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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 2009

Flétan de l'Atlantique sur le plateau néo-écossais et dans le sud des Grands Bancs (divisions 3NOPs4VWX5Zc de l'OPANO) – Résultats des opérations de marquage et du relevé à la palangre de l'industrie et du MPO jusqu'en 2009

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ABSTRACT

Four catch rate analyses of the halibut survey show recent increases in the exploitable population of Northwest Atlantic Fisheries Organization (NAFO) divisions 3NOPs4VWX5Zc Atlantic halibut, with the largest increase in 2009. Standardizing the catch rate with a general linear model (GLM) is considered the most credible analysis. When vessels effects are accounted for, there is a significant positive trend in catch rates over the past 12 years. Recruitment has increased over the past five years in the halibut survey, has declined in the research vessel (RV) survey over the last two years, but remains above the long term mean. This recruitment is starting to show up as exploitable biomass, and the 2009 catch rates in the halibut survey are the highest on record. The 2008 exploitation rate of the exploitable biomass (>81cm) was estimated to be 15.0% (90% Confidence Interval (CI): 13.3–16.8%) based on the tagging results, although this value is expected to increase as more tags are sent in. As noted in Trzcinski et al. (2009), this exploitation rate is higher than natural mortality (10%) and $F_{0.1}$ (9%), and it is not known whether this rate is sustainable. The surplus production to catch ratio is expected to remain approximately the same as in 2008 (3:1), and the longer-term consequences of utilizing this ratio should be evaluated in the context of stock management objectives, reference points, and a risk management framework. Based on the abundance indices presented here, there is no basis to advise on a change in harvest level in 2010/2011.

RÉSUMÉ

Quatre analyses des taux de captures dans le relevé sur le flétan dénotent des augmentations récentes de la population exploitable de flétan de l'Atlantique dans les divisions 3NOPs4VWX5Zc de l'Organisation des pêches de l'Atlantique Nord Ouest (OPANO), la plus forte hausse étant survenue en 2009. L'analyse fondée sur la normalisation du taux de captures d'après un modèle linéaire général est jugée la plus crédible. Quand on tient compte des effets dus au bateau, une tendance positive significative se dégage dans les taux de captures des 12 dernières années. Le recrutement a augmenté ces 5 dernières années dans le relevé sur le flétan, tandis qu'il a diminué dans le relevé par navire scientifique (NS) depuis 2 ans, tout en restant supérieur à la moyenne à long terme. Ce recrutement commence à apparaître dans la biomasse exploitable et les taux de captures de 2009 dans le relevé sur le flétan sont les plus hauts à ce jour. Le taux d'exploitation de la biomasse exploitable (> 81 cm) en 2008 a été estimé à 15,0 % (intervalle de confiance [IC] de 90 % : 13,3-16,8 %) selon les résultats des opérations de marquage, mais ce pourcentage devrait encore augmenter avec le retour d'autres étiquettes. Tel qu'indiqué dans Trzcinski et coll. (2009), ce taux d'exploitation est supérieur à la mortalité naturelle (10 %) ainsi qu'à $F_{0,1}$ (9 %), et on ne sait pas s'il est viable. Le rapport entre la production excédentaire et le taux de captures devrait rester à peu près le même qu'en 2008 (3/1). Il conviendrait d'évaluer les conséquences à long terme de l'utilisation de ce rapport en fonction des objectifs de gestion, des points de référence et d'un cadre de gestion du risque. D'après les indices d'abondance présentés ici, rien ne justifie de recommander un changement dans le niveau de captures pour 2010-2011.

INTRODUCTION

The status of Atlantic halibut (*Hippoglossus hippoglossus*) on the Scotian Shelf and southern Grand Banks Northwest Atlantic Fisheries Organization (NAFO) divisions 3NOPs4VWX5Zc; Figure 1) was recently assessed by Trzcinski et al. (2009). This assessment was based largely on the indices of abundance generated from the annual Industry/DFO longline halibut survey (halibut survey), the annual Department of Fisheries and Oceans (DFO) groundfish research vessel (RV) trawl survey and estimates of exploitation from 2 years of tagging. Based on this data, Trzcinski et al. (2009) concluded that the resource was increasing but that the catch to production ratio (3.2:1) was high, and that it was impossible to know whether current catches could be sustained in the long term without biological reference points. The Total Allowable Catch (TAC) for the 2009-2010 fishing year was increased by 225t to 1700t (Figure 2), a level which would maintain the current catch to production ratio.

This assessment for the 2010-2011 fishing year follows the same methodology as Trzcinski et al. (2009), without the estimate of production. As such, it is essentially an update of the last assessment. Consequently, this document presents a more concise version of the assessment and refers to Trzcinski et al. (2009) as necessary.

METHODS AND MATERIALS

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 were added from 2005 to 2008. The number of stations fished has varied from year to year and has averaged 200 stations/year. Only 50 have been consistently completed since 1999 and are primarily located on the Scotian Shelf of NAFO Div. 4X and the western half of NAFO Div. 4W. 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.).

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). The catchability of the RV trawl survey is low for halibut >81cm, and is considered to be an unreliable index of adult abundance. Recruitment to the fishery, however, can be estimated since the median size of halibut caught in the trawl survey is between 40 and 50cm. Growth data indicate that these fish will enter the fishery (grow to ≥81cm) in 2 to 3 years.

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). Four separate catch rate analyses were compared to determine whether irregular station sampling over the course of the survey affected the catch rate estimate. The four analyses examined were: 1) data for all stations covered in 4VWX (n = 126 to 225), 2) data for stations completed since 1999 (n = 50), 3) a generalized linear model (GLM) applied to the 50 stations completed since 1999 (GLM 50), and 4) data for all stations covered in 5 or more years and standardized using a generalized linear model (GLM ALL). The GLMs 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 soak time, 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.

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 with t-bar anchor tags during the halibut survey (May - July) from 2006-2008. 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 returnees' names were entered into a quarterly lottery of $1000. Tags were returned to the Halibut Assessment Team at the Bedford Institute of Oceanography (Dartmouth, NS) for analysis. A map of release and recovery locations, and an estimate of exploitation rate (*F*) using the Peterson equation are presented. A more rigorous analysis of these tags will be reported in future publications.

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

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 = 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).

Exploitation rate was only estimated for the exploitable biomass (≥81cm). Tagged halibut <81cm were removed from the analysis (n=25). Recaptures recovered prior to the 2 month mixing period (n=20) were subtracted from the recoveries as in the equation above. Because the analysis was done separately for each year, fish recaptured >420 days (n=115) were removed from the data. A multi-year estimate of exploitation will be done in the future. Ten recaptures were removed due to inadequate information (no recapture date or fish information either from the release table or the recapture table). Consequently, the database consisted of 1617 halibut (≥81cm) tagged and released from 2006 to 2008 and 206 recaptured to date. Updated information resulted in a few more recaptures in 2006 (1 addition, n=45) and 2007 (15 additions, n=93) and exploitation rate was recalculated.

To estimate the uncertainty, 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) based on observations of 47 individuals. To estimate uncertainty in release mortality, a binomial distribution with n=47 was assumed. Natural mortality was assumed to be 0.1, a value which is based on halibut longevity of 50 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, 2007, and 2008, 55 out of 206 tags recovered in a 12-month period were returned as a single tag for a loss rate of 27%. 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).

Ageing and Growth

Ages were estimated by counting growth increments from approximately 2400 thin-sectioned sagittal otoliths removed from halibut collected from the Scotian Shelf and southern Grand Banks. The accuracy of age estimates made from otolith thin sections was validated using bomb radiocarbon assays of 13 otolith cores whose year of formation ranged from 1949 to 1975, encompassing the timeframe of the global radiocarbon pulse. Known-age juvenile halibut from a culture facility were used to identify the approximate location of the first annulus (Armsworthy and Campana, 2010).

RESULTS AND DISCUSSION

Total reported Canadian and foreign landings are provided in Table 1 and Figure 2. Landings data were taken from NAFO Table 21A as reported on 2 September 2009. Landings are based on calendar year and do not correspond to the April-March fishing year. Landings for 5Zc were only separated from the rest of 5Z in 1986. The Total Allowable Catch (TAC) from 2000 to present was set for April through March. The TAC for 2009 was set at 1700t, and as of November 2009: 146t was caught in 3NOPs, 1191t in 4VWX, 13t in 5Zc, and totalling 1350t for the management unit.

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 2008 and they covered a record number of stations (271 in 2008). Participation decreased to 14 vessels in 2009 and coverage decreased to 201 stations (Figure 3).

Over the course of the halibut survey, station coverage has been irregular. Of the 295 fixed station locations (Figure 4), only 50 have been consistently completed since 1999 and are primarily located on the Scotian Shelf of 4X and the western half of 4W (Table 2, Figure 5). To expand the sampling range, 4, 51, 8 and 10 fixed stations were added to the survey area in 2005, 2006, 2007, and 2008, respectively (Figure 4 in Trzcinski et al. 2009). Stations created in 2008 were located on the northeast edge of Georges Bank, the first time this area has been sampled, but none of these stations were covered in 2009.

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 6). This is largely due to the high cost of getting to these areas by Nova Scotia-based participants, and to cod by-catch 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), but dropped to the lowest on record in 2009 (471 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 6 and 7). Despite variability in coverage, there was no obvious indication of a change in the distribution of Atlantic halibut in the survey (Figure 6) or commercial index (Figure 7).

Halibut Survey Catch Rates

Four separate catch rate analyses were compared to determine whether irregular station sampling over the course of the survey affected the catch rate estimate. The four analyses examined were: 1) data for all stations covered in 4VWX (n = 126 to 225), 2) data for stations completed since 1999 (n = 50), 3) a GLM applied to the 50 stations completed since 1999 (GLM 50), and 4) data for all stations covered in 5 or more years and standardized using a generalized linear model (GLM ALL, Figure 8). In general, all analyses indicate that halibut survey catch rates have increased in the past several years. When only stations covered in 4VWX were included, catch rates were generally flat from 1998 to 2006, increased slightly in 2007 and showed the largest increase on record in 2009. The 50 stations that have been covered every year since 1999 showed sharp increases in catch rates in 2006 and 2007 with some decrease but still moderately high catch rates in 2008 and 2009. The GLM standardized catch rates (GLM ALL) showed a slower more steady increase from 2003 to 2008 with the largest increase in catch rates occurring in 2009 (Figure 8). When year was treated as a factor, which is necessary for standardizing the data, it was statistically significant (p=0.008) (Table 4). This is different from what was found in last year's assessment and is due to the large increase in catch rates in 2009. When year was treated as a continuous variable in a linear regression inversely weighted by the variance in the annual catch rate, catch rates increased although the trend was not statistically significantly (1.6 kg/1000 hooks/10 hours soak time per year (p = 0.126, Table 5). However, a lack of a statistically significant trend could be due to vessel effects. When the data was further restricted to only include vessels that have participated in the survey for 3 or more years, a positive and statistically significant (p = 0.015) trend in catch rates was found (2.05 kg/1000 hooks/10 hours soak time). This analysis is not equivalent to estimating vessel effects, which would be difficult in this case because of aliasing (vessels tend to sample the same stations so that independent effects of each can not be estimated). However, the results obtained when the data set is restricted to vessels that have participated in the survey in 3 or more years indicates that either vessel effects or captain effects need to be examined further. The GLM of the 50 stations showed a relatively flat trend until 2006 when catch rates increased and remained moderately high before increasing dramatically in 2009. Analyses using data from 4VWX or the 50 stations consistently fished are assumed to be representative of the whole 3NOPs4VWX5Zc management unit. Survey catch rates (no GLM) for each NAFO division are plotted in Figure 9.

