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Assessment of White Hake (*Urophycis tenuis*, Mitchill 1815) in NAFO Division 3P

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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

White Hake in NAFO Subdivision (Subdiv.) 3Ps and Divisions (Divs.) 3NO inhabits the southern Grand Bank and St. Pierre Bank of Newfoundland and Labrador (NL), associated with the warmest bottom temperatures (>4^{o}C). White Hake is a demersal gadoid species, subject to ongoing mortality in directed and bycatch fisheries conducted by Canada (Divs. 3NOPs within its Exclusive Economic Zone (EEZ)) and other countries (in the Northwest Atlantic Fisheries Organization's (NAFO) Regulatory Area of Divs. 3NO). Fisheries and Oceans Canada's (DFO) NL spring survey abundance index for Divs. 3NOPs peaked in 2000, due to a very large 1999 year-class. Annual NAFO-reported landings from Subdiv. 3Ps averaged 619 tons in 1994-2002, increased to an average of 1,450 t in 2003-07 (following recruitment of the 1999 year-class to the fishery), then decreased to a 338 t average in 2008-14. Since 2003, the Subdiv. 3Ps biomass index has been in decline, while recruitment remains low.

Available evidence suggests that current White Hake productivity, like other piscivores, may be hindered in Subdiv. 3Ps, therefore it is advised that higher than usual risk-aversion be considered in the management of these stocks. If White Hake in Subdiv. 3Ps is to recover, it will be due to favourable changes in environmental conditions that allow successive years of good recruitment. The most effective way to assist in rebuilding the White Hake population is to conserve as much spawning biomass as possible.

Évaluation de la merluche blanche (*Urophycis tenuis*, Mitchill 1815) dans la division 3P de l'OPANO

RÉSUMÉ

La merluche blanche dans la sous-division 3Ps et les divisions 3NO de l'Organisation des pêches de l'Atlantique Nord-Ouest (OPANO) habite au sud du banc de Saint-Pierre et du Grand Banc à Terre-Neuve-et-Labrador, où la température au fond est la plus chaude (> 4 °C). La merluche blanche est un gadidé de fond qui subit une mortalité continue causée par les pêches dirigées et les prises accessoires du Canada (divisions 3NOPs dans sa zone économique exclusive) et d'autres pays (dans la zone réglementée des divisions 3NO de l'OPANO). Dans les divisions 3NOPs, l'indice d'abondance du relevé de printemps mené à Terre-Neuve-et-Labrador par Pêches et Océans Canada (MPO) a atteint son sommet en 2000 en raison de la très importante classe d'âge de 1999. Les débarquements annuels déclarés par l'OPANO dans la sous-division 3Ps, qui s'élevaient en moyenne à 619 tonnes de 1994 à 2002, ont augmenté à 1 450 tonnes en moyenne de 2003 à 2007 (à la suite du recrutement de la classe d'âge de 1999 à la pêche); ils ont ensuite diminué à 338 tonnes en moyenne de 2008 à 2014. Depuis 2003, l'indice de biomasse dans la sous-division 3Ps est à la baisse et le taux de recrutement demeure faible.

Les preuves disponibles indiquent que la productivité actuelle de la merluche blanche, comme celle des autres piscivores, pourrait être entravée dans la sous-division 3Ps. Par conséquent, il est conseillé de prendre en compte une aversion pour le risque plus élevée qu'à l'habitude dans la gestion de ces stocks. Si la merluche blanche dans la sous-division 3Ps devait se rétablir, cela serait dû à des changements favorables dans les conditions environnementales qui permettraient des années successives de bon recrutement. La façon la plus efficace pour aider à rétablir la population de merluches blanches est de conserver autant de biomasse du stock reproducteur que possible.

INTRODUCTION

White Hake (*Urophycis tenuis*, Mitchill 1815) is a highly fecund gadoid species distributed in the Northwest Atlantic from Cape Hatteras to southern Labrador. Present knowledge of its biology for the Grand Banks and southern Newfoundland has been summarized in previous assessments of this species in Newfoundland waters (Han and Kulka 2007; Simpson et al. 2012; Simpson et al. 2016).

Stock structure of White Hake has been investigated using morphological characteristics and parasitic fauna (Hurlburt and Clay 1998; Melendy et al. 2005), tagging work (Kohler 1971), and allozyme data (Clay et al. 1992). More recently, polymorphic micro-satellite loci have been applied to investigate stock structure in White Hake (Seibert and Ruzzante 2006; Zinck 2007; Roy et al. 2012). Three genetically distinct populations were identified, which straddle several NAFO Divisions and overlap in their distributions (Roy et al. 2012). One such population of White Hake includes Divs. 3OP. For management purposes, White Hake in Divs. 3NO and Subdiv. 3Ps are assessed separately, despite the fact that, biologically, hakes in both areas constitute one biological stock.

This paper presents an assessment of White Hake in NAFO Div. 3P (Fig. 1), which includes Subdivisions 3Ps and 3Pn, and focuses on available commercial fisheries data and DFO-NL research survey information.

ECOSYSTEM OVERVIEW

Han and Kulka (2007) investigated dispersion and survival potential of White Hake eggs, larvae, and small pelagic juveniles with a three-dimensional regional ocean circulation model. These early life stages passively inhabit the upper water layer, where they develop and are dispersed by ocean currents for two to three months (depending on water temperature) before resultant juveniles settle on the bottom (Markle et al. 1982; Lang et al. 1996). Modelling results suggested that a weak along-slope current and strong on-bank flow increase juvenile retention on the southern Grand Banks. In addition, spawning below the surface Ekman layer in late spring maximizes chances for White Hake juveniles to settle on the southern Grand Banks in autumn.

White Hake larvae and small pelagic juveniles consume plankton (Coates et al. 1982). Diet analysis of demersal juveniles collected from the Mid-Atlantic Bight to the southern Scotian Shelf indicated that White Hake prey almost exclusively on crustaceans, such as shrimp, isopods, amphipods, and crabs; however, polychaetes are also consumed (Bowman 1981). It has been suggested that White Hakes can recognize benthic food items (e.g., shrimp, crabs) by contact with their long, sensitive pelvic fins, which they appear to drag over the bottom. Although adult White Hakes prey heavily on small fish, including juveniles of their own species (Langton et al. 1994), shrimp and other crustaceans are still important in their diet (Langton and Bowman 1980). According to Langton and Bowman (1980), fish most often consumed on the Scotian Shelf and southward were clupeids (primarily Atlantic Herring, *Clupea harengus*), gadids (especially Silver Hake, *Merluccius bilinearis*; Red Hake, *Urophycis chuss*; and Longfin Hake, *Phycis chesteri*), Atlantic Mackerel (*Scomber scombrus*), argentines, and Wrymouth (*Cryptacanthodes maculatus*). Diet analysis of White Hakes collected from the southwest slope of the Grand Bank and St. Pierre Bank indicated that the following fish species were their most common prey: Atlantic Cod (*Gadus morhua*), Haddock (*Melanogrammus aeglefinus*), flatfish, sand lances, Capelin (*Mallotus villosus*), argentines, and grenadiers, followed by planktonic crustaceans, such as shrimp (Petrov 1973). Benthic molluscs (e.g., clams, scallops) and echinoderms (e.g., sea urchins, sea stars) do not appear to be important prey for White Hake in

Newfoundland and Labrador waters (Petrov 1973), or elsewhere (Collette and Klein-MacPhee 2002).

White Hakes are cannibalistic, and also consumed by Porbeagle Shark (*Lamna nasus*), Blue Shark (*Prionace glauca*), and Bluefin Tuna (*Thunnus thynnus*; Aasen 1961; Compagno 1984; Scott and Scott 1988). Off of the coast of Maine (USA), Atlantic Puffins (*Fratercula arcitca*) and Arctic Terns (*Sterna paradisaea*) prey on pelagic juvenile White Hakes in surface waters (Fahay and Able 1989). In the Gulf of St. Lawrence, White Hake constitutes a large part of the diet of both Grey Seals (*Halichoerus grypus*) and Harp Seals (*Phoca groenlandica;* Hammill and Stenson 2002; Hammill et al. 2014). Benoit et al. (2011) suggested that predation by Grey Seals on White Hake in the southern Gulf of St. Lawrence has elevated adult natural mortality to the extent that it is responsible for a decline in White Hake abundance. Hammill et al. (2007) did not find any White Hake in Grey Seal stomachs collected along Newfoundland's south coast in 1985-2004, although the sample size was very small (n=24). Predation by seals in Newfoundland waters may contribute to low levels of White Hake abundance, but further studies using larger sample sizes are necessary to quantify any effects of seal predation on White Hake abundance in Div. 3P.

COMMERCIAL FISHERIES REMOVALS

Commercial fisheries removals of White Hake in NAFO Div. 3P were examined for 1960-2014, using three data sources: the Northwest Atlantic Fisheries Organization (NAFO) STATLANT-21A landings data (1960-2014), which were reported by NAFO member countries; DFO-NL Zonal Interchange File Format (ZIFF) landings data (1985-2014), as recorded in logbooks by Canadian fishers operating in Canada's EEZ; and Canadian At-Sea Fisheries Observers' catch and discards data (1978-2013), collected at sea on a set-by-set basis in a standardized format. It must be noted that Canadian At-Sea Observers constitute the only reliable source of data on total catch by species, and discarding at sea.

NAFO-reported landings of White Hake in Div. 3P were largely attributed to fishing by Canadian fleets (Table 1; Fig. 2). Since 1989, only France (St. Pierre and Miquelon) has reported landings in Div. 3P: all of which were taken in Subdiv. 3Ps. Historically, Spain (1965-72) and Russia (1971-76) conducted fisheries in Div. 3P. In addition, other countries (e.g., Ireland, Japan, Poland) occasionally reported landings in Div. 3P during the 1960s and 1970s.

Currently in Subdiv. 3Ps the directed White Hake fishery is open to two fleets, the <65 and the 65'-100'fleet, in both cases hook and line, and gillnets are authorized. In Subdiv. 3Pn the fishery is only open to the 65' fleet, the season runs from July 15-September 30 and is restricted to using longline with a maximum of 4,000 hooks. Fishing is also restricted to water depths <125 fathoms.

Overall, NAFO-reported landings of White Hake in Div. 3P were mainly from Subdiv. 3Ps (Table 1; Fig. 2). During the 1960s, annual landings in Subdiv. 3Ps averaged 266 t, then increased significantly in 1971 and averaged 1,608 t over 1971-78. Landings were variable throughout 1979-93, but remained relatively high (averaging 1,044 t). During 1994-99, landings declined to an average of 517 t, then significantly increased to 1,241 t on average over 2000-08. In 2009-14, landings averaged 310 t (i.e., comparable to those reported in the 1960s). NAFO-reported landings from Subdiv. 3Ps were 191 t in 2013, and 383 t in 2014.

ZIFF-reported annual landings of White Hake in Div. 3P also showed a majority from Subdiv. 3Ps, with none reported from Subdiv. 3Pn after 2003 (Table 2; Fig. 3). However, most of the reported landings from Subdiv. 3Ps during the mid-1980s to early 90s should be interpreted with caution, as landings of Atlantic Cod by Canadian longline fisheries during this period were misreported as White Hake. In 2000-08, ZIFF-reported landings of White Hake from Subdiv. 3Ps averaged 1,031 t annually, and 243 t in 2009-14.

ZIFF data indicated that White Hakes in Subdiv. 3Ps over 2003-14 were primarily landed from gillnets (71% on average), secondarily from longlines (25% ave.), and a small proportion from otter trawls (4% ave.; Fig. 4). This species was landed predominantly from Subdiv. 3Ps directed fisheries and also as bycatch (Fig. 5). White Hake bycatch in 1998-2014 was landed mainly from gillnet fisheries targeting Atlantic Cod (62% on average) and Redfish (*Sebastes* spp.; 33% ave.), with a small proportion from the Monkfish (*Lophius americanus*) fishery (5% ave.; Fig. 6). White Hake bycatch over 1998-2014 also occurred in Atlantic Cod (75% on average) and Atlantic Halibut (*Hippoglossus hippoglossus*; 25% ave.) longline fisheries, and in otter trawl fisheries targeting Atlantic Cod, redfish, and Witch Flounder (*Glyptocephalus cynoglossus*; 33% on average for each directed species; Fig. 6). In White Hake-directed fisheries, bycatch of other commercially important species occurred, such as Atlantic Cod, Atlantic Halibut, American Plaice (*Hippoglossoides platessoides*), Haddock, and Monkfish.

NAFO-reported landings of White Hake from Subdiv. 3Pn were a small portion of the Div. 3P total (Table 1; Fig. 2). During the 1970s, landings of this species from Subdiv. 3Pn averaged 173 t, with a maximum of 295 t in 1972. Throughout the 1980s and 1990s, landings averaged 88 t annually. Reported landings from Subdiv. 3Pn then averaged 38 t over 2004-11, and 18 t in 2012-14.

ZIFF-reported annual landings of White Hake from Subdiv. 3Pn averaged 63 t annually over 1985-2003, with 5 t in 2003 and none reported afterwards (Table 2; Fig. 3). This species was primarily reported from longlines (62% on average), secondarily from otter trawls (22% ave.), and from gillnets (15% ave.; Fig. 4). White Hake landings from Subdiv. 3Pn were almost all reported as bycatch (Fig. 5) from longline fisheries targeting Atlantic Cod (57% on average) and Atlantic Halibut (43% ave.), and from otter trawl fisheries directing for redfish (81% ave.) and Atlantic Cod (19% ave.; Fig. 7).

Although dependent on the percentage of actual At-Sea Observer coverage of each fishery in each year, observed total catches (including discards; not scaled up to entire fisheries) of White Hake in Div. 3P over 1997-2008 were the largest annually in the gillnet and longline fisheries directing for this species (14 t and 3 t on average, respectively; Fig. 8). Observed catches decreased to 3 t (gillnets) and 1 t (longlines) over 2009-13. White Hake bycatch in 1997-2008 was observed mainly in the Atlantic Cod otter trawl and gillnet fisheries (4 t and 1 t, respectively; Fig. 8), the Witch Flounder and redfish otter trawl fisheries (3 t and 2 t, respectively), and the Atlantic Cod and Atlantic Halibut longline fisheries (4 t and 1 t, respectively). Although observed bycatch of White Hake decreased over 2009-12 for most of those groundfish fisheries, it increased in the Atlantic Cod and Atlantic Halibut longline fisheries (7 t and 3 t, respectively). It should be noted that changes in these observed catches may be a reflection of the changes in annual Observer coverage of these fisheries in Div. 3P.

To estimate annual total catch of White Hake (i.e., landings + discards at sea) in gillnet and longline fisheries directing for this species in Div. 3P, a method based on Campana et al. 2011 was used with the Canadian At-Sea Fisheries Observer database for 1985-2013 (see Simpson and Miri 2013 for detailed methodology). However, catch estimates were dependent on the percentage of actual Observer coverage of each fishery in each year, as well as whether the DFO-NL ZIFF database contained reported landings of this species for each year of Observer coverage. Combined estimates for both gears peaked at 1,080 t in 2006, although most catches occurred in the White Hake-directed gillnet fishery during this period (Fig. 9). Annual catch estimates for Div. 3P remained below 69 t since 2009.

Annual estimates of White Hake bycatch in Div. 3P over 1997-2008 suggested that the Atlantic Cod longline fishery averaged 219 t annually, the redfish gillnet fishery 216 t, the Atlantic Cod gillnet fishery 152 t, the Atlantic Halibut longline fishery 63 t, the redfish otter trawl fishery 29 t, the Monkfish gillnet fishery 15 t, and the Witch Flounder otter trawl fishery 11 t (Fig. 9). Combined bycatch estimates peaked in 2008. Furthermore, combined annual bycatch estimates for White Hake in 2009-12 have not exceeded 500 t, and were primarily from the longline fishery directing for Atlantic Cod (250 t average annually), while the Atlantic Halibut longline and Atlantic Cod gillnet fisheries annually averaged 25 t and 40 t (respectively); although a bycatch estimate for the latter fishery suggested 730 t of White Hake in 2013.

Length distributions of White Hake observed in Canadian gillnet fisheries (using 152 mm mesh) in Subdiv. 3Ps indicated that a range of 41-109 cm fish was caught; with modes of 77-78 cm in 2005, 78 cm in 2006, 67 and 71 cm in both 2007 and 2008, and 71 cm in 2009 (Fig. 10). The Atlantic Cod gillnet fishery (using 140 mm mesh) caught a contracted range of 52-74 cm White Hake in 2011, with a mode at 61 cm. Canadian longline fisheries captured 39-105 cm fish; with modes of 66 and 68 cm in 2008, 62 cm in 2010, and 68 cm in 2011; and a contracted size range of 45-73 cm with a 55-cm mode in 2012 (Fig. 11).

SPRING RESEARCH SURVEY

Stratified-random bottom trawl surveys have been conducted by Canadian research vessels in the spring (April-June) of each year from 1972 to the present in Subdiv. 3Ps, and from 1986 to 2013 in Subdiv. 3Pn. The most significant alterations in the DFO-NL standardized survey design are changes in survey gear. Accordingly, the spring survey can be separated into three time series, based on the trawl used in each period: 1972-1983 (Yankee 41.5), 1984-1995 (Engel 145), and 1996 to the present (Campelen 1800). McCallum and Walsh (1996) and Walsh and McCallum (1996) described the geometry and specifications of the Engel and Campelen trawls. While sampling design remained constant, additional shallower and deeper strata were included after 1993, along with modifications to some of the original strata (Bishop 1994). Additional causes of variation in spring survey coverage are discussed in detail by Brodie and Stansbury (2007), and Healey and Brodie (2009). No size-based conversion factors between trawls were derived from comparative surveys for White Hake; therefore, standardized catch rate estimates and the resulting biomass and abundance indices cannot be directly compared between trawl types. Furthermore, most of Subdiv. 3Ps was not surveyed in 2006 due to mechanical difficulties with research vessels. In addition, Subdiv. 3Pn could not be sampled in 2008 and 2014-15 due to research vessels' mechanical difficulties. Thus, survey estimates for those years are not comparable to others in the Campelen time series.

SURVEY ABUNDANCE AND BIOMASS INDICES

The spring biomass index for White Hake on the Grand Banks in Divs. 3NOPs increased rapidly in 1999-2000 to approximately 26,000 t, but then declined steeply, and is presently at low levels compared to earlier estimates in the Campelen time series (Fig. 12). During the DFO-NL spring survey of 2000, the estimated abundance of about 117,000,000 fish was 10 times greater than that observed in either the first years of the Campelen series or during recent years, due to the very large 1999 year-class. In 2011, the abundance index increased from low levels to about 27,000,000 fish (three times the 2007-09 average), primarily due to a moderate 2010 year-class. Average spring abundance estimates were 16,110,814 White Hakes in 2013-15.

