibut survey station catch rates (+/- 2SE) of Atlantic halibut by NAFO area for the Scotian Shelf (NAFO divisions 4V, 4W, 4X) from the halibut survey.

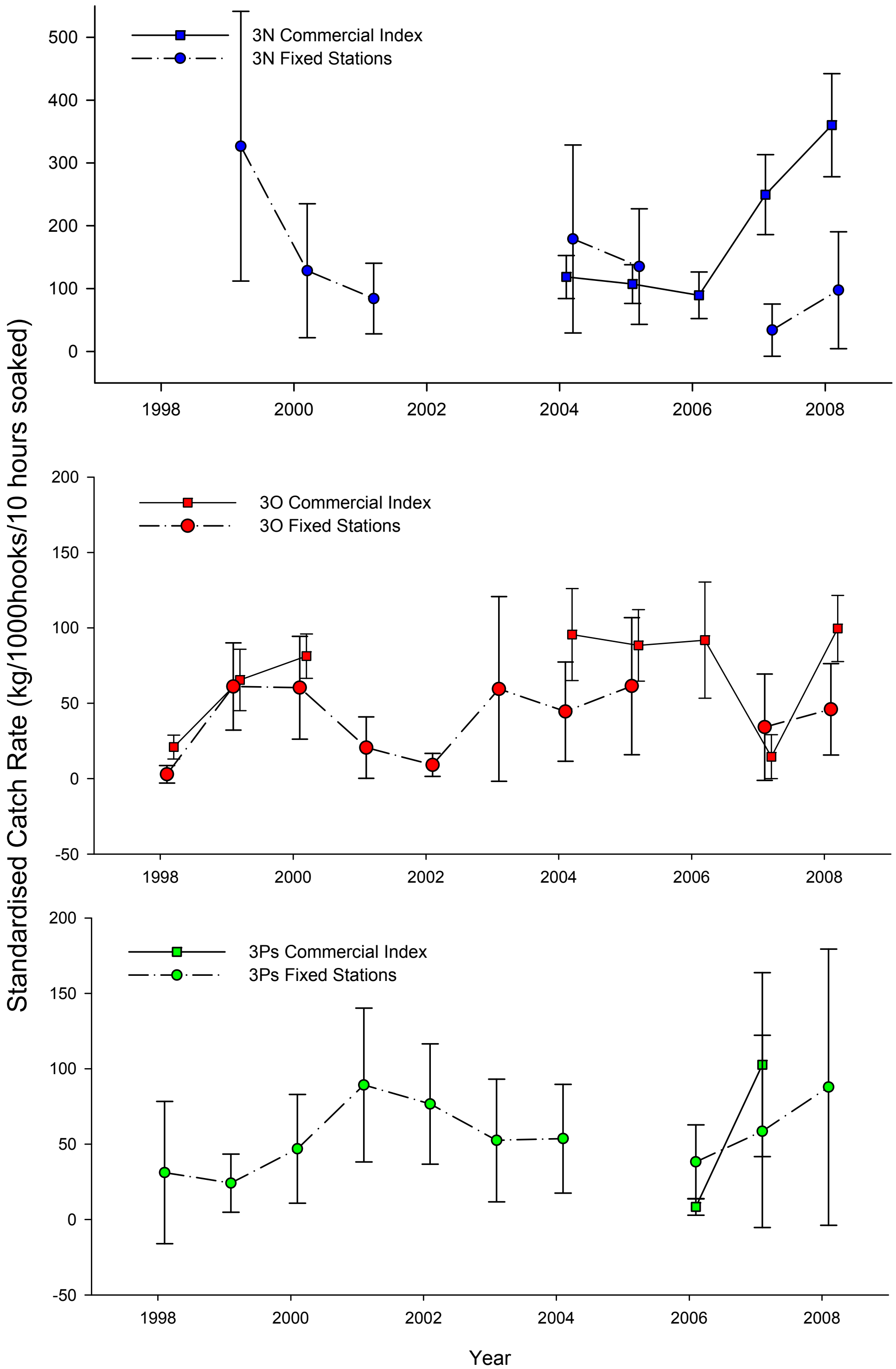
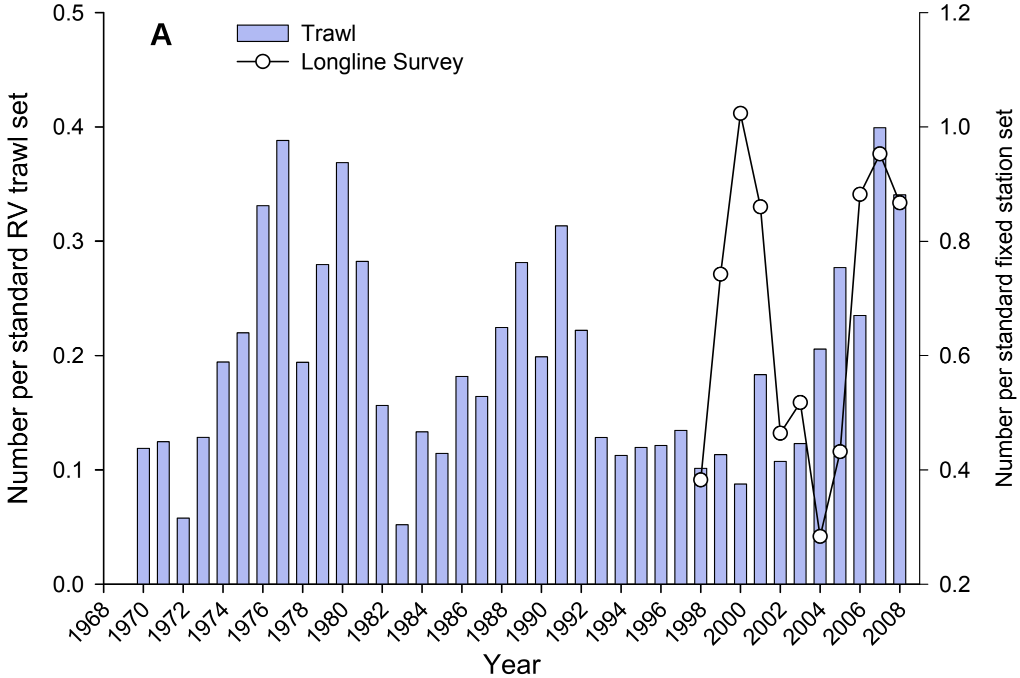


Figure 9 continued. Mean commercial index and halibut survey station catch rates (+/- 2SE) of Atlantic halibut by NAFO area for the Scotian Shelf (NAFO divisions 4V, 4W, 4X) from the halibut survey.



