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# Assessment of Monkfish (*Lophius americanus* Valenciennes 1837) in NAFO Divisions 3LNO and Subdivision 3Ps

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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

Monkfish in the Northwest Atlantic Fisheries Organization (NAFO) Subdivision 3Ps and Divisions 3LNO constitute one biological stock, and encounters ongoing mortality in directed and bycatch fisheries conducted by Canada. Annual NAFO-reported landings from Div. 3LNOPs indicated that the Monkfish-directed gillnet fishery averaged 1,664 t in 2001-06, then declined to 255 t over 2007-14. Landings were 160 and 374 t in 2015 and 2016, respectively, and were reported mainly from Div. 3O. In Fisheries and Oceans Canada's (DFO)- Newfoundland and Labrador (NL) spring surveys, NAFO Div. 3LNO Monkfish abundance and biomass indices were lower in recent years (2014-17) relative to 2008-12, and values for 2017 were the smallest since 1998. Based on Div. 3LNO fall surveys, indices of abundance and biomass generally declined after their peaks over 2007-08; in 2017, they reached their lowest values since 1998-99. The area occupied by Monkfish remained relatively constant throughout DFO-NL surveys in both spring and fall; they were found primarily along the shelf edge in Div. 3O and Subdiv. 3Ps, and occasionally along the shelf edge in Div. 3N. Recruitment of Age 3 Monkfish in Div. 3LNOPs over 2014-17 was less than 50% of the 2001-2017 average, and the lowest during this period. The relative fishing mortality index for Div. 3LNOPs peaked during 2002-03, and then remained below the average since 2007.

Ecosystem signals observed in Subdiv. 3Ps in recent years indicated that structural changes are occurring, and overall ecosystem productivity may be low. Although the direct impacts of these changes on Monkfish life stages (i.e., pelagic eggs and larvae, bottom-dwelling juveniles and adults) are unknown, they imply that at least some aspects of Monkfish productivity may be affected.

Using NAFO average landings for 2013-15 as *status quo*, total landings from Div. 3LNOPs in 2016 were 374 t: greater than twice the *status quo* of 160 t. In addition, recent declines in spring survey abundance and biomass in Div. 3LNO causes concern for the future of this stock when combined with recent low recruitment. For 2017, the Monkfish biomass index for Div. 3LNOPs is estimated to be above the accepted proxy Limit Reference Point.

## INTRODUCTION

Monkfish *(Lophius americanus* Valenciennes 1837) is distributed in the Northwest Atlantic from Florida (USA) to Cape Chidley, Labrador (Scott and Scott 1988). Though widely dispersed, very limited research has been conducted on this species. In Canadian waters, Beanlands and Annand (1996) carried out a preliminary assessment on the Scotian Shelf, and Beanlands et al. (2000) reported on preliminary aged-based analyses. Assessments of Monkfish have previously been conducted for the Grand Banks and St. Pierre Bank (Fig. 1) in NAFO Divisions 3LNO and Subdivision 3Ps (Kulka and Deblois 1996; Kulka and Miri 2001, 2003).

This paper provides information on the current status of Monkfish in Div. 3LNO and Subdiv. 3Ps, using commercial fisheries and DFO-NL research survey data.

## OCEANOGRAPHY AND ECOSYSTEM OVERVIEW

Oceanographic conditions in Div. 3O and Subdiv. 3Ps are influenced by several factors: local atmospheric climate conditions, advection by the Labrador Current from the east and warmer and saltier Gulf Stream waters from the south, and complex bottom topography in the region. The extent of bottom areas where water temperatures exceed 3°C (Monkfish are primarily found in 3-9°C), although close to normal in 2017, has been increasing over the past two decades, and warm slope water intrusions have elevated temperatures to near 10°C in some offshore areas in recent years.

Compared to the standard reference period (1999-2010), the spring phytoplankton bloom was observed later, of a shorter duration, and reduced in magnitude during 2015-17, while zooplankton biomass was at its lowest level in this time-series (Pepin et al., in prep.).

Ecosystem signals observed in Subdiv. 3Ps in recent years indicated that structural changes are occurring, and overall ecosystem productivity may be low. Although the direct impacts of these changes on Monkfish life stages (i.e., pelagic eggs and larvae, bottom-dwelling juveniles and adults) are unknown, they imply that at least some aspects of Monkfish productivity may be affected.

## FISHERY AND MANAGEMENT

There has been a directed fishery for Monkfish in USA waters since the 1970s but, in Canadian waters, it was taken only as bycatch in other groundfish-directed fisheries, and was usually discarded at sea until the early 1990s. Since then, a directed fishery was developed on the Grand Banks as a mixed mobile- and fixed-gear fishery for Monkfish, Thorny Skate (*Amblyraja radiata)* and White Hake (*Urophycis tenuis*).

### TAC REGULATION

A precautionary quota of 200 t was adopted in 1995, but discontinued after 1997. Since then, this fishery has been regulated by gear number and type. There are also restrictions on bycatch of major commercial species and species under moratoria, and fishing season closures.

### LANDINGS TRENDS

Commercial fisheries removals of Monkfish in Div. 3LNO and Subdiv. 3Ps were examined for 1960-2016, using three data sources: the Northwest Atlantic Fisheries Organization's (NAFO) STATLANT-21A landings (1960-2016), as reported by NAFO-member countries; DFO-NL Zonal

Interchange File Format (ZIFF) landings (1985-2016), as recorded in logbooks by Canadian fishers operating in Canada's EEZ; and Canadian at-sea fisheries observers' (ASOs) reported catch and discards (1978-2016). It must be noted that Canadian ASOs constitute the sole source of data on total catch (= landings + discards) by species at sea.

NAFO-reported landings of Monkfish in Div. 3LNOPs (member countries combined) indicated that there was a very limited directed fishery in 1960-81: annual landings were less than 10 t in most years (Table 1; Fig. 2). Over 1982-2000, the Monkfish fishery was modest, with annual landings averaging 366 t (of which 181 t was reported by Canada). In 2001-06, average landings increased to 1,664 t (1,568 t by Canada), then declined to 255 t over 2007-14 (198 t by Canada). Monkfish landings were 160 t (37 t by Canada) and 374 t (89 t by Canada) in 2015 and 2016, respectively. Overall, the majority of NAFO-reported landings were from Div. 3O.

DFO-NL ZIFF-reported landings of Monkfish in Div. 3LNOPs were almost exclusively caught by gillnets in 1998-2013, then the majority by otter trawls over 2014-16 (Fig. 3). In 2001-12, the Monkfish-directed fishery reported more than 70% of the annual landings (Fig. 4). Over 2014-16, approximately 100% of landings were from Canadian bycatch fisheries targeting other commercial species such as Atlantic Cod (*Gadus morhua*), Atlantic Halibut (*Hippoglossus hippoglossus*), redfish (*Sebastes* spp.), skates, White Hake (*Urophycis tenuis*), and Witch Flounder (*Glyptocephalus cynoglossus*; Fig. 5). In 1998-2004, the skate-directed fishery reported the majority of Monkfish landings, then the White Hake fishery in 2006-12, and the Witch Flounder fishery over 2013-16.

### COMMERCIAL SIZE

Annual Observer coverage of the directed fishery for monkfish has been very low; it has varied between 0-1% since 2000. Observers' length distributions of Monkfish taken by Canadian directed gillnet fisheries (300-360 inch mesh) indicated that a range of 32-121 cm (60-66 cm modes) were caught in Div. 3O over 2000-12, and 51-117 cm (58-67 cm modes) in Subdiv. 3Ps in 2000-06 (Figs. 6a,b). Landings data (which do not include discards at sea) showed a range of 32-126 cm (61-69 cm modes) from Div. 3O over 2000-12, and 26-125 cm (62-69 cm modes) from Subdiv. 3Ps in 2001-10 (Figs. 7a,b). ASO-recorded length frequencies for Monkfish from its directed fishery in Subdiv. 3Ps were not available after 2010, nor from Div. 3O after 2012.

Regarding bycatch fisheries observed by Canadian ASOs over 2002-16, the skates-directed otter trawl (305 cm mesh) fishery in Div. 3O caught 44-73 cm Monkfish (63 cm mode; Fig. 8a). The redfish-directed trawl (95-110 cm mesh) fishery captured 47-96 cm Monkfish (82 cm mode) in Div. 3O, and 29-122 cm fish in Subdiv. 3Ps (54 cm mode; no discernable mode in 2006). The Witch Flounder-directed trawl (145-155 cm mesh) fishery caught 37-109 cm Monkfish (64-67 cm modes) in Div. 3O, and 51-103 cm fish in Subdiv. 3Ps (71-78 cm modes in 2015; 60 cm mode in 2016). The skates-directed gillnet (305-310 cm mesh) fishery in Div. 3O captured 39-99 cm Monkfish (61-65 cm modes; except for 68 and 76 cm modes in 2003; Fig. 8b).

## RESEARCH SURVEY DATA

### NL REGION

DFO-NL bottom trawl research surveys have been conducted annually over the continental shelves of Newfoundland and Labrador in spring (Div. 3LNOPs; 1972-2017) and fall (Div. 3LNO; 1990-2016). These surveys employed a stratified-random design based on depth intervals and location (latitude, longitude), and were designed to provide data on abundance, biomass, distribution, and area occupied by numerous demersal and benthic fish, as well as several

invertebrate species. Details of these surveys, including changes in gear type and spatial coverage over time, are discussed in Doubleday (1981), Bishop (1994), McCallum and Walsh (1996), Walsh and McCallum (1996), Brodie and Stansbury (2007), Healey and Brodie (2009), and Simpson and Miri (2013). In order to allow for inter-annual comparisons, only those strata that were consistently sampled in most years (i.e., core strata) are included in the calculation of spring and fall indices of population size and distribution.

It must be noted that, due to different trawls being deployed during the spring (Yankee 41.5 in 1972-82; Engel 145 in 1983-95; Campelen 1800 in 1996-2017) and fall (Engel 145 in 1990-94; Campelen 1800 in 1995-2016) surveys, combined with a lack of conversion factors to account for differences in Monkfish catchability resulting from gear changes, the various survey time-series are not directly comparable. In addition, although fall surveys cover deeper strata (~1,400 m) than those in spring (~750 m) and thus are not directly comparable to spring surveys, they do not cover the entire stock area and are not considered spatially complete. For this reason, DFO-NL spring surveys are the primary source of abundance and biomass estimates for Monkfish. Furthermore, due to Canadian research vessels' mechanical difficulties, the spring survey was incomplete in 2006 because most of Subdiv. 3Ps was not sampled, while only shallow strata in Div. 3NO (to 77 m in Div. 3N; to 103 m in Div. 3O) were surveyed; the fall survey was incomplete in 2014 due to partial coverage of Div. 3L and no sampling of Div. 3NO. Thus, survey estimates for these years are not comparable to others within each Campelen time-series. In 2015, several strata were not sampled in Div. 3L, thereby affecting abundance and biomass estimates. Additional data from Subdiv. 3Pn were also included in this assessment for comparative purposes, although this Subdivision was not surveyed in spring 2008 and 2014-17.

## SPRING SURVEY RESULTS

### Abundance and Biomass

In Div. 3LNO over 1973-82 (Yankee trawl; Table 2; Fig. 9, top-left panel), relative abundance from DFO-NL spring surveys indicated an increasing trend to a peak of 0.3 million Monkfish in 1982. In 1984-95 (Engel trawl), this abundance index fluctuated substantially and reached a peak of 0.4 million fish in 1994. Over 1996-2017 (Campelen trawl), relative abundance fluctuated along an increasing trend to a peak of 1.1 million Monkfish in 2003, then appeared to follow a decreasing trend to 0.1 million fish in 2017: its lowest estimate since 1999. Relative biomass (Table 2; Fig. 9, bottom-left panel) also suggested an increasing trend in Div. 3LNO over 1973-82, with a peak of 1,231 t in 1982. In 1984-88, this biomass index followed an increasing trend to a peak of 2,370 t in 1988, then fluctuated substantially to 232 t in 1995. Over 1996-2017, relative biomass fluctuated along an increasing trend to a peak of 3,797 t in 2013, then appeared to decline to 804 t in 2017: its lowest estimate since 1998.

Mean numbers and mean weights per spring tow for Monkfish in Div. 3LNO mirrored the trends of their respective indices over 1973-2016 (Fig. 10, left column), with peaks in mean number of 0.06/tow and mean weight of 0.23 kg/tow in 1982 (Yankee; minimums of 0.001 fish and 0.01 kg), 0.08 fish and 0.21 kg in 1994 (Engel; mins. 0.01 fish and 0.02 kg), 0.11 fish and 0.20 kg in 2003 (Campelen; mins. 0.01 fish and 0.03 kg), and 0.09 fish and 0.37 kg in 2013. Over 2014-17, mean numbers and mean weights per tow decreased to 0.02 Monkfish and 0.13 kg, respectively.

In Subdiv. 3Ps over 1972-82 (Table 2; Fig. 9, top-right panel), the abundance index from spring surveys suggested a slightly increasing trend to a peak of 0.3 million Monkfish in 1981. In 1983-95, relative abundance fluctuated around four peaks of approximately 0.4 million fish, then

appeared to decrease to an average of 0.2 million over 1992-95. Over 1996-2016, relative abundance fluctuated along an increasing trend to a peak of 1.1 million Monkfish in 2010, then seemed to follow a decreasing trend to 0.3 million fish in 2016. This index reached a smaller peak of 0.9 million fish in 2017; comparable to that observed in 2007. Relative biomass (Table 2; Fig. 9, bottom-right panel) suggested a decreasing trend in Div. 3LNO over 1972-82, with a peak of 1,221 t in 1975 and its lowest estimate of 218 t in 1982. In 1983-95, this biomass index indicated an increasing trend to a peak of 2,843 t in 1987, then fluctuated substantially to its lowest estimate of 569 t in 1993. Over 1996-2016, relative biomass fluctuated along an increasing trend to a peak of 3,445 t in 2007, then appeared to follow a decreasing trend to 1,928 t in 2016. This index reached its largest peak of 4,207 t in 2017. It must be noted that Subdiv. 3Ps estimates in isolation do not represent any changes or trends in indices for the entire Div. 3LNOPs Monkfish stock.

Mean numbers and mean weights per tow for Monkfish in Subdiv. 3Ps mirrored the trends of their respective indices over 1983-2017 (Fig. 10, right column), but appeared to follow a decreasing trend from 1975 (Yankee; 0.45 fish/tow and 3.30 kg/tow, respectively) to 1982 (0.07 fish and 0.17 kg). In 1983-95 (Engel), mean numbers per tow fluctuated around four peaks of approximately 0.32 fish/tow, then appeared to decrease to an average of 0.11 over 1992-95. Over 1996-2016 (Campelen), mean numbers per tow fluctuated along an increasing trend to a peak of 0.39 fish/tow in 2010, then seemed to follow a decreasing trend to 0.20 fish/tow in 2016. This estimate reached a smaller peak of 0.33 fish/tow in 2017, comparable to that seen in 2007. In 1983-95, mean weights per tow indicated an increasing trend to a peak of 2.17 kg in 1986, then fluctuated substantially to its lowest estimate of 0.43 kg/tow in 1993. Over 1996-2016, mean weights per tow fluctuated along an increasing trend to a peak of 1.27 kg in 2007, then appeared to follow a decreasing trend to 0.72 kg in 2016. This index reached its largest peak of 1.47 kg in 2017.

In Div. 3LNOPs (combined, i.e., the biological stock) over 1996-2017, the abundance index from spring surveys appeared to follow an increasing trend to a peak of almost 2 million Monkfish in 2003, then fluctuated along a decreasing trend to approximately 0.9 million fish in 2015-16 (Fig. 11, left panel). In 2017, abundance was 1.0 million fish. The biomass index indicated an increasing trend to a peak of 6,500 t in 2010, then decreased to a 2014-16 average of 3,800 t (Fig. 11, right panel). In 2017, biomass was estimated to be 5,000 t.

## Distribution

Geo-referenced mean numbers per tow from DFO-NL spring surveys were used to assess the spatial distribution of Monkfish in Div. 3LNOPs. Distributions of this species over 1998-2017 were consistent with historic data, indicating that Monkfish in Newfoundland and Labrador waters were found primarily along the shelf edge in Div. 3O and Subdiv. 3Ps, and occasionally along the shelf edge in Div. 3N (Figs. 12a-d).

## Survey Size Structure

Lengths of Monkfish caught in DFO-NL spring surveys of Div. 3NO (none in Div. 3L; few found in Div. 3N) and Subdiv. 3Ps in 2001-17 ranged from 5 to 100 cm (Figs. 13a,b). Females dominated length classes >65 cm each year (with variable modes), while males were usually represented by modes of 56-60 cm in 2001-09 and 61-66 cm over 2010-15. Relatively larger peaks of young-of-the-year to approximately Age 1 Monkfish (unsexed; 15-20 cm) were observed in 2004, 2007, 2009-10, and 2013 (Figs. 14a,b).

## Recruitment

In DFO-NL spring surveys, Monkfish are not aged; therefore, a length proxy from research conducted on the Northeastern USA population (Richards et al. 2007) was applied to Div. 3LNOPs survey length measurements. The number of Monkfish 12-20 cm in length was assumed to be an index of Age 2 Monkfish, and 21-30 cm fish to represent Age 3 Monkfish. Monkfish enter the directed fishery at 40+ cm; therefore, the number of Age 3 Monkfish represents fish available to the following season's fishery.

The Age 3 recruitment index was large in 2005 and less so in 2010, but over 2014-17 was less than 50% of its 2001-17 average (112), and the lowest in this time-series (Fig. 15). Similarly, abundance of Age 2 Monkfish was less than 30% of its 2001-17 average in 2014-16, but above average in 2017.

## Index of Fishing Mortality

Estimates of relative fishing mortality (Relative F=NAFO-reported commercial landings/DFO-NL spring survey biomass index) were calculated for Monkfish in Div. 3LNO and Subdiv. 3Ps. The Relative F index for Div. 3LNO peaked in 1998 at 1.00 and 2002-03 at 1.26, then decreased and remained below its 1996-2016 average index of 0.30 since 2007 (Fig. 16, top panel). For Subdiv. 3Ps, Relative F peaked in 2002 at 0.31 and 2005 at 0.35, then decreased and remained below its 1996-2016 average of 0.10 since 2007 (Fig. 16, bottom panel).

# FALL SURVEY RESULTS

In Div. 3LNO over 1990-94 (Engel trawl; Table 3; Fig. 17, top panel), relative abundance from DFO-NL fall surveys appeared to be stable at low levels, averaging 0.1 million Monkfish. Over 1995-2016 (Campelen trawl), this index fluctuated along an increasing trend to peaks of approximately 1.0 million Monkfish in 2007-08, then seemed to follow a decreasing trend to 0.1 million fish in 2016: its lowest estimate since 1998. Relative biomass (Table 3; Fig. 17, bottom panel) also appeared to be stable at low levels over 1990-94, averaging 405 t. In 1995-2016, this index fluctuated substantially along an increasing trend to a peak of 3,948 t in 2008, and then followed a decreasing trend to 473 t in 2016: its lowest estimate since 1999. It must be noted that Subdiv. 3Ps is not surveyed in the fall.

Mean numbers and mean weights per fall tow for Monkfish in Div. 3LNO mirrored the trends of their respective indices over 1990-2016 (Fig. 18). In 1990-94 (Engel), mean numbers per tow fluctuated without trend over 0.01-0.03 fish. In 1995-2016 (Campelen), mean numbers per tow fluctuated along an increasing trend to a peak of 0.1 fish over 2007-08, then seemed to follow a decreasing trend to 0.01 fish/tow in 2016. In 1990-94, mean weights per tow fluctuated without trend over 0.01-0.11 fish. In 1995-2016, mean weights per tow fluctuated along an increasing trend to a peak of 0.38 kg in 2008, and then appeared to follow a decreasing trend to 0.05 kg in 2016.

## Distribution

In Div. 3LNO, Monkfish distribution remained relatively constant throughout the fall survey time-series (Figs. 19a-d). Monkfish were found primarily along the shelf edge in Div. 3O, and occasionally along the shelf edge in Div. 3N.

# ASSESSMENT

## LIMIT REFERENCE POINTS

In the absence of an accepted analytical model for the Div. 3LNOPs Monkfish stock, precautionary limit reference points (LRPs) were not previously estimated to guide fisheries management's decision-making. Using the DFO-NL Campelen spring survey in Div. 3LNOPs with three different models (Catch-resilience, ASPIC, empirical limit reference points), various proxies for Monkfish biomass at maximum sustainable yield ($B_{MSY}$) were calculated to investigate biological reference points for application of the DFO Precautionary Approach Framework (DFO 2006).

