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# Atlantic Halibut on the Scotian Shelf and Southern Grand Banks: Data Review and Assessment Model Update

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## Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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## ABSTRACT

Atlantic halibut (*Hippoglossus hippoglossus*) is currently the most valuable groundfish fishery in Atlantic Canada. The Atlantic halibut fishery was unregulated until 1988, at which time a total allowable catch (TAC) was implemented for the Scotian Shelf and Southern Grand Banks management unit (3NOPs4VWX5Zc). In 1994, a minimum legal size limit of 81 centimetres was adopted. Changes in the groundfish fishery and the introduction of the minimum legal size for Atlantic halibut have changed the length and age composition of the catch. Between 2001 and 2013, 77% of the Canadian longline fish were caught in Northwest Atlantic Fisheries Organization (NAFO) Divisions 4VWX5ZY. In 1998, the Industry-DFO Halibut Survey was initiated to provide a fishery-independent index of exploitable biomass throughout the management unit. Prior to 2010, science advice was provided based on the research vessel (RV) abundance indices, catch per unit effort and length composition of catch. The DFO summer RV survey in 4VWX and DFO Spring survey in 3NOPs provide fisheries-independent indices of abundance. A length-based, age-structured assessment model was accepted in 2010 and stock reference points were adopted in 2011. With support of industry, a tagging program began in 2006. An updated multiyear mark-recapture model estimates natural mortality (M) at 0.14 and fishing mortality (F), from 2007 to 2013, at 0.13, 0.19, 0.13, 0.11, 0.07, 0.12 and 0.07, respectively. The data preparation for the assessment includes a new methodology for estimating the length-weight relationship and improved data handling for the DFO-Industry Halibut Survey and Commercial Index. The DFO 4VWX summer RV survey stratified mean number of halibut per tow peaked in 2011, but remains well above the long-term mean. The DFO 3NOPs Spring RV survey stratified mean number of halibut per tow has been increasing over last 10 years, and the Industry-DFO Halibut Survey biomass index is also increasing, with 2013 being the highest in the time series. The updated assessment model shows high abundance and recruitment in the 1970s. Biomass increased as fish grew and survival was good, but recruitment dropped and was relatively low in the 1980s and 1990s. Biomass has increased steadily since 1992 and reached 25,277 metric tonnes (mt) in 2013. Recruitment has been above average since 2003 and peaked in 2008. Exploitation rates were about 0.1 for the longline and otter trawl fisheries in 1970, but rapidly increased to 0.3 or greater in the late-1980s and early-1990s. Current fishing mortality is about 0.1 for the longline fishery. In recent years, fishing pressure on females appears to have been higher than for males.

## Flétan du plateau néo-écossais et du sud des Grands Bancs : Examen des données et mise à jour du modèle d’évaluation


## RÉSUMÉ

Le flétan (*Hippoglossus hippoglossus*) représente actuellement la pêche du poisson de fond la plus rentable au Canada atlantique. La pêche du flétan n’était pas réglementée avant d’être assujettie à un total autorisé de captures en 1988, pour l’unité de gestion du plateau néo-écossais et du sud des Grands Bancs (3NOPs4VWX5Zc). En 1994, une taille minimale réglementaire de 81 centimètres a été adoptée. Les changements dans la pêche du poisson de fond et l’introduction de la taille minimale réglementaire pour le flétan ont changé la longueur et la composition selon l’âge des prises. Entre 2001 et 2013, 77 % des poissons pêchés à la palangre au Canada ont été attrapés dans les divisions 4VWX5ZY de l’Organisation des pêches de l’Atlantique Nord-Ouest (OPANO). En 1998, le relevé sur le flétan mené par l’industrie et le MPO a été lancé pour fournir un indice de la biomasse exploitable indépendant de la pêche dans l’ensemble de l’unité de gestion. Avant 2010, des avis scientifiques ont été donnés selon les indices d’abondance par navire de recherche (NR), les prises par unité d’effort et la composition selon la longueur des prises. Le relevé estival par navire scientifique du MPO dans la division 4VWX et le relevé de printemps du MPO dans la division 3NOPs fournissent des indices d’abondance indépendants de la pêche. Un modèle d’évaluation fondé sur la longueur des captures et structuré selon l’âge a été accepté en 2010 et des points de référence de stock ont été adoptés en 2011. Avec le soutien de l’industrie, un programme de marquage a commencé en 2006. Un modèle pluriannuel actualisé de marquage-recapture estime la mortalité naturelle (M) à 0,14 et la mortalité par pêche (F), de 2007 à 2013, à 0,13, 0,19, 0,13, 0,11, 0,07, 0,12 et 0,07 respectivement. La préparation des données pour l’évaluation comprend une nouvelle méthode pour estimer la relation taille-poids et l’amélioration de la manipulation des données pour le relevé sur le flétan mené par l’industrie et le MPO et l’indice commercial. Le nombre moyen stratifié de flétans par coup de filet selon le relevé estival par navire scientifique du MPO dans la division 4VWX a atteint un pic en 2011, mais est resté bien au-dessus de la moyenne à long terme. Le nombre moyen stratifié de flétans par coup de filet selon le relevé de printemps par navire scientifique du MPO dans la division 3NOPs a augmenté au cours des 10 dernières années, et l’indice de biomasse du relevé sur le flétan mené par l’industrie et le MPO augmente également, 2013 étant le point culminant dans la série chronologique. Le modèle d’évaluation actualisé montre une abondance et un recrutement élevés dans les années 1970. La biomasse a augmenté à mesure que le poisson grandissait et la survie était bonne, mais le recrutement a chuté et était relativement faible au cours des années 1980 et 1990. La biomasse a augmenté de façon constante depuis 1992 et a atteint 25 277 tonnes métriques (tm) en 2013. Le recrutement a été supérieur à la moyenne depuis 2003 et a atteint un pic en 2008. Le taux d’exploitation était d’environ 0,1 dans les pêches à la palangre et au chalut à panneaux en 1970, mais il a rapidement augmenté pour atteindre 0,3 ou plus à la fin des années 1980 et au début des années 1990. La mortalité par pêche actuelle est d’environ 0,1 pour la pêche à la palangre. Au cours des dernières années, la pression de la pêche sur les femelles semble avoir été plus élevée que celle exercée sur les mâles.

# INTRODUCTION

Atlantic halibut (*Hippoglossus hippoglossus*) is the largest of the flatfishes and ranges widely over the North Atlantic Ocean and Arctic Ocean, from depths less than 50 metres (m) to more than 1,250 m. Atlantic halibut are long lived and sexually dimorphic, with females reaching lengths of roughly 200 centimetres (cm) and males of roughly 125 cm. Atlantic halibut is the most valuable groundfish species per unit weight landed on the Atlantic coast, and in recent years has become the most valuable groundfish fishery in Atlantic Canada.

In 1987, two management units, Northwest Atlantic Fisheries Organization (NAFO) Divisions 4RST and 3NOPs4VWX5Zc (Figure 1), were defined in Canadian waters based primarily on tagging studies (McCracken 1958, Bowering 1986, Stobo et al. 1988) and differences in growth rates between fish caught on the Scotian Shelf and in the Gulf of St. Lawrence (Neilson and Bowering 1989). The initial (in 1988) total allowable catch (TAC) of Atlantic halibut for the Scotian Shelf and southern Grand Banks (3NOPs4VWX5Zc) was set at 3,200 metric tonnes (mt), but subsequently was reduced to less than 1000 mt as the quota was not caught. In 1994, a minimum size of 81 cm was introduced. Since 1999, the TAC and landings have been increasing.

The Fisheries and Oceans Canada (DFO) summer Research Vessel (RV) bottom trawl survey in 4VWX and DFO Spring RV bottom trawl survey in 3NOP provide long-term fisheries-independent indices of abundance. In 1998, industry, working with DFO, initiated a longline survey to provide a fishery-independent index of exploitable biomass throughout the management unit (referred to as the Industry-DFO Halibut Survey). Between 2006 and 2008, work was undertaken to age more than 2000 halibut otoliths collected from 1962-2007 from both otter trawl and longline catches. The data was used to develop the age-length keys and fit growth models (Armsworthy and Campana 2010). Prior to 2010, science advice was provided based on DFO RV survey abundance indices and catch per unit effort (e.g. Perley et al. 1985, Zwanenburg et al. 1997). In 2010, a length-based, age-structured assessment model was adopted for Scotian Shelf and Southern Grand Banks Atlantic halibut (Trzcinski et al. 2011a).

This document describes the biology of Atlantic halibut as it pertains to the stock assessment, reports on updated landings data, and updates indices of abundance and biomass for Atlantic halibut, including the DFO summer RV survey in 4VWX, DFO Spring RV survey in 3NOPs, Industry-DFO Halibut Survey and the Commercial Index fishery. Notable changes to data preparation for the assessment include a new methodology for estimation of the annual length-weight relationship and improved handling of the Industry-DFO Halibut Survey data. Also, the catch-at-length for the longline fishery is presented separately for 3NOPs and 4VWX5Z, to better describe differences in the catch composition which may result from spatial variation in the fishery and/or distribution of the stock.

# BIOLOGY

## HABITAT

Atlantic halibut is the largest of all flatfish and ranges widely over the Northwest Atlantic from the coast of Virginia in the south to the waters off of northern Greenland. The management units 3NOPs4VWX5Zc and 4RST were established in 1987, based primarily on tagging studies demonstrating that halibut are highly mobile (McCracken 1958, Bowering 1986, Stobo et al. 1988). A small number of halibut tagged on the Scotian Shelf and Gulf of St. Lawrence have been recaptured off of Iceland (McCracken 1958, den Heyer et al. 2012) and halibut tagged in Iceland have been recaptured off of Newfoundland (Bowering 1986). While tagged halibut have moved more than 500 kilometres (km) in just a few years (McCracken 1958, Bowering 1986, Stobo et al. 1988, Kanwit 2007, den Heyer et al. 2012), halibut are generally recaptured under 30 km from the point of release (Kanwit 2007, den Heyer et al. 2012). Recent tagging in the Gulf of Maine indicated considerable trans-boundary movement, as 33% of the recaptured halibut were caught in Canadian waters (Kanwit 2007, Col and Legault 2009). However, for the 2006 to 2010 tagging on the Scotian Shelf and southern Grand Banks, only 2 of 444 recovered tags with location information were of recaptured in U.S. waters (den Heyer et al. 2012).

Atlantic halibut are a demersal species that live on or near the bottom. Recent deployments of pop-up satellite archival tags (PSAT) on large halibut (between 118 and 188 cm) suggest use of the water column, possibly associated with spawning between October and January (Armsworthy et al. 2014). These large halibut with PSAT tags maintained a narrow temperature range around 4-6 °C, and showed a seasonal pattern of movement from deeper water (>500 m) to more shallow (between 200 and 400 m) water in May and June. This is consistent with the size distribution of halibut in exploratory fishing (McCracken 1958), commercial catch (Bowering 1986) and fishery-independent trawl surveys (Sigourney et al. 2006, Trzcinski et al. 2009).

A higher proportion of smaller halibut in 4X around Browns Bank (McCracken 1958, Neilsen et al. 1993) may indicate rearing or nursery grounds. Stobo et al. (1988) also speculated that the area around The Gully near Sable Island may be rearing or nursery grounds based on the abundance of juveniles in those areas. Earlier tagging found that halibut less than 75 cm in length moved farther than halibut greater than 75 cm in length, and predominantly westward on the Scotian Shelf and Grand Banks. This suggests compensatory movement, counter to the drift of eggs and larvae from spawning areas (Stobo et al. 1988). However, there was no difference in the net movement of smaller and larger halibut tagged throughout management unit between 2006 and 2012 (den Heyer et al. 2012).

## GROWTH

Atlantic halibut are sexually dimorphic. The largest female recorded in the observer database was caught in 1992 in 3N, and measured 278 cm in length. The largest male was caught in 1991 in 3O, and measured 221 cm in length. Atlantic halibut otoliths have been collected intermittently from 1946 to present. Typically, less than 100 otoliths were collected per year from 1960-1987, and primarily on DFO RV surveys and observed commercial fishing trips. The collection increased to roughly 800 per year from 1988-1998, as at-sea observers collected otoliths from halibut caught on longline gear. Since the Industry-DFO Halibut Survey started in 1998, roughly 2000 otoliths have been collected annually. Although collection continues, no halibut otoliths have been aged since 2007.

For the most recent ageing study (Armsworthy and Campana 2010), otoliths were selected from a broad range of fish lengths collected on DFO RV surveys and from commercial trips using otter trawl or longline gear from two periods: historic (1964-1974) and recent (1997, 2001 and 2007). The accuracy of age estimates from otolith thin sections was validated with bomb-radiocarbon dating. The oldest halibut in the sample was a 50 year old male 175 cm in length. Males and females grew at a similar rate until about age 5, after which male growth slowed (Figure 2; Table 1). The standard deviation of length increased from age 2 to age 5 in males and age 10 or 11 in females, and then stabilized until small sample sizes become an issue for larger fish (Appendix 1).

## CONDITION: LENGTH-WEIGHT

The condition of Atlantic halibut varies over time. To assemble the catch-at-length the length-weight relationship is used to estimate sample weight. The length and weight of individual halibut have been measured on DFO RV surveys (4VWX and 5Z) and by observers on commercial longline trips and the Industry-DFO Halibut Survey (3NOPs, 4VWX and 5Z). Data queries on August 13, 2014, found 51,676 fish sampled for length and weight between 1970 and 2013. Two hundred and ninety-seven fish were removed from further analysis because either length or weight were deemed improbable (i.e., weight more than 175% of the predicted weight or less than 25% of predicted weight for curve fit to entire data set). Prior to 1988, few halibut lengths and weights were collected by observers (Table 2). Also, the number of fish sampled on the DFO RV surveys in 4VWX5Z was very sparse between 1985 and 1994, with no fish sampled in 6 of those years. Notably, the number of samples from the observer program has been declining in recent years, with no weights of halibut taken in 3NOPs in 2013. Almost all of the samples (87%) were of fish of known sex and most of the samples were collected in May, June and July (72%, Table 3).

A linear mixed-effects model of log-transformed length and log-transformed weight was fit with NAFO Division as a fixed effect (factor 2 levels: 3NOPs, 4VWX5Z) and year as random effect (factor: 1970-2013) on the intercept. The NAFO Division did not significantly contribute to the explained variance (Table 4). The model parameters are as follows:

Fixed effects: log(weight) ~ log(length) + as.factor(NAFO)

Random effects: ~1 | year

To estimate growth parameters for adjusting length frequency samples, a separate linear mixed-effect model was fit for males, females and all fish sampled (i.e., male, female, and unsexed). The model results are presented in Appendix 2. A plot of the predicted weight for a 90 cm halibut for each year indicates inter-annual variability and cyclicity in halibut condition (Figure 3). A more complete analysis, taking into consideration seasonal as well as area effects, could improve understanding of the stock dynamics and fine tune the catch-at-length.

## NATURAL MORTALITY, MATURITY, AND GENERATION TIME

For long-lived fish species, natural mortality (M) is typically assumed to be less than 0.2. In the recent framework stock assessment for Atlantic halibut on the Scotian Shelf and the southern Grand Banks (Trzcinski et al. 2011a), M was assumed to be 0.1. Previous yield models, used to assess the impact of changes in minimum legal size, considered M of both 0.1 and 0.175 as plausible (Neilson and Bowering 1989). Although more recent models for Pacific halibut assumed M to be 0.15 (Clark and Hare 2006), throughout the 1980s and 1990s the Pacific Halibut Commission assumed M to be 0.2. A review of indirect estimates of M for Atlantic halibut ranged from 0.02 to 0.34 for males and between 0.09 and 0.29 for females (den Heyer et al. 2013). The updated multiyear mark-recapture model, described in more detail later in this document, estimates a constant M of 0.14.

Generation time can be estimated from the age at maturity for 50% (A50%) of the population and M. Length at maturity varies throughout the geographic range of halibut (reviewed in Trzcinski et al. 2011b). Growth and maturity cycles of Atlantic halibut on the Scotian Shelf and southern Grand Banks have not been examined for some time, but older work in the region found that females reached 50% maturity at about 119 cm (total length), and males reached 50% maturity at about 77 cm (Trumble et al. 1993). Using the growth models discussed below, the age at maturity can be estimated at age 5-6 for males and 9-10 for females. According to Haug (1990), there is more variation in the age at first sexual maturity for Atlantic halibut than length at maturity and, to the extent that growth may be variable over time or throughout the management unit, these estimates should be used with caution. For females, generation time (A50%+1/M) is estimated to between 14 (M=0.2) and 19 years (M=0.1).

## DISCARD MORTALITY

In addition to the direct impact of the fishery on the stock, discarding may be a significant source of mortality. Since 1994, all fish caught less than 81 cm in length are required to be discarded. Illegal discarding of large 'whale' halibut, which have a lower value per pound, could also be occurring. Atlantic halibut are also caught and landed with other commercially-valuable groundfish species (see below). If there is limited halibut quota available, halibut caught during fisheries directed for other species may be illegally discarded.

In general, halibut are thought to be robust to handling relative to other groundfish. Neilson et al. (1989) found that 35% of otter trawl-caught halibut and 77% of longline-caught halibut survived 48 hours in holding tanks. Recent deployments of PSAT tags suggest that the survival of larger halibut caught by longline gear could be 100% (Armsworthy et al. 2014). Kaimmer and Trumble (1998) found that careful handling of Pacific halibut can increase discard survival and that even those fish with mild or moderate injuries have a higher than expected probability of survival. For example, 69% of Pacific halibut with moderate injuries survived and 43% of halibut with severe injuries survived.

## DESCRIPTION OF THE FISHERY

On the Scotian Shelf and the southern Grand Banks most of the landed halibut is from a directed longline halibut fishery. Halibut is also landed by other longline, trawl, gill net and handline fisheries. Halibut is primarily caught in deep channels and the area along the edge of the shelf, but in southwest Nova Scotia (4X) the catch is more broadly distributed (Figure 4a and 4b). There are restrictions on fishing for halibut in the haddock spawning area and in the Gully Marine Protected Area. As well, halibut fishing is not permitted in the Lophelia Coral Conservation Area and the Northeast Channel Coral Conservation Area. There are also seasonal closures in other areas, as well as trip limits and bycatch restrictions.

The North American Atlantic halibut fishery began in coastal New England in the early-1800s. Before the collapse of the fishery in the late-1800s, the fishery had expanded to deeper waters and as far as Iceland. Atlantic halibut landings have been recorded since 1867, initially by province and then by statistical area (SA). From 1920 to the late-1930s, United States vessels, fishing off the coast of New England, landed about half of the halibut caught in subareas 3 and 4 (McCracken 1958). Since that time, halibut landings have been primarily from Canadian waters. Nonetheless, NAFO statistics are used to describe removals, because landings occur in two DFO regions (i.e., DFO Maritimes and DFO Newfoundland and Labrador), as well by other countries including Portugal, Spain, and France.

Off the coast of Nova Scotia and Newfoundland, landings rose steadily for the first half of the century and nearly tripled from 1911 to 1949 (Figure 5a). The dramatic increase in landings in 1950 and 1951 is believed to have resulted from increased fishing effort post-war, as well as harvesting of an accumulated biomass of large halibut. The possibility of increased recruitment, however, cannot not be eliminated given there is limited data on the size composition of landings (McCracken 1958). In SA3, the high values in the 50s and the spike in 1967 and 1968 is believed to result from the inclusion of Greenland halibut (also known as turbot). A correction factor was applied to account for the miscoding of Greenland halibut in the plot of landings from 1960 to 2013 (Figure 5b). Average landings from 1960 to 2012 were approximately 1,800 mt annually (Table 5). Current landings on the Scotian Shelf and Southern Grand Banks (3NOPs4VWX5Zc) are below peak landings in the early 1960s and mid-1980s.

Historically, the price of halibut per unit weight was based on the size of the halibut fish (McCracken 1958, Neilson and Bowering 1989), with medium (12-60 lb or 5.4-27.2 kg) or large

(60-125 lb or 27.2-56.7 kg) commanding more than smaller, snapper (1-7 lb or 0.5-3.2 kg) and chicken (7-12 lb or 3.2-5.4 kg) halibut, or larger halibut, also known as whales (>125 lb or >56.7 kg).

Until 1988, the fishery was unregulated. The first TAC of 3,200 mt was not captured for several years. In 1994, the TAC was reduced to 1,500 mt, and was further reduced to 850 mt in 1995, in response to a protracted decline in landings. In 1999, recommendations made by the Fisheries Resource Conservation Council resulted in an increase in the TAC for this stock from 850 mt to 1,000 mt. Since that time, both the TAC and landings have been increasing (Figure 5b). The TAC in 2014 was 2,563 mt.

## LANDINGS BY GEAR

The halibut landings by gear type were taken from NAFO table 21B, including data from all gear types, countries and NAFO Divisions 3N, 3O, 3P, 3 Unknown (3NK), 3Ps, 4V, 4Vn, 4Vs, 4W, 4X, and 5Zc. In 2003, 2008 and 2009, the landings are underreported in NAFO table 21B. Inspection of the data (Appendix 3) found little or no landings reported from the DFO Maritimes Region in those years. The landings plotted in Figure 6 include landings from the DFO Maritimes Fisheries Information System (MARFIS) database that represents a complete census of almost all commercial fishing activities in the DFO Maritimes Region. As NAFO reporting can be incomplete for recent years, landings for 2011 to 2013 are total landings from MARFIS and the DFO Newfoundland and Labrador Region. These landings will increase when international landings are included. The MARFIS query of halibut landings in 3N, 3O, 3P, 4V, 4W, 4X, 5Y, and 5Z included landings from nine gear types (longline, Danish seine, otter trawl –pair, otter trawl – stern, Scottish seine, gill net (set or fixed), hand line, midwater trawl –stern, midwater trawl-side, and trap). The DFO Newfoundland and Labrador Region commercial data included all landings of halibut in 3N, 3O, 3Ps, 3Pn, 4Vs, 4Vn, using longline, bottom otter trawl (stern), gill net (set or fixed), hand line (baited), and trap gear. Historically, a large portion of landings came from otter trawl, but more recently landings are dominated by longline fishing (Figure 6). In 2011-2013, 91% of the Canadian landings were from the longline fishery.

### Longline Landings in DFO Maritimes Region

Commercial halibut longline landings between 2002 and 2013 were extracted from the MARFIS database for 3NOPs and 4VWX. In general, halibut are landed head on and gutted. The round weights reported in MARFIS are adjusted using weight to live-weight conversion factors (Zwanenburg and Wilson 1999). The total number of sets capturing halibut was 60,254 (Table 6), with total halibut landings of 14,777 mt (Table 7). Forty-five percent of landed halibut (by weight) is from 4VW, 38% from 4X and 17% from 3NOPs. The halibut fishery on the Scotian Shelf is a small boat (vessels less than 45 feet in length) fishery. In 4VWX, 95% of the sets were completed by vessels less than 45 feet in length. In contrast, in 3NOPs 72% of all sets were conducted by vessels greater than 45 feet in length.

Figure 7 shows total landings by vessel length and NAFO Division from 2002-2013. The proportion of halibut landed by vessels less than 45 feet in 3NOPs has increased from 6% in 2002 to 46% in 2013. Large (greater than 100 feet in length) vessels operated briefly from 2006-2008. The highest landings in 3NOPs occurred in 2007, although annual landings have been about 10% of the total annual DFO Maritimes Region landings since then. In 4VW, total landings by 45-65 foot and greater than 65 foot vessels have remained about the same over 2002-2013. All of the increase in catch per year in 4VW and 4X since 2007 has been due to landings by the 35-45 feet vessel class.

# CATCH LENGTH COMPOSITION

Despite the economic importance of Atlantic halibut and the increase in observer and shore sampling associated with the Industry-DFO Halibut Survey, onboard observer and port sampling of halibut directed trips has been sparse.

## PORT SAMPLING

The groundfish port sampling program started in 1948, although halibut were not measured at that time since most fish were landed without a head. The first halibut length in the DFO Maritimes Port Sampling database was in 1989 (Table 8). Halibut have only been sampled from landings from longline and otter trawl gear. All samples are unculled samples (no size grading). In total, 781 trips were analyzed. When shore sampling of halibut caught in the Commercial Index began in 1999, the number of halibut trips sampled increased to an average of 48 per year. The proportion at length was generated separately for otter trawl (sex=unknown) and longline gear (sex=male, female, combined=unknown, male and female). While collecting samples by sex is not regular protocol for port sampling, there are occasions where fish were landed whole and the sample sex and length is recorded (such as in 1994 and 1997). Halibut landed as part of the Commercial Index shore sampling (1999 to present, see description below) are marked at sea to indicate sex. The samples sizes are presented in Tables 9 and 10.

The length of halibut sampled ranged from 31 to 233 cm. With the introduction of the minimum size, the proportion at length is truncated (Figure 8).

## AT-SEA OBSERVERS

At-sea observers monitor and record fishing activities in greater detail than can be obtained from fishery monitoring documents submitted by fishermen. The catches of all species, whether retained or discarded, are recorded. In addition to the information on the catch, at-sea observers also record information on the fishing practices, including nature and location of the fishing activity, and may sample fish to assess sex, weight, and maturity, collect otoliths and other samples or data. The at-sea observer data is maintained by the DFO Maritimes Region in the Industry Surveys Database (ISDB).

At-sea observer data on halibut catch by otter trawl and longline gear is used to characterize the length composition of the commercial fishery. A number of fisheries which would catch small amounts of halibut incidentally (silver hake, mackerel, shrimp, squid, and silver hake/squid/argentine) were excluded. Industry-DFO surveys such as the 4Vn and 4VsW Sentinel, 4X Mobile Gear, 4X Monkfish, and 5Z Fixed Gear, as well as the Industry-DFO Halibut Survey fixed-stations, were excluded. Commercial Index sets completed with at-sea observers are included.

Prior to 1988, there were a small number of sets observed at sea (Table 11). Observer coverage increased in 1988 and increased again in 1999 with the beginning of the Commercial Index. The number of sets observed from the otter trawl fleet peaked during the collapse of the cod fishery and then rapidly declined, averaging 33 sets per year since 1994. Since 1995, the number of observed trips from the longline fleet has been over 300 in all but two years (2004 and 2006), and has averaged 595 sets since 1999. The sample sizes are presented in Tables 9 and 10.

The proportion at length was generated separately for otter trawl and longline gear. Here, the length composition separately for 3NOPs and 4VWX5Z is presented, as there is a difference in the size composition of the landings across the management unit. The proportion of the fishery observed at sea also varies, with a greater proportion of the landings observed in 3NOPs. The length of halibut observed at sea ranged from 10-278 cm. One report of a halibut over 400 cm was excluded. Overall, the sampling of otter trawl has been quite variable (Figure 9; Table 10), while the number of fish caught by longline and sampled at sea by observers increased in 1998 with the introduction of the beginning of the Industry-DFO Halibut Survey (Table 9). As the sex of the fish cannot be assessed until a fish is gutted, the length composition for the catch of males and females has been truncated since the introduction of the minimum size limit in 1994. There are sub-legal fish that presumably died during capture or were part of special sampling (e.g. 2011), for which sex is available. Smaller halibut comprise a larger portion of the catch of male halibut than female. Similarly, 4VWX had more small halibut than 3NOPs. In 3NOPs the female catch tends to be more evenly distributed, with some indication of strong cohorts recruiting and moving through over recent years.

# INDICES OF ABUNDANCE

## RESEARCH VESSEL SURVEYS

The longest and most comprehensive fisheries-independent data on the distribution and abundance of halibut are from the DFO RV bottom trawl surveys. Over the years there have been a number of surveys in both 3NOPs and 4VWX, most of which have been recently reviewed with respect to Atlantic halibut catches (Trzcinski et al. 2011b). For this assessment, only the Spring RV survey in areas 3N, 3O and 3Ps, and the 4VWX summer RV survey have been included.

### DFO Maritimes 4VWX Summer RV Survey

The Scotian Shelf and Bay of Fundy (4VWX) DFO Maritimes summer RV survey has low catchability for larger (>81 cm) halibut and does not provide a good index of exploitable biomass, but the expanded numbers and numbers per tow are accepted as an index of the abundance of pre-recruits. The median size of halibut caught in the 4VWX summer RV surveys is between 40 and 50 cm. The growth model (Armsworthy and Campana 2010) suggests that these fish will enter the fishery in 2 to 4 years.

The RV survey in 4VWX has been completed every July-August since 1970. Each year, about 231 stations are sampled from the Upper Bay of Fundy to the northern tip of Cape Breton Island, and offshore to the 400 fathom contour (approximately 700 m) (Branton and Black 2004). The number of strata covered and the survey duration vary from year to year. There have also been changes to the ship and gear type used. From 1970-1981, the survey was conducted by the *A.T. Cameron* using a Yankee 36 trawl. Since 1982, Western IIA trawl gear was used with a variety of boats: in 1982 the survey was completed by the *Lady Hammond*; in 1983-2004, 2006, 2009-2013 by the *Alfred Needler*; in 2004, 2005 and 2007 by the *Teleost*; and in 2008 by the *Wilfred Templeman*. In 2005, some stations were surveyed by both the *Teleost* and the *Alfred Needler*. The change of fishing gear in 1982 is known to have had important effects on the catchability of cod and haddock, but appears to have had little effect on halibut. Almost all halibut caught on the DFO Maritimes summer RV surveys have been measured and the sex assessed and reported, except in 2000 when the sex was not recorded (Table 12). As has been done for similarly-sized flatfish (e.g. American plaice in COSEWIC 2009), correction factors for gear changes were not calculated for the index of abundance (Figure.10) or the length frequency.

#### Index of Abundance

There was a moderate increase in the abundance of halibut caught in the 4VWX RV survey in the 1970s, followed by a sharp decline in the early-1980s (Figure 10). The abundance increased again in late-1980s early-1990s, but then remained low until the early-2000s. Since 2004, the mean number per tow has been above the long term average. The peak number per tow occurred in 2011.

#### Catch Composition

While in some recent years the catches were dominated by a few size classes, in 2013 length composition of the survey catch was more uniform (Figure.11).

### DFO Newfoundland and Labrador Spring RV Survey

DFO has also been conducting research surveys to monitor groundfish resources off of Newfoundland and Labrador since 1946. Although these surveys are conducted to monitor Canadian resources, they extend beyond the Canadian Exclusive Economic Zone (i.e., outside Canada's 200-mile limit). From 1946-1970, groundfish abundance was estimated using line transect surveys over a range of depths. Between 1971 and 1982, the *A.T. Cameron* with a Yankee-41.5 otter trawl completed an annual stratified-random survey in the spring in 3LNO. The survey was stratified based on depth, with the allocation of sets proportional to the stratum area (Doubleday and Rivard 1981). In 1983, the Yankee trawl was replaced with an Engels-145 high-lift otter trawl. In 1984, the *A.T. Cameron* was replaced by the *Alfred Needler.* From 1996-2013, the Spring RV survey was conducted using a Campelen-1800 shrimp trawl. Spring RV stratified-random surveys have been conducted in 3Ps and 3Pn since 1972. Survey coverage has been relatively constant in recent years, with the exception of 2006, when mechanical problems prevented sampling of 3Ps and permitted only minimal coverage of 3NO.

Conversion factors during periods of comparative tows between different survey trawls were not derived for many fish species. Plots of the raw length frequency of Atlantic halibut for 1972 to 1982 (Yankee), 1983 to 1995 (Engels-145) and 1996 to 2013 (Campelen-1800) suggest a broader size selectivity of the Campelen-1800 shrimp trawl than the Yankee or Engels-145 trawls (Figure 12, Table 13). This is consistent with the change in mesh size, but should be interpreted with caution as changes in the size composition in the population could also contribute to the change in length composition of the survey catch. Further, the length frequencies are not weighted by the stratification scheme. Notably, the mean length of halibut caught by each of the gears used for the Spring RV survey in 3NOP was between 80.5 and 90.5 cm (Table 14). Therefore, much of the catch in the survey is of sufficient size (>81 cm) to be available to the fishery, and unlike the 4VWX summer RV survey, the 3NOP Spring RV survey does not provide an index of the abundance of pre-recruits.

The time series is divided into three periods to reflect the different survey gear: 1971 to 1982 (Yankee trawl); 1983 to 1995 (Engel); and 1996 to 2013 (Campelen). The numbers per tow have been standardized for area swept (Mariano Koen-Alonso, Northwest Atlantic Fisheries Centre). Strata areas (provided by Phillip Greyson, Bedford Institute of Oceanography) were used to calculate the stratified number per tow. As with the 4VWX summer RV survey, numbers rather than weight of catch are used as an index because the catch of large halibut can inflate the variance in the index. During the first 10 years (Yankee trawl) of the survey the catch of halibut increased (Figure 13). Between the mid-1980s to the mid-1990s the catch declined. After the Campelen gear was introduced in 1996 there was little change in the mean number per tow until 2007. Since 2007, the number per tow has been increasing with 2013 being the highest catch in the Campelen time series.

## INDUSTRY-DFO HALIBUT SURVEY

On the Scotian Shelf and southern Grand Banks a collaborative Industry-DFO Halibut Survey, using longline gear with established stations and directed fishing, has been conducted since

1998 to monitor the abundance and distribution of a broad size range of halibut (50-230 cm) over a wide range of depths (50 – 800 m) (Zwanenburg and Wilson 2000, Zwanenburg et al. 2003, Trzcinski et al. 2009). Commercial fishermen complete the survey following established protocols, and data are collected by at-sea observers and housed in the ISDB (Zwanenburg and Wilson 2000). The halibut Commercial Index fishery is completed in conjunction with the Industry-DFO Halibut Survey (Table 15). The Industry-DFO Halibut Survey has been reviewed in earlier assessment documents (Zwanenburg et al. 2003, Trzcinski et al. 2009). Since 2009, the survey protocols have been reviewed and documented, and data management has been improved with enhanced quality control and changes to the handling of replicate survey sets. Below, some details on the survey are presented, although a more thorough stand-alone review would be useful.

## FIXED-STATION SURVEY

The fixed-station survey covers the entire stock area. An initial 222 predetermined stations were identified when the survey started in 1998 (Figure 14). Thirty stations were reserved for 3NOPs and the remainder allocated proportionally over 4Vn, 4VsW and 4X based on areas of low, medium and high historic catch rates. Over the entire stock area, station locations were allocated at a ratio of 5:7:10; that is, 50 stations in low catch areas, 70 stations in medium catch areas and 100 in high catch areas. In 1999, stations were rearranged and reallocated, and new fixed-stations were added in 2005 (4 stations), 2006 (51 stations), 2007 (8 stations) and 2008 (10 stations) to increase coverage in the Bay of Fundy, north of Cape Breton Island and Georges Bank. In 2005, one station (Station 46) was relocated a short distance to avoid fishing in a newly-protected sensitive habitat.