White Hake abundance and biomass estimates from spring surveys indicate that the majority of the Div. 3P stock component is consistently found in Subdiv. 3Ps, ranging from approximately 0.25 to 15 million fish and 467-13,000 t; and from 0.19 to 2 million fish and 170-2,900 t in Subdiv. 3Pn (Table 3). Temporal trends in stock size were similar in both Subdivisions, despite a difference in the magnitude of estimates (Fig. 13). White Hake abundance and biomass increased through the first half of the Yankee and Engel time-series. In Subdiv. 3Ps, abundance and biomass peaked in 1981 (4.7 million fish; 7,500 t, respectively) and 1988 (5.5 million fish; 13,000 t), then declined towards the end of each time-series; while estimates for the Campelen time-series increased through the late 1990s and peaked in 2002 (15 million fish; 10,000 t), with a sharp decline thereafter. Estimates of abundance and biomass ranged from 4 to 7 million fish, and 2,600-7,000 t (respectively) in 2003-15. In recent years, there was a marked decline in the biomass of White Hake in Subdiv. 3Ps.

In Subdiv. 3Pn (Fig. 14), abundance and biomass peaked in 1988 (1.1 million fish; 2,900 t, respectively), then declined, and increased through the late 1990s to early 2000s and again during the last 5-6 years, with peaks in 2000 (1.5 million fish; 970 t) and 2009 (1.9 million fish; 700 t).

Estimates of mean number and mean weight per tow from spring surveys in Subdiv. 3Ps ranged from 0.5 to 7.1 fish/tow and 0.9-12.4 kg/tow, with almost no differences between Engel and Campelen time-series; whereas these estimates tended to be higher and more variable (i.e., larger Confidence Intervals or CIs) for the Yankee time-series (Fig. 15). Catch rates increased through the mid-1970s then declined until the early 1980s; similar trends occurred from the 1980s until the mid-2000s, when catch rates stabilized at very low levels. Mean number and mean weight per tow ranged from 1.1 to 9.3 fish/tow and 0.8-23.5 kg/tow, respectively, in Subdiv. 3Pn, and the precision of mean number per tow was generally lower when compared to catch rates in Subdiv. 3Ps. Catch rates followed a similar pattern to those in Subdiv. 3Ps: peaking in the late 1980s, then declining over subsequent years.

Using NAFO-reported landings and the DFO-NL spring survey biomass index, estimates of Relative F were calculated for White Hake in Subdiv. 3Ps. Relative fishing mortality (Rel. F = NAFO-reported landings/Can. spring biomass), increased to a high peak in 2003-05 supported by the very large 1999 year-class, then declined to its lowest levels in 2011-13 (Fig. 16). Relative fishing mortality in 2014 is near the average of the 1996-2014 time period.

MATURITY, SIZE STRUCTURE, SEX RATIOS, AND RECRUITMENT

Maturity analysis with data collected by DFO-NL spring surveys in 1996-2014 indicated that length at 50% maturity for White Hake is different between sexes; but very similar for each sex among years and between areas (Divs. 3NO *versus* Subdiv. 3Ps; Fig. 17). Females reach 50% maturity at 54 cm, and males do so at 38 cm.

Regarding abundance by life stage, White Hakes in their first year correspond to lengths ≤26 cm, while 27-57 cm represents Age 2+ juveniles, and 58+ cm fish are primarily mature adults (Kulka et al. 2005). A 2010 cohort was seen as a moderate peak of 1-year-olds in 2011, as a small peak of 2+ juveniles in 2012, and as a small peak of larger immatures in 2013 (Fig. 18). Note that almost all of the Age 1 White Hakes were found in Divs. 3NO, whereas 2+ juveniles were observed almost equally in Divs. 3NO and in Subdiv. 3Ps. For mature White Hakes (58+ cm), percent abundance was higher in Divs. 3NO relative to Subdiv. 3Ps, and almost all adults surveyed in 2014 were found in Divs. 3NO.

Concerning the sex ratio of White Hakes in Subdiv. 3Ps, the abundance index from DFO-NL spring surveys indicated two peaks of females in 2007: one at 44 cm in length, and another at 52-62 cm (Fig. 19). Males comprised 37% of the 2007 survey results, with mainly 46-51 cm and 62-67 cm fish. Peaks of females were again observed in 2008: a small one at 30-32 cm in length, one at 37-45 cm, and a predominant one at 51-60 cm. Males constituted 41% of the 2008 results, with primarily 36-49 cm fish. In 2009, a small peak of Age 1 White Hakes was observed (33% female). This 2008 cohort was also found as juveniles in 2010; with 23% of all immatures comprised of 32-42 cm females, and 30% being 29-39 cm males. In 2011, 35-57 cm females dominated the immatures (52%), and a peak of 32-41 cm males (31%) was also observed. Results were similar for immature females (54%) and males (27%) in 2012. In 2013, a small peak of 1-year-olds (46% female; 2012 year-class), and other small peaks of 28-32 cm females (20% of all immatures), 46-49 cm females (9%), 27-30 cm males (14%), and 43-48 cm males (10%) were seen. In 2014, almost no Age 1 or mature White Hakes were found in Subdiv. 3Ps, and 71% of 2+ juveniles were observed in a 28-39 cm range (34% female).

In Canadian spring research surveys, the number of White Hakes ≤26 cm in length is assumed to be an index of recruitment at Age 1. Abundance of Age 1 White Hakes in 2000 was very large, but no large year-classes were observed since 1999 (Fig. 20). The index of recruitment (sexes combined) for 2011 was comparable to that seen in 1999, and a smaller peak in 2013 was similar to one in 2005. In 2014, the index was low.

DISTRIBUTION AND HABITAT ASSOCIATIONS

Geo-referenced catch and hydrographic data (e.g., water depth, bottom temperature, salinity) from DFO-NL spring research surveys were used to assess spatial distribution and habitat associations of White Hake in Divs. 3NOPs. Maps of their mean numbers per survey tow were plotted for 2001-05 (Fig. 21), 2006-10 (Fig. 22), and 2011-15 (Fig. 23). Similar maps were also created for Div. 3P (Figs. 24-26). Recent distributions of White Hake mean numbers per tow in Divs. 3NO and Subdiv. 3Ps were consistent with historic survey catch data (see Simpson et al. 2016 for details), and indicated that White Hakes in Newfoundland waters were found mostly along the continental shelf slope of the southwestern Grand Bank (Div. 3O), and in the Laurentian and Hermitage Channels (Div. 3P).

A relationship between White Hake distribution and the habitat variables of depth and bottom temperature were determined for Subdiv. 3Ps in 2002-14 using the methods described by Perry and Smith (1994) and Smith (1996; see Simpson et al. 2016 for detailed methodology). Unweighted cumulative frequency distributions (CFDs) of depth and bottom temperature were compared to catch-weighted CFDs, and indicated strong associations for this species with both bottom temperature (Fig. 27) and depth (Fig. 28). Results were also consistent with previous studies in Newfoundland waters, which indicated that White Hake are temperature-keepers: preferring bottom waters warmer than 4°C (Kulka and Mowbray 1998; Kulka and Simpson 2002; Kulka et al. 2005; Simpson et al. 2012). In addition to water temperature, inshore eelgrass beds constitute an important nursery habitat for small demersal juveniles to avoid detection by larger predators (Fahay and Able 1989; Heck et al. 1989; Gregory et al. 1997; Collette and Klein-MacPhee 2002; Lazzari and Stone 2006; Ings et al. 2008).

There is no evidence to suggest that the availability of suitable habitat is limiting White Hake population size, or that it will constrain future population increases. However, the ongoing effects of climate change on ocean temperature, salinity, and currents may cause significant impacts on White Hake habitats in Divs. 3NOPs, and should be considered in management decisions concerning the Subdiv. 3Ps component.

ASSESSMENT RESULTS

Limit reference points for White Hake in Div. 3P have not been defined. Previous investigations of limit reference points for this species were conducted (Simpson et al. 2015*c,* 2016) for the stock area Divs. 3NOPs using a Bayesian surplus production model, Catch-resilience models (Martell and Froese 2013), and empirical methods based on Canadian research survey indices of biomass. During its June 2015 Meeting, NAFO Scientific Council concluded that none of these assessment models were acceptable in capturing the episodic character of this White

Hake population and, therefore, the resulting limit reference points were not accepted (Simpson et al. 2015*b*, 2015*c*).

Since limit reference points have not been established for the stock area (Divs. 3NOPs), it is inappropriate to establish them for Subdiv. 3Ps alone. However, as an example, B_{msy} proxies based on B_{max}, as well as periods associated with high productivity, were calculated for White Hake in Subdiv. 3Ps (Fig. 28). These calculations yielded similar estimates for B_{msy} and the associated B_{lim}; the latter being defined as 40% of the B_{msy} proxy, as outlined in the DFO Precautionary Approach Framework (DFO 2009, 2013*a*). Limit reference points based on B_{loss} from the Canadian survey biomass index was also considered.

B_{max} during recent Canadian Campelen spring surveys occurred in 2000, with an estimated biomass of 10,293 t; resulting in a hypothetical estimated limit reference point of 4,120 t. Based on a geometric mean of the highest productivity period in 2000-02, the resulting hypothetical limit reference point was 3,780 t. Biomass in 2009 was the lowest estimate of the recent spring surveys, from which the Subdiv. 3Ps component of the population increased; therefore, the associated B_{loss} was 2,582 t.

PERSPECTIVE ON SUBDIV. 3PS WHITE HAKE

In Div. 3P, White Hake was generally in decline since its peak biomass of 10,293 t in 2000. However, biomass has been generally stable during the period 2008-14. Based on accepting a B_{loss} of 2,582 t, White Hake in Subdiv. 3Ps is currently above the hypothetical limit reference point (Fig. 29). Accepting either $B_{max2000}$ or $B_{max2000\text{-}2003}$ as proxies for B_{msy}, the resulting limit reference points are above the current estimate of population status, thereby indicating that this population is in the Critical Zone of the DFO Precautionary Approach Framework (DFO 2009, 2013*a*). Furthermore, while total biomass remains low for this population, of equal importance is that recruitment remains very low for White Hake in Subdiv. 3Ps, as well as for its entire Divs. 3NOPs population.

Using the past three years as status quo, current landings from Subdiv. 3Ps are below their historic levels. In Subdiv. 3Ps, status quo landings was 261 t, while the status quo was 18 t for Subdiv. 3Pn. It must be noted that, without a recruitment pulse such as that seen for White Hake in 1999-2000 (thereby supporting high landings over 2003-07), higher catch rates are not sustainable. In addition, given the overall decline in White Hake biomass since 2000, coupled with persistently poor recruitment, there is no evidence that this decline will cease in the near future. Given the current decline rate, and using B_{loss} as a limit reference point, there is a 63% probability that its biomass in 2016 will be below B_{loss}. Similarly, the probability of being below B_{loss} in 2017 and 2018 are 70% and 76%, respectively. If White Hake in Subdiv. 3Ps is to recover, it will be due to favourable changes in environmental conditions that allow successive years of good recruitment. The most effective way to assist in rebuilding the White Hake population is to keep as much spawning biomass in the water as possible.

ASSESSMENT REVIEW AND GUIDANCE

The status of White Hake in NAFO Subdiv. 3Ps was first assessed in 1996 (DFO 1996), followed by assessments in 1998 (DFO 1998) and 2002 (DFO 2002). Subsequently, following an assessment of White Hake in NAFO Divs. 3LNO and Subdiv. 3Ps for NAFO Scientific Council (Kulka et al. 2004), White Hake in Divs. 3NO came under NAFO quota regulation in September 2004. NAFO Fisheries Commission decided that a Total Allowable Catch (TAC) of 8,500 t be established for Divs. 3NO for 2005-07. This fishing allocation was between Canada at 2,500 t, the EU at 5,000 t, Russia at 500 t, and remaining NAFO-member countries at 500 t.

No quota was implemented for Div. 3L, nor did Canada implement a TAC for Subdiv. 3Ps in its EEZ. The TAC for Divs. 3NO was maintained at 8,500 t for 2008-09. In September 2009, NAFO Fisheries Commission reduced the TAC for White Hake in Divs. 3NO from 8,500 t to 6,000 t for 2010-2011. This TAC was further reduced to 5,000 t for 2012, and to 1,000 t for 2013 with a *caveat* that the TAC for 2013 can be increased in-season to 5,000 t, based on evidence of an "exceptional" increase in the availability of White Hake (see Table 2 footnote). For 2016, the TAC remains at 1,000 t, with the increase under exceptional conditions lowered to 2,000 t.

Following the implementation of the TAC in Divs. 3NO and the assessment of White Hake on a two-year schedule at NAFO Scientific Council, White Hake has not been assessed domestically. The assessment of White Hake, and interim monitoring reports that are produced in non-assessment years, include the assessment information for Subdiv. 3Ps White Hake due to the prevailing viewpoint that Divs. 3NO and Subdiv 3Ps White Hake constitute a single stock (Simpson et al. 2015*a*).

Given the NAFO assessment framework described above, a domestic assessment of Subdiv. 3Ps White Hake on a five-year schedule would be sufficient. Although more frequent updates on this population component may be recommended by the fact that it may already be in the Critical Zone of DFO's Precautionary Approach Framework and a Canadian White Hake-directed fishery continues, the annual peer review by NAFO Scientific Council will ameliorate any negative outcomes. Interim-year assessments should be triggered by significant negative changes in DFO-NL spring survey biomass and abundance indices for this species (as peer-reviewed annually in June by NAFO Scientific Council). Based on guidance from TESA (DFO 2016), if the DFO research survey biomass index statistically declines by more than two standard deviations, a re-assessment and revised advice on the population will be required. Furthermore, interim-year assessments should also be triggered by an increase in reported landings relative to the existing status quo for Subdiv. 3Ps, without a concomitant significant positive change in the DFO spring survey biomass index.

CONCLUSION

Recent DFO-NL spring survey indices indicate that the abundance and biomass of White Hake in Div. 3P remain at low levels.

Given that good recruitment rarely occurs and remains unpredictable for this White Hake population, commercial fishing pressure should be regulated in Div. 3P by a TAC set at a level that will allow survival and growth to maturity of larger year-classes. This strategy is crucial to rebuilding the population; especially given that the drastic decline in White Hake biomass following the large recruitment event of 1999-2000 was attributed to fishing (Kulka and Miri 2007).

Regulations that limit the amount of White Hake bycatch for other directed fisheries in Canada's EEZ could also be implemented under DFO's new *Policy for Managing Bycatch* (DFO 2013*b*).

Given that Canadian At-Sea Fisheries Observers constitute the only reliable source of data on total catch by species and discarding at sea, annual Observer coverage of Canadian White Hake-directed and bycatch fisheries should be increased to significantly improve the reliability and representativeness of estimates of total removals of this species due to fishing.

A five-year assessment schedule is recommended with interim reporting using the Canadian Science Advisory Secretariat's (CSAS) Science response statements, based on the biennial Divs. 3NOPs White Hake stock assessments and interim monitoring reports (i.e., for non-assessment years) produced for NAFO Scientific Council. A full assessment is warranted if the major population indicator (i.e., DFO spring survey biomass index) statistically declines more than two standard deviations. This re-assessment may result in revised catch advice for White Hake-directed and bycatch fisheries.

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TABLES

Table 1. NAFO STATLANT-21A reported landings (tonnes) of White Hake in Div. 3P, 1960-2014.

Year	Subdiv. 3Pn non-Canada	Subdiv. 3Pn Canada	Subdiv. 3Pn Total	Subdiv. 3Ps non-Canada	Subdiv. 3Ps Canada	Subdiv. 3Ps Total	Div. 3P Total
1960	-	-	-	500	232	732	732
1961	4	4	8	32	100	132	140
1962	-	21	21	1	74	75	96
1963	-	4	4	8	103	111	115
1964	-	18	18	-	124	124	142
1965	-	22	22	60	71	131	153
1966	-	-	-	45	39	84	84
1967	72	8	80	43	67	110	190
1968	-	133	133	20	403	423	556
1969	-	202	202	6	375	381	583
1970	30	153	183	227	397	624	807
1971	-	177	177	221	1443	1664	1841
1972	-	295	295	115	2062	2177	2472
1973	-	203	203	84	1330	1414	1617
1974	-	169	169	18	1305	1323	1492
1975	-	59	59	765	1432	2197	2256
1976	-	109	109	10	1344	1354	1463
1977	-	122	122	-	1683	1683	1805
1978	-	176	176	-	1051	1051	1227
1979	-	235	235	-	660	660	895
1980	-	144	144	-	546	546	690
1981	-	130	130	-	1030	1030	1160
1982	-	123	123	-	773	773	896
1983	-	83	83	-	425	425	508
1984	-	122	122	-	683	683	805
1985	-	63	63	-	1156	1156	1219
1986	-	57	57	14	1228	1242	1299
1987	-	92	92	-	1318	1318	1410
1988	-	66	66	12	683	695	761
1989	-	22	22	3	706	709	731
1990	-	13	13	35	1441	1476	1454
1991	-	44	44	36	1445	1481	1524
1992	-	80	80	-	1208	1208	1324
1993	-	244	244	-	741	741	985
1994	-	294	294	-	382	382	676
1995	-	59	59	-	420	420	479
1996	-	80	80	-	362	362	442
1997	-	9	9	-	315	315	324
1998	-	8	8	1	561	562	570
1999	-	34	34	-	575	575	609
2000	-	60	60	134	976	1110	1170
2001	-	141	141	10	920	930	1071
2002	-	52	52	3	915	918	970

Table 1. Continued.

Year	Subdiv. 3Pn non-Canada	Subdiv. 3Pn Canada	Subdiv. 3Pn Total	Subdiv. 3Ps non-Canada	Subdiv. 3Ps Canada	Subdiv. 3Ps Total	Div. 3P Total
2003	-	210	210	3	1105	1108	1318
2004	-	77	77	22	1361	1383	1460
2005	-	45	45	23	1615	1638	1683
2006	-	15	15	1	1484	1485	1500
2007	-	35	35	2	1253	1255	1290
2008	-	45	45	6	659	665	710
2009	-	26	26	-	362	362	388
2010	-	19	19	-	378	378	397
2011	-	41	41	-	200	200	241
2012	-	18	18	-	208	208	226
2013	-	25	25	-	191	191	216
2014	-	11	11	-	383	383	394

Table 2. DFO-NL ZIFF reported landings of White Hake in Div. 3P, 1985-2014.