### Catch-Resilience MSY Model

The Catch-resilience Maximum Sustainable Yield (MSY) model (Martell and Froese 2013) estimates MSY from catch data, and is intended for data-poor stocks where only a time-series of commercial catch is available. This method is based on a Bayesian Schaefer model (Schaefer 1954), which characterizes biomass dynamics in terms of intrinsic rate of increase (r) and carrying capacity (K); identifying values of r and K that give viable stock trajectories for observed data, from which applicable r-K pairs are used to derive an MSY distribution. Catch-resilience models were applied with various input parameters, in order to investigate the robustness of model estimates. A sensitivity analysis was also conducted, using variations in process error, range of K, final biomass, and resilience.

#### Catch-resilience Results

Estimates of MSY were very robust to variation in process error and final biomass (Table 4; Figs. 20-21). Variation in process error had little impact on the $B_{MSY}$ estimate. $B_{MSY}$ was 6,009 t on average, which produced a proxy LRP of 2,403 t and an upper stock reference point of 4,807 t. In 2017, the survey biomass index of 5,010 t was two times larger than this proxy LRP.

### ASPIC Models

Several model formulations of the ASPIC surplus production software (ASPIC Version 5.24; Prager 1994) were applied to Div. 3LNOPs NAFO-reported commercial landings and DFO-NL spring survey Monkfish biomass indices. ASPIC models were then assessed using their R-squared values (on Catch per Unit Effort), residual patterns, correlation between biomass indices, and consideration of estimated parameters (Table 5).

#### ASPIC Results

None of these model runs produced a good fit to these data: R-squared values were very low, and catchabilities in the models did not appear reasonable. Therefore, no ASPIC surplus production model was accepted, and no LRP estimated.

### Empirical Limit Reference Points

Various proxies for $B_{MSY}$ were derived as geometric means using: (1) the entire Campelen spring survey time-series (1996-2017); (2) a period of high productivity (successive years of high stock biomass; 2007-13); (3) the highest annual biomass estimate ($B_{MAX}$); and (4) the two highest biomass estimates. These proxies were then used to calculate probable values for LRPs.

### LRP Results

A proxy for $B_{lim}$ may be the point at which a biomass index declines by 85% from its maximum observed value. The highest Monkfish biomass estimate was 6,496 t (2010), from which a minimum biomass estimate (i.e., a commercial stock may not recover below this limit; $B_{lim}$) of 974.4 t was then calculated. Given that commercial landings of Monkfish began in the late 1970s, the highest survey abundance estimate cannot represent the non-exploited biomass (i.e., biomass prior to the onset of fishing; $B_o$) for this stock; therefore, applying the 85% decline criterion to establish a LRP is not prudent.

Although not representative of $B_o$, a high biomass estimate can constitute a benchmark, and may represent $B_{MSY}$ for this stock. Resultant $B_{MSY}$ proxies ranged from 3,706 t to 6,448 t, and LRPs from 1,430 t to 2,579 t (Fig. 22; Table 6).

Using a single-peak annual biomass estimate to derive LRPs for this stock was problematic, because this DFO-NL spring survey index has a considerable degree of variability. For example, use of the smallest observed spawning biomass ($B_{loss}$; in Campelen spring time-series) as a biological reference point was considered inappropriate for Div. 3LNOPs Monkfish. Therefore it was considered that using a geometric mean for a period of high biomass (2007-13), or for the entire Campelen spring time-series (1996-2017), was more appropriate. A $B_{lim}$ of 40% of the two highest biomass years in the Campelen time-series was 2,579 t. The spring biomass index declined below this level in 1996, and 1998-99, before increasing above $B_{lim}$ in 2001. The most recent period (2007-13) of higher annual estimates occurred during lower reported landings (261-t average). Over 2014-16, biomass estimates declined to a 3,832-t average. In 2017, the biomass index (5,010 t) was 2.5 times larger than the accepted LRP of 2000 t (based on the 2007-13 geometric mean). However, continued high landings can potentially jeopardize the status of this stock.

## PERSPECTIVE ON DIV. 3LNO AND SUBDIV. 3PS MONKFISH

In DFO-NL spring surveys, Div. 3LNO Monkfish abundance and biomass indices were lower in recent years (2014-17) relative to 2008-12, with 2017 indicating their smallest estimates since 1998. Based on Div. 3LNO fall surveys, Monkfish generally declined in abundance and biomass after their peaks over 2007-08, reaching their lowest estimates since 1998-99 in 2017. These declines cause concern for the future of this stock when combined with recent low recruitment. In addition, higher landings of Monkfish in 2016 were due mainly to increased bycatch in the Canadian Witch Flounder-directed trawl fishery.

In 2017, the Monkfish biomass index for Div. 3LNOPs was estimated to be above the accepted limit reference point.

## ASSESSMENT REVIEW AND GUIDANCE

The status of Div. 3LNOPs Monkfish was first assessed in 1996 (DFO 1996), and then in 2000 and 2003 (DFO 2000, 2003). Monkfish in Div. 3LNO and Subdiv. 3Ps constitute a single biological stock.

A five-year assessment schedule is recommended for Div. 3LNOPs Monkfish. Although more frequent updates on this stock may be required as a consequence of an ongoing (but greatly reduced) Canadian Monkfish-directed gillnet fishery, the Canadian Witch Flounder trawl fishery (which more than doubled its bycatch landings of Monkfish in 2016), and renewed interest in the Canadian Thorny Skate fishery (which historically landed 50-90% of reported Monkfish bycatch), the annual review of DFO-NL research survey data (Rideout et al. 2017) should

mitigate any negative outcomes. Based on guidance from TESA (Technical Expertise in Stock Assessment; DFO 2016), a full assessment must be required if its major population indicator (i.e., DFO-NL spring survey biomass index) statistically changes by more than two standard deviations. This re-assessment may result in revised landings advice for Monkfish-directed and bycatch fisheries. Furthermore, interim-year assessments should also be triggered by an increase in annual landings of two standard deviations above the 2001-to-current average landings - without a significant, concomitant positive change in the DFO-NL spring survey biomass index for this species.

## SOURCES OF UNCERTAINTY

- Discarding at sea of Monkfish bycatch remains unreported or very poorly reported in Canadian and other fisheries. Canadian at-sea fisheries observers constitute the sole source of data on total catch (= landings + discards) by species at sea. However, there is very low to non-existent at-sea observer coverage in most Canadian Atlantic fisheries; thereby grossly underestimating fishery impacts on this stock, and preventing at-sea collections of important biological data on Monkfish (length, weight, sex, maturity, otoliths).
- Monkfish age data are not available from DFO-NL research surveys. In addition, data on length, weight, and maturity of Monkfish in DFO-NL survey catches are incomplete.
- Although recruitment of Div. 3LNOPs Monkfish was large in 2005 and less so in 2010, this index over 2014-17 was less than 50% of the 2001-17 average, and the lowest in this time-series.
- Ecosystem signals observed in Subdiv. 3Ps in recent years indicated that structural changes are occurring, and overall ecosystem productivity may be low. Although the direct impacts of these changes on Monkfish life stages (i.e., pelagic eggs and larvae, bottom-dwelling juveniles and adults) are unknown, they imply that at least some aspects of Monkfish productivity may be affected.
- Impacts of anthropogenic activities (e.g., marine plastics pollution, seismic surveys, oil and gas drilling, oil pollution) and climate change (i.e., increasing ocean temperatures, decreasing salinities, decreasing marine dissolved oxygen) on Monkfish life stages and their habitats remain unknown.

## CONCLUSIONS

Given that recruitment for Div. 3LNOPs Monkfish over 2014-17 was less than 50% of the 2001-17 average (and the lowest in this time-series), commercial fishing pressure should be regulated by a TAC set at a level that will allow survival and growth to maturity of larger year-classes. This strategy (coupled with enforcement) is crucial to rebuilding this stock, especially given that their lowest Div. 3LNO abundance and biomass indices in both spring and fall surveys were seen in 2017. Furthermore, if increased landings result from the increasing commercial interest in harvesting Monkfish due to declining stocks of other groundfish and shellfish in this region, inhibitive pressures on the Div. 3LNOPs stock may be further exacerbated. It should be noted that higher landings of Monkfish in 2016 were due mainly to increased bycatch in the Canadian Witch Flounder-directed trawl fishery.

In the absence of a TAC, regulations that limit the amount of Monkfish bycatch for other groundfish-directed fisheries in Canada's EEZ could also be implemented, in view of DFO's new Policy for Managing Bycatch (DFO 2013).

In 2017, the Monkfish biomass index for Div. 3LNOPs (5,010 t) was estimated to be 2.5 times larger than the accepted proxy limit reference point of 2,000 t.

Given that Canadian at-sea fisheries observers constitute the sole source of data on total catch (= landings + discards) by species at sea, annual observer coverage of Canadian Monkfish-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, and allow at-sea collections of important biological data on Monkfish (length, weight, sex, maturity, otoliths).

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The authors thank Fisheries and Oceans Canada staff who participated in Canadian research surveys, and Canadian at-sea fisheries observers who collected data and specimens aboard commercial fishing vessels under difficult conditions over many years. We also thank D.W. Kulka (DFO-NL *Scientist emeritus*) for providing insightful and constructive comments on an earlier version of this manuscript.

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## APPENDICES

*Table 1. NAFO-reported landings (tonnes; STATLANT-21A) of Monkfish in Div. 3LNOPs, 1960-2016.*

| - | 3LNOPs | | | 3Ps | | |
|---|---|---|---|---|---|---|
| Year | non-Can | Canada | Total | non-Can | Canada | Total |
| 1960 | 4 | - | 4 | 3 | - | 3 |
| 1961 | - | - | - | - | - | - |
| 1962 | 5 | - | 5 | 1 | - | 1 |
| 1963 | 3 | - | 3 | 1 | - | 1 |
| 1964 | 5 | - | 5 | 4 | - | 4 |
| 1965 | 4 | - | 4 | 4 | - | 4 |
| 1966 | 3 | - | 3 | 1 | - | 1 |
| 1967 | - | - | - | - | - | - |
| 1968 | 2 | - | 2 | 2 | - | 2 |
| 1969 | 888 | - | 888 | 144 | - | 144 |
| 1970 | 464 | - | 464 | 135 | - | 135 |
| 1971 | 7 | - | 7 | 6 | - | 6 |
| 1972 | 5 | 1 | 6 | 5 | - | 5 |
| 1973 | 2 | 2 | 4 | 2 | 1 | 3 |
| 1974 | 0 | 1 | 1 | - | - | - |
| 1975 | 3 | 7 | 10 | 3 | 7 | 10 |
| 1976 | 4 | 2 | 6 | 4 | 1 | 5 |
| 1977 | 1739 | 4 | 1743 | 1 | 4 | 5 |
| 1978 | 228 | 1 | 229 | - | 1 | 1 |
| 1979 | - | 13 | 13 | - | 10 | 10 |
| 1980 | - | - | - | - | - | - |
| 1981 | 91 | - | 91 | - | - | - |
| 1982 | 58 | - | 58 | - | - | - |
| 1983 | - | 5 | 5 | - | - | - |
| 1984 | 70 | 14 | 84 | - | 10 | 10 |
| 1985 | 101 | 27 | 128 | - | 17 | 17 |
| 1986 | 498 | 86 | 584 | 1 | 33 | 34 |
| 1987 | 1808 | 63 | 1871 | 25 | 25 | 50 |
| 1988 | 479 | 20 | 499 | 45 | 9 | 54 |
| 1989 | 230 | 28 | 258 | 30 | 6 | 36 |
| 1990 | 237 | 21 | 258 | 52 | 8 | 60 |
| 1991 | 328 | 192 | 520 | 42 | 48 | 90 |
| 1992 | 42 | 345 | 387 | 4 | 92 | 96 |
| 1993 | 2 | 487 | 489 | - | 51 | 51 |
| 1994 | - | 510 | 510 | - | 359 | 359 |
| 1995 | - | 291 | 291 | - | 188 | 188 |
| 1996 | - | 257 | 257 | - | 111 | 111 |
| 1997 | 1 | - | 1 | - | - | - |
| 1998 | 3 | 434 | 437 | 1 | 163 | 164 |
| 1999 | - | 178 | 178 | - | 66 | 66 |
| 2000 | 4 | 127 | 131 | - | 34 | 34 |
| 2001 | 9 | 795 | 804 | - | 274 | 274 |
| 2002 | 167 | 2346 | 2513 | 1 | 659 | 660 |
| 2003 | 274 | 2802 | 3076 | 1 | 630 | 631 |

| - | 3LNOPs | | | 3Ps | | |
|---|---|---|---|---|---|---|
| Year | non-Can | Canada | Total | non-Can | Canada | Total |
| 2004 | 83 | 1046 | 1129 | - | 327 | 327 |
| 2005 | 9 | 1181 | 1190 | - | 566 | 566 |
| 2006 | 35 | 1236 | 1271 | - | 670 | 670 |
| 2007 | 46 | 275 | 321 | - | 167 | 167 |
| 2008 | 44 | 233 | 277 | - | 37 | 37 |
| 2009 | 4 | 297 | 301 | 1 | 84 | 85 |
| 2010 | 35 | 233 | 268 | 2 | 56 | 58 |
| 2011 | 27 | 314 | 341 | 2 | 55 | 57 |
| 2012 | 39 | 177 | 216 | 32 | 27 | 59 |
| 2013 | 51 | 51 | 102 | 7 | 12 | 19 |
| 2014 | 215 | 2 | 217 | 4 | 1 | 5 |
| 2015 | 123 | 37 | 160 | 3 | 10 | 13 |
| 2016 | 285 | 89 | 374 | 4 | 29 | 33 |

*Table 2. Abundance (x1,000) and biomass (tonnes) of Monkfish from DFO-NL spring research surveys in Div. 3LNOPs, 1972-2017. Surveys were conducted with a Yankee trawl (1972-1982), an Engel trawl (1983-spring 1995), and a Campelen trawl (spring 1996-2017). Subdiv. 3Ps was not surveyed in 2006; Div. 3O was not surveyed in 1972, 1974, 1983; and Div. 3N was not surveyed in 1983.*

Yankee series

| - | Abundance (000s) | Abundance (000s) | Biomass (t) | Biomass (t) |
|---|---|---|---|---|
| Year | 3LNO | 3Ps | 3LNO | 3Ps |
| 1972 | - | 116 | - | 446 |
| 1973 | 67 | 165 | 296 | 882 |
| 1974 | 3 | 190 | 0 | 746 |
| 1975 | 8 | 166 | 27 | 1,221 |
| 1976 | 25 | 120 | 194 | 442 |
| 1977 | 123 | 184 | 332 | 1,053 |
| 1978 | 89 | 157 | 510 | 597 |
| 1979 | 108 | 142 | 131 | 370 |
| 1980 | 181 | 208 | 821 | 223 |
| 1981 | 18 | 283 | 71 | 538 |
| 1982 | 313 | 94 | 1,231 | 218 |

Engel series

| - | Abundance (000s) | Abundance (000s) | Biomass (t) | Biomass (t) |
|---|---|---|---|---|
| Year | 3LNO | 3Ps | 3LNO | 3Ps |
| 1983 | - | 421 | - | 1,130 |
| 1984 | 128 | 357 | 246 | 1,098 |
| 1985 | 129 | 419 | 681 | 2,580 |
| 1986 | 64 | 412 | 535 | 2,843 |
| 1987 | 157 | 360 | 916 | 1,430 |
| 1988 | 206 | 235 | 2,370 | 1,445 |
| 1989 | 44 | 341 | 359 | 2,220 |
| 1990 | 34 | 425 | 452 | 2,187 |
| 1991 | 196 | 187 | 909 | 710 |
| 1992 | 34 | 92 | 93 | 611 |
| 1993 | 29 | 43 | 185 | 474 |
| 1994 | 429 | 26 | 1,224 | 1,217 |
| 1995 | 38 | 99 | 232 | 1,098 |

*Table 2. Continued.*

Campelen series

| - | Abundance (000s) | Abundance (000s) | Biomass (t) | Biomass (t) |
|---|---|---|---|---|
| Year | 3LNO | 3Ps | 3LNO | 3Ps |
| 1996 | 92 | 296 | 590 | 1,136 |
| 1997 | 461 | 778 | 1,515 | 2,881 |
| 1998 | 51 | 452 | 274 | 1,187 |
| 1999 | 509 | 370 | 1,165 | 640 |
| 2000 | 883 | 596 | 1,266 | 1,324 |
| 2001 | 616 | 629 | 2,452 | 1,626 |
| 2002 | 362 | 754 | 1,374 | 2,153 |
| 2003 | 1,136 | 800 | 2,107 | 3,008 |
| 2004 | 706 | 641 | 1,410 | 1,935 |
| 2005 | 654 | 653 | 1,449 | 1,633 |
| 2006 | - | - | - | - |
| 2007 | 732 | 886 | 2,956 | 3,445 |
| 2008 | 458 | 598 | 1,736 | 2,436 |
| 2009 | 662 | 362 | 2,424 | 1,393 |
| 2010 | 641 | 1,068 | 3,408 | 3,088 |
| 2011 | 707 | 747 | 2,055 | 2,685 |
| 2012 | 725 | 682 | 3,410 | 1,454 |
| 2013 | 968 | 508 | 3,797 | 1,466 |
| 2014 | 404 | 659 | 1,873 | 2,083 |
| 2015 | 405 | 460 | 2,075 | 1,440 |
| 2016 | 322 | 549 | 2,096 | 1,928 |
| 2017 | 131 | 901 | 804 | 4,207 |

*Table 3. Abundance (x1,000) and biomass (tonnes) of Monkfish from DFO-NL fall research surveys in Div. 3LNO, 1990-2016. Surveys were conducted with an Engel trawl (1990-fall 1994), and a Campelen trawl (fall 1995-2016). Deep strata of Div. 3NO were not surveyed in 2003, 2004, 2006, 2008, and none of Div. 3NO was surveyed in 2014.*

Engel series

| - | Abundance (000s) | Biomass (t) |
|---|---|---|
| Year | 3LNO | 3LNO |
| 1990 | 59 | 292 |
| 1991 | 178 | 515 |
| 1992 | 58 | 75 |
| 1993 | 123 | 610 |
| 1994 | 123 | 536 |

Campelen series

| - | Abundance (000s) | Biomass (t) |
|---|---|---|
| Year | 3LNO | 3LNO |
| 1995 | 300 | 846 |
| 1996 | 368 | 1,335 |
| 1997 | 220 | 585 |
| 1998 | 28 | 153 |
| 1999 | 438 | 257 |
| 2000 | 584 | 1,194 |
| 2001 | 708 | 2,313 |
| 2002 | 540 | 2,114 |
| 2003 | 832 | 1,642 |
| 2004 | 308 | 860 |
| 2005 | 525 | 1,503 |
| 2006 | 545 | 1,753 |
| 2007 | 1,023 | 2,857 |
| 2008 | 1,009 | 3,948 |
| 2009 | 714 | 2,238 |
| 2010 | 717 | 2,492 |
| 2011 | 230 | 596 |
| 2012 | 539 | 2,011 |
| 2013 | 362 | 2,043 |
| 2014 | - | - |
| 2015 | 316 | 1,869 |
| 2016 | 125 | 473 |

*Table 4. Results of Catch-resilience model for Monkfish in Div. 3LNOPs.*

| Resilience | $F_{MSY}$ | $B_{MSY}$ | MSY | K | r |
|---|---|---|---|---|---|
| very low | 0.138 | 4,557 | 631 | 9,114 | 0.277 |
| low | 0.0761 | 6,364 | 484 | 12,728 | 0.152 |
| medium | 0.138 | 4,557 | 631 | 9,114 | 0.277 |
| B/K | - | - | - | - | - |
| 0.05-.1 | 0.065 | 6,074 | 395 | 12,147 | 0.13 |
| .1-.2 | 0.0757 | 5,766 | 436 | 11,532 | 0.151 |
| .2-.3 | 0.0807 | 5,781 | 467 | 11,562 | 0.319 |
| .3-.4 | 0.0761 | 6,364 | 484 | 12,728 | 0.152 |
| σ | - | - | - | - | - |
| 0.05 | 0.0769 | 6,021 | 463 | 12,042 | 0.154 |
| 0.075 | 0.0718 | 6,079 | 436 | 12,157 | 0.144 |
| 0.1 | 0.0713 | 6,009 | 428 | 12,018 | 0.143 |
| 0.125 | 0.073 | 5,798 | 423 | 11,596 | 0.146 |
| 0.15 | 0.08 | 5,292 | 423 | 12,522 | 0.16 |
| 0.175 | 0.0749 | 5,637 | 422 | 11,274 | 0.15 |