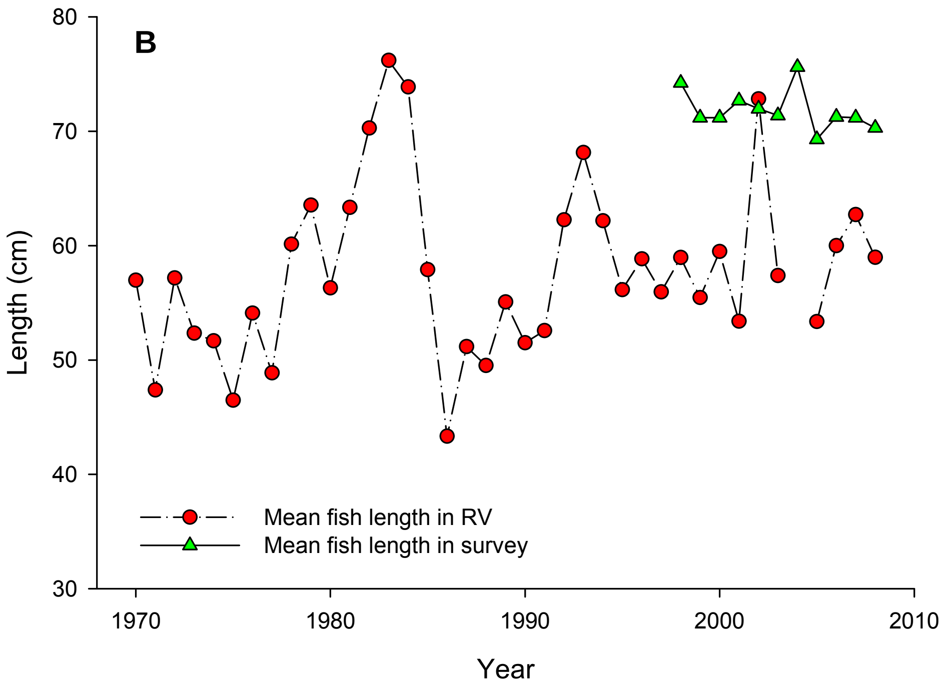


Figure 10. A) Atlantic halibut pre-recruit (<81cm) catch (number per standard set) from DFO research vessel (RV) trawl survey (bars) and from NAFO divisions 4VWX fixed stations in the halibut survey (circles). B) Mean size of fish caught in the RV survey and the mean size of fish <81cm caught in the halibut survey.

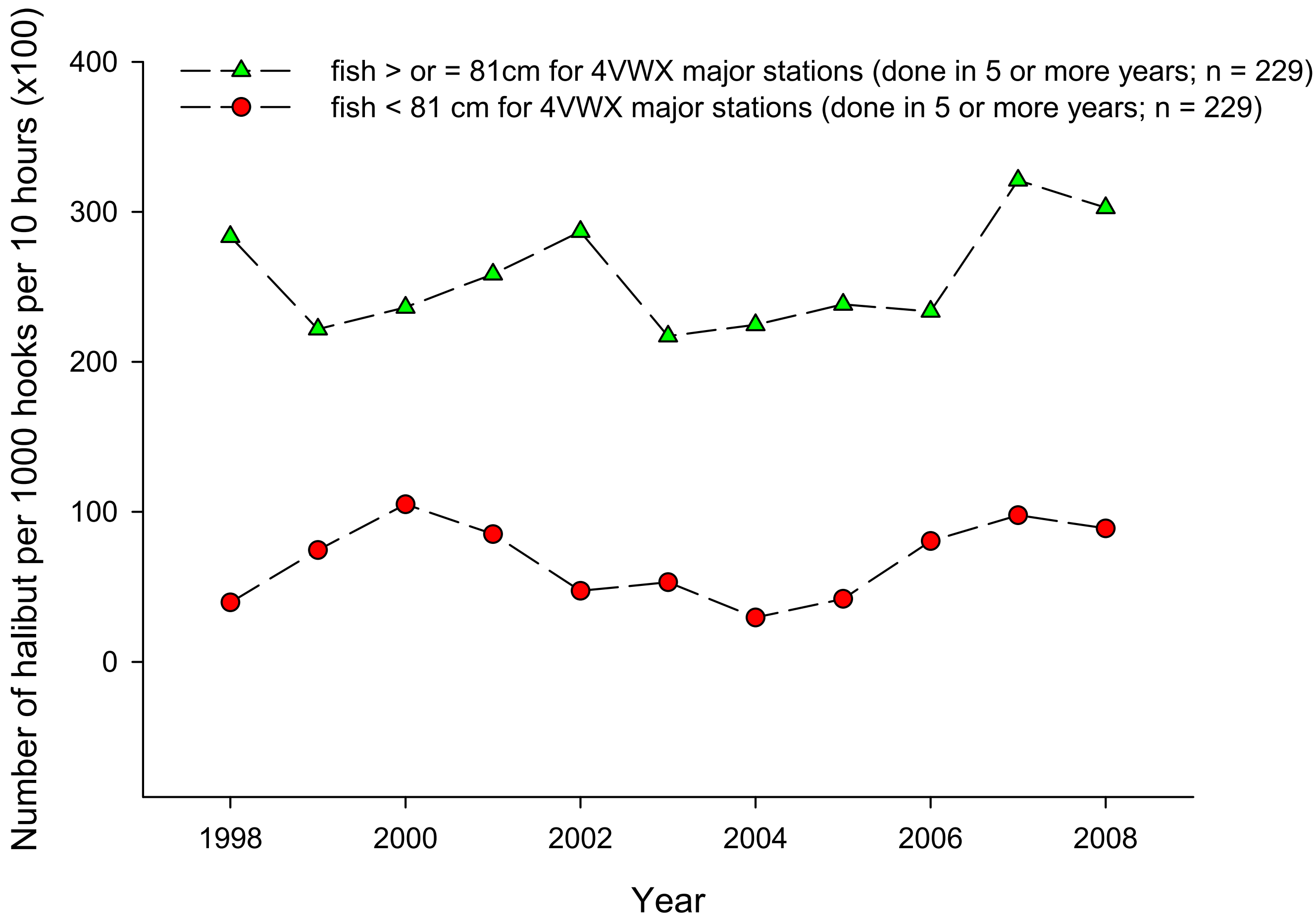


Figure 11. Halibut survey catch rates (number) of Atlantic halibut from stations done in more than 5 years in NAFO divisions 4VWX, separated into pre-recruit (<81cm) and fishable (≥81cm) size classes.