The protocol for the fixed-station survey is 1000 hooks set for 10 hours with Mustad circle hooks #14 or greater with gear set between 4 am and 12 noon. There is some variation in the number of hooks and the soak time (Figure 15), and some sets were set after 12 noon. Some variance in soak time is to be expected as participants adjust for high catch rates of dogfish. A small number of stations (n=198 of 3,299 stations fished since 1998) have been fished with two sets of roughly 500 hooks. For these split sets, the catch from the two sets is summed, and the soak time is estimated by a number-of-hooks weighted average. Notably, there is also variation in the size of hooks used during the survey, and this varies by NAFO Division and year, with size #16 hooks becoming more common, particularly in 3N and 3O (Tables 16 and 17). Either the start or end of a gear set is usually within 3- nautical miles of the station, although some set locations are further from the planned station location. It is not uncommon for more than one string of gear to be fished at a station by more than one boat in a year. Where there were replicate sets by different boats, the first set that followed the protocol is considered the fixed-station survey set, and the other sets are assigned to the Commercial Index survey.

The number of boats involved in the survey has stabilized at 14 (Table 15). The number of stations completed has also stabilized (Table 18), but in the last few years the amount of halibut caught has been increasing. In 2005 and 2006, there were fewer stations completed in 3NOPs, but in recent years the distribution of stations has stabilized. In the first few years of the survey, there was variable coverage of survey stations particularly in the Southern Grand Banks (i.e., 3NOPs). As the longline survey is completed by Nova Scotia-based boats, there is a high cost to access these areas. Further, cod bycatch limits in 3Ps limit the number of fixed-stations that can be done and preclude fishing Commercial Index sets. For all but two years, the majority of stations were fished in June, with a smaller number of stations fished in May and July. In 2007 and 2013, the survey was delayed by approximately one month.

## Index of Abundance

In the early years of the survey, assessments used halibut catches from the most consistently-sampled stations (known as the 50 golden stations) as a biomass index (Figure 16). As the survey time series grows, there are a large number of stations that have been fished for several years (Table 19). The geographic distribution of sampling effort has also remained more constant in recent years. Here a generalized linear model (GLM) approach is used, which was first introduced to the assessment in 2008 (Trzcinski et al. 2009). For the index of abundance, only stations with soak times greater than three hours and with more than 500 hooks were included. This resulted in approximately 6% being excluded (210 of 3,299). Further to this, only stations fished in four or more years (n=287) are retained for the model of abundance. Catch rate ranged from 0-1205 kg. The GLM used a negative binomial error distribution where year (unordered factor) and station (unordered factor) effects were estimated and the response variable (weight in kilograms) was offset by the log number of hooks (Trzcinski et al. 2009). Other effects, such as area and vessel, were not considered. No effort was made to account for gear saturation. Further, differences in bait, vessel or hook size have not been assessed. In 2009, the GLM did not have a significant year effect, but recent years have significantly higher catch than early years (Table 20). The model criteria are as follows:

Catch (kg) ~ year + station + offset(log(number of hooks))
family=neg. binom; theta =0.4323; link = log

The Industry-DFO Halibut Survey biomass index for 3NOPs4VWX5Z Atlantic halibut has more than doubled in the past five years (Figure 13).

## Catch Composition

The proportion at length (bin size 3 cm, range 10-223 cm) by year was calculated using all stations in each year. The length frequencies for males and females are almost exclusively from retained (>81 cm) fish, while the combined sample (males, females, and unsexed) includes the undersized fish and those returned to the water with tags (Table 21, Figure 17). As with the commercial longline fishery, the male catch had a greater number of smaller halibut than the female catch, with some indication of cohorts recruiting to the survey gear (as with fishery, >81 cm) and moving through in subsequent years.

## Commercial Index

Commercial vessels that complete Industry-DFO Halibut Survey fixed-station sets also make Commercial Index sets. The number of Commercial Index sets is approximately three times that of the Industry-DFO Halibut Survey. The greatest number of Commercial Index sets was done in 2008 (1016 sets). On average, 30% of these sets are completed with onboard observers (Table 15). Notably, almost 100% of the Commercial Index sets in 3NOPs are completed with at-sea observers (Table 22). For the other 70% of Commercial Index sets, observers meet the vessel at port and collect detailed length frequency data on the halibut catch. While most halibut are landed gutted, halibut are marked at sea so that the length frequencies can be completed by sex. These length frequencies are entered into the port sampling database. In addition, the boat Captains collect information at sea that allows for a set-by-set analysis of the catch rate (numbers of fish and estimated weight in kilograms). The set-by-set information is housed in the ISDB, and the length frequency data are apportioned to a set based on the proportion of the total estimated weight of the trip caught on a given set.

As with the fixed-station survey, the number of vessels involved have varied from year-to-year but has stabilized in recent years at 14 (Table 15). Further, with the exception of 2007 and 2013, the Commercial Index was conducted primarily in June and July. There is more variation in the fishing protocols with the Commercial Index than the fixed-station survey, with longer soak times on average (mean=829 mins; median=720 mins), but the number hooks per set are similar (mean=1000; median=1040) to the fixed-station protocol (Figure 18). As with the fixed-station survey, the use of #16 hooks is becoming more common (Table 23), particularly in area 3N (Table 24).

### Index of abundance

The halibut catch rates in the Commercial Index range from 0-2,372 kg per set. The interpretation of this data set would also benefit from standardization with a GLM; however, this analysis has not yet been completed. As with previous assessments, the Commercial Index catch rate was standardized to 1000 hooks and 10 hours soak time. No stratification scheme or model was used. The Commercial Index catch rate does not show a linear trend over the survey time series (Figure 19). This index is more difficult to interpret than the Industry-DFO Halibut Survey biomass indices because the fishing practices vary, and these important sources of variability have not been included in standardization.

### Length frequency

Commercial Index length frequencies are included in the observer and port sampling data.

## MULTI-YEAR TAGGING MODEL TO ESTIMATE M AND F

In 2006, DFO and the Atlantic Halibut Council (AHC) began the Halibut All Sizes Tagging (HAST) program to estimate population size, exploitation rate and evaluate the distribution of halibut within the Scotian Shelf and southern Grand Banks management unit. More than 3000 halibut were double-tagged with T-bar anchor tags during the Industry-DFO Halibut Surveys in 2006, 2007, 2008, 2010, and 2012. Fishers are asked to report the recapture of tagged halibut with the date, location, length and sex. For each fish recaptured (one or both tags returned) fishers are rewarded with $100 from the AHC, and their name is put into the pool for four lotteries per year that offer a prize of $1000. As of August 8, 2014, 670 tag reports had sufficient information to be used in the multi-year mark recapture model (Table 25).

The HAST tagging experiment is an example of a band-recovery experiment (Brownie et al. 1985). Following the methods of Hoenig et al. (1998a), the expected number of fish released and recaptured can be expressed as a function of the expected number of recoveries given a constant instantaneous M, year-specific instantaneous fishing mortality ($F_i$), constant initial-tagging survival (ITS) rate and constant tag-reporting rate (RR), assuming that fishing takes place uniformly over the entire year with tagged-fish released at the start of each year. The incomplete mixing model estimates fishing mortality (F*) in the first 6 months of release, when fish behavior might be altered and would bias estimates of F. This model was chosen because it fit data better than a complete mixing model.

There are two extensions to the Hoenig et al. (1998a) in the Atlantic halibut multiyear mark-recapture model (den Heyer et al. 2011). First, as the majority of tagging takes place in June and July, fish tagged and released in the first year are only subject to half of a year fishing and natural mortality. Second, tag-loss is considered in the model. It is assumed that survival after tagging and the tag reporting rate are constant over time. The model also assumes that fishing is equally spread over the year. This is not strictly true for the halibut fishery, although Hoenig et al. (1998a) note that estimates are relatively insensitive to this assumption. The plot of cumulative tag-loss over time (Figure 20) indicates that most tag loss occurs in the first year after release. Consequently, the two retention parameters in the model should be sufficient to account for the general shape of the cumulative tag-retention curve.

Initial tagging survival and reporting are fixed based on outside studies. Neilson et al. (1989) found that initial tagging survival for halibut caught on long-lines ranged from 80% to near 100% depending on handling time, total catch, fish length, depth fished, etc. In 2010, 0.9 and 1.0 were used in model fitting (den Heyer et al. 2011). Between 2007 and 2014, 50 PSAT tags have been successfully deployed on Atlantic halibut (Armsworthy et al. 2014, S.C. Smith, unpublished data). As with the tagging study, PSAT tags were only deployed on healthy fish. Of those deployments, there was no indication of tagging-induced mortality. Tag reporting is expected to be high because of the $100 cash reward for reporting a tagged fish and lottery supported by AHC. Values of 0.5, 0.6, 0.7, 0.8 and 0.9 for the reporting rate were used in model fitting (Table 26). A review of the tagging data management (den Heyer et al. 2012) found that only 90% of tag reports are sufficiently detailed to be used in the tagging model, and it is known that even with the high tag rewards some tags are not reported by fishers. A reporting rate (rate of complete tag reports) of 80% would seem an appropriate estimate.

A substantial number of fish below the legal size limit (81 cm) were tagged and released. In 2010, only fish that were of legal size at time of release were analyzed (den Heyer et al. 2011). Here, all tagged fish are used, as the sub-legal fish will be available to fishery in one or two years, as both tag retention and growth rate is high. As with the earlier analysis, the incomplete mixing model, which estimates F in the first 6 months of release is the preferred model, with both lower AIC and over-dispersion parameter (Table 26). As discussed above, the model provides no information on the assumptions of ITS and RR.

Assuming 80% tag reporting and 100% survival from tagging, instantaneous M for halibut was estimated. The updated multiyear mark-recapture model estimates M at 0.14 and F, from 2007 to 2013, as 0.13, 0.19, 0.13, 0.11, 0.07, 0.12 and 0.07, respectively. As commercial fishing continues, the 2014 reports are incomplete and the 2014 F is underestimated (Table 27, Figure 21).

## ASSESSMENT HISTORY

Prior to 2010, assessment advice was provided based on the RV survey abundance indices, catch per unit effort and length composition of catch (e.g. Perley et al. 1985, Zwanenberg et al. 2003). In 1987, two management units, 4RST and 3NOPs4VWX5Zc, were defined in Canadian waters based primarily on tagging studies (McCracken 1958, Bowering 1986, Stobo et al. 1988) and differences in growth rates between fish caught on the Scotian Shelf and in the Gulf of St. Lawrence (Neilson and Bowering 1989). Assuming moderate survival (35-67%) of discarded, undersized fish and no change in the size composition of the fishery, Neilson and Bowering (1989) concluded that the introduction of a minimum size of 81 cm would have little effect on yield, unless natural mortality was low (M=0.1), but that the value of the fishery would increase, owing to the increased value per weight of midsized halibut. A minimum legal size of 81cm was adopted on an interim basis in 1988 and subsequently ‘enforced’ in 1990 (Annand and Beanlands 1993). Enforcement is only apparent from port sampling of the otter trawl fleet in 1994. The assessments in the early-1990s recommended a decrease in the TAC based on declining catch rates of halibut in the DFO RV surveys, commercial fishery (CPUE), and total catch (Annand and Beanlands 1993, 1996). *Z*wanenberg et al. (1997) completed an in-depth review of halibut landings catch rate and distribution and several DFO RV surveys. From these data, they estimated that total mortality (*Z*) increased from 0.32 in the 1960s to 0.51-0.53 in the 1990s. Their yield per recruit analysis resulted in $F_{0.1}$ = 0.08 and $F_{max}$ = 0.24. Notably, they also demonstrated that there was a reduction in the number of larger individuals from 1960s to the 1990s. Recognizing the limitations of the DFO RV surveys to provide indices of abundance for halibut, the joint Industry-DFO Halibut Survey using longline gear was initiated in 1998, to provide an index of biomass of the exploitable population. The Industry-DFO Halibut Survey has produced a wealth of data. In particular, the Industry-DFO Halibut Survey produces estimates of annual catch rate and size composition.

The last assessment of Atlantic halibut was conducted in November 2010 (DFO 2011). A new length-based, age-structured assessment model and produced estimates of spawning stock biomass (SSB) and F. The consequences of different harvest levels and the risk to productivity of the stock were assessed in 2012 (DFO 2012), assuming two different spawner-recruit curves. Based on model projections, 3NOPs4VWX5Zc Atlantic halibut SSB was expected to increase in size, and the population was concluded to be in a productive period due to high recruitment. It was also concluded that there was little risk in harming the productivity of the stock in three years at harvest levels less than 4,000 mt. A stock status update in November 2013 concluded that the 3NOPs4VWX5Zc Atlantic halibut stock was increasing despite moderate increases in the TAC (DFO 2014).

## ACCEPTED MODEL (VPOP)

The assessment model used in the 2010 framework can be broadly described as a length-based, age-structured model (Trzcinski et al. 2011a). It is presented here and updated with the most recent data to provide continuity with previous assessments. The primary input to the model is the same as the new assessment model: length frequency data from surveys and the fishery, including the Industry-DFO Halibut Survey and the 4VWX RV survey abundance indices. The model converts the lengths to ages using the ageing information and variability used in the 2010 framework model (Trzcinski et al. 2011a). Since this time, the length-age key has been refined (Armsworthy and Campana 2010), but this has not been updated. The population dynamics then becomes age-based (i.e., processes such as recruitment, maturity, selectivity, fishing and natural mortality occur at age). The model predicts the catch rate in the abundance indices and the length frequency in the surveys and commercial catch. These predictions are fitted to the data by minimizing the negative log likelihood. The model was written in AD Model Builder, which uses automatic differentiation to fit non-linear models to multiple data sets.

More specifically, the 2010 model is a forward-projecting, age- and sex-structured population dynamics model similar to that of Gibson and Campana (2005). Total mortality was partitioned into natural mortality and fishing mortality. Natural mortality was updated from 0.1 to 0.15, based on the preferred tagging model (Table 27). The catch was extrapolated to total removals based on the annual estimate of the proportion discarded. Total removals were then assumed to be known without error. A discard mortality of 23% was assumed based on the study by Neilson et al. (1989) and was applied within the model. The annual F was estimated iteratively using the Baranov equation. It is assumed that F could be separated into the selectivity of the commercial fishery and an annual F (Quinn and Deriso 1999). The selectivity of the longline fishery was assumed to be asymptotic (logistic), and the selectivity of the DFO RV survey and the otter trawl fishery were assumed to be double-half Gaussian. The model fits to the observed numbers at length in the male and female total catch, as well as the 4VWX summer RV survey and Industry-DFO Halibut Survey. The model also fits to the abundance indices of the 4VWX summer RV surveys and Industry-DFO Halibut Surveys. The equations for the model can be found in Table 28.

Catch-at-length was constructed as follows:

1) Observer samples numbers-at-length were adjusted for subsampling.
2) The set length frequency and parameters from a length-weight relationship (see discussion above) were used to estimate the sample weight of all halibut caught including discards for two fisheries: longline and otter trawl.

3) The proportion of the catch by weight less than 81cm was calculated for the years 1994-2012.
4) Port samples were prorated by estimating the weight of fish which would have been caught and discarded from observer data.
5) The estimated discard weight was divided by the average weight of a fish at length to estimate the numbers of discards at length for port sampled trips.
6) The resulting observer and port sampled length frequencies were combined using a weighted average.
7) The combined length frequency was extrapolated to the total catch.
8) Unsexed fish in the longline samples were allocated to males and females based on the sex ratio at length.

The model was initialized in 1970 by estimating the number of age 1 fish. Ages 2 to 20 are then estimated using an assumed Z of 0.2. Sensitivity to the starting values is discussed further in a section below. The only data available on halibut abundance from 1970 to 1984 is the 4VWX summer RV survey data (abundance index and length composition), and the landings without length composition data. As with the 2010 model run, data on the length frequency in the otter trawl catch starts in 1977, but sampling was very low in the first five years so only length frequency data starting in 1984 was used. Data on the length frequency in the longline catch starts in 1988 and the Industry-DFO Halibut Survey time series used for both an index of abundance and length composition begins in 1998. The model was much better informed as one proceeds from 1970 to present. The influence of each dataset on the estimate of population size was partially affected by the amount of process error that was assumed. Reasonable values for the variation of the lognormal likelihoods ($\sigma = 0.1$) for the abundance indices and multinomial likelihoods ($n_t = \leq 150$) for the length composition were assumed based on an understanding of the data (Table 28). Fishing mortality values greater than 1.0 were penalized by adding large values to the negative log likelihood. Recruitment to age 1 was assumed to be a random walk with lognormal error and $\sigma = 0.5$, which is large enough to allow for variability in recruitment. Since recruitment is always difficult to estimate in the terminal year, recruitment in 2012 and 2013 was assumed to be the geometric mean of the previous three years. The model was run out to 2013.

During the initial exploration of the model and data, it was noted that the periodic catch of small or large fish had strong leverage on the fit to the length composition data. As with 2010, the lengths from 10-130 cm were used from the otter trawl and 4VWX summer RV survey data. Lengths from 41-160 cm for males and from 41-187 for females were used from the longline data. Recent changes to the proportions at length, as a result of improved modelling of length-weight relationship, as well as an increase in both 4VWX summer RV survey and the Industry-DFO Halibut Survey index of abundance have improved the overall fit over the 2010 version of the model.

### Assessment Results

The parameter estimates for the model are listed in Table 10. In general, the model parameters are well estimated as the Coefficients of Variation (CV) are below 5%. Several parameters could not be estimated and were fixed at values listed in Table 10. These included the otter trawl selectivity parameters and the shape parameters for the longline fishery and Industry-DFO Halibut Survey selectivities. These were set at values which effectively make the selectivity knife-edged (Figure 22). It was assumed that halibut are fully-selected to the otter trawl gear at age 5, corresponding to about 58-61 cm. For longline gear, halibut were 50% selected at age

5.5 and 5.7 for males and females, respectively, which corresponds to about 83-85 cm (Figure 22).

The fits to the abundance indices are shown in Figure 23. The fit to the DFO RV survey data was fairly good, with a short string of positive residuals in the late-1980s and early-90s. The 2011 DFO RV survey estimate was the highest on record and indicates high recruitment. Catch rates in the Industry-DFO Halibut Survey have more or less steadily increased since 2003, with 2013 being the highest catch rate (Figures 16 and 23).

Atlantic halibut population dynamics, as estimated by the assessment model, show high abundance and recruitment in the 1970s. Biomass increased as fish grew and survival was good, but recruitment dropped and was relatively low in the 1980s and 1990s (Figure 24). During this period, biomass peaked at 16,543 mt in 1982 then decreased rapidly to 4,615 mt in 1992. Biomass increased steadily since 1992 and reached 25,277 mt in 2013. Recruitment has been above average since 2003 and peaked in 2008 at an estimated 1,207,250 Age 1 recruits (Figure 24). The SSB in 2013 was estimated at 15,297 mt (6,350 mt females only).

Fishing mortality rates were about 0.1 for the longline and otter trawl fisheries in 1970, but rapidly increased to 0.3 or greater in the late-1980s and early-1990s, as the population decreased (Figure 25). Current F is about 0.1 for the longline fishery, but in recent years fishing pressure on females appears to have been higher than for males (Figure 25). Fishing mortality from the otter trawl fishery has been low since the mid-1990s, and in 2013 was 0.01.

### Sensitivity and Model Comparisons

Changing the assumption of M from 0.1 to 0.15 served to lower the estimate of $q$ (i.e., catchability of the stock) and produced higher estimates of abundance and biomass. Fitting the model up to 2013 with an M of 0.1 also produced higher estimates of abundance and biomass than the 2010 model run. A retrospective analysis would be useful to further explore the sensitivity of the model.

## DISCUSSION

Halibut are a large long-lived species which may be particularly vulnerable to high exploitation rates. In comparison with other groundfish on the Scotian Shelf and Grand Banks, the total abundance of halibut may be small, but the high value per pound, recent increase in abundance and the depleted state of other groundfish stocks, have made this the most valuable groundfish fishery in Atlantic Canada. Atlantic halibut in Canadian waters are currently being managed as two different stocks: 4RST and 3NOPs4VWX5Zc.

In 2012, based on model projections, 3NOPs4VWX5Zc Atlantic halibut was concluded to be in a productive period due to high recruitment (DFO 2012). Over the past few years the TAC has increased, with the 2014 TAC set at 2,563 mt. The updated fishery-independent abundance indices, including the 4VWX summer RV survey, 3NOPs Spring RV survey and the Industry-DFO Halibut Survey indicate that the abundance of both pre-recruits and recruits continues to be high.

DFO RV surveys provide long-term abundance indices for Atlantic halibut. The 4VWX summer RV survey has been used as an index of recruitment, as the halibut caught in the survey are primarily sub-legal and immature fish. The 4VWX summer RV survey standardized catch rates remain well above the long term mean and suggest that the fishery will continue to benefit from high recruitment in the next couple of years. Notably, the 3NOPs Spring RV survey catches larger halibut than the 4VWX summer RV survey and, although it has not been used as an input to the assessment model, the increased catch per tow in recent years is consistent with the trends in the Industry-DFO Halibut Survey.

The Industry-DFO Halibut Survey provides a biomass index for exploitable halibut throughout the management unit. Prior to 2008, station coverage was irregular and new stations were added to improve coverage in 4Vn and 3NOPs. The influences of vessel, bait, and temperature on the Industry-DFO Halibut Survey and Commercial Index catch rates have not been fully analyzed. Further, the impact of the delayed start of the 2007 and 2013 Industry-DFO Halibut Survey and Commercial Index fishing has not been assessed.

The 2010 assessment model was updated with new data, including the improved Industry-DFO Halibut Survey data and GLM index of abundance, as well as the improved catch composition data, to provide a baseline for the new stock assessment model (DFO 2015). Given the differences in observer coverage and catch composition between 3NOPs and 4VWX, the catch-at-length used in the 2010 assessment model could be improved by weighting the catch composition from 3NOPs by the landings in that area. There are also a number of parameters in the assessment model that are fixed. Only the sensitivity of model results to the choice of M was explored. Given the increased time series for the Industry-DFO Halibut Survey, and the strong signal in the DFO RV survey data, Industry-DFO Halibut Survey and catch composition, there may be sufficient information in the data to inform some of the other fixed parameters; however, the model documentation is lacking and a thorough analysis has not been completed.

The updated 2010 assessment model (assuming M=0.15) estimates the 2013 biomass at 25,277 mt, which is the peak biomass in the model time series (1970- 2013). The model also estimated SSB in 2013 at 15,297 mt, and found that recruitment has been above average since 2003 and peaked in 2008. Despite moderate increases in TAC, the Atlantic halibut stock appears to be increasing. Current F was about 0.1 for the longline fishery, but in recent years fishing pressure on females appears to have been higher than for males. Fishing mortality from the otter trawl fishery has been low since the mid-1990s, and in 2013 was 0.01. Similarly, F estimated from the multiyear tagging study indicates that fishing mortality has been stable or slightly reduced between 2007 and 2013.

## REFERENCES


Annand, C., and D. Beanlands. 1993. A review of the status of the 4VWX, 3NOPs halibut stocks. DFO Atl. Fish. Res. Doc. 93/058.

Annand, C., and D. Beanlands. 1996. A review of the 4VWX3NOPs halibut stock. DFO Atl. Fish. Res. Doc. 96/033.

Armsworthy, S.A., and S.E. Campana. 2010. Age determination, bomb-radiocarbon validation and growth of Atlantic halibut (*Hippoglossus hippoglossus*) from the Northwest Atlantic. Environ. Biol. Fish. 89: 279-295.

Armsworthy, S.A, M.K. Trzcinski, and S.E. Campana. 2014. Movements, environmental associations, and presumed spawning locations of Atlantic Halibut (*Hippoglossus hippoglossus*) in the northwest Atlantic determined using archival satellite pop‐up tags. Mar. Biol.161: 645–656.

Bowering, W.R. 1986. The distribution, age and growth and sexual maturity of Atlantic Halibut (*Hippoglossus hippoglossus*) in the Newfoundland and Labrador area of the Northwest Atlantic. Can. Tech. Rep. Fish. Aquat. Sci. 1432: 34p.

Branton, R., and G. Black. 2004. 2004 summer groundfish survey update for selected Scotia-Fundy groundfish stocks. DFO Can. Sci. Advis. Sec. Res. Doc. 2004/108.

Brownie, C., D.R. Anderson, K.P. Burnham, and D.S. Robson. 1985. Statistical inference from band recovery data: A handbook. 2nd ed. U.S. Fish Wildl. Serv. Res. Publ.156.

Clark, W. and S. Hare. 2006. Assessment and management of Pacific Halibut: Data, methods, and policy. Int. Pac. Halibut Comm. Scientific Rep. No. 83.

Col, L.A., and C.M. Legault. 2009. The 2008 assessment of Atlantic Halibut in the Gulf of Maine-Georges Bank region. U.S. Dept. Commer. Northeast Fish. Sci. Cent. Ref. Doc. 09-08: 39 p. Available from: National Marine Fisheries Service, 166 Water Street, Woods Hole, MA 02543-1026.

COSEWIC. 2009. COSEWIC assessment and status report on the American Plaice *Hippoglossoides platessoides*, Maritime population, Newfoundland and Labrador population and Arctic population, in Canada. Committee on the Status of Endangered Wildlife in Canada. Ottawa. x + 74 pp.

den Heyer, C., C. Schwarz, and K. Trzcinski. 2011. Atlantic Halibut fishing mortality estimated from tagging on the Scotian Shelf and the Southern Grand Banks. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/001.

den Heyer, C.E, S. Armsworthy, S. Wilson, G. Wilson, L., Bajona, S. Bond, and M.K.Trzcinski, 2012. Atlantic Halibut all-sizes tagging program summary report for 2006 to 2011. Can. Tech. Rep. Fish. Aquat. Sci. 2992: vii + 34 p.

den Heyer, C.E., C.J. Schwarz, and M.K. Trzcinski. 2013. Fishing and natural mortality rates of Atlantic Halibut estimated from multiyear tagging and life history. Trans. Am. Fish. Soc. 142: 690-702.

DFO. 2007. The Grand Banks of Newfoundland: Atlas of human activities. Published by the Oceans and Coastal Management Division, Newfoundland and Labrador Region. ISBN: 978-0-662-49898-8

DFO. 2011. Assessment of Atlantic Halibut on the Scotian Shelf and Southern Grand Banks (NAFO Divisions 3NOPs4VWX5Zc). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2011/001.

DFO. 2012. Projections of the Atlantic Halibut population on the Scotian Shelf and Southern Grand Banks (NAFO Divisions 3NOPs4VWX5Zc). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2012/027.

DFO. 2014. Stock status update of Atlantic Halibut on the Scotian Shelf and Southern Grand Banks (NAFO Divs. 3NOPs4VWX5Zc). DFO Can. Sci. Advis. Sec. Sci. Resp. 2014/016.

DFO. 2015. 2014 Assessment of Atlantic Halibut on the Scotian Shelf and Southern Grand Banks (NAFO Divisions 3NOPs4VWX5Zc). DFO Can. Sci. Advis. Sec. Sci. Advis. Rep. 2015/012.

Doubleday, W. G., and D. Rivard. 1981. Bottom trawl surveys. Can. Spec.Publ. Fish.Aquat. Sci. 58: 1-273.

Gibson, A.J.F., and S.E. Campana. 2005. Status and recovery potential of porbeagle shark in the Northwest Atlantic. DFO Can. Sci. Adv. Sec. Res. Doc. 2005/053.

Haug, T. 1990. Biology of the Atlantic halibut, *Hippoglossus hippoglossus* (L., 1758) Adv. Mar. Biol. 26: 1-70.

Hoenig, J.M., N.J. Barrowman, W.S. Hearn, and K.H. Pollock. (1998a). Multiyear tagging studies incorporating fishing effort data. Can. J. Fish. Aquat. Sci. 55: 1466-1476.

Kaimmer, S. M., and R.J. Trumble. 1998. Injury, condition, and mortality of Pacific Halibut bycatch following careful release by Pacific Cod and sablefish longline fisheries. Fish. Res. 38: 131-144.

Kanwit, J.K. 2007. Tagging results from the 2000-2004 federal experimental fishery for Atlantic Halibut (*Hippoglossus hippoglossus*) in the eastern Gulf of Maine. J. Northw. Atl. Fish. Sci. 38: 37-42.

McCracken, F.D. 1958. On the biology and fishery of the Canadian Atlantic Halibut *Hippoglossus hippoglossus* L. J. Fish. Res. Bd. Canada. 15(6): 1269-1311.

Neilson, J.D., and W.R. Bowering. 1989. Minimum size regulations and the implications for yield and value in the Canadian Atlantic halibut fishery. Can. Atl. Fish.Sci. Adv. Comm. 89/5.

Neilson, J.D., K.G. Waiwood, and S.J. Smith. 1989. Survival of Atlantic Halibut (*Hippoglossus hippoglossus*) caught by longline and otter trawl gear. Can. J. Fish. Aquat.Sci.46:887-897.

Neilson, J.D., J.F. Kearney, P. Perley, and H. Sampson. 1993. Reproductive biology of Atlantic halibut (*Hippoglossus hippoglossus*) in Canadian waters. Can. J. Fish. Aquat. Sci. 50: 551-563.

Perley, P., J.D. Neilson, and K. Zwanenberg. 1985. A review of the status of the 4VWX halibut stocks. Can. Atl. Fish. Sci. Advis. Comm. Res. Doc. 85/43 23p.

Quinn, T.J., and R.B. Deriso. 1999. Quantitative fish dynamics. New York; Toronto: Oxford University Press. xv. 542 p.

Sigourney, D.B., M.R. Ross, J. Brodziak, and J. Burnett. 2006. Length at age, sexual maturity and distribution of Atlantic Halibut, *Hippoglossus hippoglossus L.*, off the Northeast USA. J. Northw. Atl. Fish. Sci. 36: 81-90.

Stobo, W., J.D. Neilson, and P. Simpson. 1988. Movements of Atlantic halibut (*Hippoglossus hippoglossus*) in the Canadian North Atlantic: Inference regarding life history. Can. J. Fish. Aquat. Sci. 45: 484-491.

Trumble, R.J., J.D. Neilson, W.R. Bowering, and D.A. McCaughran. 1993. Atlantic Halibut (*Hippoglossus hippoglossus*) and Pacific Halibut (*H. stenolepis*) and their North American fisheries. Can. Bull. Fish. Aquat. Sci. 227: 1-84.

Trzcinski, M.K., S.L. Armsworthy, S. Wilson, R.K. Mohn, M. Fowler, and S.E. Campana. 2009. Atlantic Halibut on the Scotian Shelf and Southern Grand Banks (NAFO Divisions 3NOPs4VWX5Zc) – Industry/DFO longline survey and tagging results to 2008. DFO Can. Sci. Advis. Sec. Res. Doc. 2009/026.

Trzcinski, M.K., S.L. Armsworthy, S. Wilson, R.K. Mohn, and S.E. Campana. 2011a. A framework for the assessment of the Scotian Shelf and Southern Grand Banks Atlantic Halibut stock. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/02.

Trzcinski, M.K., C. den Heyer, S. Armsworthy, S. Whoriskey, D. Archambault, M. Treble, M. Simpson, and J. Mossman. 2011b. Pre-COSEWIC review of Atlantic Halibut (*Hippoglossus hippoglossus*) on the Scotian Shelf and Southern Grand Banks Atlantic (Divs. 3NOPs4VWX5Zc), Gulf of St. Lawrence (Divs. 4RST), Newfoundland and Labrador, and Central and Arctic. DFO Can. Sci. Advis. Sec. Res. Doc. 2011/030.

Zwanenburg, K.C.T., and S. Wilson. 1999. Processed weight to live-weight conversion factors for Atlantic Halibut (*Hippoglossus hippoglossus*) of the Scotia Shelf and Southern Grand Banks. DFO Can. Sci. Advis. Sec. Res. Doc. 1999/157.

Zwanenburg, K.C.T., and S. Wilson. 2000. Scotian Shelf and southern Grand Banks Atlantic Halibut (*Hippoglossus hippoglossus*) survey – Collaboration between the fishing and fisheries science communities. Theme session on Cooperative Research with the Fishing Industry: Lessons Learned. ICES CM 2000/W: 20.

Zwanenburg, K.C.T., G. Black, P. Fanning, R. Branton, M. Showell, and S. Wilson. 1997. Atlantic Halibut (*Hippoglossus hippoglossus*) on the Scotian Shelf and Southern Grand Banks: Evaluation of resource status. DFO Can. Sci. Advis. Sec. Res. Doc. 1997/050.

Zwanenburg, K.C.T., S. Wilson, R. Branton, and P. Brien. 2003. Halibut on the Scotian Shelf and Southern Grand Banks – Current estimates of population status. DFO Can. Sci. Advis. Sec. Res. Doc. 2003/046.