*Table 5. Results of ASPIC models for Monkfish in Div. 3LNOPs.*

| Parameter | Parameter Description | Run 1* | Run 2** | Run 3*** |
|---|---|---|---|---|
| $B_{1/K}$ | Starting relative biomass (in 1985) | 9.97E-02 | 1.24E+00 | 1.47E+00 |
| K | Maximum population size | 3.39E+06 | 4.77E+05 | 1.40E+05 |
| MSY | Maximum sustainable yield | 4.07E+04 | 8.61E+04 | 1.07E+04 |
| $B_{MSY}$ | Population biomass providing MSY | 1.70E+06 | 2.38E+05 | 6.99E+04 |
| $F_{MSY}$ | Fishing mortality rate at MSY | 2.40E-02 | 3.61E-01 | 1.53E-01 |
| $B./B_{MSY}$ | Ratio: B(2017)/$B_{MSY}$ | 6.63E-01 | 2.00E+00 | 1.99E+00 |
| $Y.(F_{MSY})$ | Approximate yield available at $F_{MSY}$ in 2017 | 2.71E+04 | 1.49E+05 | 1.99E+04 |
| Ye. | Equilibrium yield available in 2017 | 3.61E+04 | 4.44E+02 | 5.69E+01 |
| phi | Shape of production curve ($B_{MSY}$/K) | 0.5 | 0.5 | - |
| q | FC/3Ps spring Campelen survey | 2.15E-03 | 3.53E-03 | 1.22E-02 |
| q | 3LNO spring Campelen | 2.00E-03 | 3.35E-03 | 1.16E-02 |
| q | 3LNO spring Engel | 1.17E-03 | 1.05E-03 | 3.36E-03 |
| q | fall 3LNO Campelen | 1.60E-03 | 2.59E-03 | - |
| q | fall 3LNO Engel | 6.94E-04 | - | - |
| R2 | FC/3Ps spring Campelen survey | -0.125 | -0.063 | -0.072 |
| R2 | 3LNO spring Campelen | 0.228 | -0.103 | -0.104 |
| R2 | 3LNO spring Engel | -0.187 | -0.122 | -0.108 |
| R2 | fall 3LNO Campelen | -0.02 | -0.139 | - |
| R2 | fall 3LNO Engel | -0.089 | - | - |
| - | Estimated contrast index | 0.2313 | 0.2444 | 0.4985 |
| - | Estimated nearness index | 0.8313 | 0.5073 | 0.5328 |
| - | Total Objective Function | 3.70E+01 | 3.70E+01 | 2.32E+01 |
| MSE | Mean Square Error | 5.20E-01 | 5.52E-01 | 4.93E-01 |
| - | Number of Restarts | 49 | 23 | 7 |

*Run 1 =stats in 1985, FC catch with 3Ps spring Campelen, 3LNO spring Camplelen, 3LNO spring Engel, 3LNO fall Campelen, 3LNO fall Engel

**Run 2 = Run 1 - 3LNO fall Engel

***Run 3 = Run 2 - 3LNO fall Campelen

*Table 6. Estimated empirical reference points for Monkfish in Div. 3LNOPs based on DFO-NL spring research surveys, 1996-2017.*

| Series | proxy $B_{MSY}$ | LRP (40% $B_{MSY}$) | TRP (80% $B_{MSY}$) | $B_{(2017)}$/LRP |
|---|---|---|---|---|
| 2007-2013 geometric mean | 5019.84 | 2007.93 | 4015.87 | 2.50 |
| 2007-2017 geometric mean | 4660.42 | 1864.17 | 3728.33 | 2.69 |
| geometric mean of series (1996-2017) | 3706.06 | 1482.42 | 2964.85 | 3.38 |
| Average (1996-2017) | 3970.66 | 1588.26 | 3176.53 | 3.15 |
| geometric mean (2014-17) | 4092.24 | 1636.90 | 3273.80 | 3.06 |
| geometric mean ( 2010-13) | 5298.29 | 2119.31 | 4238.63 | 2.36 |
| Average (2007+2010) | 6448.37 | 2579.35 | 5158.70 | 1.94 |

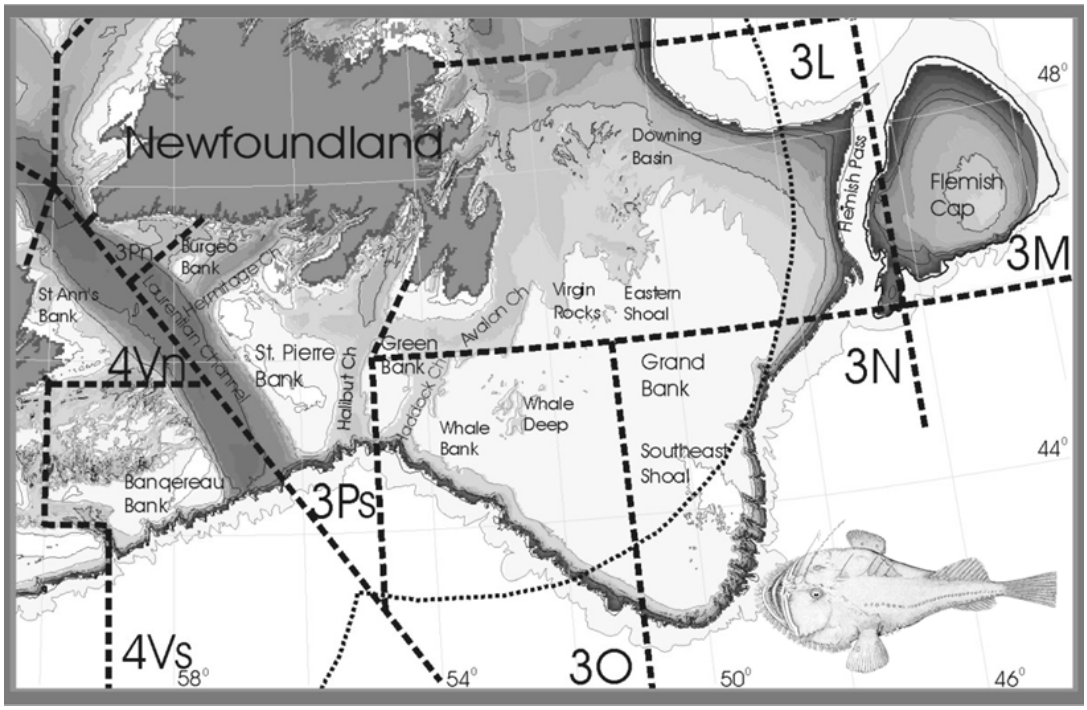


*Figure 1. Map of the Grand Banks and southern Newfoundland, showing various banks, basins, and NAFO Divisions. Thick black dashed lines delineate NAFO Divisions. The thin black dotted curved line depicts the boundary between Canada's Exclusive Economic Zone (EEZ) and the NAFO Regulatory Area (NRA).*

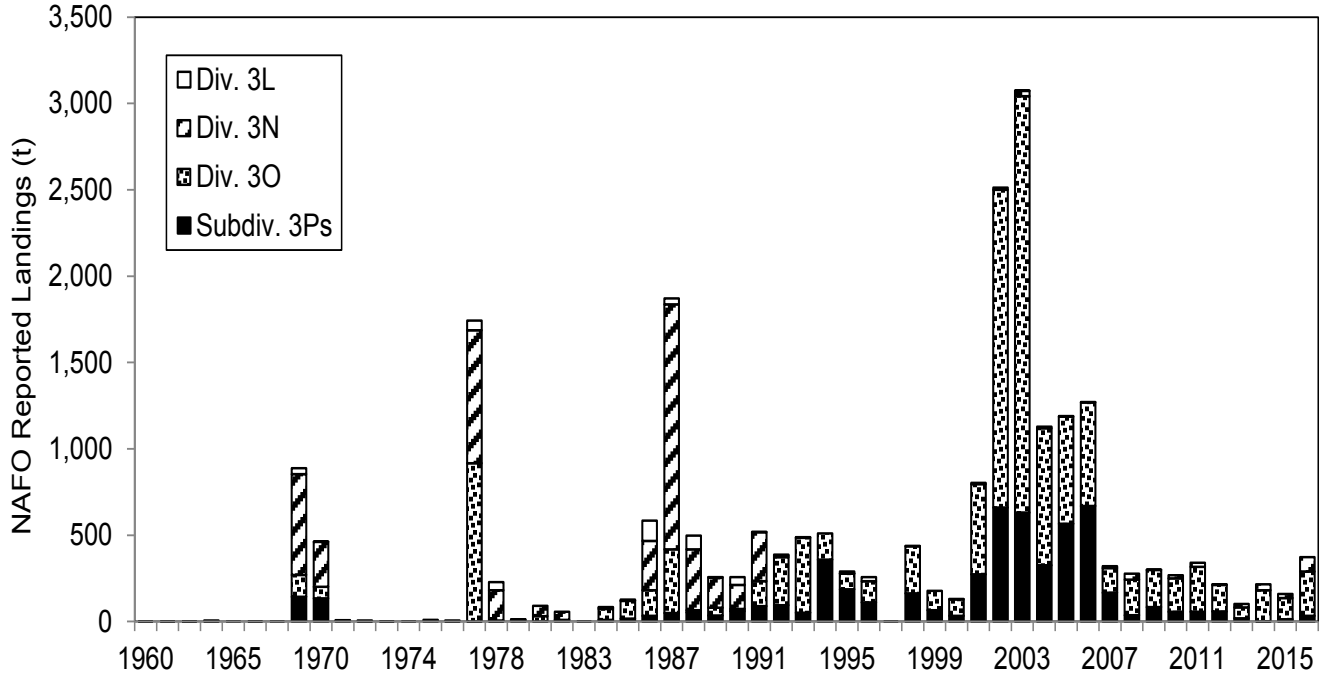


*Figure 2. NAFO-reported landings (tonnes) of Monkfish by member countries in Div. 3LNO and Subdiv. 3Ps, 1960-2016 (STATLANT-21A).*

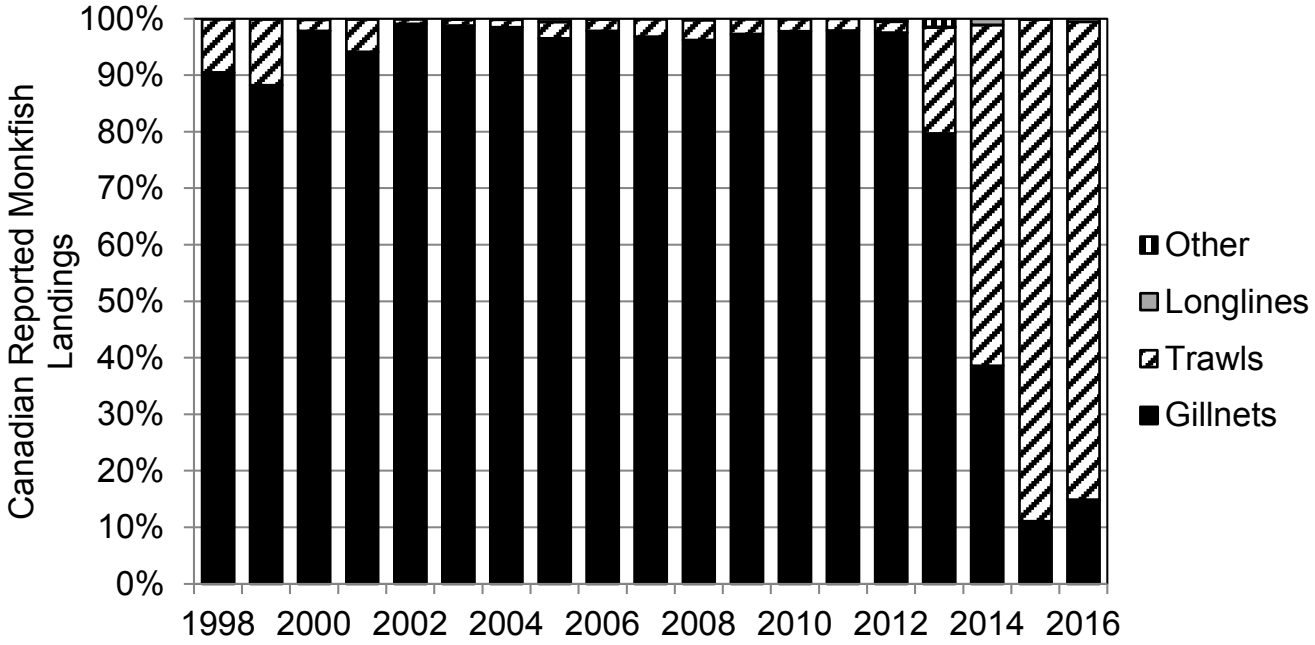


*Figure 3. DFO-NL ZIFF-reported Canadian landings of Monkfish by gear in Div. 3LNO and Subdiv. 3Ps, 1998-2016*

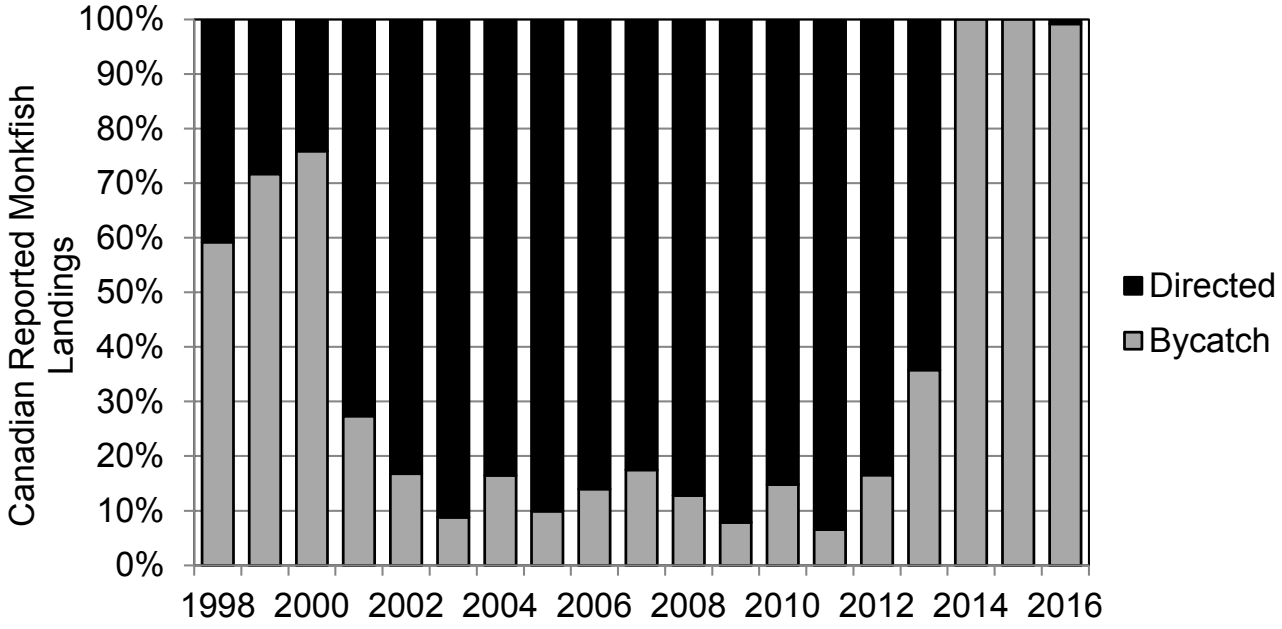


*Figure 4. DFO-NL ZIFF-reported directed and bycatch landings of Monkfish in Div. 3LNO and Subdiv. 3Ps, 1998-2016.*

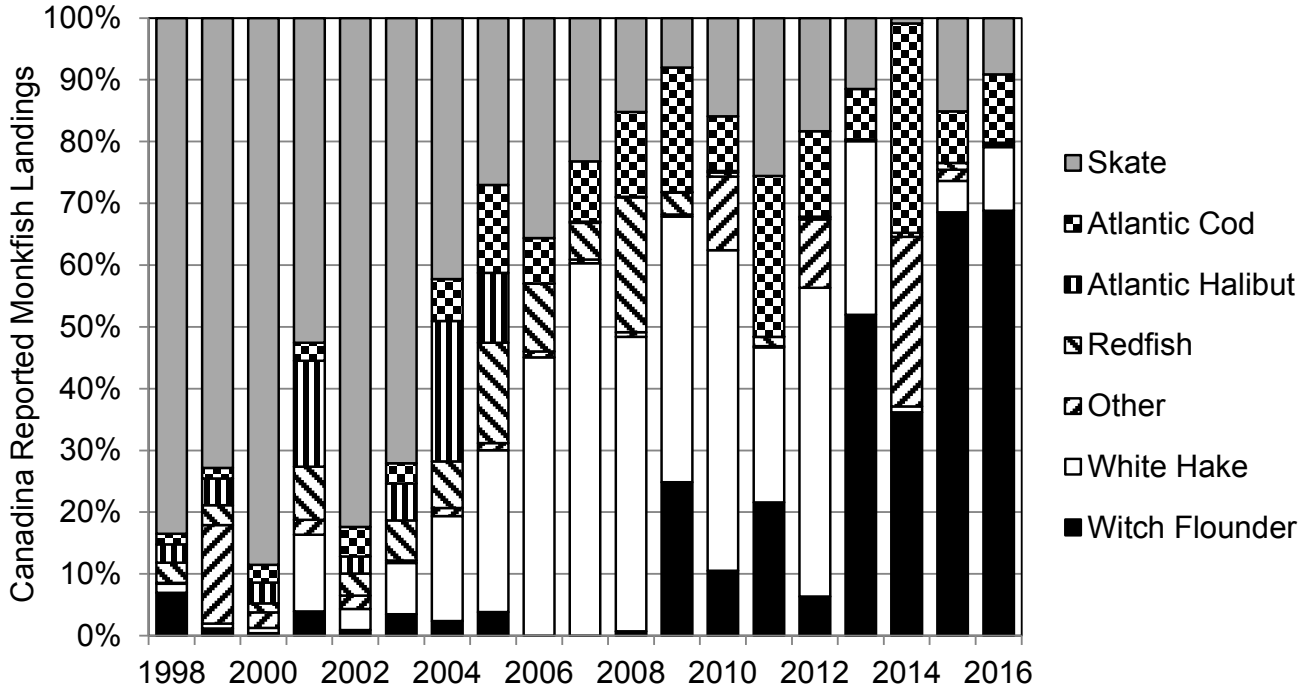


*Figure 5. DFO-NL ZIFF-reported landings of Monkfish bycatch by directed species in Div. 3LNO and Subdiv. 3Ps, 1998-2016.*

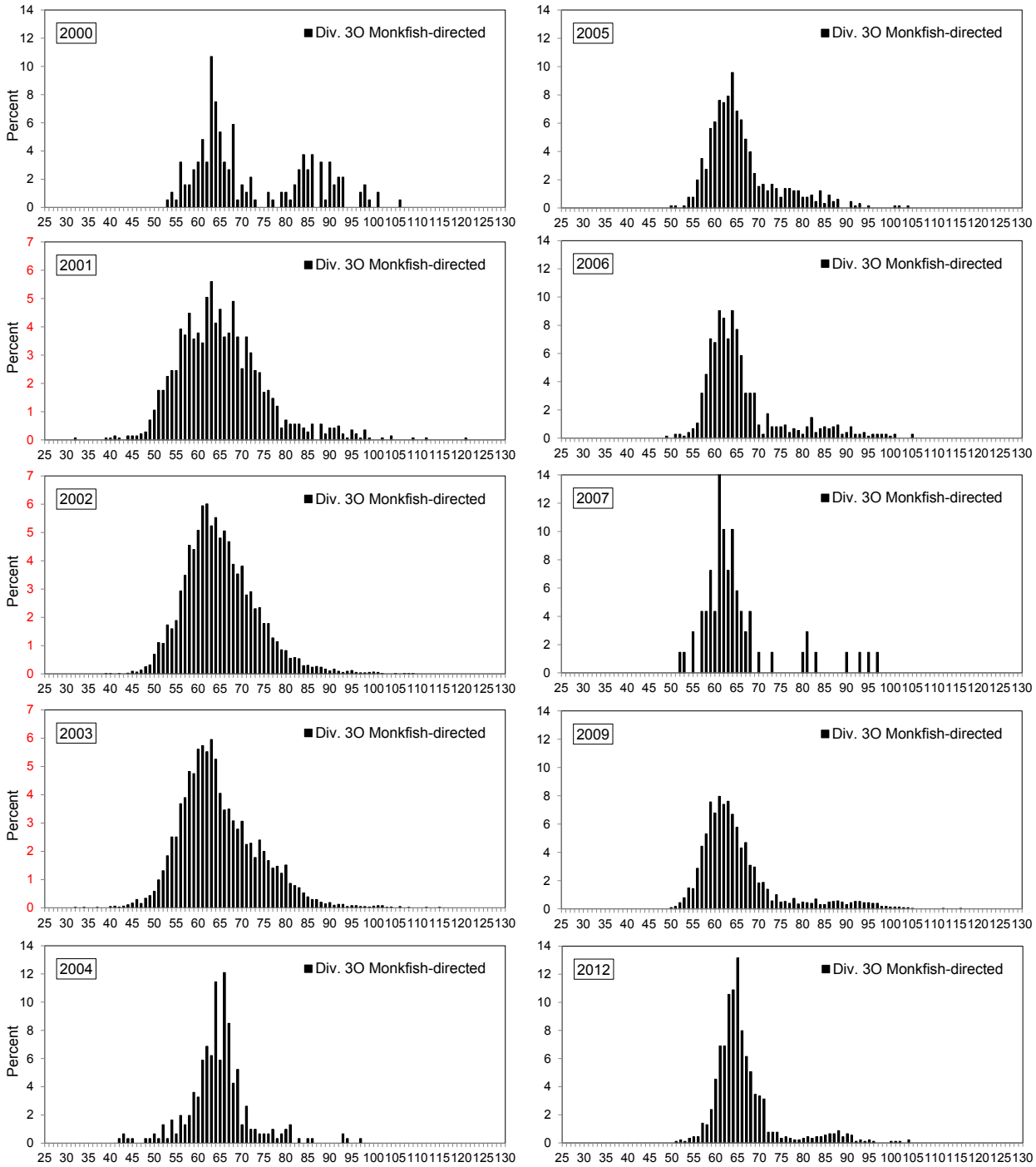


*Figure 6a. Monkfish-directed length frequencies (in cm) in Div. 3O from Canadian gillnet fisheries, 2000-2012. Data are from Canadian at-sea fisheries observers and include discards. Note that different Y-axis values are represented in red font, and Monkfish were not sampled in this Div. 3O fishery after 2012.*