Year	Subdiv. 3Pn	Subdiv. 3Ps	Div. 3P
1985	39	1,138	1,177
1986	60	876	936
1987	93	1,314	1,407
1988	68	687	755
1989	22	680	702
1990	13	1,441	1,453
1991	43	1,401	1,444
1992	80	1,163	1,242
1993	243	732	975
1994	293	383	676
1995	58	396	454
1996	74	565	639
1997	9	407	416
1998	7	498	505
1999	34	570	604
2000	0	975	975
2001	0	919	919
2002	-	868	868
2003	5	1,054	1,059
2004	-	1,096	1,096
2005	-	1,406	1,406
2006	-	1,221	1,221
2007	-	1,134	1,134
2008	-	601	601
2009	-	282	282
2010	-	308	308
2011	-	161	161
2012	-	183	183
2013	-	170	170
2014	-	356	356

*Table 3a. Abundance and biomass estimates of White Hake from 1972-2015 DFO-NL spring research surveys – Yankee series.**

Year	Abundance (000s) Subdiv. 3Ps	Abundance (000s) Subdiv. 3Pn	Biomass (tonnes) Subdiv. 3Ps	Biomass (tonnes) Subdiv. 3Pn
1972	1556	-	2725	-
1973	247	-	465	-
1974	2055	-	5224	-
1975	2646	-	4491	-
1976	3856	-	4778	-
1977	3935	-	7168	-
1978	4058	-	6774	-
1979	3077	-	6310	-
1980	2053	-	3970	-
1981	4743	-	7448	-
1982	1340	-	4283	-
1983	1508	-	2539	-

*Table 3b. Abundance and biomass estimates of White Hake from 1972-2015 DFO-NL spring research surveys – Engel series.**

Year	Abundance (000s) Subdiv. 3Ps	Abundance (000s) Subdiv. 3Pn	Biomass (tonnes) Subdiv. 3Ps	Biomass (tonnes) Subdiv. 3Pn
1984	1179	-	2558	-
1985	3045	-	5303	-
1986	4186	299	11105	234
1987	4438	662	9866	1395
1988	5533	1136	13005	2870
1989	4130	756	6884	1745
1990	2941	312	3988	563
1991	3800	189	4591	392
1992	2699	193	3008	170
1993	2670	236	2929	282
1994	2274	226	2433	198
1995	2104	208	2334	305

*Table 3c. Abundance and biomass estimates of White Hake from 1972-2015 DFO-NL spring research surveys – Campelen series.**

Year	Abundance (000s) Subdiv. 3Ps	Abundance (000s) Subdiv. 3Pn	Biomass (tonnes) Subdiv. 3Ps	Biomass (tonnes) Subdiv. 3Pn
1996	8089	318	6282	230
1997	12432	617	8507	260
1998	4765	315	4007	367
1999	8654	949	8236	599
2000	11743	1504	10294	967
2001	13792	1569	8092	940
2002	15098	806	10118	654
2003	6904	262	5762	180
2004	6977	538	6622	262
2005	5506	970	5249	490
2006	-	722	-	472
2007	6061	862	6940	676
2008	3991	-	3633	-
2009	4547	1957	2582	690
2010	5285	1851	3739	701
2011	6745	1032	4727	589
2012	4657	1468	3686	917
2013	5581	1791	3987	703
2014	5834	-	3630	-
2015	6032	-	3596	-

*Surveys were conducted with a Yankee trawl (1972-83), Engel trawl (1984-95), and Campelen trawl (1996-2015). Note that Yankee, Engel, and Campelen time series are not standardized, and all of Subdiv. 3Ps was not surveyed in spring 2006, due to Canadian research vessels' mechanical difficulties.

FIGURES

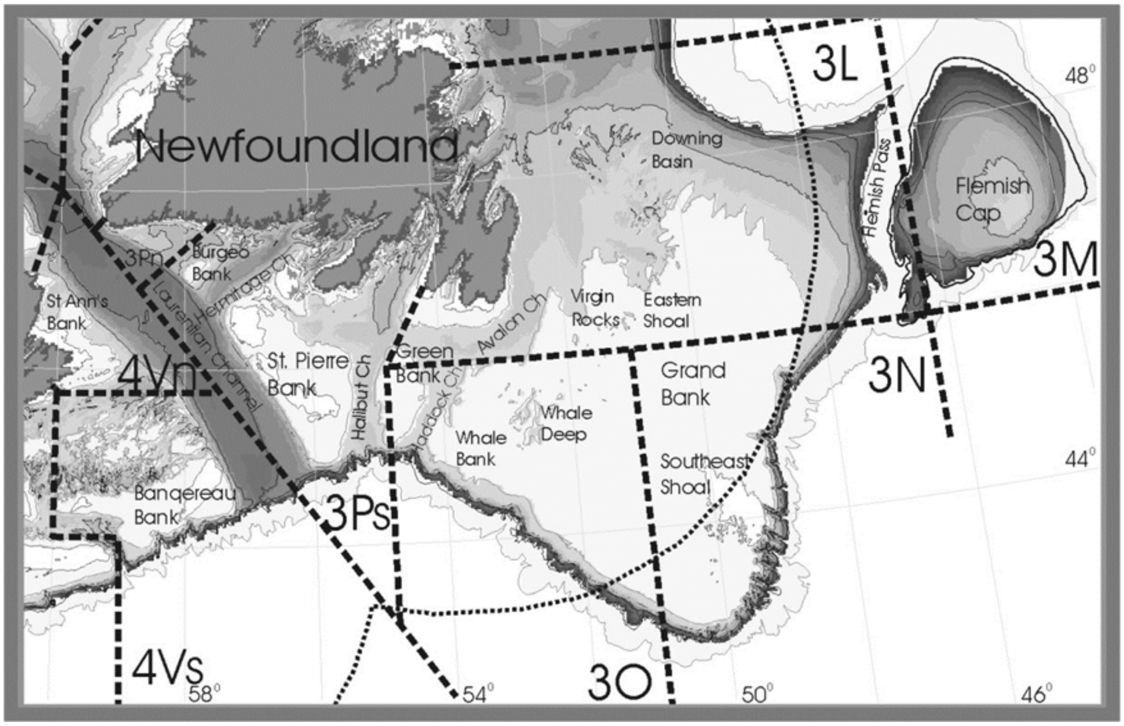


Figure 1. Map of the Grand Bank and southern Newfoundland, showing various banks, basins, and NAFO Divisions. Thick dotted lines delineate NAFO Divisions. The thin dotted curved line shows the boundary between Canada's EEZ and the NAFO Regulatory Area (NRA).

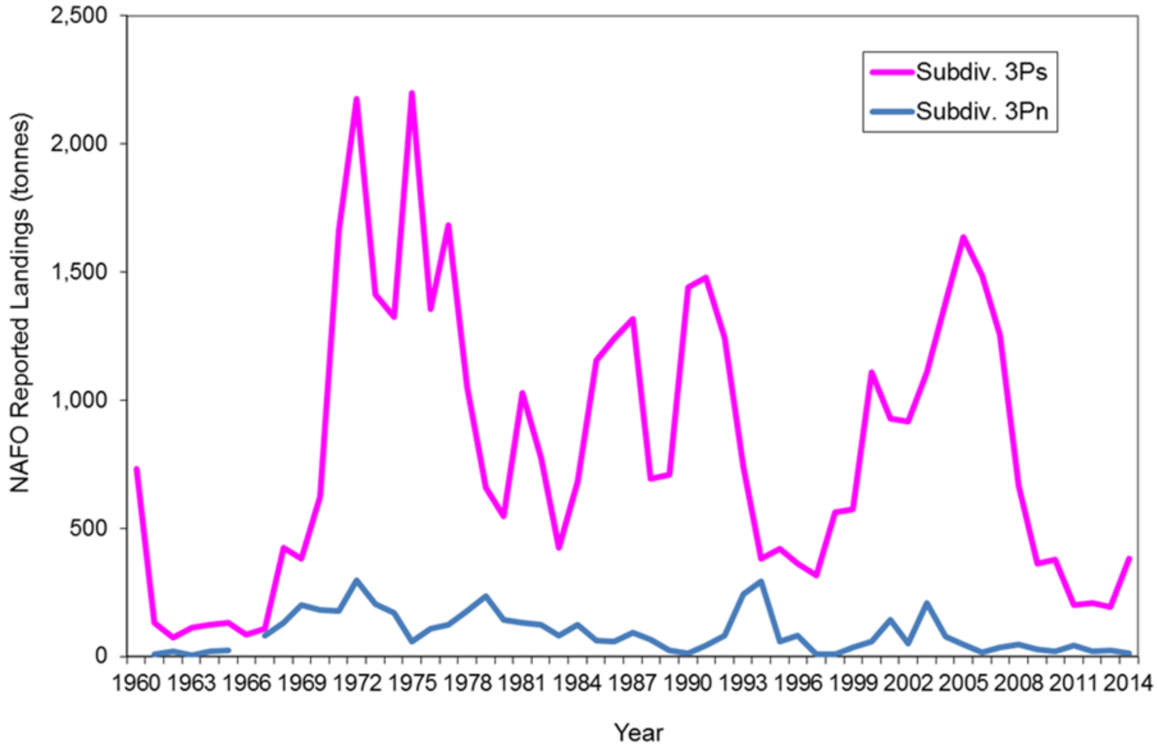


Figure 2. NAFO-reported landings (tonnes) of White Hake by member countries in Subdiv. 3Ps and 3Pn, 1960-2014 (STATLANT-21A).

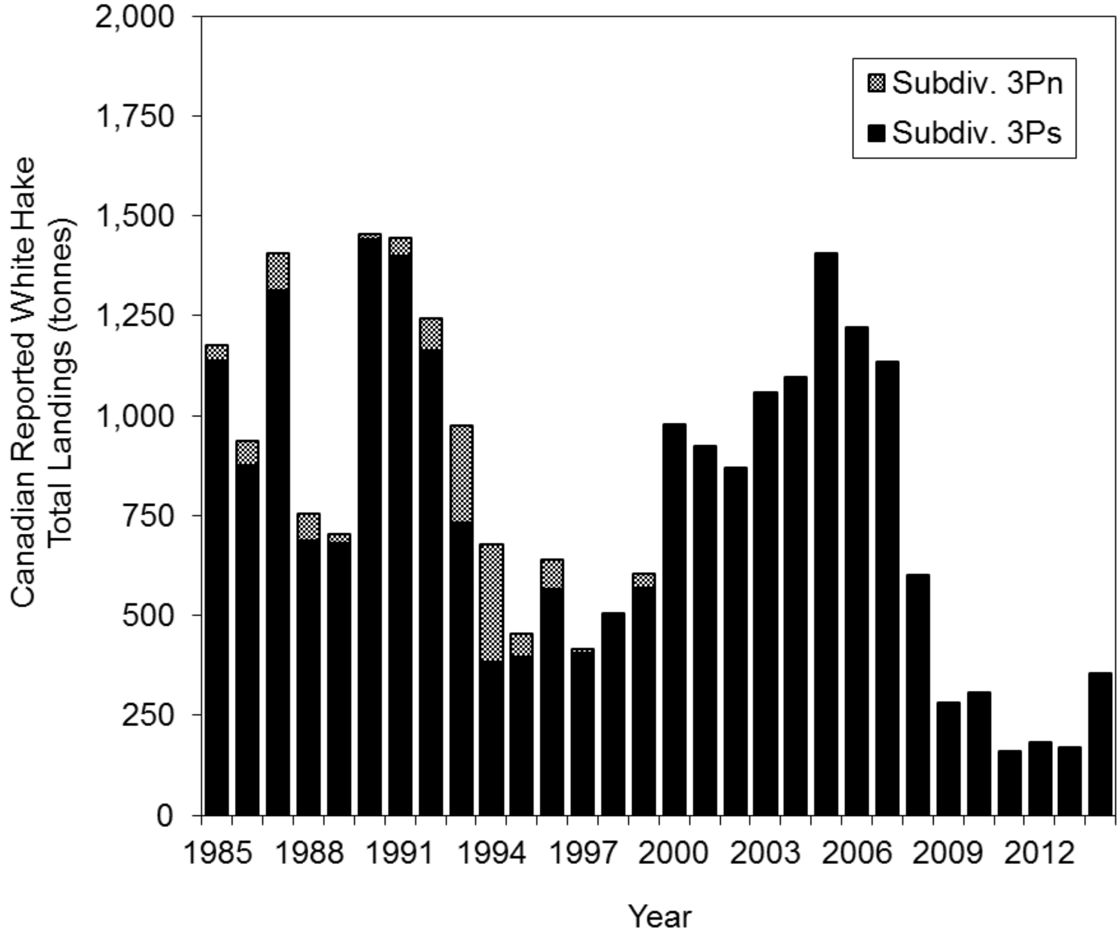


Figure 3. DFO-NL ZIFF-reported landings (tonnes) of White Hake in Subdiv. 3Ps and 3Pn, 1985-2014.

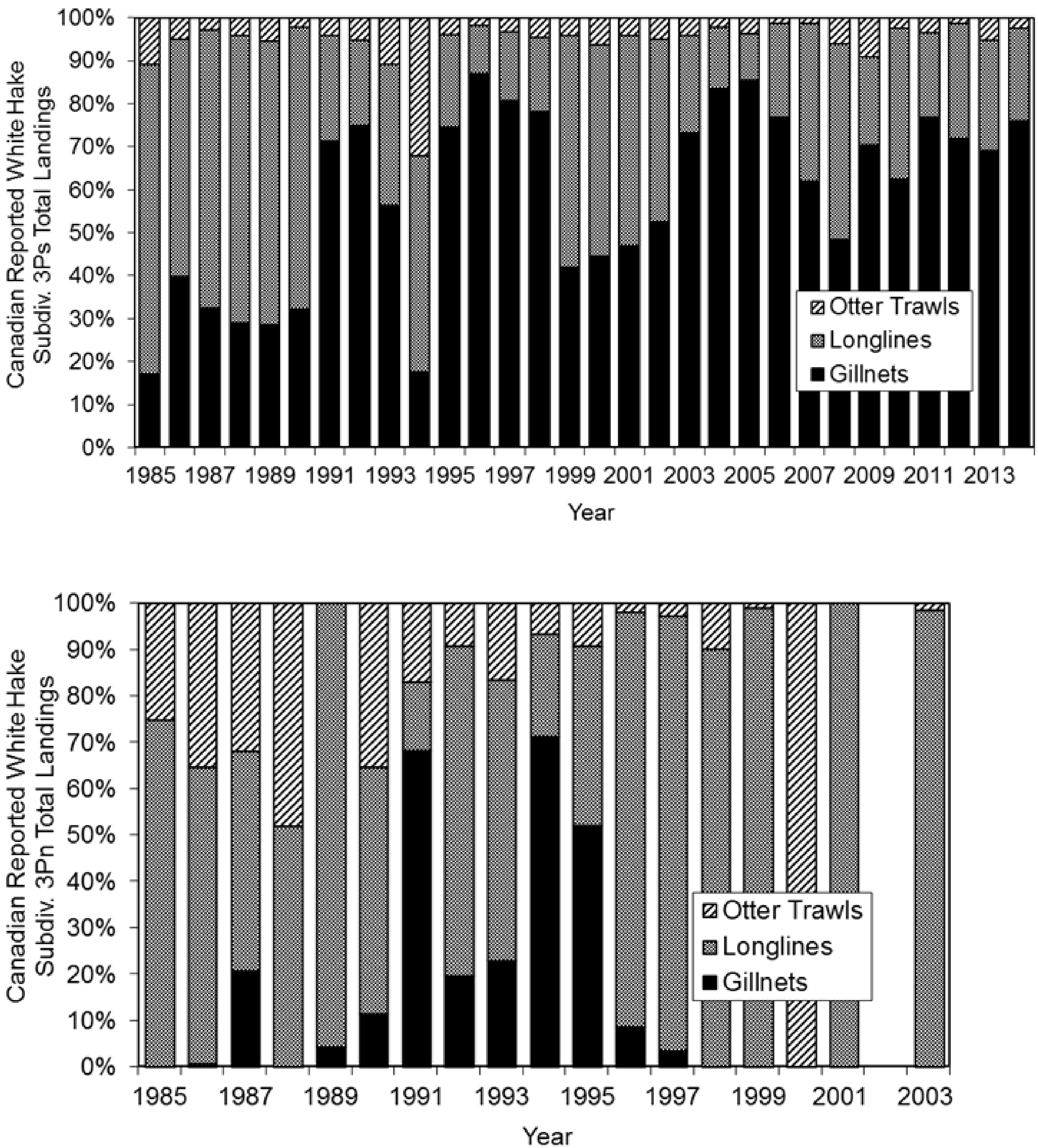


Figure 4. DFO-NL ZIFF-reported landings of White Hake by gear in Subdiv. 3Ps (top panel) and 3Pn (bottom panel), 1985-2014. Note that no landings were reported from Subdiv. 3Pn after 2003.

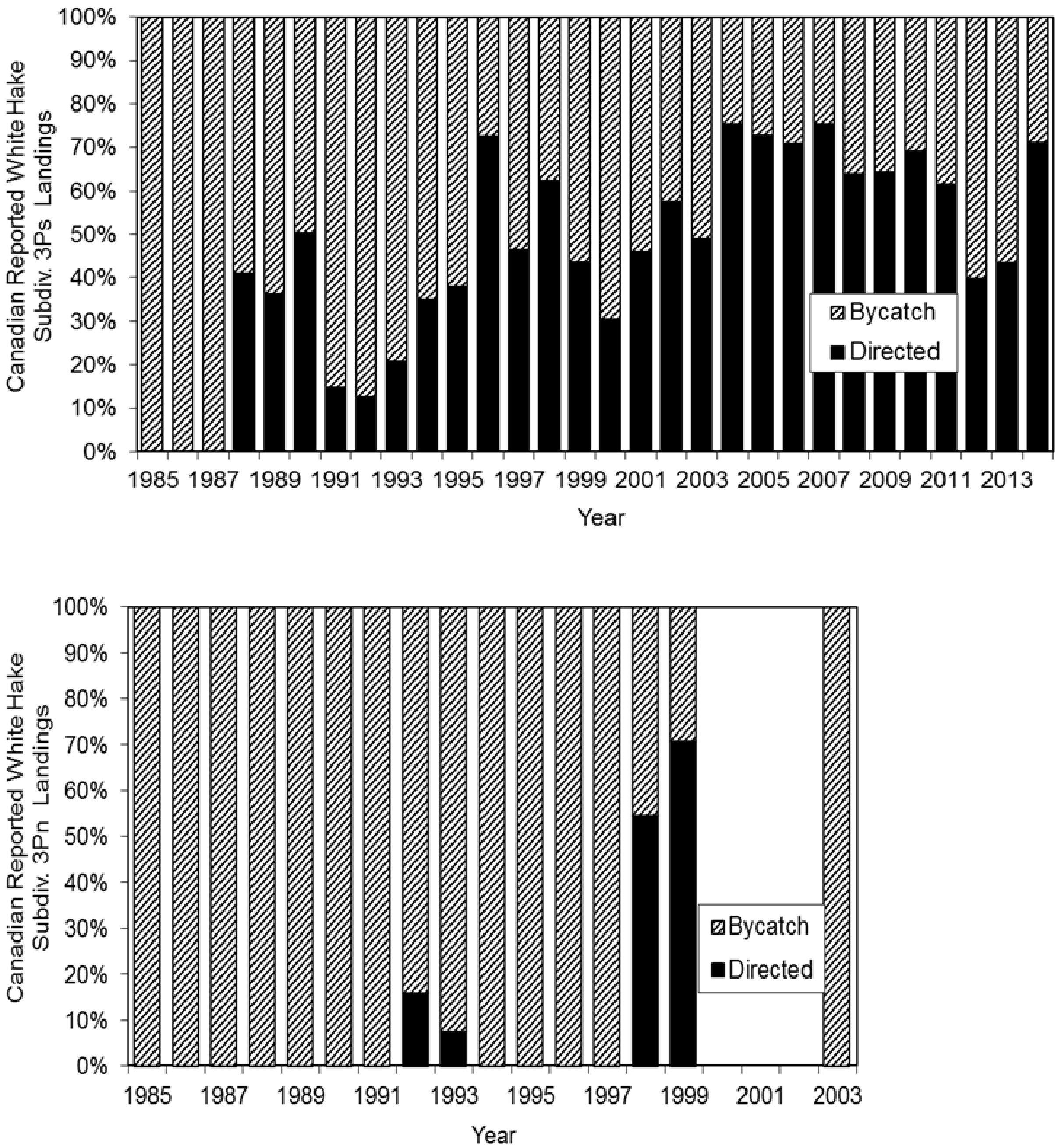


Figure 5. DFO-NL ZIFF-reported directed and bycatch landings of White Hake in Subdiv. 3Ps (top panel) and 3Pn (bottom panel), 1985-2014. Note that no landings were reported from Subdiv. 3Pn after 2003.