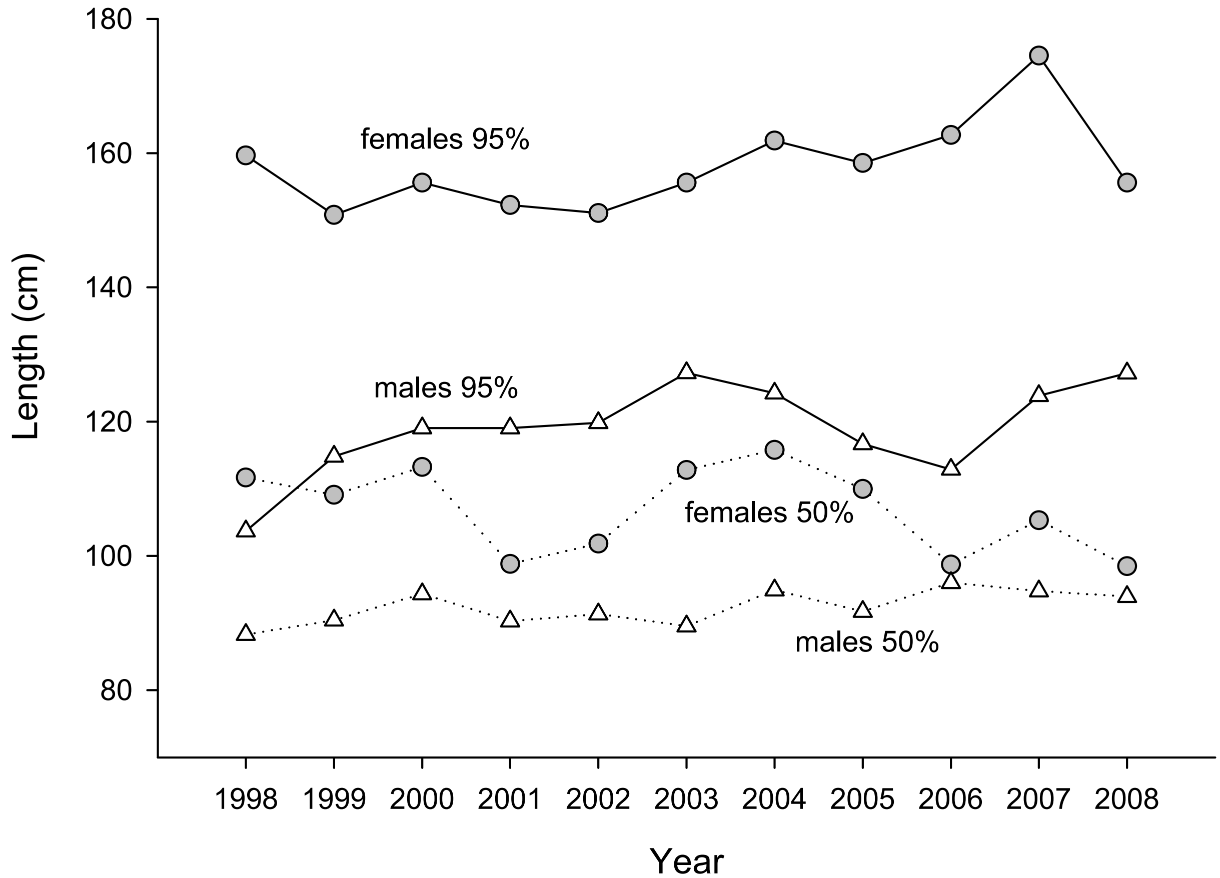


Figure 12. Size composition of Atlantic halibut caught in the NAFO divisions 4VWX portion of the halibut survey, expressed as the median (50%) and 95th percentiles.

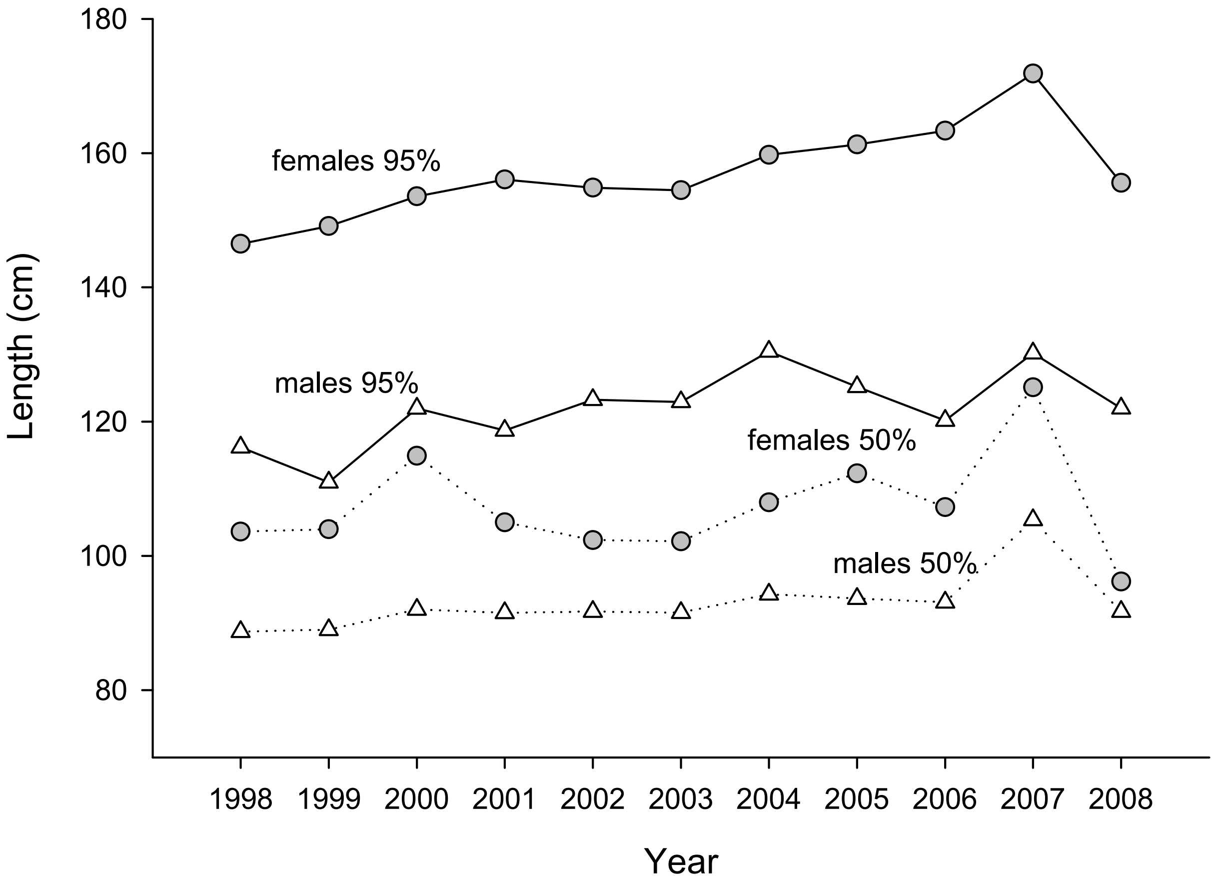


Figure 13. Size composition of Atlantic halibut caught in the commercial index in NAFO divisions 4VWX, expressed as the median (50%) and 95th percentiles.