Fixed station catch rates in the halibut survey estimated for each of the 3 strata have shown some variability from year to year, but have been increasing since 2005. Strata 2, which was expected to have intermediate catch rates, exceeded the catch rates in strata 3, which was expected to have the highest catch rates (Figure 10). These results indicate that the stratification scheme may need to be re-evaluated.

Commercial Index Catch Rates

The catch rate in the commercial index in 4VWX is the highest since being first recorded in 1998 (Figure 8). This index is less standardized than the halibut survey, and not all sources of variability have been considered at this time. When Trzcinski et al. (2009) fit a regression through the commercial index, they found a significant decline over time. The same analysis with the 2009 data does not show any trend in catch rates over time (p=0.98). Commercial index catch rates for each NAFO division are plotted in Figure 9.

Pre-recruitment

The number of pre-recruits (<81cm) in the halibut survey has been increasing since 2005 and in 2009 was the highest since the start of the survey. However, pre-recruits caught on the DFO RV trawl surveys, which tend to be smaller and are probably a year or two younger, have been decreasing since 2007 (Figure 11a). There is a high correlation between the DFO RV trawl survey and a two year lag in the catch of pre-recruits in the halibut survey (Figure 12). While the current levels of recruitment are some cause for optimism, there is some time delay in this measure and exploitable biomass (1 to 3 years). The declining number of pre-recruits in the DFO RV survey may indicate that recruitment has reached a peak. Recruitment peaks in 1980 and 1991 were followed by rapid decreases which may be occurring now. Recruitment levels over the next several years will be important in future management advice. Halibut survey catch rates in terms of number of pre-recruits (as in Figure 11a) and number of halibut >81cm are plotted in Figure 13. The mean length of fish caught in the RV survey has been stable at approximately 60cm, whereas there may be a slight decline in the mean length of pre-recruits caught in the halibut survey (Figure 11b).

Tagging

Over 3 years, 2076 halibut ranging in size from 50 to 207cm were tagged with 2 pink t-bar anchor tags. As of April 2009, 250 tagged halibut were recovered (Figure 11). 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.

To date, no tagged halibut have been recovered in Maine, 6 in the Gulf of St. Lawrence (NAFO Div. 4RST), 22 outside the Exclusive Economic Zone on the southern Grand Banks, and 2 have been recovered in coastal Icelandic waters, and the rest have been recovered within the current management unit (Figure 14). Halibut are capable of moving long distances, supporting the need for large management units. There appears to be little movement into the Gulf of St. Lawrence, and it has been reported that 85% of the halibut tagged in the Gulf are recaptured in the Gulf (DFO, 2009). Overall, it appears that the management unit is supported by the current tagging data.

Exploitation rate was calculated for the exploitable biomass (≥81cm). Revised values for 2006 and 2007 are: 18.2% (90% CI: 16.1-20.3%) and 24.0% (90% CI: 21.4-26.9%) respectively, which is slightly higher than in Trzcinski et al. (2009). The 2009 exploitation rate was estimated to be 15.0% (90% CI: 13.3-16.8%) (Table 6, Figure 15); however, this number is expected to go up some as more tags are returned and are entered into the database. The parameters, their mean, distribution standard deviation, and sample sizes are shown in Table 7.

Ageing and Growth

Growth rate for males and females was similar up to about 80cm (~6 years), after which point male growth slowed, while female growth continued to a maximum size of 232 cm (Armsworthy and Campana, 2010). The longevity of Atlantic halibut is up to 50 years. A comparison of age estimates for otoliths collected in a ‘historic’ time frame (1963–1974) with those from recent years (1997-2007) showed that growth rate has not changed appreciably between the two time periods. Small but significant growth differences were observed between the Scotian Shelf and southern Grand Banks for both sexes, while large differences in length at age were observed between halibut caught with longline compared to otter trawl due to differences in length-based gear selectivity.

CONCLUSION

Four catch rate analyses of the halibut survey show recent increases in the exploitable population of 3NOPs4VWX5Zc Atlantic halibut. Standardizing the catch rate with a GLM is considered the most credible analysis. When vessels effects are not accounted for, there is no trend in catch rates. When vessels effects are accounted for, there is a significant positive trend in catch rates over the past 12 years.

Based on the catch rate analyses of the halibut survey, there appears to be stability or potential increase in the population of 3NOPs4VWX5Zc Atlantic halibut in the past 3 to 4 years.

The catch rate in the commercial index in 4VWX is the highest since first being recorded in 1998. However, the commercial index catch rate does not show a linear trend over the survey time series. This index is more difficult to interpret than the halibut survey abundance indices.

Recruitment has increased over the past 5 years in the halibut survey, has declined in the RV survey over the past 2 years, but remains above the long-term mean. This recruitment is starting to show up as exploitable biomass, and the 2009 catch rates in the halibut survey are the highest on record.

The 2008 exploitation rate of the exploitable biomass (>81cm) was estimated to be 15.0% (90% CI: 13.3–16.8%) based on the tagging results. It is likely that the 2008 estimate will increase as additional tags are returned. As noted in Trzcinski et al. (2009), this is higher than either natural mortality (10%) or $F_{0.1}$ (9%), and it is not known whether this rate is sustainable.

The surplus production to catch ratio is expected to remain approximately the same as in 2008 (3:1), and the longer-term consequences of utilizing this ratio should be evaluated in the context of stock management objectives, reference points, and a risk management framework.

Based on the abundance indices presented here, there is no basis to advise on a change in harvest level in 2010/2011.

A lack of a population model and biological reference points make it impossible to know whether the stock is rebuilt or what is a precautionary harvest level. A population model is needed to provide an estimate of sustainable catch levels.

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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	3NOPs4VWX5Zc Landings[2]	TAC[3] (3NOPs4VWX5Zc)
Avg	1960-69	996	1464		2460	
Avg	1970-79	488	850		1338	
Avg	1980-89	955	1561	50	2536	
Avg	1990-99	503	790	30	1323	1855
	2000	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	916	10	1378	1475
	2007	558	944	32	1534	1475
	2008	450	979	29	1458	1475
	2009					1700

[1] Landings from NAFO Table 21A dated 2 September 2009.
[2] Landings from 2000 to present are based on calendar year, and do not correspond to the April-March fishing year.
[3] The Total Allowable Catch (TAC) from 2000 to present was set for April through March.

Table 2. The distribution of halibut survey stations fished every year since 1999 (n=50) by NAFO division and stratum.

Stratum	Count	Proportion	Area	Count	Proportion
1	10	0.20	4V	5	0.10
2	26	0.52	4W	20	0.40
3	14	0.28	4X	25	0.50
Total	50	1.00	Total	50	1.00

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

Year	Halibut Survey	Comm. Index	Total
1998	12.1	72.4	84.5
1999	8.6	70.0	78.6
2000	10.6	89.6	100.2
2001	8.9	77.7	86.6
2002	9.1	79.6	88.7
2003	9.0	78.6	87.6
2004	10.7	87.5	98.2
2005	8.7	57.3	66.0
2006	2.9	62.5	65.5
2007	6.1	80.1	86.2
2008	8.2	125.1	133.3
2009	8.8	125.7	134.5
Mean	8.6	83.8	92.5

*Table 4. Generalized linear model summary table for the standardization of the halibut survey catch rates (*GLM ALL*); both year and station had a significant effect on catch rates. 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 in thousands.*

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

	Df	Deviance	Resid. Df	Resid. Dev.	P(>|Chi|)
Null			2138	3605	
Year	11	25.4	2127	3579	0.008
Station	237	1348.2	1890	2231	< 0.0001

Call: glm.nb(formula = bothwgt ~ year + station + offset(log(hooks)), data = x, init.theta = 0.3684, link = log).

Table 5. Results of linear regression of the halibut survey standardized catch rates over time for the entire period of the survey (1998-2009).

	Df	Sum Sq	Mean Sq	F-value	Pr (>F)
Year	1	174.4	174.4	2.79	0.126
Resid	10	624.2	62.4		

Coefficients: Intercept=-2419.2, slope=1.222

Table 6. The number of fish released (double tagged) and recaptured during the mixing period (2 months) and during the 12 month recapture period. Exploitation rate and CI calculated as in the Methods section.

Release Year	No. released	No. recaptured within 2 months	No. recaptured in 2 to 14 months	Exploitation rate (90% CI)
2006	420	5	45	18.2 (16.1-20.3)
2007	653	6	93	24.0 (21.4-26.9)
2008	544	9	48	15.0 (13.3-16.8)

Table 7. 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	0.27	206
Waiting period	w	NA	2 months	
Time interval	Δt	NA	1 year	
Reporting rate	λ	B	0.90	70
Percent exploitation rate	F	NA		

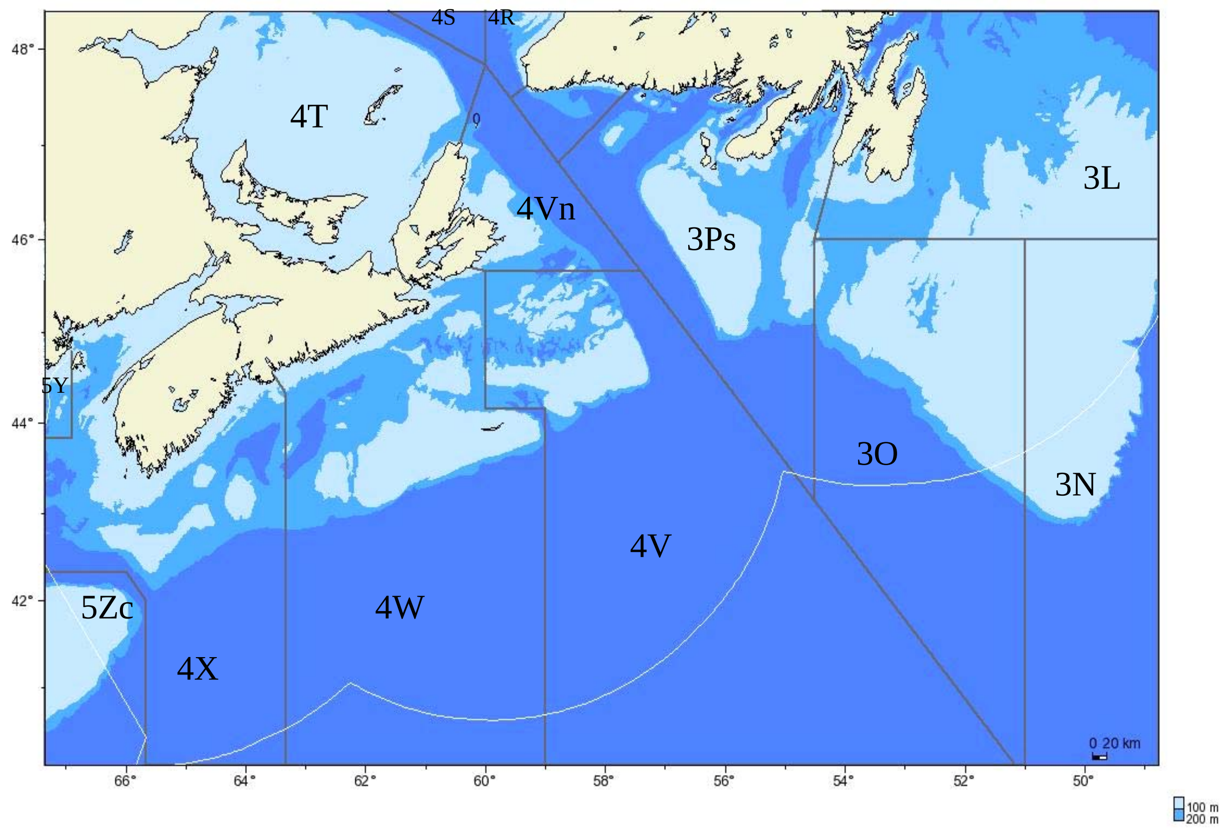

Figure 1. Map of the management unit for Atlantic halibut (NAFO divisions 3NOPs4VWX5Zc). The Gulf of St. Lawrence (4RST), the northern Grand Banks (3L), and US waters are outside the management unit. The grey lines indicate NAFO division boundaries and the white line indicates the boundary for the Exclusive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