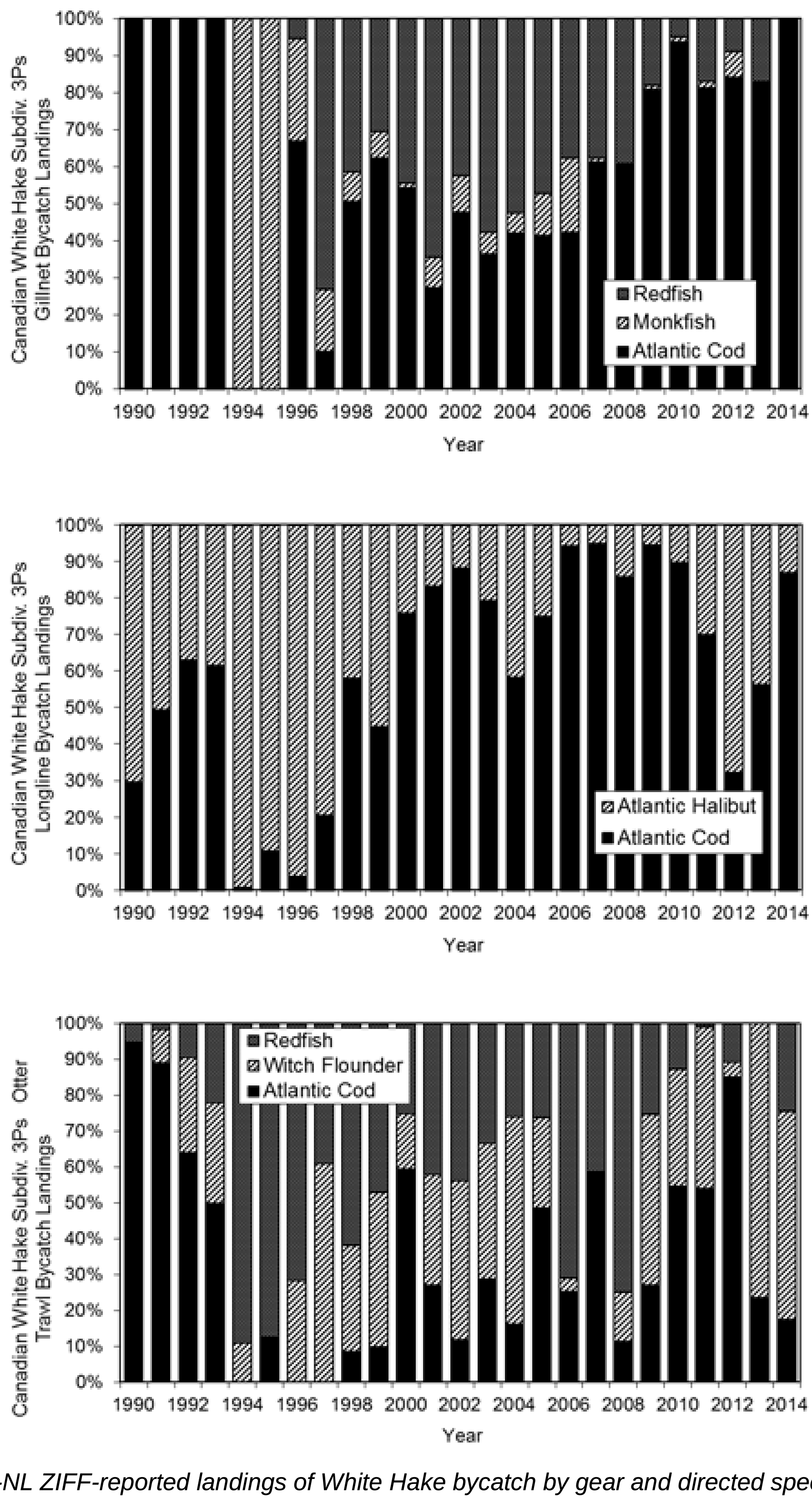
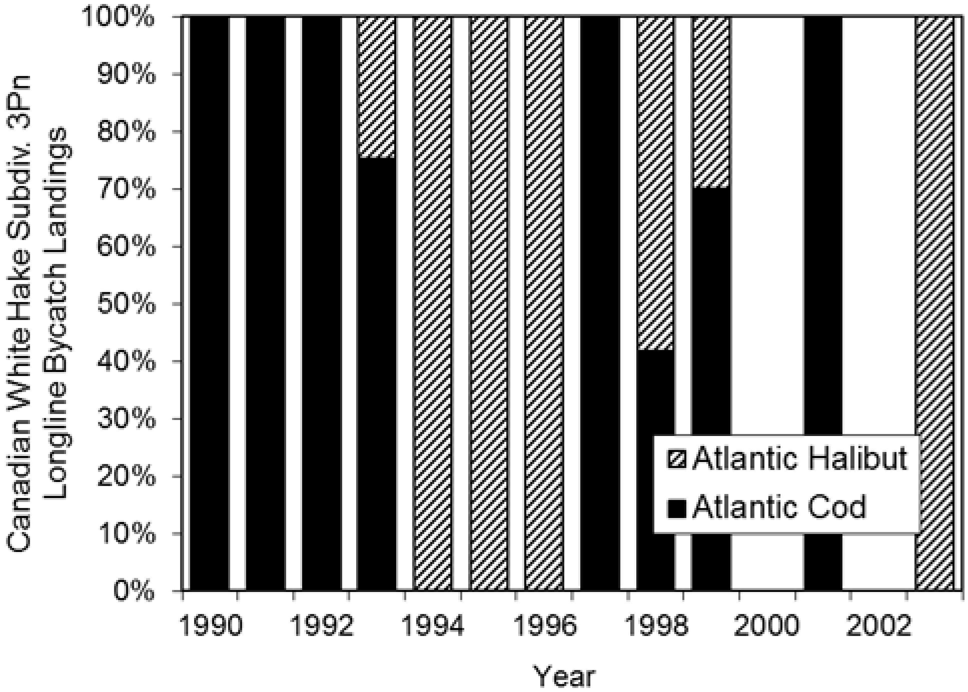


Figure 6. DFO-NL ZIFF-reported landings of White Hake bycatch by gear and directed species in Subdiv. 3Ps, 1990-2014.



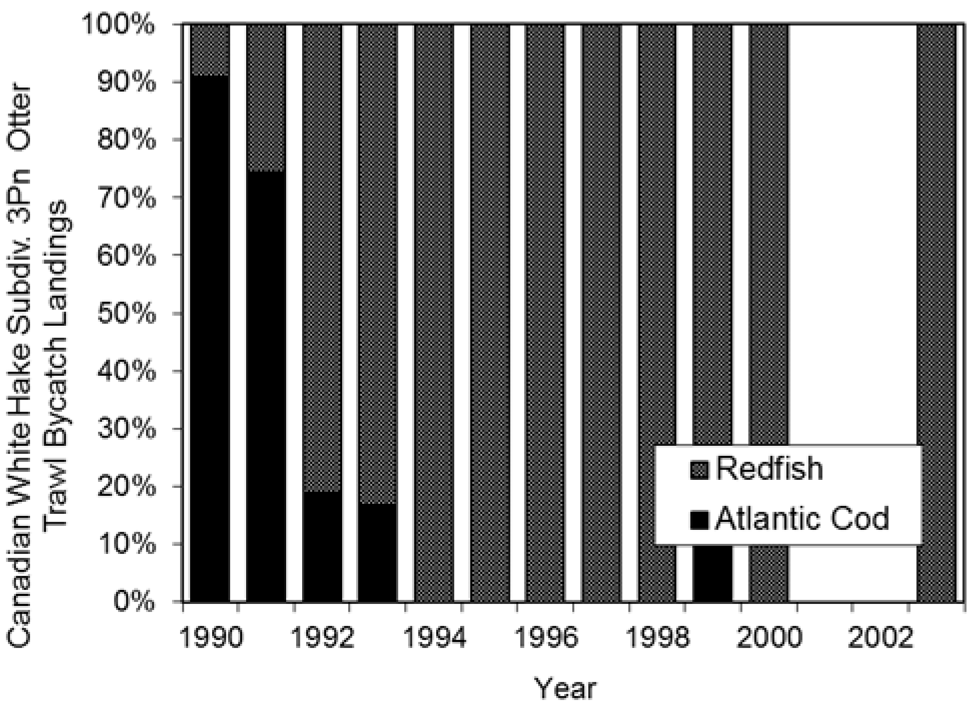


Figure 7. DFO-NL ZIFF-reported landings of White Hake bycatch by gear and directed species in Subdiv. 3Pn, 1990-2014. Note that no landings were reported from Subdiv. 3Pn after 2003.

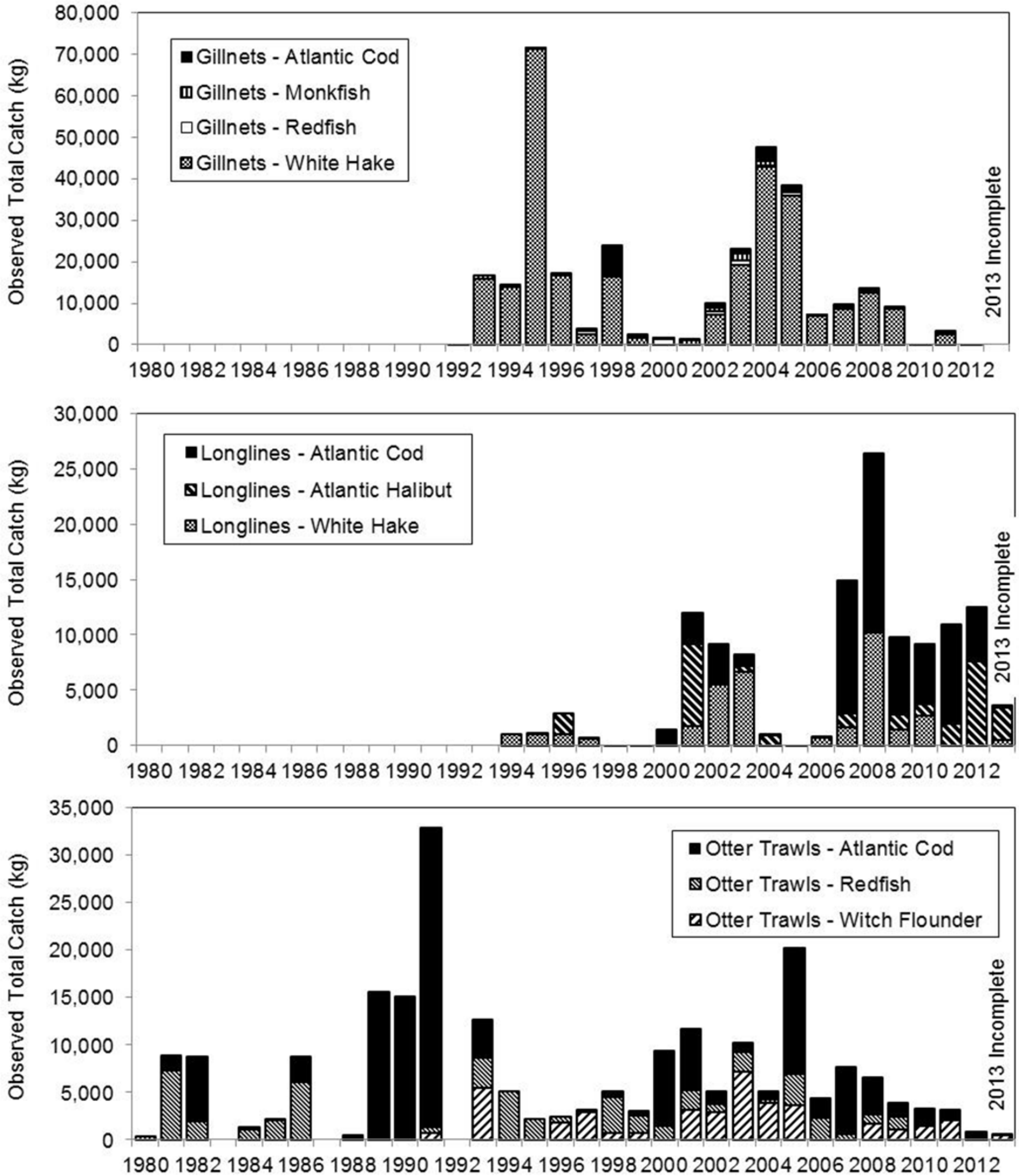


Figure 8. Observed White Hake catch (kg) in Div. 3P by gear and directed species, 1980-2013. Data are from Canadian At-Sea Fisheries Observers, include discards, and were not scaled up to the entire fishery.

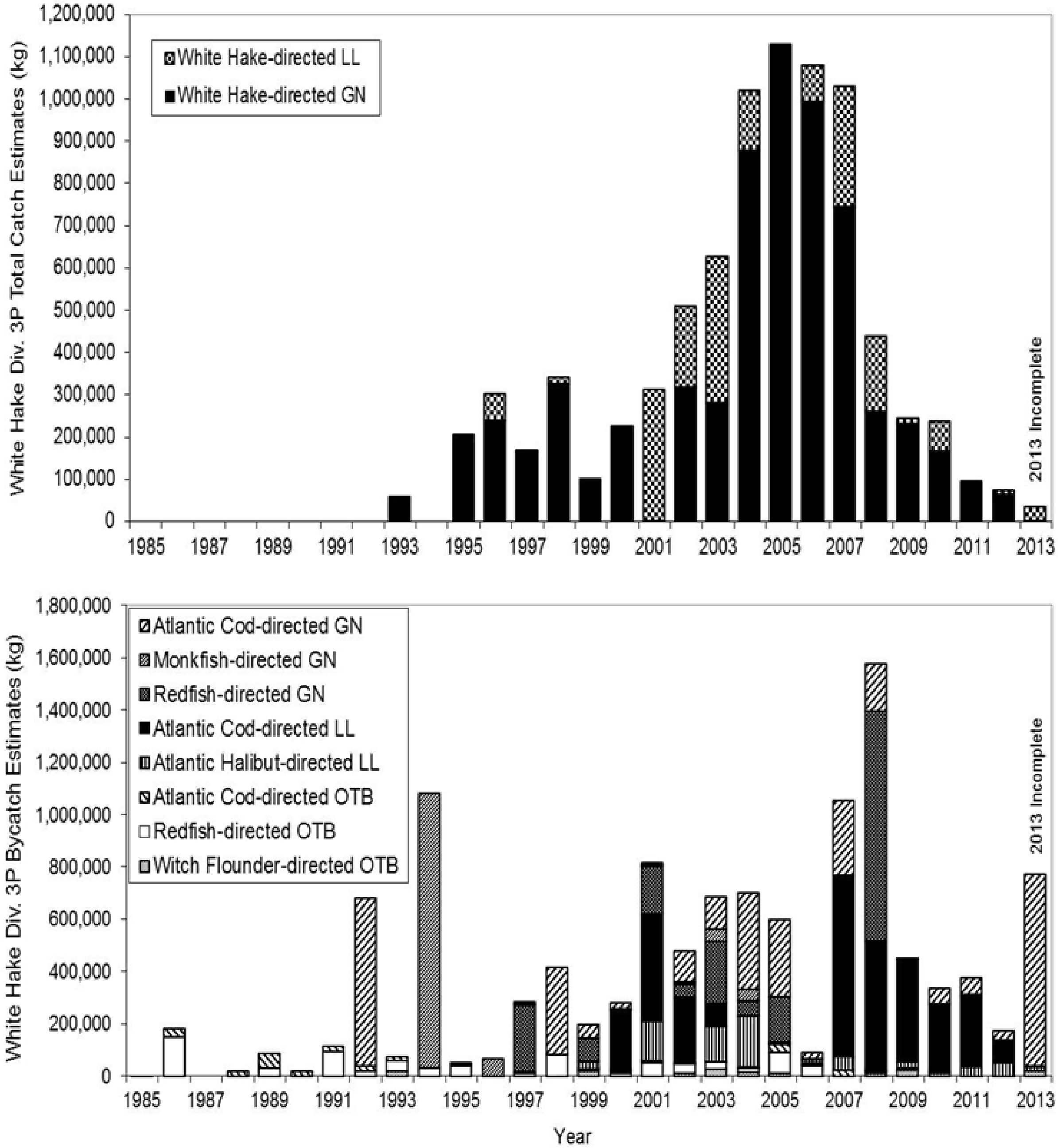


Figure 9. Estimated annual total catch (kgs) of White Hake in directed (top panel) and bycatch (bottom panel) fisheries using gillnets (GN), longlines (LL) and otter trawls (bottom; OTB) in Div. 3P, 1985-2013. Data are from Canadian At-Sea Fisheries Observers and DFO-NL ZIFF in comparable years.