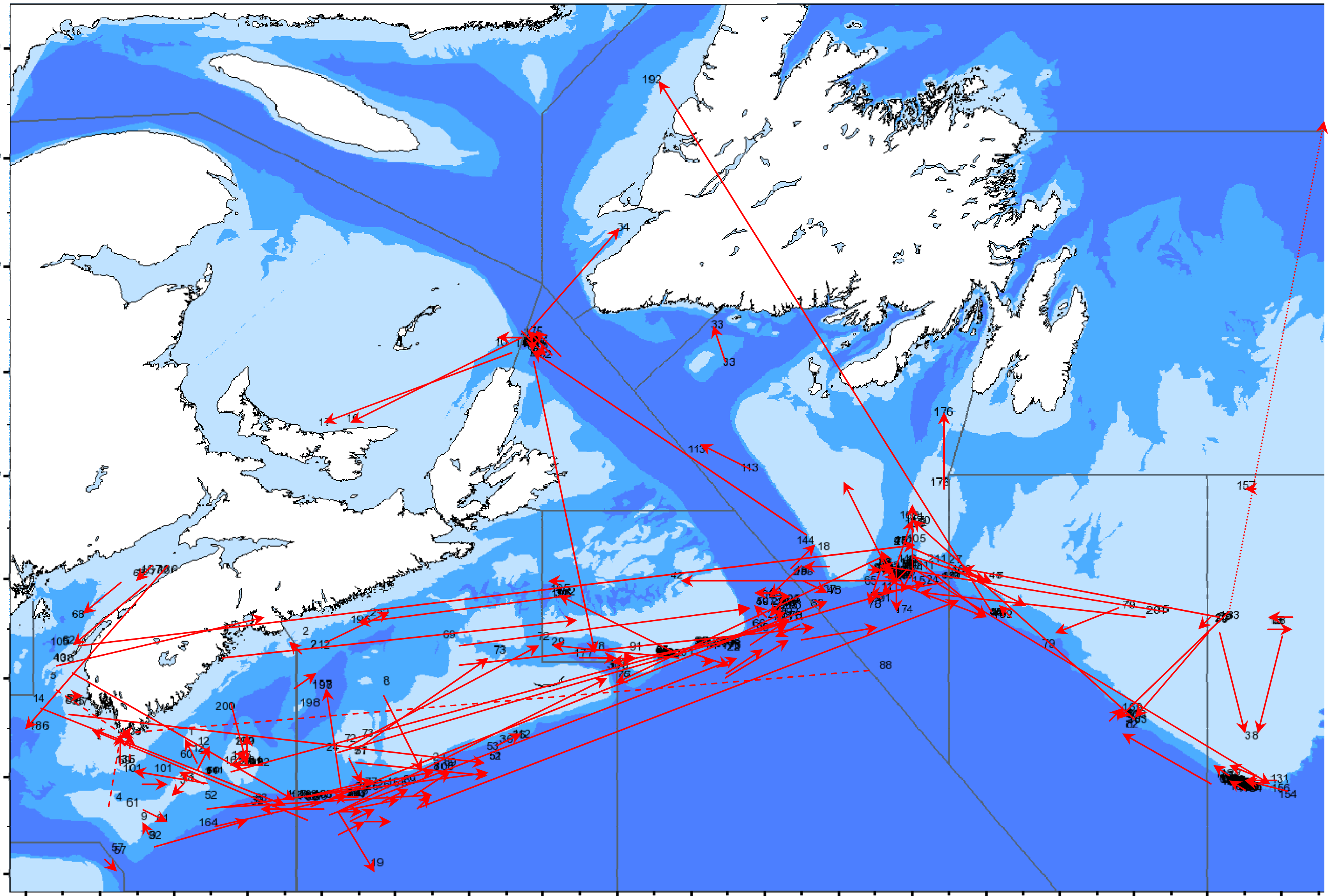


Figure 14. Results of the all-sizes mark recapture project as of February 2009. Movements of tagged halibut released in 2006 (n=526), 2007 (n=848), and 2008 (n=702). Numbered arrows represent the movement of each recaptured halibut (224 recaptures out of 2076 releases).

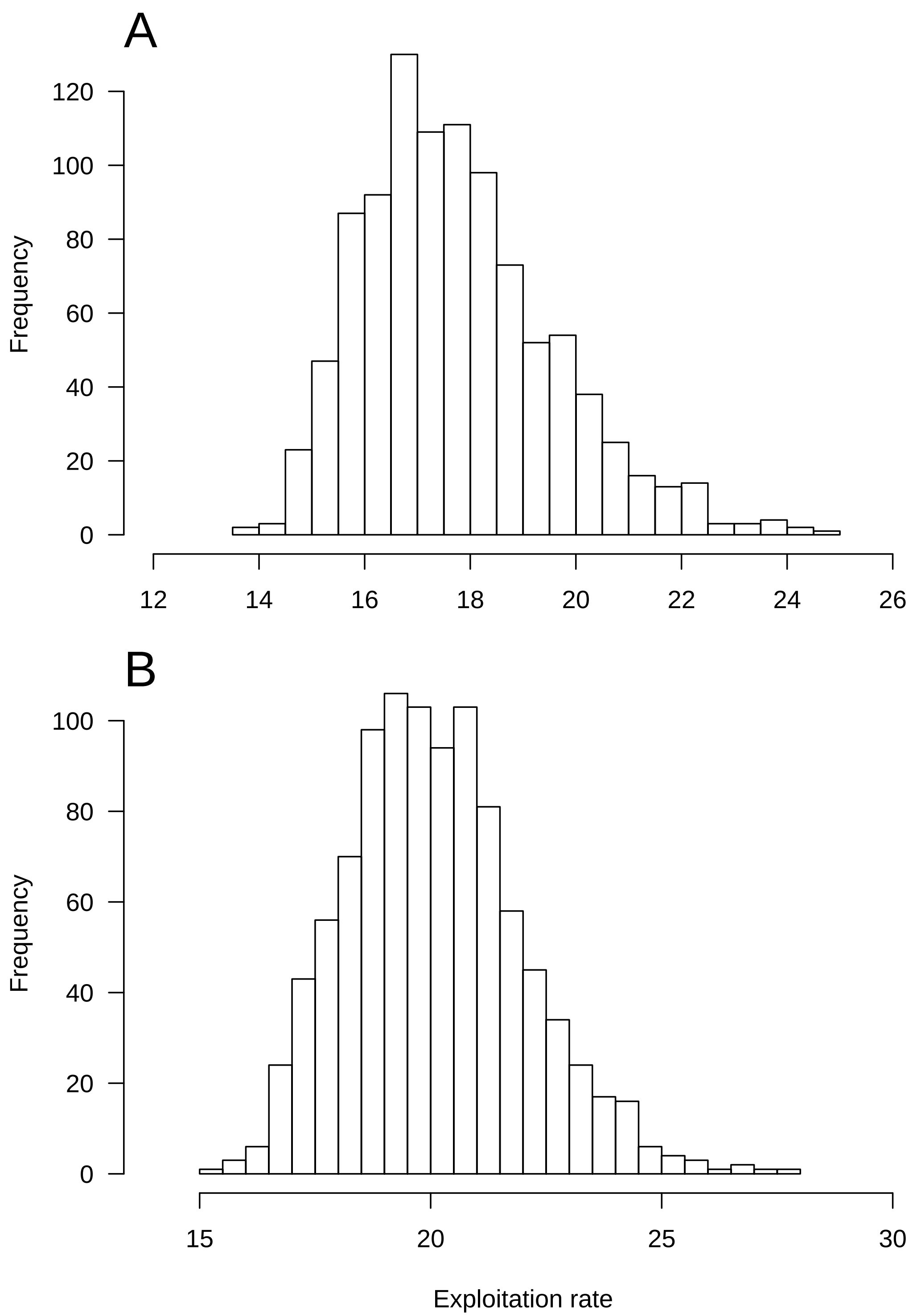


Figure 15. Estimates of exploitation rate from fish ≥81cm tagged in A) 2006 and B) 2007 using a simulation model with mean and variances in Table 2. The mean and confidence limits were estimated to be 17.7% (90% CI: 15.7 - 19.8 %) in 2006, and 20.1% (90% CI: 17.7 - 22.7 %) in 2007.