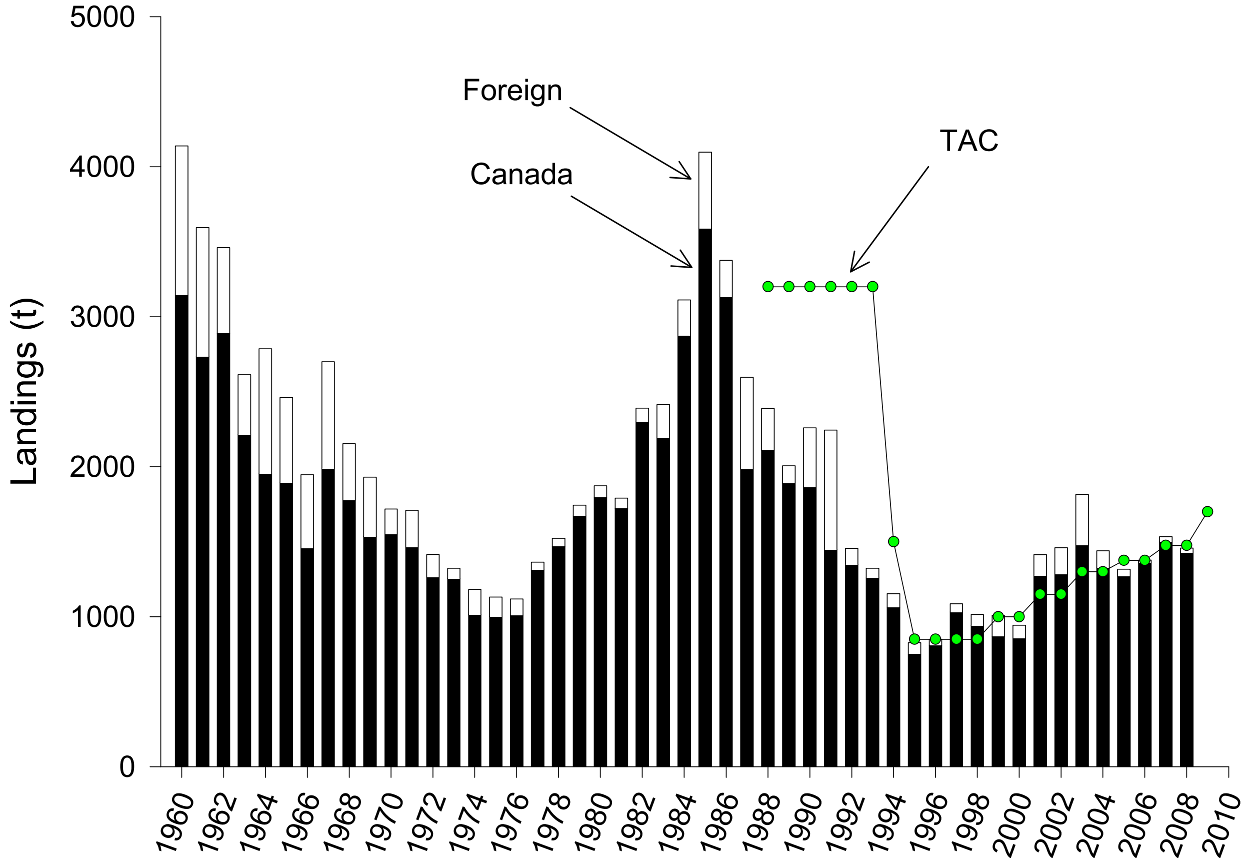

Figure 2. Canadian (black bars) and foreign (white bars) landings (metric tonnes), total allowable catch (TAC), and survey catch limit for Atlantic halibut from the Scotian Shelf and southern Grand Banks (NAFO divisions 3NOPs4VWX5Zc). A size limit of 81cm was introduced in 1994.

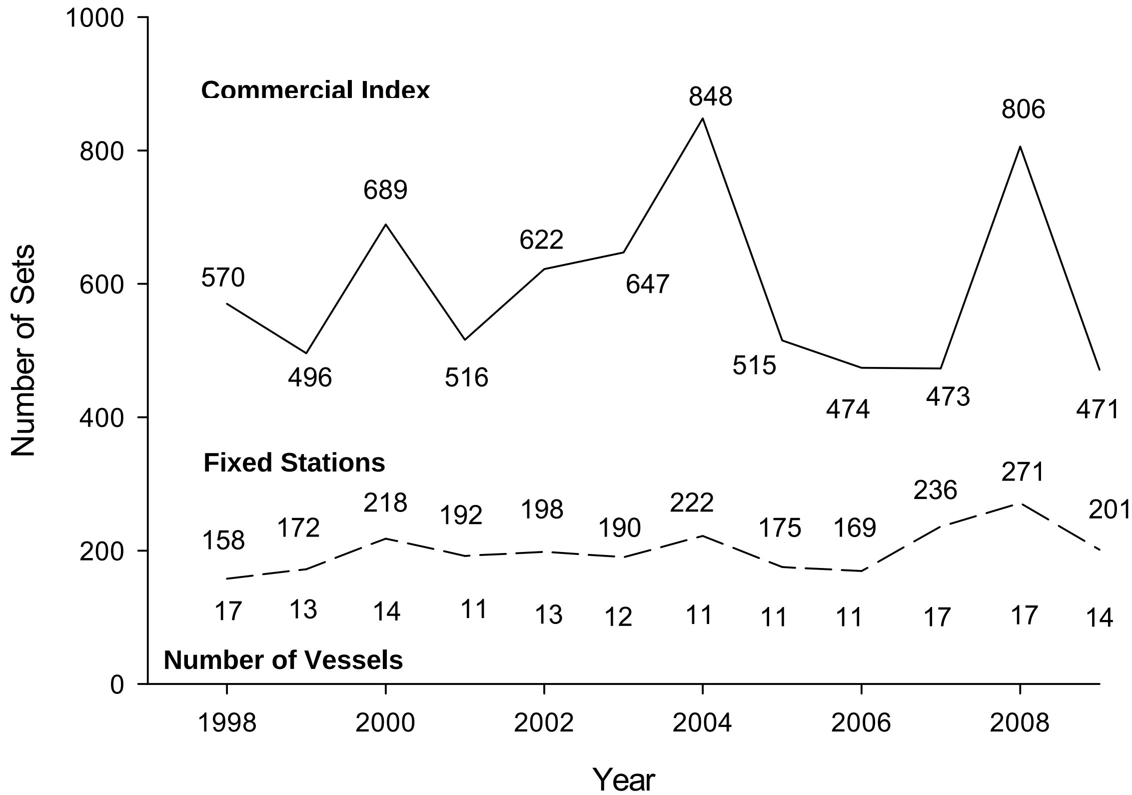

Figure 3. Number of vessels and number of sets completed per year in the halibut survey and the commercial index for NAFO divisions 3NOPs4VWX5Zc. The number of vessels is the same for both set types.

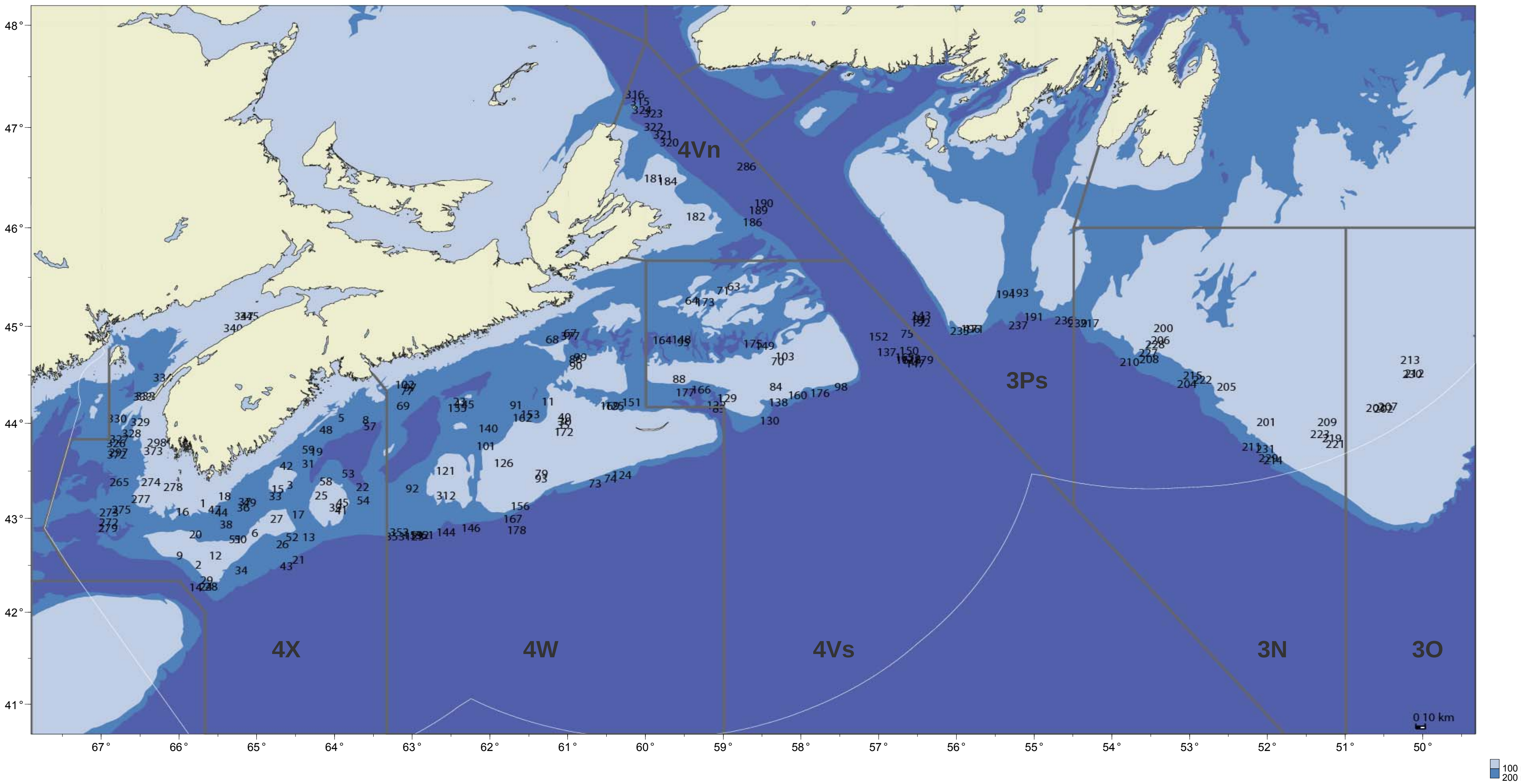

Figure 4. Halibut survey station locations sampled in 2009. Numbers indicate station identification, grey lines indicate NAFO division boundaries, and the white line indicates the boundary for the Exclusive Economic Zone.

