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An Assessment of White Hake (*Urophycis tenuis*, Mitchill 1815) in NAFO Divisions 3N, 3O, and Subdivision 3Ps

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ABSTRACT

White Hake in NAFO Divisions 3NO and Subdivision 3Ps inhabit the southern Grand Bank and St. Pierre Bank of Newfoundland and Labrador. The spring survey index for Divs. 3NOPs peaked in 2000, due to a very large 1999 year-class. Annual landings, which were at low levels in 1995-2001 (422 t average), increased to 6 718 t in 2002 and 4 823 t in 2003, following recruitment of the very large 1999 year-class. Since 2004, the stock has remained at a level of abundance similar to that observed in the mid-1990s. Over 2002-2020, this population exhibited little recruitment; however, during Canadian spring 2019 and autumn 2020 surveys, there were increases in White Hake numbers less than 27 cm relative to previous years. It should be noted that these recent increases were not comparable to those observed in 1999-2000. Increases in White Hake spawner biomass in Divs. 3NOPs will require a number of large year-classes that survive to maturity.

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 has been summarized in previous stock assessments of this species (Han and Kulka 2007, Simpson *et al.* 2019).

Formerly one of the most commercially important species in the Southern Gulf of St. Lawrence (NAFO Division 4T) and the Scotian Shelf (NAFO Division 4VWX and 5), White Hake stocks have declined in these regions in recent years. Their status as a commercial resource was assessed by Fisheries and Oceans Canada for Div. 4T (Swain *et al*. 2012) and Divs. 4VWX5 (Simon and Cook 2013) in 2012. More recently, White Hake populations in Atlantic Canada have been assessed by Fisheries and Oceans Canada within a Species at Risk recovery potential context (Nozères *et al.* 2015, Guénette and Clark 2016, Simpson *et al.* 2016, Swain *et al.* 2016). Stock structure of White Hake has been investigated using morphological and parasite load data (Hurlbut and Clay 1998, Melendy *et al*. 2005), tagging work (Kohler 1971), and allozyme data (Clay *et al*. 1992). In addition, polymorphic micro-satellite loci have been applied to investigate stock structure in this species (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 distribution (Roy *et al*. 2012). One such population of White Hake includes Divs. 3OPs.

This paper presents an updated assessment of White Hake in Divs. 3NO and Subdiv. 3Ps (Fig. 1), focusing on available research survey information and fisheries data.

Fisheries and Management

A. TAC Regulation

White Hake in Divs. 3NO came under quota regulation in September 2004, when the Fisheries Commission established a Total Allowable Catch (TAC) of 8 500 t for 2005-2007, which was maintained for 2008-2009. In September 2009, the Fisheries Commission reduced the TAC for White Hake in Divs. 3NO to 6 000 t for 2010-2011. The TAC was further reduced to 5 000 t for 2012, and to 1 000 t for 2013-2021.

In 2018, Canada established a TAC of 500 t for Subdiv. 3Ps for the 2018-2020 fishing seasons, which has been extended until the end of the 2023-2024 management period.

B. Catch Trends

Reported landings of White Hake in Divs. 3NO (all countries combined; STATLANT-21A) peaked in 1985 and 1987 at approximately 8 100 t (with about half reported by non-Canadian sources as bycatch), then declined to an average of 1 765 t in 1988-1994 (Table 1; Fig. 2). With the restriction of fishing by other countries to areas outside Canada's Exclusive Economic Zone (Divs. 3NO in the NAFO Regulatory Area, or NRA) in 1992, reported non-Canadian landings suddenly decreased to zero. Average landings were low over 1994-2001 (406 t), then increased to 5 365 t in 2002 and 6 158 t in 2003, following recruitment of the very large 1999 year-class. Reported landings declined to an average of 333 t during 2009-2018, then were 304 t in 2019 and 343 t in 2020 (Table 2).

Commercial landings of White Hake in Subdiv. 3Ps were less variable (Tables 1, 2; Fig. 2): averaging 1 114 tons in 1985-93, then decreasing to an average of 619 t in 1994-2002. Subsequently, reported landings increased to an average of 1 374 t in 2003-2007, then decreased to a 300 t average over 2009-2018. Subdiv. 3Ps landings were 274 t in 2019, and 116 t in 2020.

Fisheries Interactions

White Hake are captured in directed fisheries in Divs. 3NOPs, and as bycatch primarily in fisheries targeting Atlantic Cod (*Gadus morhua*), Atlantic Halibut (*Hippoglossus hippoglossus*), Monkfish (*Lophius americanus*), Redfish (*Sebastes* spp.) and, since 2015, Witch Flounder (*Glyptocephalus cynoglossus*; Fig. 3). White Hake are caught mainly by gillnets, longlines, and otter trawls (Fig. 4). In White Hake-directed fisheries, bycatch of other commercially important species occurs including Atlantic Cod, Haddock (*Melanogrammus aeglefinus*), American Plaice (*Hippoglossoides platessoides*), Atlantic Halibut, and Monkfish.

Size

Length distributions for White Hake taken in Canadian commercial directed fisheries in Div. 3O from 2013-2019 indicated that trawls captured 34-110 cm fish, with 56-66 cm modes in 2015-2017 (Fig. 5a;). Canadian longlines in Div. 3O caught 36-114 cm White Hakes (70 cm mode) in 2016, and 41-103 cm in 2019 (86 cm mode); although the latter only represented 27 fish. In 2018, the Canadian longline fishery in Subdiv. 3Ps caught 41-120 cm White Hakes (61 cm mode; Fig. 5a). Canadian trawlers in Subdiv. 3Ps captured a contracted range of fish: 41-90 cm, with the majority 43-67 cm in length (59 and 66 cm modes). Note that there were no gillnet samples taken after 2012, and no Canadian At-Sea Observer coverage in 2020 (due to COVID-19).

Commercial catches of White Hake by Portuguese trawlers (130 mm mesh) in the NRA of Div. 3O in 2013-2016 contained 24-76 cm fish (Fig. 5b). EU-Portugal did not sample White Hake in 2017-2020. Russian trawl fisheries in the NRA of Divs. 3NO in 2013-2015 captured 32-84 cm White Hakes (Fig. 5c). Russia sampled few White Hakes over 2016-2018. In 2019-2020, Russia reported a wider range of lengths (30-107 cm) in White Hake bycatch. Spanish trawlers using 130 mm mesh in the NRA of Divs. 3NO in 2014-2016 caught 15-81 cm White Hakes, a wider range (29-104 cm) in 2017, and 18-87 cm fish in 2018 (Fig. 5di). EU-Spain reported a contracted range of 31-71 cm fish in 2019. Using 280 mm mesh gear in Divs. 3NO, EU-Spain also captured a range of 20-95 cm White Hakes in 2014-2015, and a wider range of lengths (14-106 cm) in 2017 (Fig. 5dii). EU-Spain did not sample this species from 280 mm mesh gear in 2018-2020.

C. Research Surveys

Canadian Research Surveys -Spring

Stratified-random demersal surveys have been conducted by Canadian research vessels in the spring (April-June) of each year since 1971. The most significant alterations in Canadian standardized survey design were changes in survey gear. The spring survey can be separated into three time periods, based on the trawl used in each period: 1971-1983 (Yankee 41.5), 1984-spring 1995 (Engel 145), and spring 1996 to 2019 (Campelen 1800). McCallum and Walsh (1996) and Walsh and McCallum (1996) described the geometry and specifications of the Engel and Campelen trawls. While survey design remained constant, additional strata were included, along with modifications to some of the original strata (Bishop 1994). A significant change in the surveys was the addition of shallower and deeper strata after 1993. Additional causes of variation in spring survey coverage are discussed in detail most recently by Rideout (2020), and Rideout and Ings (2020). No size-based conversion factors for the two gears were derived for White Hake from comparative surveys; therefore, catch rate data and resulting biomass and abundance indices cannot be directly compared between trawl types. Similarly, no conversion factor exists for White Hake between Yankee and Engel trawls.

In the 2006 Canadian spring survey, most of Subdiv. 3Ps was not surveyed, and only shallow strata in Divs. 3NO were surveyed, due to Canadian research vessels' mechanical difficulties. Thus, survey estimates for that year are not comparable to others in the Campelen time-series. Due to COVID-19, the Canadian spring survey was not conducted in 2020. Only Subdiv. 3Ps was surveyed in spring 2021, due to mechanical difficulties aboard the research vessel.

Spring Survey Biomass and Abundance Indices

Spring survey estimates of biomass and abundance are presented for Divs. 3NO and Subdiv. 3Ps in Table 3. Mean weights and mean numbers per tow with 95% confidence intervals are presented in Figure 6a.

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 steeply declined and is presently at low levels which are comparable to earlier estimates in the Campelen time series. During the Canadian 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 Average biomass over 2015-2018 was 8 858 t. The average spring abundance estimate was 13 837 907 White Hakes during this same period. In 2019, the spring biomass was 9 208 t, with an abundance estimate of 69 379 530 White Hakes, which is comparable to the abundance observed in 1999.

Canadian Research Surveys -Autumn

Stratified-random autumn surveys have been conducted by Canada in Divs. 3NO from 1990 to the present. Beginning in autumn 1995, Canadian survey gear was changed from the Engel 145 otter trawl to the Campelen 1800 shrimp trawl. Additional causes of variation in autumn survey coverage are discussed in detail most recently by Rideout (2020), and Rideout and Ings (2020). In addition, Canada does not survey Subdiv. 3Ps in autumn. Furthermore, autumn surveys reach deeper maximum depths (~1 400 m) than those in spring (~750 m). Therefore, autumn survey data are not directly comparable to spring survey data. Because the autumn series is not spatially complete, as it does not cover the entire designated stock area, Canadian spring surveys are used as the primary estimator of biomass and abundance trends for White Hake.

Autumn Survey Biomass and Abundance Indices

Autumn biomass and abundance estimates (1990-present) are restricted to Divs. 3NO. These indices show a large increase in Divs. 3NO White Hake between 1998 and 1999 (Table 4; Fig. 6b). Of particular interest is the large increase in abundance in Div. 3N in 1999, to levels never previously observed (~83 000 000 fish). The pattern of Campelen autumn indices is offset by one year (earlier) as compared to that from spring surveys, because autumn surveys catch newly settled YOY that were spawned in the previous spring (Kulka *et al.* 2005*b*). About twenty-five weeks later, the next spring survey samples the previous year's cohort as 1-year-old White Hakes. This pattern was most apparent when a very large year-class was produced in 1999. After 2003, autumn abundance indices drastically declined to low levels (4 500 000-average annually in 2004-2010). In 2011-2013, the autumn abundance index for Divs. 3NO increased to approximately 16 400 000 White Hakes, but then declined to 6 500 000 fish over 2015-2018. Abundance increased in 2019 to approximately 13 000 000

White Hakes, and then tripled to 36 000 000 hakes during the 2020 autumn survey. Biomass has declined from the 2010-2013 average of 9 423 t to an average of 5 254 t over 2015-2018. In 2019 and 2020, abundance of White Hake in Divs. 3NO was 13 100 000 and 36 500 000 fish (respectively), while biomass was 4 501 t and 10 286 t, respectively.

EU-Spain Divs. 3NO Survey

Spain initiated a survey in the NRA of Divs. 3NO in 1995. Initially, the survey was carried out in spring with the C/V *Playa de Menduiña* using a Pedreira bottom trawl. Since 2001, the R/V *Vizconde de Eza* replaced the C/V *Playa de Menduíña*, and a Campelen 1800 trawl replaced the Pedreira (González-Troncoso *et al.* 2020). Results of this survey are available for White Hake from 2001-2019. This survey was not conducted in 2020, due to COVID-19.

The generally increasing trend of the EU-Spain biomass index over 2008-2013 is similar to that depicted by Canadian spring surveys, which cover all of Divs. 3NO (Fig. 7). The Canadian index continued to increase in 2014, followed by declines over 2015-2017; whereas the EU-Spain index increased in 2015 and 2016, followed by a decline in 2018 and 2019. The Canadian index increased in 2019.

Survey Length Frequencies

Survey length frequencies were available from Canadian spring and autumn research surveys and the EU-Spain 3NO survey. Prior to 2019, the dominant feature of the length frequency distributions was the 1999 cohort observed in autumn with the increase in 10-20 cm fish that can be tracked until 2004 (Fig. 8a). The same cohort is apparent in the spring survey as an increase in 15-28 cm fish from 2000-2004 (Fig. 8b). In the EU-Spain survey, this cohort is visible in 2001 as 26-30 cm White Hakes (Fig. 9; González-Troncoso *et al.* 2020). Recently, an increase in small fish (15-25 cm) was visible in the Canadian 2019 spring survey, and also tracked as 20-30cm White Hakes in the autumn 2020 survey. These peaks are not comparable to those observed during 1999 and 2000, but are a positive sign of small fish entering this population.

Landings/Biomass Ratios

Using NAFO STACFIS-reported landings and the Canadian spring survey biomass index, estimates of Relative F were calculated for White Hake in Divs. 3NO and in Divs. 3NO + Subdiv. 3Ps. Relative fishing mortality (Rel. F = NAFO-reported landings/Can. spring biomass) declined to low levels in 1999-2001, increased to a high peak in 2002-2003 (supported by the very large 1999 year-class), then declined to its lowest levels in 2012 (Fig. 10). Relative F was higher in Divs. 3NO than in Subdiv. 3Ps during 2002-2003, because of new directed fisheries for White Hake by EU-Spain, EU-Portugal, and Russia. Relative F increased marginally over 2012-2018 and declined slightly in 2019.

D. Biological Studies

Recruitment

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 comparable large year-classes were observed since then (Fig. 11). The index of recruitment (sexes combined) for 2019 was the largest value observed since the year 2000 but is not comparable to that large value.

Given the lack of spring surveys in Divs. 3NO during 2020 and 2021, a fall index of fish ≤26 cm in length was developed to monitor the potential recruitment in both missing years. Canadian autumnl surveys catch newly-settled young-of-the-year (YOY) that were spawned in the previous spring, which appear in the following spring survey as 1-year-old White Hakes. Overall, this new fall index has been increasing since 2017, and the 2020 value is the largest observed since 1999 (Fig. 12). Similar to the spring recruitment index, the more recent value is not comparable to the size of the 1999 value.

Stage-based Analysis

Information on White Hake abundance by life stage from Canadian spring surveys is presented for 1996-2019 in Figure 13. 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*).