# TABLES

*Table 1. von Bertalanffy growth parameters of Atlantic halibut by sex (Armsworthy and Campana 2010).*

| Sex | Ages fitted, yrs | N | $L_{inf}$ | K | $t_o$ |
|---|---|---|---|---|---|
| Male | 2 to 32 | 995 | 134.2 | 0.18 | 0.88 |
| Female | 2 to 38 | 1428 | 205.1 | 0.10 | 0.49 |

*Table 2. Sample size for halibut length and weight by NAFO Division and year and gear type (observed longline and other, DFO RV survey). NAFO 3 includes divisions NOPs; NAFO 4 includes divisions VWX; and NAFO 5 includes YZc.*

| Year | Observer | | | RV survey | | |
|---|---|---|---|---|---|---|
| | NAFO 3 | NAFO 4 | NAFO 5 | NAFO 3 | NAFO 4 | NAFO 5 |
| 1970 | 0 | 0 | 0 | 0 | 23 | 0 |
| 1971 | 0 | 0 | 0 | 0 | 38 | 0 |
| 1972 | 0 | 0 | 0 | 0 | 25 | 0 |
| 1973 | 0 | 0 | 0 | 0 | 37 | 0 |
| 1974 | 0 | 0 | 0 | 0 | 45 | 0 |
| 1975 | 0 | 0 | 0 | 0 | 58 | 0 |
| 1976 | 0 | 0 | 0 | 0 | 69 | 0 |
| 1977 | 0 | 0 | 0 | 0 | 109 | 0 |
| 1978 | 0 | 0 | 0 | 0 | 195 | 0 |
| 1979 | 0 | 0 | 0 | 0 | 277 | 0 |
| 1980 | 0 | 22 | 0 | 0 | 294 | 0 |
| 1981 | 0 | 16 | 0 | 0 | 237 | 0 |
| 1982 | 0 | 0 | 0 | 0 | 179 | 0 |
| 1983 | 0 | 0 | 0 | 0 | 134 | 0 |
| 1984 | 0 | 21 | 0 | 0 | 109 | 0 |
| 1985 | 37 | 0 | 0 | 0 | 25 | 0 |
| 1986 | 0 | 0 | 0 | 0 | 4 | 0 |
| 1987 | 6 | 66 | 7 | 0 | 0 | 0 |
| 1988 | 387 | 179 | 3 | 0 | 0 | 0 |
| 1989 | 589 | 1876 | 3 | 0 | 14 | 2 |
| 1990 | 515 | 2578 | 24 | 0 | 0 | 0 |
| 1991 | 549 | 3109 | 11 | 0 | 0 | 0 |
| 1992 | 652 | 1292 | 6 | 0 | 0 | 0 |
| 1993 | 292 | 456 | 0 | 0 | 0 | 0 |
| 1994 | 2 | 170 | 0 | 0 | 44 | 0 |
| 1995 | 258 | 91 | 0 | 0 | 42 | 0 |
| 1996 | 195 | 354 | 0 | 0 | 72 | 1 |
| 1997 | 339 | 128 | 0 | 0 | 105 | 0 |
| 1998 | 127 | 4462 | 0 | 0 | 53 | 0 |
| 1999 | 463 | 2187 | 0 | 0 | 78 | 0 |
| 2000 | 392 | 1328 | 1 | 0 | 73 | 3 |
| 2001 | 346 | 1245 | 2 | 0 | 73 | 0 |
| 2002 | 364 | 1466 | 5 | 0 | 80 | 0 |
| 2003 | 332 | 1850 | 0 | 0 | 74 | 0 |
| 2004 | 670 | 558 | 2 | 0 | 57 | 0 |
| 2005 | 658 | 1080 | 1 | 0 | 218 | 1 |
| 2006 | 161 | 547 | 0 | 0 | 178 | 0 |
| 2007 | 427 | 925 | 15 | 0 | 121 | 1 |
| 2008 | 205 | 630 | 3 | 0 | 140 | 1 |
| 2009 | 1320 | 2873 | 20 | 0 | 94 | 2 |
| 2010 | 603 | 2531 | 5 | 0 | 212 | 0 |
| 2011 | 746 | 2399 | 0 | 0 | 220 | 8 |
| 2012 | 247 | 1219 | 0 | 0 | 169 | 5 |
| 2013 | 0 | 608 | 0 | 0 | 117 | 7 |

*Table 3. The number of halibut with length and weight measurements by sex and month.*

| Sex | Total | Month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| Unknown | 6670 | 91 | 237 | 190 | 148 | 829 | 2398 | 1767 | 106 | 479 | 293 | 88 | 44 |
| Male | 22893 | 746 | 847 | 1643 | 2354 | 4607 | 7078 | 4429 | 399 | 109 | 281 | 265 | 135 |
| Female | 21816 | 709 | 735 | 1405 | 1805 | 4413 | 8170 | 3396 | 357 | 161 | 296 | 290 | 79 |
| All | 51379 | 1546 | 1819 | 3238 | 4307 | 9849 | 17646 | 9592 | 862 | 749 | 870 | 643 | 258 |

*Table 4. Summary of fixed effects from the linear mixed effects model log weight with log length and NAFO Division (divisions defined as 3NOPs and 4VWX5Z) year as random effect (factor: 1970-2013).*

| Variable | Value | Std.Error | DF | t-value | p-value |
|---|---|---|---|---|---|
| Intercept | -5.021361 | 0.012315829 | 51333 | -407.7161 | 0.0000 |
| log(length) | 3.124185 | 0.002424709 | 51333 | 1288.4785 | 0.0000 |
| NAFO 4VWX5Z | 0.000002 | 0.001753527 | 51333 | 0.0014 | 0.9989 |

*Table 5. Total reported Canadian and foreign landings (metric tonnes) of Atlantic halibut from 3NOPs4VWX5Zc1. Ten year annual average landings are presented for 1960 to 2009. A dash (-) indicates no value.*

| Temporal interval | Year(s) | Landings | | | Landings[2] | TAC[3] |
|---|---|---|---|---|---|---|
| | | 3NOPs | 4VWX | 5Zc | 3NOPs4VWX5Zc | 3NOPs4VWX5Zc |
| Decadal Average | 1960-69 | 996 | 1464 | 0 | 2460 | - |
| Decadal Average | 1970-79 | 487 | 851 | 0 | 1338 | - |
| Decadal Average | 1980-89 | 955 | 1561 | 50 | 2566 | - |
| Decadal Average | 1990-99 | 503 | 790 | 30 | 1286 | 1855 |
| Decadal Average | 2000-09 | 607 | 863 | 15 | 1484 | 1318 |
| Annual | 2010 | 556 | 1279 | 11 | 1846 | 1850 |
| Annual | 2011 | 475 | 1322 | 19 | 1816 | 1850 |
| Annual | 2012 | 639 | 1464 | 28 | 2131 | 2128 |
| Annual | 2013 | 535 | 1726 | 33 | 2294 | 2447 |
| Annual | 2014 | [4]NA | NA | NA | NA | 2563 |

[1] Landings 1960-2010 from NAFO Table 21A as of 02 September 2014; Landings 2011-2013 from DFO Maritimes Region and DFO Newfoundland and Labrador Region commercial data.
[2] NAFO Table 21A reported by calendar year.
[3] Total Allowable Catch (TAC) set for April-March fishing year for Canadian commercial fishery. Prior to 1988 the Atlantic halibut catch was unregulated.
[4] NA = Not available

*Table 6. Number of commercial sets landing halibut by NAFO Division and vessel class from 2002-2013 from MARFIS database (July 2014).*

| NAFO Division | Vessel Length (feet) | | | | | |
|---|---|---|---|---|---|---|
| | Less than 35 | 35-45 | 45-65 | 65-100 | Greater than 100 | Total |
| 3N | 0 | 126 | 115 | 273 | 0 | 514 |
| 3O | 0 | 99 | 127 | 287 | 15 | 528 |
| 3Ps | 11 | 438 | 196 | 1,722 | 78 | 2,445 |
| 4V | 1,021 | 4,548 | 1,158 | 291 | 69 | 7,087 |
| 4W | 2,719 | 8,114 | 904 | 54 | 60 | 11,851 |
| 4X | 6,630 | 30,843 | 349 | 7 | 0 | 37,829 |
| Total | 10,381 | 44,168 | 2,849 | 2,634 | 222 | 60,254 |

*Table 7. Weight of halibut landed (mt) by NAFO Division and vessel class form 2002-2013 from MARFIS database (July 2014).*

| NAFO Division | Vessel Length (feet) | | | | | |
|---|---|---|---|---|---|---|
| | Less than 35 | 35-45 | 45-65 | 65-100 | Greater than 100 | Total |
| 3N | 0 | 162 | 140 | 306 | 0 | 608 |
| 3O | 0 | 61 | 78 | 119 | 4 | 263 |
| 3Ps | 4 | 342 | 121 | 1,148 | 49 | 1,664 |
| 4V | 183 | 1,670 | 690 | 181 | 38 | 2,763 |
| 4W | 392 | 2,794 | 589 | 37 | 38 | 3,851 |
| 4X | 585 | 4,938 | 96 | 9 | 0 | 5,628 |
| Total | 1,164 | 9,968 | 1,714 | 1,801 | 130 | 14,777 |

*Table 8. The number of trips sampled by port sampling commercial fishing longline, shore sampled Commercial Index longline, and port sampling otter trawl.*

| Year | Longline | | Otter trawl |
|---|---|---|---|
| | Commercial Index | Commercial | Commercial |
| 1989 | 0 | 0 | 2 |
| 1990 | 0 | 1 | 0 |
| 1991 | 0 | 1 | 1 |
| 1992 | 0 | 0 | 1 |
| 1993 | 0 | 1 | 1 |
| 1994 | 0 | 6 | 2 |
| 1995 | 0 | 10 | 1 |
| 1996 | 0 | 12 | 0 |
| 1997 | 0 | 10 | 2 |
| 1998 | 0 | 11 | 2 |
| 1999 | 20 | 15 | 12 |
| 2000 | 25 | 16 | 2 |
| 2001 | 23 | 15 | 5 |
| 2002 | 25 | 17 | 3 |
| 2003 | 23 | 7 | 3 |
| 2004 | 33 | 7 | 8 |
| 2005 | 25 | 11 | 5 |
| 2006 | 31 | 6 | 1 |
| 2007 | 57 | 12 | 6 |
| 2008 | 47 | 5 | 1 |
| 2009 | 23 | 14 | 3 |
| 2010 | 28 | 7 | 3 |
| 2011 | 36 | 7 | 4 |
| 2012 | 31 | 11 | 19 |
| 2013 | 37 | 23 | 1 |

*Table 9. The number of halibut sampled by sex (M=male, F=female, Combined=male, female and unsexed), year and area, by at-sea observers and port sampling of longline fishery.*

| Year | 3NOPs Observer | | | 4VWX Observer | | | Port Sampling | | |
|---|---|---|---|---|---|---|---|---|---|
| | M | F | Combined | M | F | Combined | M | F | Combined |
| 1988 | 392 | 371 | 781 | 58 | 68 | 126 | 0 | 0 | 0 |
| 1989 | 426 | 460 | 887 | 0 | 4 | 4 | 0 | 0 | 0 |
| 1990 | 941 | 755 | 2275 | 0 | 0 | 0 | 0 | 0 | 169 |
| 1991 | 579 | 618 | 1628 | 6 | 9 | 20 | 0 | 0 | 173 |
| 1992 | 812 | 1009 | 2358 | 162 | 159 | 405 | 0 | 0 | 0 |
| 1993 | 43 | 60 | 310 | 27 | 26 | 912 | 0 | 0 | 28 |
| 1994 | 58 | 63 | 329 | 3 | 9 | 93 | 21 | 31 | 538 |
| 1995 | 409 | 585 | 1987 | 82 | 62 | 483 | 0 | 0 | 455 |
| 1996 | 174 | 286 | 1268 | 2038 | 1646 | 5065 | 0 | 0 | 284 |
| 1997 | 701 | 713 | 2246 | 1230 | 875 | 3053 | 10 | 12 | 302 |
| 1998 | 771 | 1158 | 2359 | 3909 | 2531 | 7742 | 0 | 0 | 707 |
| 1999 | 903 | 1116 | 2200 | 1614 | 914 | 2861 | 2519 | 1347 | 4649 |
| 2000 | 978 | 1892 | 2975 | 1840 | 1405 | 3620 | 3099 | 1814 | 5573 |
| 2001 | 1619 | 1608 | 3444 | 1112 | 1112 | 2764 | 3384 | 2535 | 6707 |
| 2002 | 1249 | 1092 | 2541 | 1266 | 1318 | 3310 | 2982 | 1862 | 6056 |
| 2003 | 1443 | 1295 | 3039 | 1700 | 1539 | 3778 | 2363 | 1825 | 4507 |
| 2004 | 996 | 666 | 1772 | 287 | 265 | 625 | 8499 | 8205 | 17220 |
| 2005 | 792 | 1304 | 2214 | 459 | 332 | 885 | 2019 | 1154 | 3455 |
| 2006 | 602 | 428 | 1262 | 329 | 334 | 1045 | 1922 | 1972 | 4541 |
| 2007 | 3027 | 5683 | 9235 | 414 | 581 | 1248 | 2735 | 1961 | 5250 |
| 2008 | 2946 | 3300 | 7021 | 1336 | 1415 | 3423 | 2054 | 3022 | 5592 |
| 2009 | 1966 | 2867 | 5318 | 2729 | 2109 | 6963 | 739 | 2128 | 3554 |
| 2010 | 2094 | 3581 | 6063 | 2031 | 2248 | 6683 | 929 | 2029 | 3608 |
| 2011 | 2309 | 2278 | 4725 | 1707 | 2385 | 5538 | 1857 | 2955 | 5273 |
| 2012 | 3067 | 3753 | 7240 | 1311 | 1562 | 4625 | 2228 | 5080 | 8446 |
| 2013 | 2357 | 6299 | 9063 | 1256 | 1297 | 3510 | 1239 | 3505 | 6277 |

*Table 10. The number of halibut sampled by sex (Male, Female, Combined=male, female and unsexed) and year from at-sea observers and port sampling of otter trawl fishery.*

| Year | Observer | | | Port Sampling | |
|---|---|---|---|---|---|
| | Male | Female | Combined | Combined | Total |
| 1977 | 0 | 0 | 54 | 0 | 54 |
| 1978 | 0 | 0 | 0 | 0 | 0 |
| 1979 | 0 | 0 | 18 | 0 | 18 |
| 1980 | 0 | 0 | 16 | 0 | 16 |
| 1981 | 2 | 12 | 37 | 0 | 37 |
| 1982 | 0 | 0 | 24 | 0 | 24 |
| 1983 | 0 | 0 | 0 | 0 | 0 |
| 1984 | 255 | 39 | 294 | 0 | 294 |
| 1985 | 149 | 59 | 993 | 0 | 993 |
| 1986 | 0 | 2 | 87 | 0 | 87 |
| 1987 | 87 | 63 | 309 | 0 | 309 |
| 1988 | 137 | 98 | 407 | 0 | 407 |
| 1989 | 151 | 130 | 394 | 309 | 703 |
| 1990 | 207 | 517 | 1733 | 0 | 1733 |
| 1991 | 175 | 228 | 767 | 438 | 1205 |
| 1992 | 106 | 86 | 863 | 137 | 1000 |
| 1993 | 99 | 95 | 370 | 106 | 476 |
| 1994 | 51 | 56 | 157 | 55 | 212 |
| 1995 | 16 | 6 | 88 | 50 | 138 |
| 1996 | 2 | 9 | 65 | 0 | 65 |
| 1997 | 3 | 0 | 12 | 31 | 43 |
| 1998 | 3 | 0 | 30 | 33 | 63 |
| 1999 | 3 | 2 | 59 | 106 | 165 |
| 2000 | 8 | 6 | 267 | 12 | 279 |
| 2001 | 11 | 10 | 58 | 134 | 192 |
| 2002 | 6 | 17 | 44 | 68 | 112 |
| 2003 | 3 | 8 | 43 | 63 | 106 |
| 2004 | 54 | 92 | 1022 | 186 | 1208 |
| 2005 | 11 | 10 | 77 | 109 | 186 |
| 2006 | 12 | 6 | 47 | 23 | 70 |
| 2007 | 10 | 26 | 858 | 305 | 1163 |
| 2008 | 1 | 2 | 8 | 14 | 22 |
| 2009 | 1 | 4 | 24 | 66 | 90 |
| 2010 | 102 | 90 | 420 | 247 | 667 |
| 2011 | 2 | 3 | 291 | 520 | 811 |
| 2012 | 1 | 1 | 236 | 912 | 1148 |
| 2013 | 31 | 34 | 179 | 35 | 214 |

*Table 11. The number of observed sets that caught halibut by fishery by year. TRIP TYPE: 12-White Hake, 23-Redfish, 30-Halibut, 31-Turbot, 49-Flatfish, 211-Skate, 230-Porbeagle, 312 –Sculpin, 7001-Cod, Haddock, Pollock, 7057 – Halibut Survey, 7099 – other.*

| Year | Fishery | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 12 | 23 | 30 | 31 | 49 | 211 | 230 | 312 | 7001 | 7057 | 7099 |
| 1979 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 1980 | 0 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 1981 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 0 |
| 1982 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |
| 1984 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 4 | 0 | 0 |
| 1985 | 0 | 0 | 18 | 0 | 0 | 0 | 0 | 0 | 13 | 0 | 0 |
| 1986 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 0 |
| 1987 | 0 | 10 | 0 | 0 | 0 | 0 | 0 | 0 | 59 | 0 | 0 |
| 1988 | 0 | 7 | 0 | 0 | 0 | 0 | 0 | 0 | 117 | 0 | 13 |
| 1989 | 0 | 26 | 21 | 0 | 0 | 0 | 0 | 0 | 117 | 0 | 6 |
| 1990 | 34 | 49 | 0 | 0 | 22 | 0 | 0 | 0 | 266 | 0 | 31 |
| 1991 | 13 | 43 | 17 | 0 | 4 | 0 | 4 | 0 | 221 | 0 | 9 |
| 1992 | 37 | 29 | 19 | 0 | 8 | 0 | 0 | 0 | 364 | 0 | 10 |
| 1993 | 0 | 60 | 10 | 0 | 1 | 1 | 1 | 0 | 107 | 0 | 20 |
| 1994 | 46 | 49 | 7 | 0 | 2 | 0 | 0 | 0 | 29 | 0 | 12 |
| 1995 | 144 | 9 | 84 | 0 | 0 | 16 | 0 | 0 | 37 | 0 | 54 |
| 1996 | 127 | 1 | 260 | 0 | 3 | 4 | 0 | 0 | 43 | 0 | 12 |
| 1997 | 47 | 4 | 209 | 0 | 0 | 76 | 0 | 0 | 67 | 0 | 0 |
| 1998 | 44 | 6 | 192 | 14 | 0 | 0 | 0 | 0 | 9 | 569 | 0 |
| 1999 | 25 | 7 | 215 | 0 | 0 | 12 | 0 | 0 | 34 | 162 | 38 |
| 2000 | 0 | 6 | 330 | 0 | 0 | 0 | 0 | 0 | 113 | 228 | 0 |
| 2001 | 11 | 11 | 444 | 0 | 0 | 0 | 0 | 2 | 92 | 90 | 3 |
| 2002 | 0 | 24 | 311 | 0 | 0 | 0 | 0 | 0 | 26 | 160 | 1 |
| 2003 | 0 | 6 | 397 | 0 | 0 | 0 | 0 | 1 | 19 | 162 | 0 |
| 2004 | 0 | 23 | 74 | 0 | 5 | 0 | 0 | 0 | 97 | 142 | 0 |
| 2005 | 0 | 9 | 206 | 0 | 0 | 0 | 0 | 2 | 38 | 202 | 0 |
| 2006 | 0 | 0 | 119 | 0 | 0 | 10 | 0 | 1 | 37 | 127 | 0 |
| 2007 | 16 | 12 | 548 | 0 | 0 | 0 | 0 | 0 | 111 | 101 | 0 |
| 2008 | 10 | 0 | 491 | 0 | 0 | 0 | 0 | 0 | 57 | 343 | 0 |
| 2009 | 0 | 7 | 406 | 0 | 0 | 0 | 0 | 0 | 10 | 313 | 0 |
| 2010 | 0 | 9 | 393 | 0 | 3 | 0 | 0 | 0 | 105 | 341 | 0 |
| 2011 | 0 | 24 | 386 | 0 | 0 | 0 | 0 | 0 | 68 | 253 | 0 |
| 2012 | 0 | 3 | 399 | 0 | 3 | 0 | 0 | 0 | 84 | 202 | 0 |
| 2013 | 0 | 11 | 455 | 0 | 0 | 0 | 0 | 0 | 55 | 217 | 0 |

*Table 12. Number of fish sampled on the DFO summer RV survey in 4VWX from 1970-2013.*

| Year | Unknown | Male | Female | Not Recorded |
|---|---|---|---|---|
| 1970 | 4 | 9 | 11 | 0 |
| 1971 | 0 | 19 | 18 | 0 |
| 1972 | 0 | 9 | 16 | 0 |
| 1973 | 0 | 24 | 12 | 0 |
| 1974 | 0 | 15 | 31 | 0 |
| 1975 | 1 | 33 | 28 | 0 |
| 1976 | 0 | 39 | 30 | 0 |
| 1977 | 0 | 41 | 68 | 0 |
| 1978 | 0 | 29 | 27 | 0 |
| 1979 | 0 | 37 | 39 | 0 |
| 1980 | 0 | 35 | 33 | 0 |
| 1981 | 1 | 30 | 19 | 0 |
| 1982 | 0 | 27 | 18 | 0 |
| 1983 | 0 | 10 | 12 | 0 |
| 1984 | 0 | 19 | 14 | 0 |
| 1985 | 0 | 15 | 13 | 0 |
| 1986 | 1 | 21 | 20 | 0 |
| 1987 | 0 | 21 | 24 | 0 |
| 1988 | 0 | 39 | 17 | 0 |
| 1989 | 0 | 34 | 39 | 0 |
| 1990 | 0 | 36 | 43 | 0 |
| 1991 | 4 | 36 | 34 | 0 |
| 1992 | 0 | 34 | 26 | 0 |
| 1993 | 2 | 17 | 26 | 0 |
| 1994 | 3 | 20 | 23 | 0 |
| 1995 | 1 | 24 | 15 | 0 |
| 1996 | 2 | 25 | 23 | 0 |
| 1997 | 1 | 20 | 24 | 0 |
| 1998 | 0 | 35 | 19 | 0 |
| 1999 | 0 | 13 | 21 | 0 |
| 2000 | 32 | 1 | 0 | 2 |
| 2001 | 2 | 31 | 21 | 0 |
| 2002 | 0 | 21 | 24 | 0 |
| 2003 | 0 | 22 | 26 | 0 |
| 2004 | 0 | 33 | 26 | 0 |
| 2005 | 2 | 56 | 46 | 0 |
| 2006 | 4 | 34 | 30 | 1 |
| 2007 | 3 | 58 | 28 | 1 |
| 2008 | 0 | 50 | 45 | 0 |
| 2009 | 3 | 45 | 32 | 0 |
| 2010 | 1 | 105 | 79 | 0 |
| 2011 | 3 | 118 | 106 | 0 |
| 2012 | 4 | 59 | 68 | 3 |
| 2013 | 2 | 58 | 53 | 1 |

*Table 13. Number of male, female, unknown and total, halibut measured during the Spring RV survey in 3NOP. Note, length-frequency files missing 1971, 1992 and 1993; no halibut lengths for Spring 1972.*

| Year | Male | Female | Unknown | Total |
|---|---|---|---|---|
| 1973 | 8 | 3 | 0 | 11 |
| 1974 | 8 | 4 | 0 | 12 |
| 1975 | 2 | 7 | 0 | 9 |
| 1976 | 15 | 13 | 0 | 28 |
| 1977 | 19 | 18 | 0 | 37 |
| 1978 | 22 | 17 | 0 | 39 |
| 1979 | 19 | 19 | 0 | 38 |
| 1980 | 44 | 32 | 0 | 76 |
| 1981 | 9 | 9 | 0 | 18 |
| 1982 | 19 | 15 | 0 | 34 |
| 1983 | 9 | 11 | 0 | 20 |
| 1984 | 15 | 9 | 0 | 24 |
| 1985 | 20 | 19 | 0 | 39 |
| 1986 | 18 | 22 | 0 | 40 |
| 1987 | 16 | 13 | 0 | 29 |
| 1988 | 7 | 3 | 0 | 10 |
| 1989 | 9 | 7 | 0 | 16 |
| 1990 | 4 | 3 | 0 | 7 |
| 1991 | 9 | 10 | 0 | 19 |
| 1994 | 7 | 6 | 0 | 13 |
| 1995 | 11 | 11 | 0 | 22 |
| 1996 | 2 | 6 | 0 | 8 |
| 1997 | 15 | 10 | 0 | 25 |
| 1998 | 6 | 9 | 0 | 15 |
| 1999 | 6 | 4 | 0 | 10 |
| 2000 | 9 | 3 | 0 | 12 |
| 2001 | 3 | 8 | 1 | 12 |
| 2002 | 7 | 4 | 0 | 11 |
| 2003 | 7 | 6 | 0 | 13 |
| 2004 | 3 | 3 | 3 | 9 |
| 2005 | 1 | 3 | 0 | 4 |
| 2006 | 1 | 0 | 0 | 1 |
| 2007 | 8 | 7 | 0 | 15 |
| 2008 | 7 | 6 | 0 | 13 |
| 2009 | 11 | 6 | 0 | 17 |
| 2010 | 16 | 12 | 0 | 28 |
| 2011 | 17 | 14 | 1 | 32 |
| 2012 | 9 | 15 | 2 | 26 |
| 2013 | 20 | 13 | 0 | 33 |

*Table 14. Summary of the distribution of the length of halibut caught in 3NOP during the Spring RV survey for each trawl gear.*

| Gear | 1rst Quarter | Median | Mean | 3rd Quarter |
|---|---|---|---|---|
| Yankee | 68.0 | 80 | 81.9 | 89.0 |
| Engel | 71.0 | 89 | 90.5 | 106.2 |
| Campelen | 61.3 | 80 | 80.5 | 95. |

*Table 15. Total number of boats that participated in the Industry- DFO Halibut Survey and Commercial Index. The number of sets completed with on-board observers and shore sampling and the total catch of halibut in the Commercial Index.*

| | Industry-DFO Halibut Survey | | | Commercial Index | | | |
|---|---|---|---|---|---|---|---|
| Year | Number of Boats | Number of Stations | Halibut catch, mt | Number of shore sampled sets | Number of observed sets | Total number of sets | Halibut catch, mt |
| 1998 | 17 | 175 | 7 | 0 | 669 | 669 | 84 |
| 1999 | 13 | 167 | 8 | 388 | 180 | 568 | 75 |
| 2000 | 14 | 217 | 12 | 529 | 280 | 809 | 93 |
| 2001 | 11 | 190 | 9 | 488 | 95 | 583 | 83 |
| 2002 | 13 | 200 | 9 | 534 | 172 | 706 | 84 |
| 2003 | 12 | 189 | 8 | 503 | 193 | 696 | 83 |
| 2004 | 11 | 215 | 10 | 775 | 131 | 906 | 90 |
| 2005 | 11 | 164 | 9 | 344 | 204 | 548 | 59 |
| 2006 | 11 | 163 | 7 | 453 | 135 | 588 | 71 |
| 2007 | 16 | 241 | 13 | 538 | 109 | 647 | 87 |
| 2008 | 17 | 283 | 15 | 644 | 372 | 1016 | 133 |
| 2009 | 13 | 213 | 18 | 339 | 335 | 674 | 102 |
| 2010 | 14 | 215 | 18 | 395 | 312 | 707 | 100 |
| 2011 | 14 | 217 | 25 | 602 | 280 | 882 | 116 |
| 2012 | 14 | 217 | 22 | 549 | 179 | 728 | 128 |
| 2013 | 14 | 233 | 24 | 555 | 229 | 784 | 109 |

*Table 16. The number of stations fished by hook size 14, 15, or 16 by year in the halibut fixed-station survey. Note in the first 2 years of the survey (1998 and 1999) hook size was not recorded.*

| Year | Hook Size | | |
|---|---|---|---|
| | 14 | 15 | 16 |
| 2000 | 217 | 0 | 0 |
| 2001 | 174 | 16 | 0 |
| 2002 | 157 | 26 | 17 |
| 2003 | 138 | 51 | 0 |
| 2004 | 175 | 40 | 0 |
| 2005 | 61 | 94 | 0 |
| 2006 | 110 | 53 | 0 |
| 2007 | 174 | 47 | 0 |
| 2008 | 195 | 44 | 34 |
| 2009 | 77 | 136 | 0 |
| 2010 | 105 | 74 | 36 |
| 2011 | 100 | 34 | 83 |
| 2012 | 98 | 34 | 85 |
| 2013 | 89 | 76 | 68 |

*Table 17. The number of stations fished with hook size (14, 15 or 16) by NAFO Division in the halibut fixed-station survey.*

| NAFO Division | Hook Size | | |
|---|---|---|---|
| | 14 | 15 | 16 |
| 3N | 22 | 24 | 38 |
| 3O | 65 | 55 | 75 |
| 3P | 106 | 51 | 33 |
| 4V | 335 | 126 | 124 |
| 4W | 638 | 128 | 35 |
| 4X | 702 | 324 | 18 |
| 5Y | 1 | 7 | 0 |
| 5Z | 1 | 10 | 0 |

*Table 18. The number of stations fished by year and NAFO Division in the halibut fixed-station survey.*

| Year | 3N | 3O | 3Ps | 4V | 4W | 4X | 5Y | 5Z | Total |
|---|---|---|---|---|---|---|---|---|---|
| 1998 | 1 | 3 | 8 | 44 | 57 | 59 | 0 | 3 | 175 |
| 1999 | 5 | 20 | 14 | 27 | 54 | 47 | 0 | 0 | 167 |
| 2000 | 6 | 24 | 20 | 45 | 68 | 54 | 0 | 0 | 217 |
| 2001 | 6 | 10 | 23 | 32 | 67 | 52 | 0 | 0 | 190 |
| 2002 | 1 | 5 | 18 | 47 | 65 | 64 | 0 | 0 | 200 |
| 2003 | 0 | 3 | 19 | 47 | 57 | 63 | 0 | 0 | 189 |
| 2004 | 8 | 23 | 16 | 44 | 62 | 62 | 0 | 0 | 215 |
| 2005 | 7 | 13 | 0 | 33 | 44 | 67 | 0 | 0 | 164 |
| 2006 | 0 | 0 | 9 | 29 | 52 | 72 | 1 | 0 | 163 |
| 2007 | 8 | 15 | 13 | 33 | 56 | 115 | 1 | 0 | 241 |
| 2008 | 8 | 17 | 13 | 60 | 60 | 114 | 1 | 10 | 283 |
| 2009 | 8 | 17 | 13 | 48 | 56 | 70 | 1 | 0 | 213 |
| 2010 | 8 | 17 | 13 | 46 | 55 | 75 | 1 | 0 | 215 |
| 2011 | 8 | 17 | 9 | 47 | 53 | 82 | 1 | 0 | 217 |
| 2012 | 8 | 17 | 11 | 45 | 55 | 80 | 1 | 0 | 217 |
| 2013 | 8 | 17 | 13 | 45 | 61 | 87 | 1 | 1 | 233 |
| Total | 90 | 218 | 212 | 672 | 922 | 1163 | 8 | 14 | 3299 |

*Table 19. Count of the number of Industry-DFO Halibut Survey fixed-stations that were completed with the accepted protocol for between and 1 and 16 years, and the cumulative count of the number of stations completed between 1 and 15 years or more.*

| Num. of Years | Count of Stations | Cumulative count |
|---|---|---|
| 16 | 20 | 20 |
| 15 | 25 | 45 |
| 14 | 34 | 79 |
| 13 | 31 | 110 |
| 12 | 18 | 128 |
| 11 | 24 | 152 |
| 10 | 19 | 171 |
| 9 | 16 | 187 |
| 8 | 14 | 201 |
| 7 | 20 | 221 |
| 6 | 15 | 236 |
| 5 | 18 | 254 |
| 4 | 10 | 264 |
| 3 | 23 | 287 |
| 2 | 24 | 311 |
| 1 | 29 | 340 |

*Table 20. Generalized linear model summary table; year and station have significant effect on catch. Stations had to be covered in 4 or more years to be included in the analysis. The response variable, halibut catch (kg), was offset by the log number of hooks (1000s). A dash (-) indicates no value.*

| Parameter | DF | Deviance | Resid. Df | Resid. Dev. | P(>\|Chi\|) |
|---|---|---|---|---|---|
| NULL | - | - | 3088 | 5627.6 | - |
| Year | 15 | 150.63 | 3073 | 5476.9 | <0.001 |
| Station | 265 | 2084.83 | 2808 | 3392.1 | <0.001 |

*Table 21. The number of fish sampled in the fixed-station Industry-DFO Halibut Survey by sex.*

| Year | Sex | | |
|---|---|---|---|
| | Unknown | Male | Female |
| 1998 | 64 | 156 | 159 |
| 1999 | 92 | 212 | 220 |
| 2000 | 143 | 274 | 301 |
| 2001 | 180 | 251 | 268 |
| 2002 | 181 | 220 | 202 |
| 2003 | 84 | 175 | 213 |
| 2004 | 64 | 208 | 300 |
| 2005 | 117 | 214 | 261 |
| 2006 | 393 | 71 | 74 |
| 2007 | 516 | 141 | 184 |
| 2008 | 560 | 198 | 259 |
| 2009 | 332 | 458 | 522 |
| 2010 | 578 | 273 | 475 |
| 2011 | 215 | 624 | 703 |
| 2012 | 683 | 395 | 479 |
| 2013 | 611 | 531 | 704 |

*Table 22. Number of Commercial Index sets in each NAFO Division by year and data collection methodology.*

| Year | NAFO Division | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 3N | 3O | 3Ps | 4T | 4V | 4W | 4X | 5Z |
| Observed at-sea | | | | | | | | |
| 1998 | 0 | 20 | 0 | 0 | 257 | 272 | 120 | 0 |
| 1999 | 0 | 39 | 3 | 0 | 94 | 36 | 8 | 0 |
| 2000 | 0 | 95 | 0 | 0 | 155 | 14 | 16 | 0 |
| 2001 | 0 | 1 | 0 | 0 | 81 | 12 | 1 | 0 |
| 2002 | 0 | 0 | 1 | 0 | 137 | 29 | 5 | 0 |
| 2003 | 0 | 0 | 0 | 0 | 164 | 26 | 3 | 0 |
| 2004 | 21 | 40 | 0 | 0 | 44 | 25 | 1 | 0 |
| 2005 | 59 | 58 | 0 | 0 | 50 | 10 | 27 | 0 |
| 2006 | 21 | 8 | 7 | 0 | 75 | 15 | 9 | 0 |
| 2007 | 41 | 5 | 10 | 0 | 40 | 10 | 3 | 0 |
| 2008 | 52 | 22 | 0 | 0 | 127 | 93 | 13 | 65 |
| 2009 | 105 | 25 | 57 | 0 | 114 | 19 | 15 | 0 |
| 2010 | 75 | 2 | 37 | 1 | 139 | 14 | 44 | 0 |
| 2011 | 94 | 9 | 9 | 0 | 65 | 15 | 88 | 0 |
| 2012 | 84 | 14 | 6 | 1 | 62 | 1 | 11 | 0 |
| 2013 | 21 | 72 | 18 | 0 | 55 | 18 | 45 | 0 |
| Sum | 573 | 410 | 148 | 2 | 1659 | 609 | 409 | 65 |
| Shore sampled | | | | | | | | |
| 1998 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 1999 | 0 | 0 | 0 | 0 | 152 | 200 | 36 | 0 |
| 2000 | 0 | 0 | 0 | 0 | 148 | 343 | 38 | 0 |
| 2001 | 0 | 0 | 0 | 0 | 153 | 235 | 100 | 0 |
| 2002 | 0 | 0 | 1 | 0 | 229 | 198 | 106 | 0 |
| 2003 | 0 | 0 | 0 | 0 | 251 | 166 | 86 | 0 |
| 2004 | 0 | 0 | 0 | 0 | 302 | 240 | 233 | 0 |
| 2005 | 0 | 0 | 0 | 0 | 181 | 59 | 104 | 0 |
| 2006 | 0 | 0 | 0 | 0 | 134 | 62 | 257 | 0 |
| 2007 | 0 | 0 | 0 | 1 | 38 | 61 | 438 | 0 |
| 2008 | 0 | 0 | 0 | 0 | 151 | 44 | 449 | 0 |
| 2009 | 0 | 0 | 0 | 0 | 0 | 21 | 318 | 0 |
| 2010 | 0 | 0 | 0 | 0 | 0 | 10 | 385 | 0 |
| 2011 | 0 | 0 | 0 | 2 | 70 | 30 | 500 | 0 |
| 2012 | 0 | 0 | 0 | 2 | 21 | 50 | 476 | 0 |
| 2013 | 0 | 0 | 0 | 1 | 22 | 40 | 492 | 0 |
| Sum | 0 | 0 | 1 | 6 | 1852 | 1759 | 4018 | 0 |