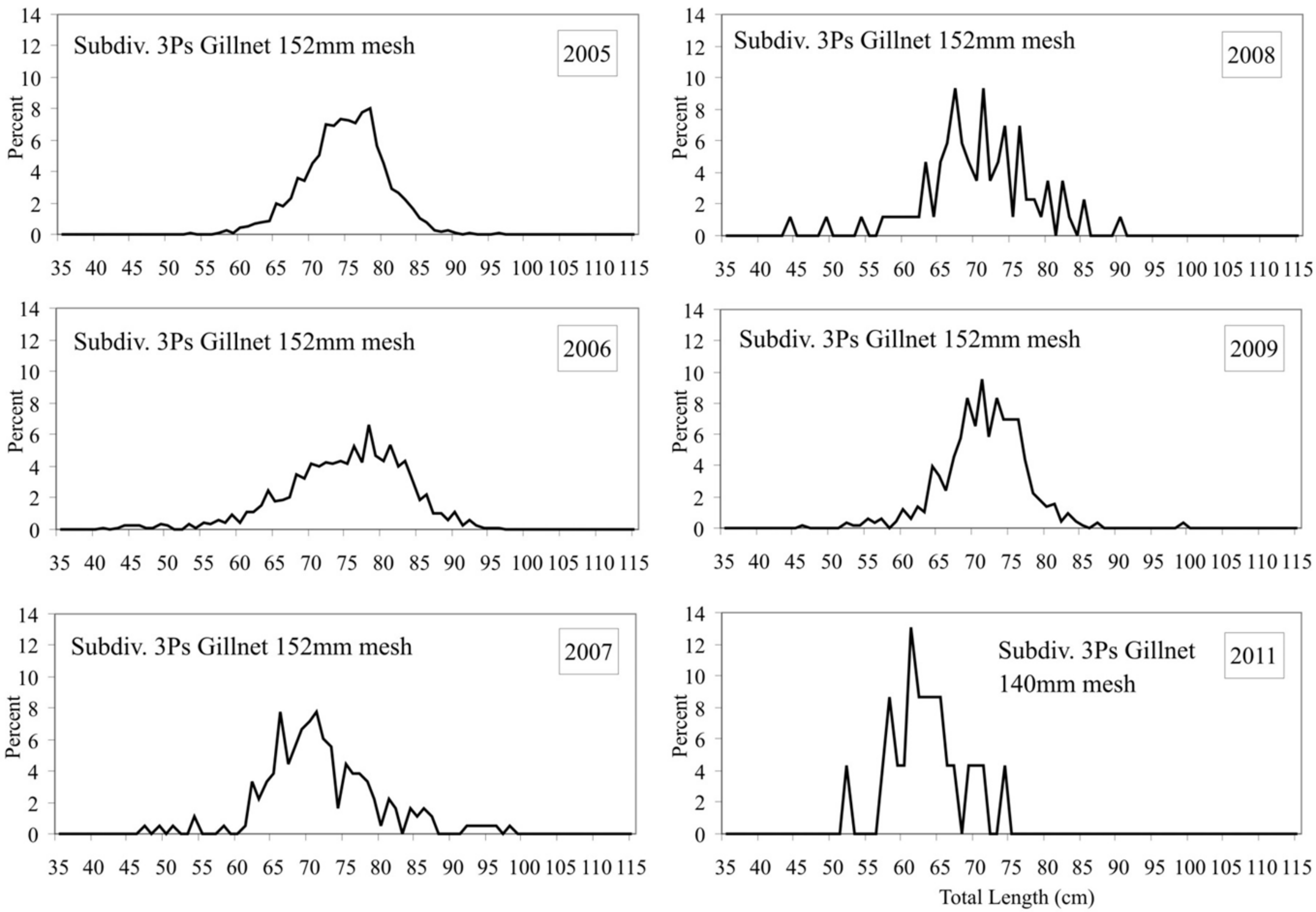


Figure 10. Size of White Hake caught in Subdiv. 3Ps by Canadian commercial gillnets, 2005-12. Data are from Canadian At-Sea Fisheries Observers. No Canadian gillnet length frequencies were available for Subdiv. 3Ps in 2010 and 2012.

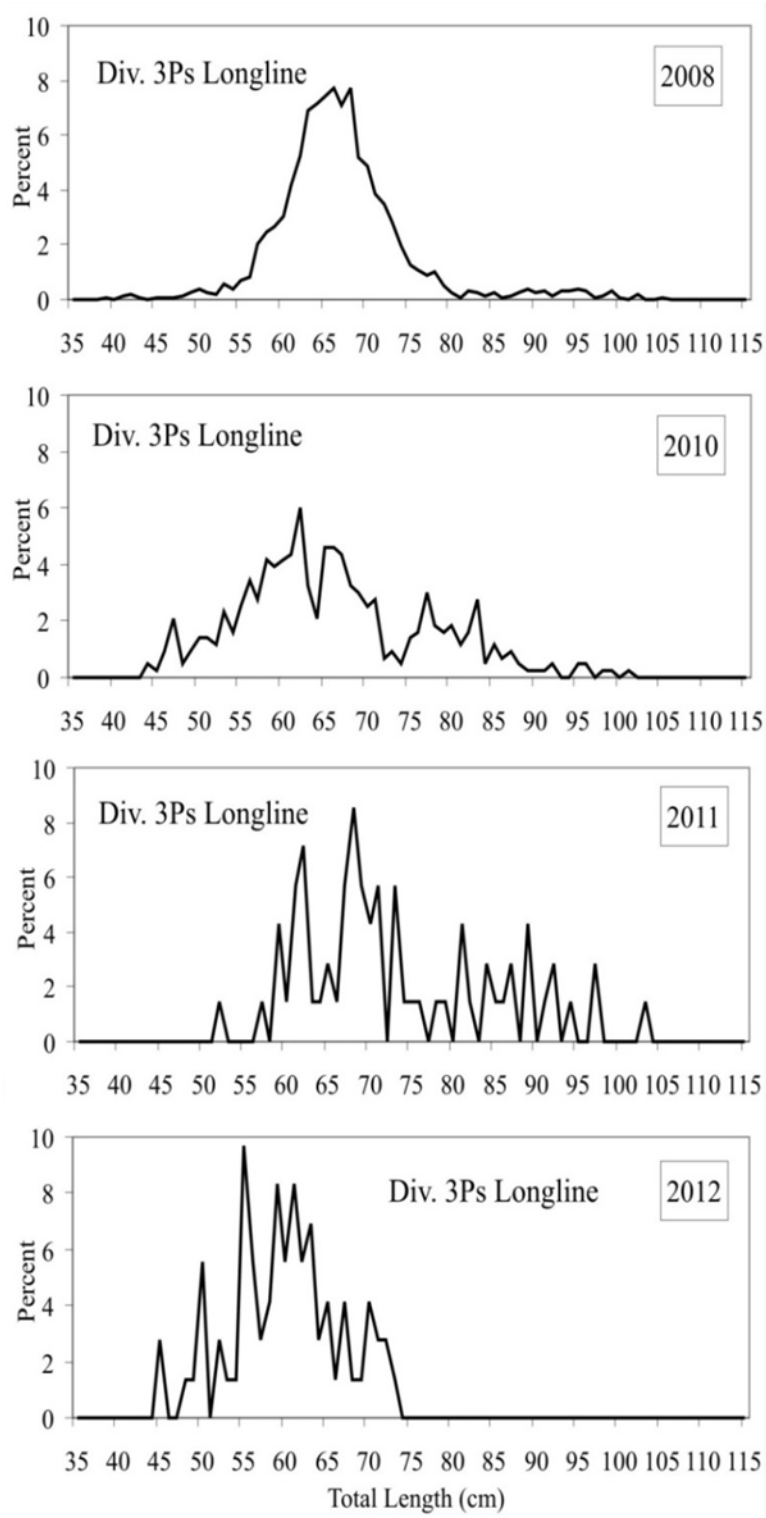


Figure 11. Size of White Hake caught in Subdiv. 3Ps by Canadian commercial longlines, 2008, 2010-12. Data are from Canadian At-Sea Fisheries Observers.

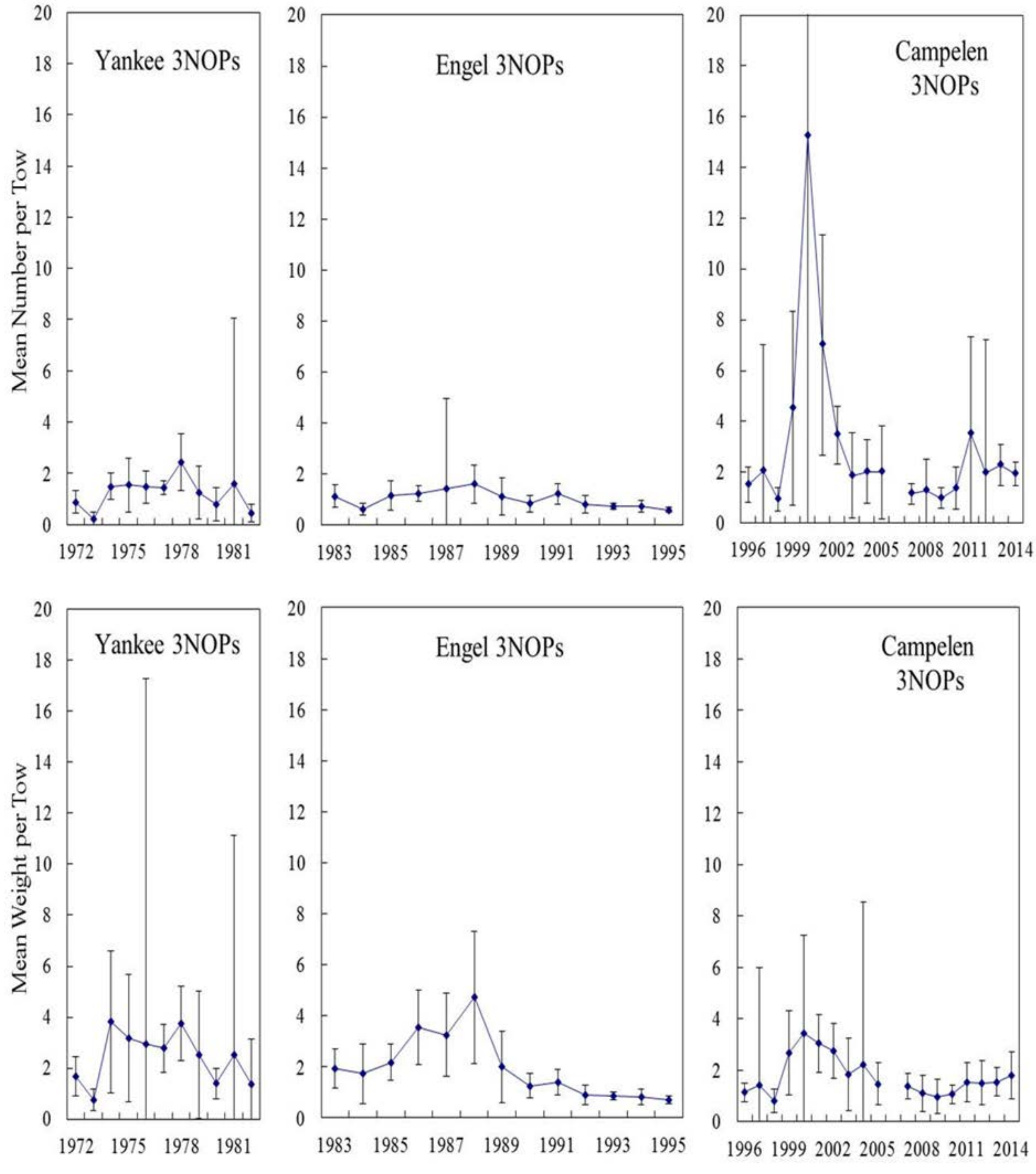


Figure 12. White Hake mean numbers (top panels) and mean weights (kg; bottom panels) per tow (+/- 95% CI) from DFO-NL spring research surveys in Divs. 3NO and Subdiv. 3Ps, 1972-2014. Yankee, Engel, and Campelen time series are not standardized, and thus are presented on separate panels. Note that deep strata in Divs. 3NO and all of Subdiv. 3Ps were not surveyed in spring 2006, due to Canadian research vessels' mechanical difficulties.

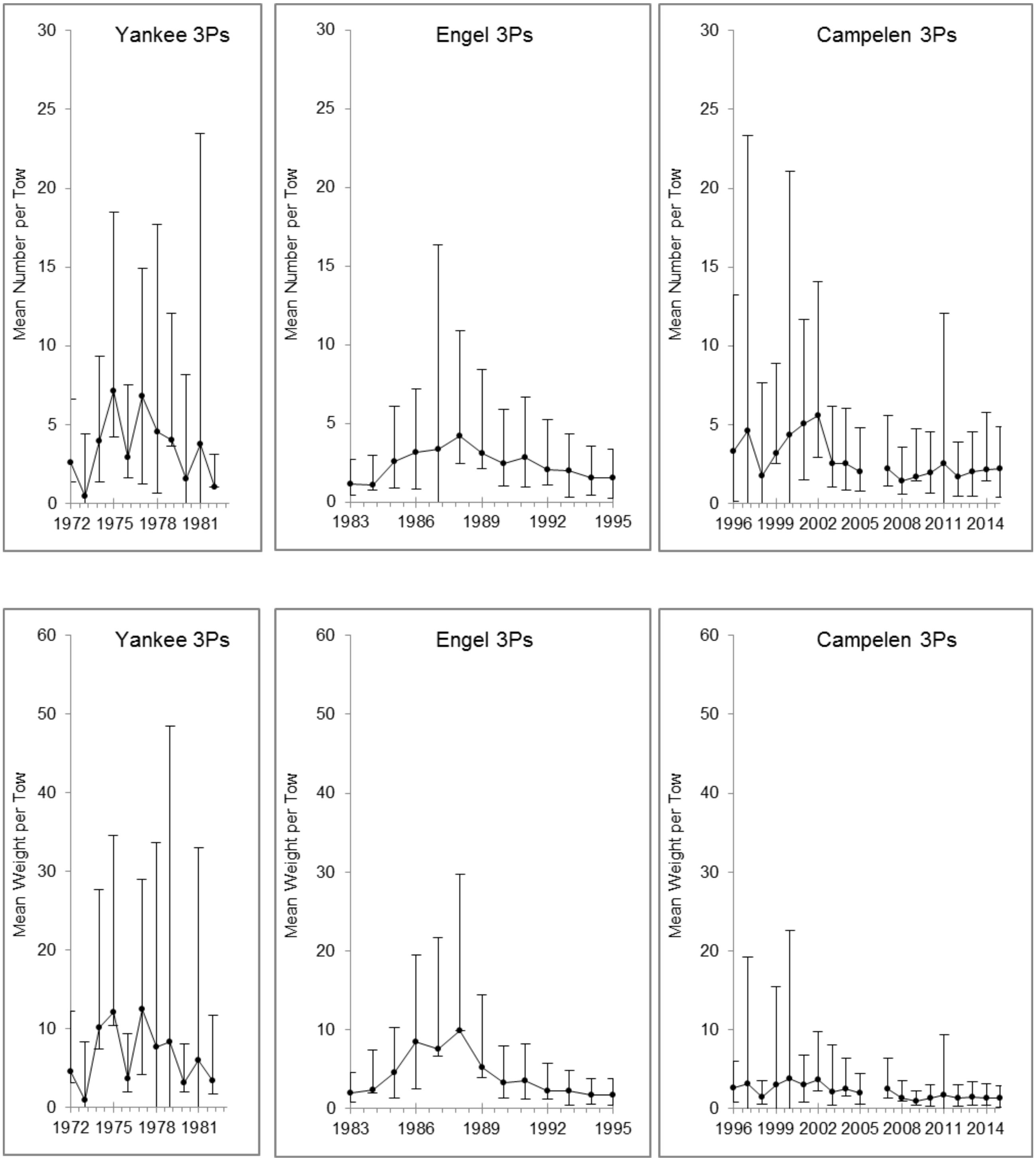


Figure 13. White Hake mean numbers (top panels) and mean weights (kg; bottom panels) per tow (+/- 95% CI) from DFO-NL spring research surveys in Subdiv. 3Ps, 1972-2015. Yankee, Engel, and Campelen time series are not standardized, and thus are presented on separate panels. Note that all of Subdiv. 3Ps was not surveyed in spring 2006, due to Canadian research vessels' mechanical difficulties.

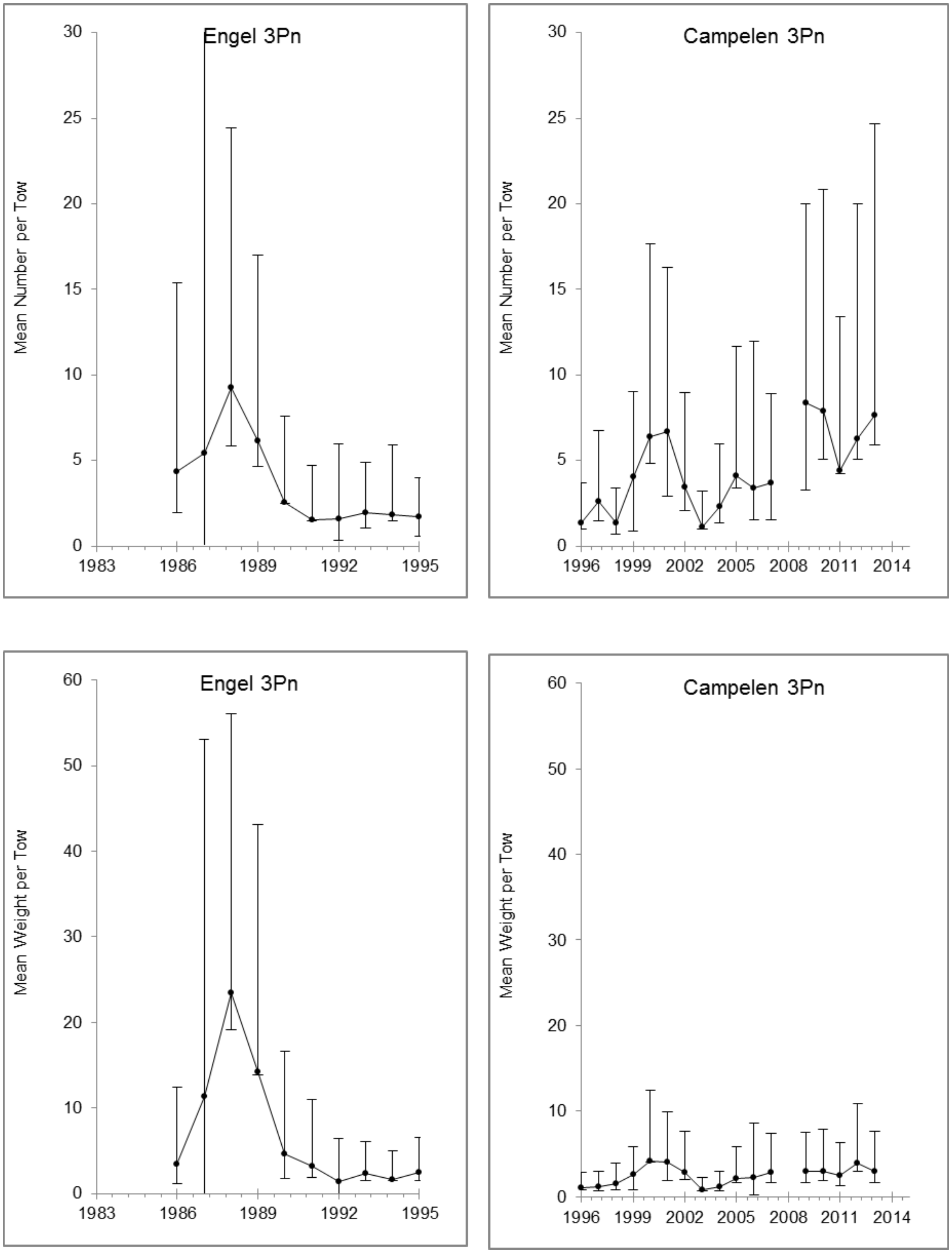


Figure 14. White Hake mean numbers (top panels) and mean weights (kg; bottom panels) per tow (+/- 95% CI) from DFO-NL spring research surveys in Subdiv. 3Pn, 1986-2013. Engel and Campelen time series are not standardized, and thus are presented on separate panels.