Canadian spring survey trends in abundance for 1996-2019 were staged based on length as one-year-olds (≤26 cm; YOY), 2+ Immatures (27-57 cm), and mature adults (58+ cm; Fig. 13). Stage-based analysis of abundance from Canadian spring surveys in Divs. 3NOPs for 2001-2020 indicated that for both males and females, immature White Hakes older than two years dominated the population in most years between 1996-2020. A small peak of YOY fish was observed in 2000, when the 1999 cohort settled; this was followed by an increase in immature fish in 2001. Although spawning stock abundance was generally low throughout the time-series, there was an increase in mature White Hakes from 2003-2007 while the 1999 cohort matured in this population. In 2019, there has been a large increase in the proportion of YOY, and a decline in the proportion of immature White Hakes: similar to the pattern observed in 2000; although not on the same scale.

Maturity

Maturity analysis from data collected by Canadian Campelen spring surveys in 1996-2019 indicated that length at 50% maturity is different between sexes: but very similar for each sex among years and between areas (Div. 3NO *versus* Subdiv. 3Ps; Fig. 14). Females reach 50% maturity at 53 cm, and males do so at 38 cm.

Aging

Aging of White Hake has been initiated by Fisheries and Oceans Canada in Newfoundland & Labrador, employing methods adopted by the US Northeast Fisheries Science Center (NEFSC; National Oceanic and Atmospheric Administration). Otoliths are sectioned and yearly rings (annuli) are visually counted, in order to determine fish age. Currently, only a reference collection has undergone quality control and verification by experienced White Hake agers at NEFSC. This reference collection of 192 otoliths represents ages from 1 to 13 years old, and total lengths of 11 to 130 cm (Fig. 15.)

E. Environmental Relationships

An exploratory analysis investigated the relationships between White Hake recruitment/biomass and various environmental variables. White Hake recruitment appears to be affected by the strength of the Labrador Current and subsequent retention of eggs and pelagic juveniles on banks south of the Island of Newfoundland (in Divs. 3OP; Han and Kulka 2007). However, impacts of other variables, such as strength of the North Atlantic Oscillation (NAO), presence/absence of sea ice, and water temperature, have not been investigated. In addition, the potential for lower trophic levels (e.g., zooplankton) affecting White Hake recruitment and biomass was also explored. Climatic indices were derived from the Newfoundland and Labrador Climate Index (Cyr and Galbraith 2020), while biological indices were obtained from the Canadian Atlantic Zone Monitoring Program (AZMP; Belanger *et al.* 2021).

Correlations between environmental variables and White Hake biomass and recruitment are presented in Figure 16. Biomass was associated with sea surface temperature in a relatively strong positive correlation, and with *Calanus hyperboreus* in a negative relationship on the southeastern Grand Bank. White Hake recruitment was relatively negatively associated with the extent of the Cold Intermediate Layer (CIL), *Calanus hyperboreus, C. glacialis,* and *C. finmarchicus* on St. Pierre Bank. Recruitment was also positively correlated with *C. glacialis* on the southeastern Grand Bank.

A preliminary analysis of time-lagged relationships between White Hake biomass/recruitment and environmental indices was conducted with Cross-Correlations (CCF) in R. This analysis indicated that bottom temperature was significantly correlated to White Hake biomass with a 1–3-year time-lag: positive correlations suggested that an above-average bottom temperature will likely lead to an above-average biomass 1-3 years later. Similarly, larger abundances of *Calanus finmarchicus* on the southeastern Grand Bank appeared to be associated with an increase in White Hake biomass 2-3 years later.

F. Stock Distribution

White Hake in Divs. 3NO and Subdiv. 3Ps are confined largely to an area associated with the warmest bottom temperatures (4-8°C) along the southwest fringe of the Grand Banks, edge of the Laurentian Channel, and the south-west coast of Newfoundland (Kulka *et al.* 2005*a*).

Distributions of White Hake from Canadian spring surveys in Divs. 3NOPs during 2015-2019 are shown in Figure 17. Earlier distribution maps are available in Simpson *et al.* (2019). In addition, distributions of White Hake from Canadian autumn surveys in Divs. 3NO during 2016-2020 are shown in Figure 18. As in previous

years, this stock continues to occupy the southwest shelf edge areas of Divs. 3NO. It is important to note that, during the 2019 spring survey and the 2020 autumn survey, there was a noticeable increase in White Hakes distributed along the shelf in Div. 3O and into Div. 3N. Strata with higher stratified biomass estimates on the slope edge of Div. 3O during 2014, and less so in 2015, were not present in 2016-2018, but reappeared in 2019 (Fig. 19). In Subdiv. 3Ps, White Hakes were distributed along the shelf edge, and in the Laurentian and Hermitage Channels.

G. Modelling

White Hake biomass in Divs. 3NO and Subdiv. 3Ps were modelled using a SPICT surplus production model (Pedersen and Berg, 2017). Input data consisted of Canadian autumn (1984-1994 Engel trawl; 1995-2020 Campelen trawl) and spring (1984-1995 Engel; 1996-2019 Campelen) biomass indices and STATLANT 21A reported commercial landings in 1984-2020. Note that survey biomass estimates have not been corrected to exclude fish that were not usually caught in the commercial fishery (i.e., White Hakes less than 30 cm in length).

This assessment converged, all variance parameters of the model parameters were finite, and there were no violations of model assumptions based on one-step-ahead residuals (Fig 20). While the retrospective trajectories of B/B_{MSY} and F/Fmsy were within credible intervals of the main model, there was consistent overestimation of B/B_{MSY} in some cases (Fig. 21). Overall, the model fit was uncertain, with credible intervals for F/F_{MSY} spanning more than 2 orders of magnitude (Fig. 22). The Kobe plot (i.e., fishing mortality as a function of spawning biomass) indicated that White Hake in Divs. 3NOPs is in the "no risk" area: fishing mortality is below F_{MSY}, and biomass is above B_{MSY}. Furthermore, the White Hake stock in Divs. 3NOPs has not been in either the "overfished and overfishing phase" (red zone: biomass below B_{MSY}, and fishing mortality greater than F_{MSY}), or in the intermediate zone of "overfishing and overfished".

H. Assessment Results

Resource Status

Recent spring survey indices indicate that the White Hake stock size in Divs. 3NOPs remains at levels comparable to those observed during the Canadian Campelen spring surveys of 1996-1999.

Age-structured assessment of this stock is currently not feasible. However, population abundance-at-length estimates from Canadian spring surveys suggest that no significant recruitment has occurred for White Hake in Divs. 3NO. In fact, there has been extremely low recruitment since that generated by the very large 1999 year-class.

Given that good recruitment rarely occurs and remains unpredictable for this White Hake population, commercial fishing pressure should be regulated in the NRA of Divs. 3NO by a TAC set at a level that will allow survival and growth to maturity of larger year-classes: a strategy crucial to rebuilding this stock.

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Table 1. NAFO STATLANT-21A reported landings of White Hake (in tonnes) by NAFO Division in 1960-2020.

	3N			3O			3Ps			3NO	3NOPs
Year	non-Can	Canada	Total	non-Can	Canada	Total	non-Can	Canada	Total	Total	Total
1960	164	37	201	210	181	391	500	232	732	592	1324
1961	9	17	26	25	152	177	32	100	132	203	335
1962	1	2	3	1384	406	1790	1	74	75	1793	1868
1963	-	12	12	5	129	134	8	103	111	146	257
1964	-	14	14	-	113	113	-	124	124	127	251
1965	125	5	130	18	28	46	60	71	131	176	307
1966	4	9	13	102	51	153	45	39	84	166	250
1967	549	24	573	967	34	1001	43	67	110	1574	1684
1968	-	5	5	22	64	86	20	403	423	91	514
1969	9	1	10	7	49	56	6	375	381	66	447
1970	21	48	54	44	107	151	227	397	624	205	829
1971	366	132	498	4110	2584	6694	221	1443	1664	7192	8856
1972	259	34	293	1594	1998	3592	115	2062	2177	3885	6062
1973	33	59	92	307	2508	2815	84	1330	1414	2907	4321
1974	214	31	245	358	2476	2834	18	1305	1323	3079	4402
1975	1186	43	1227	2430	1926	4356	765	1432	2197	5583	7780
1976	663	237	900	1272	1225	2497	10	1344	1354	3397	4751
1977	1005	22	1027	976	1095	2071	-	1683	1683	3098	4781
1978	670	42	712	1199	682	1881	-	1051	1051	2593	3644
1979	246	44	290	919	360	1279	-	660	660	1569	2229
1980	209	242	451	1856	311	2167	-	546	546	2618	3164
1981	809	22	831	564	310	874	-	1030	1030	1705	2735
1982	687	5	692	913	336	1249	-	773	773	1941	2714
1983	271	30	301	1912	683	2595	-	425	425	2896	3321
1984	400	108	508	3182	645	3827	-	683	683	4335	5018
1985	1542	110	1652	2835	1672	4507	-	1156	1156	6159	7315
1986	473	394	867	1569	2169	3738	14	1228	1242	4605	5847
1987	4019	1321	5340	990	1731	2721	-	1318	1318	8061	9379
1988	866	830	1696	111	954	1065	12	683	695	2761	3456
1989	5	878	883	23	1103	1126	3	706	709	2009	2718
1990	228	832	1060	7	1053	1060	35	1441	1476	2120	3596
1991	1507	20	1527	-	960	960	36	1445	1481	2487	3968
1992	-	19	19	-	1647	1647	-	1208	1208	1666	2874
1993	-	18	18	-	1004	1004	-	741	741	1022	1763

Table 1. continued-

	3N			3O			3Ps			3NO	3NOPs
Year	non-Can	Canada	Total	non-Can	Canada	Total	non-Can	Canada	Total	Total	Total
1994	20	16	36	4	253	257	-	382	382	293	675
1995	5	-	5	1	276	277	-	420	420	282	702
1996	28	-	28	1	311	312	-	362	362	340	702
1997	92	-	92	6	329	335	-	315	315	427	742
1998	81	-	81	8	188	196	1	561	562	277	839
1999	51	43	94	13	322	335	-	575	575	429	1004
2000	124	21	145	29	393	422	134	976	1108	567	1677
2001	73	18	91	49	493	542	10	920	930	633	1563
2002	1221	-	1221	3132	1014	4146	3	915	918	5365	6285
2003	2688	-	2688	3053	417	3470	3	1105	1108	6158	7266
2004	170	6	176	1364	375	1739	22	1361	1383	1915	3298
2005	21	0	21	258	685	943	23	1615	1638	964	2602
2006	73	2	75	178	950	1128	1	1484	1485	1203	2688
2007	12	10	22	74	627	701	2	1253	1255	723	1978
2008	26	6	32	60	778	838	6	659	665	870	1535
2009	19	3	22	70	389	459	3	362	365	481	843
2010	20	13	33	65	174	239	-	378	378	272	650
2011	3	0	3	94	66	160	-	200	200	163	363
2012	3	3	9	84	49	133	5	208	213	139	352
2013	10	10	20	112	101	213	-	191	191	233	424
2014	26	15	41	216	59	275	1	384	385	316	701
2015	18	18	36	269	106	375	1	330	331	411	742
2016	51	6	57	192	198	390	3	299	302	447	749
2017	54	1	55	109	333	442	-	308	308	497	805
2018	1	-	1	32	233	265	-	328	328	269	597
2019	16	1	17	93	192	285	1	273	274	302	576
2020	37	51	88	165	90	255	-	119	119	343	462

Table 2. White Hake NAFO STACFIS estimates (in 000s of tonnes), STATLANT-21A reported landings, and Total Allowable Catch (TAC) limits for NAFO Divisions 3NO and Subdivision 3Ps.

	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Divs. 3NO:												
TAC	6	6	5	1	1	1	1	1	1	1	1	1
STATLANT-21A[1]	0.3	0.2	0.1	0.2	0.3	.4	.3	.5	.3			
STACFIS	0.2	0.3	0.1	0.2	0.3	.5	.4	.5	.4	.3	.3	
Subdiv. 3Ps:												
TAC									.5	.5	.5	.5
STATLANT-21A	0.4	0.2	0.2	0.2	0.4	.3	.4	.3	.3	.3	.1	

Table 3. Biomass and abundance of White Hake from Canadian spring research vessel surveys, 1971-2019. Surveys were conducted with a Yankee bottom trawl (1971-1983), an Engel trawl (1984-spring 1995), and a Campelen trawl (spring 1996-2016). NAFO Subdiv. 3Ps was not surveyed in 1971, 2006; Div. 3O was not surveyed in 1971, 1972, 1974, 1983; and Div. 3N was not surveyed in 1983. 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. There was no spring survey in 2020, due to COVID-19.