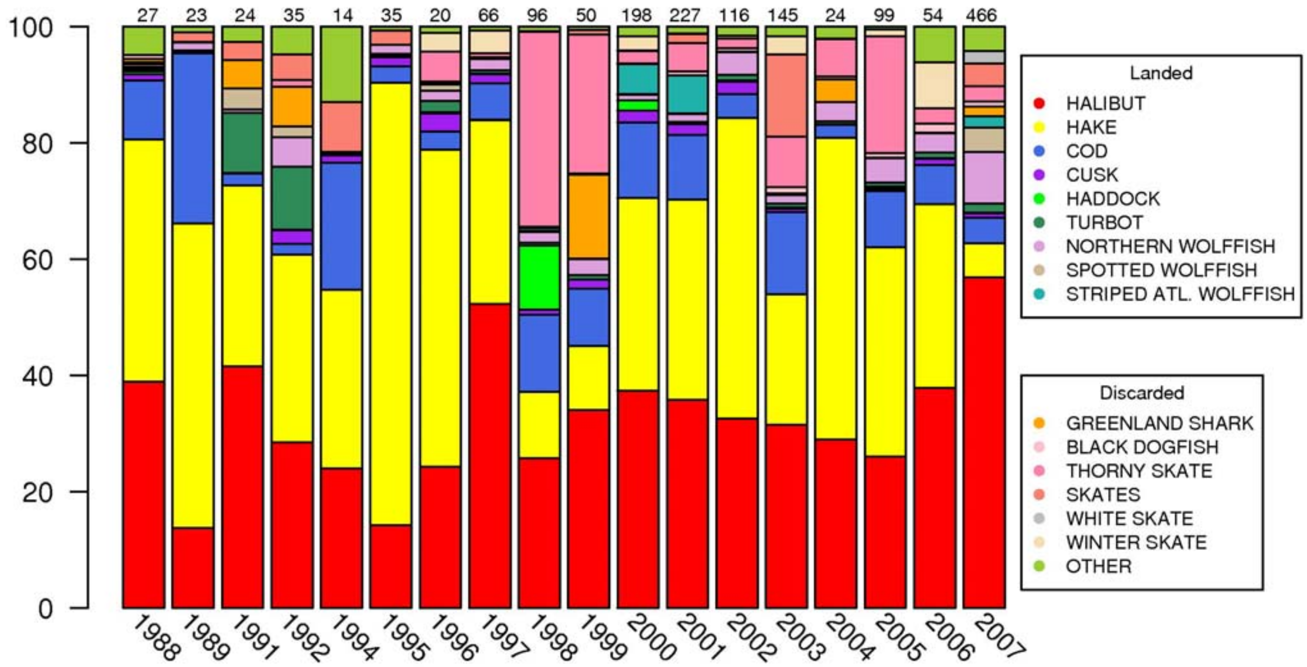


Figure 16. Percent of halibut and bycatch species in the halibut longline fishery estimated from observed trips in 1988 to 2007 in NAFO divisions 3OP4V (including Subdivision Pn). The number above the bars is the total observed catch (t).

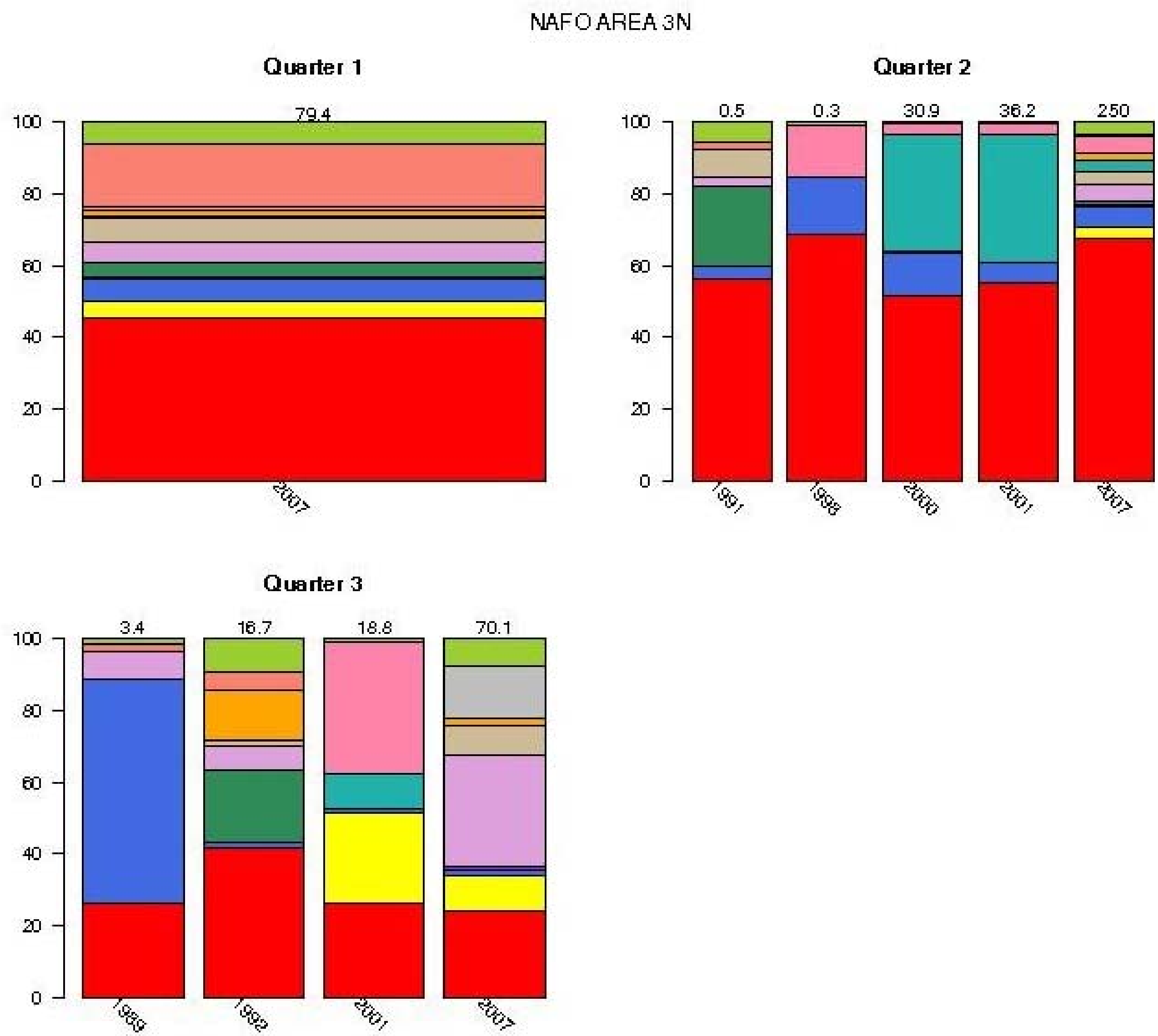


Figure 17. Percent bycatch in NAFO Division 3N for each quarter. Not enough data existed to analyze the final quarter. The number above the bars is the total observed catch (t). See legend of species in Figure 15.