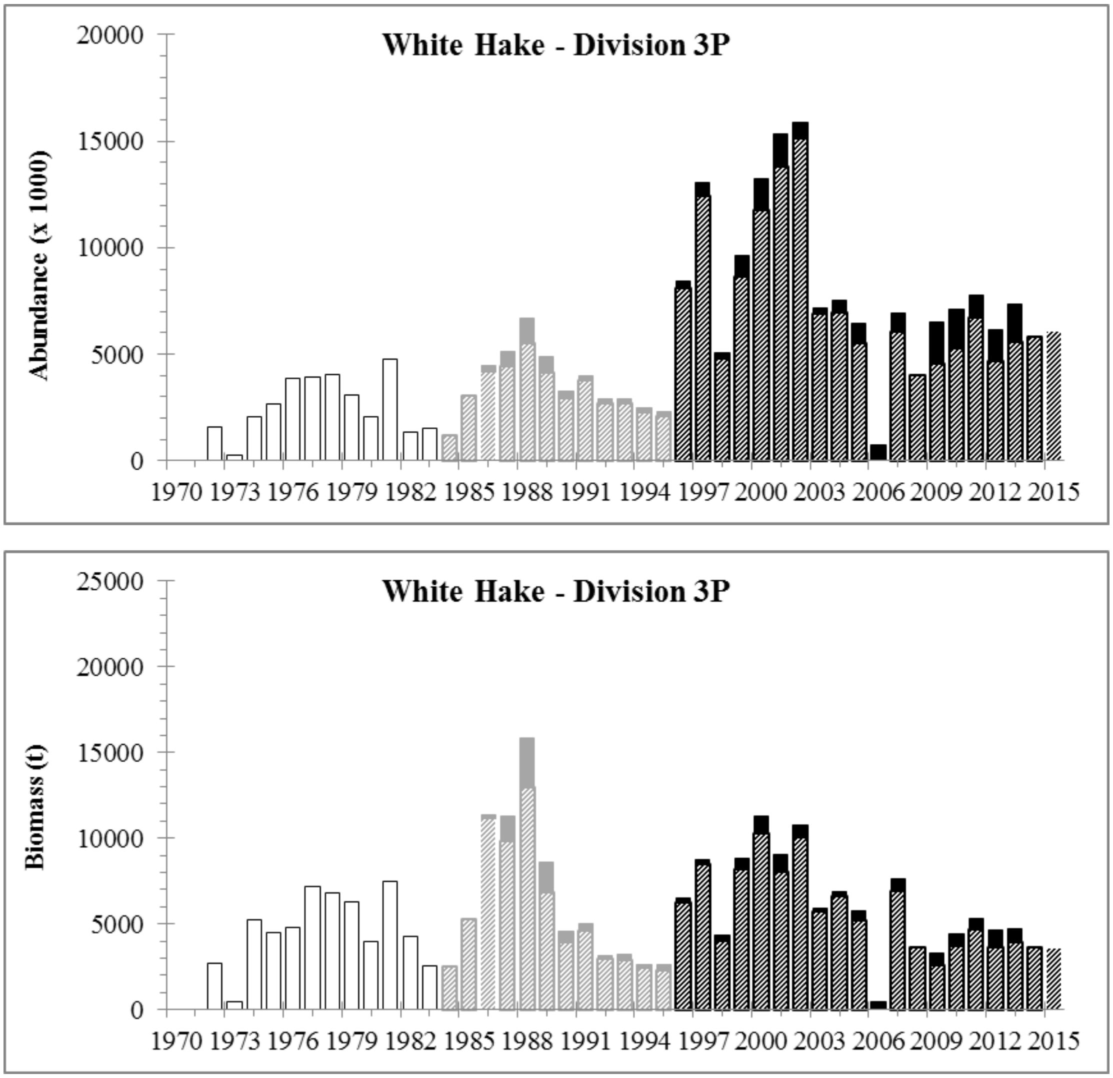


Figure 15. Annual estimates of abundance and biomass for White Hake from DFO-NL spring research surveys in Subdiv. 3Ps (open column and diagonal lines) and Subdiv. 3Pn (solid color). Note that there is no conversion factor between Yankee (open columns), Engel (grey columns), and Campelen (black columns) time-series, and all of Subdiv. 3Ps was not surveyed in spring 2006 due to Canadian research vessels' mechanical difficulties.

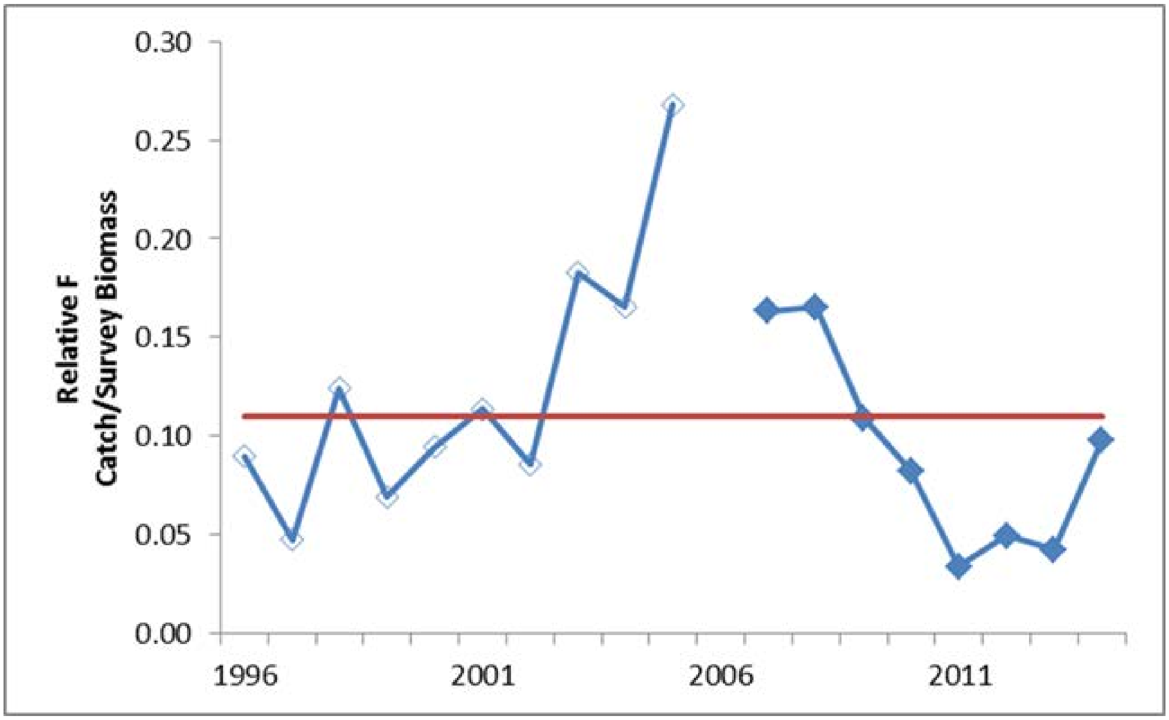


Figure 16. Relative F index (= NAFO commercial landings/Canadian Campelen spring survey biomass) for White Hake in Subdiv. 3Ps, 1996-2014. Note that most of Subdiv. 3Ps were not surveyed in 2006, due to Canadian research vessels' mechanical difficulties.

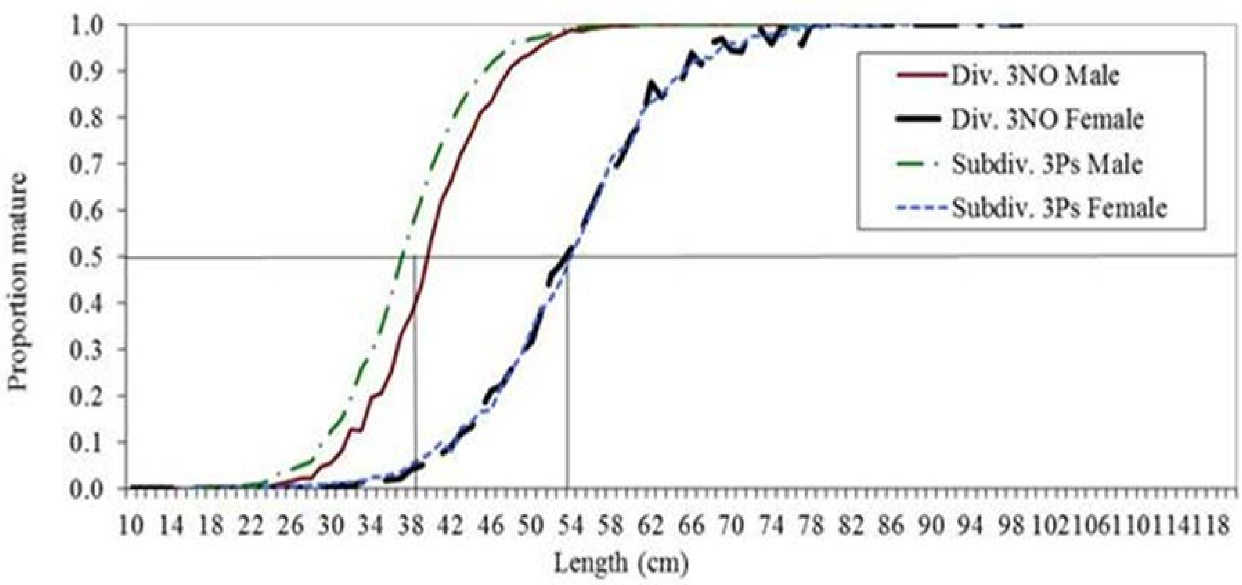


Figure 17. White Hake in Divs. 3NO and Subdiv. 3Ps: Maturity ogives calculated for each sex from DFO-NL Campelen spring surveys, and averaged over 1996-2014 (excluding 2006, when deep strata in Divs. 3NO and all of Subdiv. 3Ps could not be surveyed).

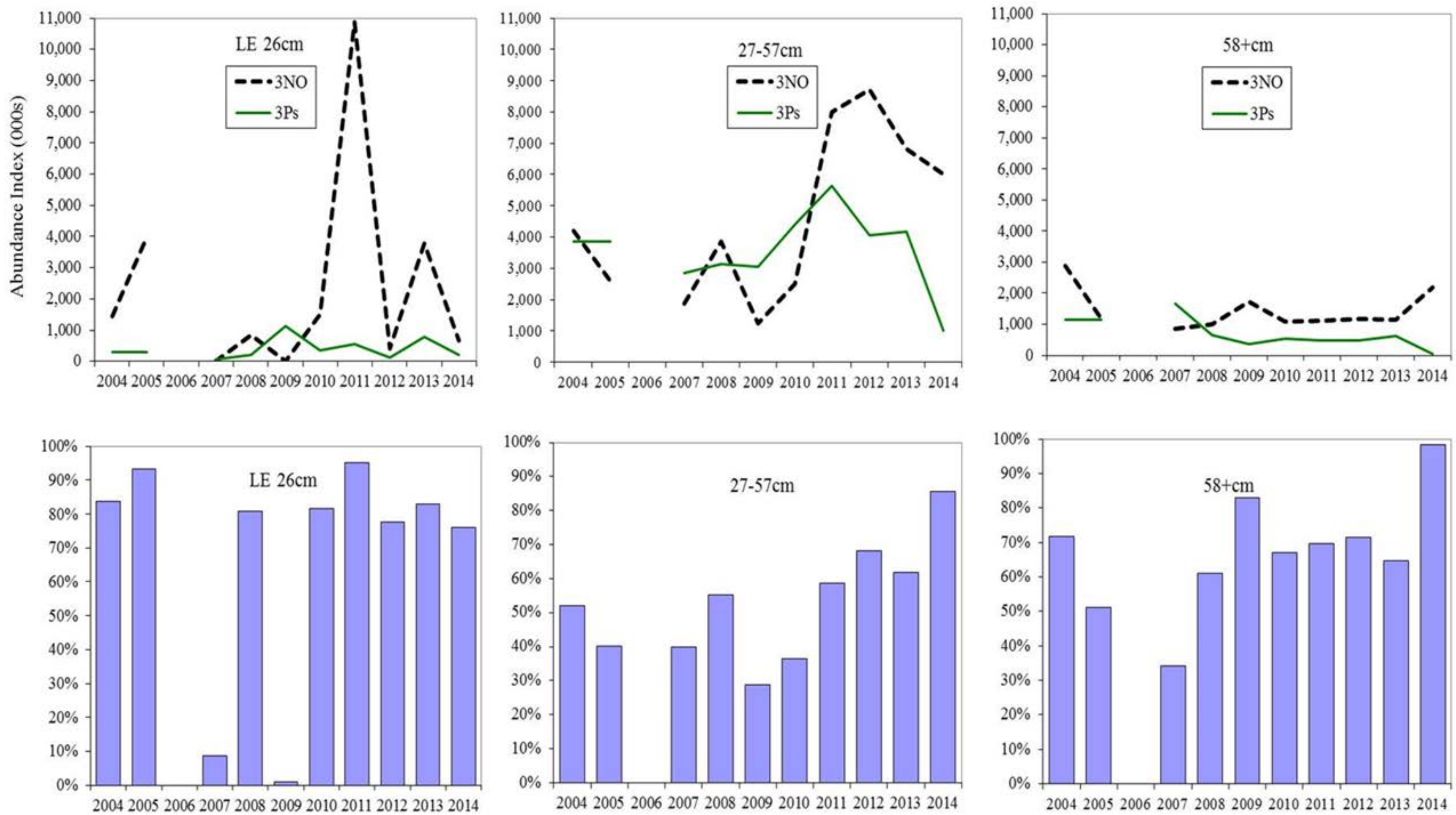


Figure 18. Abundance Index of White Hake by life stage, 2004-2014: Less than or Equal to 26 cm is mainly year-class 1; 27-57 cm contains mainly juveniles; and 58+cm is mainly mature fish. Top panels: Abundance Index (000s). Bottom panels: Percent abundance in Divs. 3NO as compared to the entire area of Disv. 3NOPs. Note that deep strata in Divs. 3NO and all of Subdiv. 3Ps were not surveyed in spring 2006, due to Canadian research vessels' mechanical difficulties.

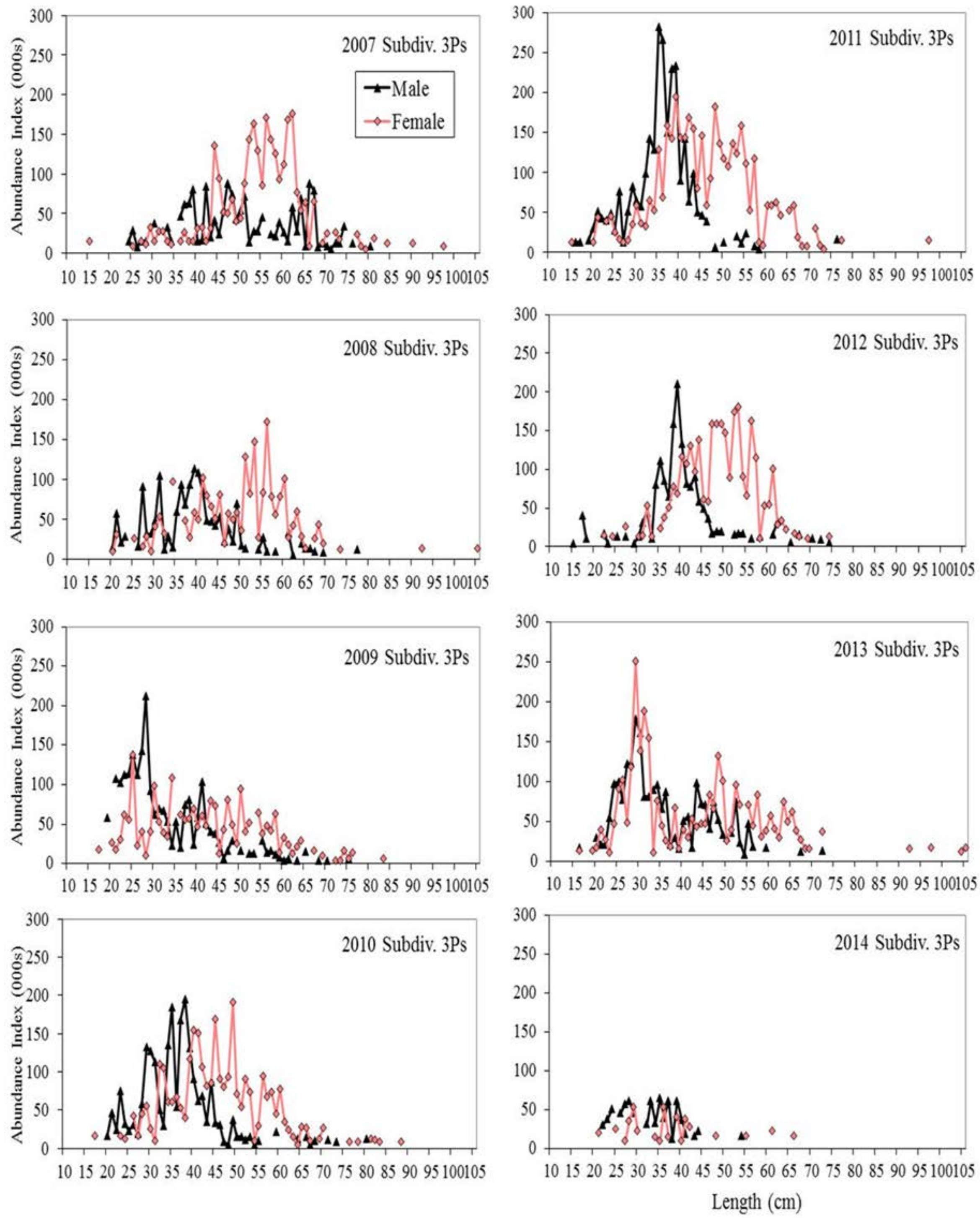


Figure 19. Abundance Index at length of male and female White Hake from Canadian spring research surveys in Subdiv. 3Ps, 2007-14.