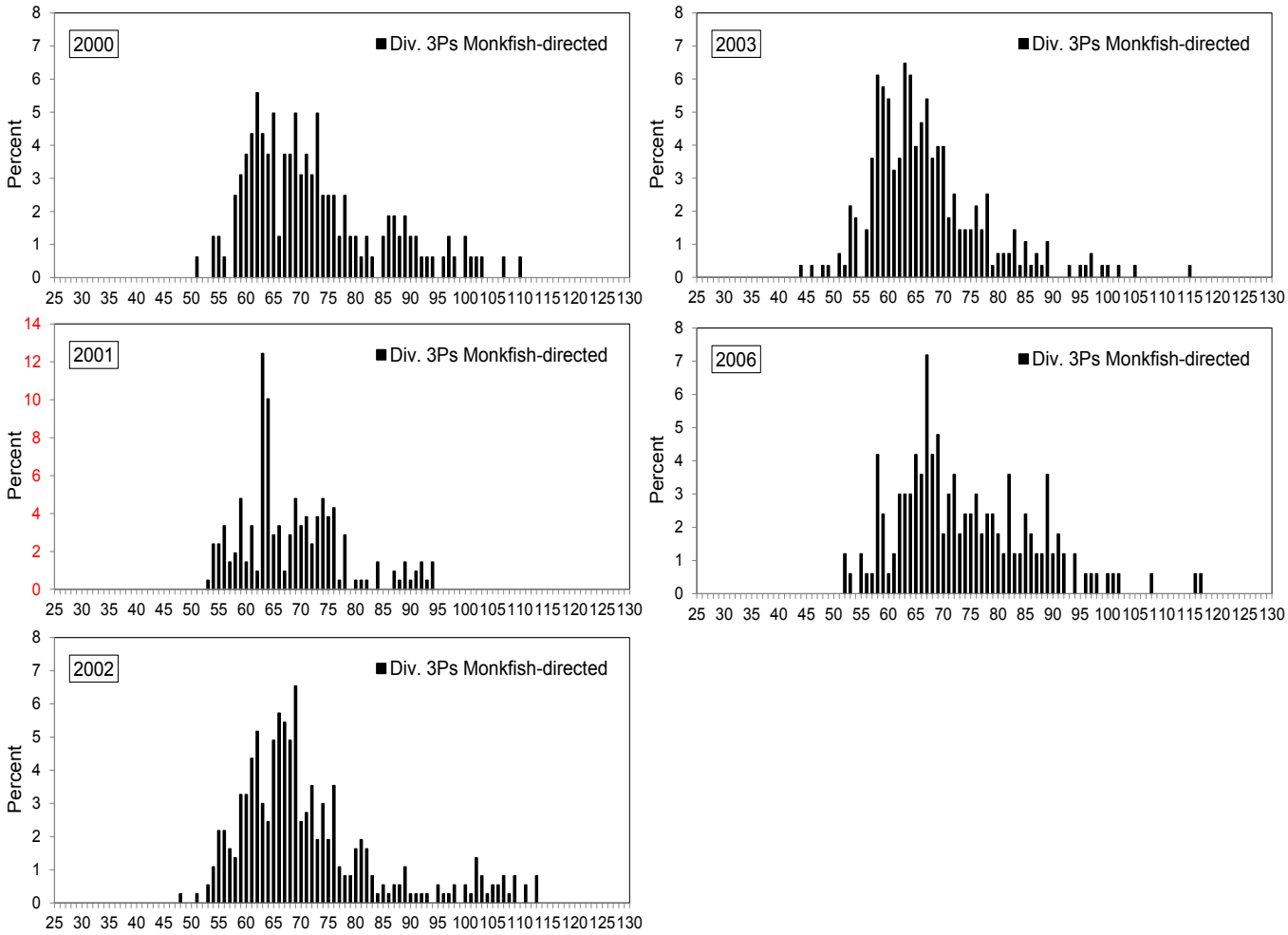


*Figure 6b. Monkfish-directed length frequencies (in cm) in Subdiv. 3Ps from Canadian gillnet fisheries, 2000-2006. Data are from Canadian at-sea fisheries observers and include discards. Note that different Y-axis values are represented in red font, and Monkfish were not sampled in this Subdiv. 3Ps fishery after 2006.*

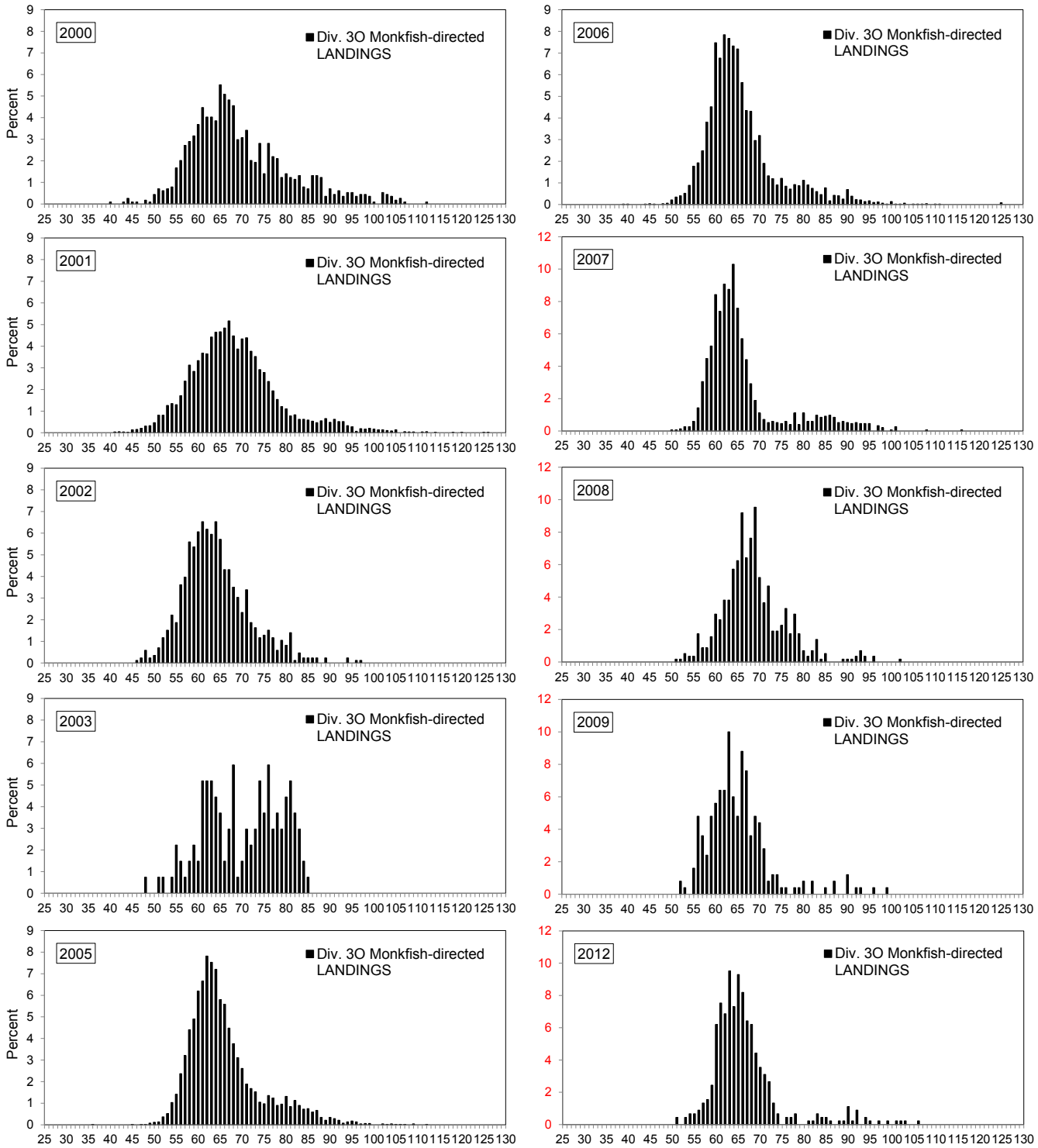


*Figure 7a. Length frequencies of Monkfish-directed landings (in cm) in Div. 3O from Canadian gillnet fisheries, 2000-2012. Note that different Y-axis values are represented in red font. Data are from Canadian at-sea fisheries observers, but do not include discards.*

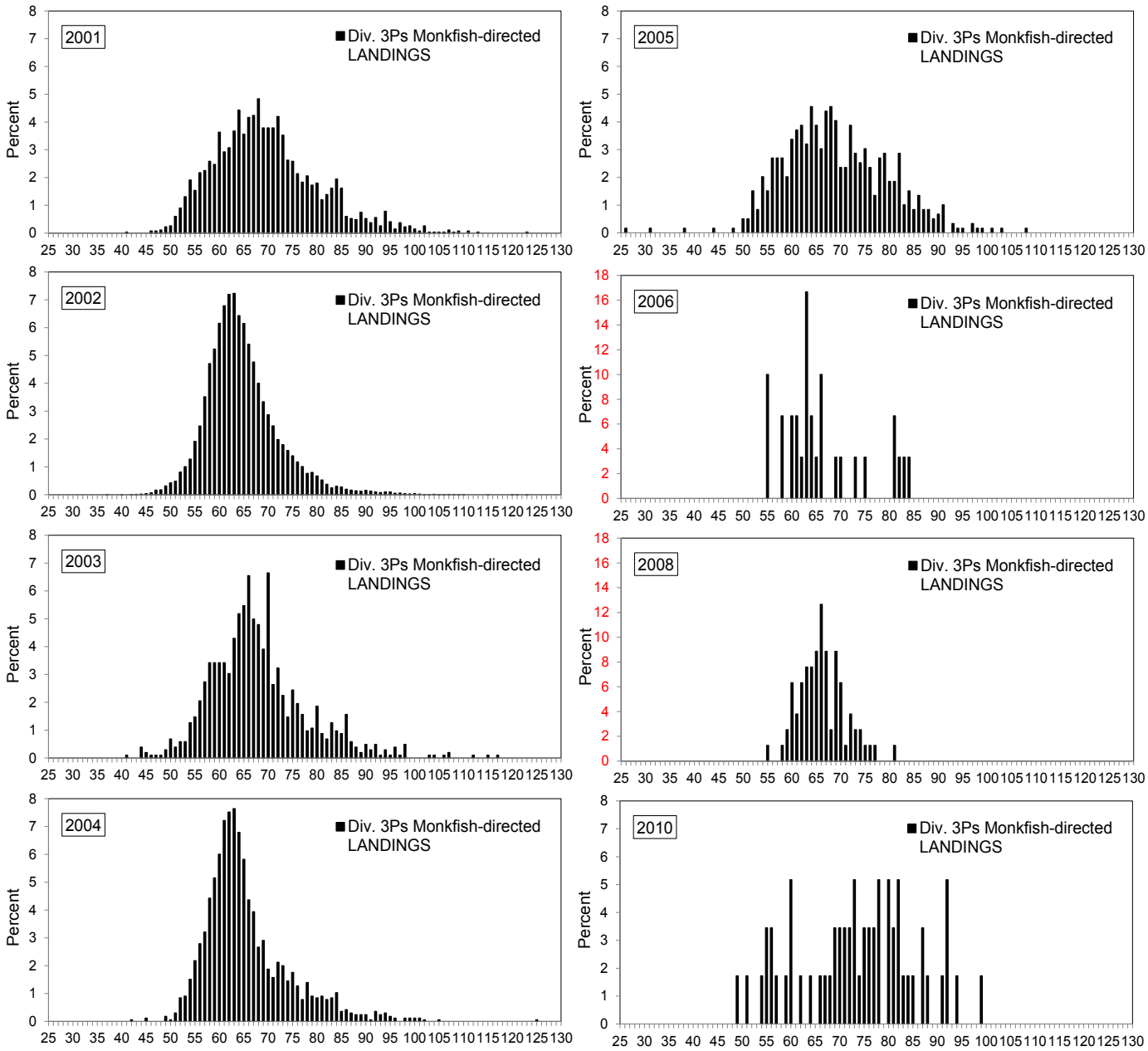


*Figure 7b. Length frequencies of Monkfish-directed landings (in cm) in Subdiv. 3Ps from Canadian gillnet fisheries, 2000-2012. Note that different Y-axis values are represented in red font. Data are from Canadian at-sea fisheries observers, but do not include discards.*

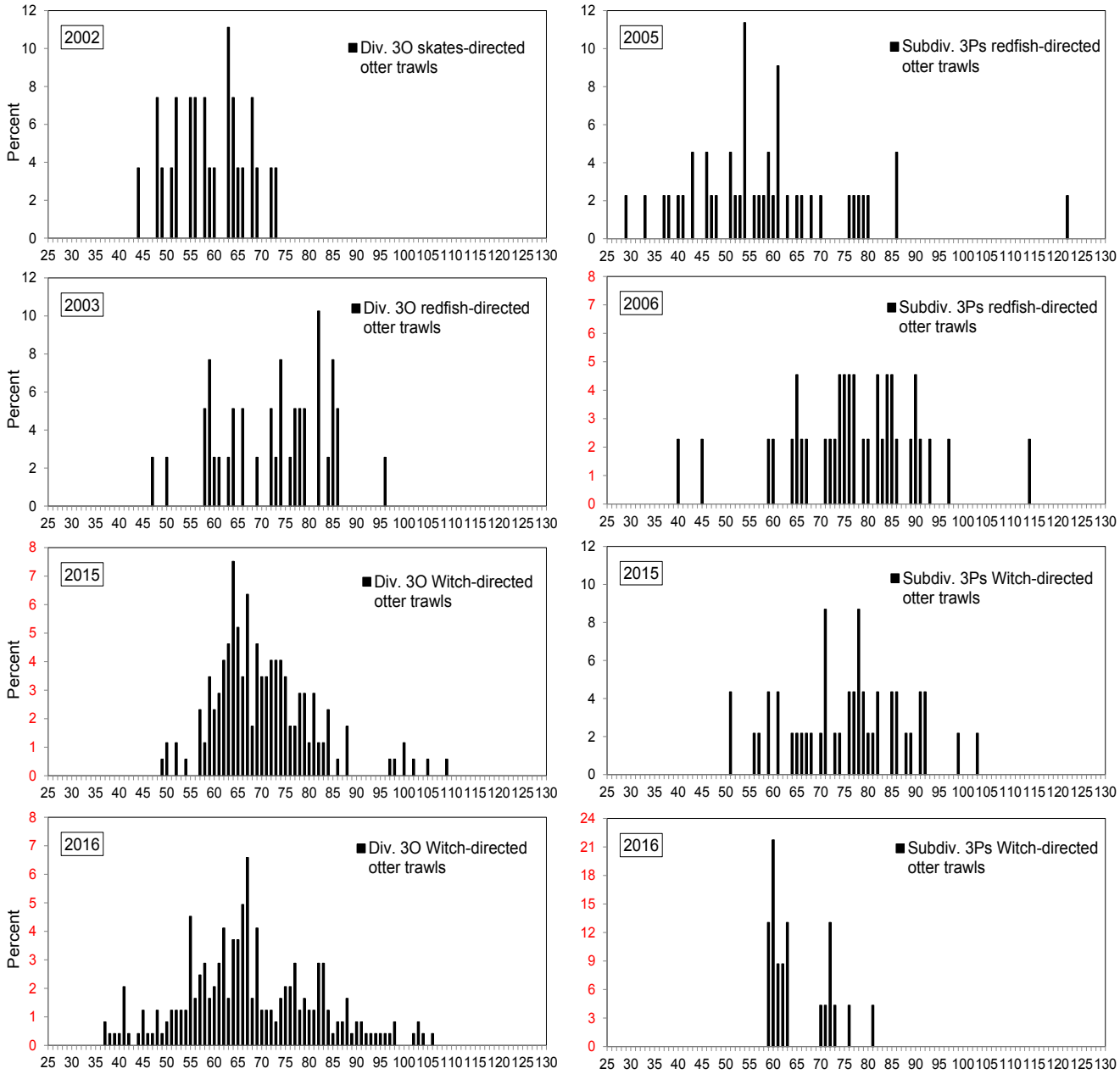


*Figure 8a. Length frequencies of Monkfish bycatch (in cm) in Div. 3O (left column) and Subdiv. 3Ps (right column) from Canadian otter trawl fisheries, 2002-2016. Data are from Canadian at-sea fisheries observers and include discards. Note that different Y-axis values are represented in red font.*

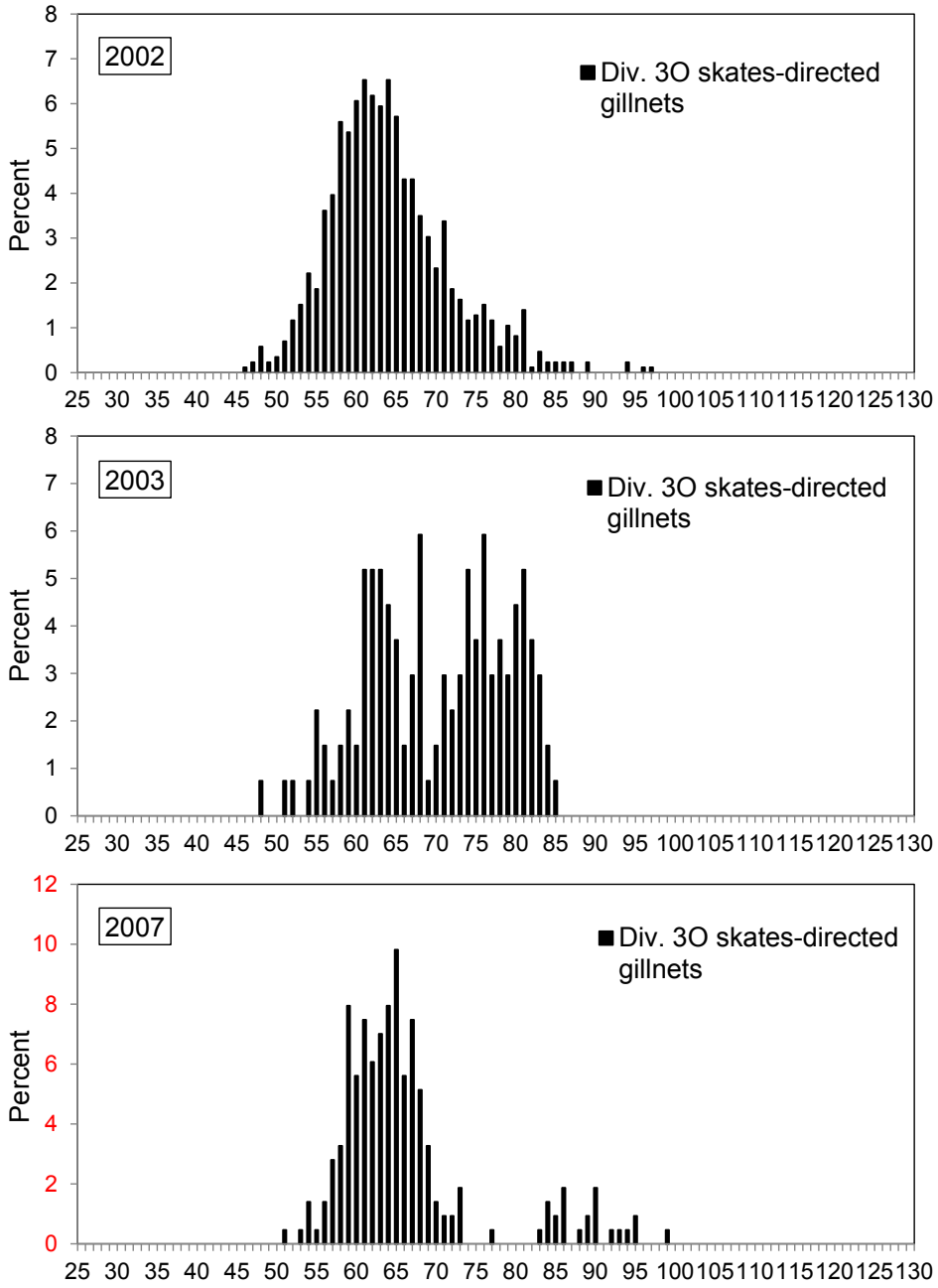


*Figure 8b. Length frequencies of Monkfish bycatch (in cm) in Div. 3O Canadian skate-directed gillnet fisheries, 2002-2007. Data are from Canadian at-sea fisheries observers and include discards. Note that different Y-axis values are represented in red font.*