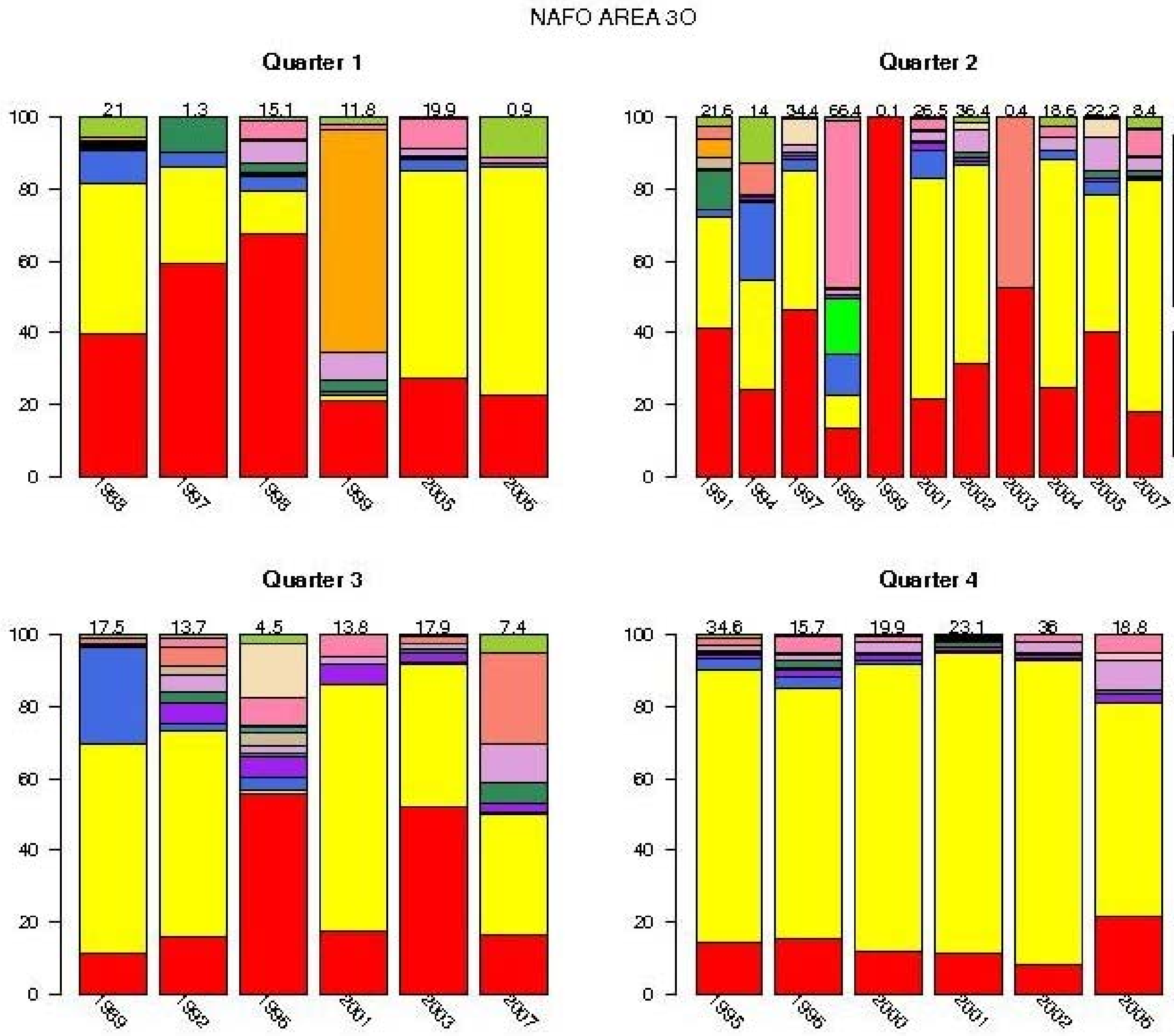


Figure 18. Percent of halibut and bycatch species in the halibut longline fishery in NAFO Division 3O for each quarter. The number above the bars is the total observed catch (t). See legend of species in Figure 15.

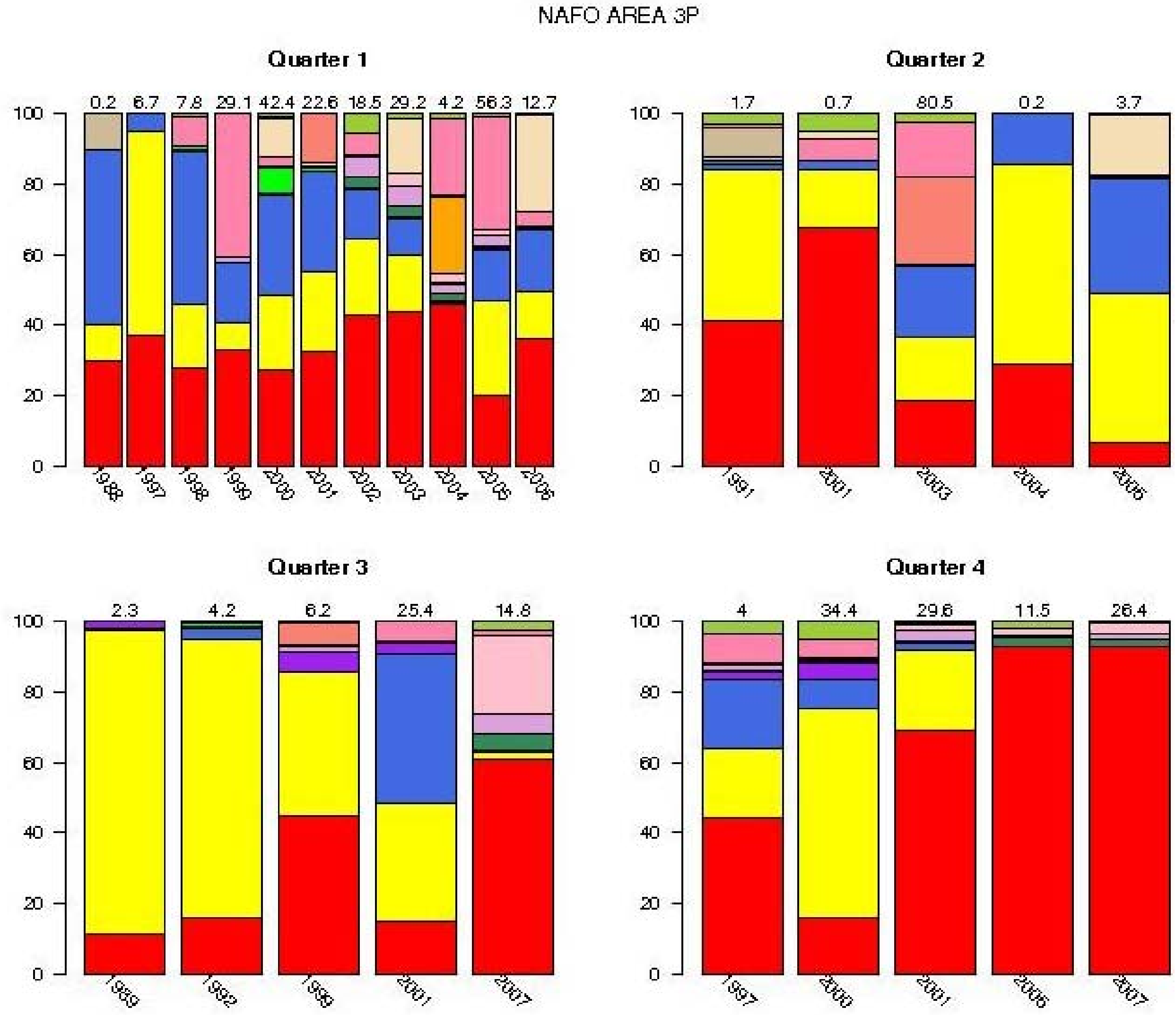


Figure 19. Percent of halibut and bycatch species in the halibut longline fishery in NAFO Division 3P (including Pn) for each quarter. The number above the bars is the total observed catch (t). See legend of species in Figure 15.