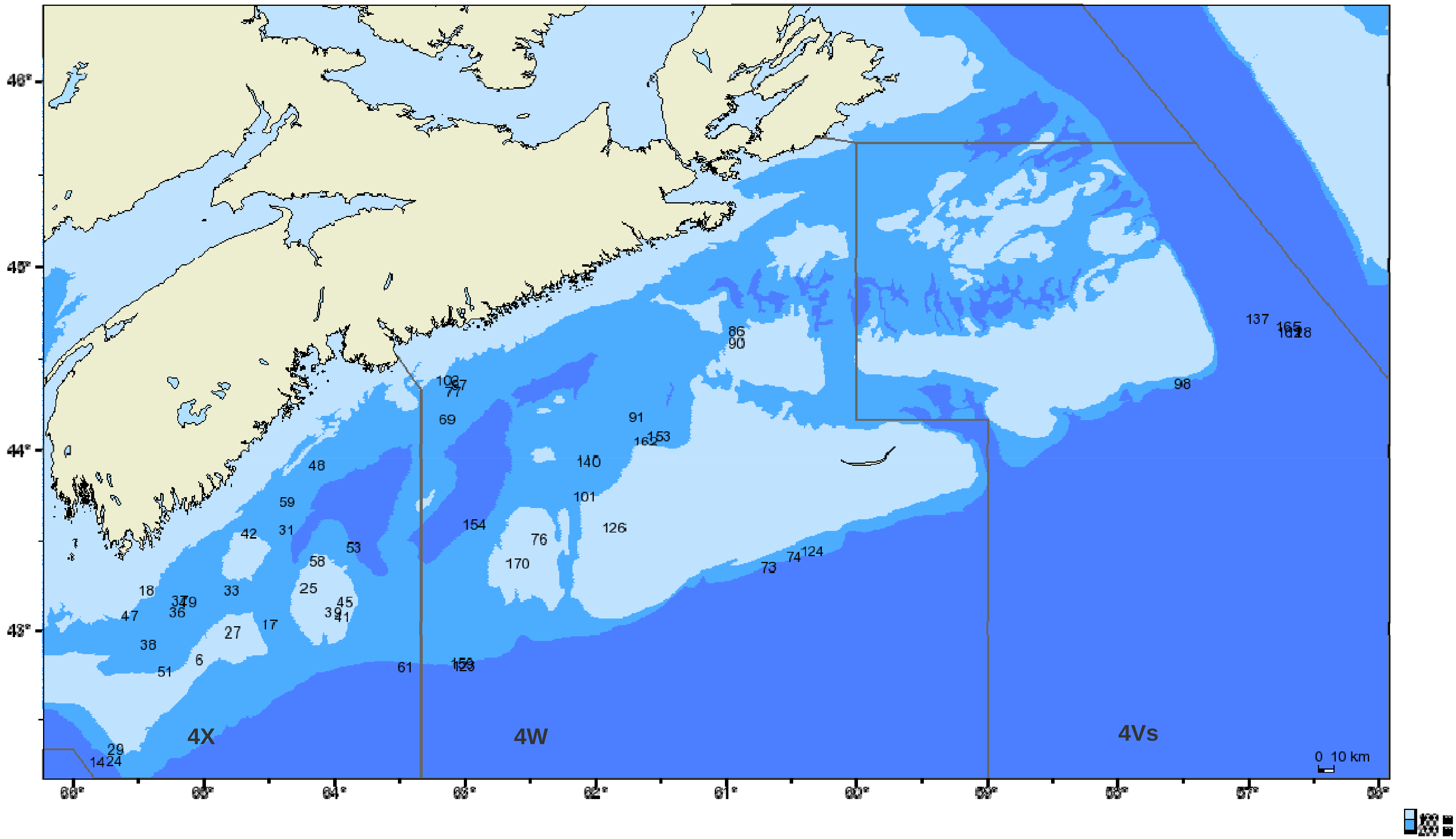

Figure 5. Location of 50 halibut survey stations conducted each year from 1999 to 2009.

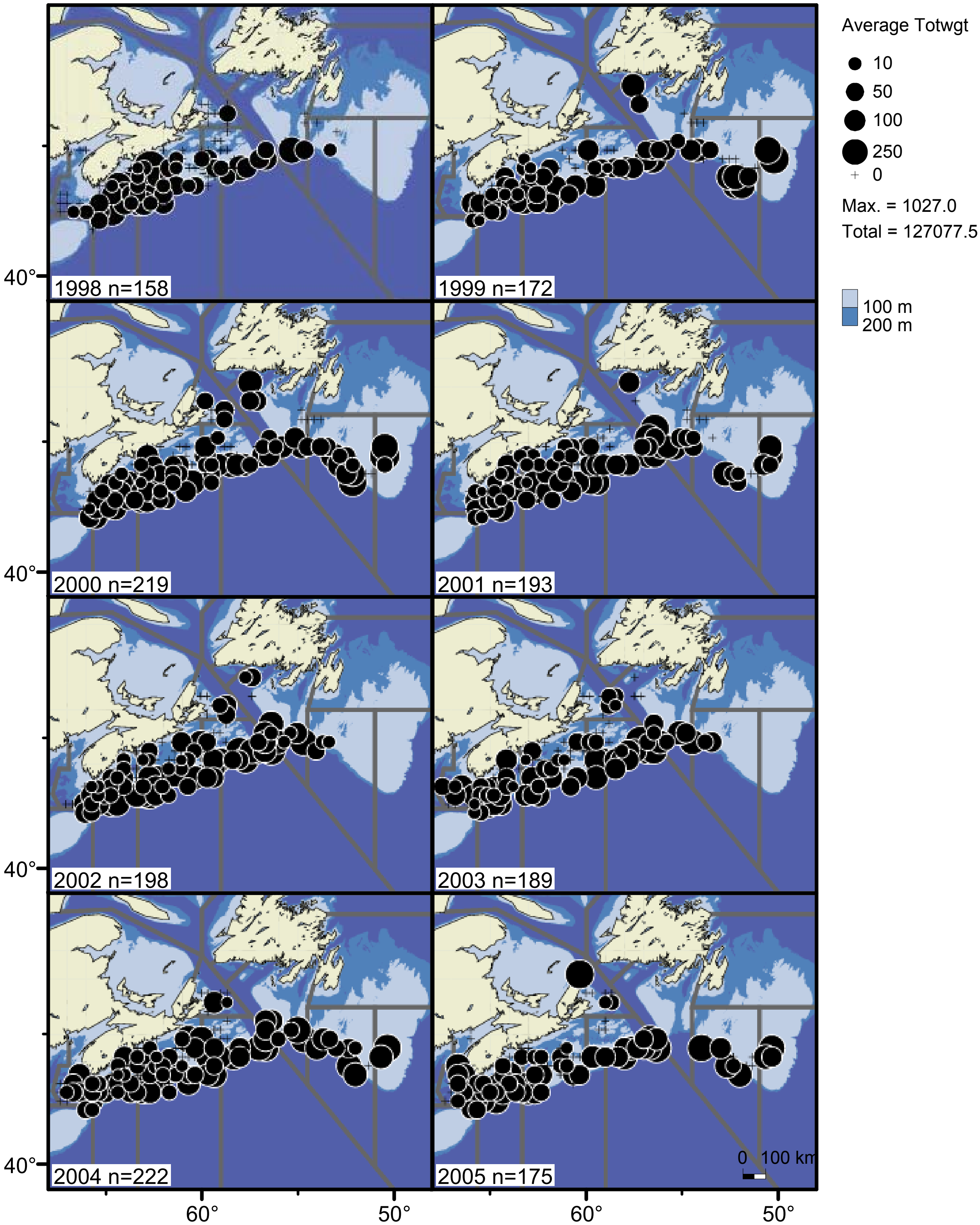

Figure 6. The distribution and average total weight of Atlantic halibut catch at halibut survey stations. Circles in legend indicate total average weight (kg). n = number of stations sampled. Year to year coverage in NAFO divisions 3NO was variable. Average total weight was calculated for a 20 min. aggregation.

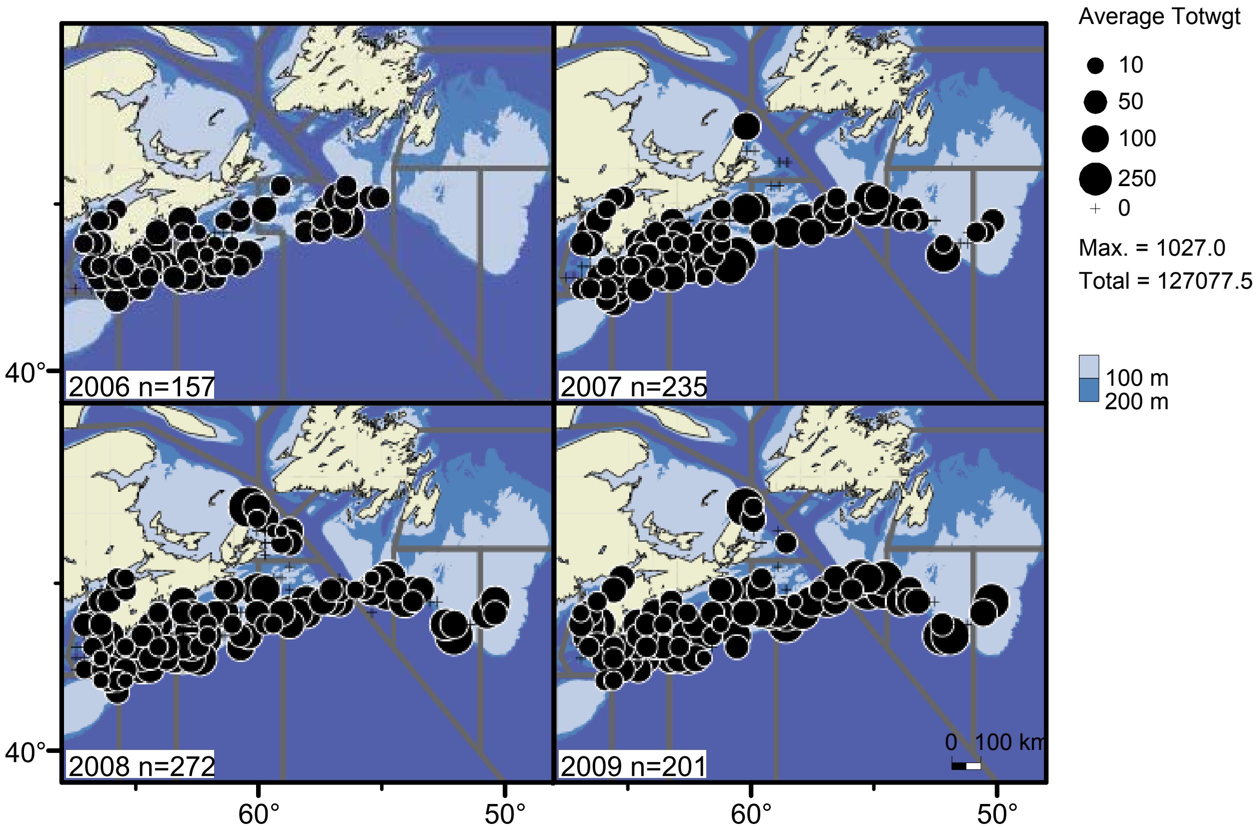

Figure 6. (Continued) The distribution and average total weight of Atlantic halibut catch at halibut survey stations. Circles in legend indicate total average weight (kg). n = number of stations sampled. Year to year coverage in NAFO divisions 3NO was variable. Average total weight was calculated for a 20 min. aggregation.