	Biomass (tonnes)				Abundance (000s)			
Year	3N	3O	3Ps	3NOPs	3N	3O	3Ps	3NOPs
Yankee series								
1971	0	0		0	0	0		0
1972	354		2,725	3,079	61		1,556	1,618
1973	36	1,532	465	2,033	11	327	247	585
1974	0		5,224	5,224	0		2,055	2,055
1975	0	3,173	4,491	7,664	0	1,080	2,646	3,726
1976	110	5,623	4,778	10,511	32	1,413	3,856	5,301
1977	50	1,339	7,168	8,557	43	466	3,935	4,444
1978	0	6,188	6,774	12,962	0	4,361	4,058	8,420
1979	165	1,978	6,310	8,453	34	1,065	3,077	4,176
1980	0	1,385	3,970	5,356	0	1,015	2,053	3,068
1981	139	96	7,448	7,682	28	93	4,743	4,865
1982	0	1,058	4,283	5,342	0	399	1,340	1,739
1983			0	0			0	0
Engel series								
1984	258	3,531	2,558	6,348	57	1,085	1,179	2,321
1985	46	2,878	5,303	8,227	8	1,315	3,045	4,368
1986	356	2,438	11,105	13,899	70	574	4,186	4,830
1987	43	2,752	9,866	12,661	95	1,114	4,438	5,647
1988	32	5,431	13,005	18,469	63	690	5,533	6,286
1989	0	925	6,884	7,809	0	251	4,130	4,382
1990	0	754	3,988	4,742	0	236	2,941	3,177
1991	0	1,039	4,591	5,630	0	1,118	3,800	4,918
1992	0	606	3,008	3,614	0	574	2,699	3,274
1993	0	522	2,929	3,451	0	301	2,670	2,970
1994	0	1,079	2,433	3,512	0	885	2,274	3,159
1995	0	334	2,334	2,668	0	189	2,104	2,294
Campelen series								
1996	4	2,020	6,282	8,306	75	2,982	8,089	11,145
1997	4	2,221	8,507	10,733	91	2,987	12,432	15,510
1998	7	2,205	4,007	6,219	79	2,249	4,765	7,093
1999	20	12,194	8,236	20,450	29	26,010	8,654	34,693
2000	30	15,900	10,294	26,224	716	104,360	11,743	116,819
2001	269	14,908	8,092	23,269	517	39,384	13,792	53,692
2002	96	10,808	10,118	21,022	105	11,334	15,098	26,537
2003	234	7,981	5,762	13,977	176	7,250	6,904	14,330
2004	33	10,369	6,622	17,024	53	8,477	6,977	15,506
2005	20	5,932	5,249	11,205	35	9,725	5,506	15,306
2006	247	12,267		12,517	69	10,370		10,463
2007	2	3,510	6,940	10,452	7	2,734	6,061	8,802
2008	108	4,660	3,633	8,400	23	5,689	3,991	9,703
2009	183	4,656	2,582	7,435	152	2,804	4,547	7,548

Table 3. continued-

	Biomass (tonnes)				Abundance (000s)			
Year	3N	3O	3Ps	3NOPs	3N	3O	3Ps	3NOPs
Campelen series								
2010	52	4,283	3,739	8,074	30	5,085	5,285	10,400
2011	571	6,423	4,727	11,722	2,175	17,834	6,745	26,754
2012	1,548	6,215	3,686	11,449	2,933	7,383	4,657	14,972
2013	49	7,755	3,987	11,792	178	11,807	5,581	17,566
2014	482	9,494	3,630	13,606	529	8,342	5,834	14,705
2015	71	6,102	3,596	9,769	31	9,999	6,032	16,062
2016	468	3,613	5,050	9,131	231	3,135	8,537	11,903
2017	348	3,352	4,848	8,548	368	7,459	7,092	14,919
2018	162	3,469	4,352	7,983	118	4,564	7,786	12,468
2019	207	5,113	3,888	9,208	280	30,059	5,625	35,963
2020								

Table 4. Biomass and abundance of White Hake from Canadian autumn research vessel surveys in Divs. 3NO, 1990-2020. Surveys were conducted with an Engel trawl (1990-autumn 1994), and a Campelen trawl (autumn 1995-2020). Note that Canadian research vessels' mechanical difficulties prevented the surveying of: deep strata in Divs. 3NO in 2003, 2004 & 2006; strata deeper than 730 m in 2008; and Divs. 3NO in 2014.

	Biomass (tonnes)			Abundance (000s)		
Year	3N	3O	3NO	3N	3O	3NO
Engel series						
1990	0	1,784	1,784	0	863	863
1991	0	2,805	2,805	0	2,047	2,047
1992	22	471	493	63	448	511
1993	0	748	748	0	490	490
1994	0	1,445	1,445	0	1,341	1,341
Campelen series						
1995	94	4,099	4,193	306	5,409	5,715
1996	3	3,960	3,966	219	3,850	3,993
1997	151	4,192	4,264	46	5,361	5,425
1998	134	2,897	3,067	862	5108	7,115
1999	3,028	4,043	7,071	83,220	11,583	94,803
2000	1,165	9,551	10,716	2,875	22,750	25,625
2001	946	10,740	11,686	1,077	18,207	19,284
2002	2,753	11,384	14,137	2,126	13,434	15,561
2003	906	13,374	14,280	748	10,628	11,376
2004	1,847	2,237	4,083	2,084	1,492	3,576
2005	539	4,739	5,277	109	4,001	4,110
2006	212	2,088	2,299	98	2,288	2,386
2007	276	10,337	10,613	543	7,859	8,402
2008	620	2,557	3,177	415	2,426	2,841
2009	132	4,189	4,321	73	4,123	4,195
2010	630	3,695	4,325	2,508	3,465	5,973
2011	270	7,293	7,563	947	13,410	14,357
2012	8,842	2,902	11,745	12,307	5,768	18,075
2013	857	13,201	14,058	993	15,721	16,714
2014	ns	ns	ns	ns	ns	ns
2015	211	10,626	10,837	356	8,687	9,043
2016	259	2,629	2,888	350	1,345	1,695
2017	89	4,114	4,203	1,324	6,240	7,564
2018	54	3,003	3,057	242	7,446	7,688
2019	102	4,400	4,502	179	12,899	13,078
2020	219	10,067	10,286	480	35,973	36,453

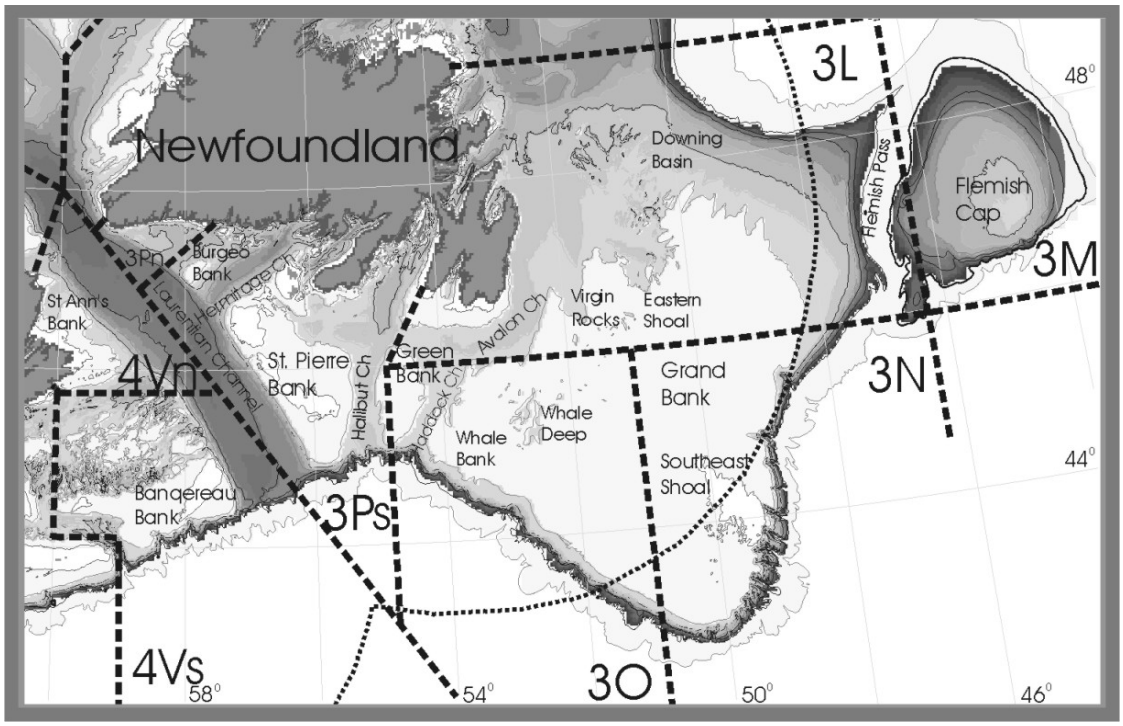


Figure 1. Map of the Grand Banks showing various banks, basins, and NAFO Divisions. Thick dotted lines delineate NAFO Divisions. The thin dotted curved line shows Canada's Exclusive Economic Zone, delineating Canadian territory from the NAFO Regulatory Area (NRA).

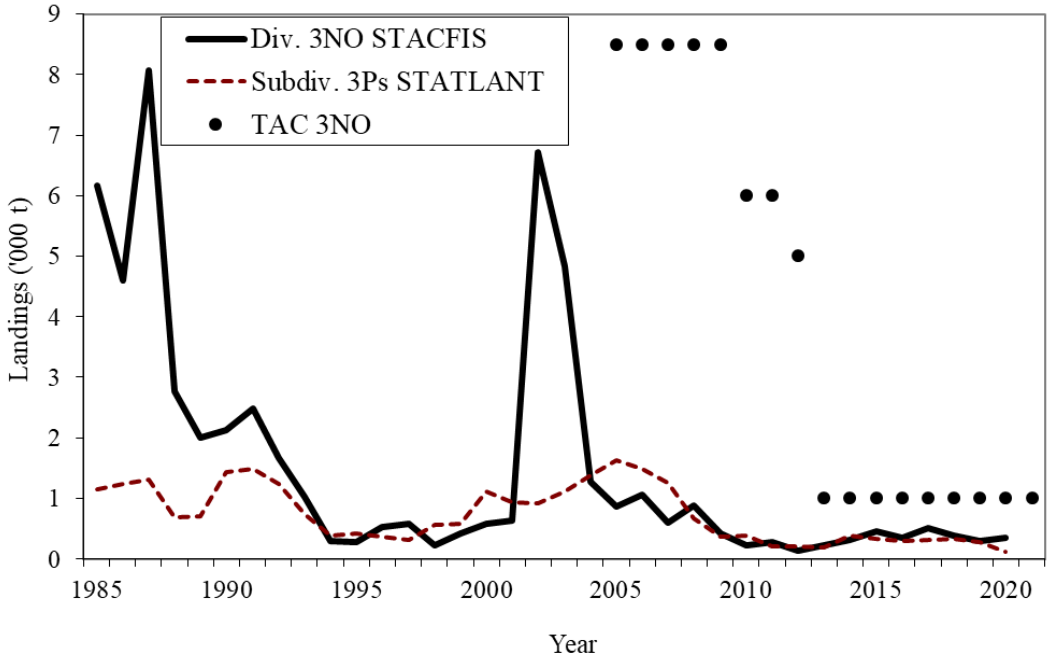


Figure 2. Total reported landings of White Hake and TAC (for the NRA of Divs. 3NO) in Divs. 3NO (STACFIS) and Subdiv. 3Ps (STATLANT-21A), 1985-2021.

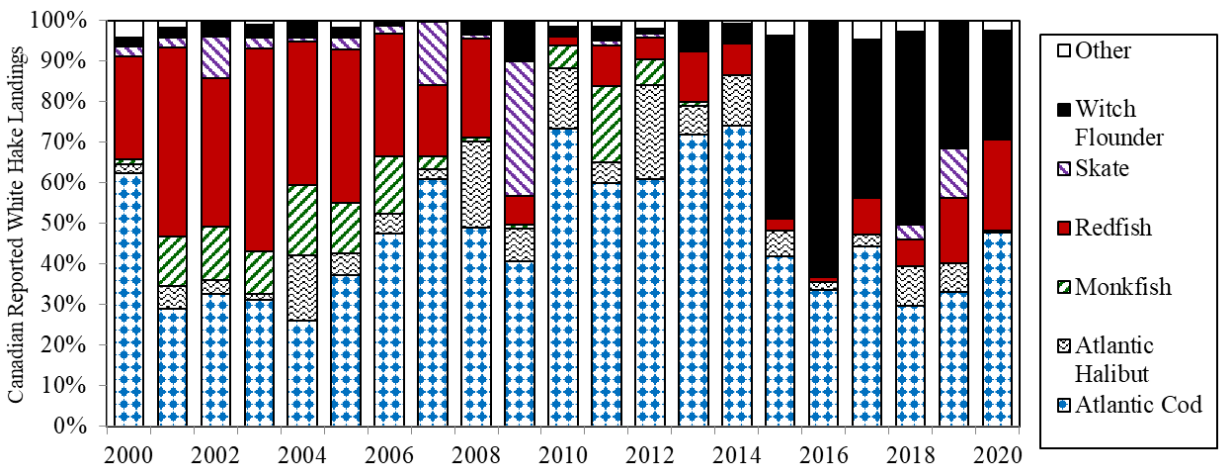


Figure 3. Canadian reported landings of White Hake bycatch from various fisheries in Divs. 3NOPs, 2000-2020.

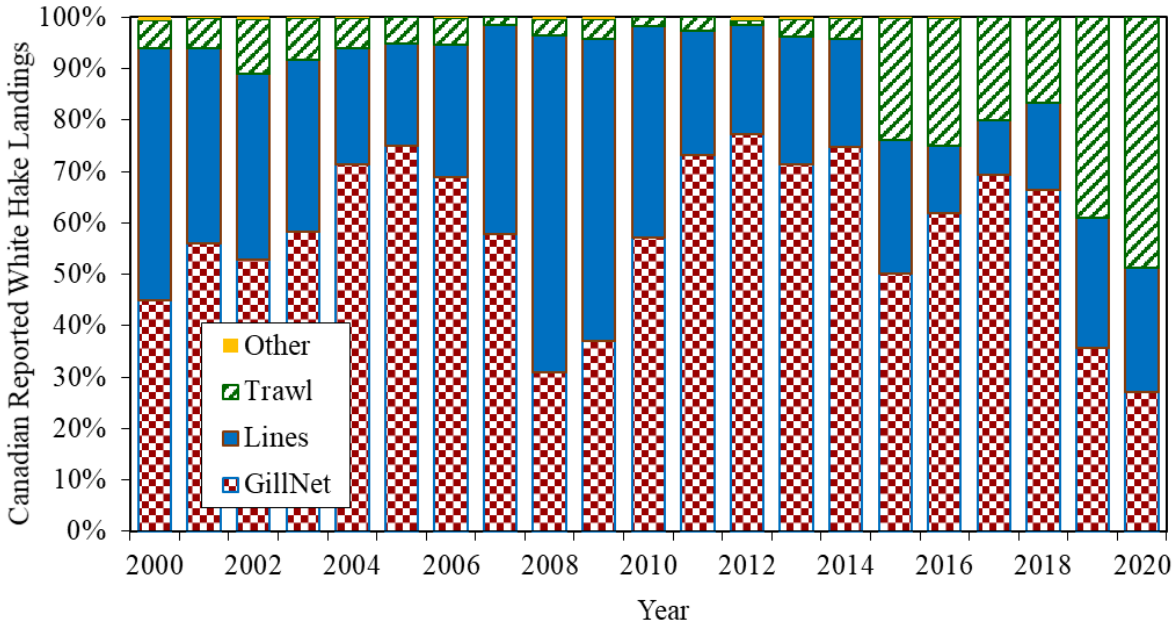


Figure 4. Canadian reported landings of White Hake by gear in Divs. 3NOPs, 2000-2020.