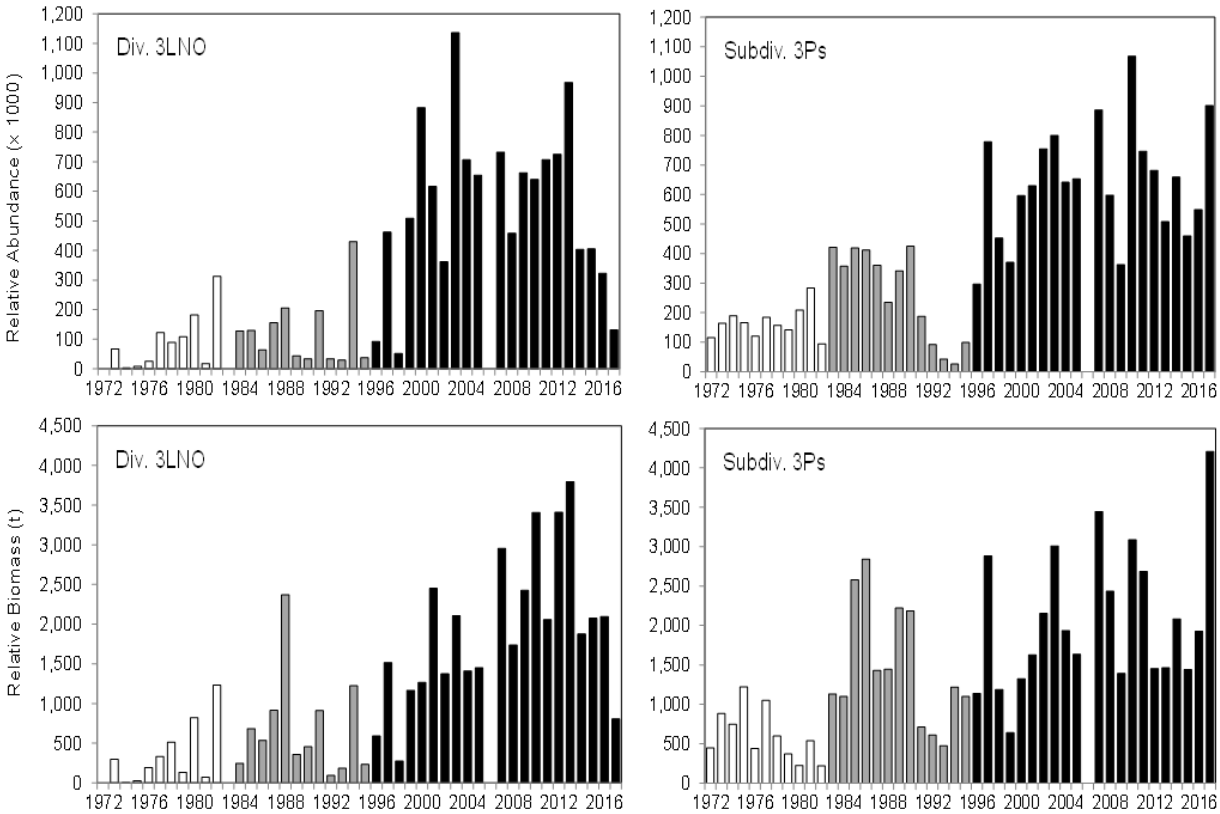


*Figure 9. Annual estimates of abundance (top panels) and biomass (tonnes; bottom panels) for Monkfish from DFO-NL spring research surveys in Div. 3LNO (left column) and Subdiv. 3Ps (right column), 1972-2017. Note that there is no conversion factor between Yankee (white columns), Engel (gray columns), and Campelen (black columns) time-series. Most of Subdiv. 3Ps and depths >103 m in Div. 3NO were not surveyed in spring 2006, so estimates are not shown for this year.*

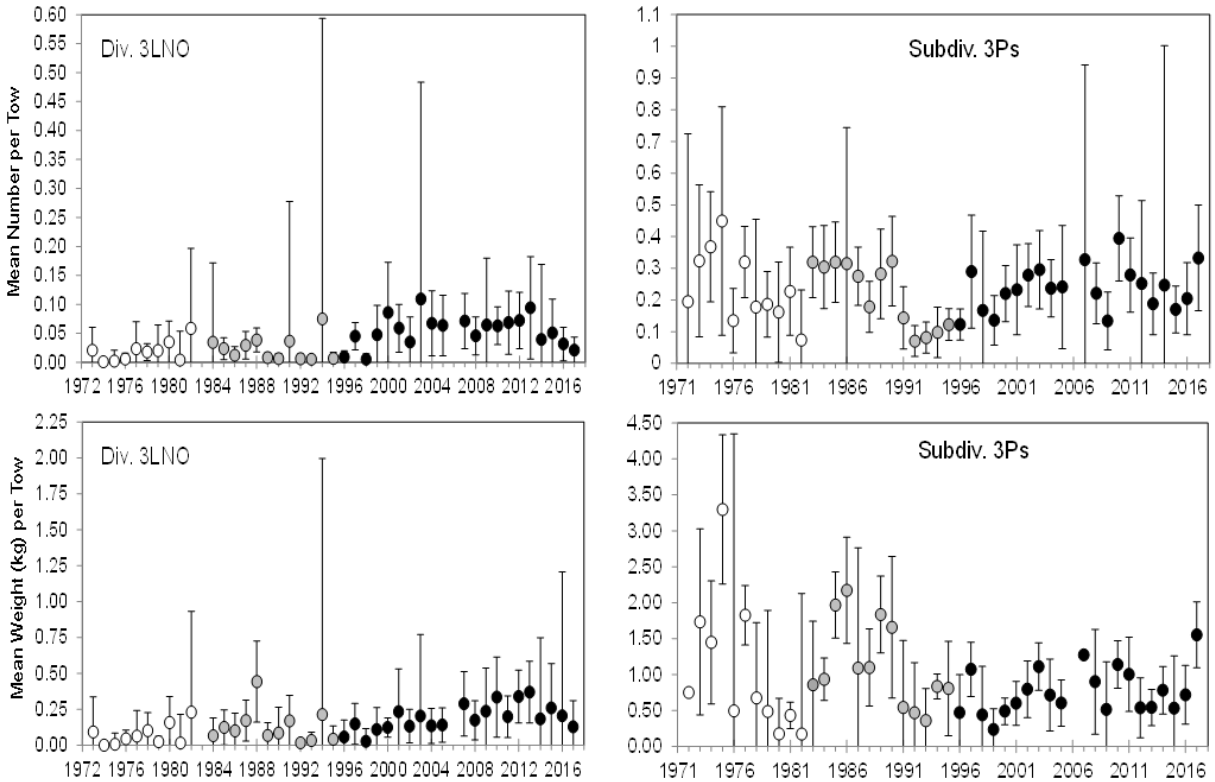


*Figure 10. Monkfish mean numbers (top panels) and mean weights (kgs; bottom panels) per tow (+/ 95% CI) from DFO-NL spring surveys in Div. 3LNO (left column) and Subdiv. 3Ps (right column), 1972-2017. Note that there is no conversion factor between Yankee (white circles), Engel (gray circles), and Campelen (black circles) time-series. Most of Subdiv. 3Ps and depths >103 m in Div. 3NO were not surveyed in spring 2006. Bounds of some error bars in the panels extend below the graph limits.*

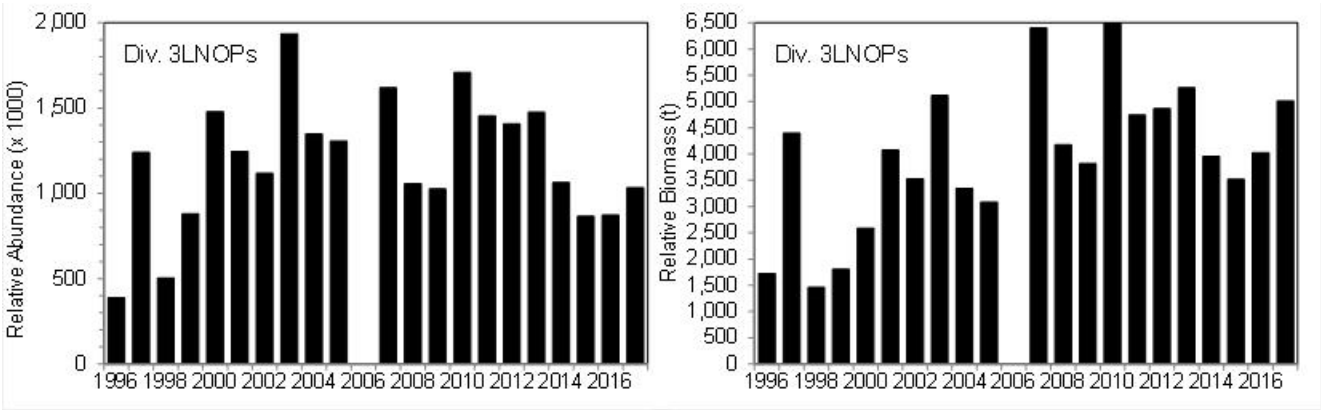


*Figure 11. Annual estimates of abundance (left panel) and biomass (tonnes; right panel) for Monkfish from DFO-NL Campelen spring surveys in Div. 3LNOPs, 1996-2017. Most of Subdiv. 3Ps and depths >103 m in Div. 3NO were not surveyed in spring 2006.*

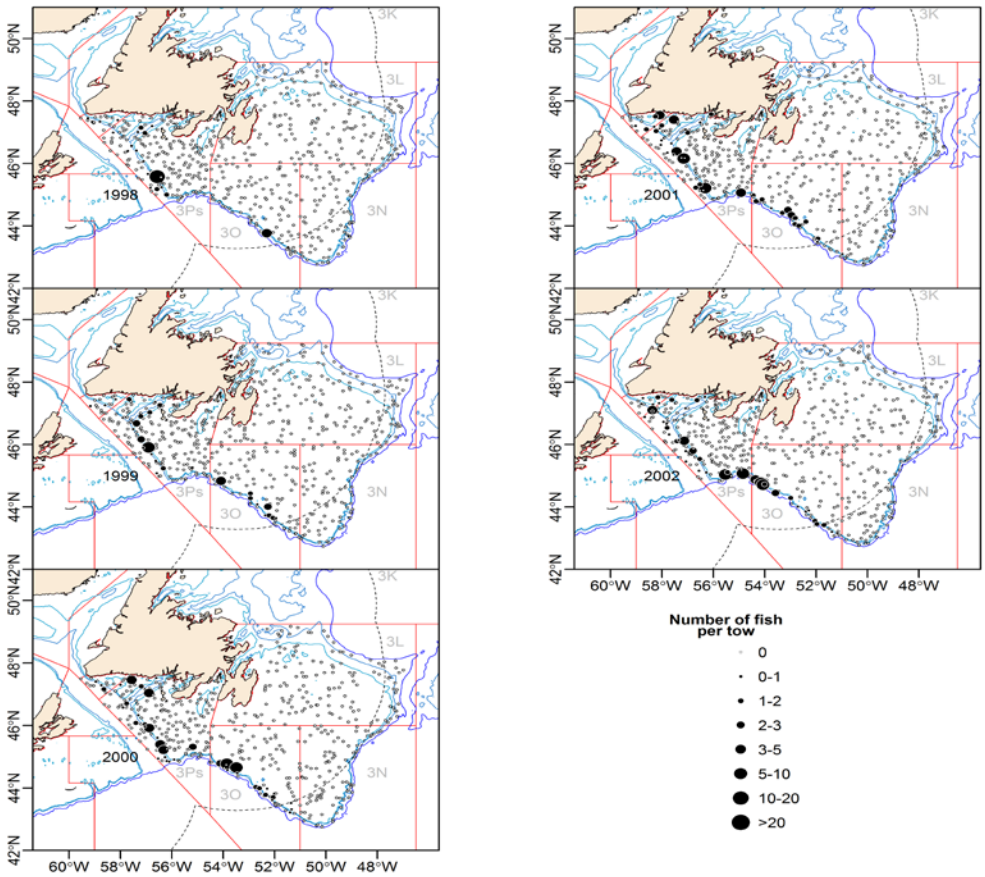


*Figure 12a. Distribution of Monkfish mean numbers per tow in Div. 3LNOP, based on DFO-NL spring research surveys in 1998-2002.*

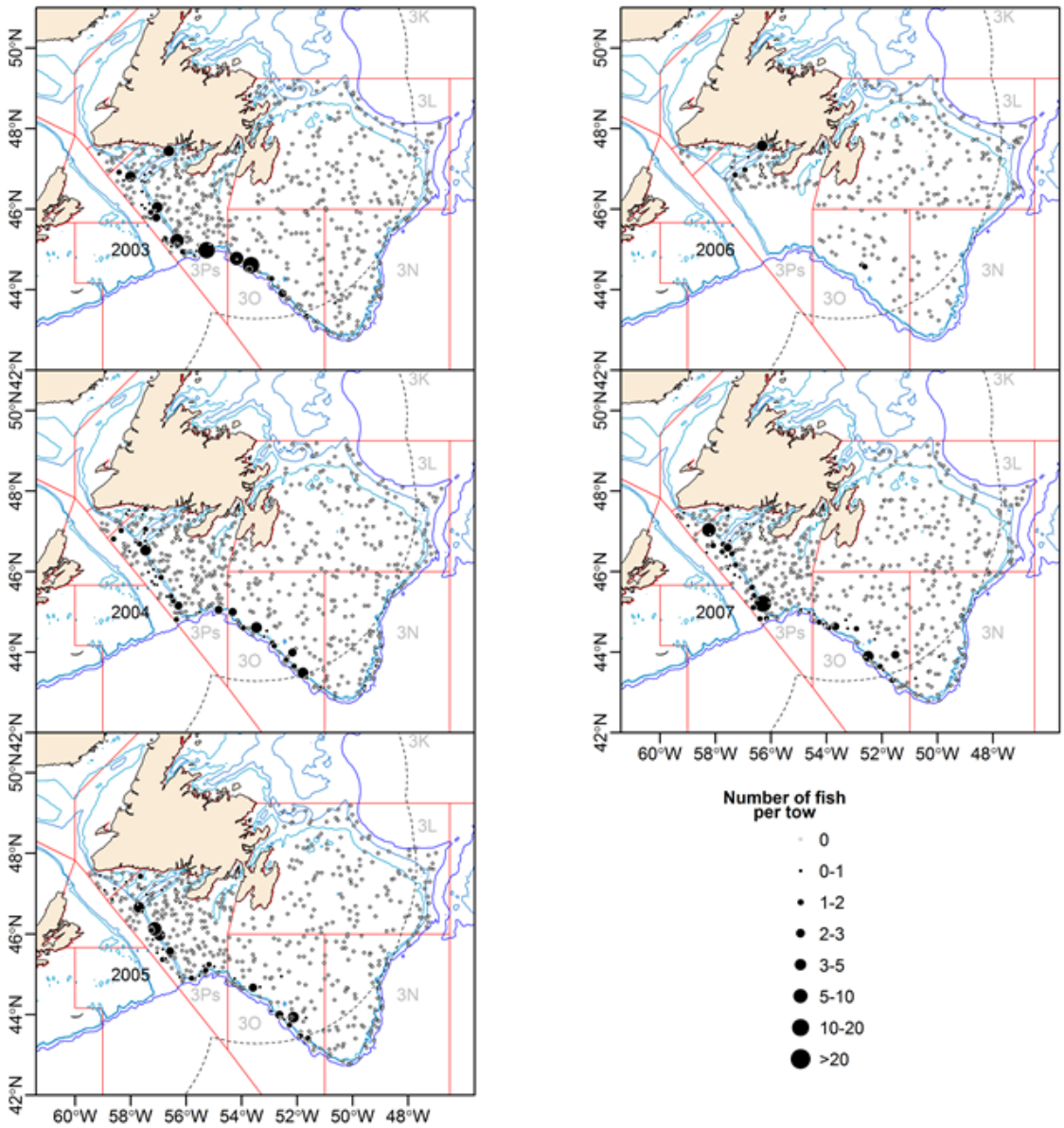


*Figure 12b. Distribution of Monkfish mean numbers per tow in Div. 3LNOP, based on DFO-NL spring surveys in 2003-07. Note that most of Subdiv. 3Ps and depths >103 m in Div. 3NO were not surveyed in spring 2006.*

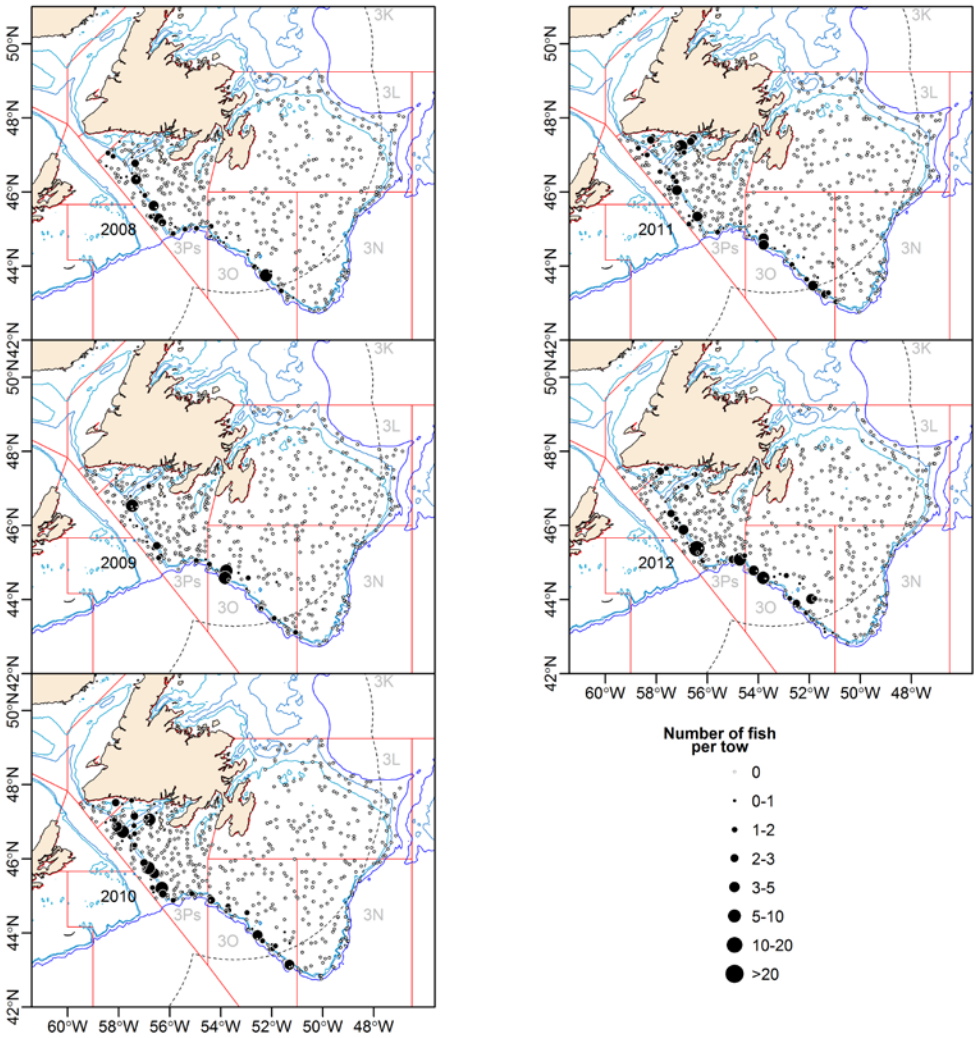


*Figure 12c. Distribution of Monkfish mean numbers per tow in Div. 3LNOP, based on DFO-NL spring surveys in 2008-12. Note that Subdiv. 3Pn was not surveyed in 2008.*