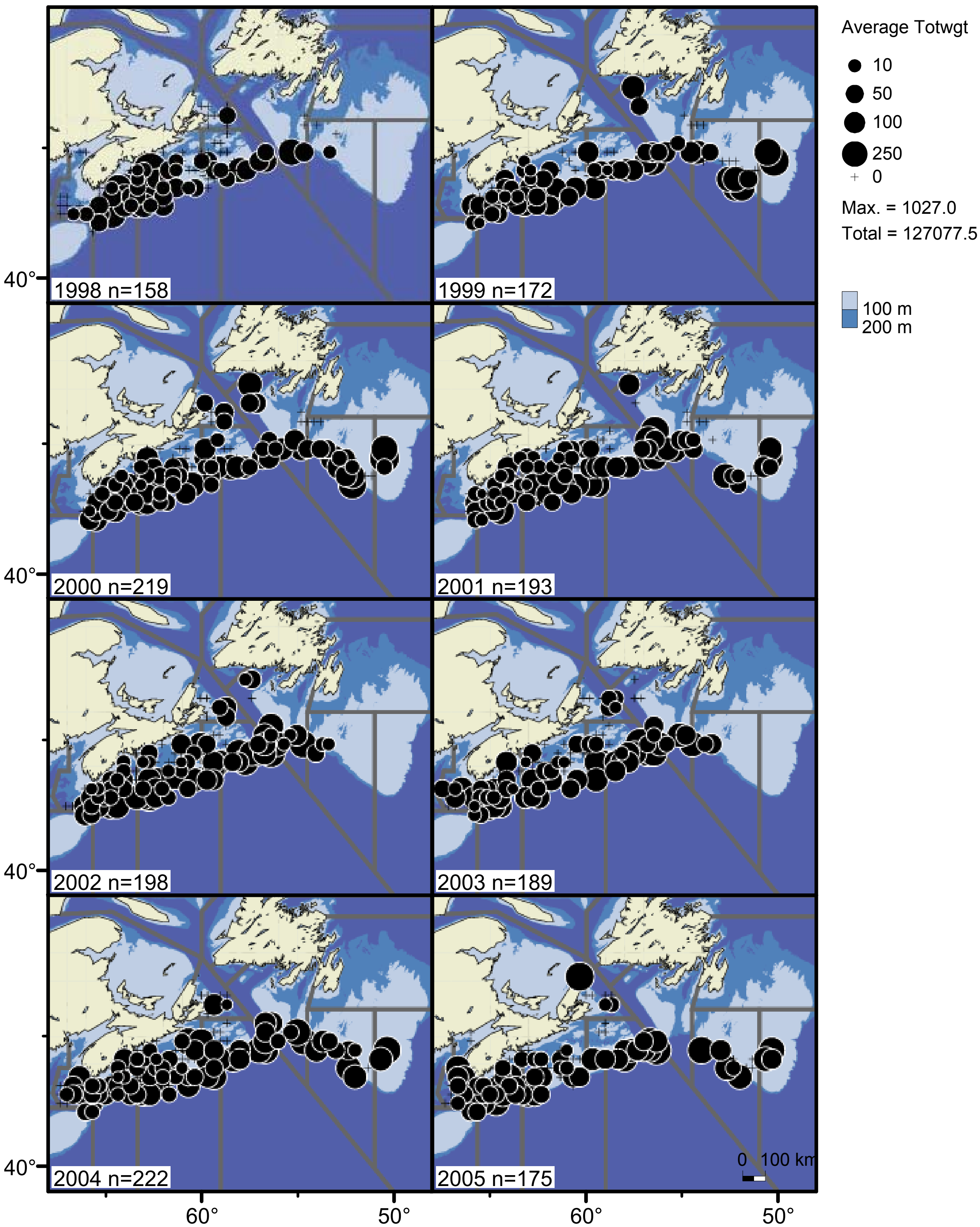

Figure 7. The distribution and average total weight of Atlantic halibut catch during the commercial index. Circles in legend indicate total average weight (kg). n = number of stations sampled. Year to year coverage in NAFO divisions 3NO was variable. Average total weight was calculated for a 20 min. aggregation.

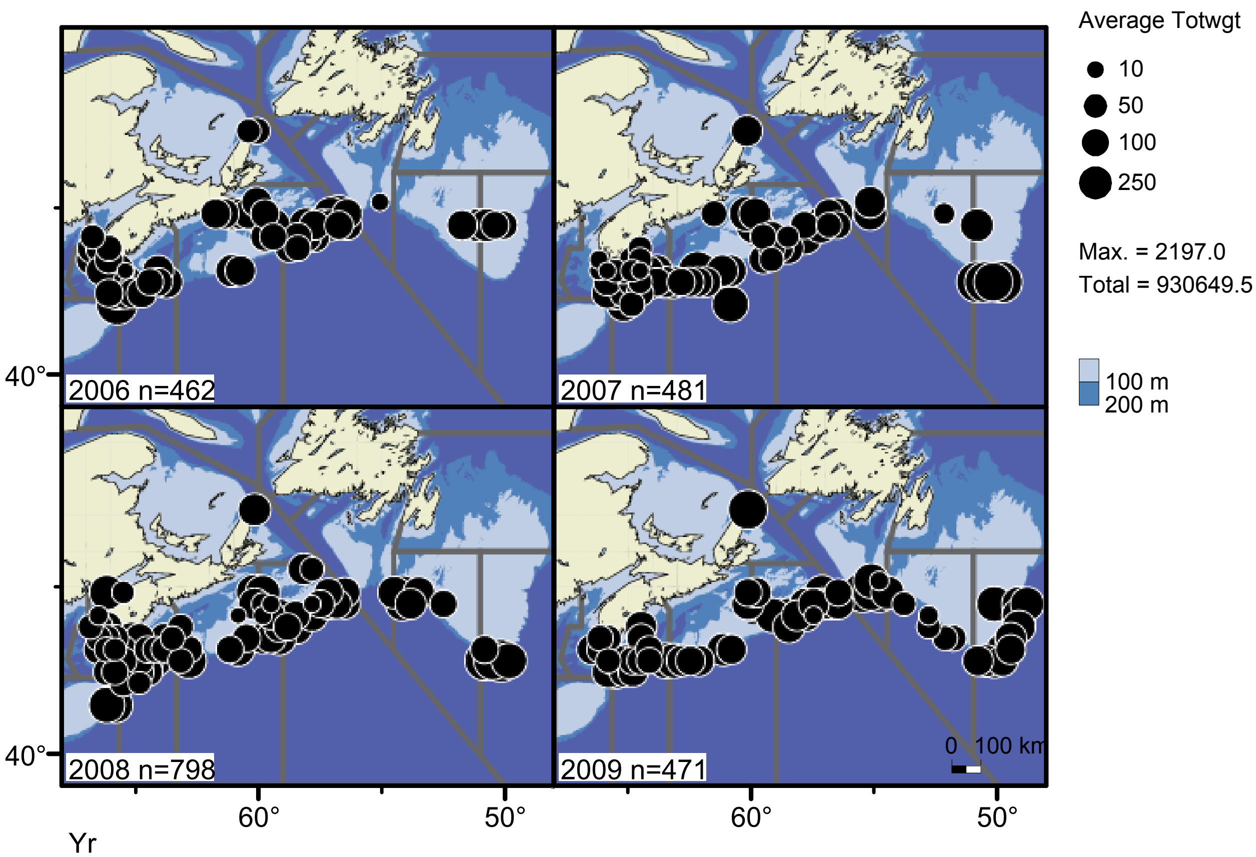

Figure 7. (Continued) The distribution and average total weight of Atlantic halibut catch during the commercial index. Circles in legend indicate total average weight (kg). n = number of stations sampled. Year to year coverage in NAFO divisions 3NO was variable. Average total weight was calculated for a 20 min. aggregation.

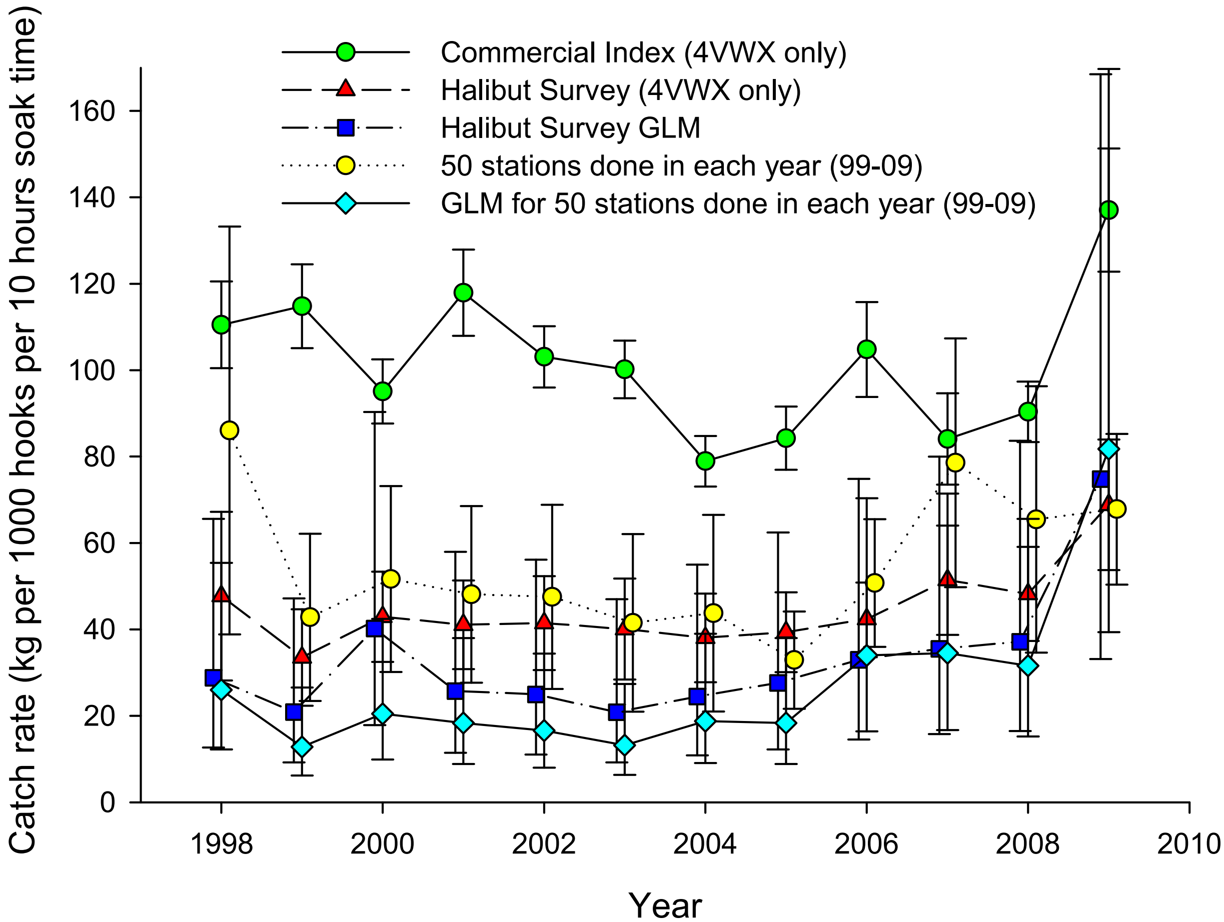

Figure 8. Trends in the halibut survey and commercial index catch rates (+/- 2SE) of Atlantic halibut. The survey was analyzed four different ways: all stations in NAFO divisions 4VWX; all stations covered 5 or more years and standardized with a generalized linear model (GLM); the 50 stations that have been covered each year since 1999; and the 50 stations that have been covered each year since 1999 and standardized with a GLM.