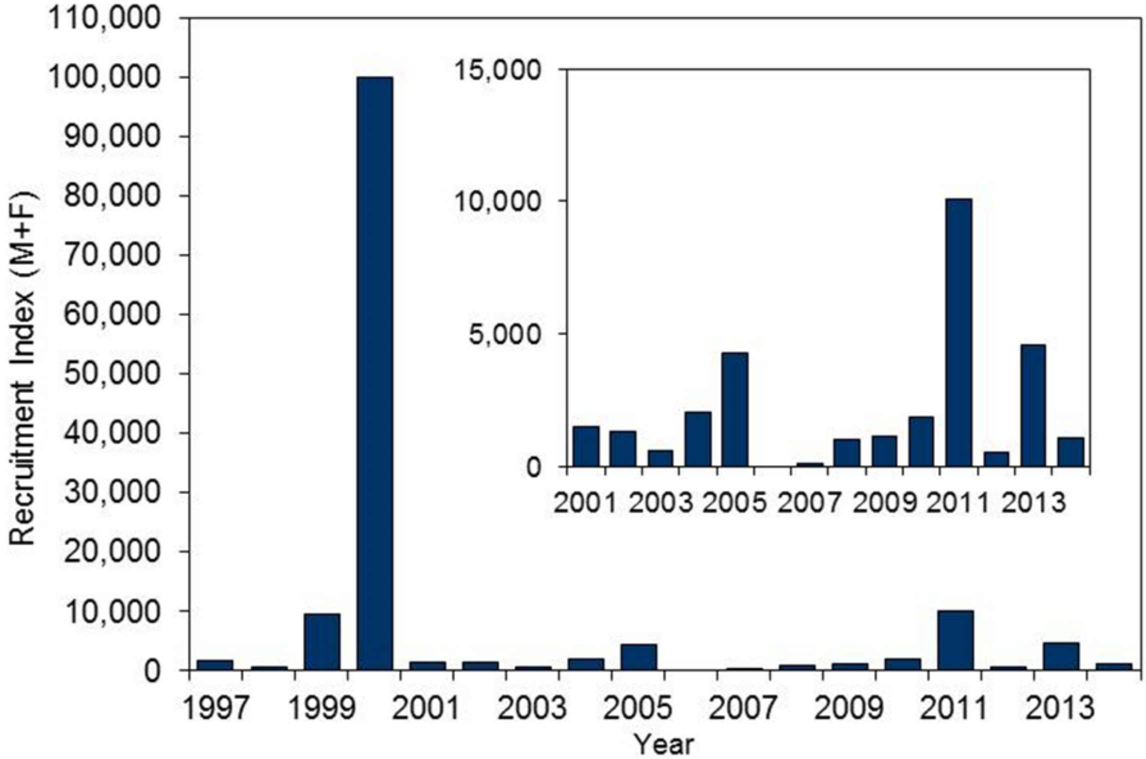


Figure 20. White Hake recruitment index for Age 1 males and females (combined) from DFO-NL Campelen spring surveys in Divs. 3NO and Subdiv. 3Ps, 1997-2014. Inset plot depicts 2001-14 on a smaller scale. Estimates from 2006 are not shown, since survey coverage in that year was incomplete.

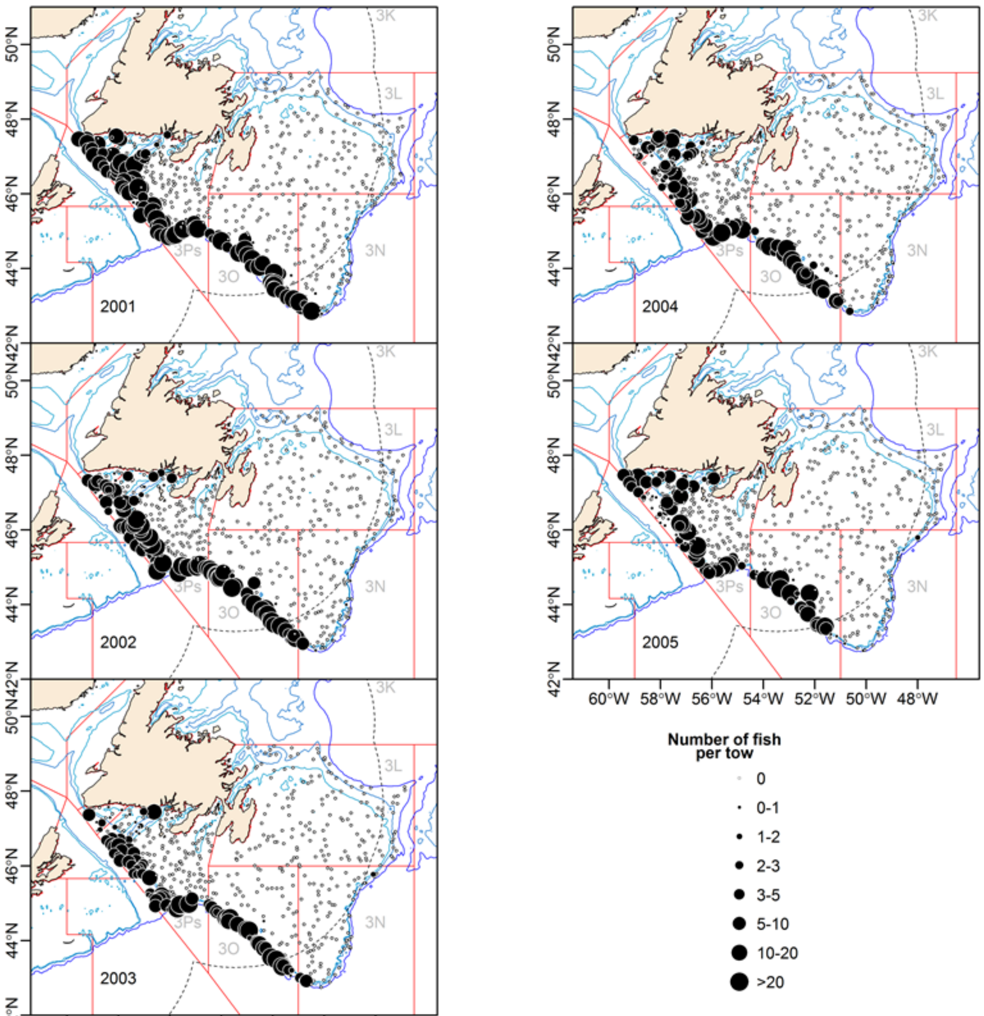


Figure 21. Distribution of White Hake mean numbers per tow in Divs. 3NOP, based on DFO-NL spring research surveys in 2001-05.

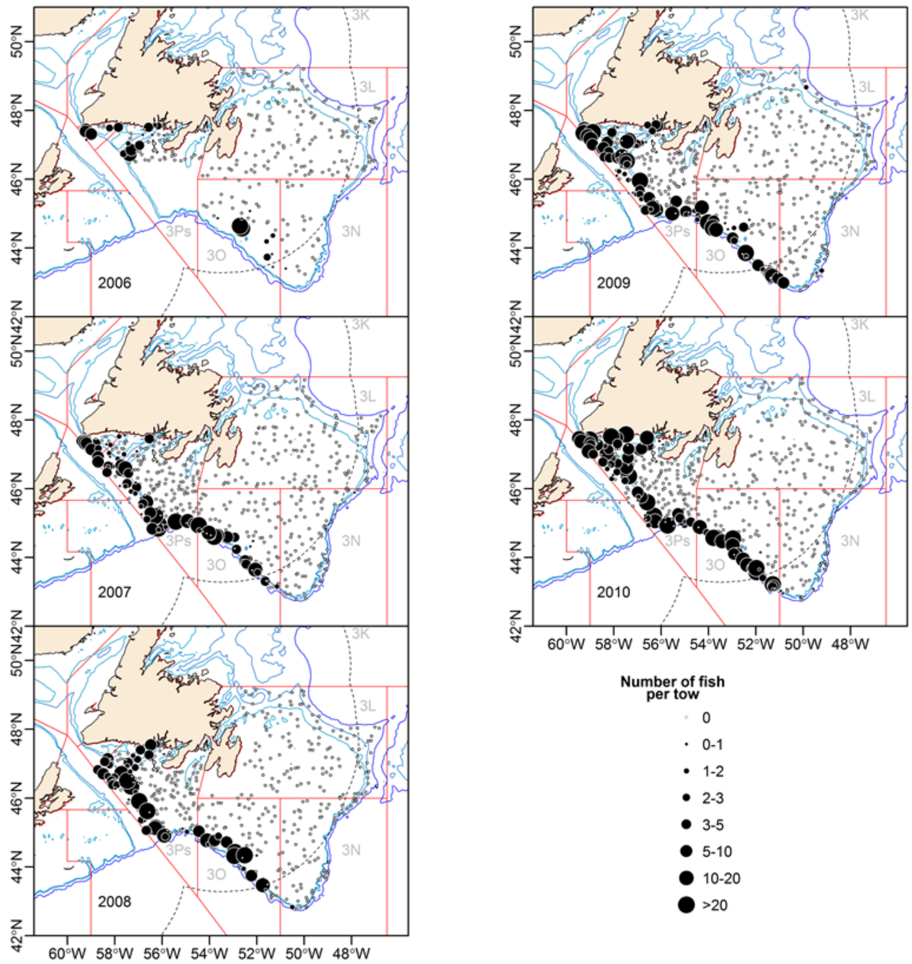


Figure 22. Distribution of White Hake mean numbers per tow in Divs. 3NOP, based on DFO-NL spring research surveys in 2006-10. Note that deep strata in Divs. 3NO and most of Subdiv. 3Ps were not surveyed in spring 2006, due to Canadian research vessels' mechanical difficulties.

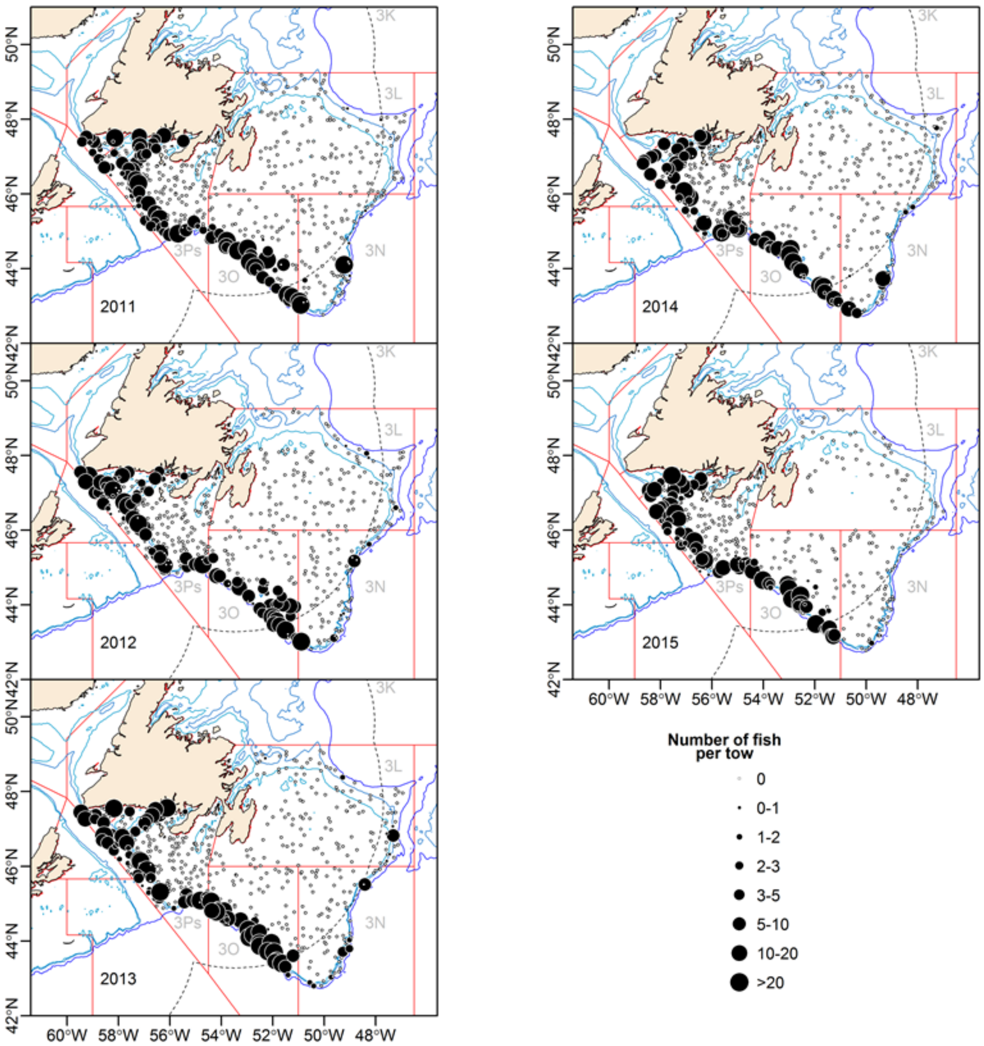


Figure 23. Distribution of White Hake mean numbers per tow in Divs. 3NOP, based on DFO-NL spring research surveys in 2011-15.

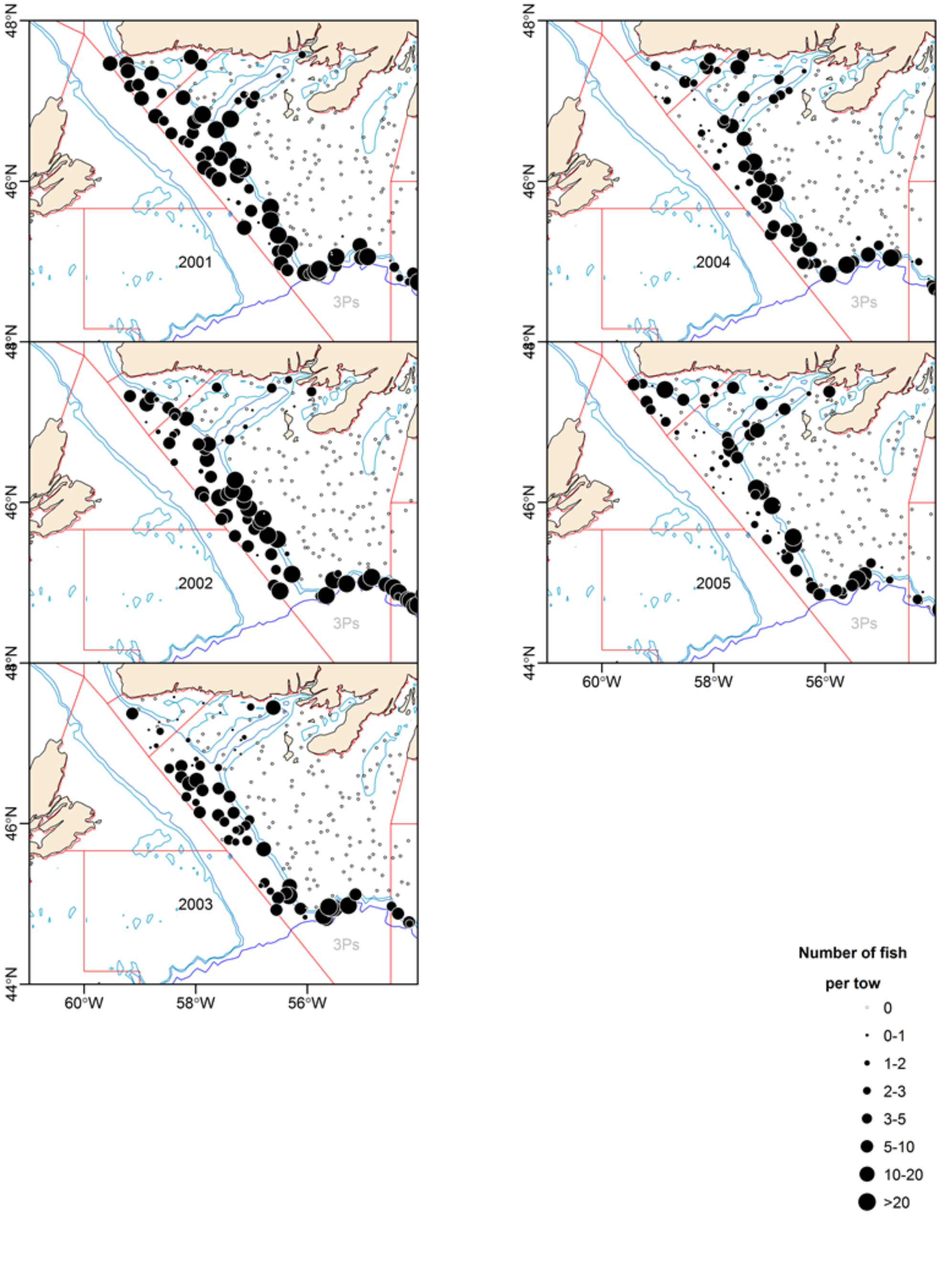


Figure 24. Distribution of White Hake mean numbers per tow in Div. 3P, based on DFO-NL spring research surveys in 2001-05.