*Table 23. The number of observed commercial sets fished with hook size 12, 14, 15 and 16 by year. Note in the first 2 years of the survey (1998 and 1999) hook size was not recorded.*

| Year | Hook Size | | | |
|---|---|---|---|---|
| | 12 | 14 | 15 | 16 |
| 2000 | 0 | 280 | 0 | 0 |
| 2001 | 0 | 88 | 7 | 0 |
| 2002 | 0 | 170 | 2 | 4 |
| 2003 | 0 | 63 | 130 | 0 |
| 2004 | 0 | 132 | 38 | 0 |
| 2005 | 0 | 23 | 175 | 0 |
| 2006 | 0 | 44 | 91 | 0 |
| 2007 | 0 | 24 | 59 | 0 |
| 2008 | 0 | 87 | 125 | 112 |
| 2009 | 0 | 41 | 294 | 0 |
| 2010 | 2 | 55 | 148 | 107 |
| 2011 | 0 | 315 | 162 | 216 |
| 2012 | 0 | 234 | 310 | 184 |
| 2013 | 0 | 155 | 437 | 144 |

*Table 24. The number of observed commercial sets fished with hook size 12, 14, 15 and 16 by NAFO Division.*

| NAFO Division | Hook size | | | |
|---|---|---|---|---|
| | 12 | 14 | 15 | 16 |
| 3N | 0 | 45 | 221 | 307 |
| 3O | 0 | 158 | 97 | 96 |
| 3P | 0 | 14 | 98 | 33 |
| 4T | 0 | 7 | 0 | 0 |
| 4V | 0 | 646 | 468 | 242 |
| 4W | 0 | 211 | 168 | 31 |
| 4X | 2 | 630 | 861 | 58 |
| 5Z | 0 | 0 | 65 | 0 |

*Table 25. The number of fish released between 2006 and 2012 and recovered between 2006 and August 8, 2014.*

| Year Released | Number Released | Number Recaptured by Year | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | |
| 2006 | 528 | 16 | 40 | 25 | 19 | 15 | 7 | 11 | 4 | 1 | 138 |
| 2007 | 679 | 0 | 12 | 98 | 42 | 25 | 10 | 13 | 10 | 3 | 213 |
| 2008 | 709 | 0 | 0 | 20 | 53 | 32 | 12 | 22 | 14 | 4 | 157 |
| 2010 | 633 | 0 | 0 | 0 | 0 | 17 | 34 | 42 | 18 | 7 | 118 |
| 2012 | 640 | 0 | 0 | 0 | 0 | 0 | 0 | 11 | 22 | 11 | 44 |
| Total | 3189 | 16 | 52 | 143 | 114 | 89 | 63 | 99 | 68 | 26 | 670 |

*Table 26. Model selection table reporting the number of parameters (npar), Akaike information criterion (AICc, QAICc, QAICv), the overdispersion parameter (chat), and log likelihood (logL) for the complete (M constant and F time variable) and incomplete mixing models (M constant and F and F* time variable) fit to the recapture of tagged Atlantic halibut). All models were fit with two parameters to describe tag loss. A range of initial tagging survivability (ITS) rates and tag reporting rates (RR) were used in the models.*

| Model | AICc | c-hat | QAICc | QAICv | logL | N par |
|---|---|---|---|---|---|---|
| Complete mixing | | | | | | |
| RR=0.5, ITS=0.9 | -2237.1 | 1.68 | -1324.5 | -1654.9 | 1130.805 | 12 |
| RR=0.5, ITS=1.0 | -2236.9 | 1.68 | -1321.1 | -1654.74 | 1130.695 | 12 |
| RR=0.6, ITS=0.9 | -2236.8 | 1.68 | -1318.7 | -1654.63 | 1130.619 | 12 |
| RR=0.6, ITS=1.0 | -2236.6 | 1.69 | -1315.6 | -1654.49 | 1130.523 | 12 |
| RR=0.7, ITS=0.9 | -2236.5 | 1.69 | -1314.3 | -1654.42 | 1130.481 | 12 |
| RR=0.7, ITS=1.0 | -2236.3 | 1.69 | -1311.6 | -1654.3 | 1130.397 | 12 |
| RR=0.8, ITS=0.9 | -2236.3 | 1.69 | -1310.9 | -1648.53 | 1130.375 | 12 |
| RR=0.8, ITS=1.0 | -2236.1 | 1.7 | -1308.4 | -1648.42 | 1130.3 | 12 |
| RR=0.9, ITS=0.9 | -2236.1 | 1.7 | -1308.2 | -1648.41 | 1130.292 | 12 |
| RR=0.9, ITS=1.0 | -2236 | 1.7 | -1306 | -1648.31 | 1130.224 | 12 |
| Incomplete mixing | | | | | | |
| RR=0.5, ITS=0.9 | -2266.8 | 0.99 | -2296.5 | -1674.78 | 1149.813 | 16 |
| RR=0.5, ITS=1.0 | -2266.6 | 0.99 | -2286.1 | -1674.6 | 1149.693 | 16 |
| RR=0.6, ITS=0.9 | -2266.4 | 0.99 | -2278.9 | -1674.48 | 1149.613 | 16 |
| RR=0.6, ITS=1.0 | -2266.2 | 1 | -2269.9 | -1674.33 | 1149.513 | 16 |
| RR=0.7, ITS=0.9 | -2266.1 | 1 | -2266 | -1674.27 | 1149.471 | 16 |
| RR=0.7, ITS=1.0 | -2265.9 | 1 | -2258.2 | -1674.14 | 1149.386 | 16 |
| RR=0.8, ITS=0.9 | -2265.9 | 1 | -2256.2 | -1668.28 | 1149.366 | 16 |
| RR=0.8, ITS=1.0 | -2265.8 | 1.01 | -2249.3 | -1668.17 | 1149.293 | 16 |
| RR=0.9, ITS=0.9 | -2265.7 | 1.01 | -2248.6 | -1668.16 | 1149.285 | 16 |
| RR=0.9, ITS=1.0 | -2265.6 | 1.01 | -2242.5 | -1668.07 | 1149.222 | 16 |

*Table 27. Parameter estimates for the complete and incomplete mixing models fit to the recapture of tagged Atlantic halibut. A range of initial tagging survivability (ITS) rates and tag reporting rates (RR) were used in the models. All models were fit with two parameters to describe tag loss: for complete mixing model, $R_1$ is estimated to be 0.8 and R2, the subsequent annual tag retention rate, is 0.94. For the incomplete mixing model R1 is 0.79 and R2 is 0.94. M= natural mortality; F = fishing mortality. The F* or fishing mortality in the year post release is not reported. The preferred model is highlighted in bold font.*

| Model | M | $F_{2006}$ | $F_{2007}$ | $F_{2008}$ | $F_{2009}$ | $F_{2010}$ | $F_{2011}$ | $F_{2012}$ | $F_{2013}$ | $F_{2014}$ [1] |
|---|---|---|---|---|---|---|---|---|---|---|
| Complete mixing | | | | | | | | | | |
| RR=0.5, ITS=0.9 | 0.01 | 0.152 | 0.154 | 0.264 | 0.211 | 0.154 | 0.1 | 0.149 | 0.098 | 0.046 |
| RR=0.5, ITS=1.0 | 0.029 | 0.136 | 0.139 | 0.238 | 0.189 | 0.138 | 0.091 | 0.135 | 0.09 | 0.042 |
| RR=0.6, ITS=0.9 | 0.042 | 0.125 | 0.128 | 0.22 | 0.174 | 0.128 | 0.084 | 0.126 | 0.084 | 0.04 |
| RR=0.6, ITS=1.0 | 0.057 | 0.112 | 0.116 | 0.198 | 0.156 | 0.114 | 0.076 | 0.114 | 0.076 | 0.037 |
| RR=0.7, ITS=0.9 | 0.064 | 0.106 | 0.11 | 0.188 | 0.148 | 0.109 | 0.073 | 0.109 | 0.073 | 0.035 |
| RR=0.7, ITS=1.0 | 0.077 | 0.095 | 0.099 | 0.169 | 0.132 | 0.098 | 0.065 | 0.098 | 0.066 | 0.032 |
| RR=0.8, ITS=0.9 | 0.08 | 0.092 | 0.096 | 0.164 | 0.129 | 0.095 | 0.064 | 0.096 | 0.064 | 0.031 |
| RR=0.8, ITS=1.0 | 0.092 | 0.083 | 0.087 | 0.148 | 0.115 | 0.085 | 0.057 | 0.087 | 0.058 | 0.029 |
| RR=0.9, ITS=0.9 | 0.093 | 0.082 | 0.086 | 0.146 | 0.114 | 0.084 | 0.057 | 0.086 | 0.058 | 0.028 |
| RR=0.9, ITS=1.0 | 0.104 | 0.073 | 0.077 | 0.131 | 0.102 | 0.076 | 0.051 | 0.077 | 0.052 | 0.026 |
| Incomplete mixing | | | | | | | | | | |
| RR=0.5, ITS=0.9 | 0.042 | 0 | 0.241 | 0.33 | 0.227 | 0.188 | 0.113 | 0.197 | 0.114 | 0.055 |
| RR=0.5, ITS=1.0 | 0.065 | 0 | 0.216 | 0.298 | 0.204 | 0.169 | 0.103 | 0.181 | 0.105 | 0.051 |
| RR=0.6, ITS=0.9 | 0.08 | 0 | 0.199 | 0.277 | 0.189 | 0.157 | 0.096 | 0.17 | 0.099 | 0.049 |
| RR=0.6, ITS=1.0 | 0.099 | 0 | 0.179 | 0.251 | 0.17 | 0.141 | 0.088 | 0.156 | 0.091 | 0.045 |
| RR=0.7, ITS=0.9 | 0.108 | 0 | 0.17 | 0.239 | 0.162 | 0.135 | 0.084 | 0.15 | 0.087 | 0.044 |
| RR=0.7, ITS=1.0 | 0.124 | 0 | 0.152 | 0.216 | 0.145 | 0.122 | 0.076 | 0.137 | 0.08 | 0.04 |
| RR=0.8, ITS=0.9 | 0.129 | 0 | 0.148 | 0.21 | 0.141 | 0.118 | 0.074 | 0.134 | 0.078 | 0.04 |
| **RR=0.8, ITS=1.0** | **0.143** | **0** | **0.133** | **0.19** | **0.127** | **0.107** | **0.067** | **0.122** | **0.071** | **0.036** |
| RR=0.9, ITS=0.9 | 0.145 | 0 | 0.131 | 0.187 | 0.126 | 0.105 | 0.067 | 0.121 | 0.071 | 0.036 |
| RR=0.9, ITS=1.0 | 0.158 | 0 | 0.117 | 0.169 | 0.113 | 0.095 | 0.06 | 0.11 | 0.064 | 0.033 |

[1] $F_{2014}$ is based on tags recovered up to 8 August 2014 and so is incomplete.

*Table 28. Parameter estimates using maximum likelihood (MLE) and the asymptotic normal standard error (SE). Parameters without an SE indicates that it was fixed and not estimated. A dash (-) indicates no value.*

| Variable | Symbol | Period | MLE | SE |
|---|---|---|---|---|
| SELECTIVITY PARAMETERS: | | | | |
| Shape parameter | | | | |
| Otter trawl fishery | $v^j_L$ | 1977-2013 | 1.2 | - |
| Otter trawl fishery | $v^j_R$ | 1977-2013 | 20 | - |
| NS RV summer survey | $v^j_L$ | 1970-2013 | 0.1 | - |
| NS RV summer survey | $v^j_R$ | 1970-2013 | 7.44 | $3.1 \times 10^{-1}$ |
| Longline fishery | $\gamma_{male}$ | 1998-2013 | 7.0 | - |
| Longline fishery | $\gamma_{female}$ | 1998-2013 | 7.0 | - |
| Halibut Survey | $\gamma_{male}$ | 1998-2013 | 7.0 | - |
| Halibut Survey | $\gamma_{female}$ | 1998-2013 | 7.0 | - |
| 50% retention: | | | | |
| Otter trawl fishery | $S^i_{full}$ | 1977-2013 | 5.00 | - |
| NS RV summer survey | $S^i_{full}$ | 1977-2013 | 3.22 | $2.1 \times 10^{-2}$ |
| Longline fishery | $\delta_{male}$ | 1998-2013 | 5.50 | $2.8 \times 10^{-2}$ |
| Longline fishery | $\delta_{female}$ | 1998-2013 | 5.70 | $4.9 \times 10^{-2}$ |
| Halibut Survey | $\delta_{male}$ | 1998-2013 | 5.54 | $3.2 \times 10^{-2}$ |
| Halibut Survey | $\delta_{female}$ | 1998-2013 | 5.48 | $4.2 \times 10^{-2}$ |
| CATCHABILITY COEFFICIENTS: | | | | |
| NS RV summer survey | $q^i$ | 1970-2013 | $5.41 \times 10^{-1}$ | $4.3 \times 10^{-2}$ |
| Halibut Survey | | 1998-2013 | -1.74 | $4.4 \times 10^{-2}$ |
| INITIALIZATION PARAMETERS: | | | | |
| Starting recruitment (age-1) | $N_1$ | 1970 | $2.26 \times 10^5$ | $1.1 \times 10^4$ |
| Total mortality in first year used to estimate ages 2 to 20 | $Z_{1970}$ | 1970 | 0.2 | - |
| MORTALITY PARAMETERS: | | | | |
| Fishing mortality (males) | F | 2013 | 0.06 | $2.4 \times 10^{-3}$ |
| Fishing mortality (females) | F | 2013 | 0.11 | $5.4 \times 10^{-3}$ |
| Natural mortality | M | 1970-2013 | 0.15 | - |
| SPAWNING STOCK BIOMASS: | | | | |
| Spawning stock biomass | SSB | 2013 | 15297 | 679 |

## FIGURES

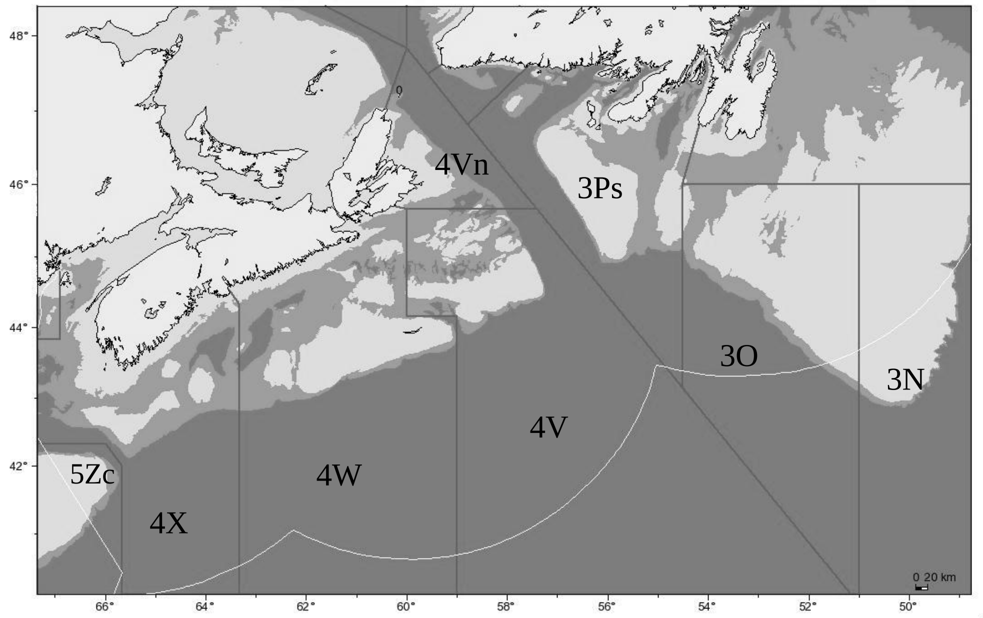


*Figure 1. Northwest Atlantic Fisheries Organization (NAFO) Divisions 3NOPs4VWX5Zc.*

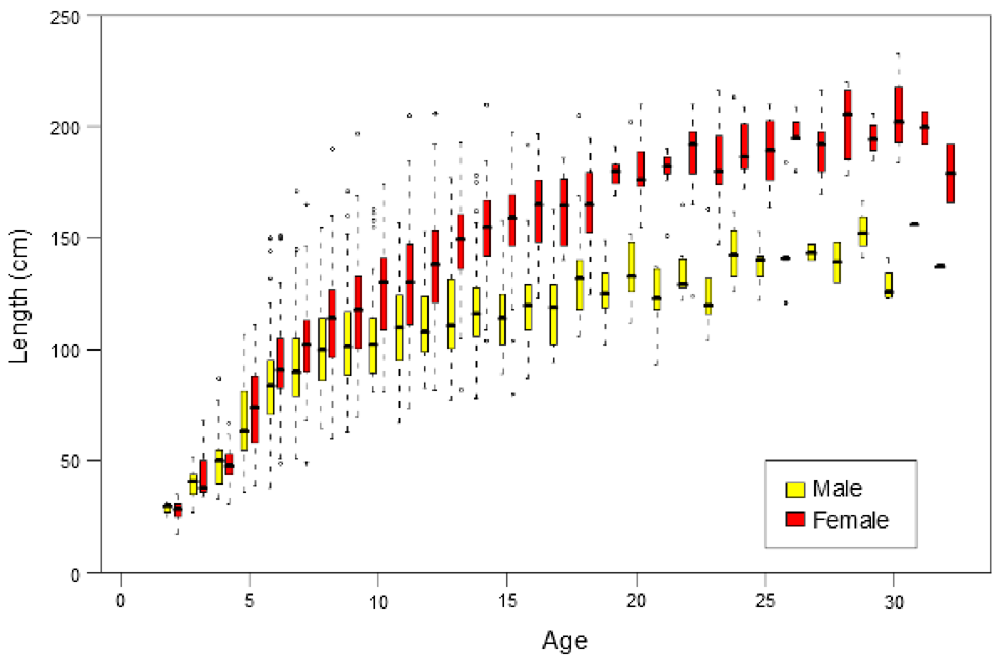


*Figure 2. Length-at-age for male and female Atlantic halibut (from Trzcinski et al 2011a).*

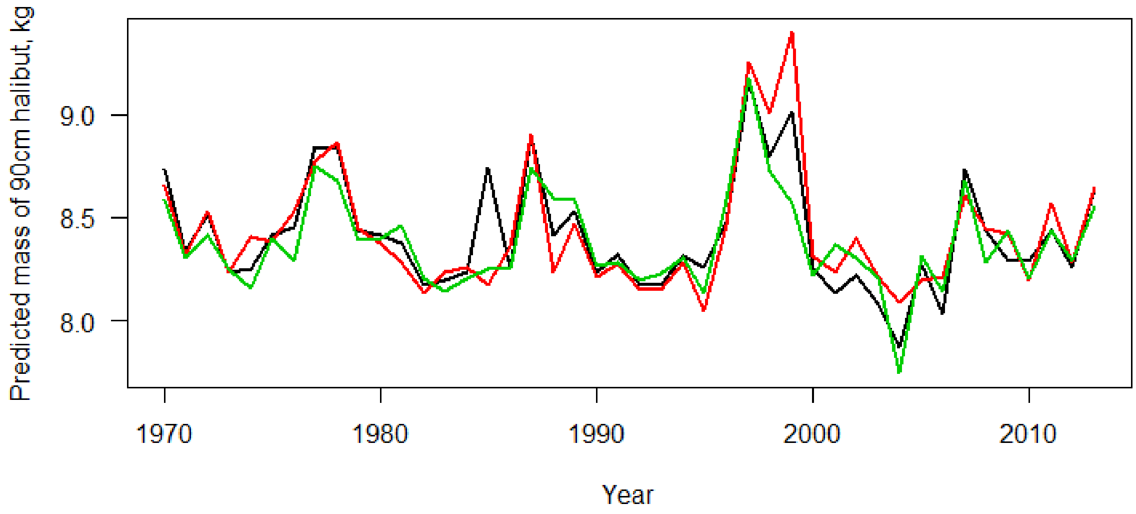


*Figure 3. Plot of a predicted weight for 90 cm fish from the length-weight models by year and sex (males red line, females green line and combined black line)*.

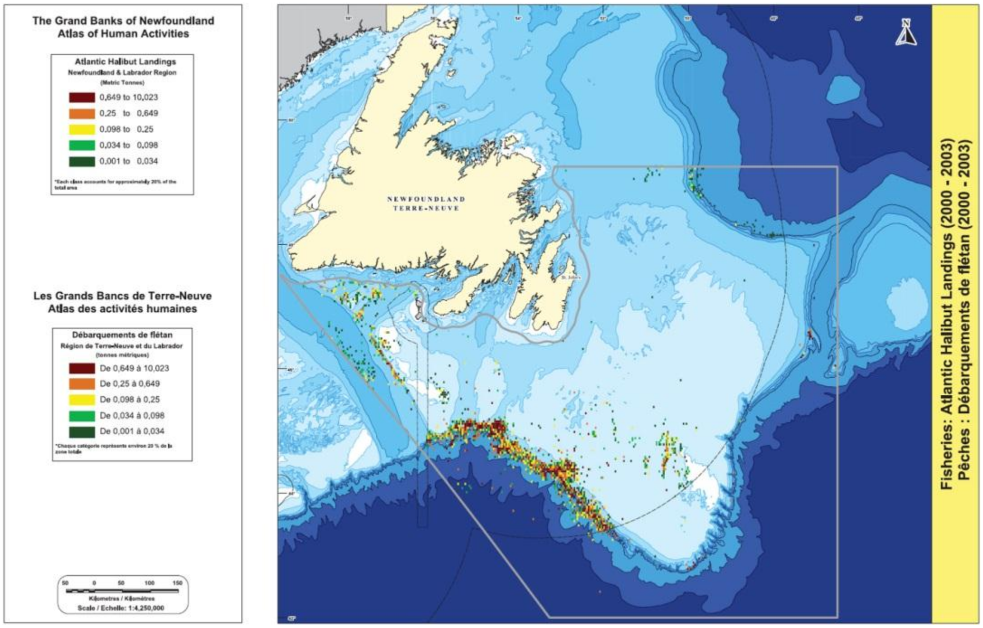


*Figure 4a. Commercial Atlantic halibut landings in 3KLNOP for the period 2000-2003 (source: DFO 2007).*

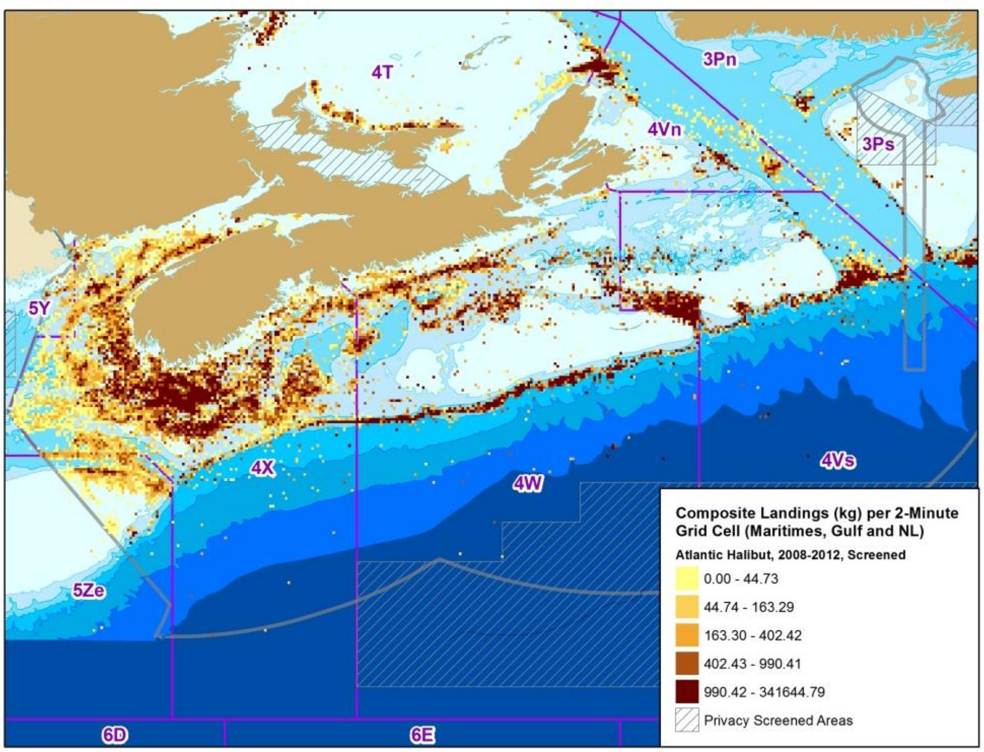


*Figure 4b. Commercial Atlantic halibut landings in 4VWX5Z for the period 2008-2012 (courtesy: DFO Oceans and Coastal Management Division, Maritimes Region).*

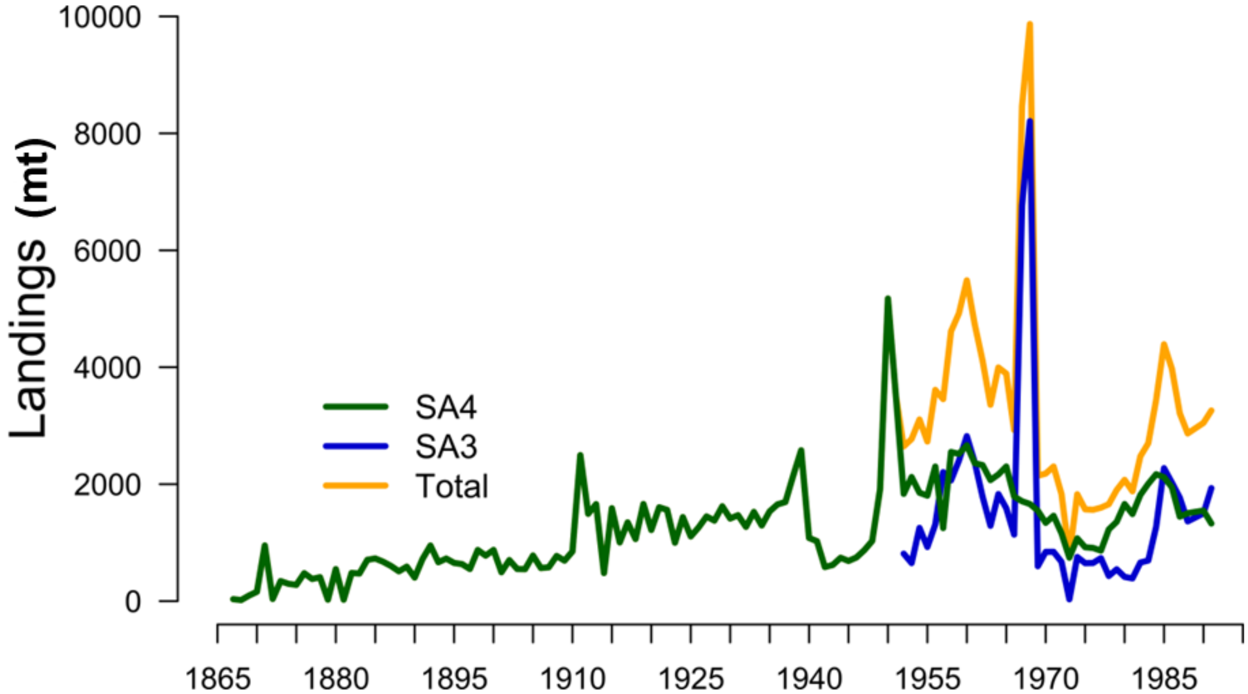


*Figure 5a. Atlantic halibut landings in Nova Scotia, New Brunswick, Prince Edward Island, and Quebec (SA4) and Newfoundland (SA3). The spike seen in the mid-1960s is believed to be due to the inclusion of Greenland halibut landings data.*

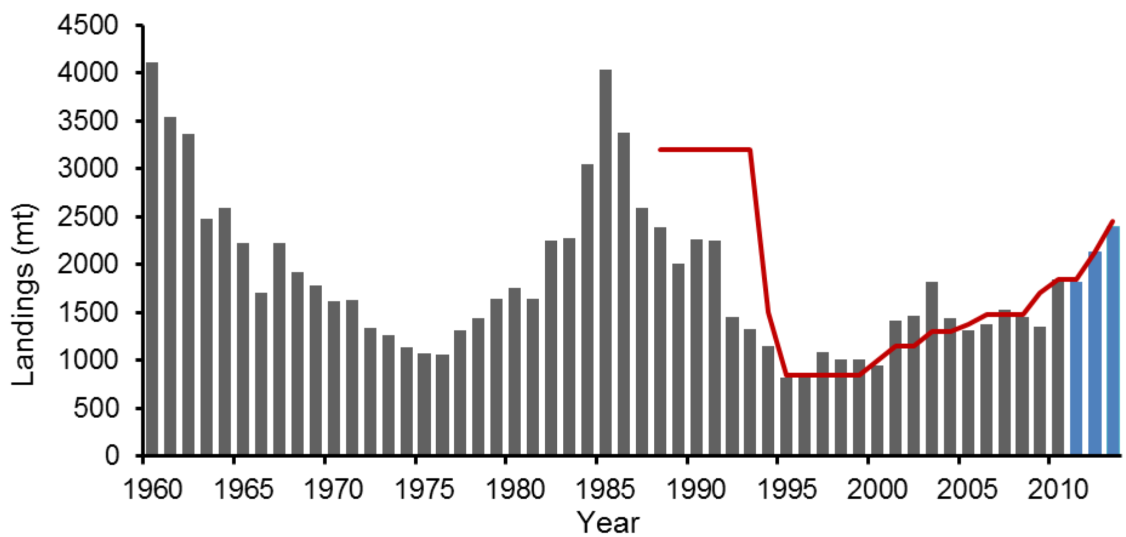


*Figure 5b. Atlantic halibut landings in 3NOPs4VWX5Zc and 3NOPs4VWX5Zc and Total Allowable Catch (TAC) in red. The 2011-2013 landings are depicted in blue as foreign landings are not included. A correction was applied to account for the inclusion of Greenland halibut landings data in the mid-1960s. See notes from Table 5.*

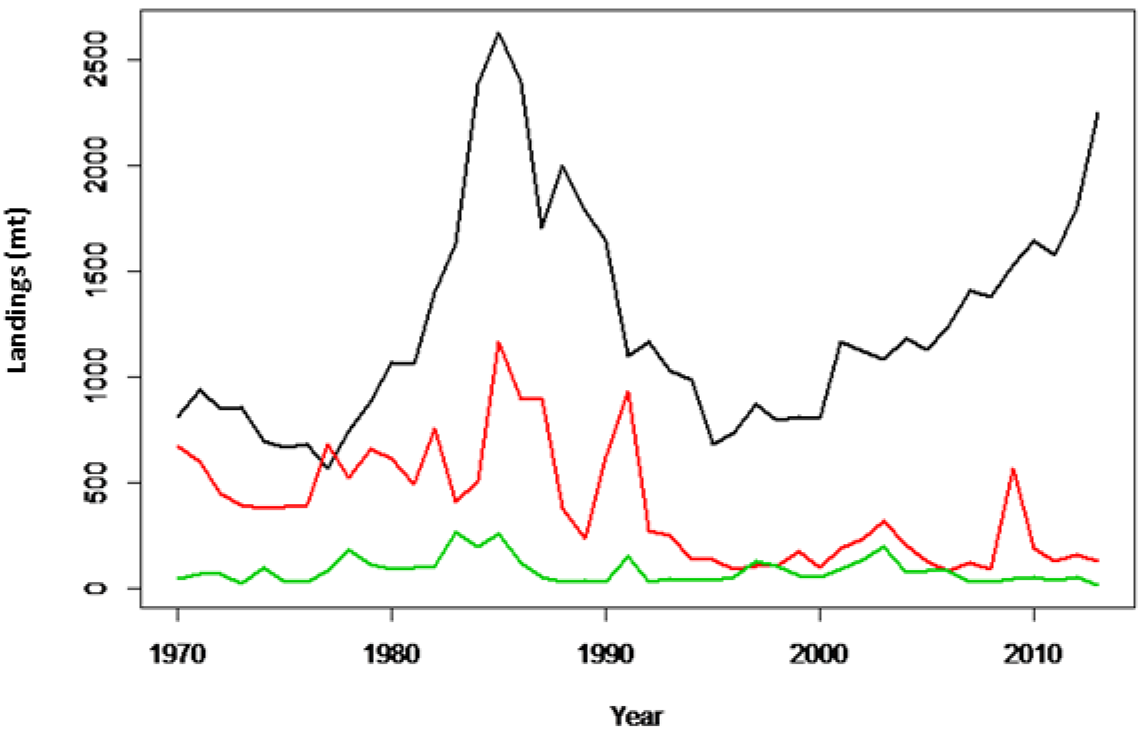


*Figure 6. Plot of Atlantic halibut landings in metric tonnes between 1970 and 2013 by longline (black), otter trawl (red), and all other gear (green).*