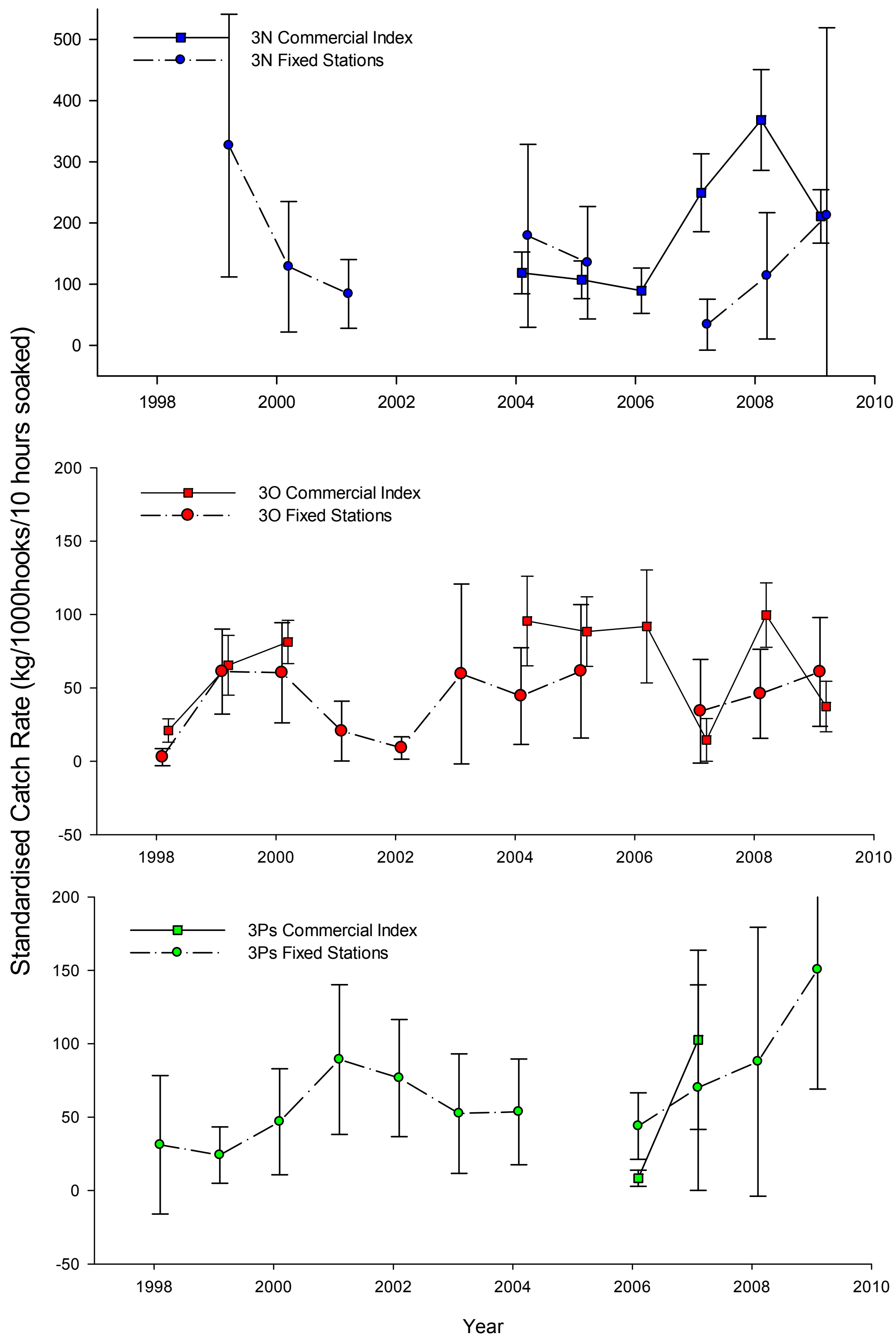

Figure 9. Mean commercial index and halibut survey station catch rates (+/- 2SE) of Atlantic halibut by NAFO divisions on the southern Grand Banks (NAFO divisions 3N, 3O, 3Ps).

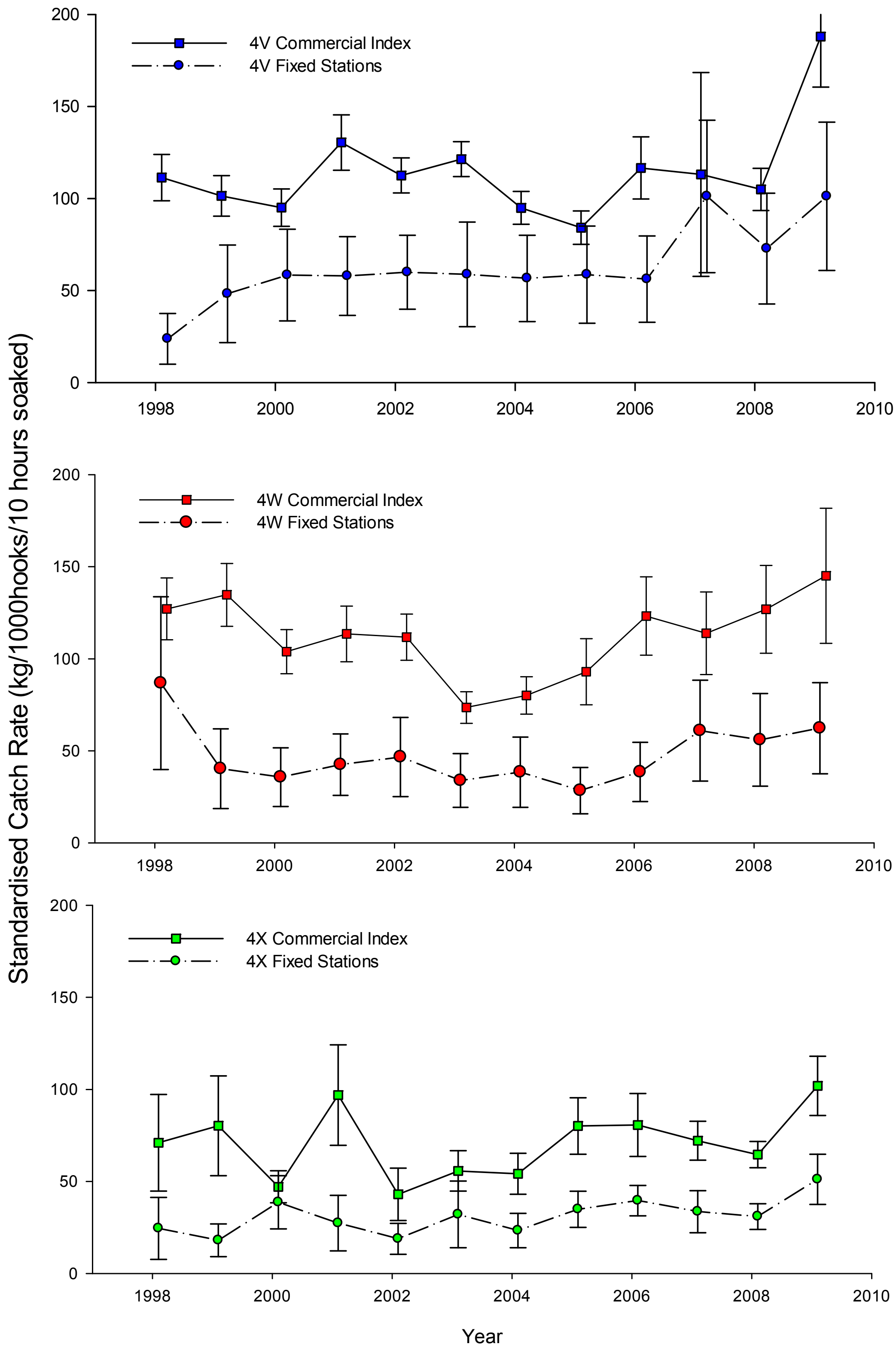

Figure 9. (Continued) Mean commercial index and halibut survey station catch rates (+/- 2SE) of Atlantic halibut by NAFO divisions on the Scotian Shelf (NAFO divisions 4V, 4W, 4X).

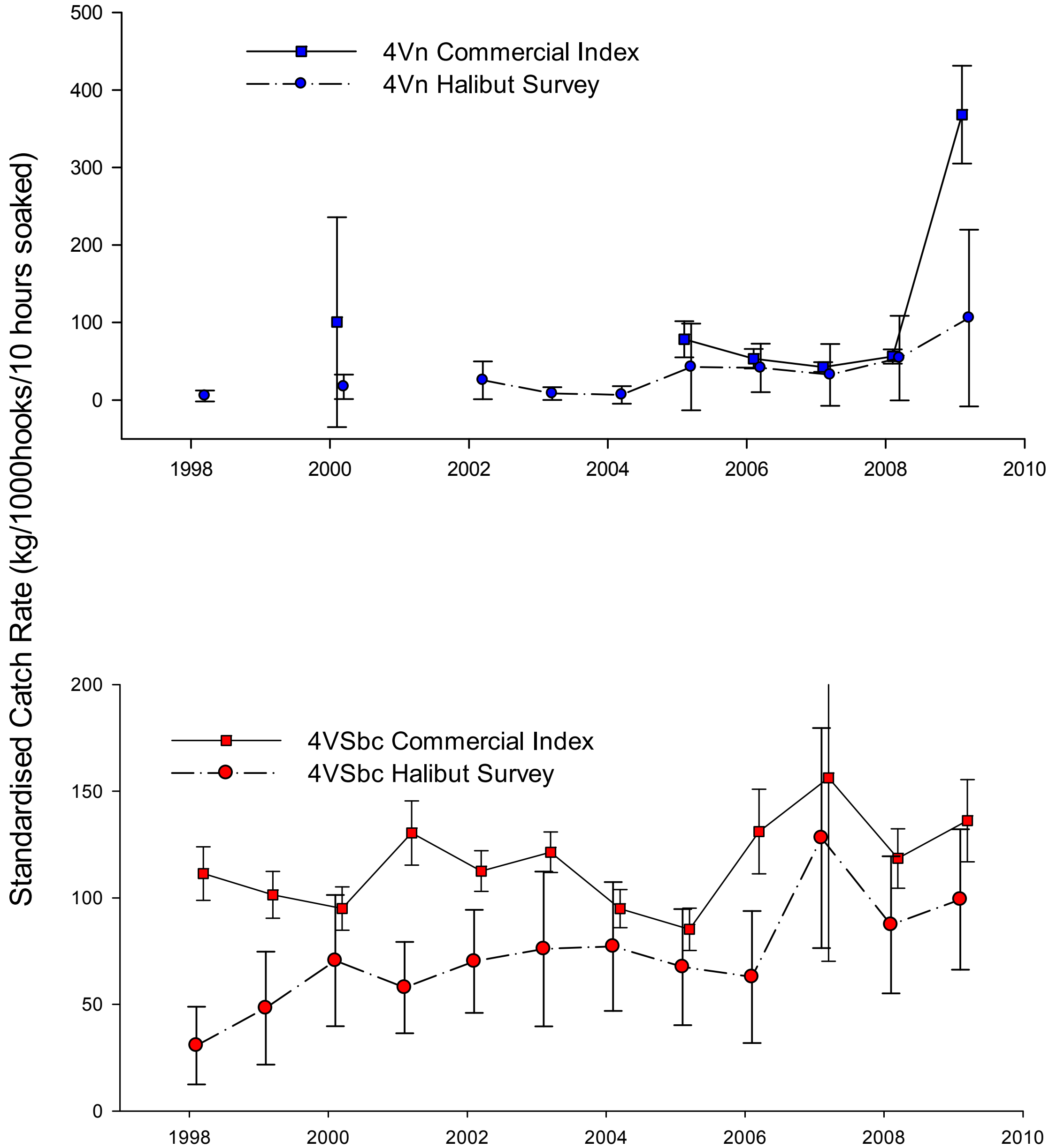

Figure 9. (Continued) Mean commercial index and halibut survey station catch rates (+/- 2SE) of Atlantic halibut in NAFO divisions 4Vn and 4Vs (NAFO divisions 4Vn, 4Vsbc).