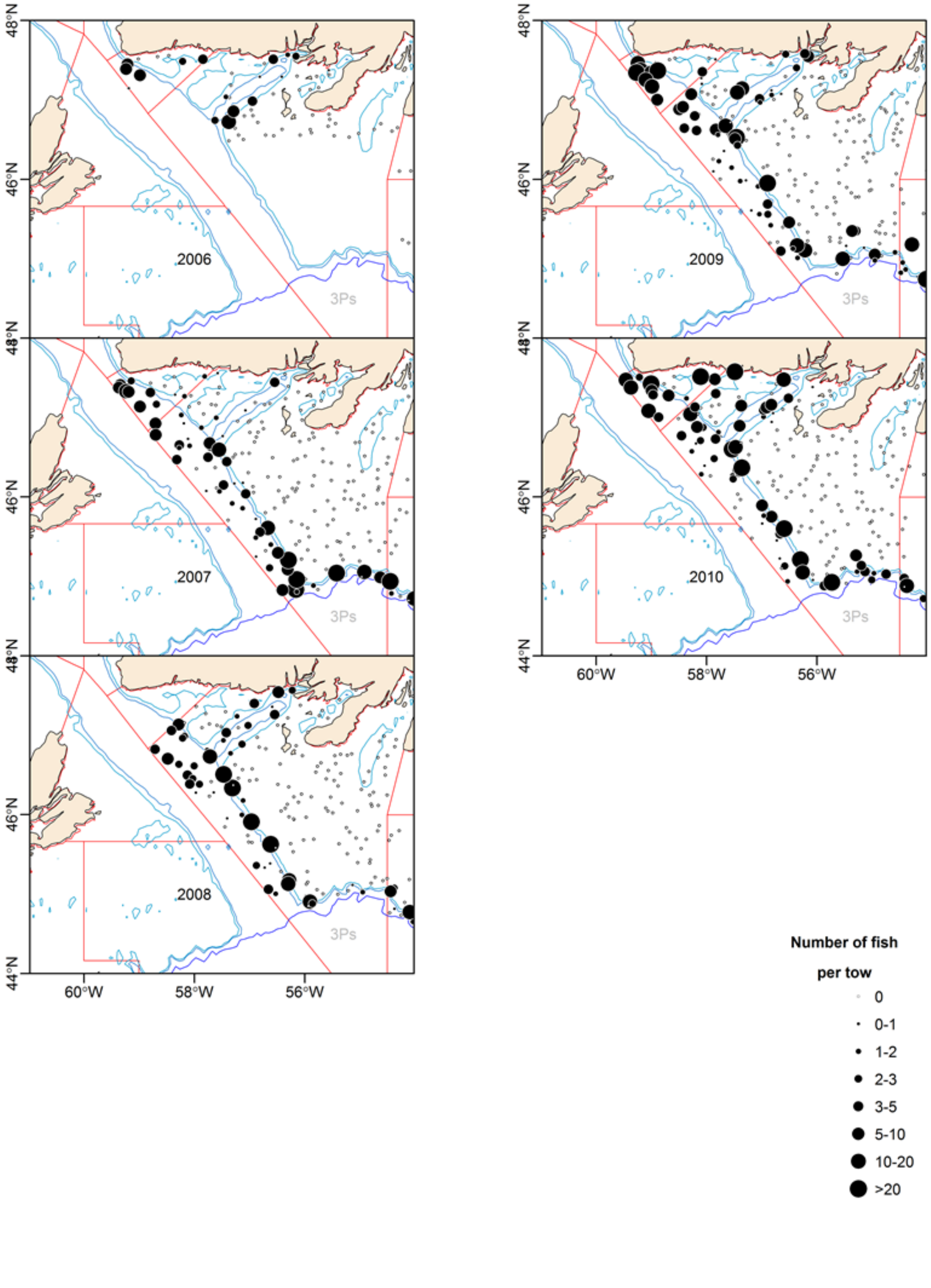


Figure 25. Distribution of White Hake mean numbers per tow in Div. 3P, based on DFO-NL spring research surveys in 2006-10. Note that most of Subdiv. 3Ps was not surveyed in spring 2006, due to Canadian research vessels' mechanical difficulties.

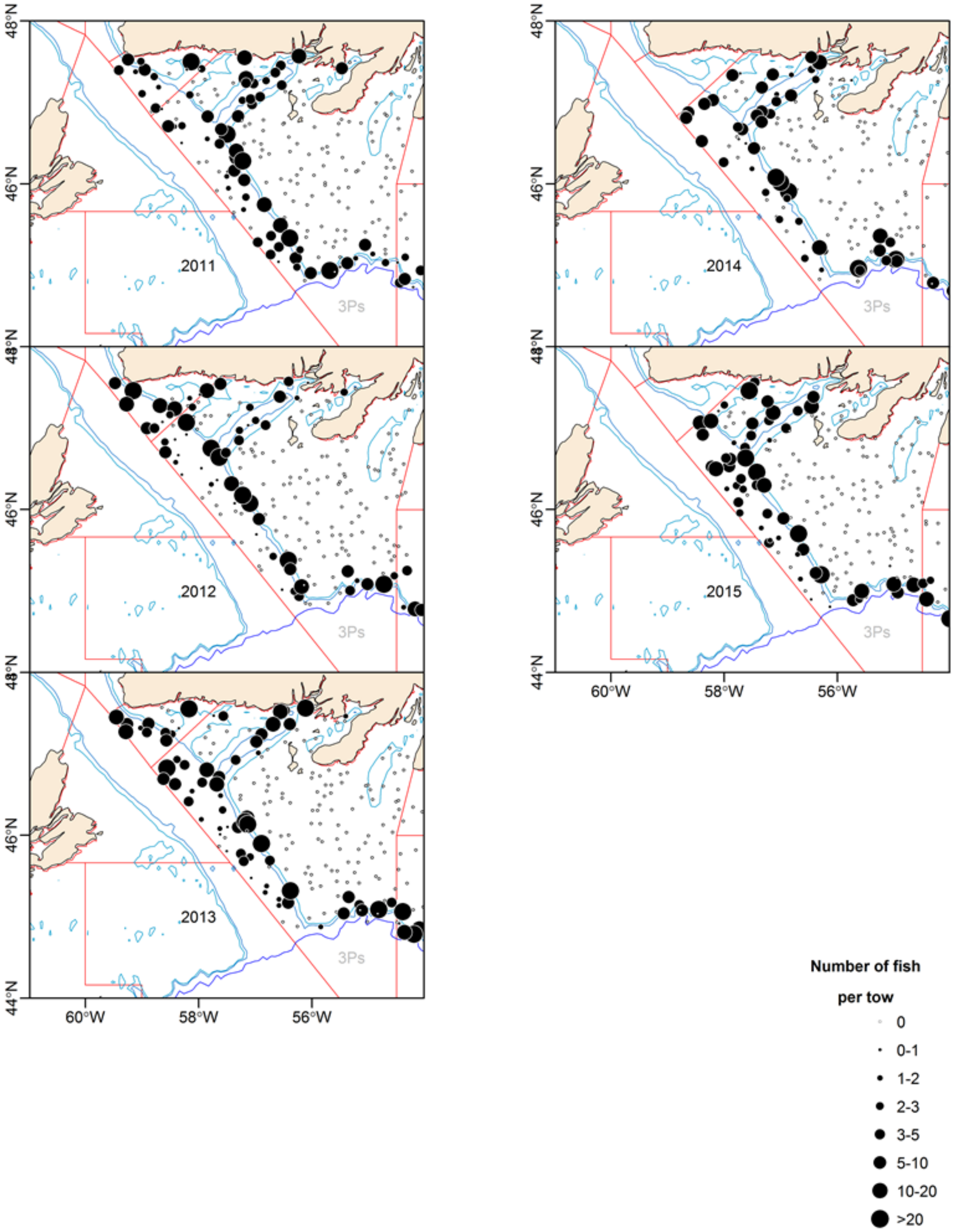


Figure 26. Distribution of White Hake mean numbers per tow in Div. 3P, based on DFO-NL spring research surveys in 2011-15.

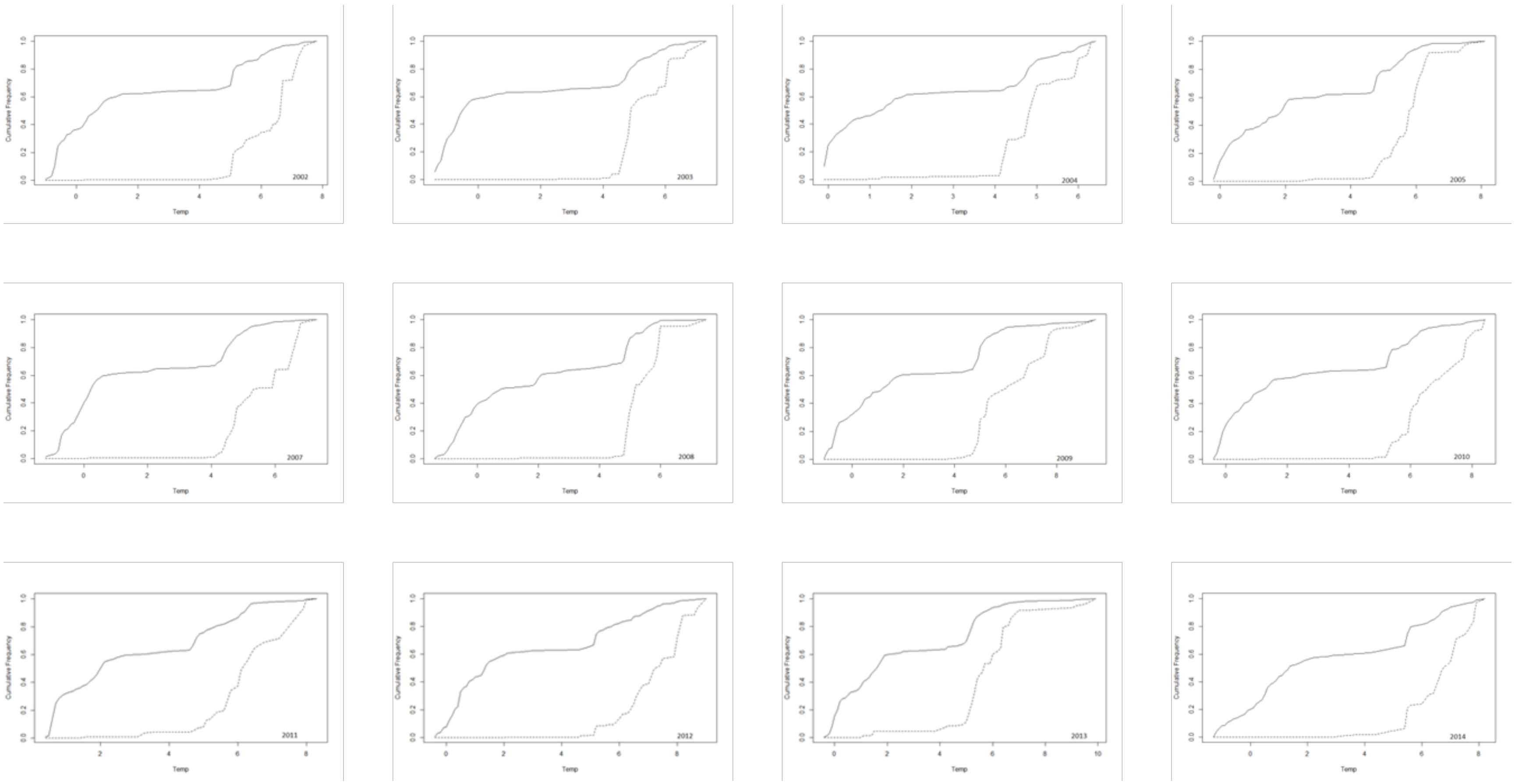


Figure 27. Cumulative frequency distributions of temperature and White Hake catch-weighted data from DFO-NL spring research surveys in Subdiv. 3Ps, 2002-14.

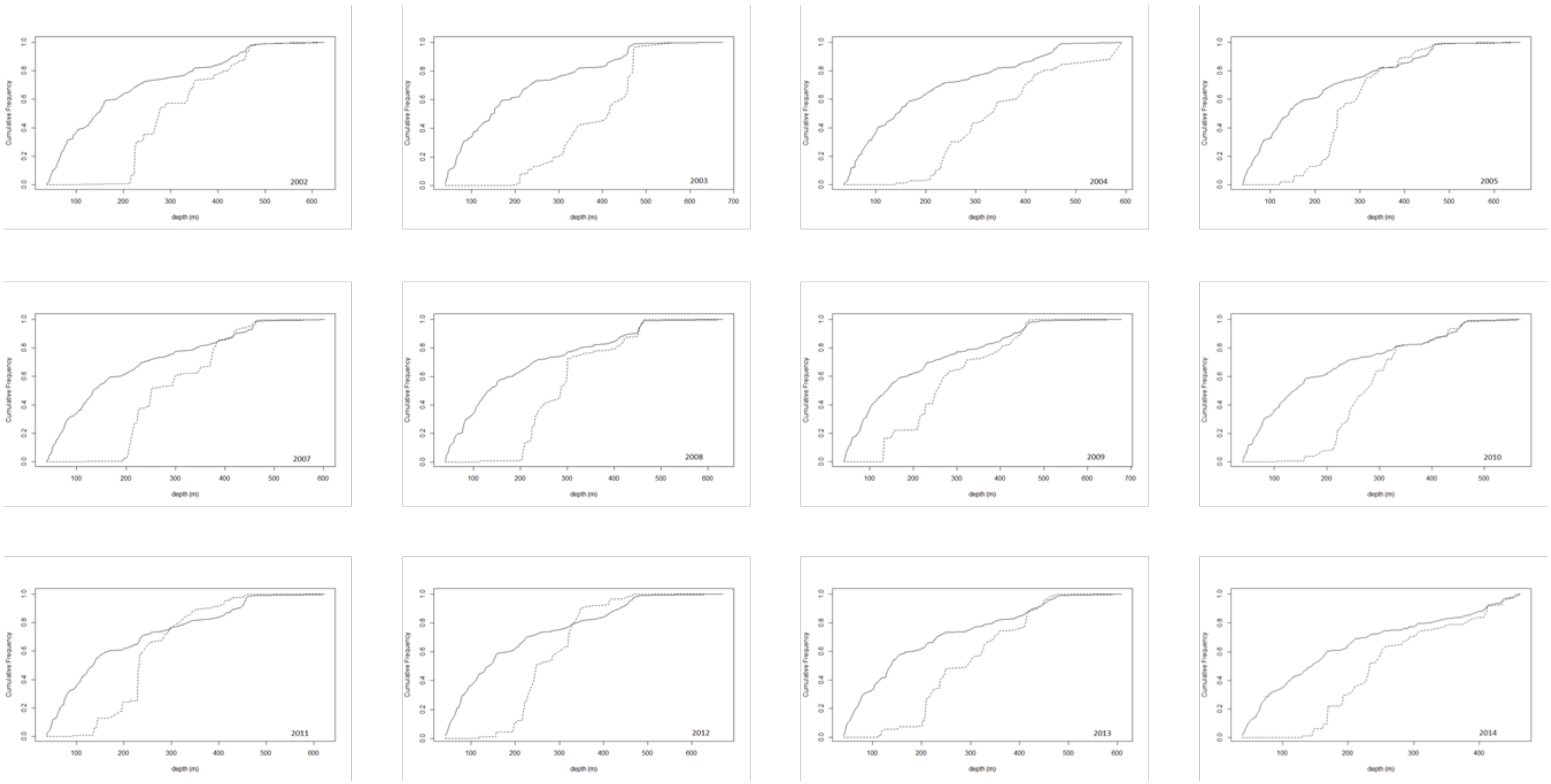


Figure 28. Cumulative frequency distributions of depth and White Hake catch-weighted data from DFO-NL spring research surveys in Subdiv. 3Ps, 2002-14.

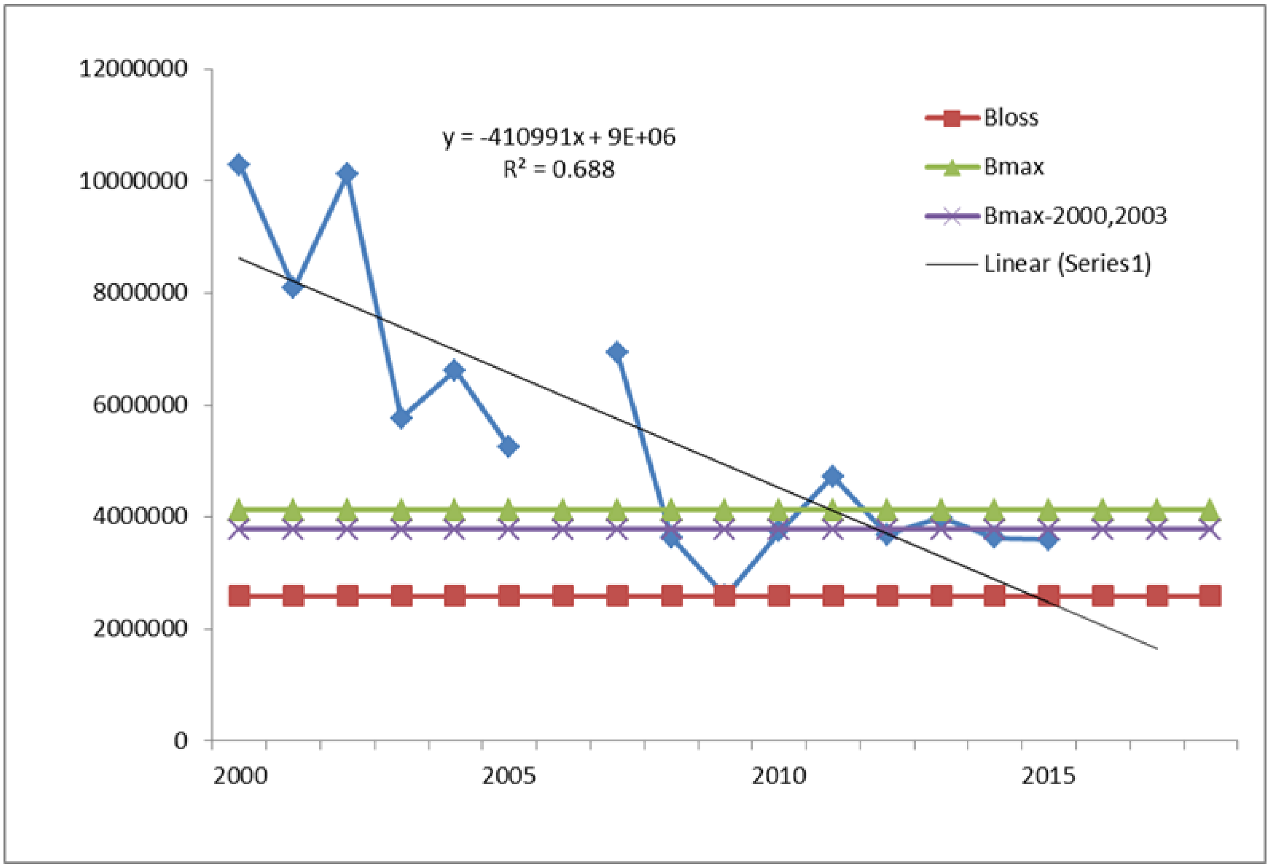


Figure 29. Biomass trends in NAFO Subdiv. 3Ps with linear trend indicated and hypothetical limit reference points based on B_{loss}, B_{max}, and $B_{max(2000\text{-}2003)}$. Note that most of Subdiv. 3Ps was not surveyed in spring 2006, due to Canadian research vessels' mechanical difficulties.