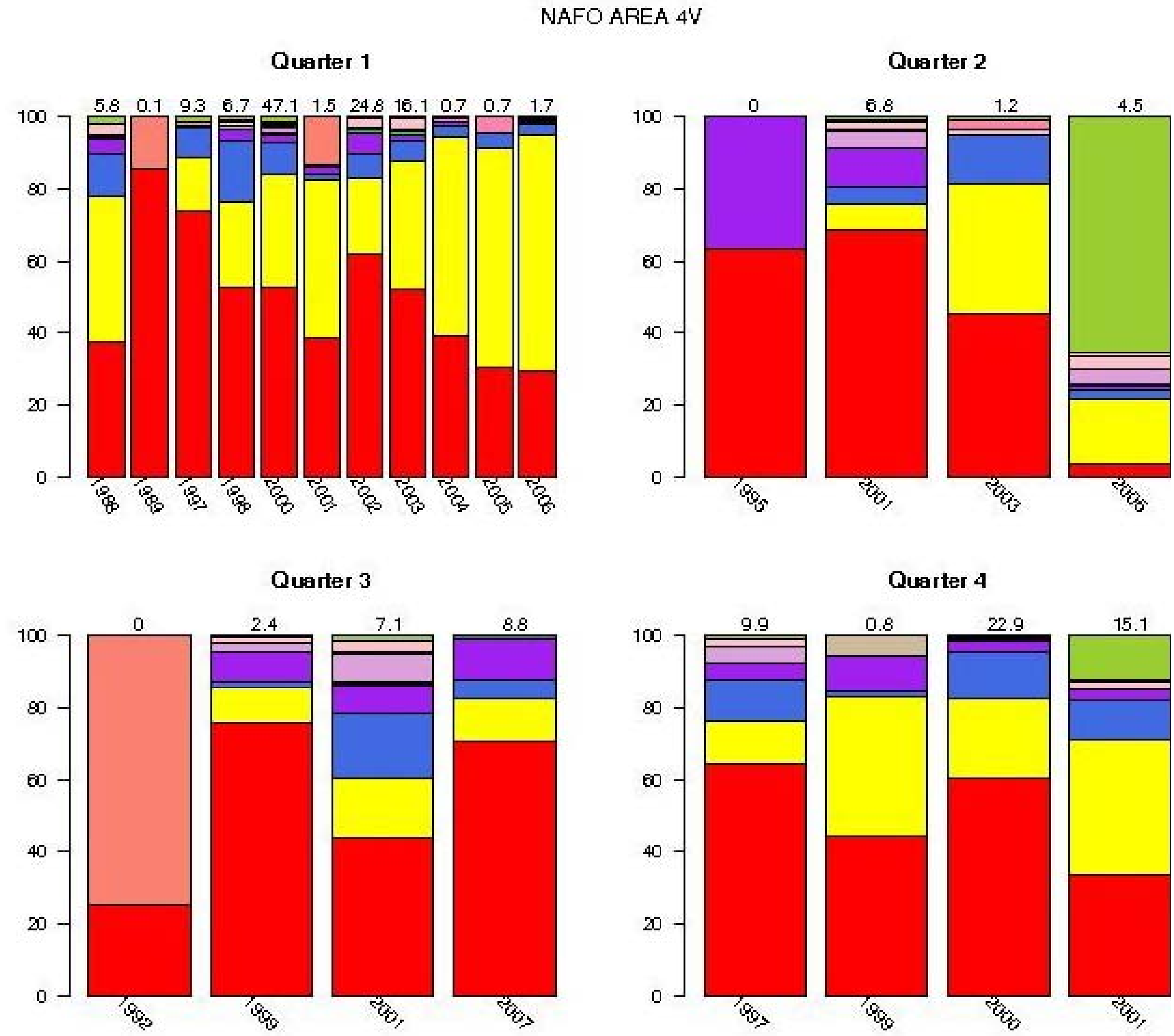


Figure 20. Percent of halibut and bycatch species in the halibut longline fishery in NAFO Division 4V for each quarter. The number above the bars is the total observed catch (t). See legend of species in Figure 15.

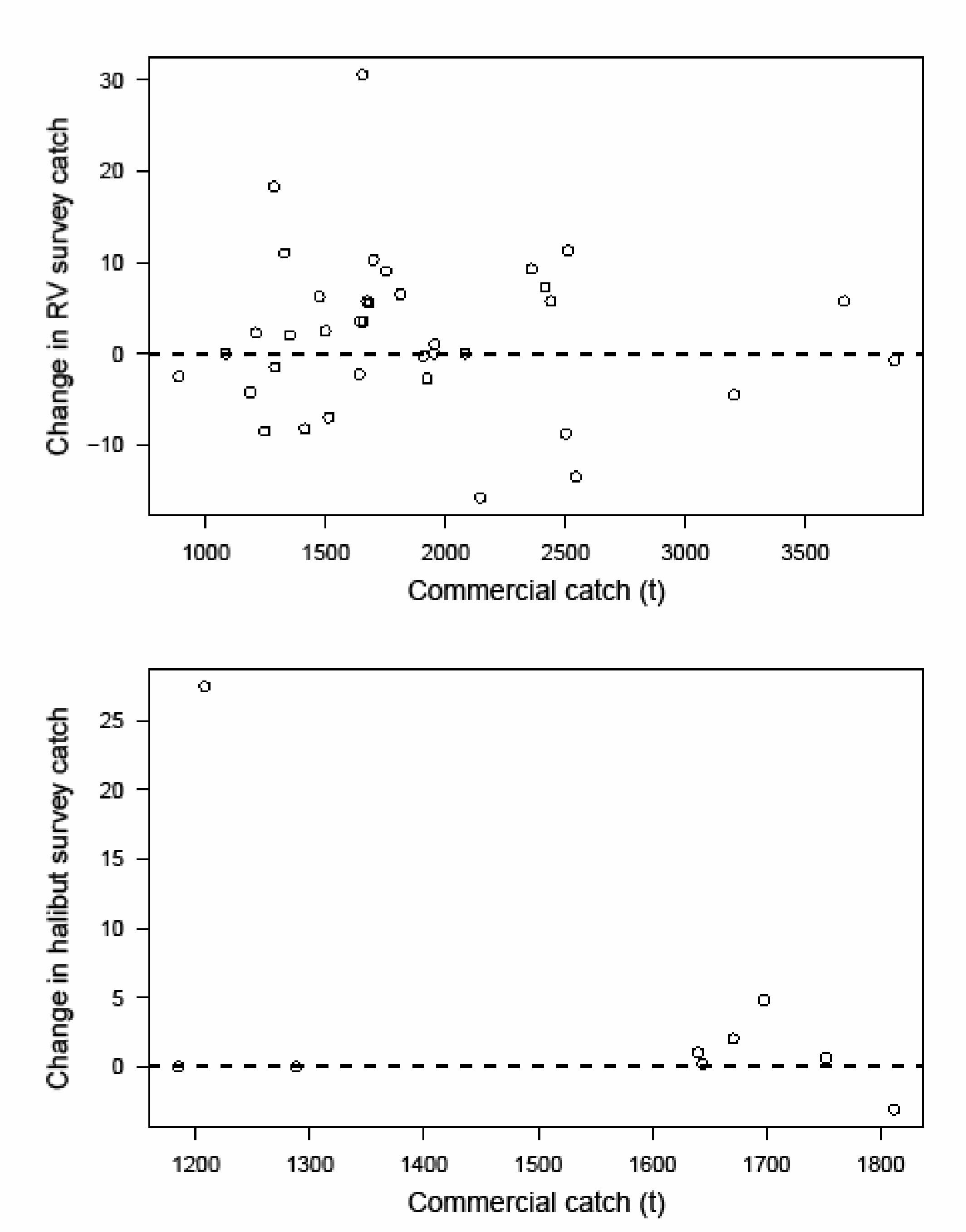


Figure 21. The annual change in the RV survey (1970-2008) measured as the annual change in the total number caught, and halibut survey (1998-2008) measured as the change in standardized catch rate versus the commercial catch.