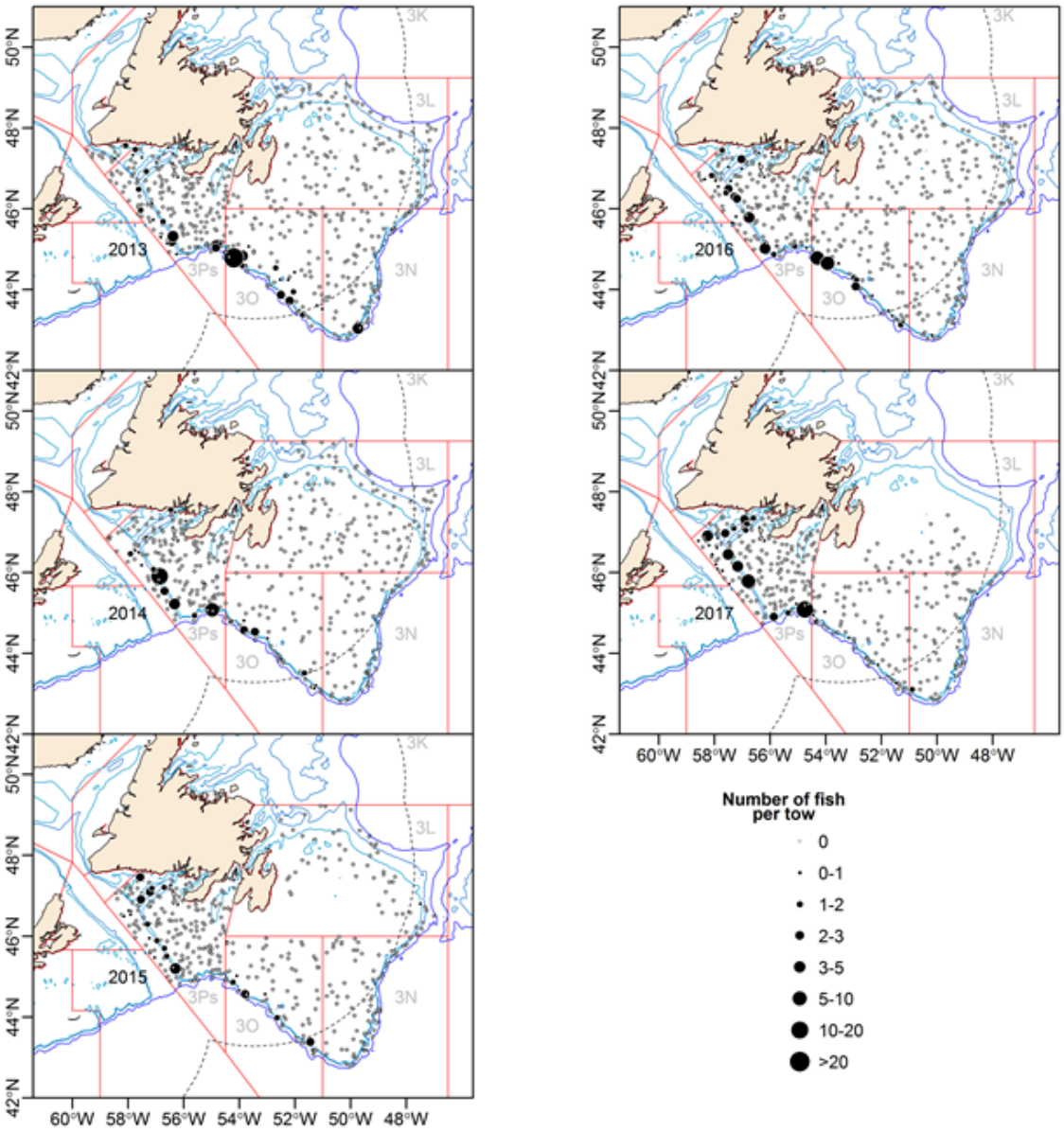


*Figure 12d. Distribution of Monkfish mean numbers per tow in Div. 3LNOP, based on DFO-NL spring surveys in 2013-17. Note that Subdiv. 3Pn was not surveyed in 2014-17.*

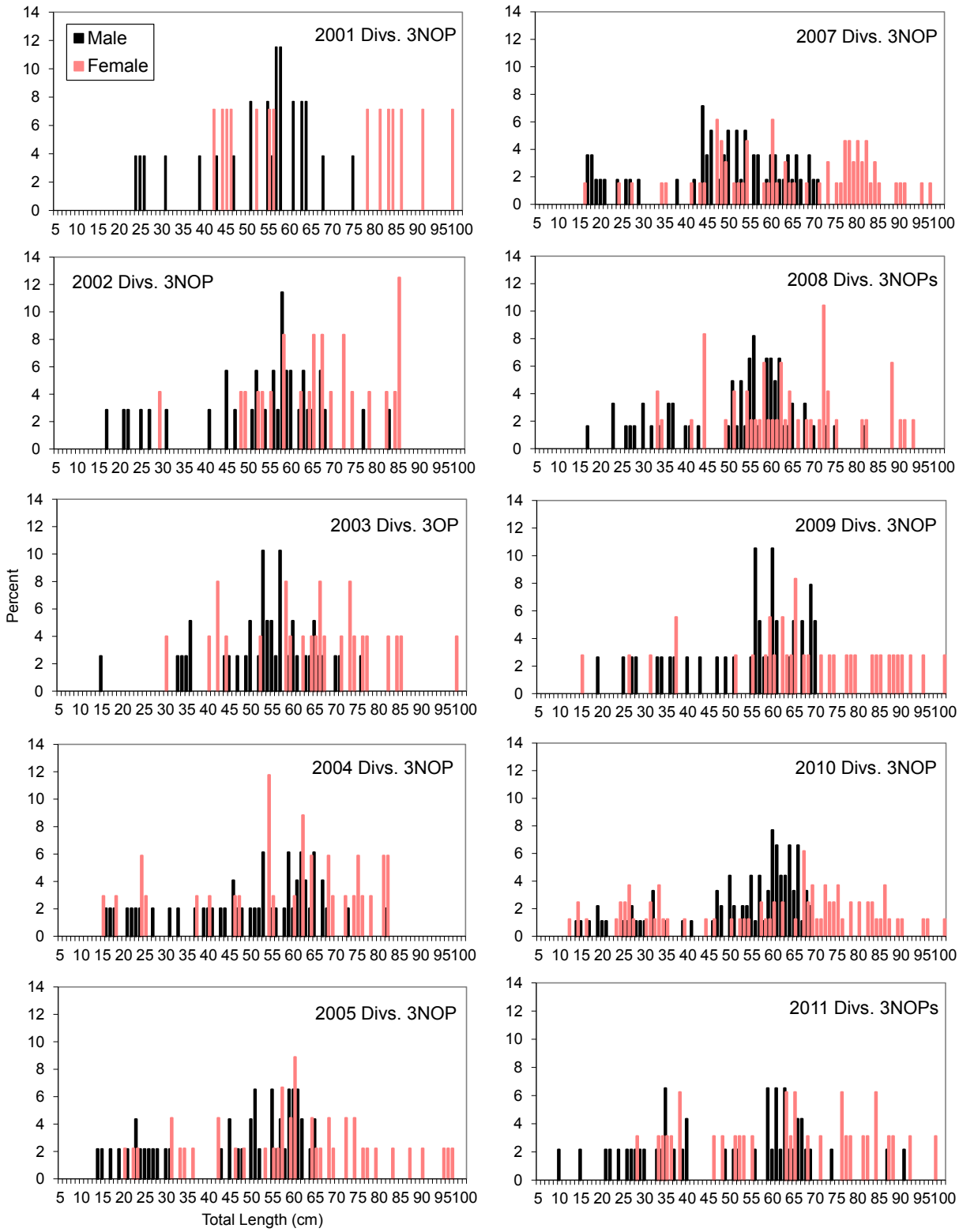


*Figure 13a. Length frequencies (in cm) of male and female Monkfish from DFO-NL spring research surveys in Div. 3NOP, 2001-11. Note that most of Subdiv. 3Ps and depths >103 m in Div. 3NO were not surveyed in spring 2006.*

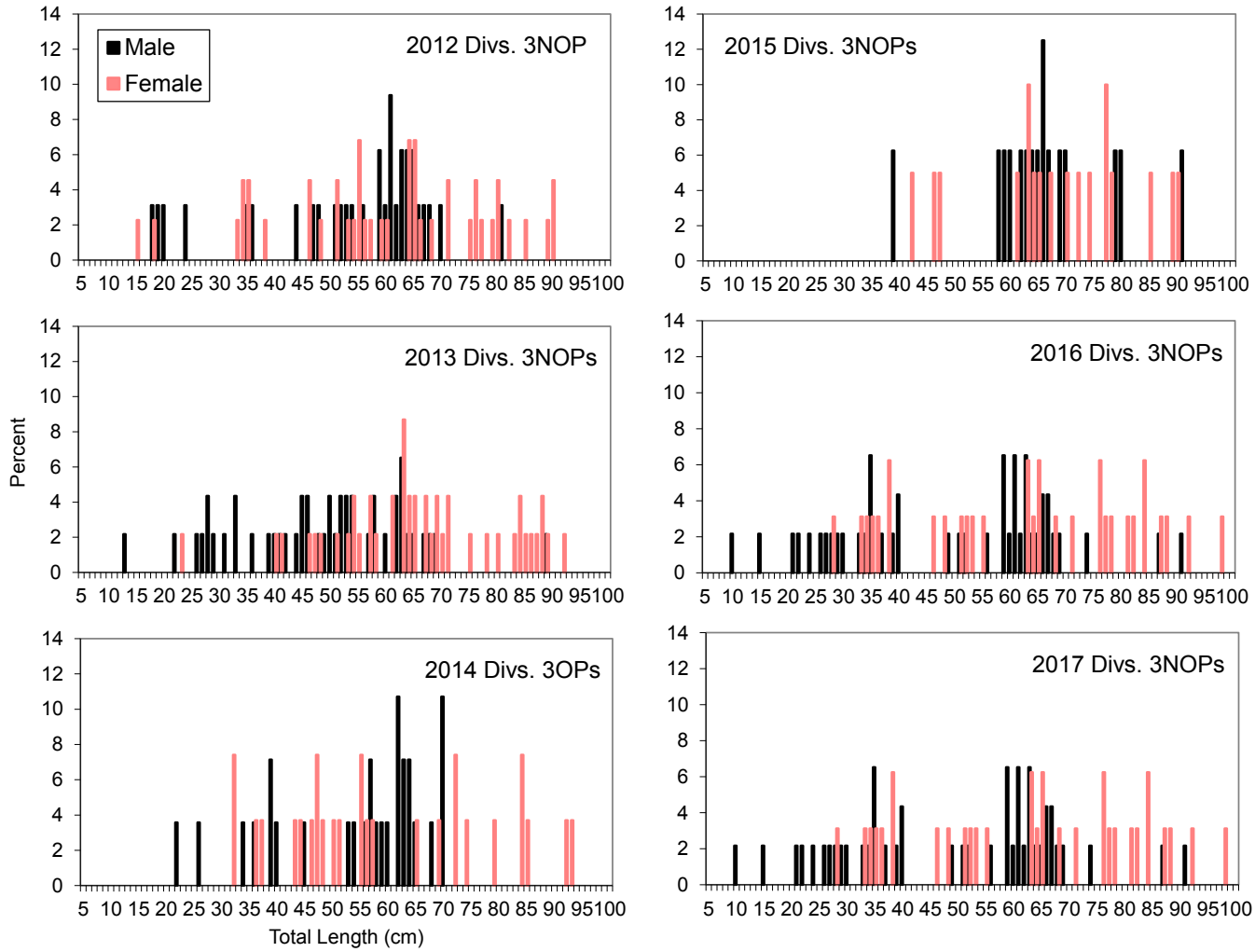


*Figure 13b. Length frequencies (in cm) of male and female Monkfish from DFO-NL spring surveys in Div. 3NOP, 2012-17.*

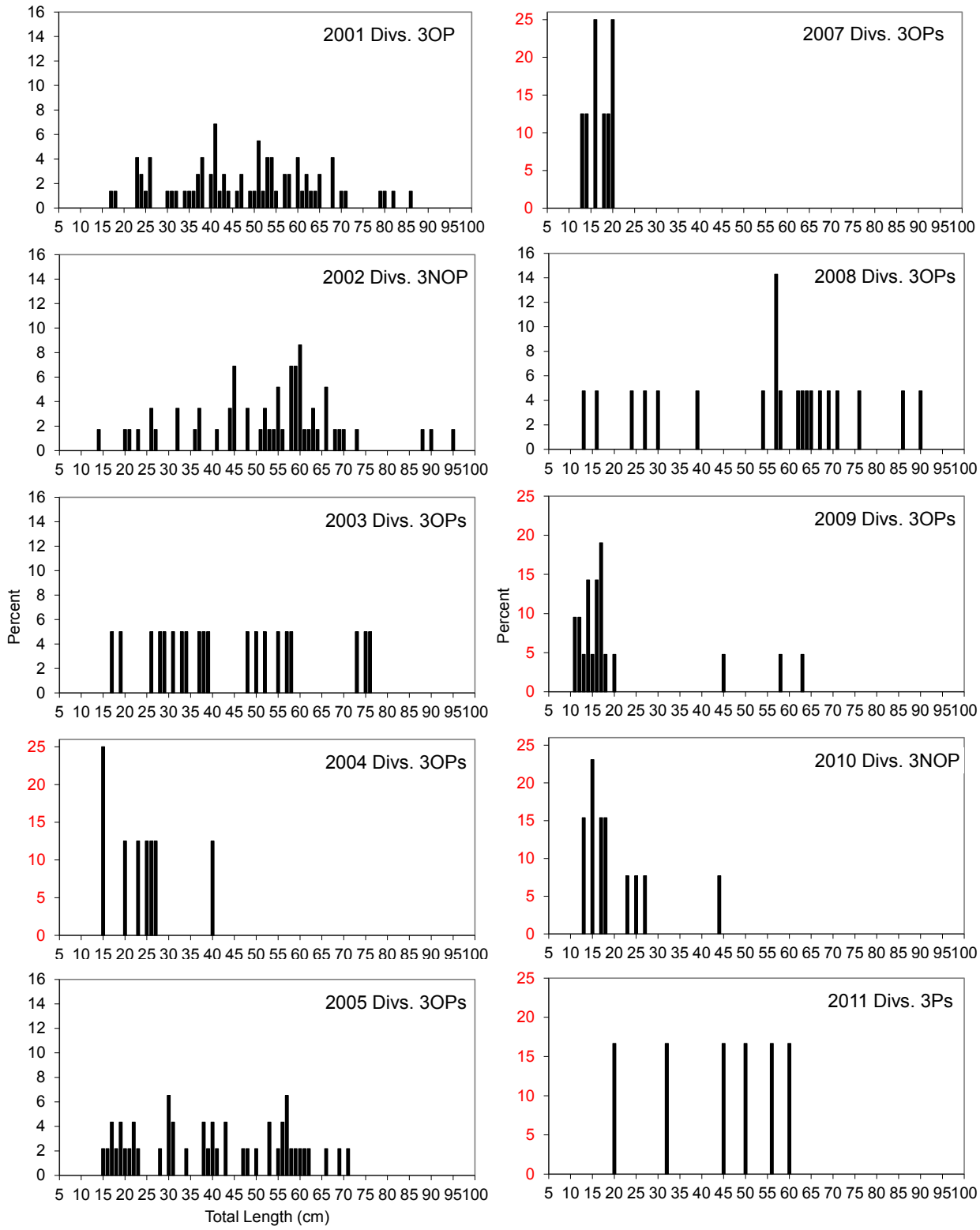


*Figure 14a. Length frequencies (in cm) of Monkfish (unsexed) from DFO-NL spring surveys in Div. 3NOP, 2001-11. Note that different Y-axis values are represented in red font.*

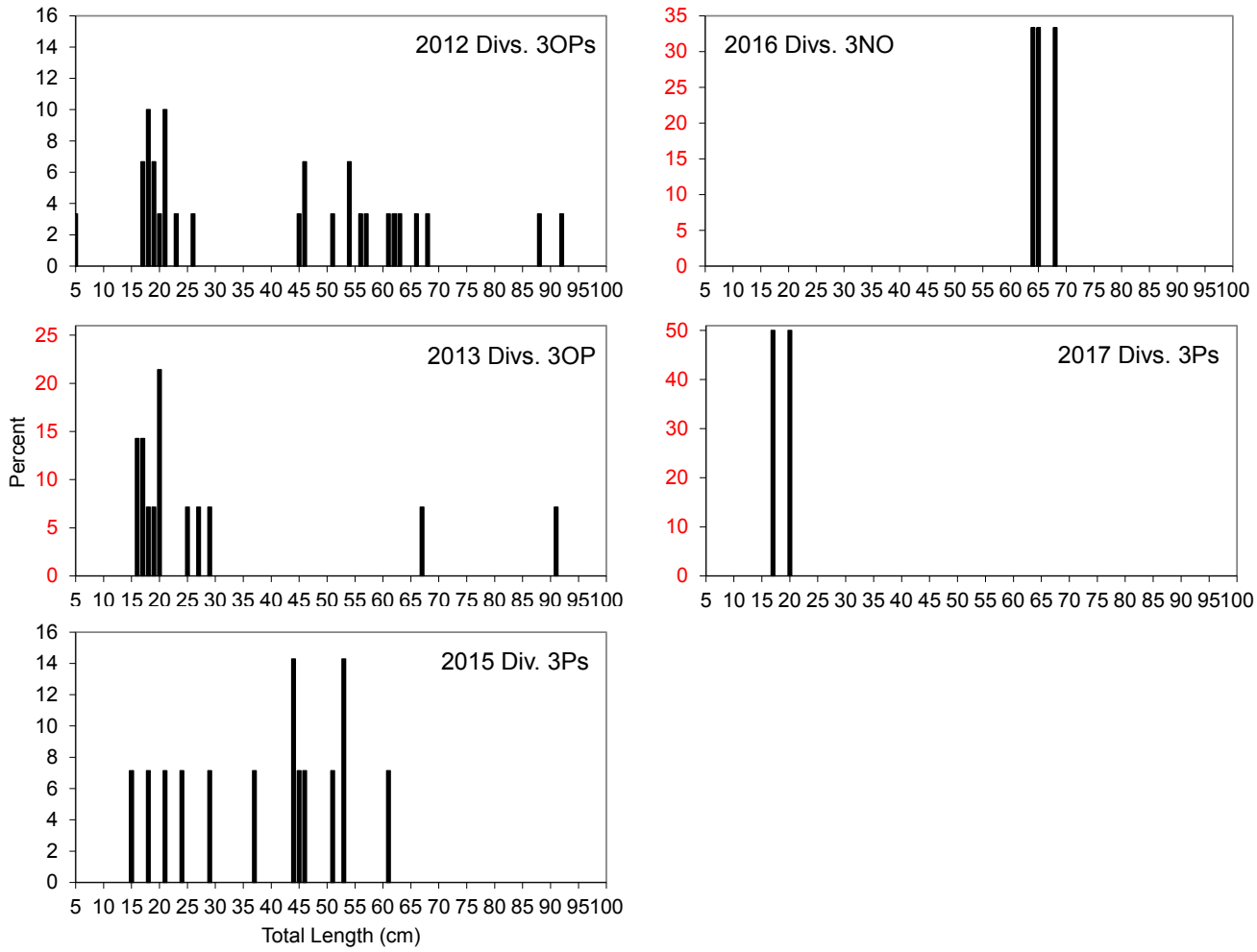


*Figure 14b. Length frequencies (in cm) of Monkfish (unsexed) from DFO-NL spring surveys in Div. 3NOP, 2012-17. Note that different Y-axis values are represented in red font.*