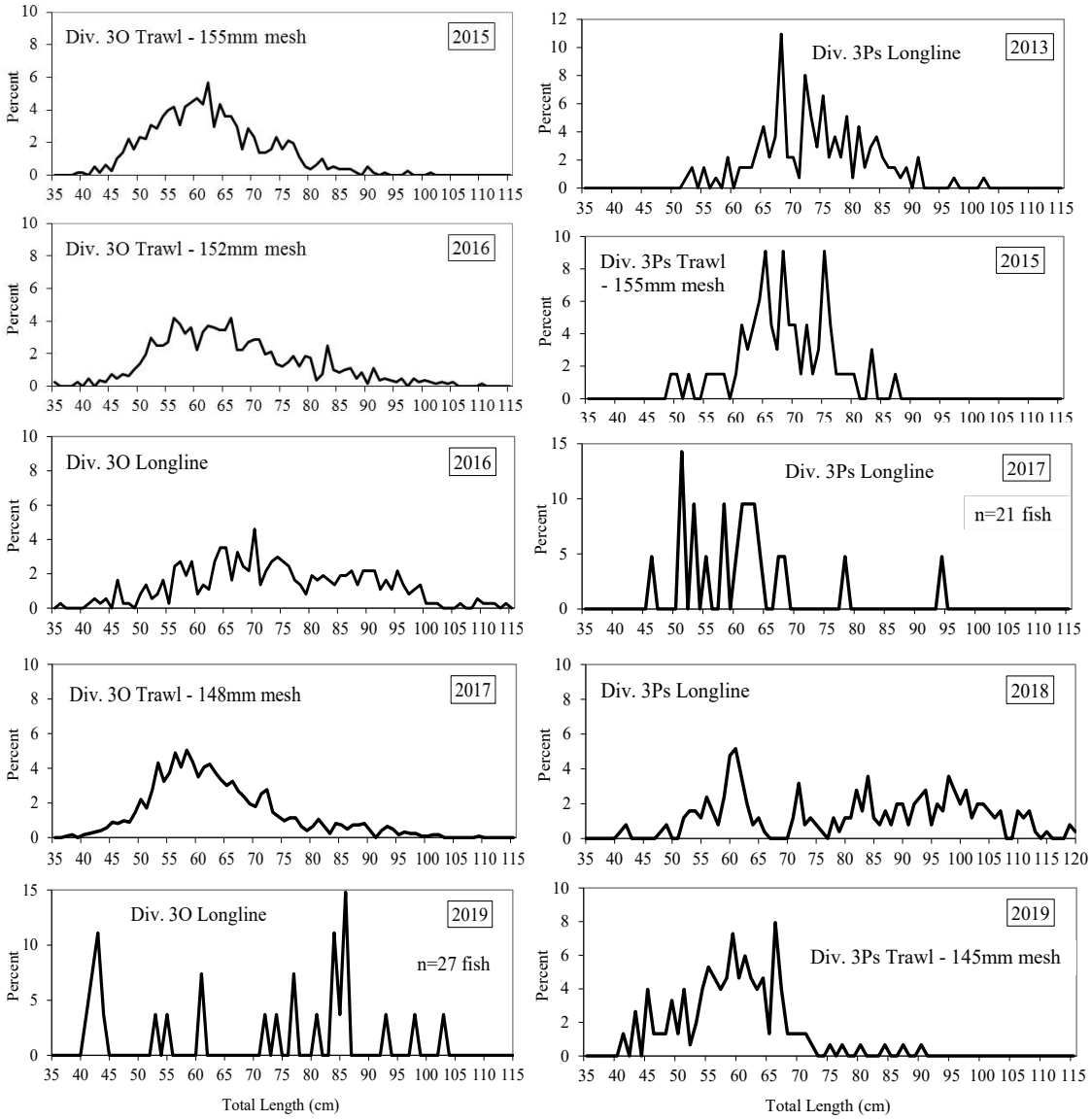


Figure 5a. Length frequencies (in cm) for White Hake in Canadian commercial fisheries in Div. 3O (left panels) and Subdiv. 3Ps (right panels), 2013-2019. Note that different gears are represented in separate graphs. Data are from Canadian At-Sea Fisheries Observers and include discards. There was no Canadian Observers coverage in 2020, due to COVID-19.

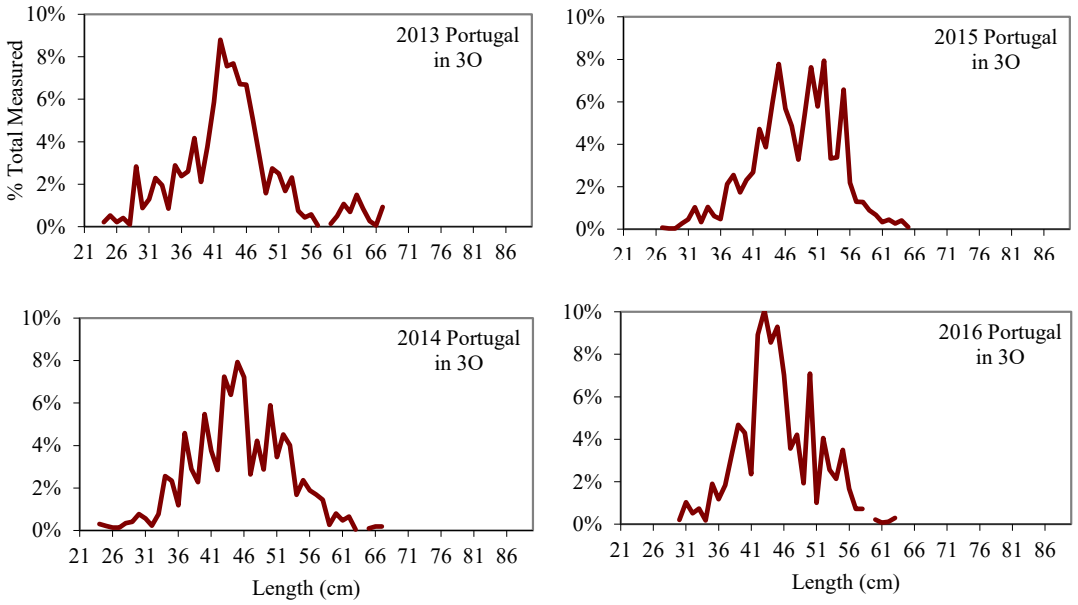


Figure 5b. Length frequencies (in cm) for White Hake bycatch in EU-Portugal commercial trawl fisheries (130mm codend mesh size) in the NAFO Regulatory Area of Div. 3O, 2013-2016. EU-Portugal did not sample White Hake in the commercial fishery in 2017-2020.

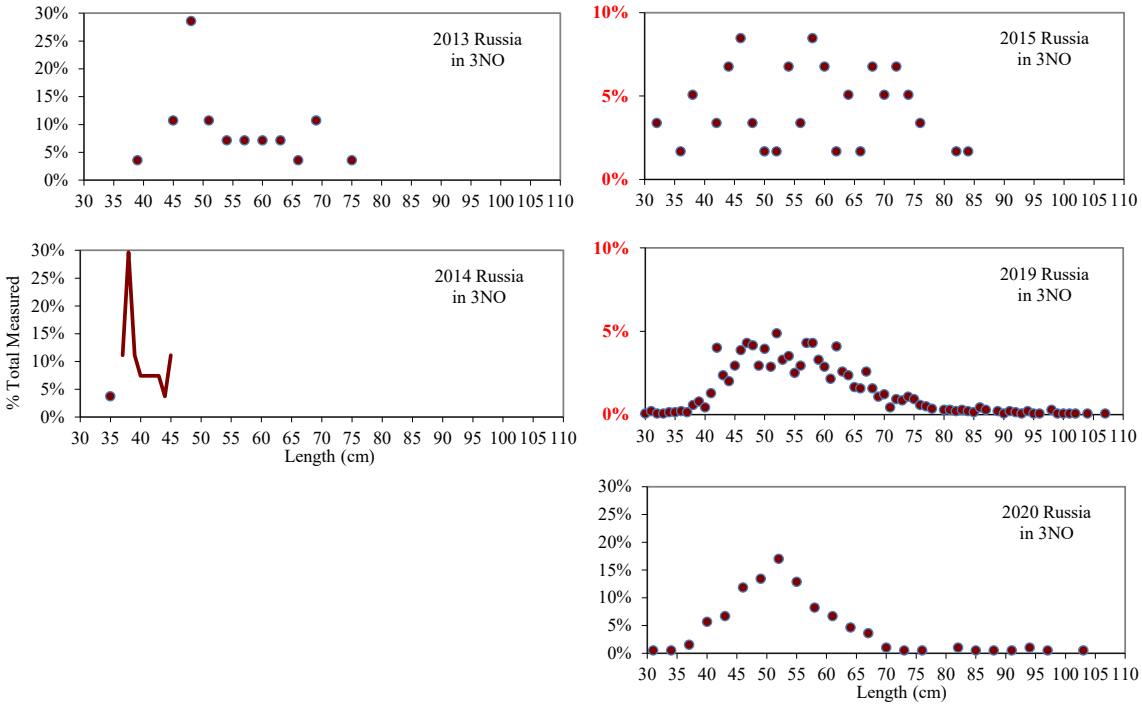
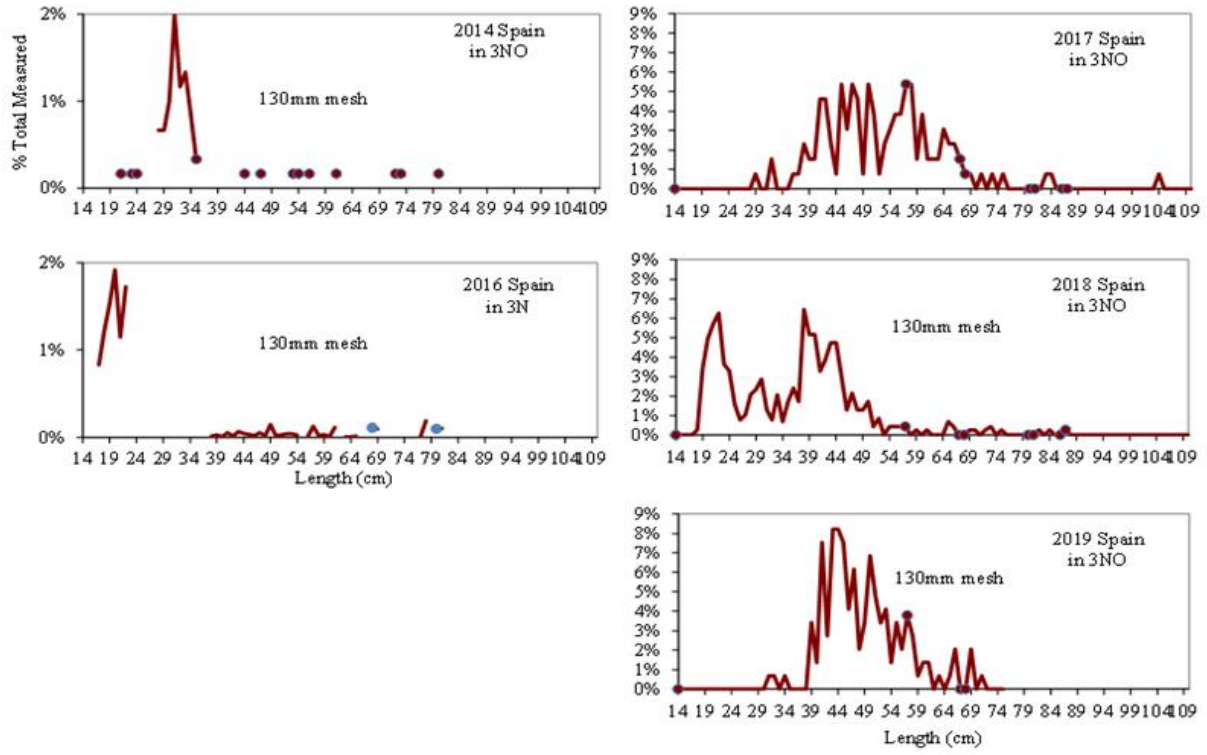


Figure 5c. Length frequencies (in cm) for White Hake bycatch in Russian commercial trawl fisheries in the NAFO Regulatory Area of Divs. 3NO, 2013-2020. The number of White Hakes sampled in 2013, 2014 & 2016 was very small. Russia did not sample commercial White Hakes in 2017 & 2018. Note that Y-axis values for 2015 & 2019 are 1/3 of those for 2013-2014 & 2020.

[i]



[ii]

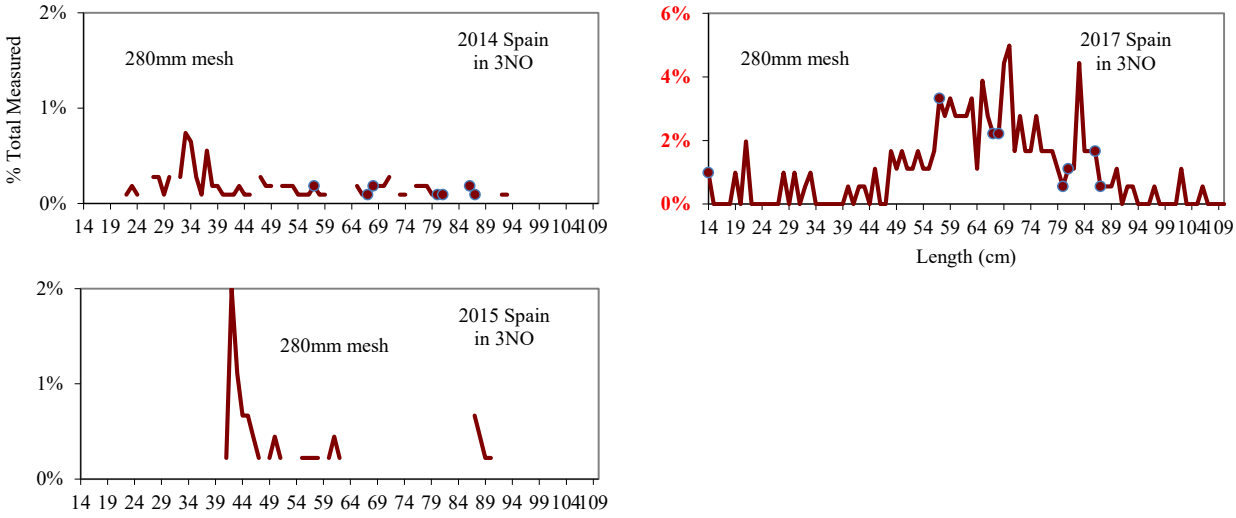


Figure 5d. Length frequencies (in cm) for White Hake bycatch in Spanish commercial trawl fisheries ([i] 130-135mm codend mesh size; [ii] 280mm codend mesh) in the NAFO Regulatory Area of Divs. 3NO, 2014-2019. EU-Spain did not sample commercial White Hakes in 2020. Note that Y-axis values for 2017 (280 mm mesh) are triple those for 2014 & 2015.