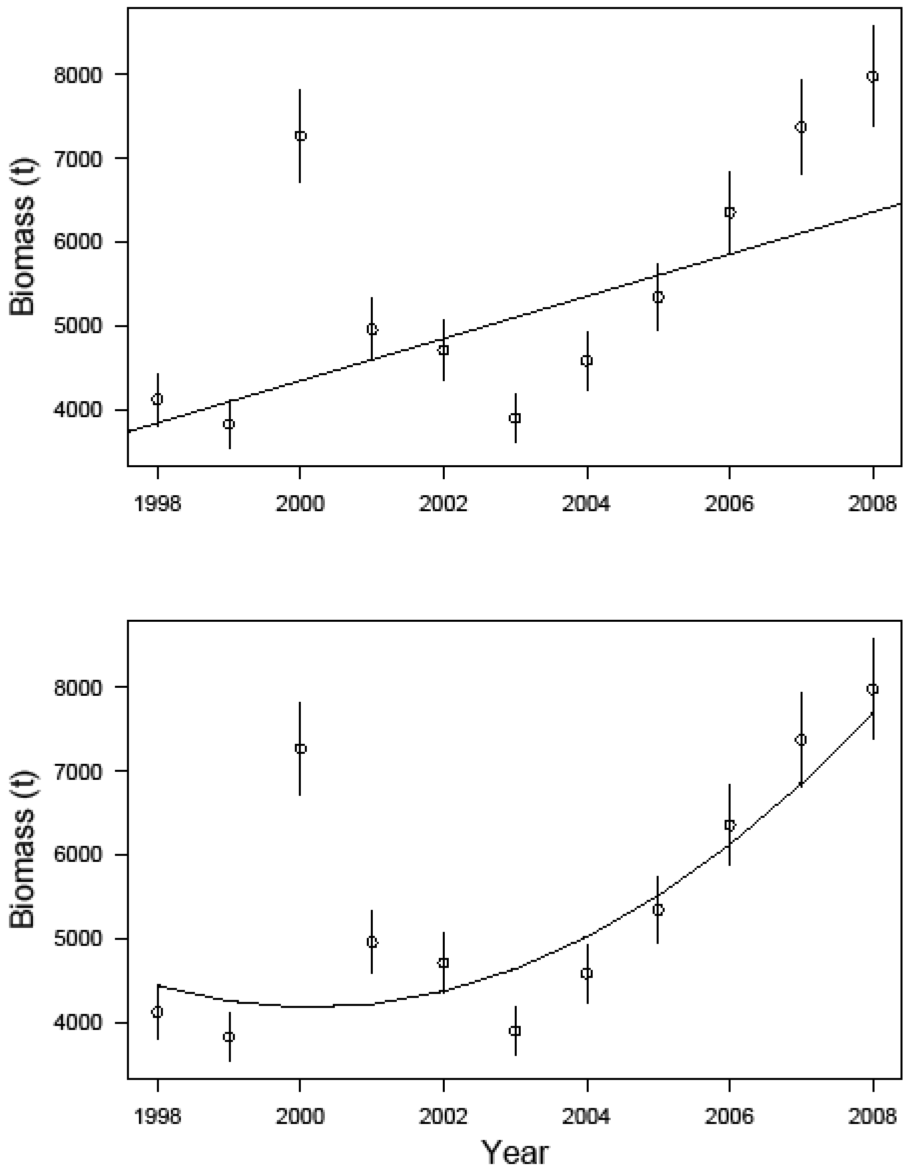


Figure 22. Biomass (t) of Atlantic halibut estimated from the halibut survey catch rates and tagging data. Top panel show a linear fit where biomass is increasing at 252t/year. The bottom panel show a quadratic fit to the data where the biomass is estimated to have increased 840t from 2007 to 2008.

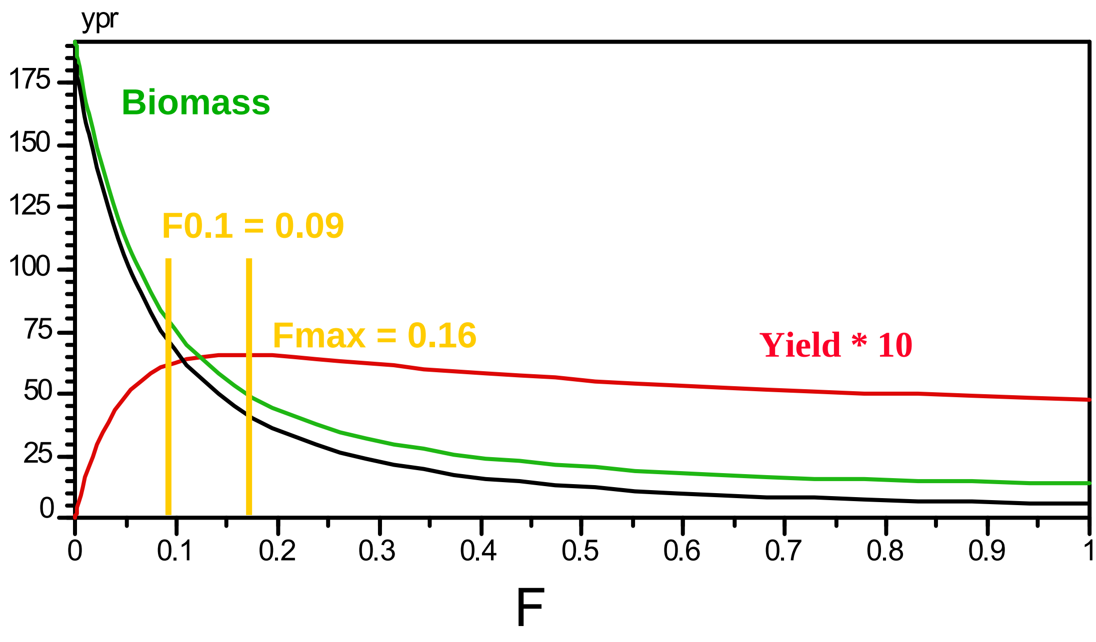


*Figure 23. Yield and biomass per recruit (kg) analysis of Atlantic halibut. Biomass (green line), spawning stock biomass (black line), yield * 10 (red line, was rescaled to make more visible), F_{max} and $F_{0.1}$.*

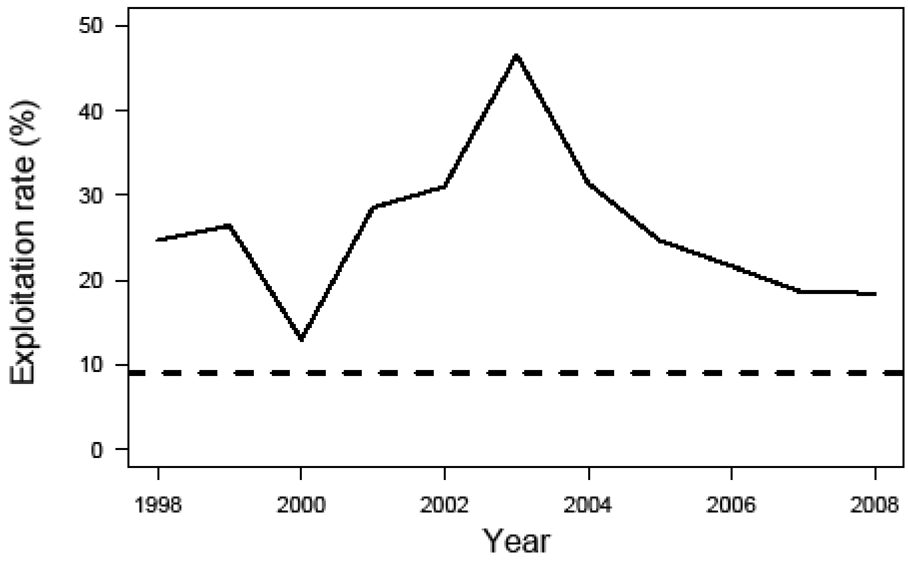


Figure 24. Estimated exploitation rate of Atlantic halibut in NAFO divisions 3NOPs4VWX5Zc (solid line). The dashed line indicates $F_{0.1}$ (9%).