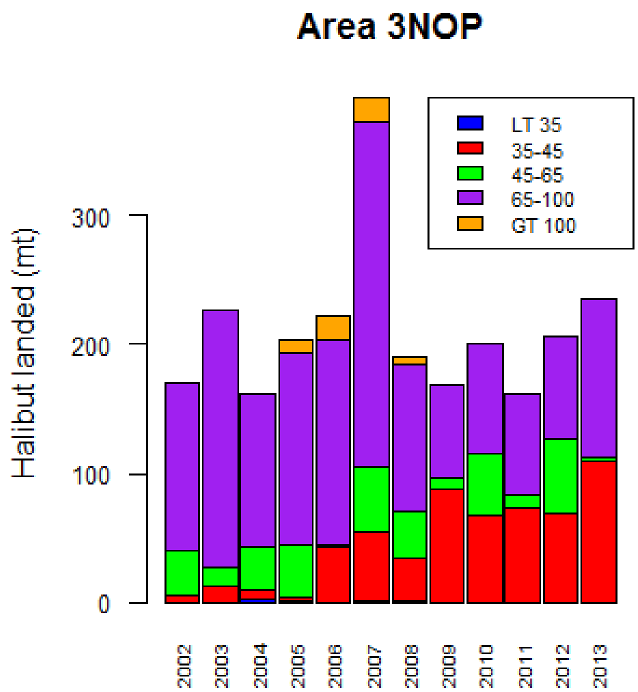


*Figure 7a. Total halibut landings (mt) from longline gear by vessel length (ft) in 3NOPs from 2002-2013.Legend shows vessel length classes (LT – less than; GT – greater than).*

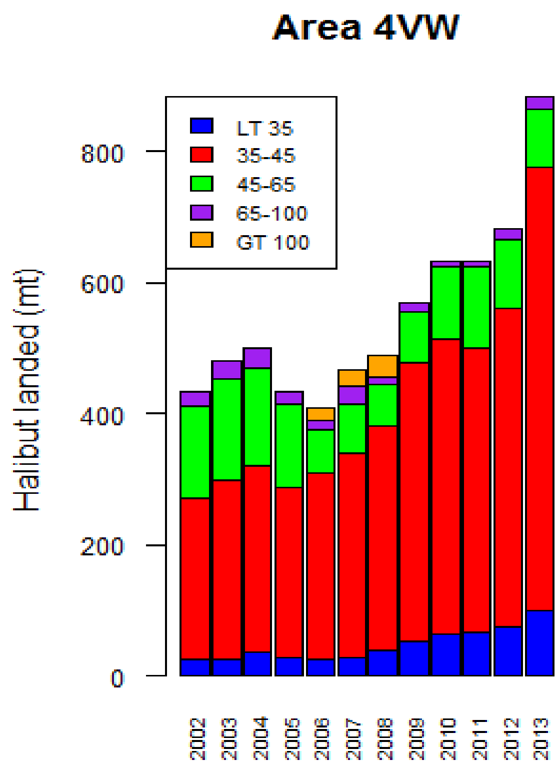


*Figure 7b. Total halibut landings (mt) from longline gear by vessel length (ft) in 4VW from 2002-2013. Legend shows vessel length classes (LT – less than; GT – greater than).*

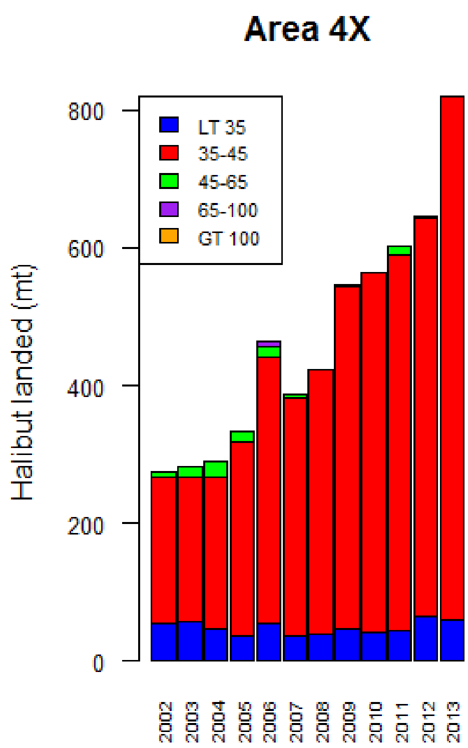


*Figure 7c. Total halibut landings (mt) from longline gear by vessel length (feet) in 4X from 2002-2013. Legend shows vessel length classes (LT – less than; GT – greater than).*

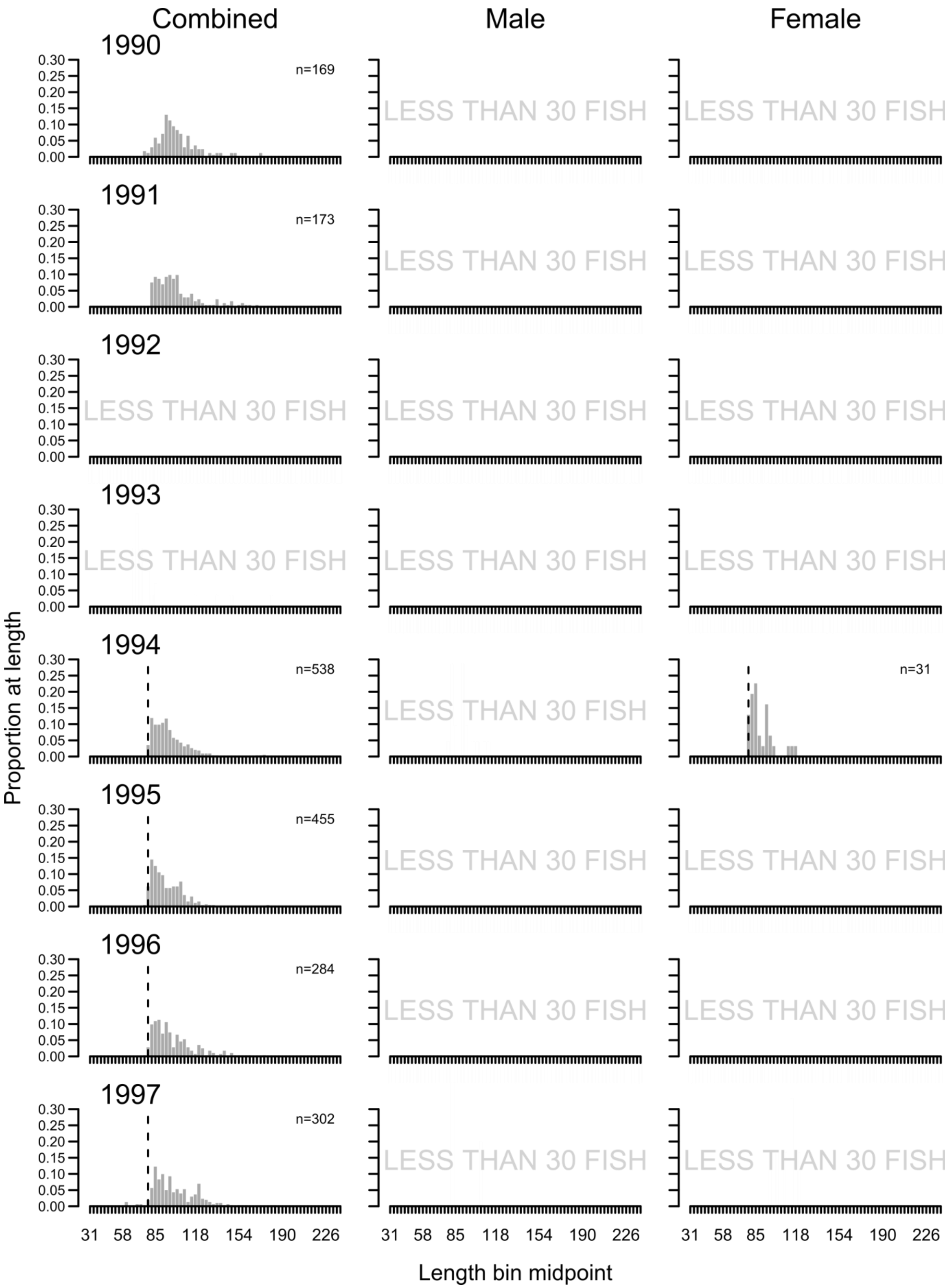


*Figure 8a. Proportion at length of port sampled longline landings in Nova Scotia (4VWX) for male, female and combined (male, female, and unsexed) 1990-1997.*

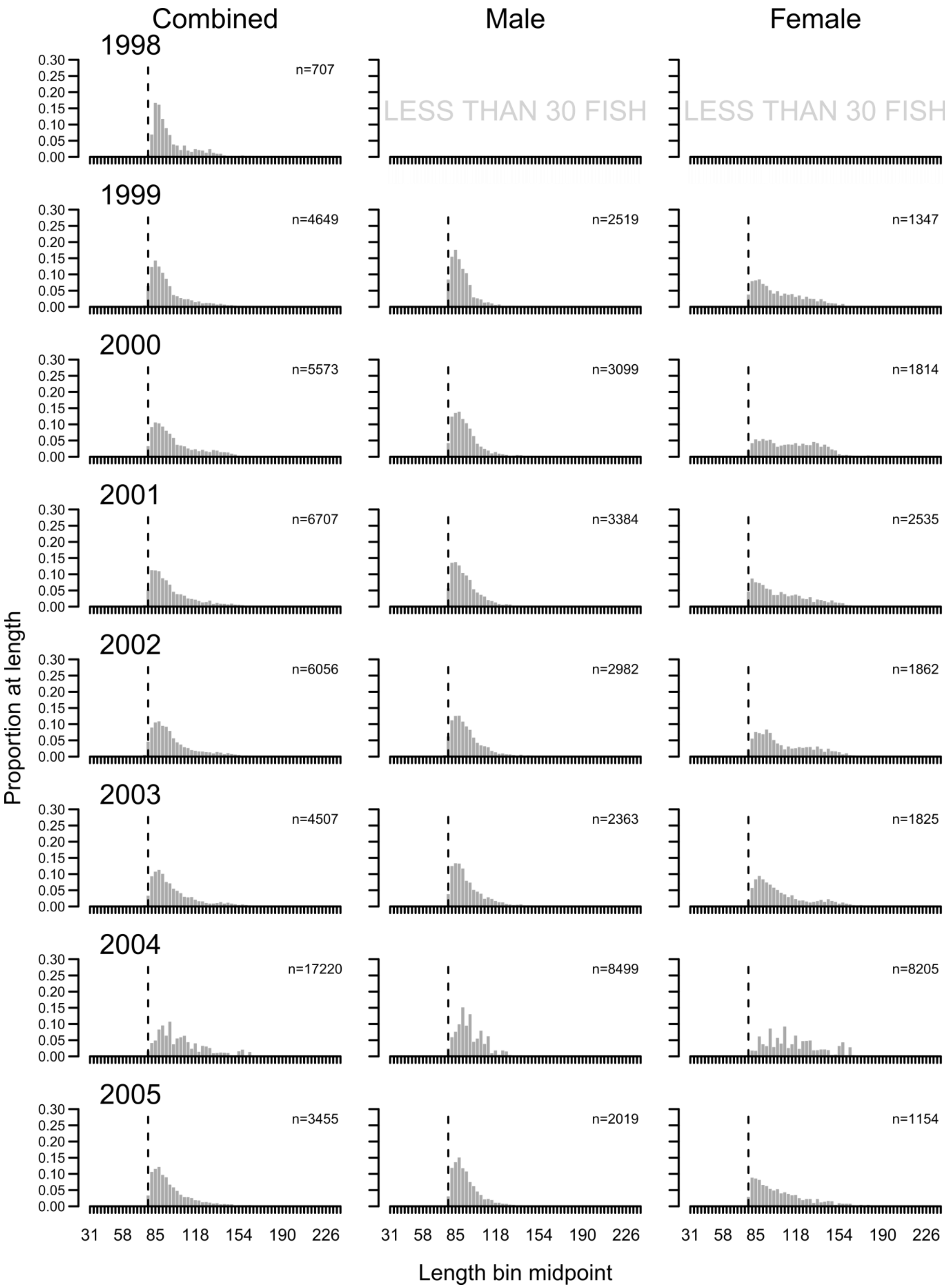


*Figure 8b. Proportion at length of port sampled longline landings in Nova Scotia (4VWX) for male, female and combined (male, female, and unsexed) 1997-2005.*

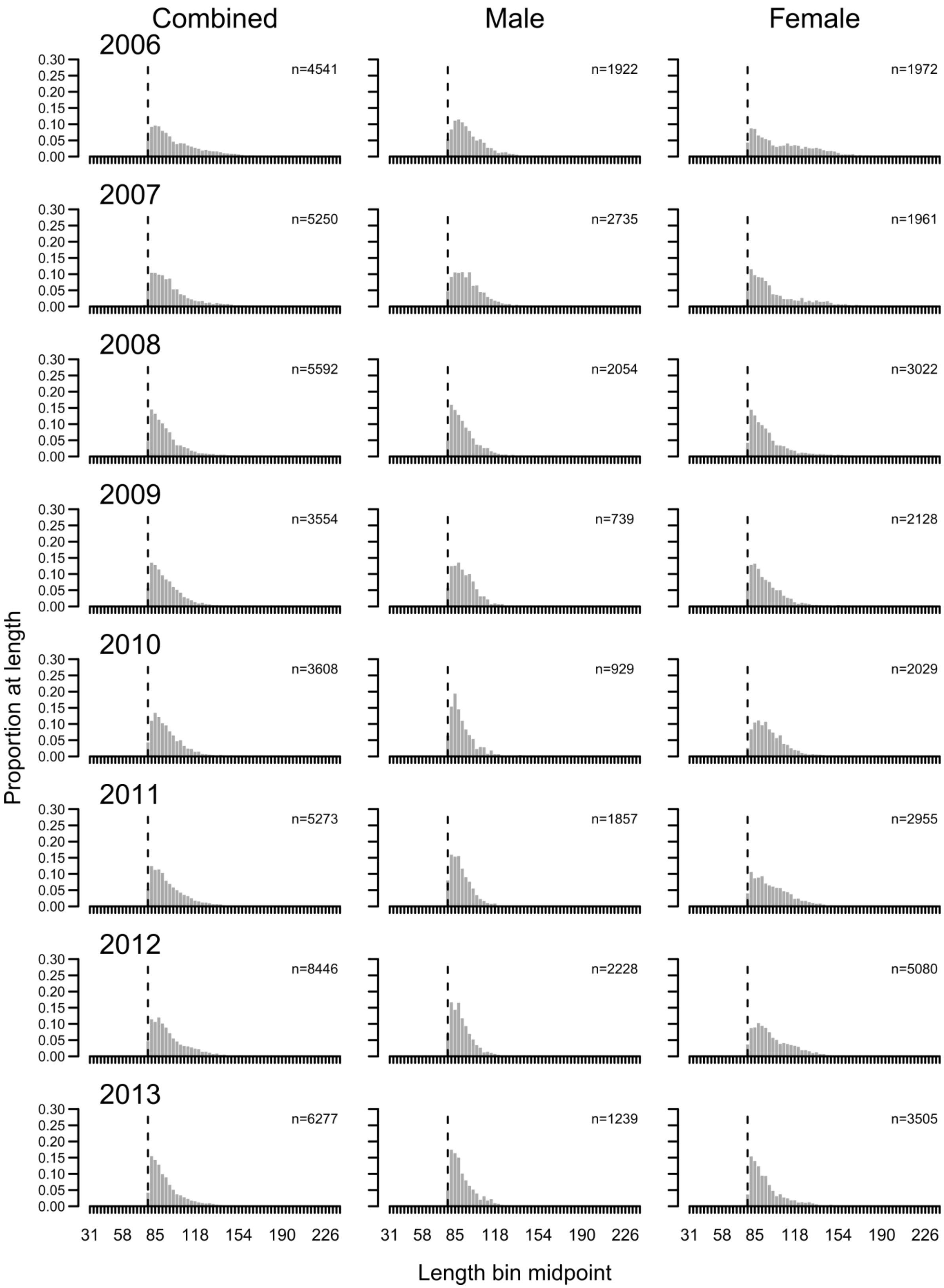


*Figure 8c. Proportion at length of port sampled longline landings in Nova Scotia (4VWX) for male, female and combined (male, female, and unsexed) 1997-2005.*

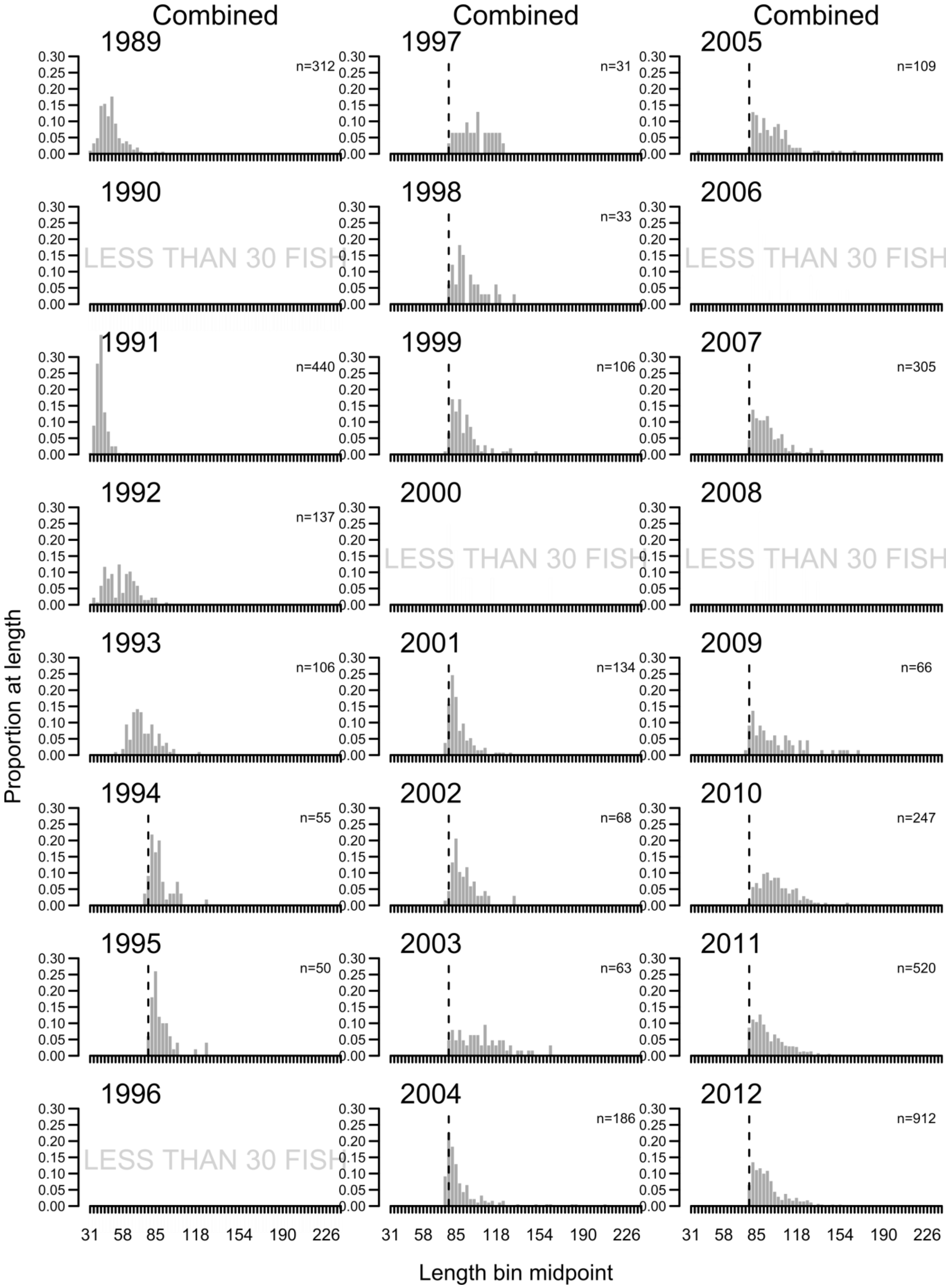


*Figure 8d. Proportion at length of port sampled otter trawl landings in Nova Scotia (4VWX) for unsexed halibut.*

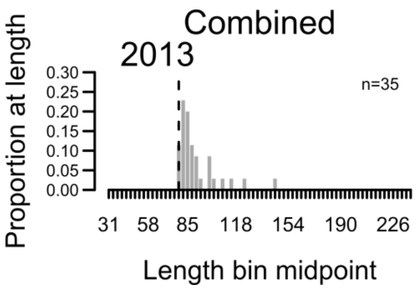


*Figure 8e. Proportion at length of port sampled otter trawl landings in Nova Scotia (4VWX) for unsexed fish 2013.*

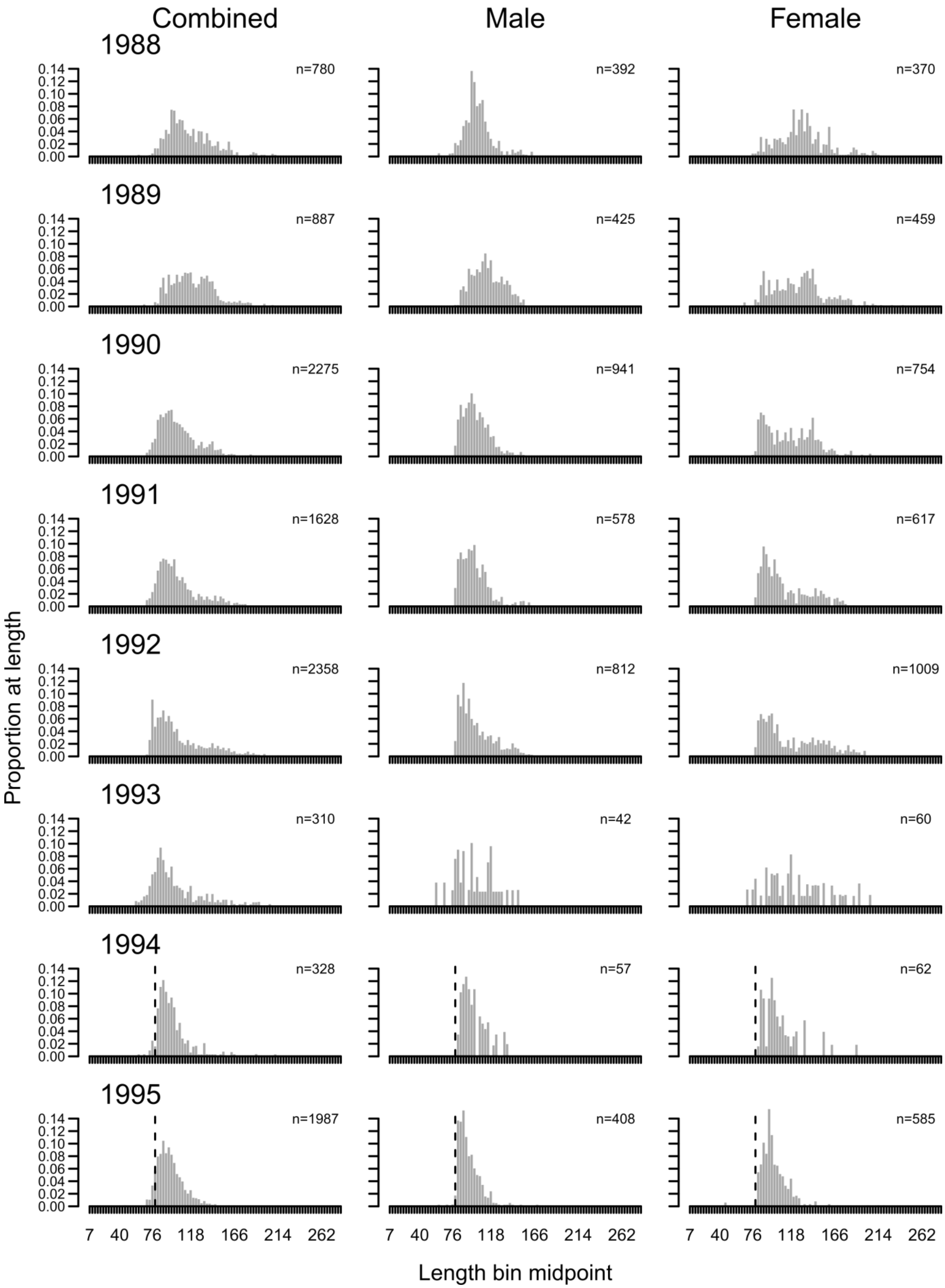


*Figure 9a. Proportion at length of observed longline sets for male, female and combined (male, female, and unsexed) in 3NOPs for 1988-1995.*

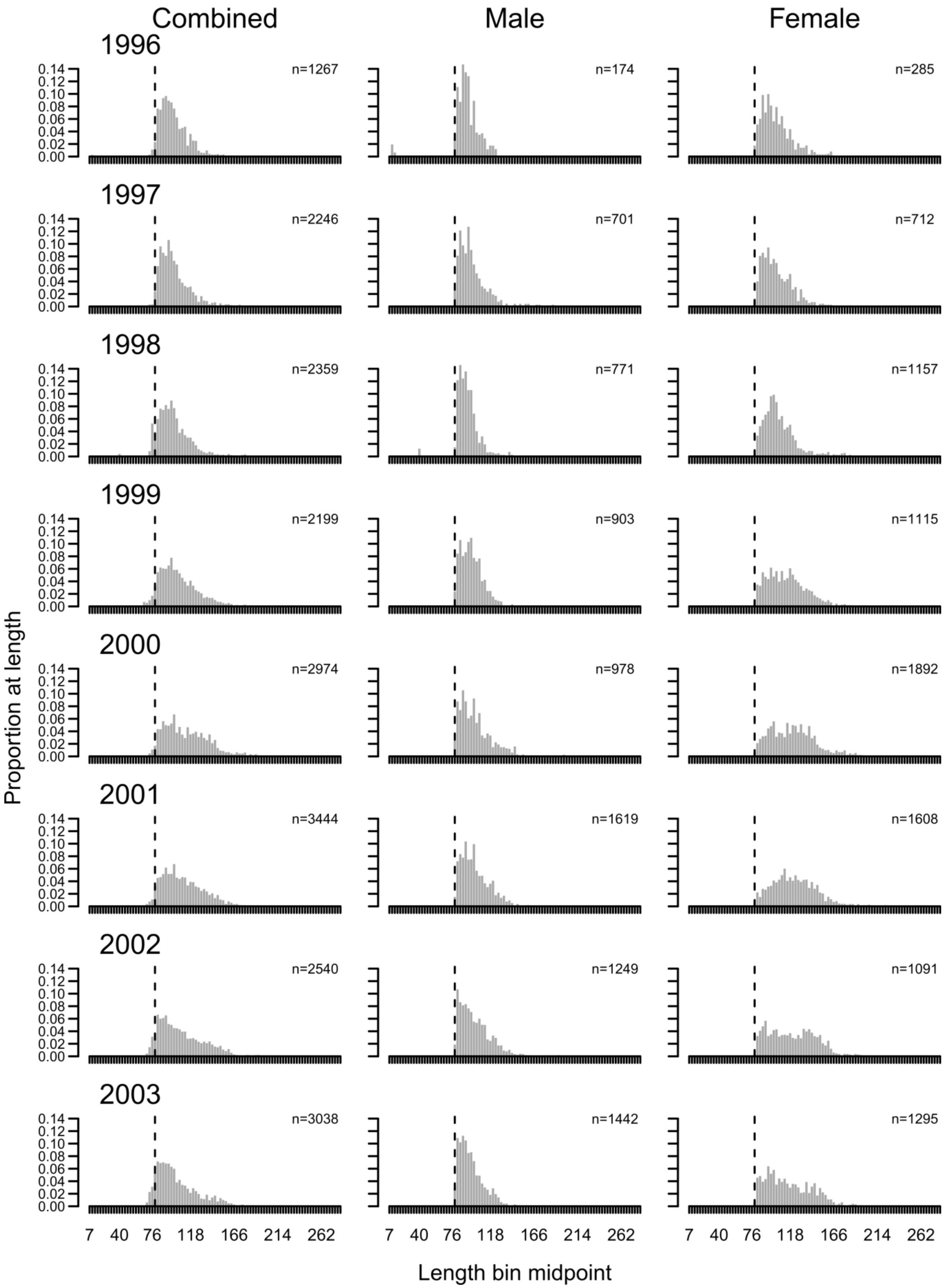


*Figure 9b. Proportion at length of observed longline sets for male, female and combined (male, female, and unsexed) in 3NOPs for 1996-2003.*

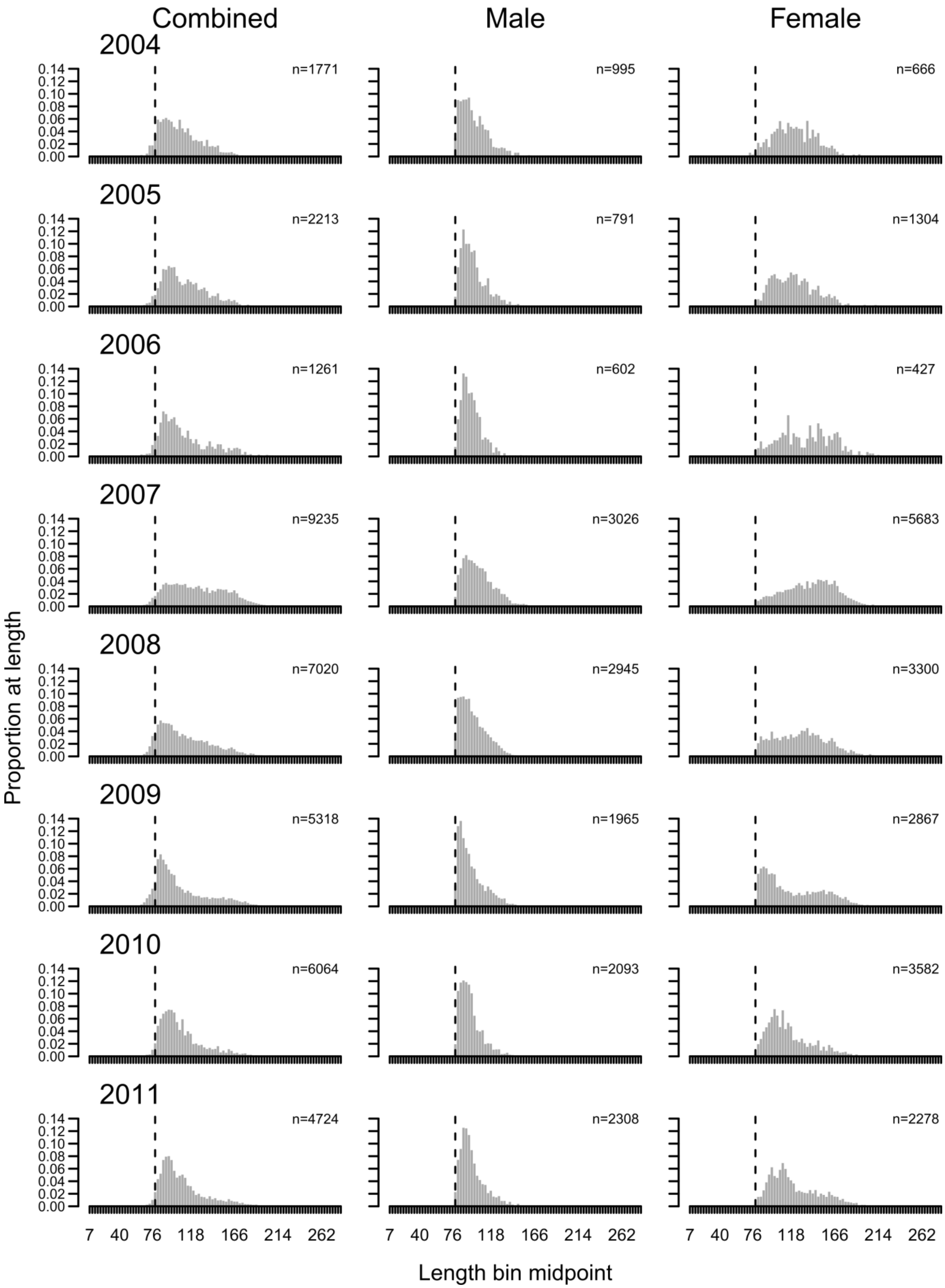


*Figure 9c. Proportion at length of observed longline sets for male, female and combined (male, female, and unsexed) in 3NOPs for 2004-2011.*

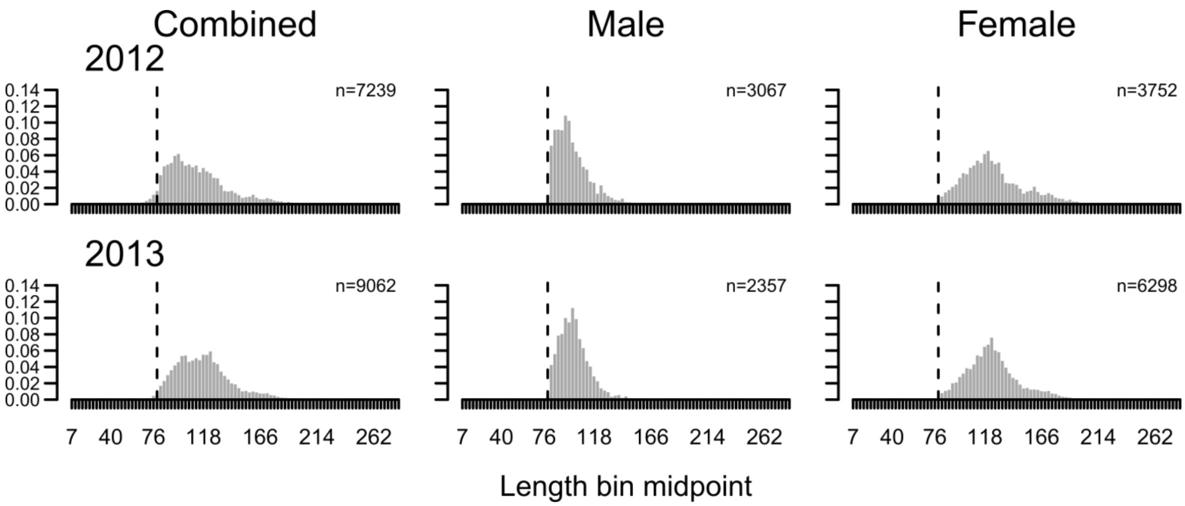


*Figure 9d. Proportion at length of observed longline sets for male, female and combined (male, female, and unsexed) in 3NOPs for 2012-2013.*