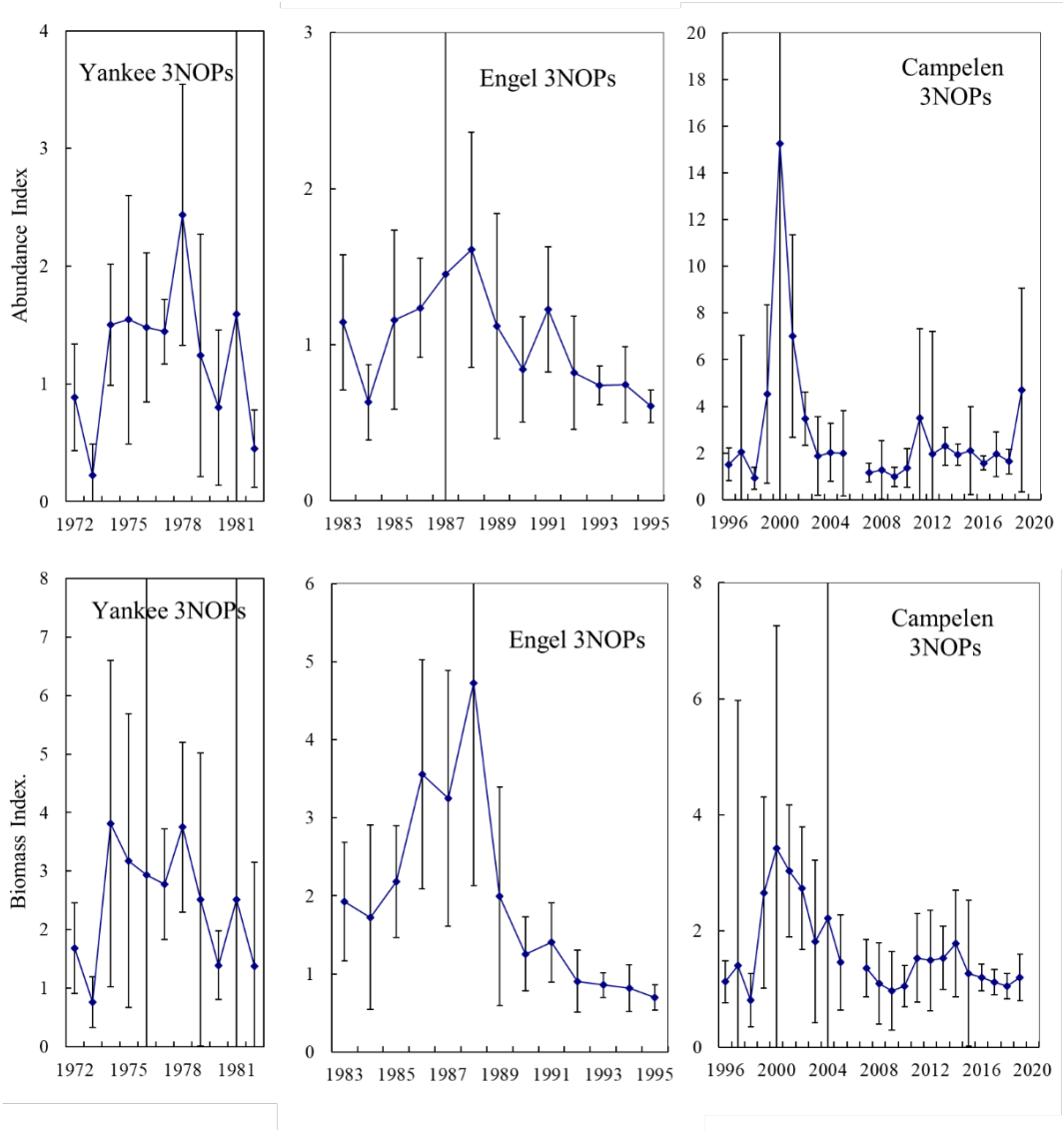


Figure 6a. White Hake mean numbers (top panels) and mean weights (kg; bottom panels) per tow (+95% CI) from Canadian spring research surveys in Divs. 3NO and Subdiv. 3Ps, 1972-2019. Yankee, Engel, and Campelen time series are not standardized, and thus are presented on separate panels. Note that the survey in 2006 was incomplete, due to Canadian research vessels' mechanical difficulties. There was no survey in 2020, due to COVID-19.

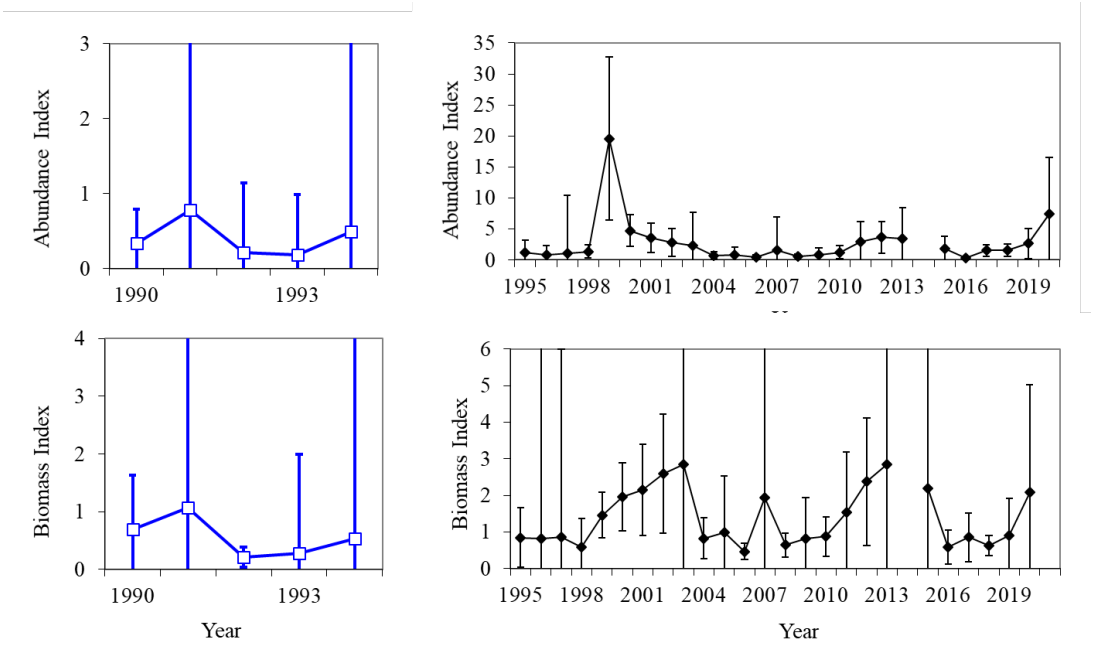


Figure 6b. White Hake mean numbers (top panels) and mean weights (kg; bottom panels) per tow (+95% CI) from Canadian autumn research surveys in Divs. 3NO, 1990-2020. Engel (□, 1990-1994) and Campelen (♦, 1995-2020) time series are not standardized. Note that Canadian research vessels' mechanical difficulties prevented the surveying of: deep strata in Divs. 3NO in autumn of 2003, 2004 & 2006; strata deeper than 730 m in autumn 2008; and Divs. 3NO in autumn 2014.

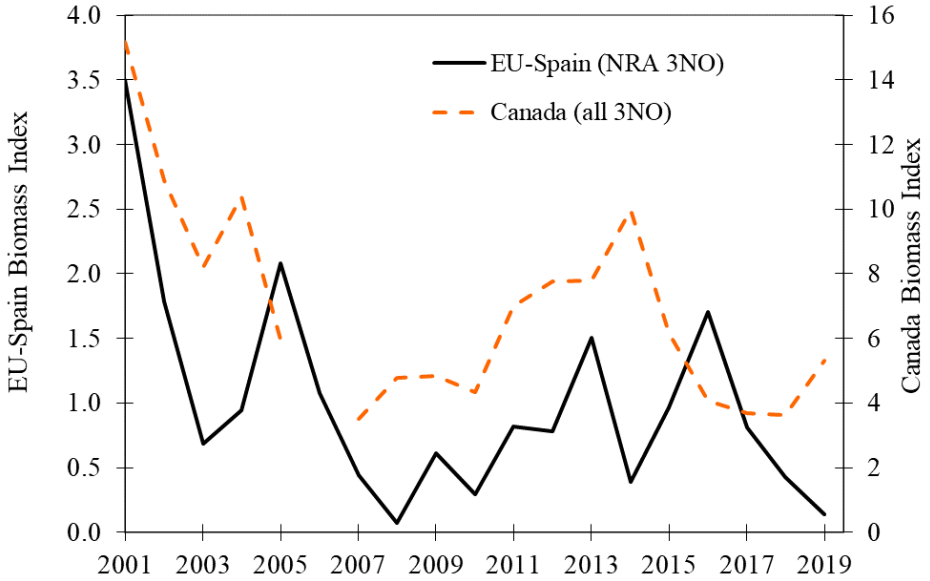


Figure 7. White Hake biomass indices (in 000s tonnes) in Divs. 3NO: EU-Spain spring surveys in the NRA of Divs. 3NO compared to Canadian spring surveys in all of Divs. 3NO, 2001-2019. Note that the Canadian survey in 2006 was incomplete, due to research vessels' mechanical difficulties. There were no spring surveys in 2020, due to COVID-19.

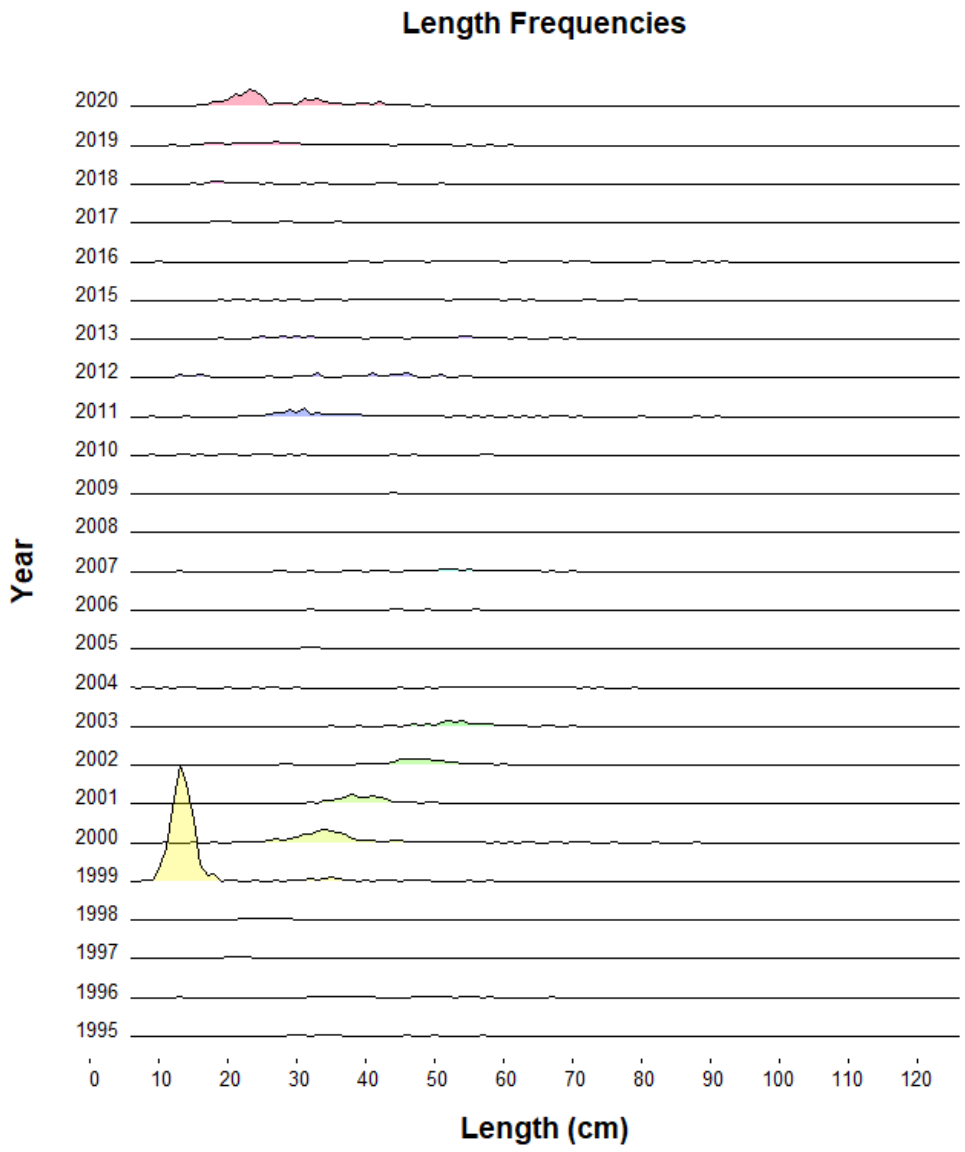


Figure 8a. Length frequencies (in cm) of White Hakes from Canadian Campelen autumn research surveys in Divs. 3NO, 1995-2020.