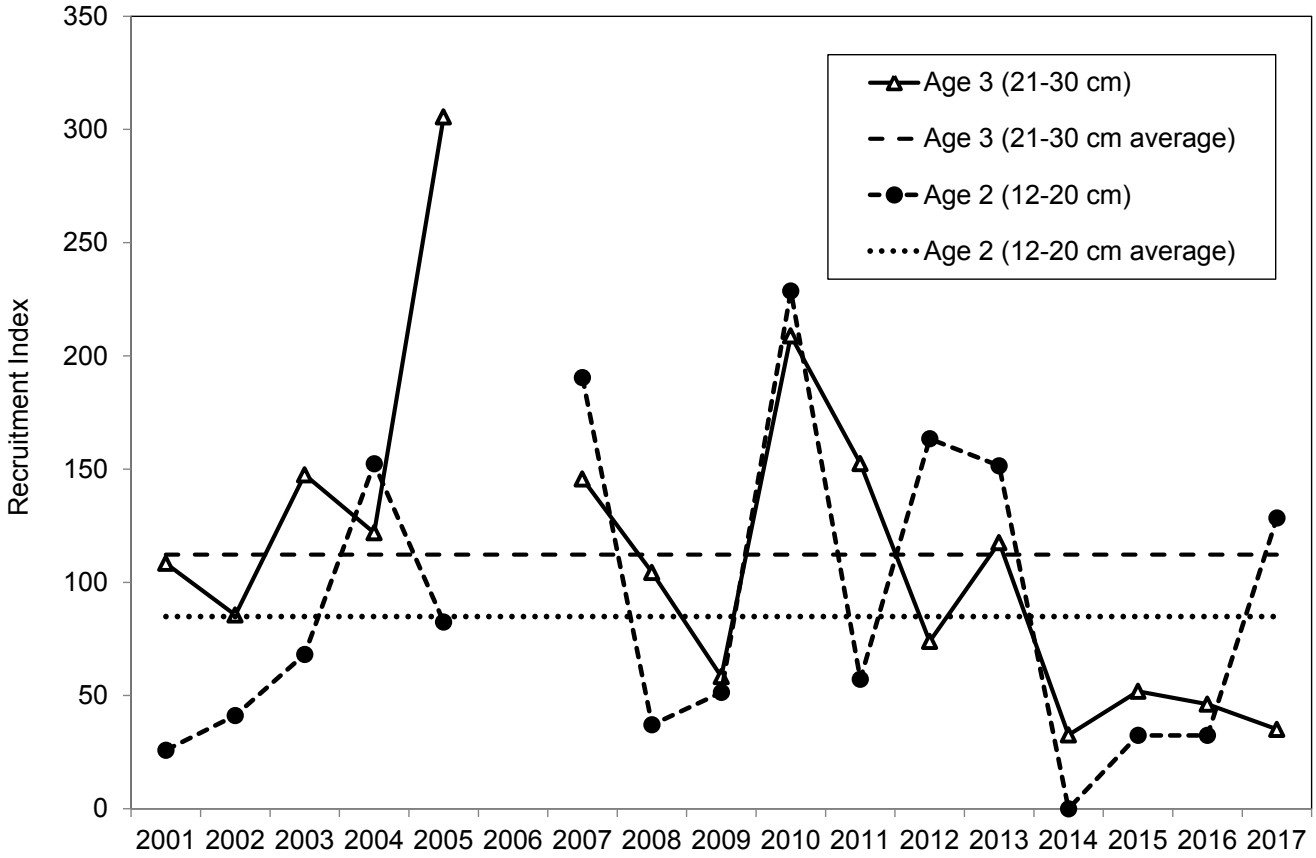


*Figure 15. Monkfish recruitment index for Age 3 males and females (combined) from DFO-NL Campelen spring surveys in Div. 3LNO and Subdiv. 3Ps, 2001-17. Estimates from 2006 are not shown, since survey coverage in that year was incomplete.*

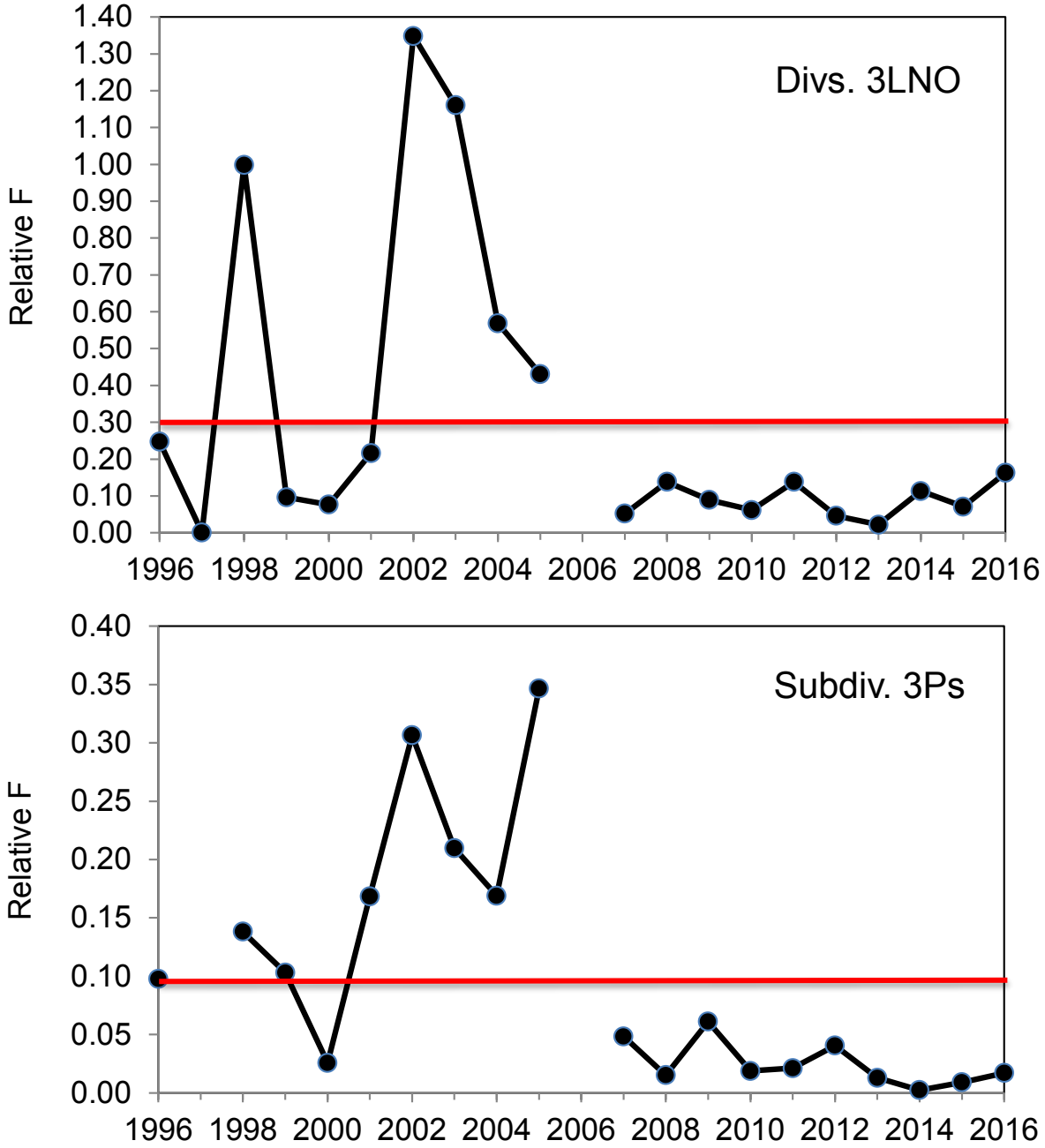


*Figure 16. Relative F index (=NAFO-reported commercial landings/DFO-NL Campelen spring survey biomass) for Monkfish in Div. 3LNO (top panel) and Subdiv. 3Ps (bottom panel), 1996-2016. Thick horizontal line depicts the average over these years. Note that most of Subdiv. 3Ps was not surveyed in 2006.*

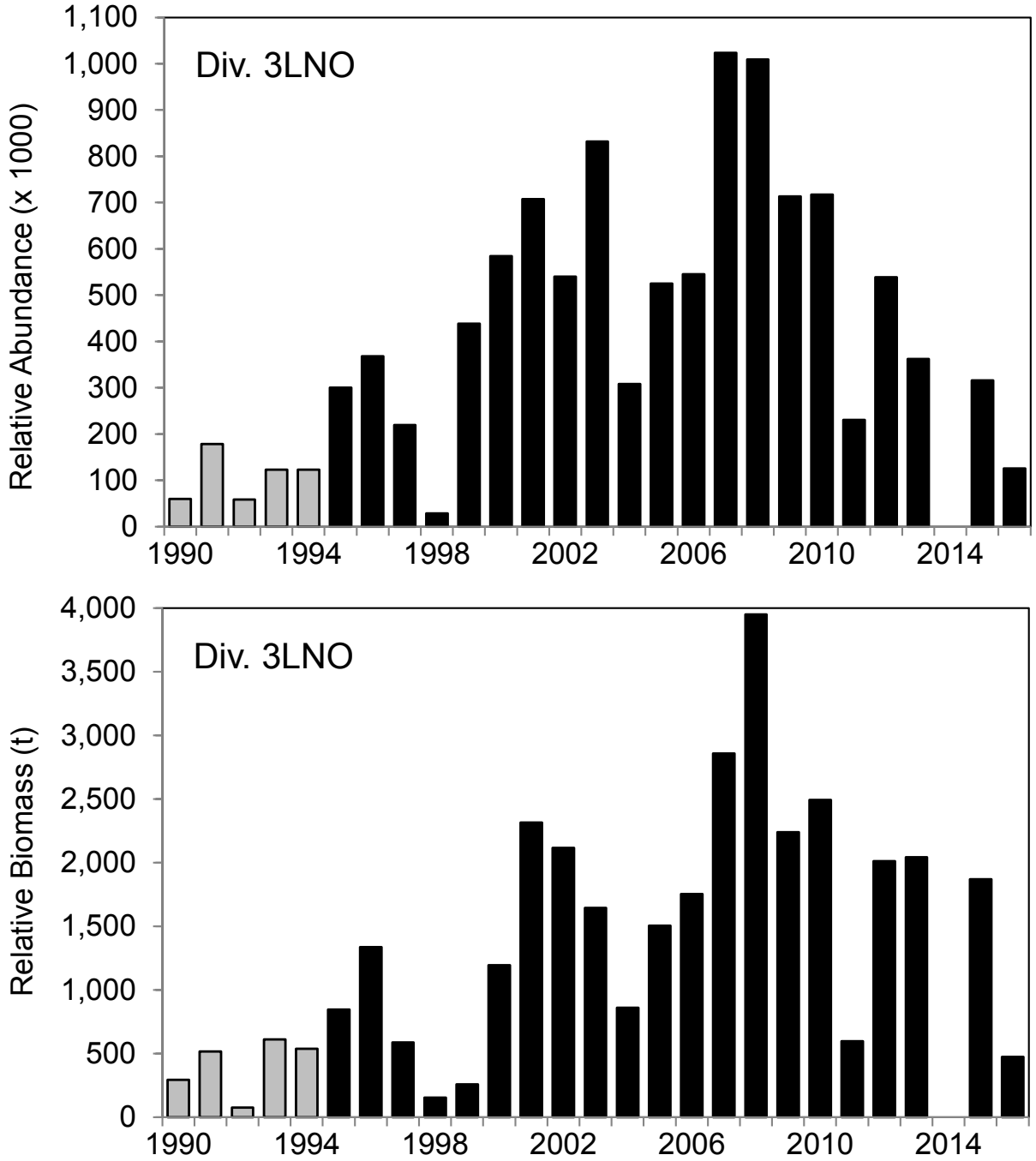


*Figure 17. Annual estimates of abundance (top panel) and biomass (tonnes; bottom panel) for Monkfish from DFO-NL fall research surveys in Div. 3LNO, 1990-2016. Note that there is no conversion factor between Engel (gray columns), and Campelen (black columns) time-series. Deep strata of Div. 3NO were not surveyed in 2003, 2004, 2006, 2008, and none of Div. 3NO was surveyed in 2014.*

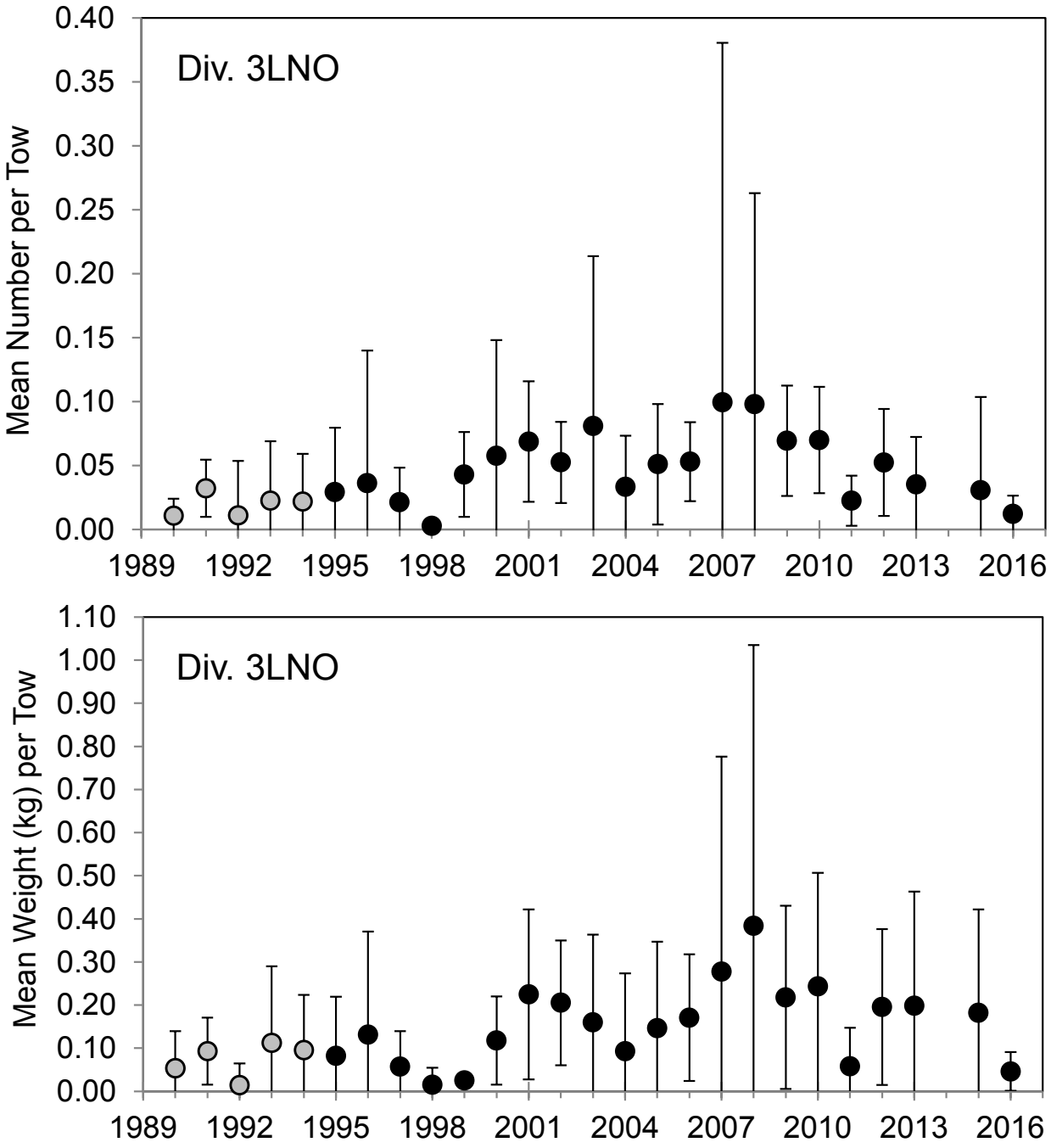


*Figure 18. Monkfish mean numbers (top panel) and mean weights (kgs; bottom panel) per tow (+/-95% CI) from DFO-NL fall surveys in Div. 3LNO, 1990-2016. Note that there is no conversion factor between Engel (gray circles), and Campelen (black circles) time-series. Deep strata of Div. 3NO were not surveyed in 2003, 2004, 2006, 2008, and none of Div. 3NO was surveyed in 2014. Bounds of some error bars in the panels extend below the graph limits.*

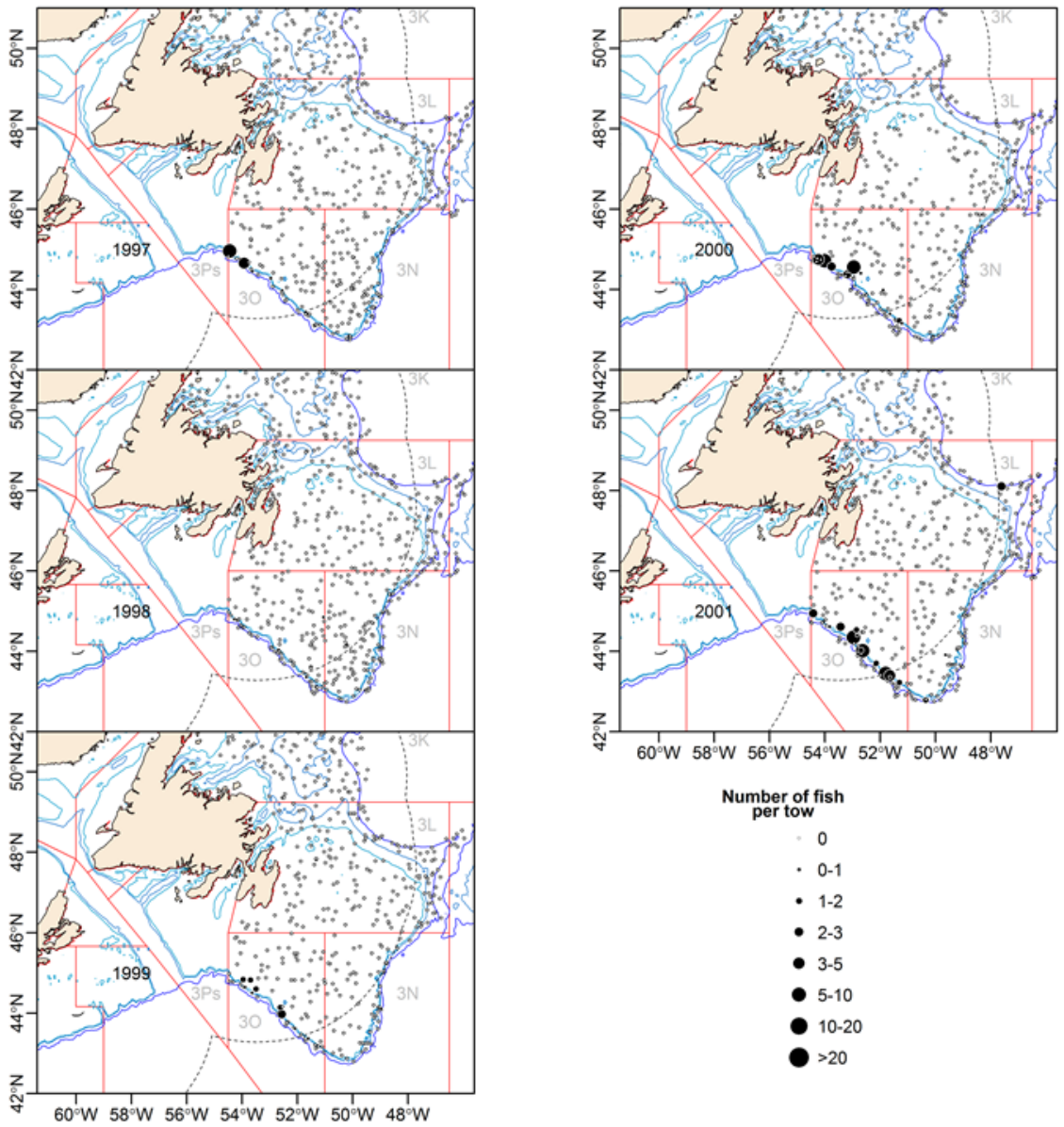


*Figure 19a. Distribution of Monkfish mean numbers per tow in Div. 3LNO, based on DFO-NL fall research surveys in 1997-2001.*