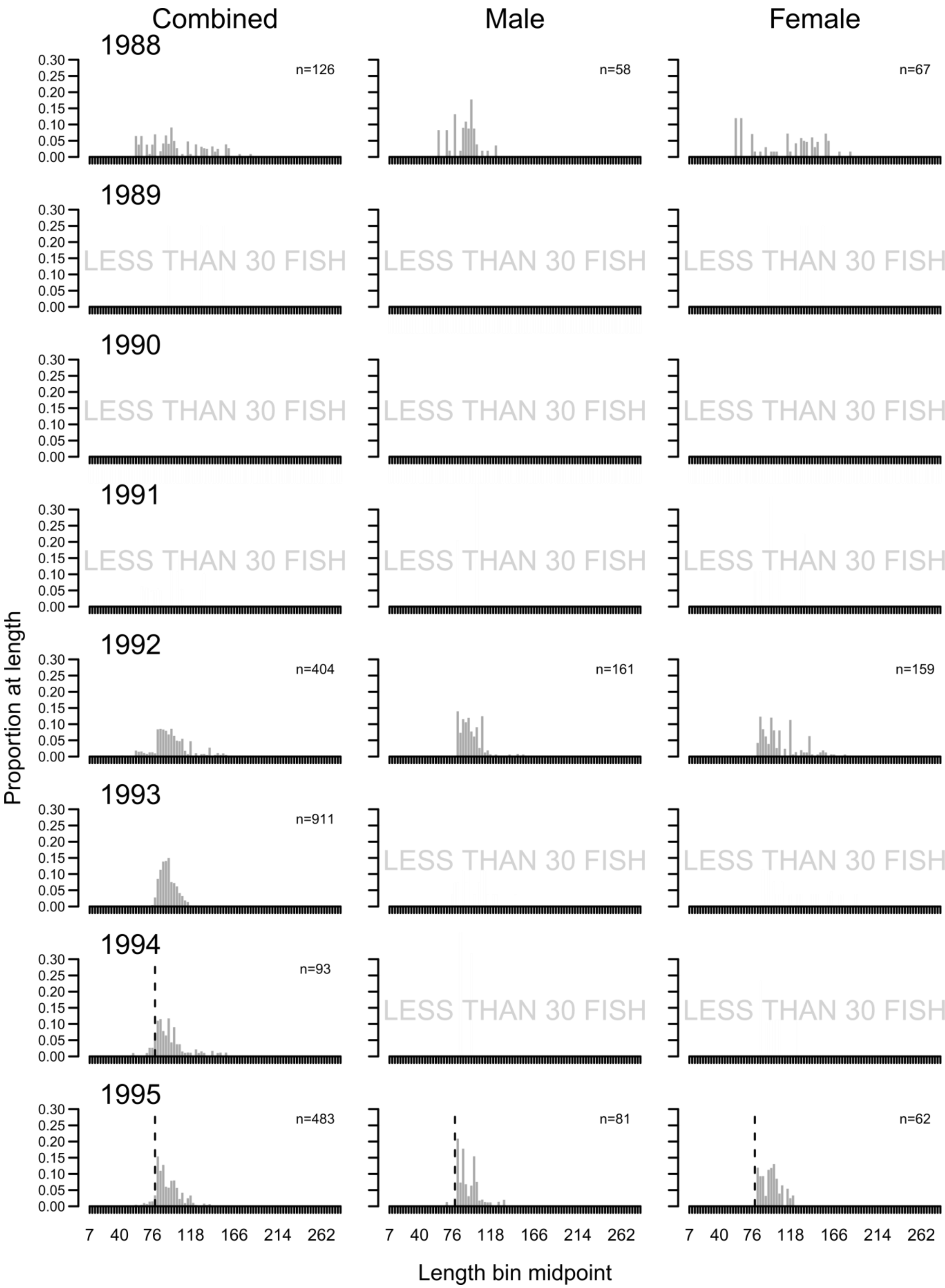


*Figure 9e. Proportion at length of observed longline sets for male, female and combined (male, female, and unsexed) in 4VWX for 1988-1995.*

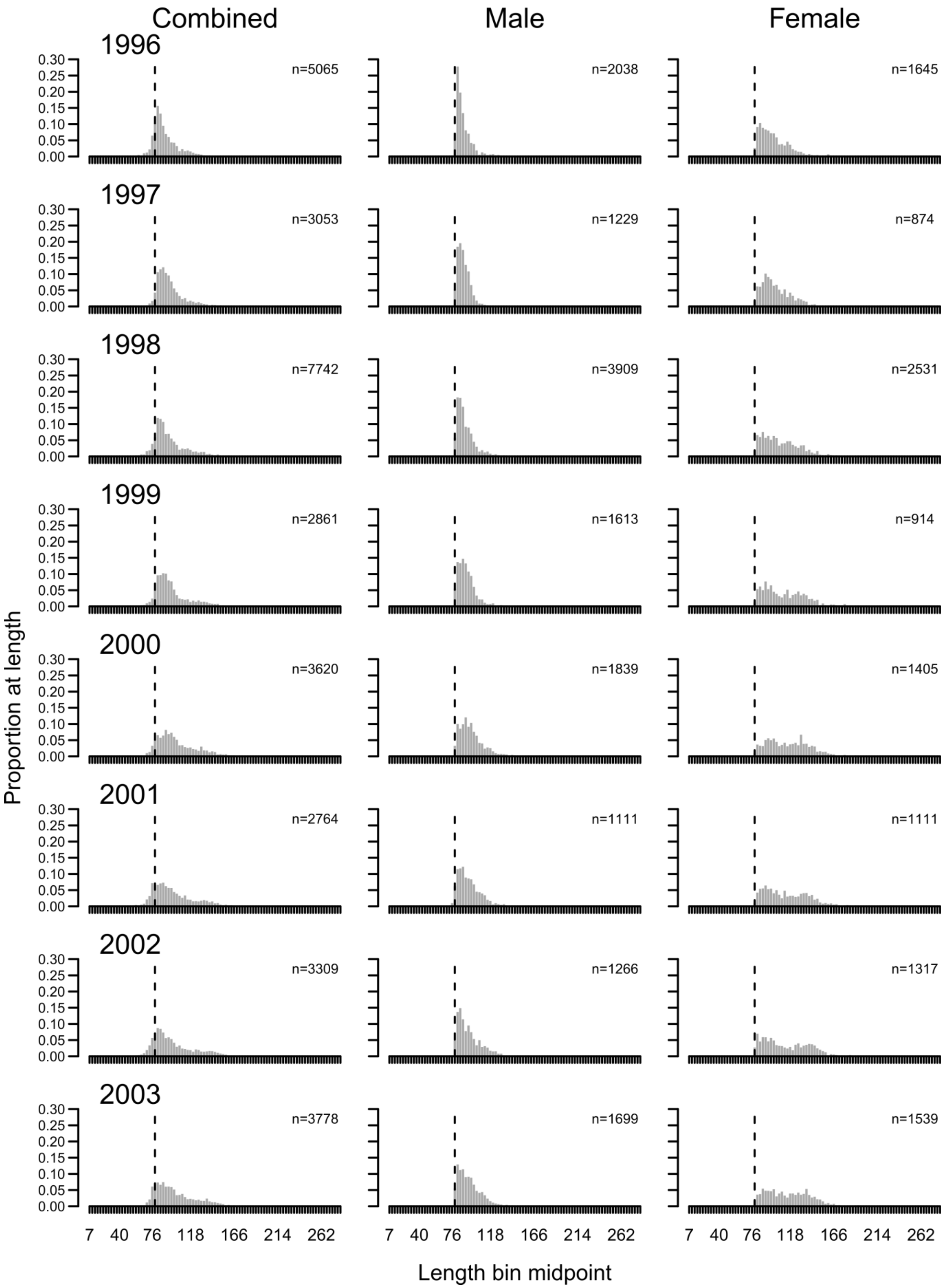


*Figure 9f. Proportion at length of observed longline sets for male, female and combined (male, female, and unsexed) in 4VWX for 1986-2003.*

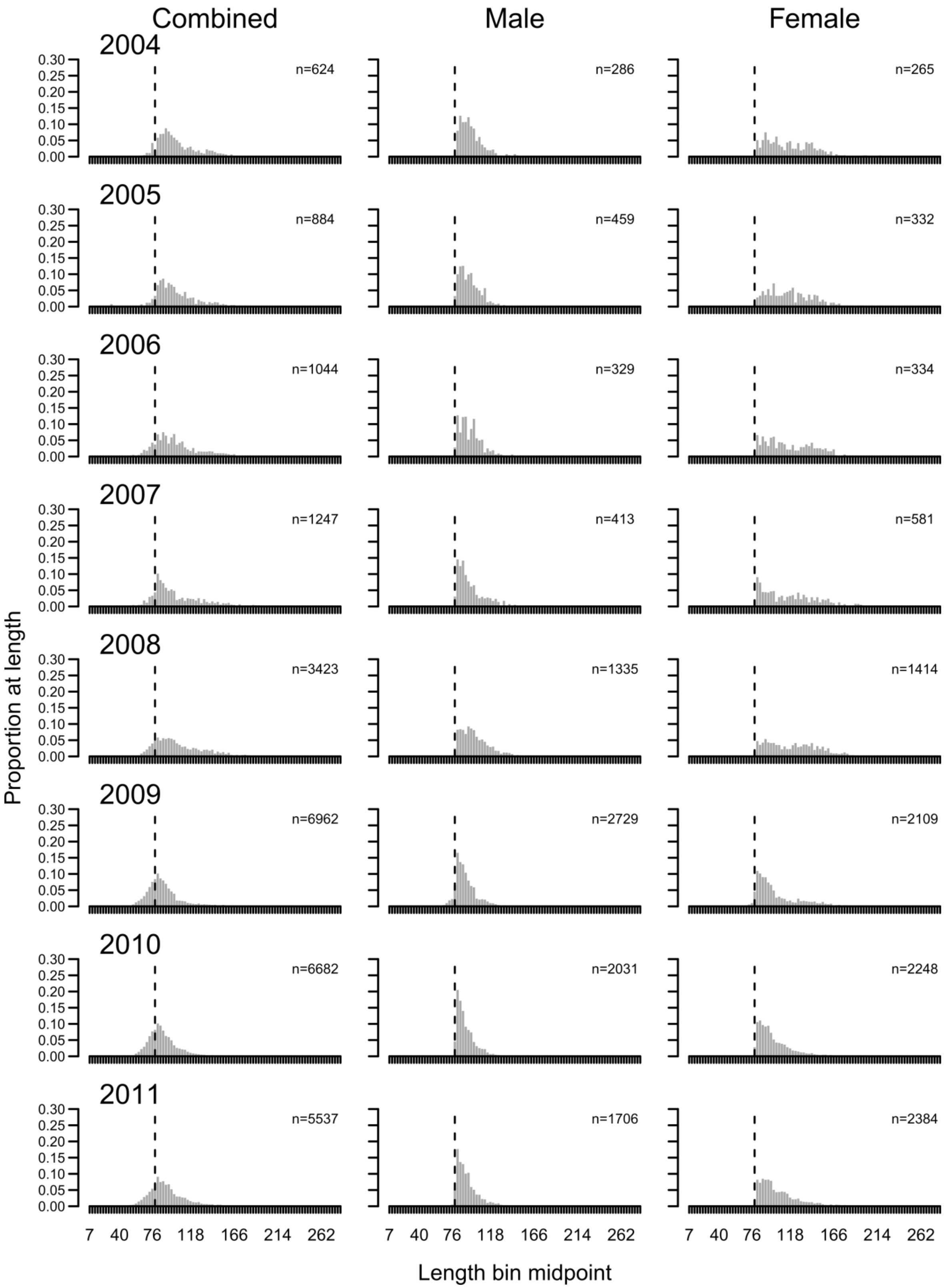


*Figure 9g. Proportion at length of observed longline sets for male, female and combined (male, female, and unsexed) in 4VWX for 2004-2011.*

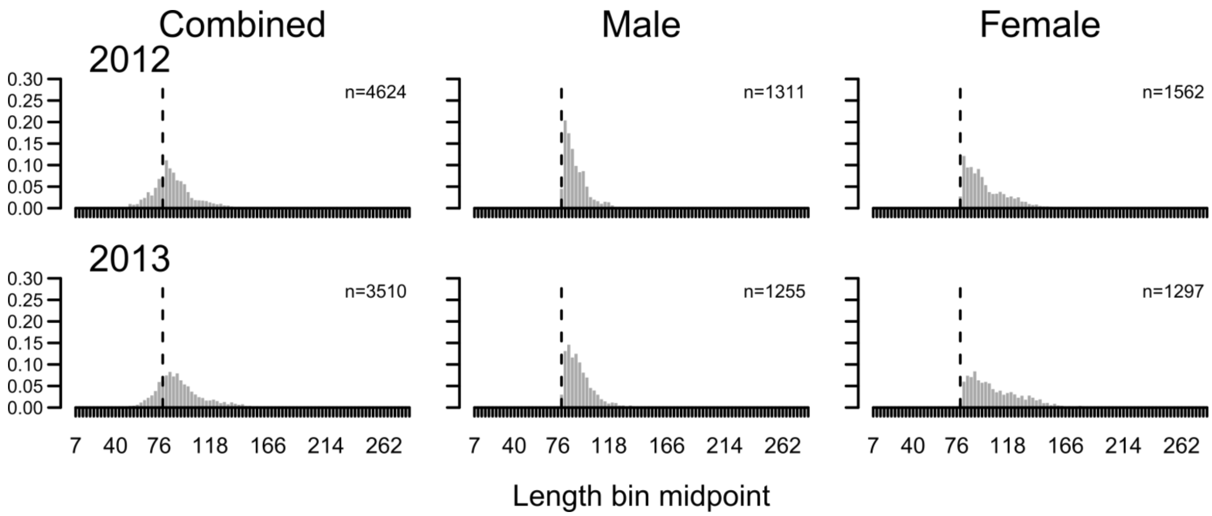


*Figure 9h. Proportion at length of observed longline sets for male, female and combined (male, female, and unsexed) in 4VWX for 2012-2013.*

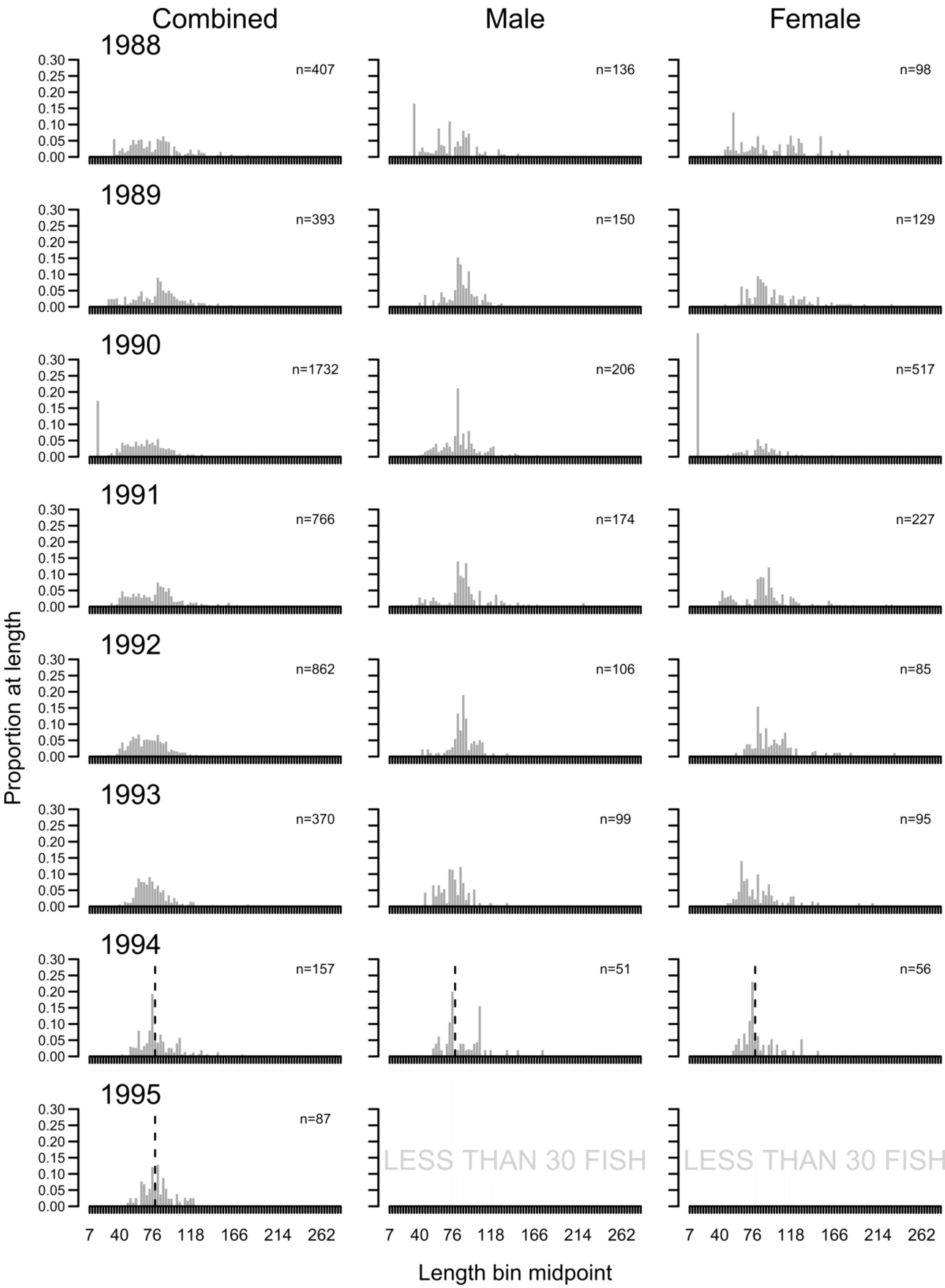


*Figure 9i. Proportion at length of observed otter trawl sets for male, female and combined (male, female, and unsexed) 1988-1995.*

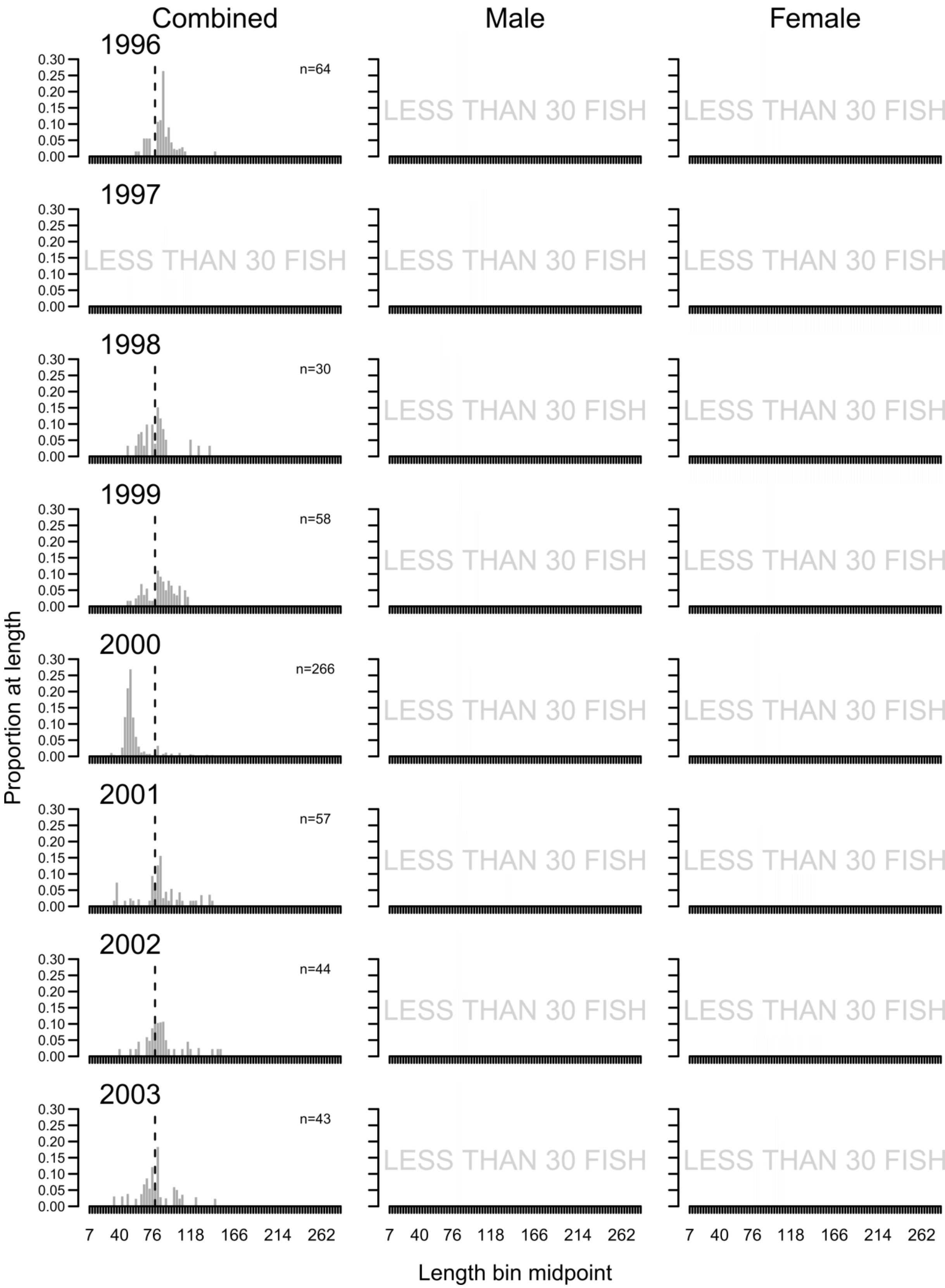


*Figure 9j. Proportion at length of observed otter trawl sets for male, female and combined (male, female, and unsexed) 1996-2003.*

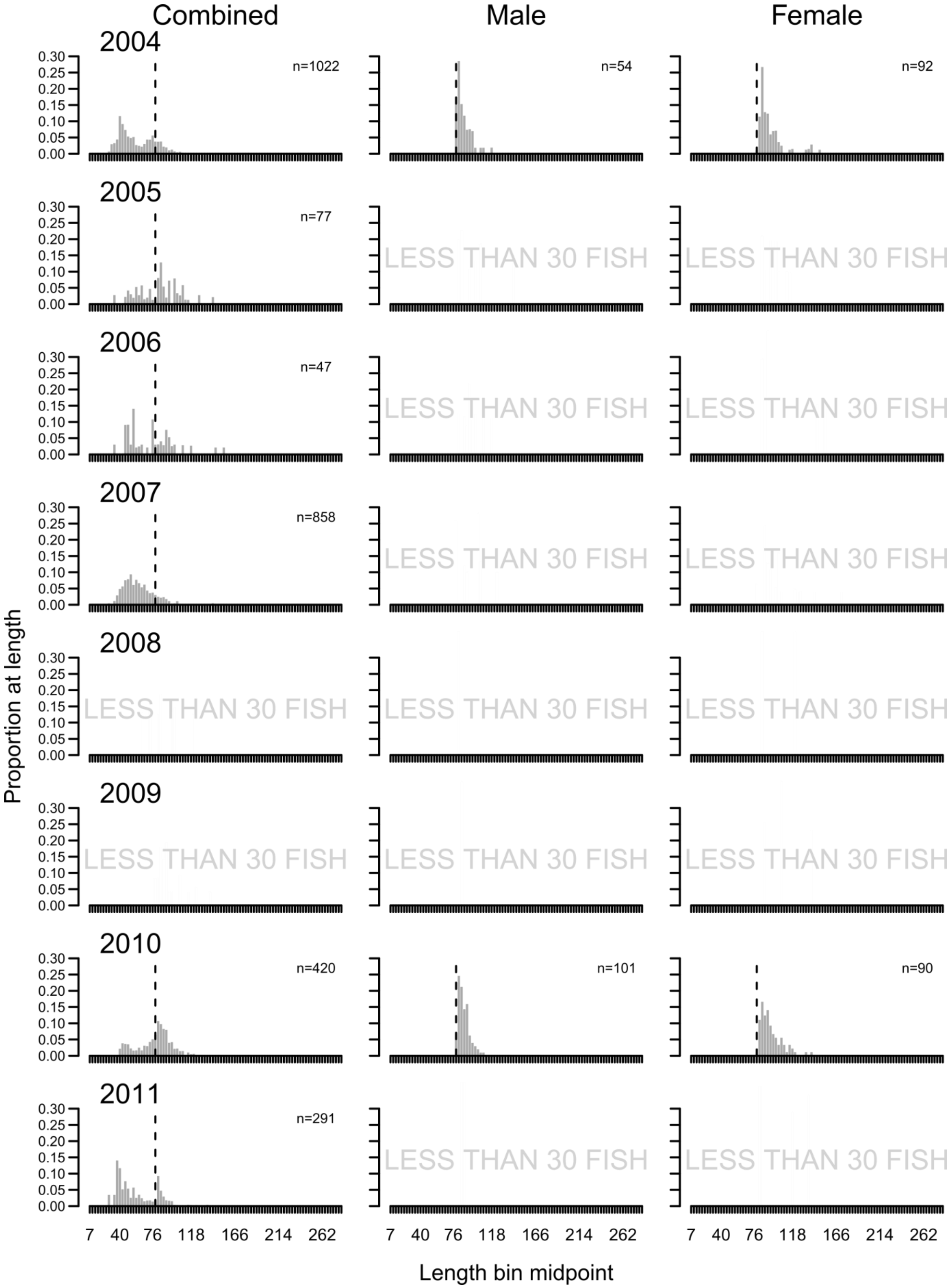


*Figure 9k. Proportion at length of observed otter trawl sets for male, female and combined (male, female, and unsexed) 2004-2011.*

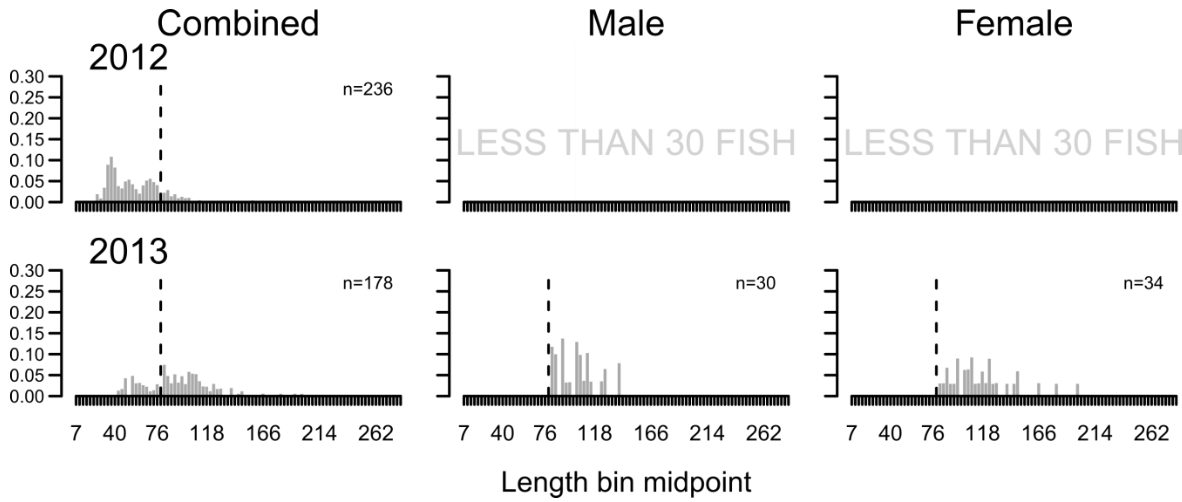


*Figure 9l. Proportion at length of observed otter trawl sets for male, female and combined (male, female, and unsexed) 2012-2013.*

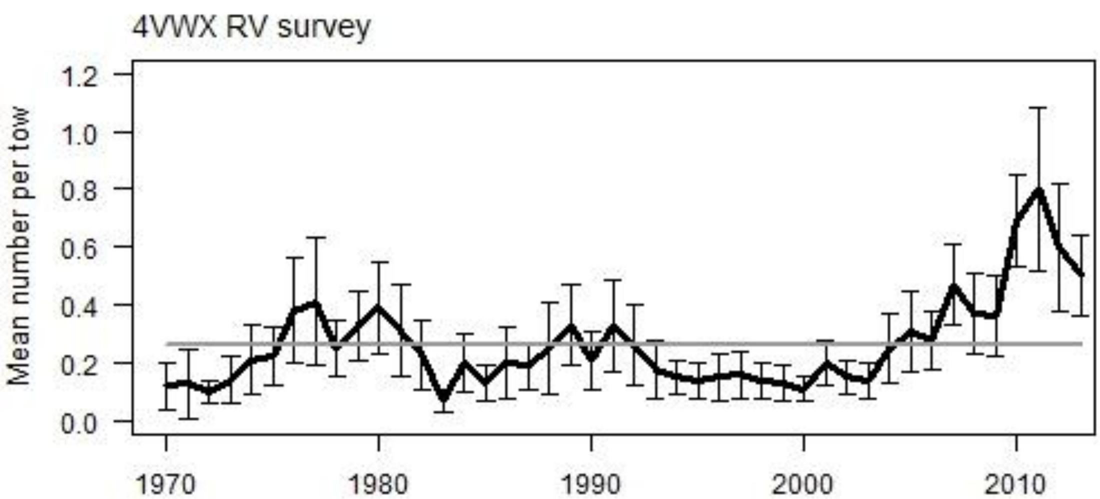


*Figure 10. Plot of standardized mean number per tow for the DFO Maritimes summer RV survey sets in 4VWX between 1970 and 2013. The grey horizontal line is the long term (1970-2012) mean (mean=0.26 per tow). The vertical bars indicate 95% confidence intervals.*

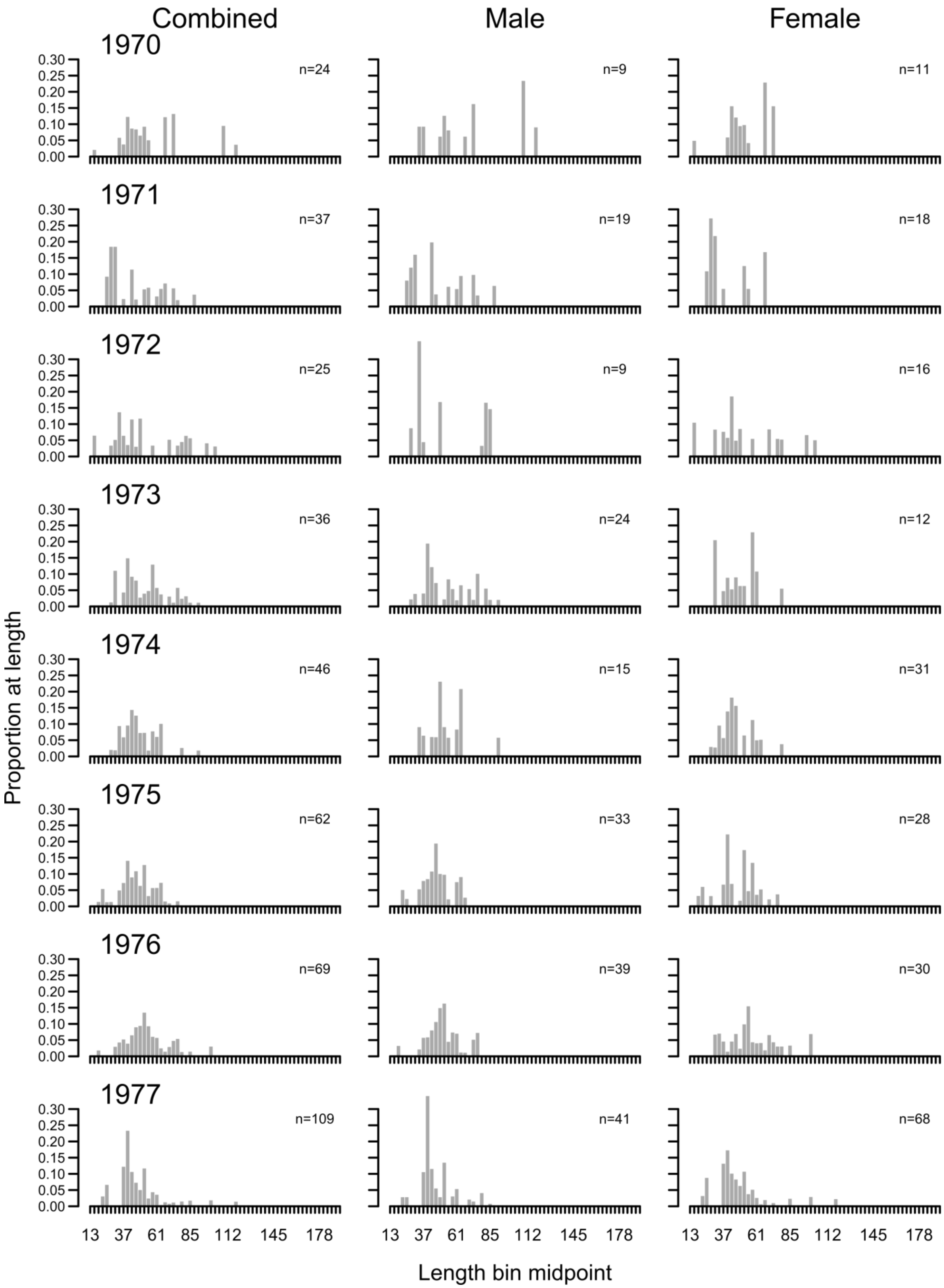


*Figure 11a. Stratified proportions at length and number of fish measured from the DFO Maritimes summer RV survey by year for 1970-1977.*