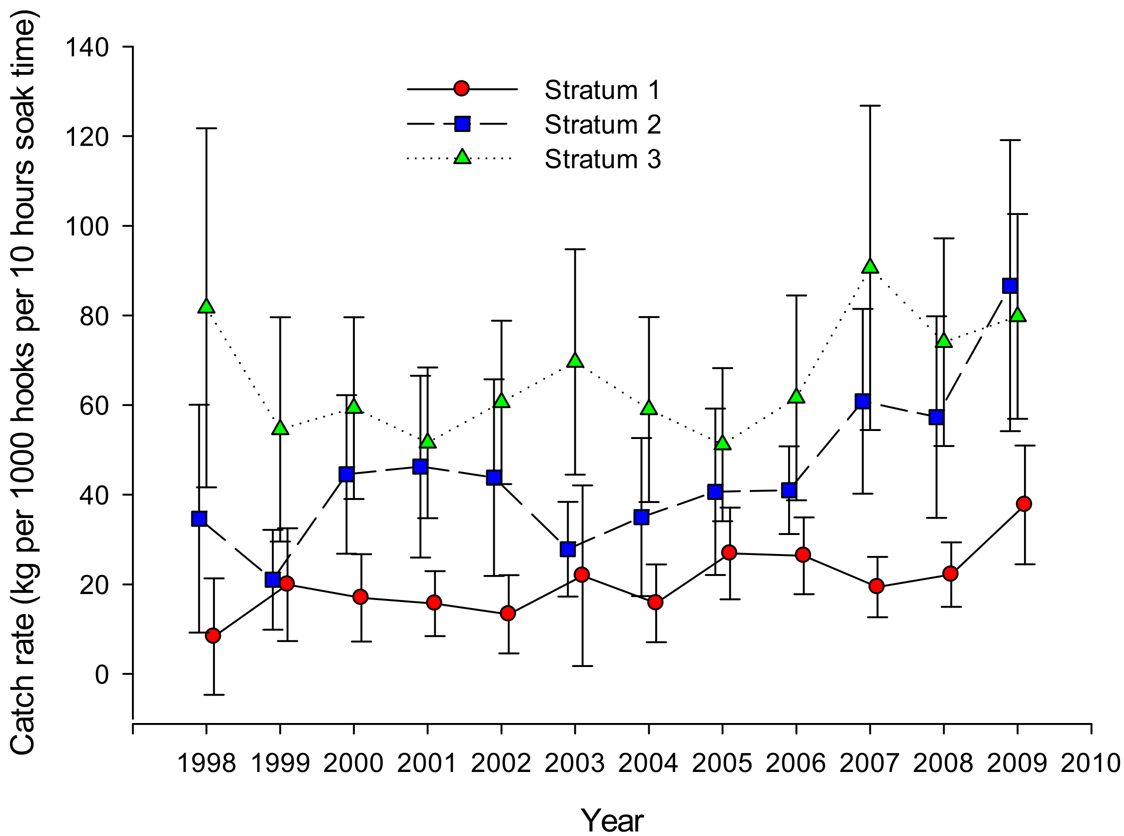

Figure 10. Mean halibut survey station catch rate (+/- 2SE) by stratum. The analysis includes all stations done in NAFO divisions 4VWX over the entire survey time frame. Note that for stratum 1, a number of sets in the Bay of Fundy, used in 1998, were abandoned for subsequent years. Stratum 1, 2, and 3 were defined as areas with low, medium, and high catch from landings data for 1996 and 1997.

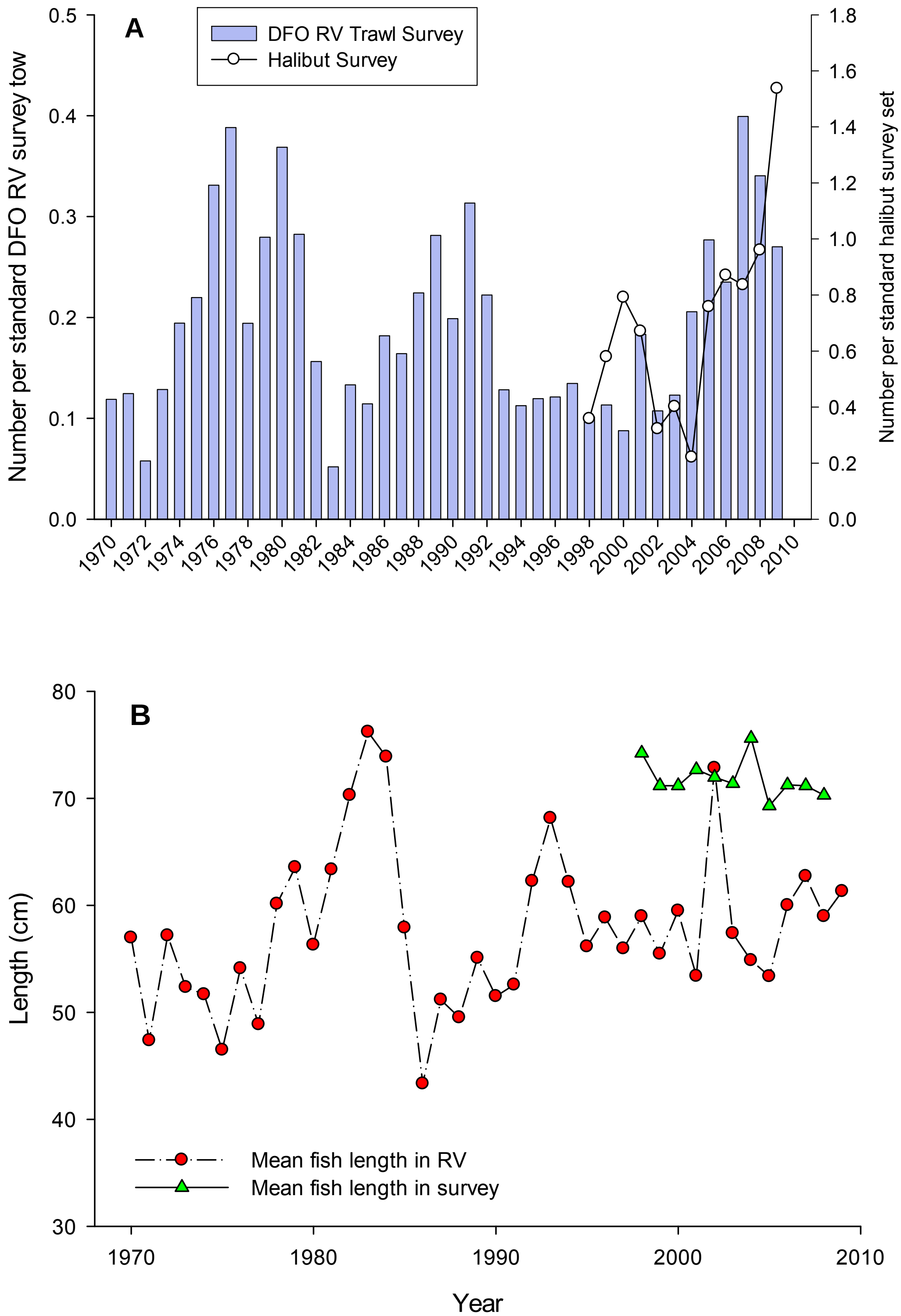

Figure 11. (A) Atlantic halibut pre-recruit (<81cm) catch (number per standard set) from DFO research vessel (RV) trawl survey (bars) and from NAFO divisions 4VWX fixed stations in the halibut survey (circles). (B) Mean size of fish caught in the RV survey and the mean size of fish <81cm caught in the halibut survey.

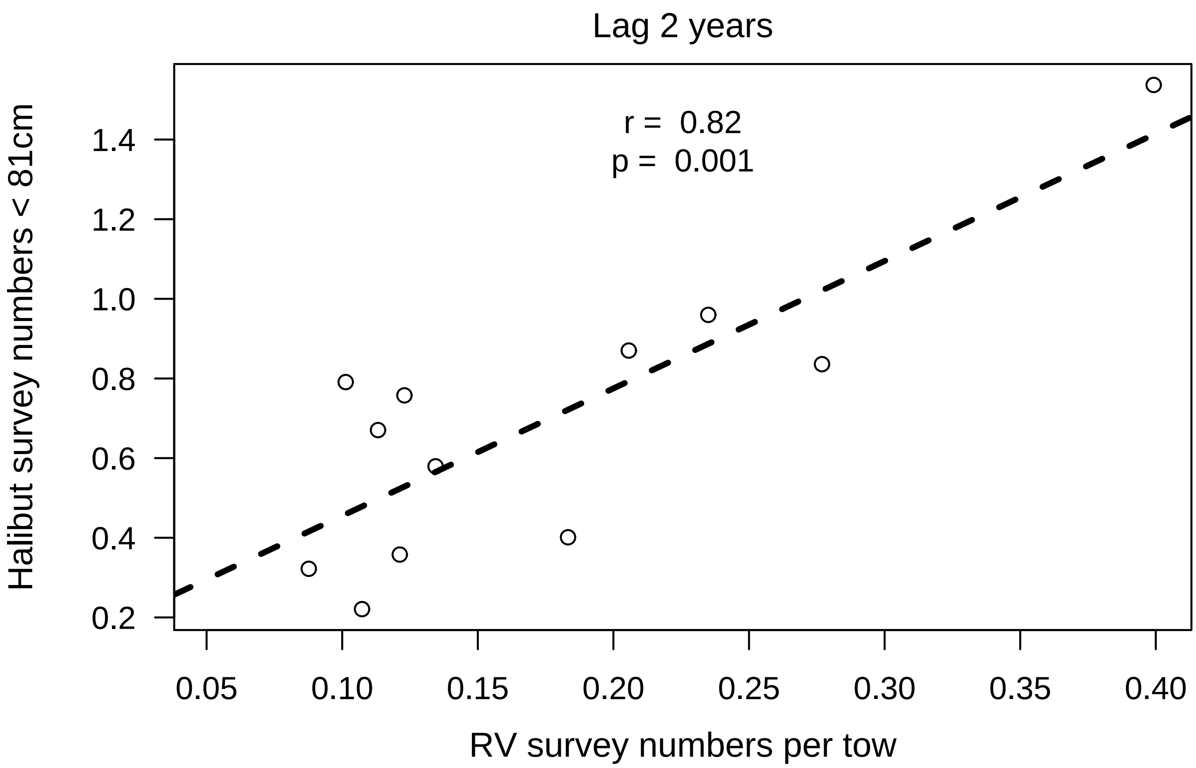

Figure 12. Correlation between Atlantic halibut catch in the DFO research vessel (RV) trawl survey and the pre-recruit (<81cm) catch (numbers per standard set) in the halibut survey two years later.