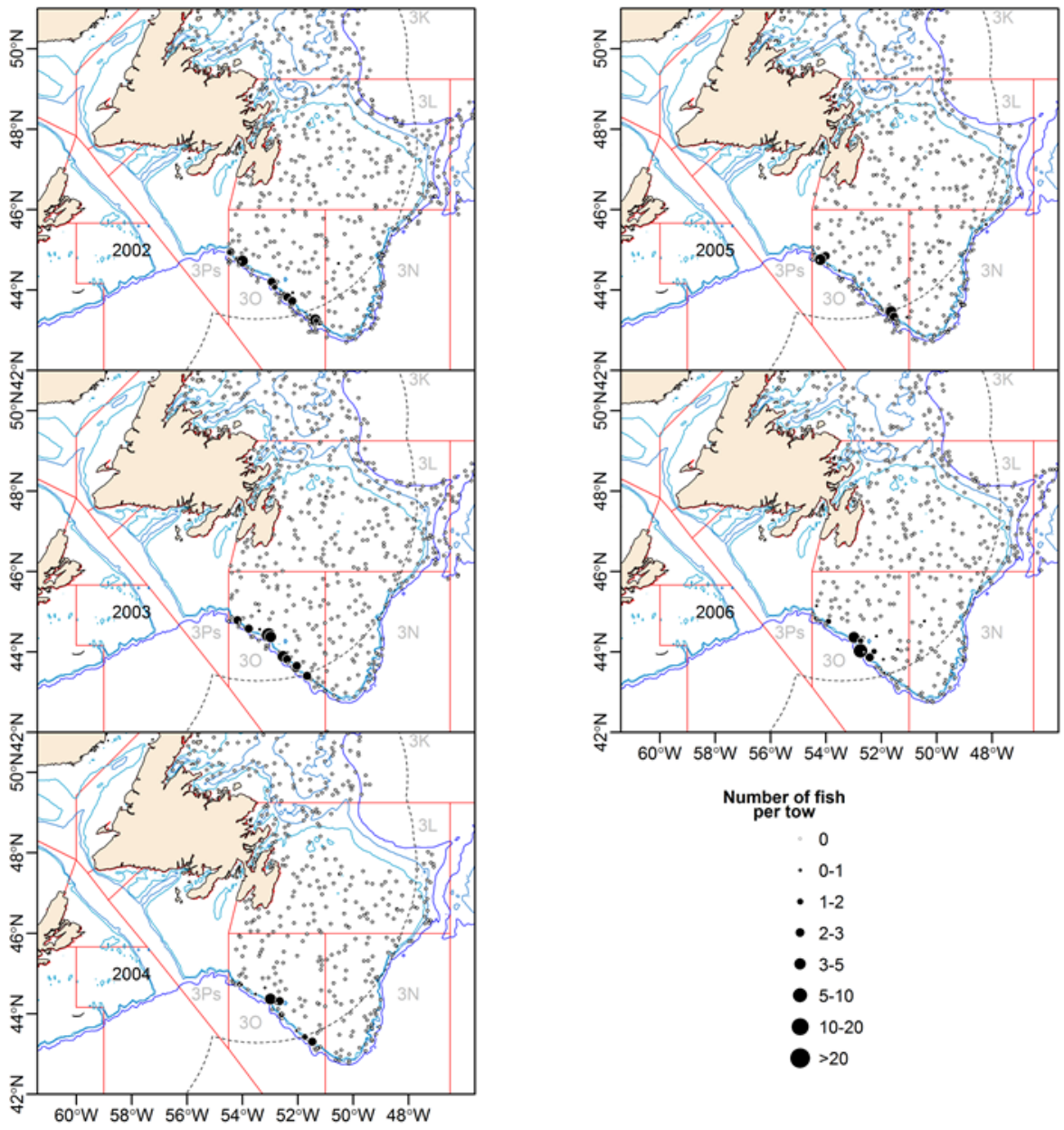


*Figure 19b. Distribution of Monkfish mean numbers per tow in Div. 3LNO, based on DFO-NL fall surveys in 2002-06.*

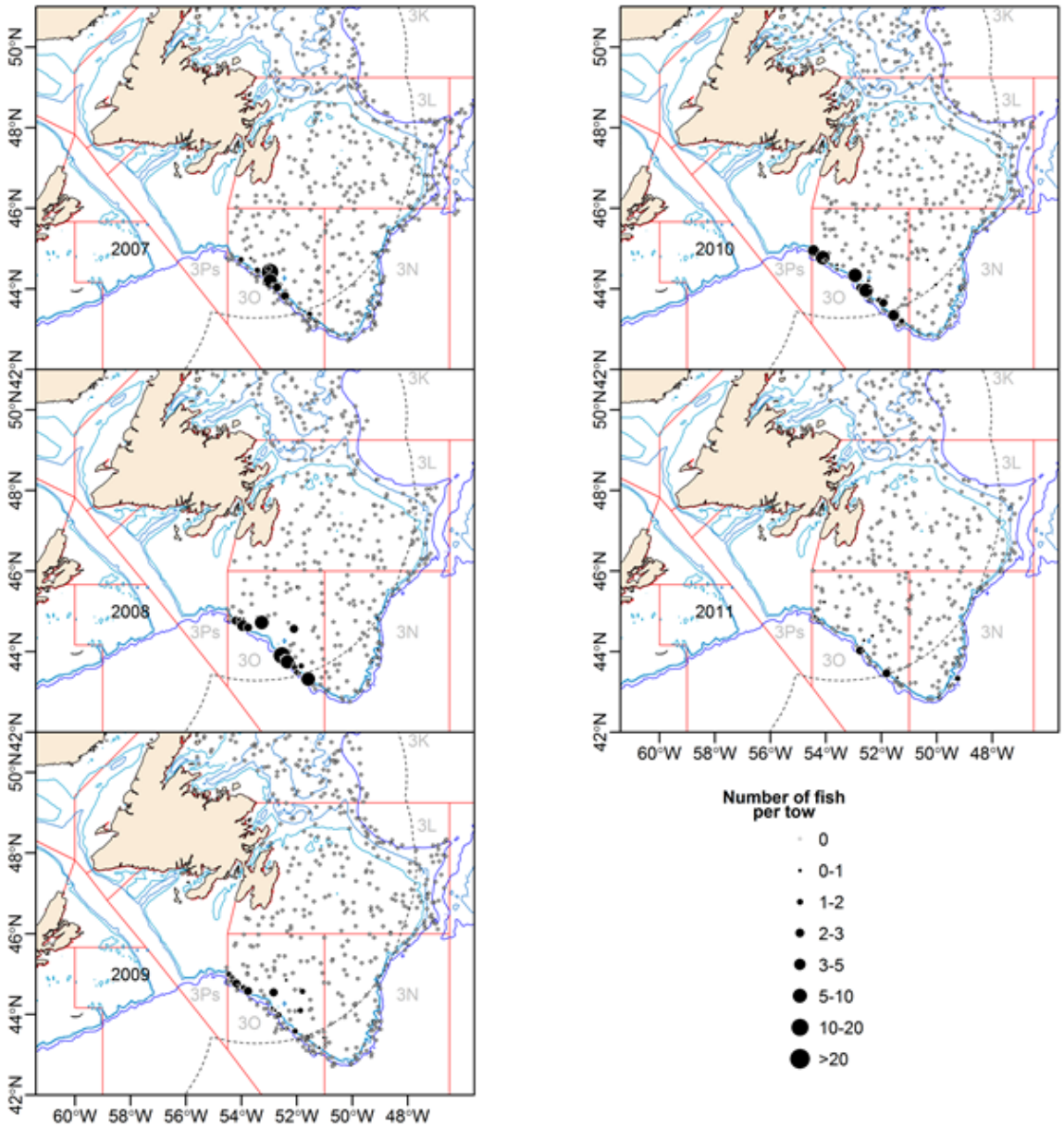


*Figure 19c. Distribution of Monkfish mean numbers per tow in Div. 3LNO, based on DFO-NL fall surveys in 2007-11.*

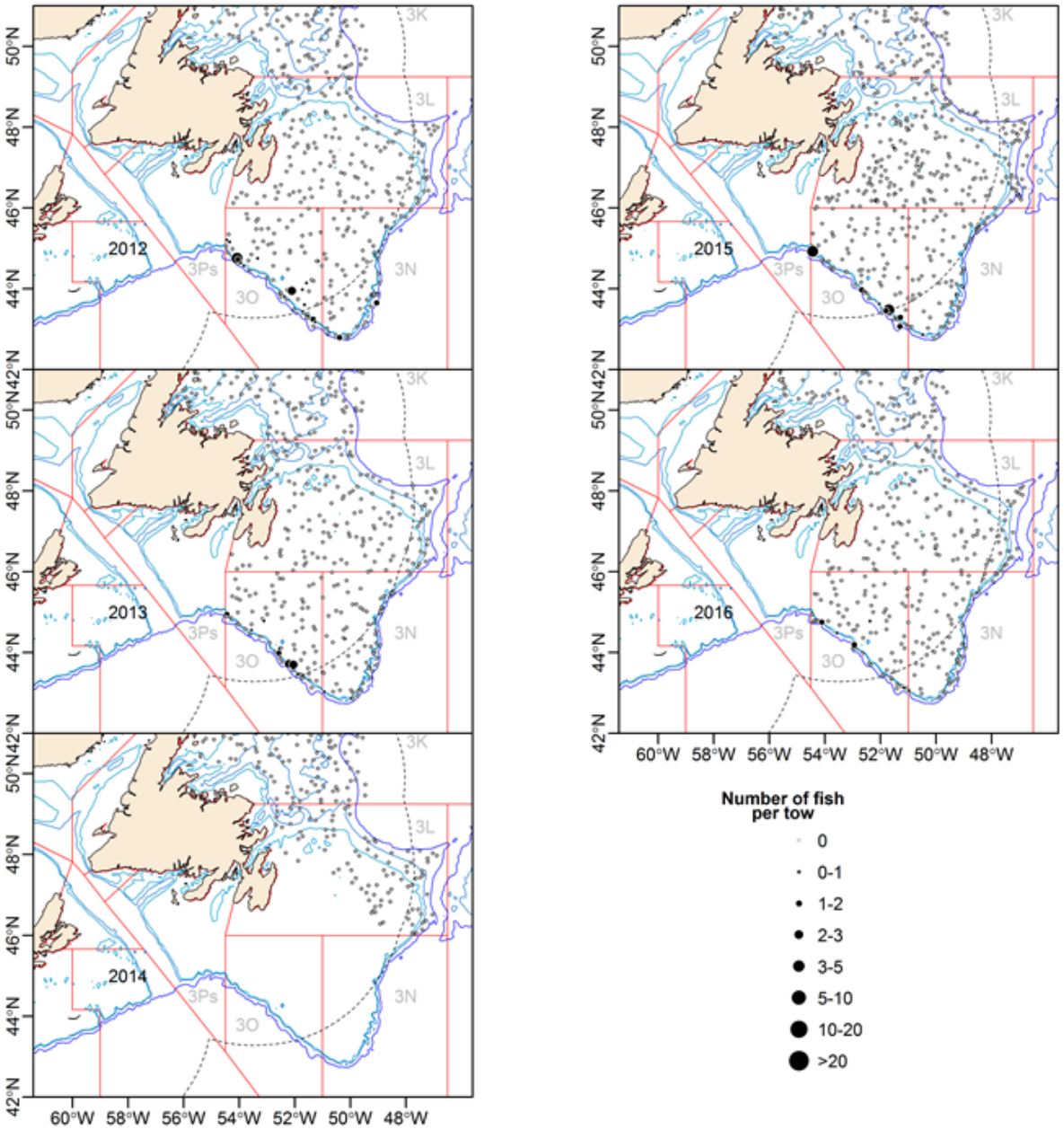


*Figure 19d. Distribution of Monkfish mean numbers per tow in Div. 3LNO, based on DFO-NL fall surveys in 2012-16. Note that Div. 3NO was not surveyed in 2014, and Div. 3L was only partially covered.*

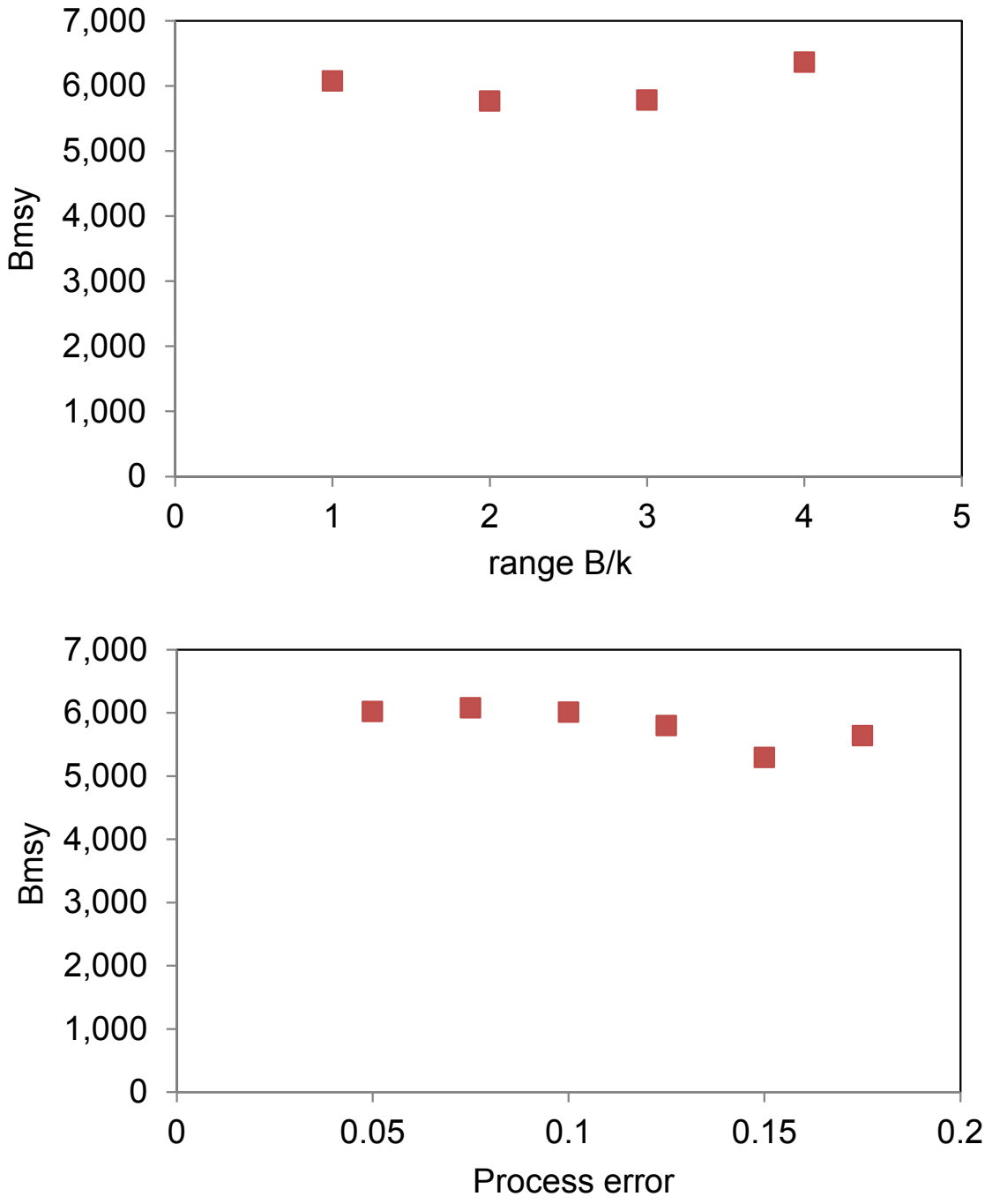


*Figure 20. Variance in $B_{msy}$ estimated from variation in Catch-resilience model a) B/k ratios and b) process error inputs for Div. 3LNOPs Monkfish.*

- Stock Monk-3LNOPs
- Last year = 2016 , last catch = 374
- Resilience = Low
- Process error = 0.1
- Assumed initial biomass (B/k) = 0.5 - 0.9 k
- Assumed intermediate biomass (B/k) in 1961 = 0 - 1 k
- Assumed final biomass (B/k) = 0.01 - 0.4 k
- Initial bounds for r = 0.05 - 0.5
- Initial bounds for k = 3076 - 92280
- First MSY = 499
- First r = 0.0799
- New upper bound for r = 0.44
- New range for k = 7035 - 11960
- Possible combinations = 744
- geom. mean r = 0.174
- r +/- 2 SD = 0.0894 - 0.338
- geom. mean k = 10763
- k +/- 2 SD = 9061 - 12784
- geom. mean MSY = 468
- MSY +/- 2 SD = 256 - 857
- Bmsy = 5381
- Fmsy= 0.087

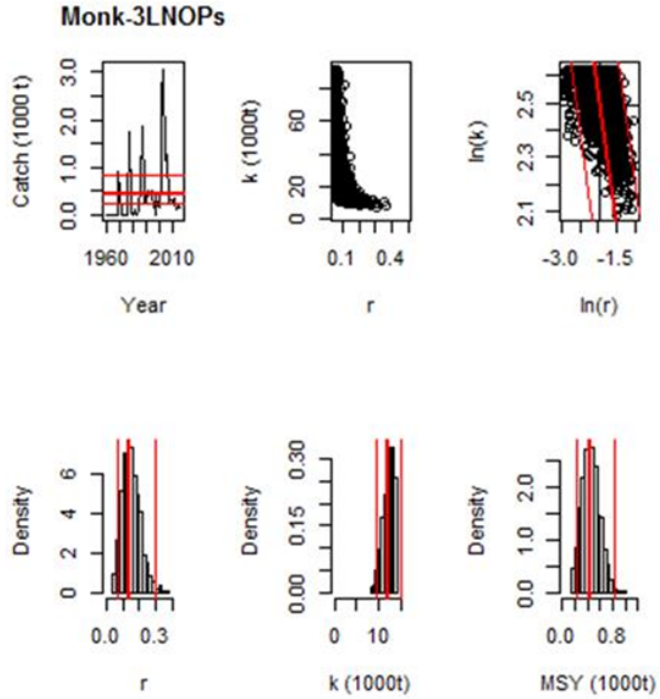


*Figure 21. Sample output from the base case (σ=0.1) Catch-Resilience model for Div. 3LNOPs Monkfish.*

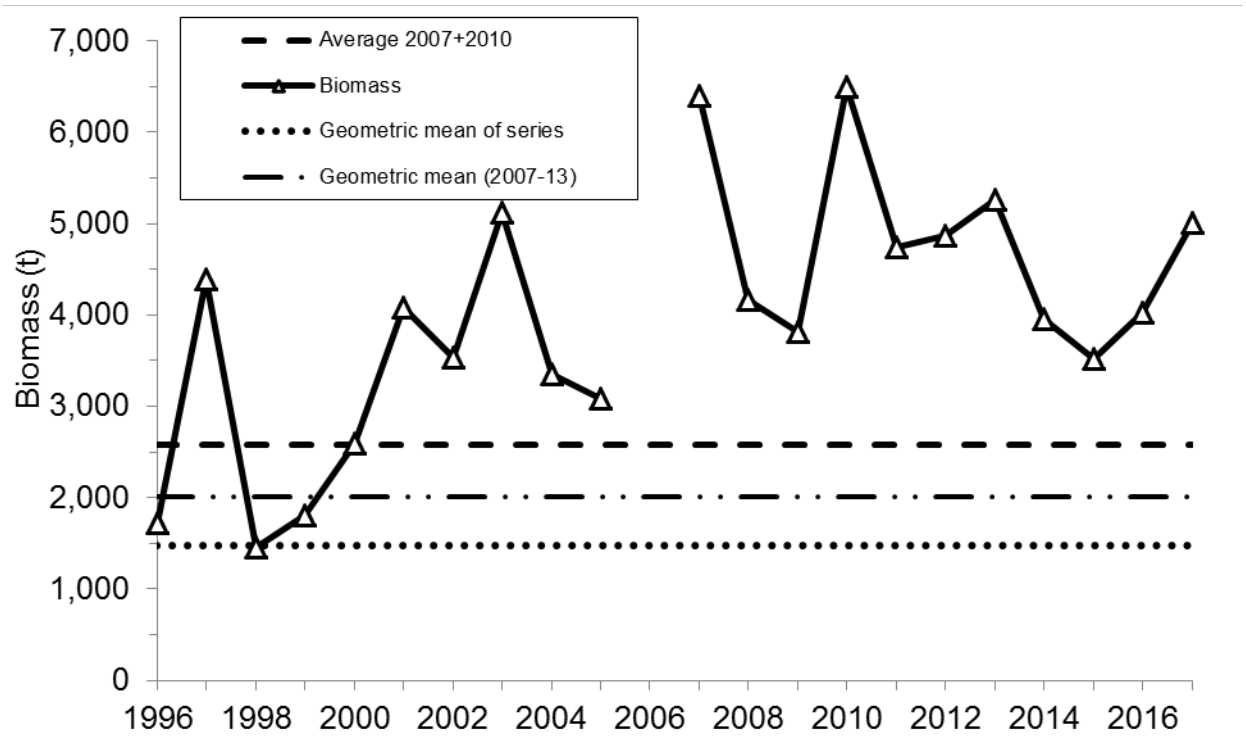


*Figure 22. Empirical reference points (40% $B_{msy}$) for Div. 3LNOPs Monkfish, based on proxy $B_{msy}$ estimates using the DFO-NL Campelen spring survey biomass index, 1996-2017.*