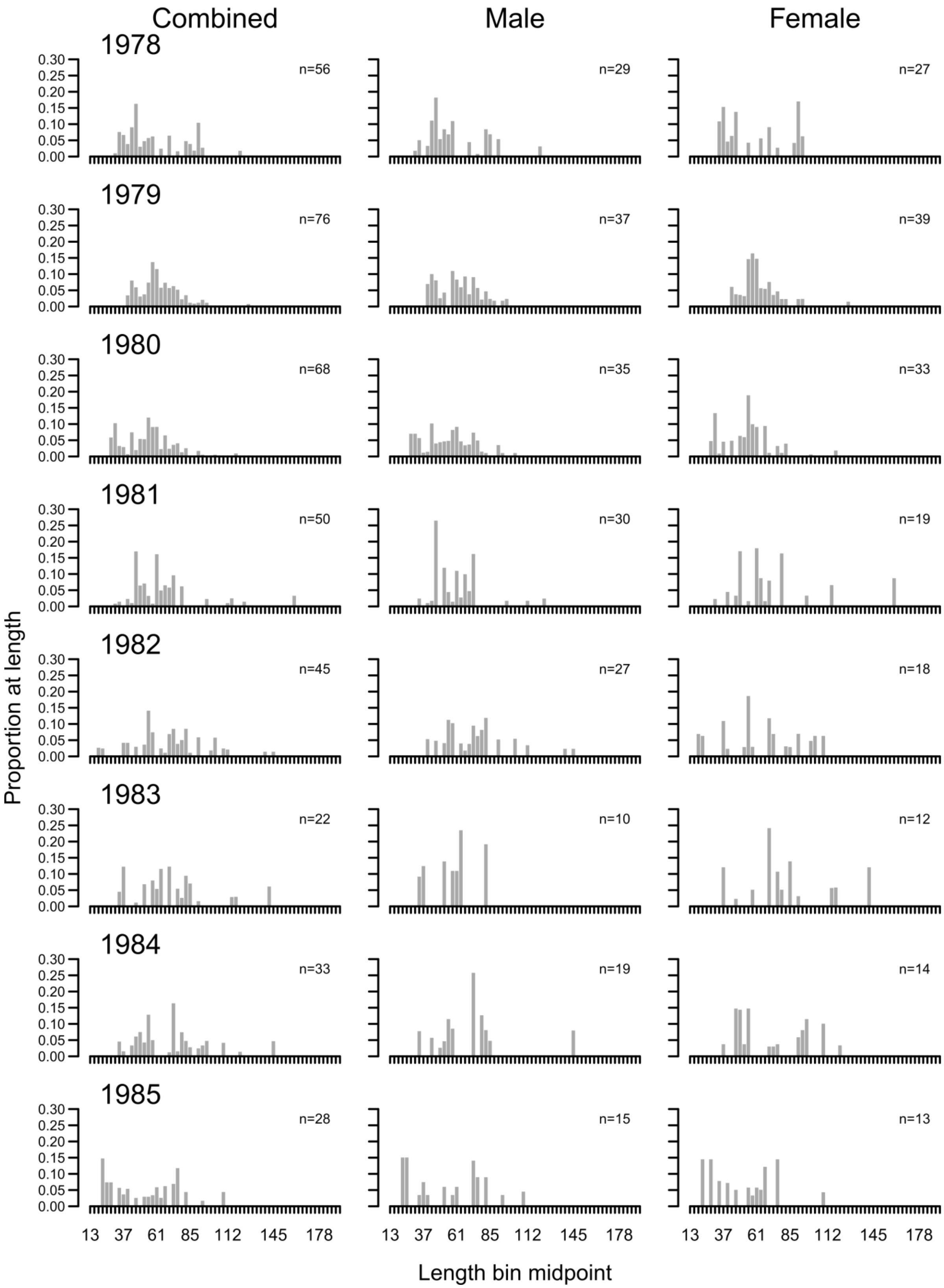


*Figure 11b. Stratified proportions at length and number of fish measured from DFO Maritimes summer RV survey by year for 1978-1985.*

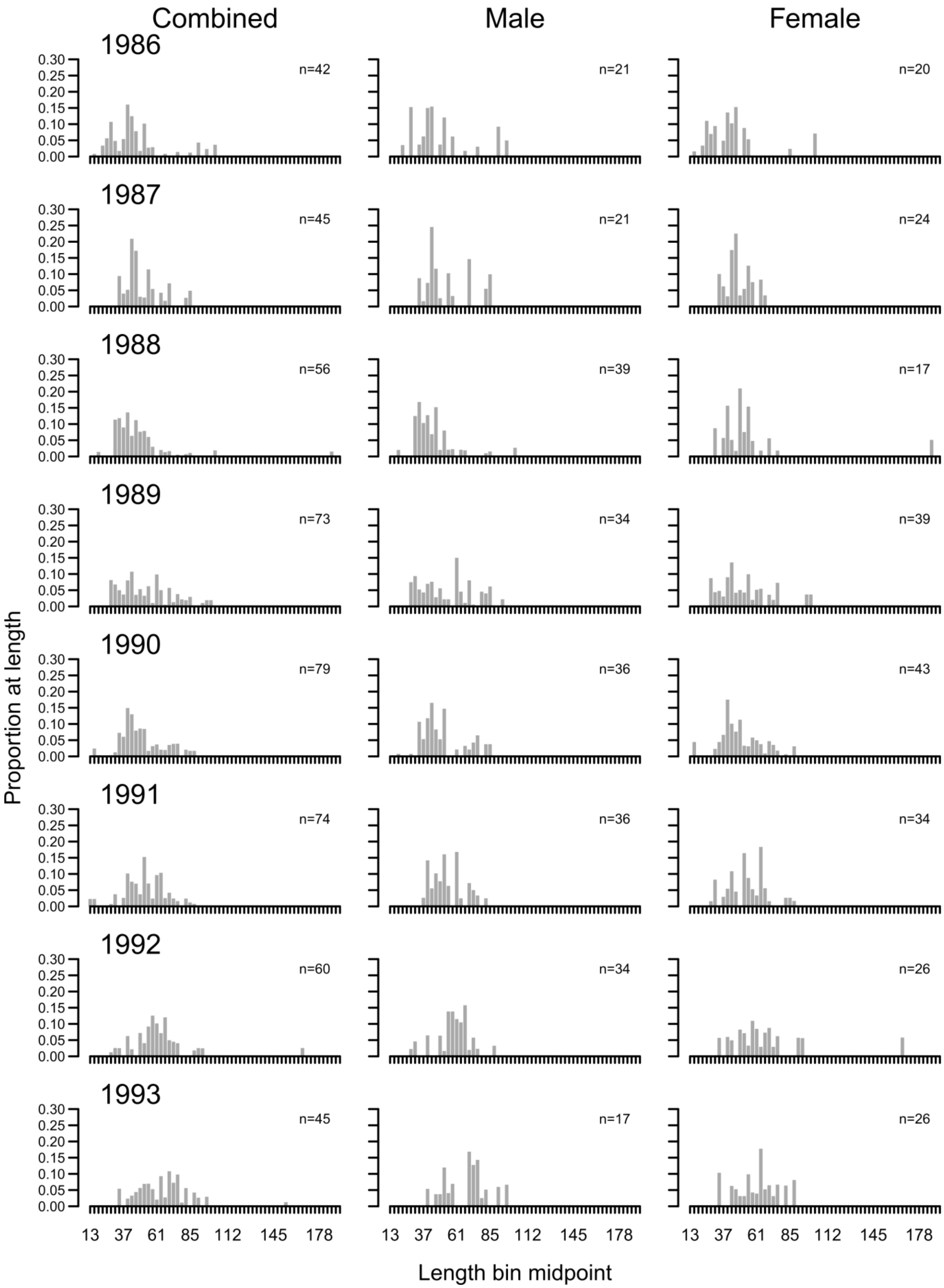


*Figure 11c. Stratified proportions at length and number of fish measured from DFO Maritimes summer RV survey by year for 1986-1993.*

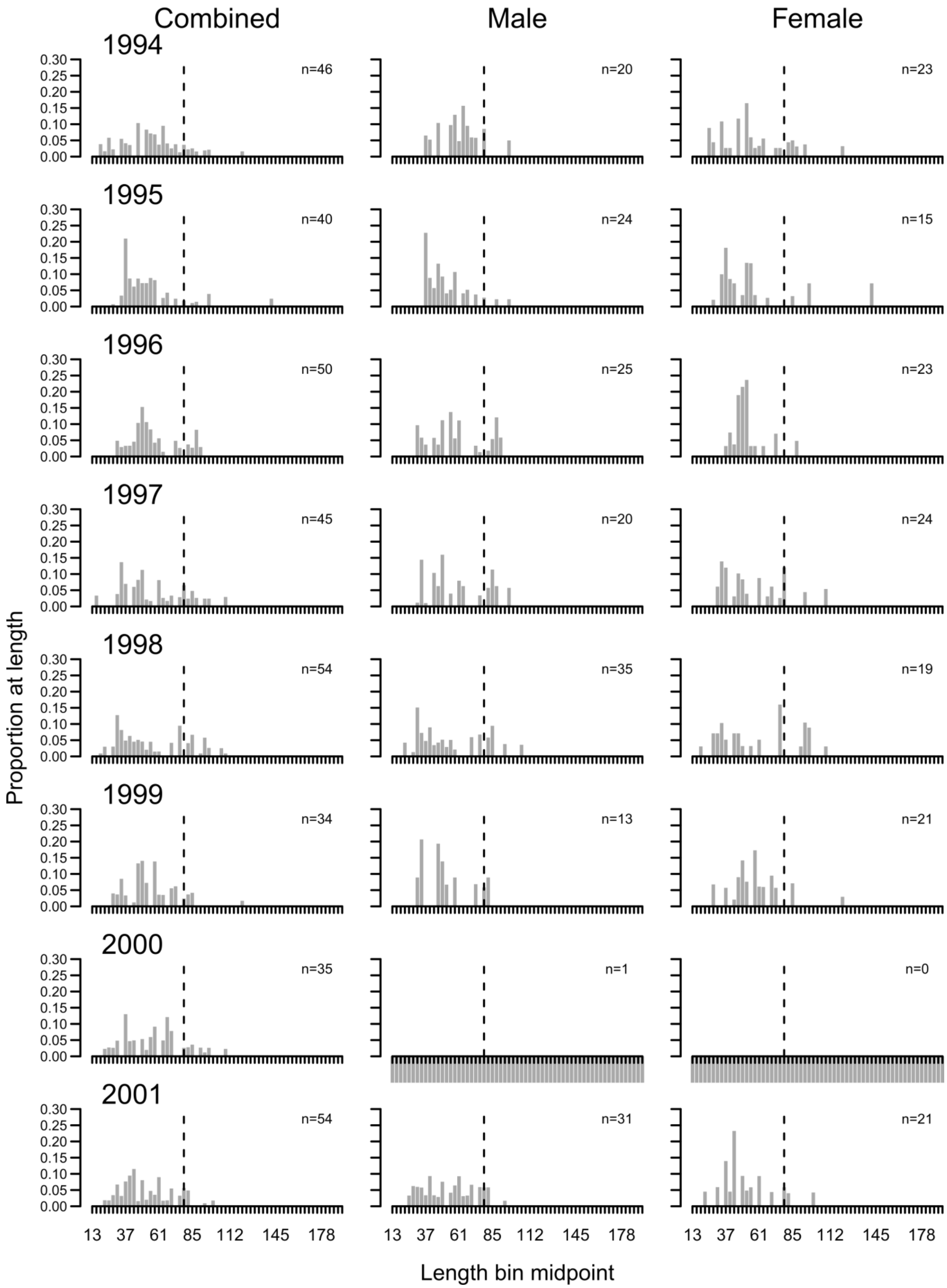


*Figure 11d. Stratified proportions at length and number of fish measured from DFO Maritimes summer RV survey by year for 1994-2001.*

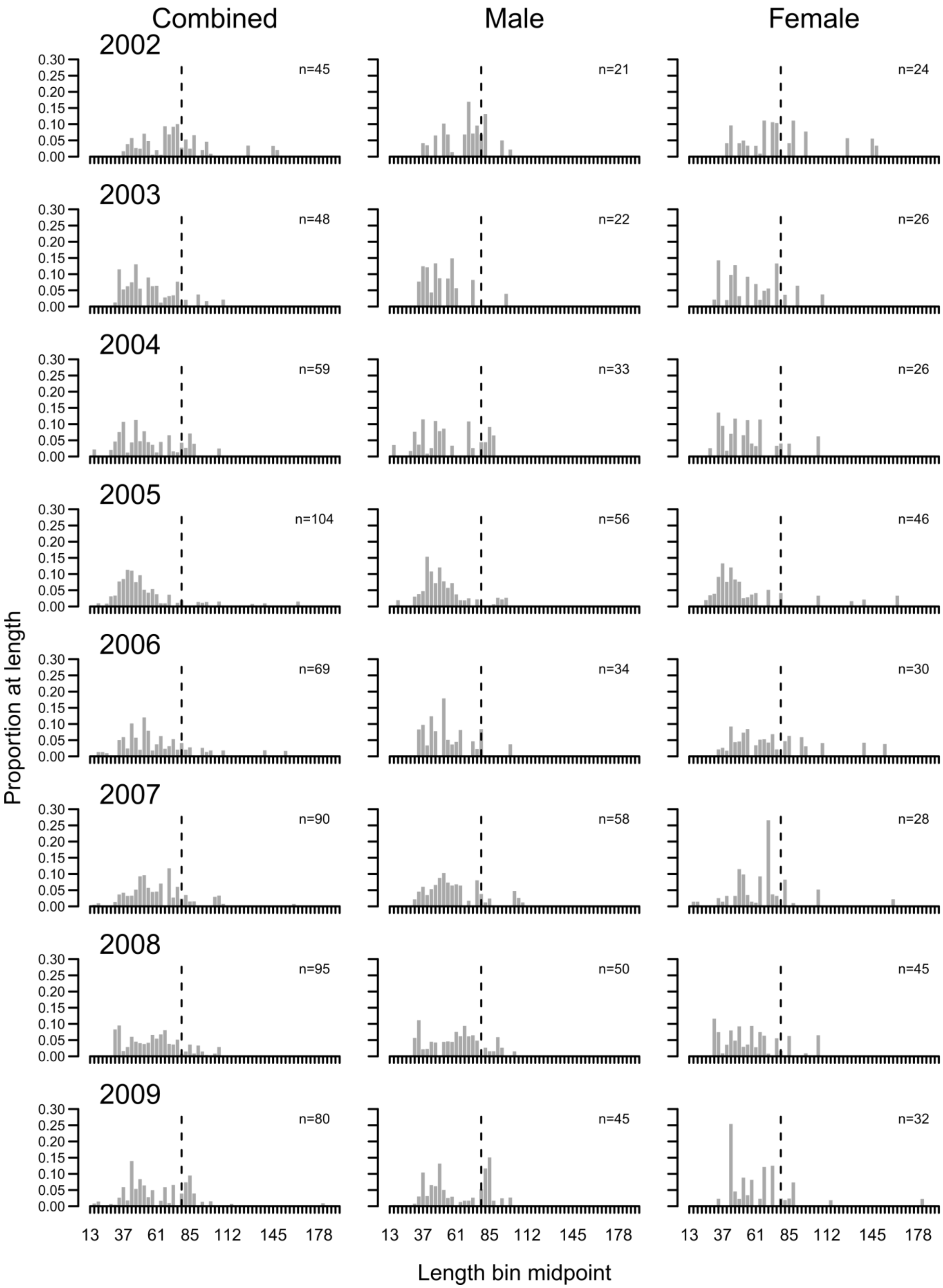


*Figure 11e. Stratified proportions at length and number of fish measured from DFO Maritimes summer RV survey by year for 2002-2009.*

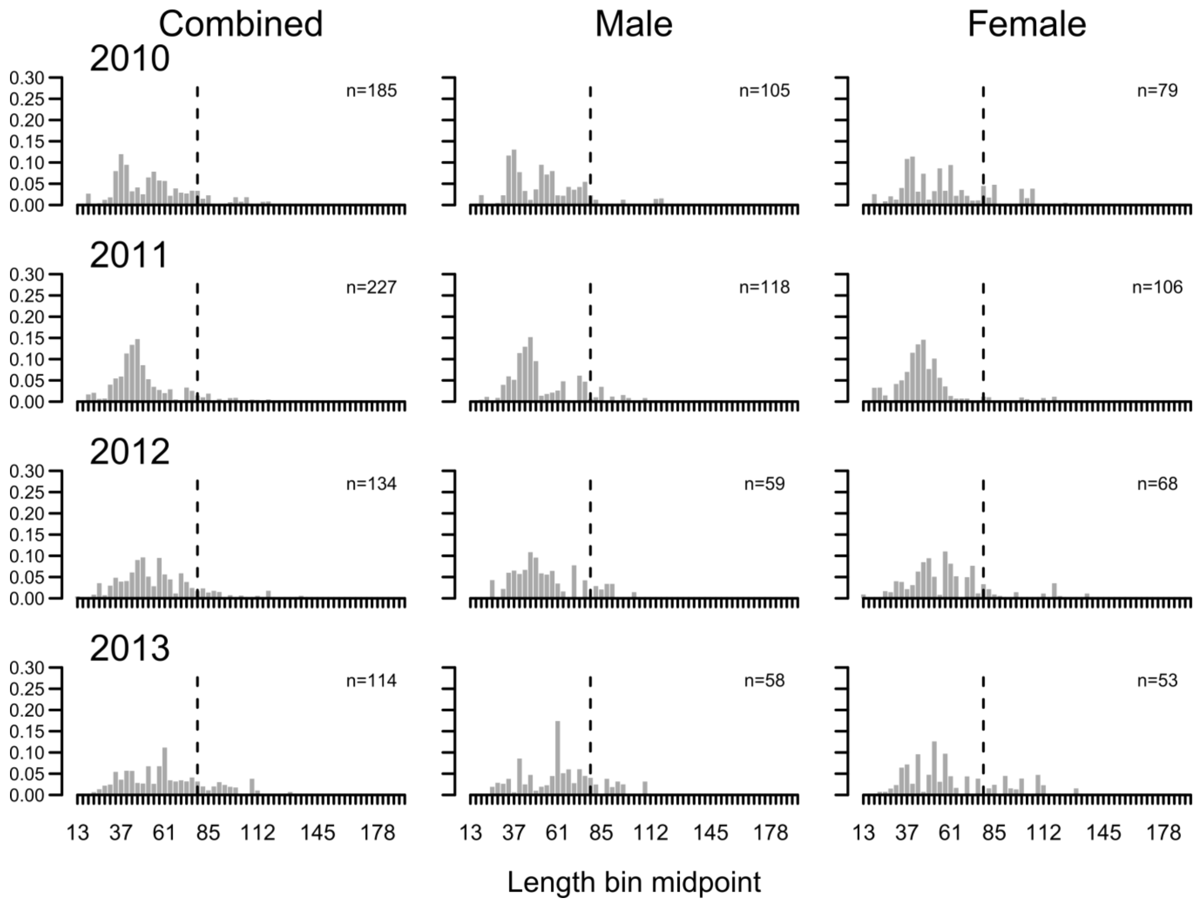


*Figure 11f. Stratified proportions at length and number of fish measured from DFO Maritimes summer RV survey by year for 2010-2013.*

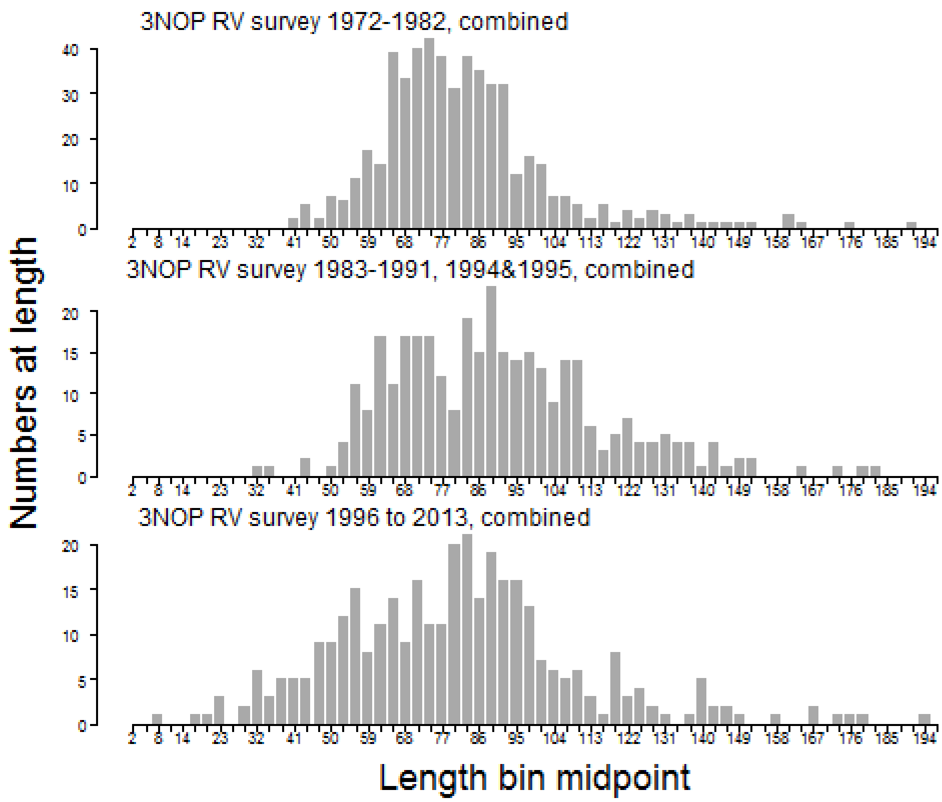


*Figure 12. Plot of the number of halibut caught in 3-cm length bins during the DFO Newfoundland and Labrador Spring RV survey in 3NOP between 1972 and 1982 and 1983 and 1995, and 1996 to 2013.*

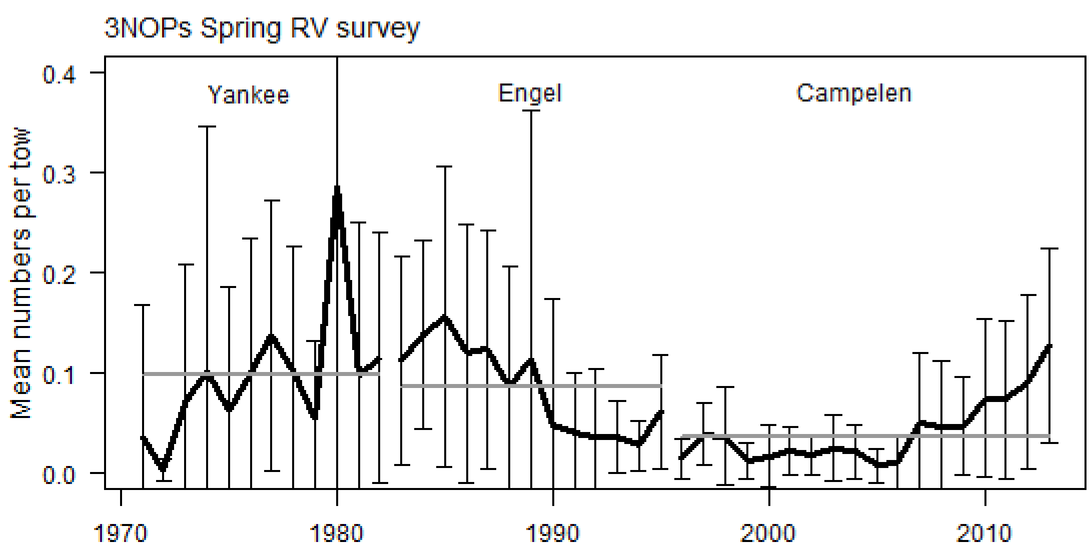


*Figure 13. Plot of standardized mean number per tow for the DFO Newfoundland and Labrador Spring RV survey in 3NOP between 1971 and 2013. The grey horizontal lines are the means for the Yankee (1971-1982), Engel (1983-1995) and Campelen (1996-2012). The vertical bars indicate 95% confidence intervals.*

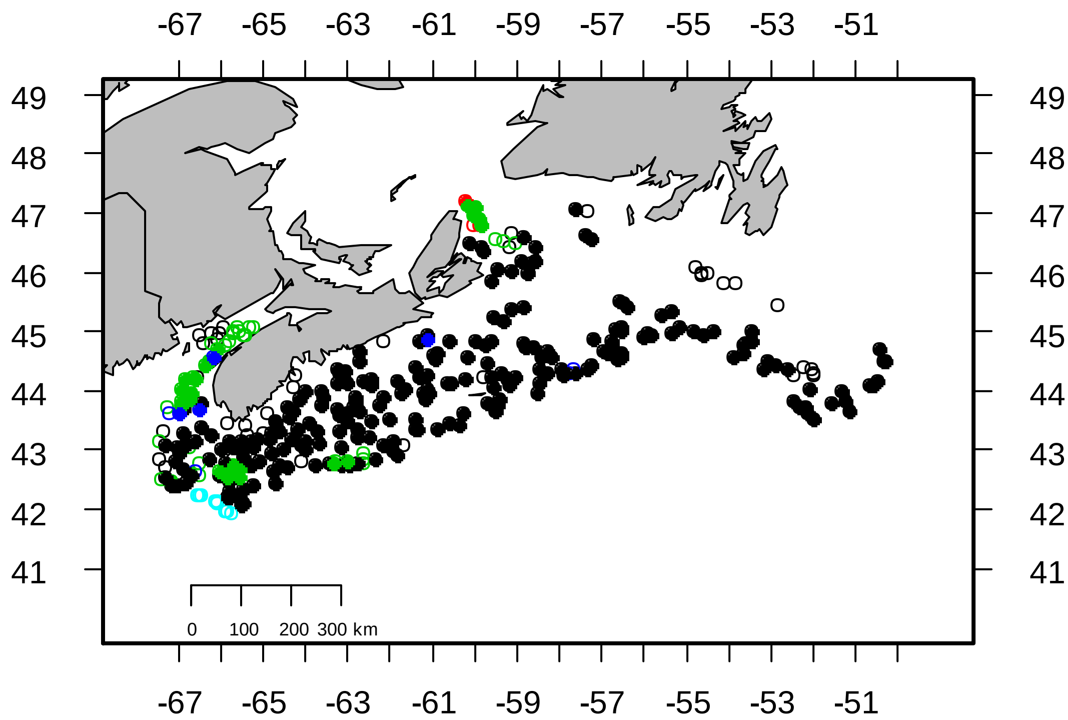


*Figure 14. Plot of Industry-DFO Halibut Survey stations. The colour indicates the year that the station was established, and open filled circles are stations that have been fished on 4 or more years. Between 1998 and 2013. 1998-black, n=218; 2005 -red, n=4; 2006-green,n=51; 2007-royal blue, n=8; 2008-aqua, n=10.*

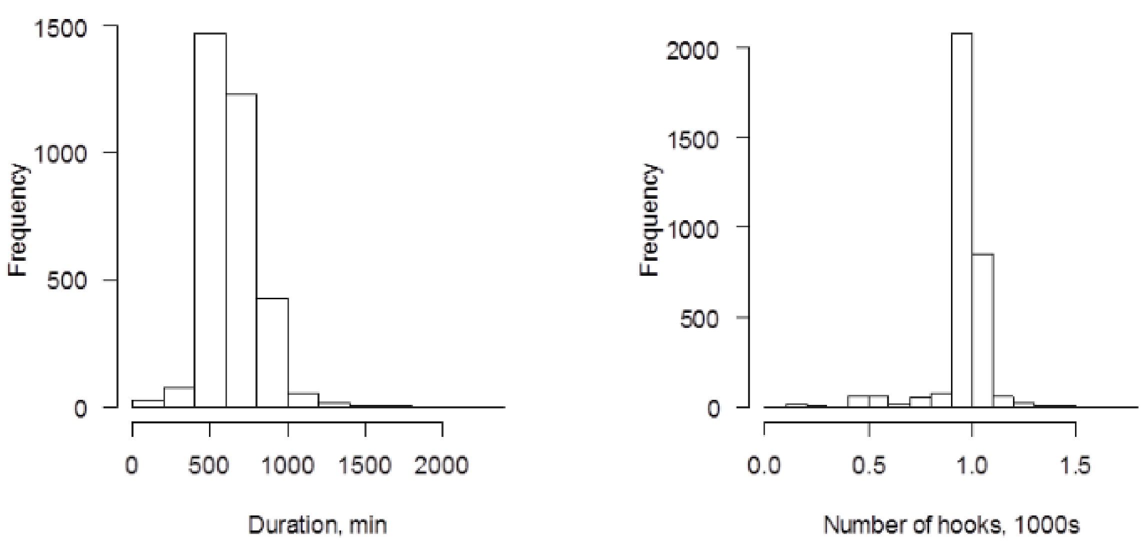


*Figure 15. Histograms of soak time (a) and number of hooks set (b) for all Industry-DFO Halibut Survey fixed-stations between 1998 and 2013.*

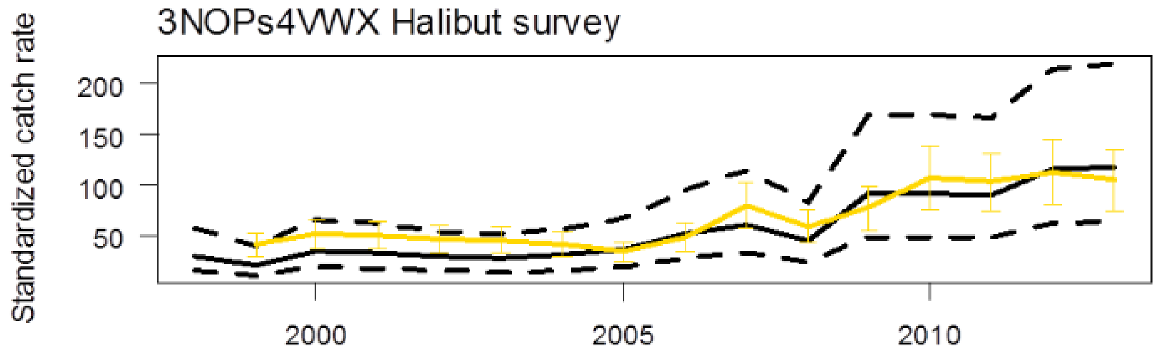


*Figure 16. Plot of the GLM index of abundance from the 3NOPs4VWX Industry-DFO Halibut Survey standardized to a 10 hour set of 1000 hooks between 1998 and 2013. Also plotted the mean catch rate with error bars for the 50 golden stations. The 95% confidence interval is indicated by dashed lines.*

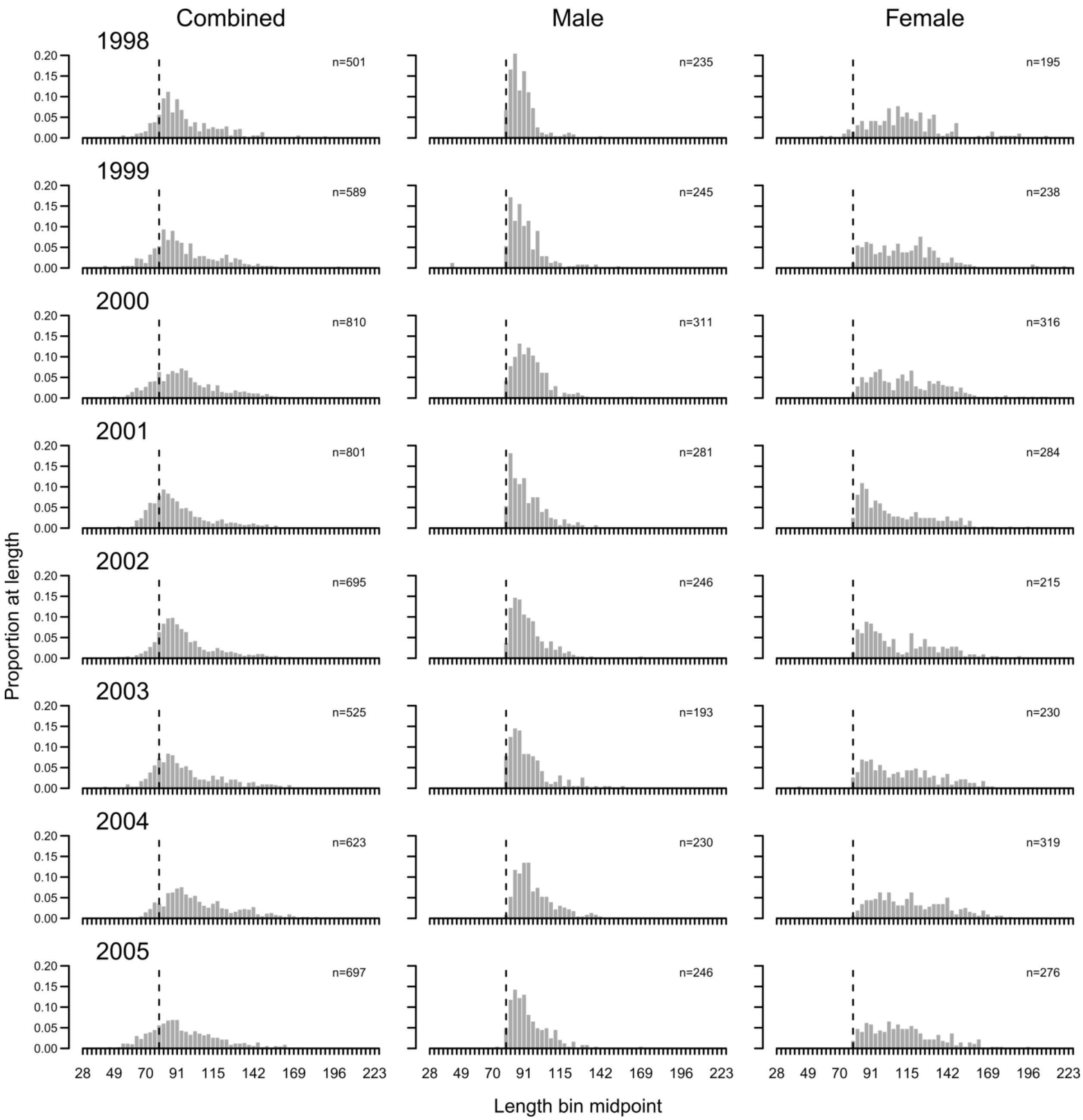


*Figure 17a. Plot of the Industry-DFO Halibut Survey proportion at length by year and sex.*