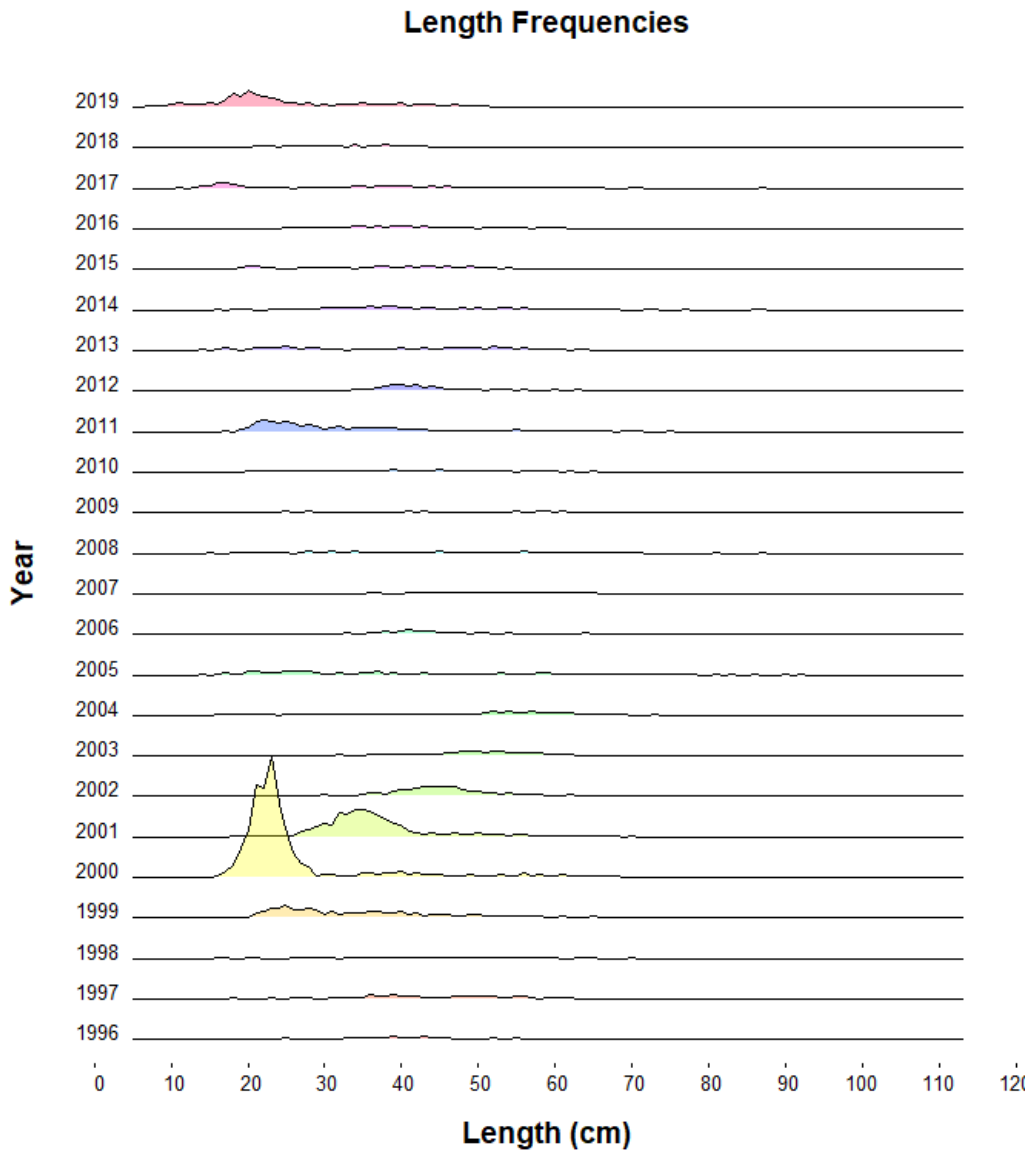


Figure 8b. Length frequencies (in cm) of White Hakes from Canadian Campelen spring research surveys in Divs. 3NO, and Subdivision 3Ps, 1996-2019. Note that the survey in 2006 was incomplete, due to Canadian research vessels' mechanical difficulties. There was no spring survey in 2020, due to COVID-19.

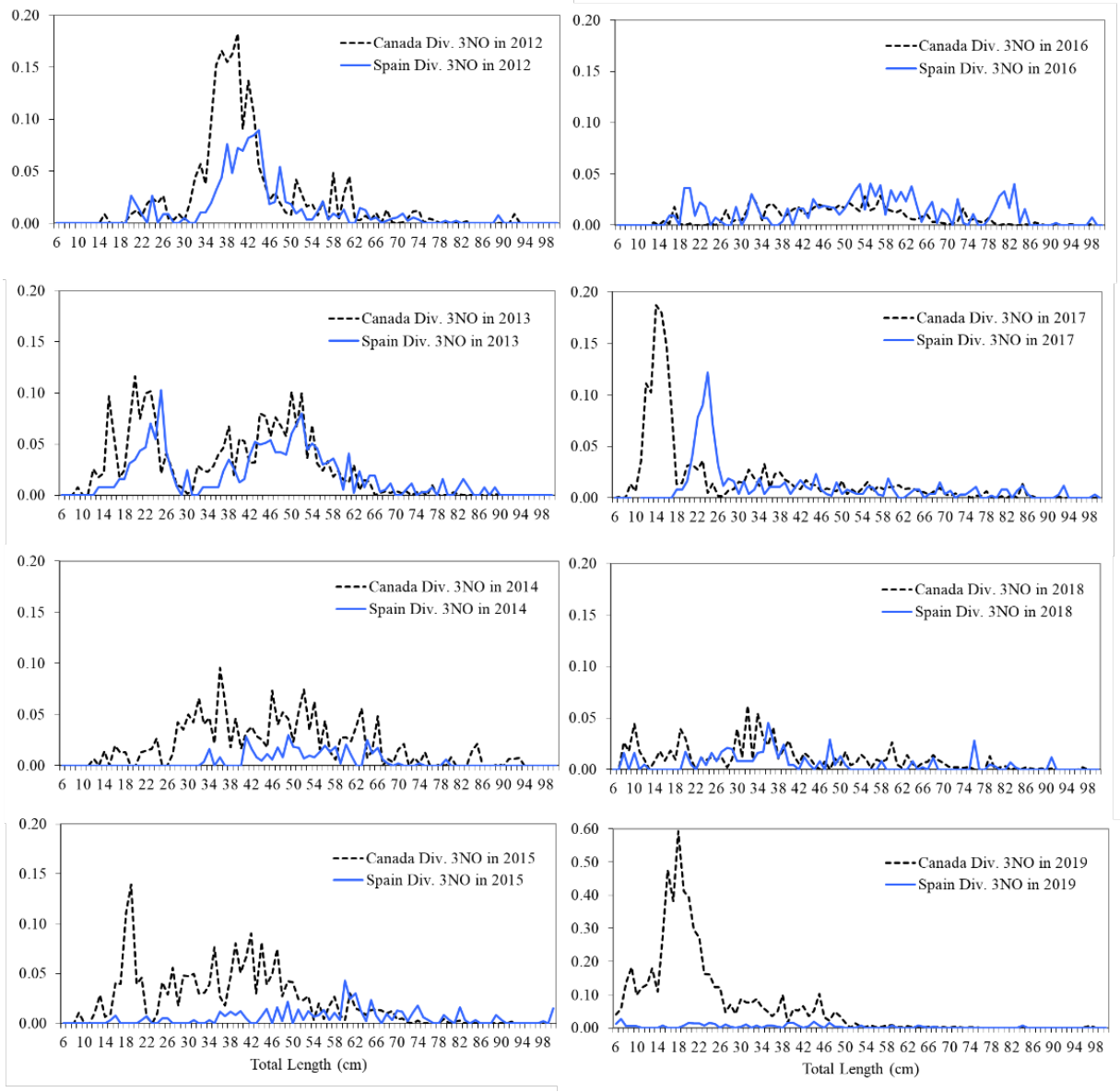


Figure 9. Abundance at length from Canadian Campelen and EU-Spain Campelen spring research surveys in Divs. 3NO (EU-Spain surveys limited to NRA), 2009-2019. Note that Y-axis values for 2019 are triple those for 2012-2018. There were no spring surveys in 2020, due to COVID-19.

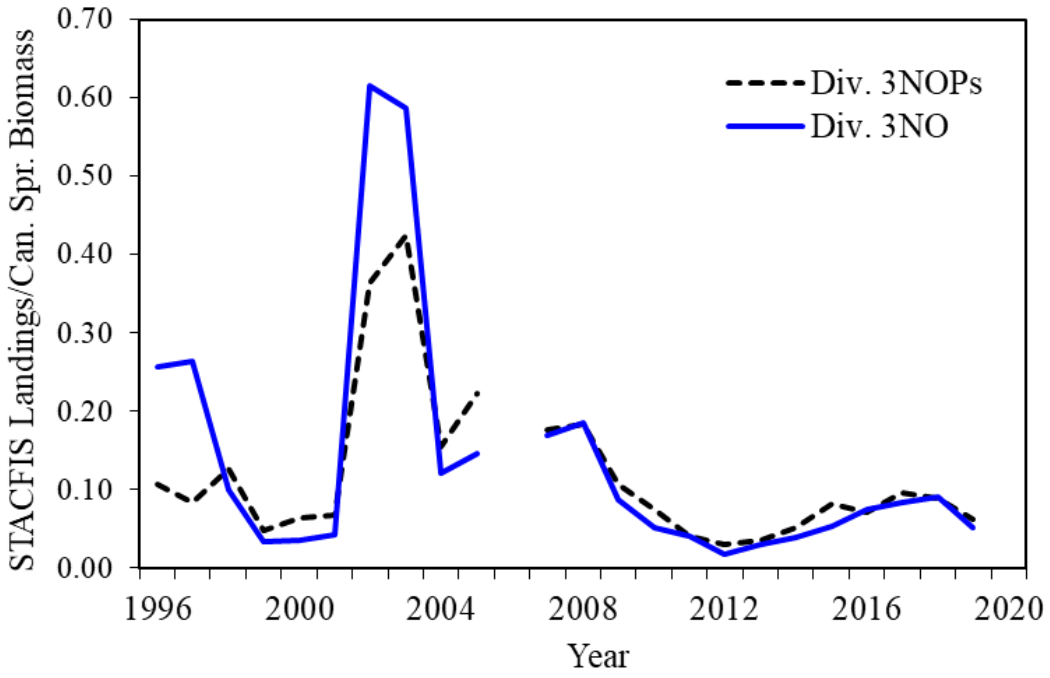


Figure 10. Relative F index (= STACFIS commercial landings/Canadian Campelen spring survey biomass) for White Hake in Divs. 3NO and Divs. 3NOPs, 1996-2019. Note that the survey in 2006 was incomplete, due to Canadian research vessels' mechanical difficulties. There was no survey in 2020, due to COVID-19.

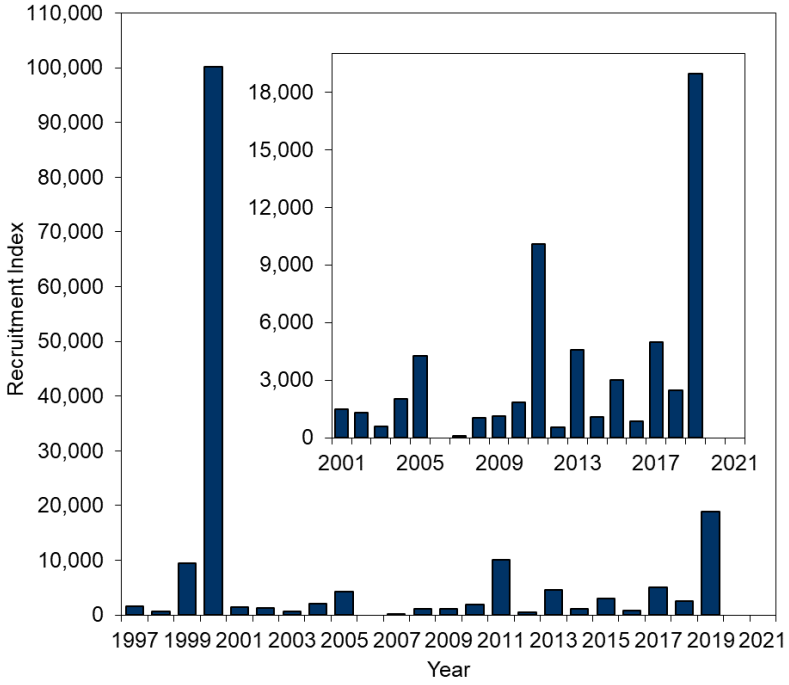


Figure 11. White Hake recruitment index for Age 1 males and females (combined) from Canadian Campelen spring surveys in Divs. 3NO and Subdiv. 3Ps, 1997-2019. Inset plot depicts 2001-2019 on a smaller scale. Note that the survey in 2006 was incomplete, due to Canadian research vessels' mechanical difficulties. There was no survey in 2020, due to COVID-19.

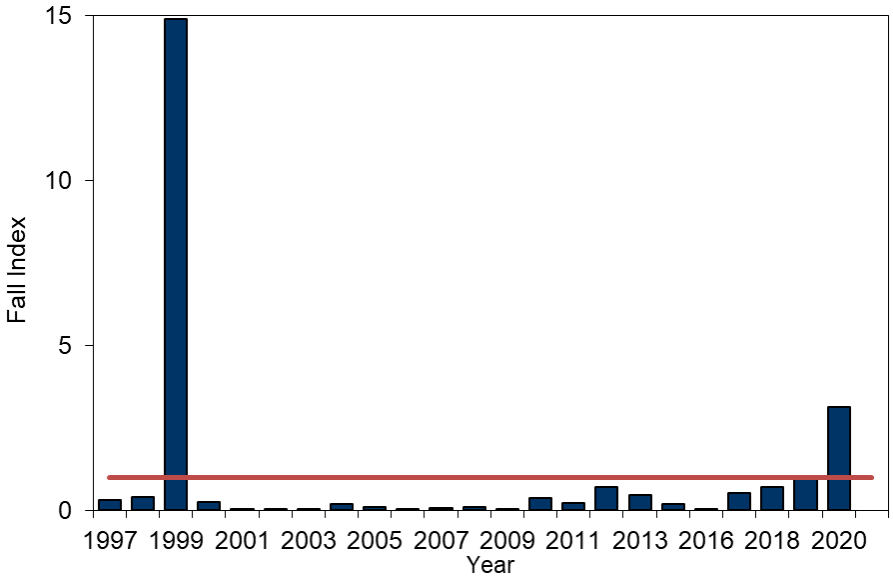


Figure 12. Standardized fall index of young-of-the-year White Hakes ≤26 cm (total length) from Canadian Campelen autumn surveys in Divs. 3NO, 1997-2020. Red horizontal line depicts the average of the index over the time series.