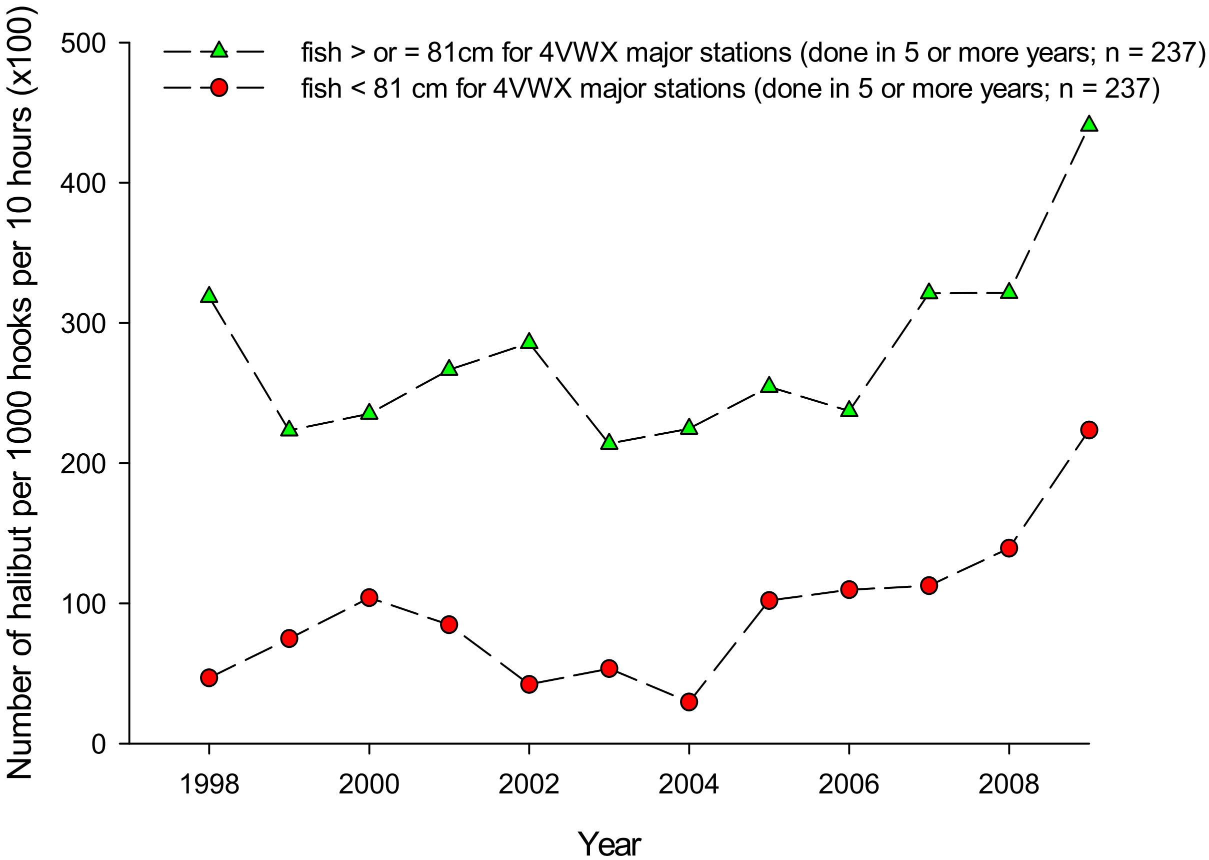

Figure 13. Halibut survey catch rates (number) from stations done in more than 5 years in NAFO divisions 4VWX, separated into pre-recruit (<81cm) and fishable (≥81cm) size classes

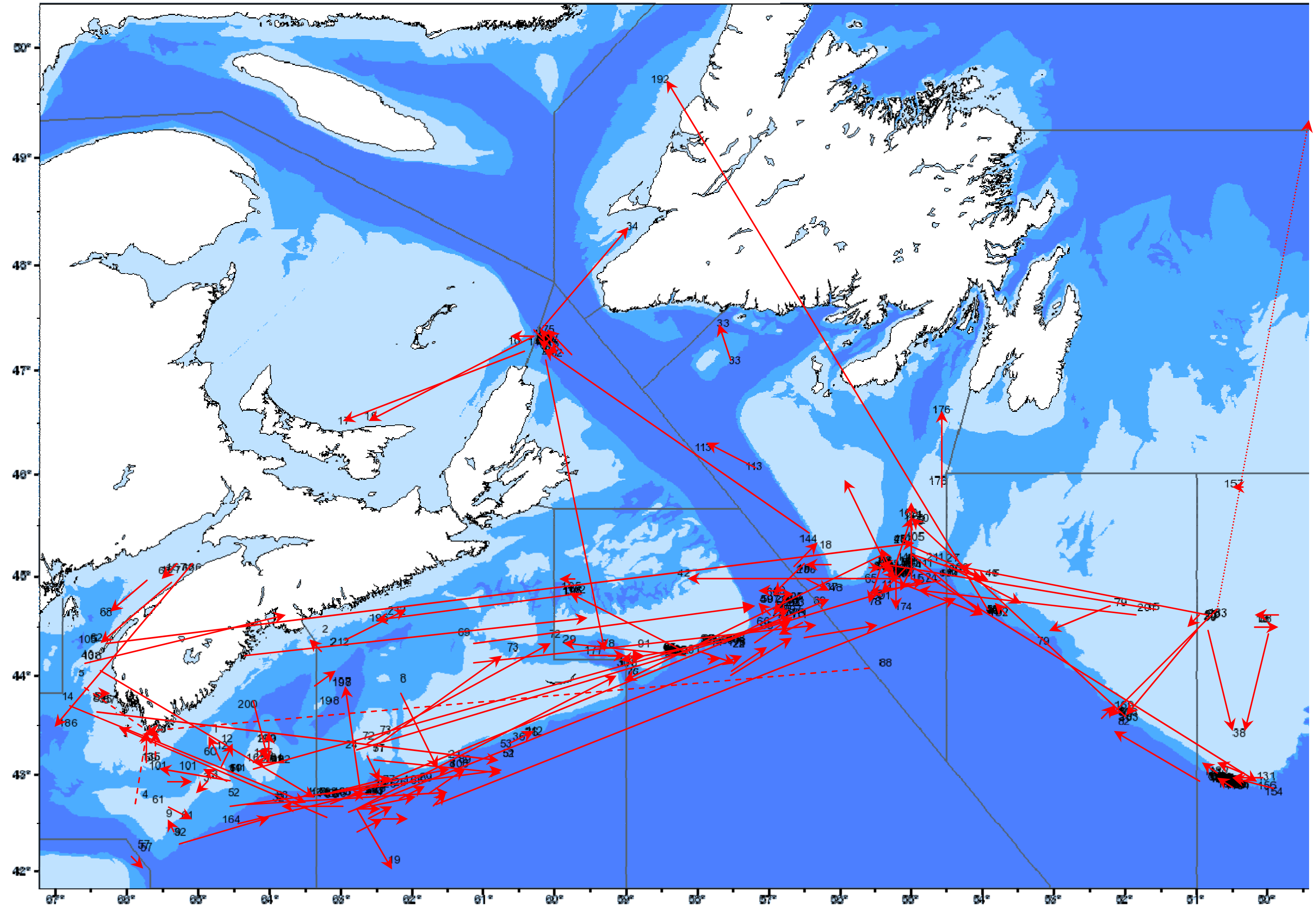

Figure 14. Results of the all-sizes mark recapture project as of February 2009 (225 recaptures out of 2076 releases). Movements of tagged halibut released in 2006 (n=526), 2007 (n=848), and 2008 (n=702). Numbered arrows represent the movement of each halibut (by April 2009, 25 additional recaptures were reported).

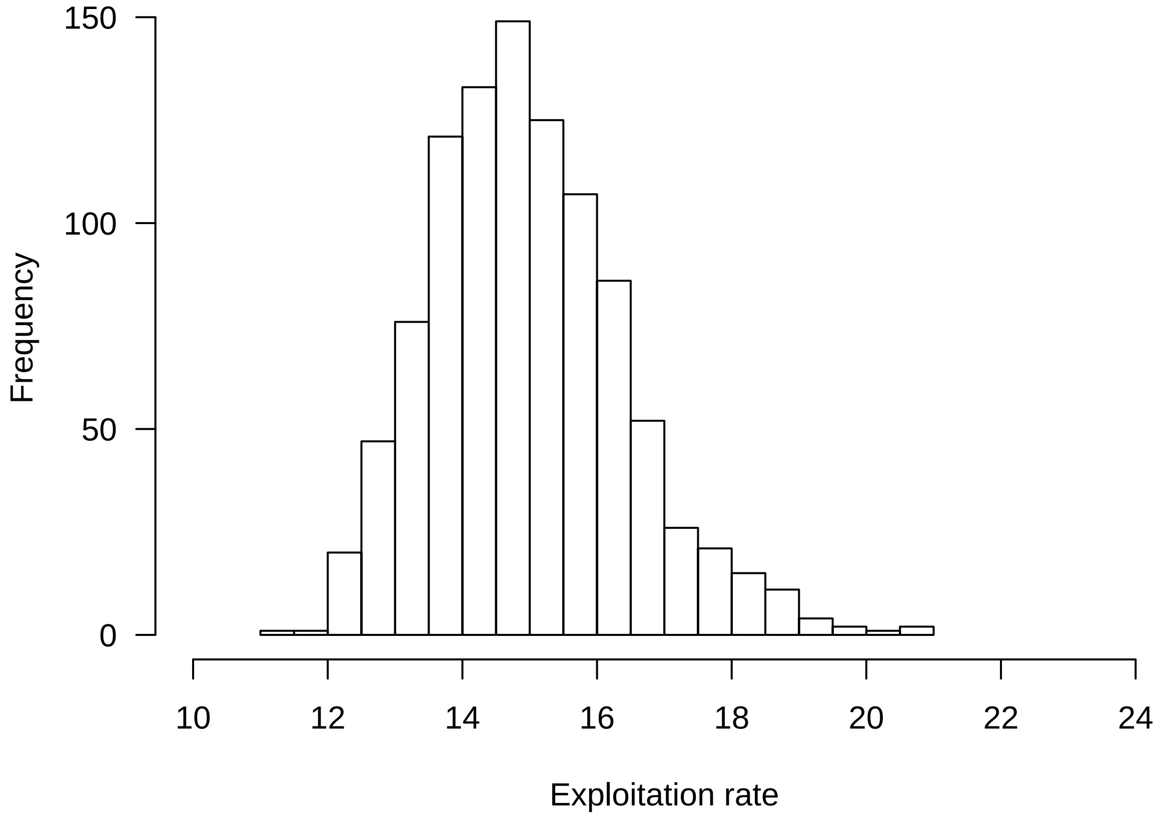

Figure 15. Estimates of exploitation rate from fish ≥81cm tagged in 2008 using a simulation model with mean and variances in Table 2. The mean and confidence limits were estimated to be 15.0% (90% CI: 13.3 - 16.8 %).