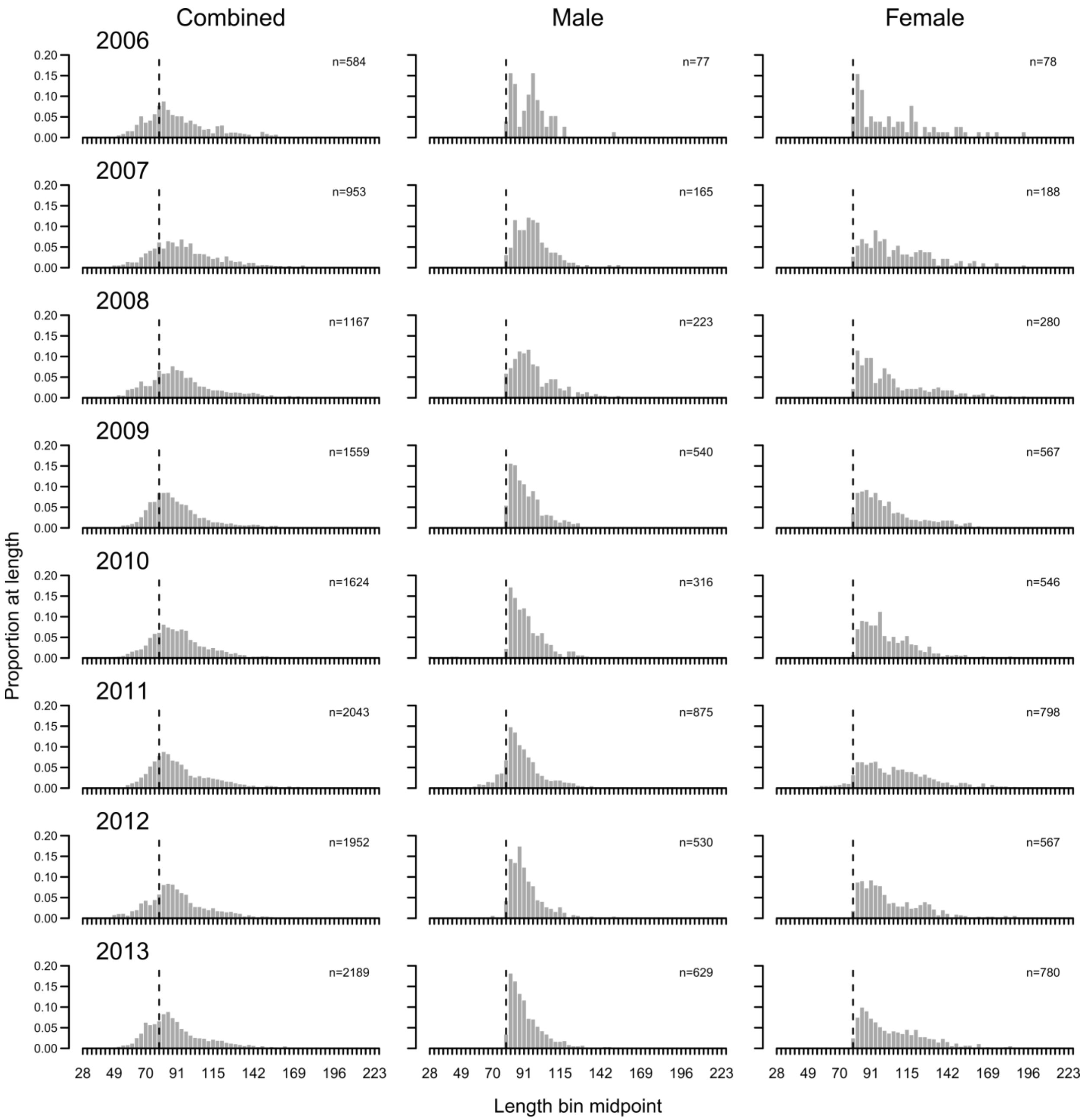


*Figure 17b. Plot of the Industry-DFO Halibut Survey proportion at length by year and sex.*

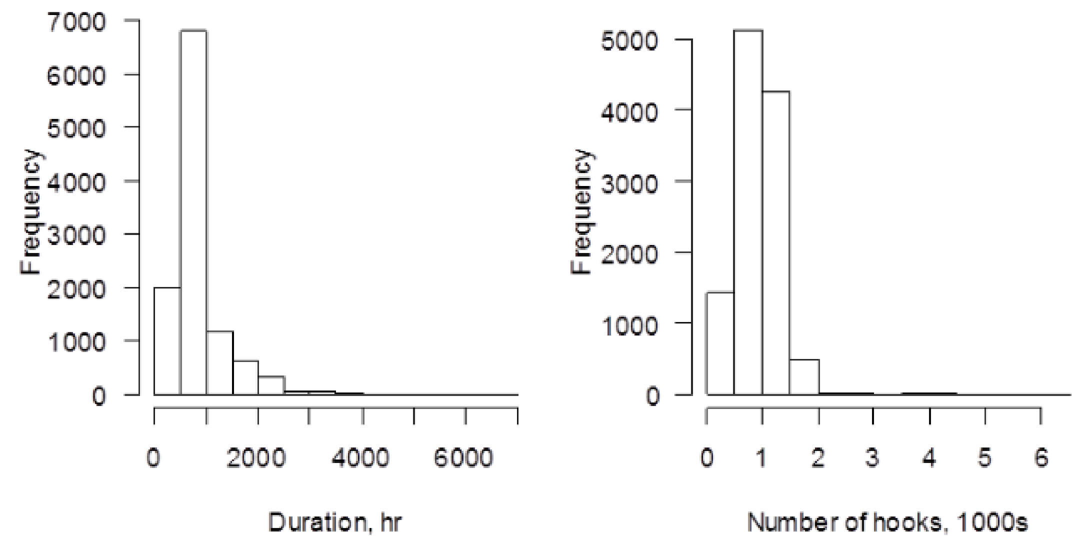


*Figure 18. Soak time and number of hooks set in Commercial Index sets.*

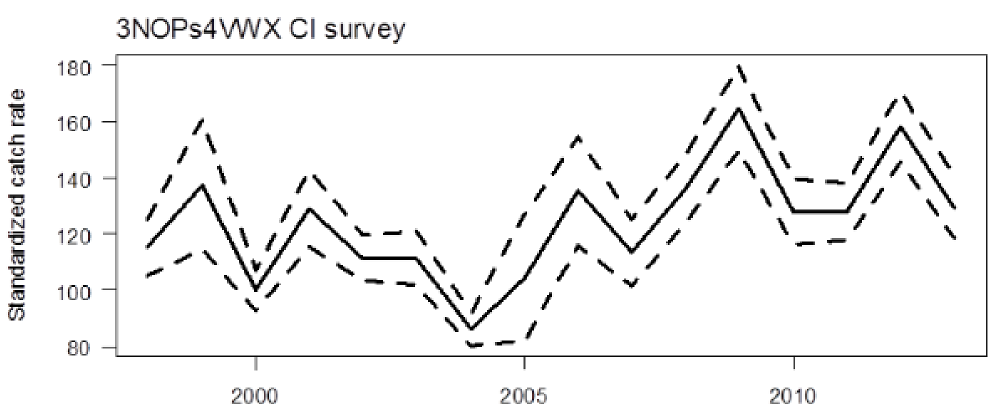


*Figure 19. Plot of the standardized catch rate (kg/1000hks/10hrs) of Commercial Index sets between 1998 and 2013.*

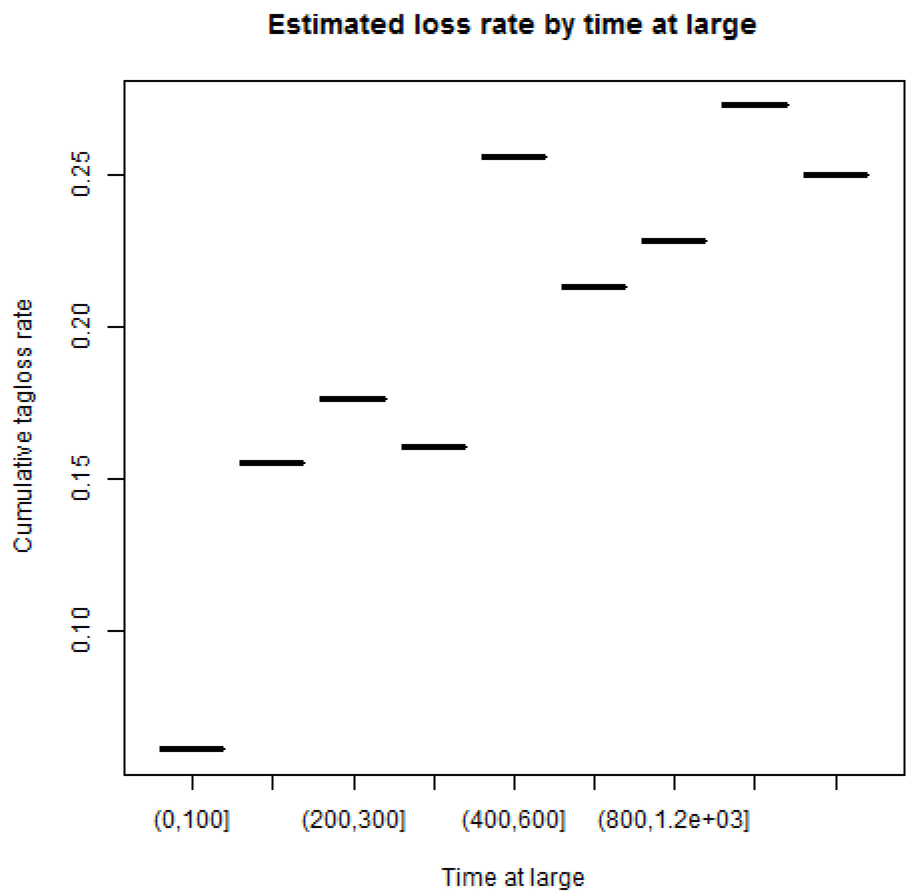


*Figure 20. Estimated cumulative tag-loss by time-at-large.*

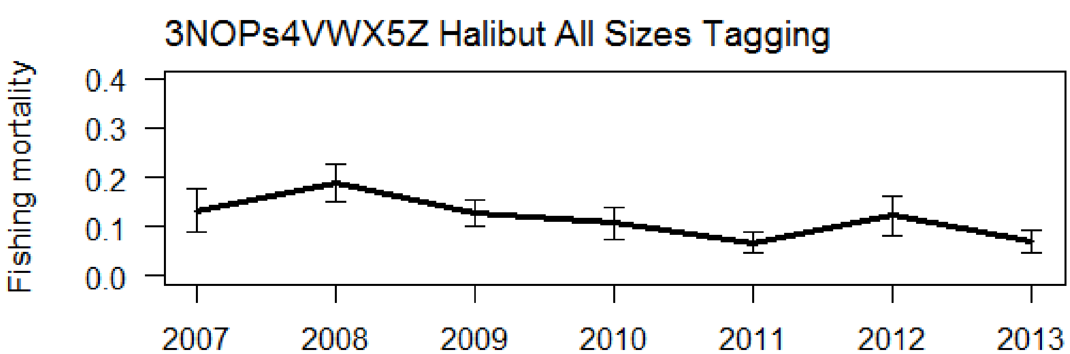


*Figure 21. Plot of instantaneous fishing mortality (M) estimated from the multiyear mark-recapture model of Atlantic halibut tagged between 2006 and 2012 and recaptured and reported by August 8, 2014.*

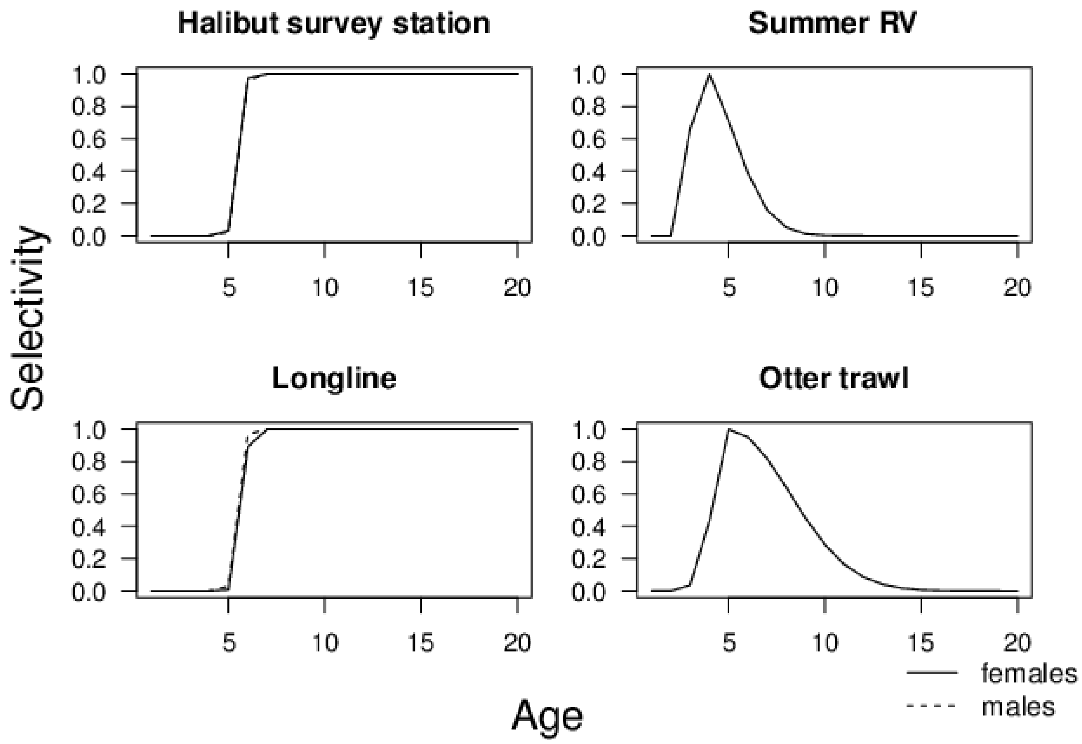


*Figure 22. Gear selectivity at age for male and female Atlantic halibut from the updated (data up to 2013) 2010 assessment model.*

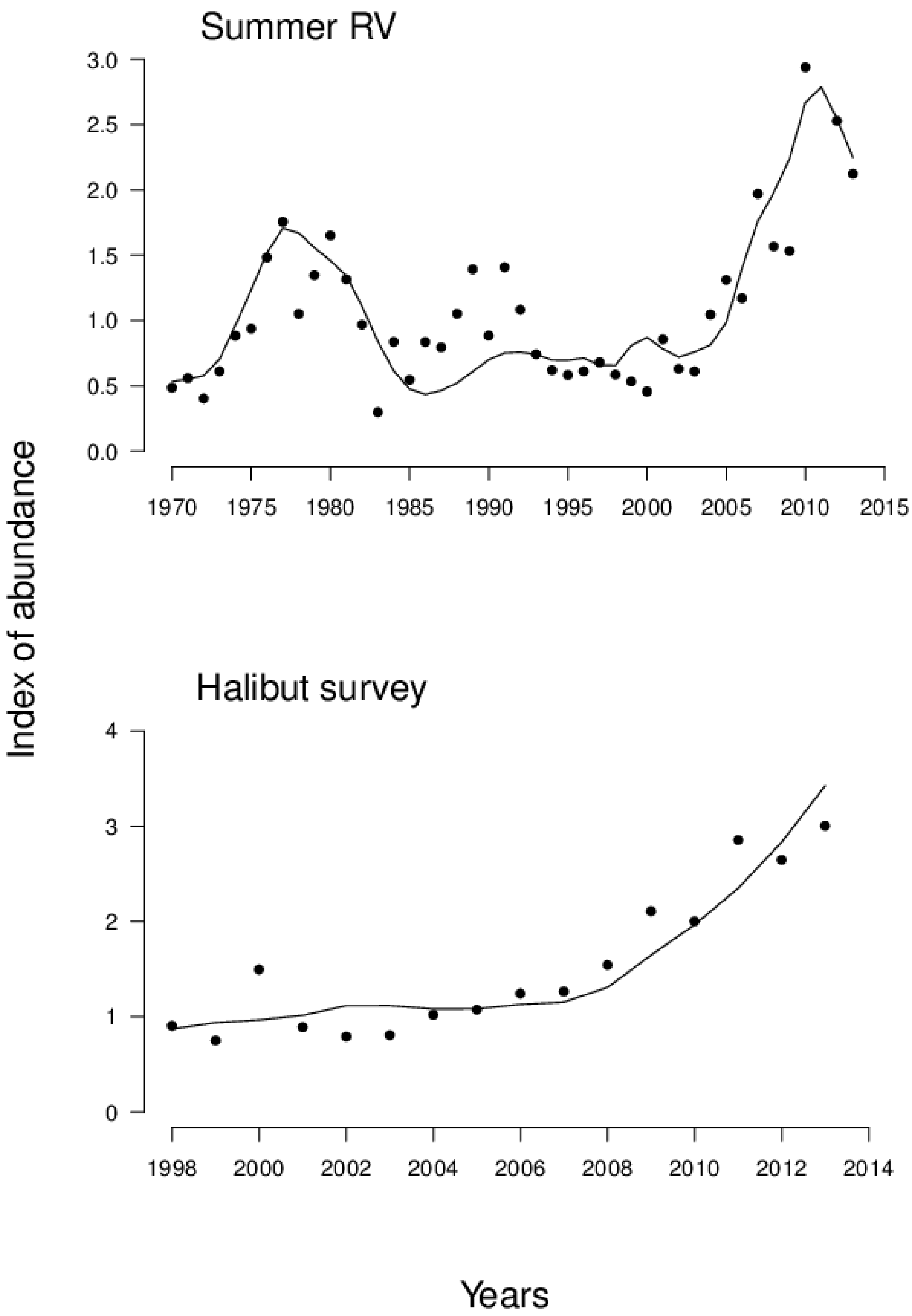


*Figure 23. Updated 2010 assessment model fit (line) to abundance indices (points).*

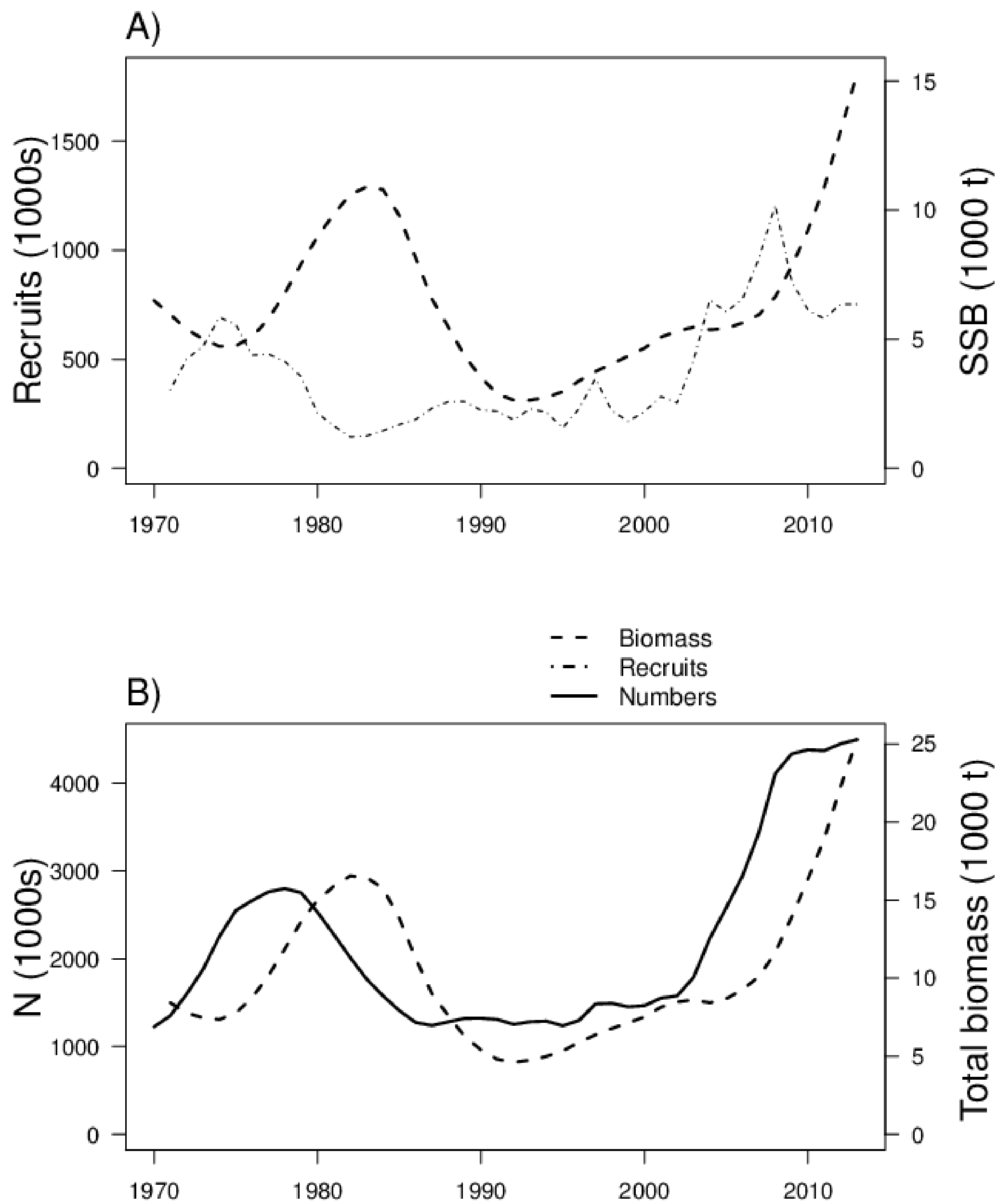


*Figure 24. A) Spawning stock biomass, spawner numbers, and the number of age-1 recruits (upper panel), B) total biomass and total number of Atlantic halibut predicted by the updated 2010 assessment model (lower panel).*

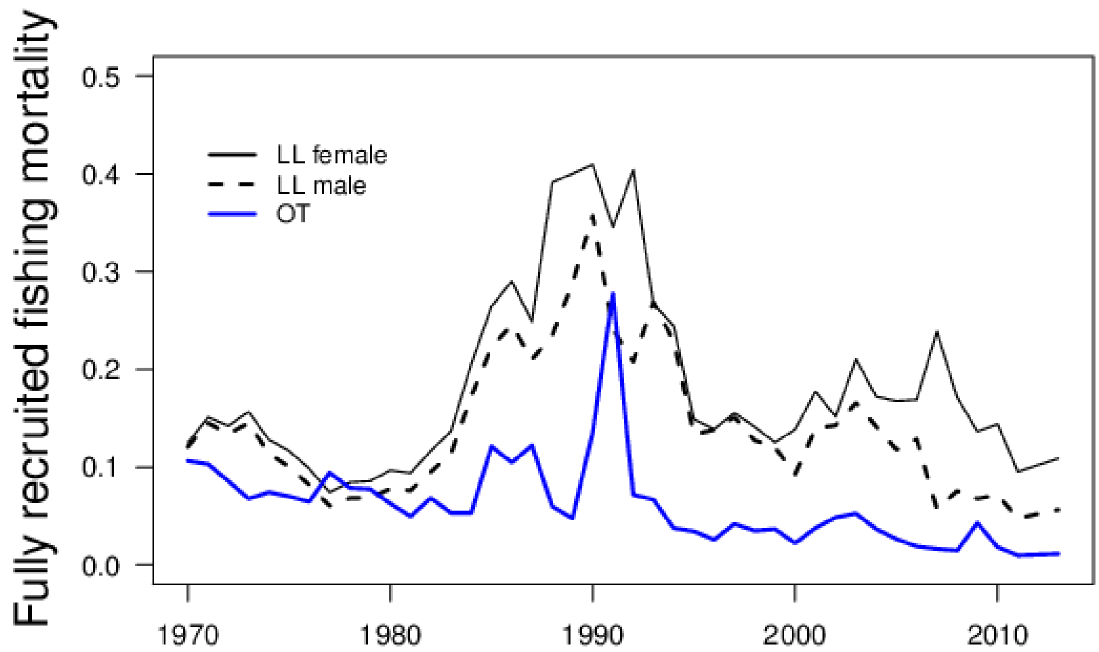


*Figure 25. Fishing mortality for fully exploited halibut caught on longline (LL) and otter trawl (OT) gear predicted from the 2010 assessment model.*

# APPENDICES

*Appendix 1. Mean fork length (cm) and standard deviation of halibut for each age class for males and females (from Armsworthy and Campana 2010). A dash (-) indicates that no information was available.*

| Age Class | Male | | | Female | | |
|---|---|---|---|---|---|---|
| | Mean FL, cm | SD | Number | Mean FL, cm | SD | Number |
| 2 | 28.7 | 2.29 | 9 | 27.4 | 5.17 | 14 |
| 3 | 40 | 6.88 | 21 | 43.8 | 9.85 | 16 |
| 4 | 49.3 | 11.76 | 34 | 47.8 | 8.71 | 34 |
| 5 | 67.3 | 17.82 | 43 | 73.2 | 18.7 | 53 |
| 6 | 82.6 | 22.41 | 68 | 92.2 | 18.96 | 99 |
| 7 | 90.4 | 18.69 | 82 | 102.7 | 15.66 | 142 |
| 8 | 100.3 | 18.23 | 94 | 112.2 | 18.94 | 152 |
| 9 | 105.8 | 20.57 | 105 | 117.5 | 21.43 | 152 |
| 10 | 104.5 | 19.31 | 66 | 126 | 21.89 | 124 |
| 11 | 113 | 21.18 | 66 | 131.6 | 24.37 | 117 |
| 12 | 111.6 | 17.92 | 73 | 137 | 22.11 | 125 |
| 13 | 115.3 | 21.93 | 64 | 147.7 | 18.43 | 67 |
| 14 | 120 | 20.17 | 48 | 153.5 | 16.97 | 74 |
| 15 | 114.4 | 15.8 | 45 | 156.9 | 20.97 | 51 |
| 16 | 122.4 | 21.56 | 39 | 161.8 | 19.87 | 38 |
| 17 | 115.8 | 15.93 | 17 | 164.1 | 15.85 | 19 |
| 18 | 129.7 | 17.22 | 18 | 164.7 | 19.54 | 19 |
| 19 | 126.1 | 13.13 | 11 | 176.4 | 9.94 | 8 |
| 20 | 139.6 | 24.85 | 10 | 180.5 | 15.81 | 11 |
| 21 | 123 | 14.23 | 8 | 178.5 | 14.63 | 6 |
| 22 | 135.9 | 15.17 | 7 | 186.9 | 20.74 | 16 |
| 23 | 127 | 22.85 | 5 | 182.2 | 17.92 | 13 |
| 24 | 148 | 23.73 | 12 | 188.4 | 11.8 | 11 |
| 25 | 138.4 | 9.74 | 13 | 189.4 | 15.54 | 10 |
| 26 | 145.6 | 23.18 | 5 | 196.6 | 10.04 | 5 |
| 27 | 138 | 10.54 | 3 | 196.6 | 13.81 | 5 |
| 28 | 139 | 12.73 | 2 | 202 | 16.97 | 8 |
| 29 | 153 | 12.12 | 3 | 194.5 | 8.66 | 4 |
| 30 | 134.6 | 14.1 | 5 | 206 | 24.25 | 3 |
| 31 | 157 | - | 1 | 200.5 | 10.61 | 2 |
| 32 | 153.5 | 21.75 | 2 | 179.5 | 19.09 | 2 |
| 34 | - | - | - | 193 | - | 1 |
| 35 | - | - | - | 211 | - | 1 |
| 37 | - | - | - | 207 | - | 1 |
| 38 | - | - | - | 187 | - | 1 |
| 42 | 148 | - | 1 | - | - | - |
| 50 | 150 | - | 1 | - | - | - |

*Appendix 2. Model Output.*

COMBINED

```
Linear mixed-effects model fit by REML
 Data: wt.gdat
       AIC       BIC   logLik
  -53320.13 -53284.75 26664.07

Random effects:
 Formula: ~1 | raneff
        (Intercept)  Residual
StdDev:  0.03423398 0.1437758

Fixed effects: log(wt) ~ log(len)
              Value   Std.Error    DF   t-value p-value
(Intercept) -5.021354 0.011175127 51334 -449.3331       0
log(len)     3.124184 0.002263476 51334 1380.2597       0
 Correlation:
         (Intr)
log(len) -0.873

Standardized Within-Group Residuals:
       Min          Q1         Med          Q3         Max
-9.65682623 -0.51410723  0.02367829  0.56454605  5.43400497

Number of Observations: 51379
Number of Groups: 44
```

---

MALES

```
Linear mixed-effects model fit by REML
 Data: wt.gdat
       AIC       BIC   logLik
  -26115.28 -26083.13 13061.64

Random effects:
 Formula: ~1 | raneff
        (Intercept)  Residual
StdDev:  0.03723945 0.1363419

Fixed effects: log(wt) ~ log(len)
              Value  Std.Error    DF   t-value p-value
(Intercept) -4.996989 0.01731391 22848 -288.6112       0
log(len)     3.119078 0.00376758 22848  827.8731       0
 Correlation:
         (Intr)
log(len) -0.937

Standardized Within-Group Residuals:
       Min         Q1        Med         Q3        Max
-9.4687593 -0.5520682  0.0129084  0.5882104  5.6141379

Number of Observations: 22893
```

```
Number of Groups: 44
```

FEMALES

```
 Data: wt.gdat
      AIC       BIC  logLik
  -25785.6 -25753.64 12896.8

Random effects:
 Formula: ~1 | raneff
        (Intercept)  Residual
StdDev:  0.03092049 0.1335785

Fixed effects: log(wt) ~ log(len)
                Value   Std.Error    DF   t-value p-value
(Intercept) -4.979120 0.014973032 21771 -332.5392       0
log(len)     3.113961 0.003215856 21771  968.3148       0
 Correlation:
         (Intr)
log(len) -0.939

Standardized Within-Group Residuals:
         Min          Q1         Med          Q3         Max
-10.45076844  -0.52713590   0.02332046   0.56906411   5.42304643

Number of Observations: 21816
Number of Groups: 44
```

*Appendix 3. NAFO 21B landings by country.*

| Year | Canada | | | | France | | Japan | Port | Spain | USSR/ Russia | Other | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nfl | Mar | Mar&Que | Que&CA | France | StP&Mq | | | | | | |
| 1970 | 230 | 0 | 1262 | 0 | 3 | 24 | 3 | 0 | 0 | 0 | 7 | 1529 |
| 1971 | 148 | 0 | 1298 | 0 | 13 | 2 | 0 | 0 | 23 | 103 | 18 | 1605 |
| 1972 | 146 | 0 | 1120 | 0 | 0 | 3 | 0 | 0 | 0 | 65 | 26 | 1360 |
| 1973 | 250 | 0 | 973 | 0 | 1 | 3 | 8 | 0 | 0 | 22 | 17 | 1274 |
| 1974 | 212 | 0 | 789 | 0 | 9 | 4 | 0 | 0 | 3 | 93 | 66 | 1176 |
| 1975 | 177 | 0 | 804 | 0 | 4 | 3 | 0 | 0 | 0 | 86 | 6 | 1080 |
| 1976 | 211 | 0 | 814 | 0 | 1 | 3 | 0 | 0 | 0 | 72 | 3 | 1104 |
| 1977 | 377 | 0 | 910 | 0 | 0 | 19 | 0 | 0 | 13 | 7 | 2 | 1328 |
| 1978 | 246 | 0 | 1188 | 0 | 0 | 1 | 0 | 0 | 4 | 0 | 11 | 1450 |
| 1979 | 300 | 1362 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 1665 |
| 1980 | 202 | 1521 | 0 | 0 | 29 | 5 | 1 | 0 | 0 | 6 | 2 | 1766 |
| 1981 | 197 | 1423 | 0 | 0 | 18 | 7 | 0 | 0 | 9 | 0 | 1 | 1655 |
| 1982 | 413 | 1792 | 0 | 0 | 0 | 18 | 9 | 0 | 28 | 0 | 2 | 2262 |
| 1983 | 131 | 1968 | 0 | 0 | 4 | 37 | 1 | 0 | 132 | 10 | 14 | 2297 |
| 1984 | 194 | 2668 | 0 | 0 | 95 | 13 | 20 | 0 | 88 | 0 | 4 | 3082 |
| 1985 | 639 | 2906 | 0 | 0 | 70 | 18 | 18 | 0 | 322 | 1 | 69 | 4043 |
| 1986 | 705 | 2463 | 0 | 1 | 11 | 17 | 23 | 0 | 134 | 0 | 58 | 3412 |
| 1987 | 338 | 1709 | 0 | 0 | 14 | 37 | 38 | 91 | 408 | 19 | 4 | 2658 |
| 1988 | 161 | 1974 | 0 | 0 | 22 | 27 | 36 | 11 | 129 | 0 | 42 | 2402 |
| 1989 | 166 | 1772 | 0 | 0 | 0 | 49 | 16 | 0 | 42 | 0 | 7 | 2052 |
| 1990 | 144 | 1755 | 0 | 0 | 0 | 91 | 8 | 27 | 245 | 0 | 25 | 2295 |
| 1991 | 177 | 1212 | 0 | 0 | 0 | 97 | 9 | 63 | 621 | 0 | 7 | 2186 |
| 1992 | 114 | 1248 | 0 | 0 | 0 | 35 | 3 | 60 | 0 | 0 | 9 | 1469 |
| 1993 | 141 | 1110 | 0 | 4 | 0 | 0 | 1 | 48 | 1 | 0 | 15 | 1320 |
| 1994 | 37 | 1031 | 0 | 0 | 0 | 0 | 0 | 34 | 57 | 0 | 0 | 1159 |
| 1995 | 107 | 671 | 0 | 0 | 0 | 0 | 1 | 18 | 56 | 0 | 0 | 853 |
| 1996 | 99 | 734 | 0 | 0 | 0 | 0 | 1 | 9 | 26 | 0 | 6 | 875 |
| 1997 | 180 | 870 | 0 | 0 | 0 | 1 | 2 | 14 | 38 | 0 | 0 | 1105 |
| 1998 | 163 | 769 | 0 | 5 | 0 | 1 | 4 | 27 | 42 | 0 | 0 | 1011 |
| 1999 | 160 | 751 | 0 | 1 | 0 | 0 | 0 | 49 | 86 | 4 | 0 | 1051 |
| 2000 | 182 | 684 | 0 | 0 | 0 | 0 | 0 | 28 | 57 | 2 | 0 | 953 |
| 2001 | 300 | 1009 | 0 | 0 | 0 | 0 | 0 | 37 | 102 | 1 | 0 | 1449 |
| 2002 | 361 | 954 | 0 | 0 | 0 | 0 | 0 | 38 | 128 | 12 | 0 | 1493 |
| 2003 | 403 | 0 | 0 | 0 | 0 | 1 | 0 | 86 | 158 | 3 | 85 | 736 |
| 2004 | 303 | 1051 | 0 | 0 | 0 | 0 | 0 | 48 | 47 | 15 | 1 | 1465 |
| 2005 | 255 | 1035 | 0 | 0 | 0 | 0 | 0 | 13 | 32 | 1 | 0 | 1336 |
| 2006 | 222 | 1153 | 0 | 0 | 0 | 0 | 0 | 20 | 0 | 0 | 0 | 1395 |
| 2007 | 160 | 1368 | 0 | 0 | 0 | 0 | 0 | 17 | 13 | 4 | 0 | 1562 |
| 2008 | 273 | 2 | 0 | 0 | 0 | 11 | 0 | 11 | 4 | 1 | 0 | 302 |
| 2009 | 290 | 0 | 0 | 0 | 0 | 0 | 0 | 453 | 14 | 1 | 0 | 758 |
| 2010 | 326 | 1471 | 0 | 0 | 0 | 1 | 0 | 45 | 37 | 2 | 5 | 1887 |
| Total | 9840 | 40436 | 9158 | 11 | 296 | 529 | 202 | 1247 | 3099 | 530 | 512 | 65860 |

Nfl – DFO Newfoundland and Labrador Region
Mar – DFO Maritimes Region
Que – DFO Quebec Region
CA – DFO Central & Arctic Region
StP&Mq – Saint Pierre and Miquelon