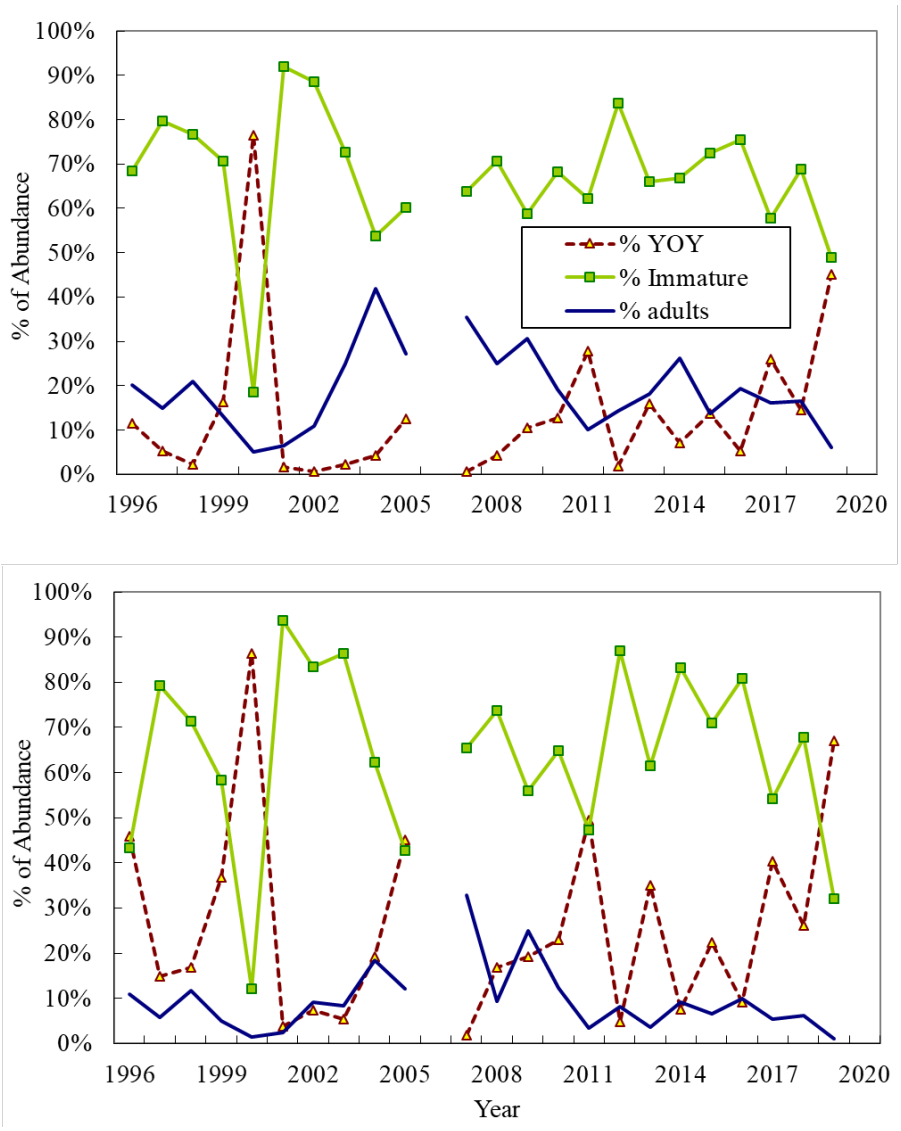


Figure 13. White Hake in Divs. 3NO and Subdiv. 3Ps: proportion of relative abundance of YOY (1-year-olds), immatures (juveniles Age 2+ years), and adults by sex (upper panel: female; lower panel: male) from Canadian Campelen spring surveys in 1996-2019. Note that the survey in 2006 was incomplete, due to Canadian research vessels' mechanical difficulties. There was no survey in 2020, due to COVID-19.

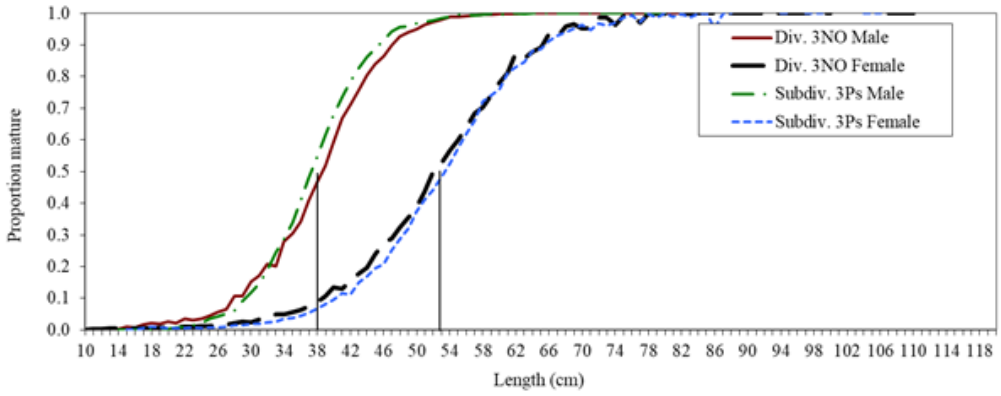


Figure 14. White Hake in Div. 3NO and Subdiv. 3Ps: Maturity ogives calculated for each sex from Canadian Campelen spring surveys and averaged over 1996-2019 (excluding 2006). Note that the survey in 2006 was incomplete, due to Canadian research vessels' mechanical difficulties. There was no survey in 2020, due to COVID-19.

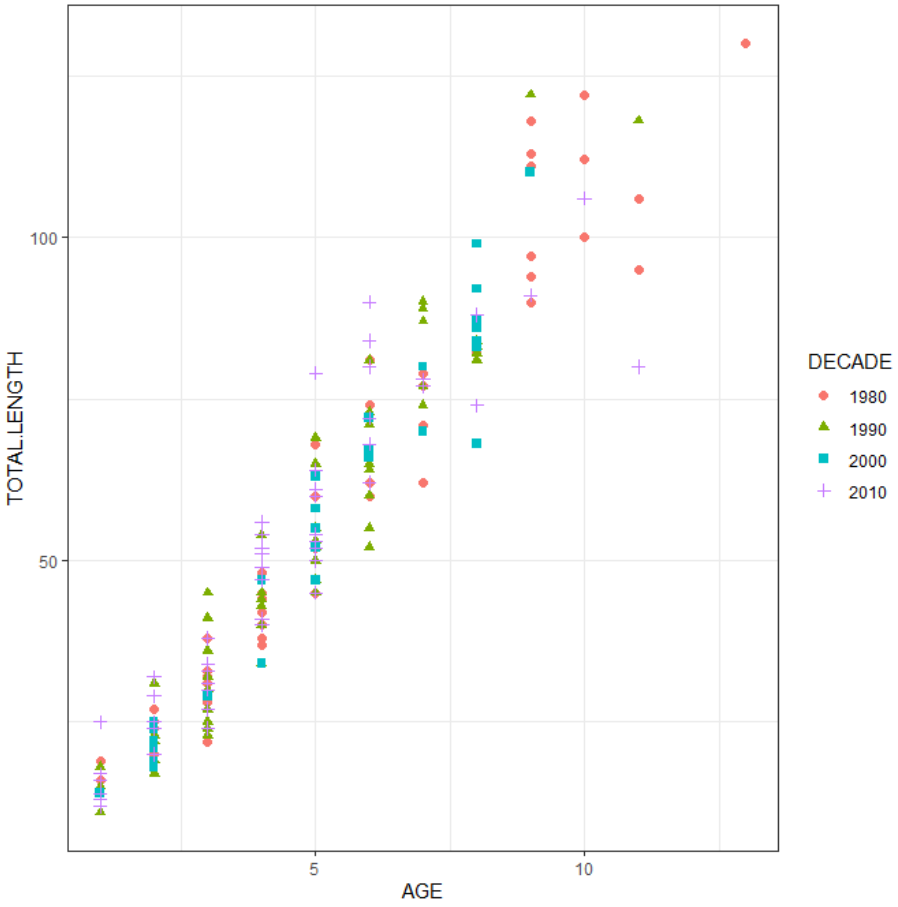


Figure 15. White Hake age-length plot representing 192 fish with verified ages of 1-13 years and total lengths of 11-130 cm.

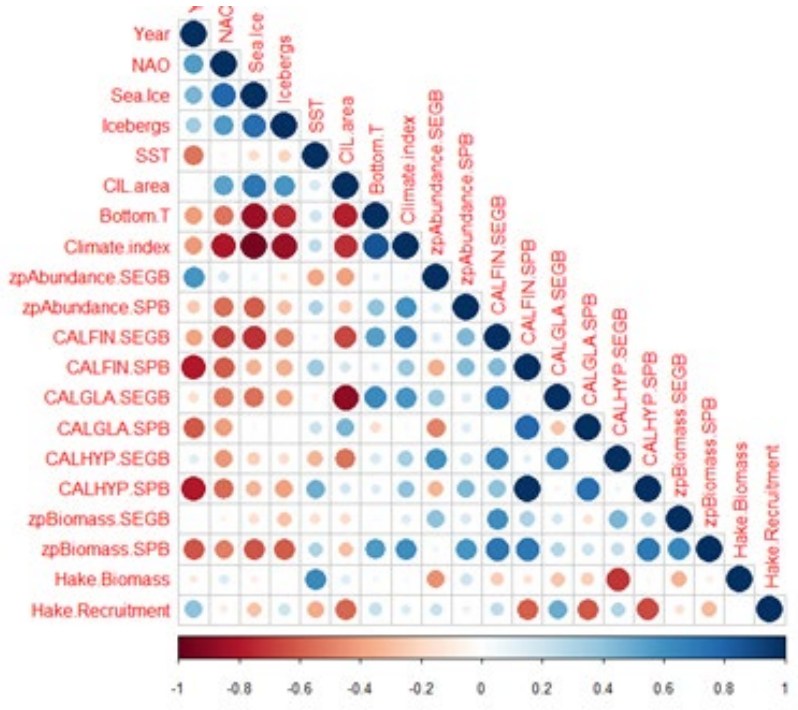


Figure 16. Correlation matrix of environmental and biological indices relative to White Hake biomass and recruitment.

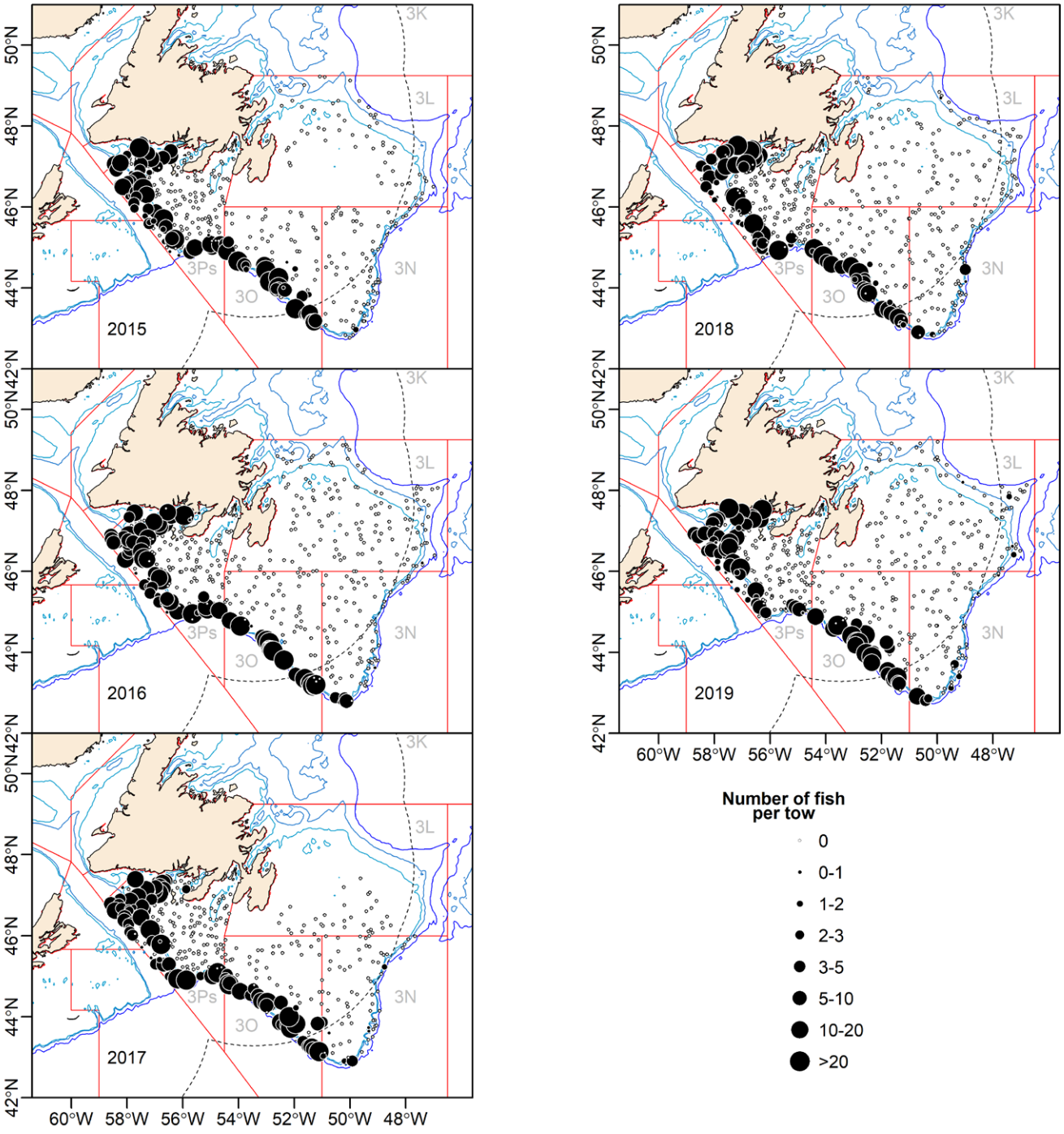


Figure 17. Distribution of White Hake mean numbers per tow in Divs. 3NO and Subdiv. 3Ps, based on Canadian spring research surveys in 2015-2019. There was no spring survey in 2020, due to COVID-19.

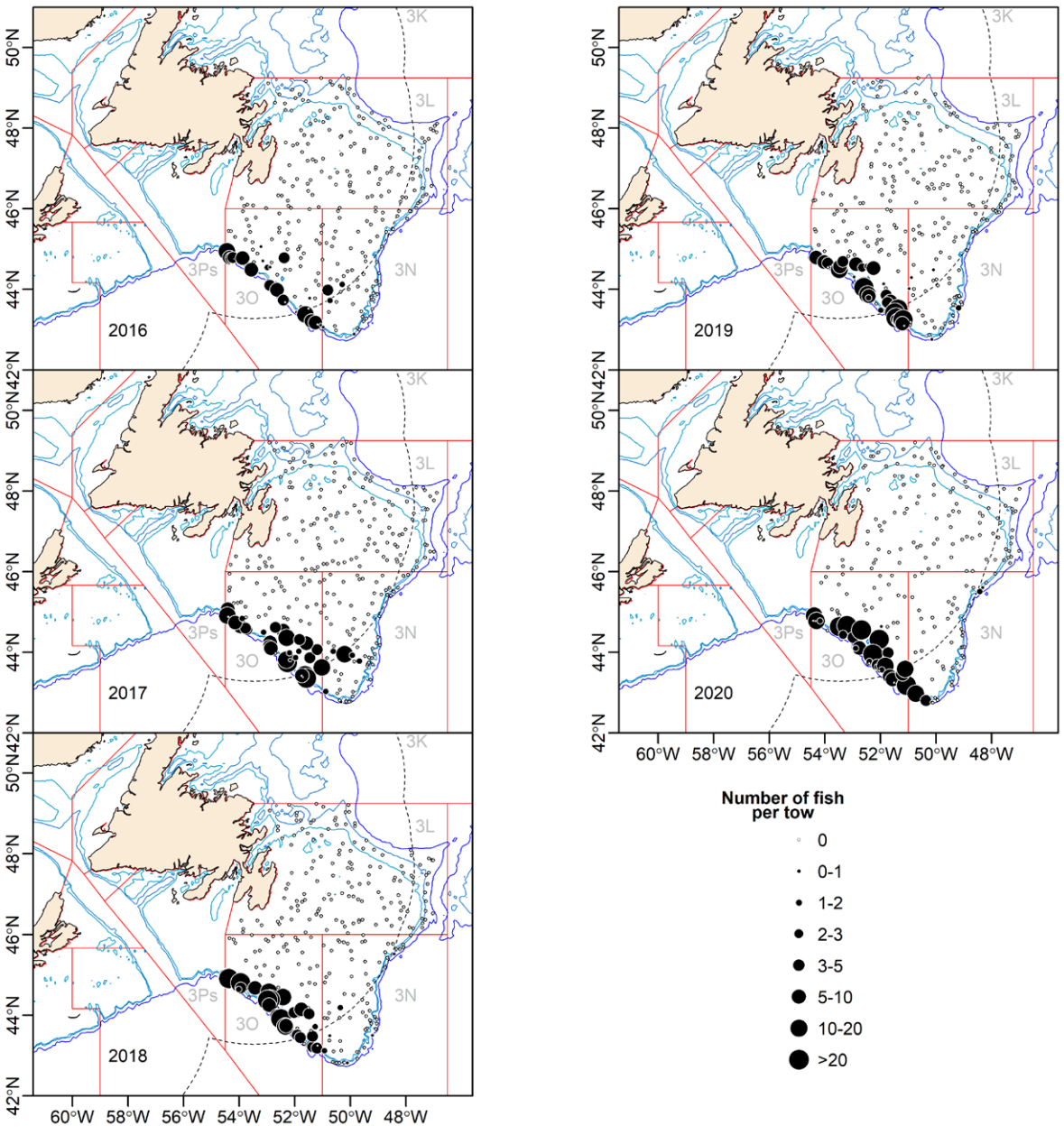


Figure 18. Distribution of White Hake mean numbers per tow in Divs. 3NO based on Canadian autumn research surveys in 2016-2020.

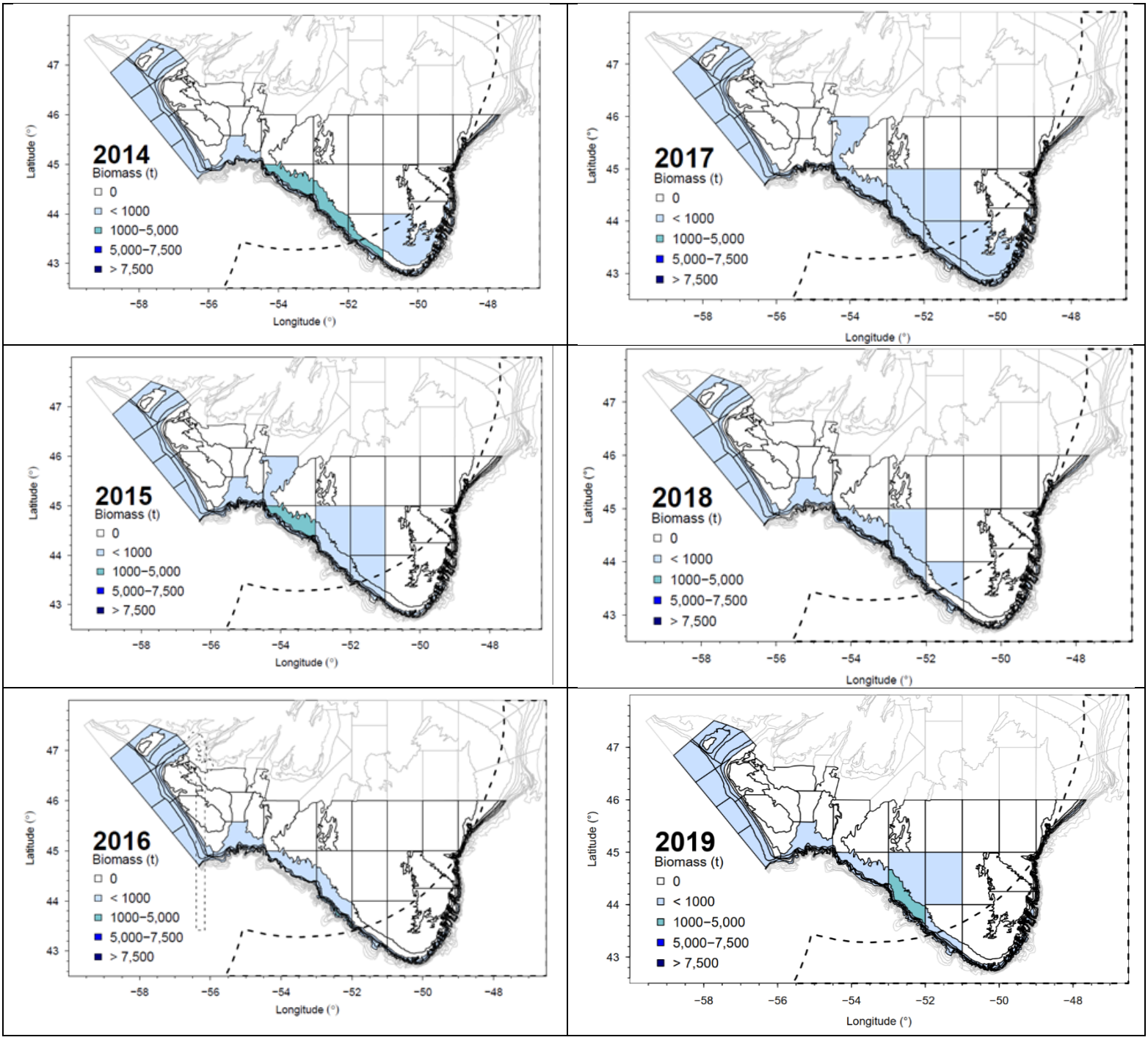


Figure 19. Distribution of White Hake stratified biomass (in tonnes) in Divs. 3NO and Subdiv. 3Ps, based on Canadian spring research surveys in 2014-2019. There was no survey in spring 2020, due to COVID-19.

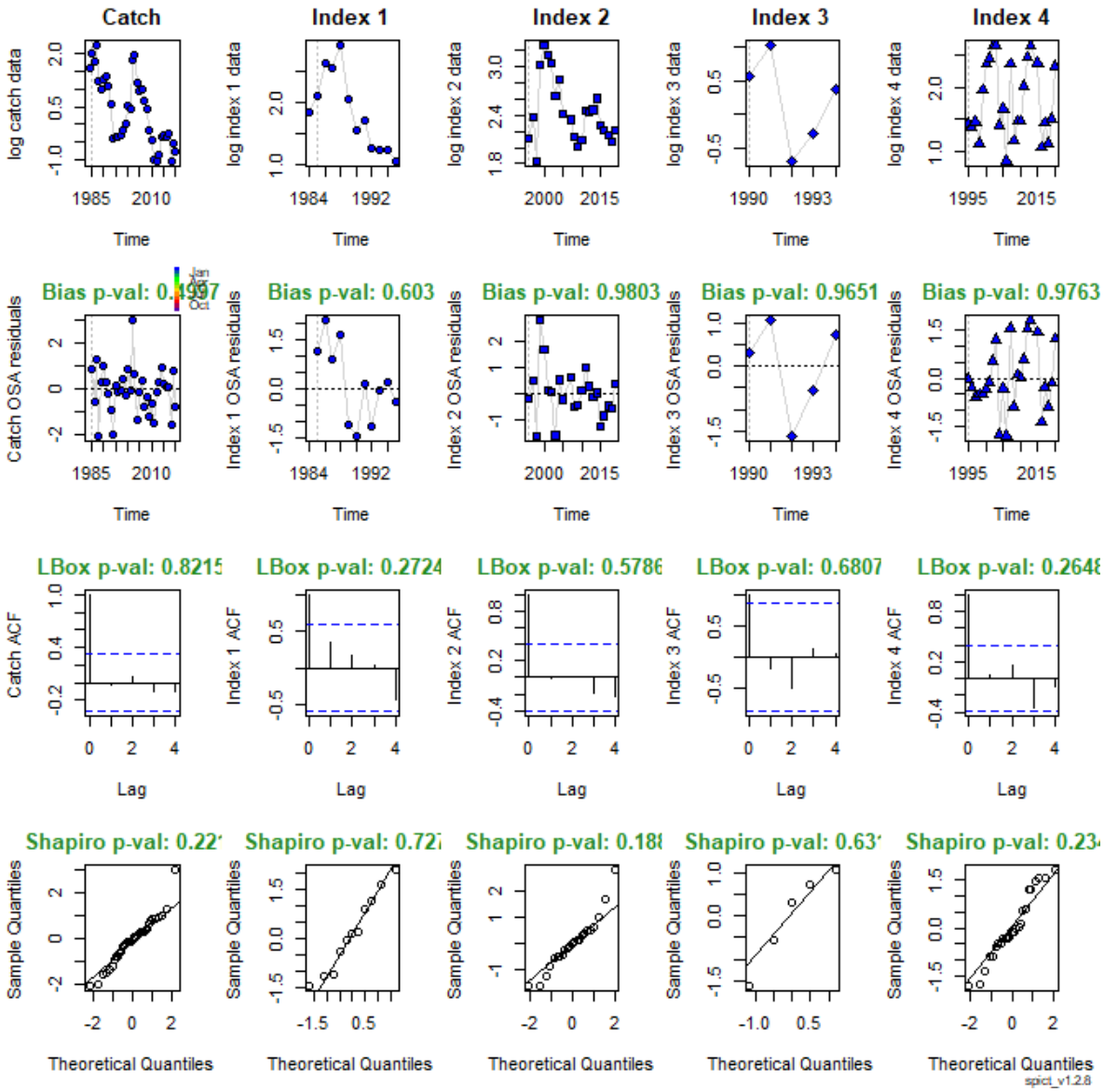


Figure 20. SPICT model diagnostics for Catch, spring Engel(Index 1), Spring Campelen(Index 2), Fall Engel(Index 3) and Fall Campelen(Index 4).

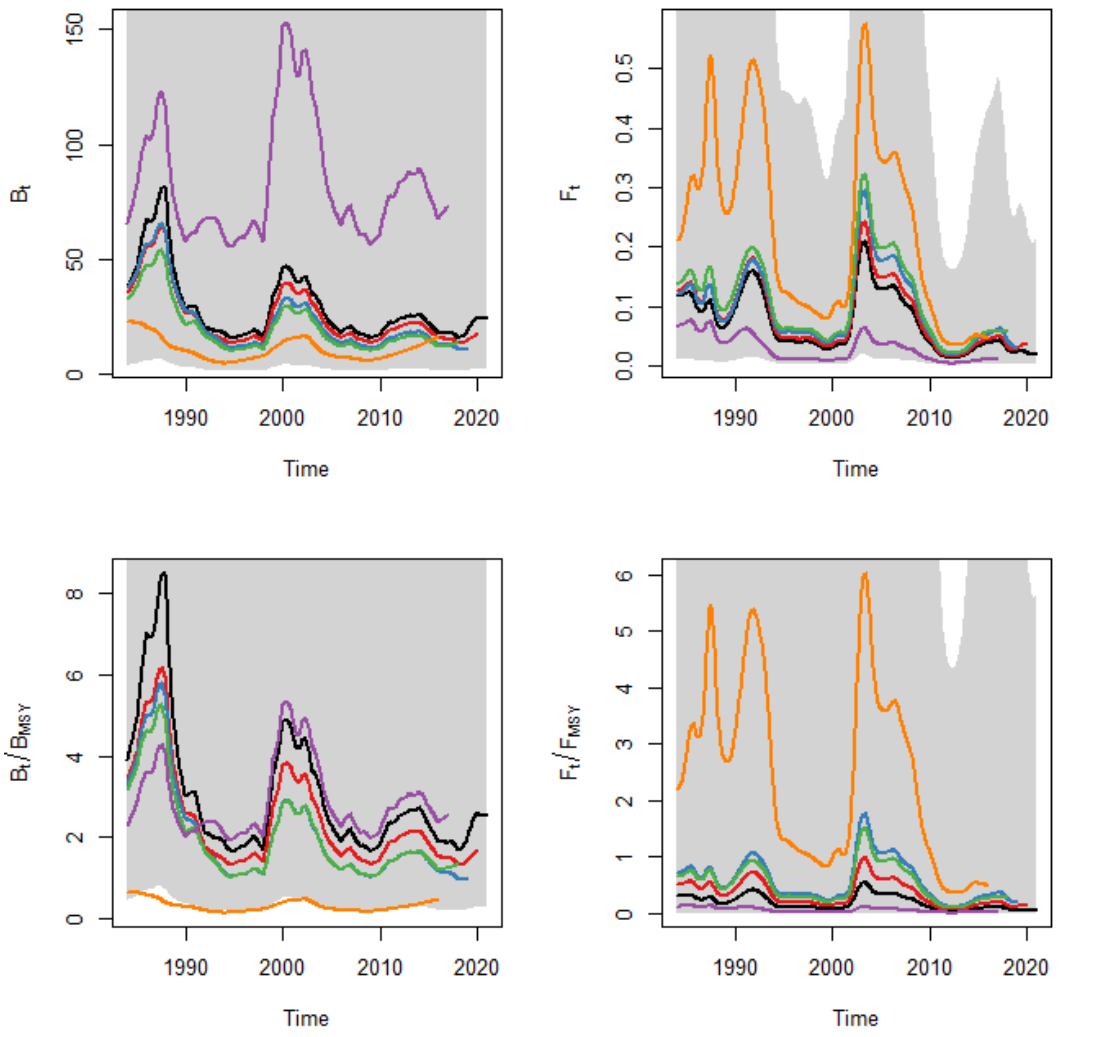


Figure 21. SPICT model retrospective output for Biomass(Top left), Fishing Mortality(Top right), relative biomass(Bottom left) and relative mortality(Bottom right).

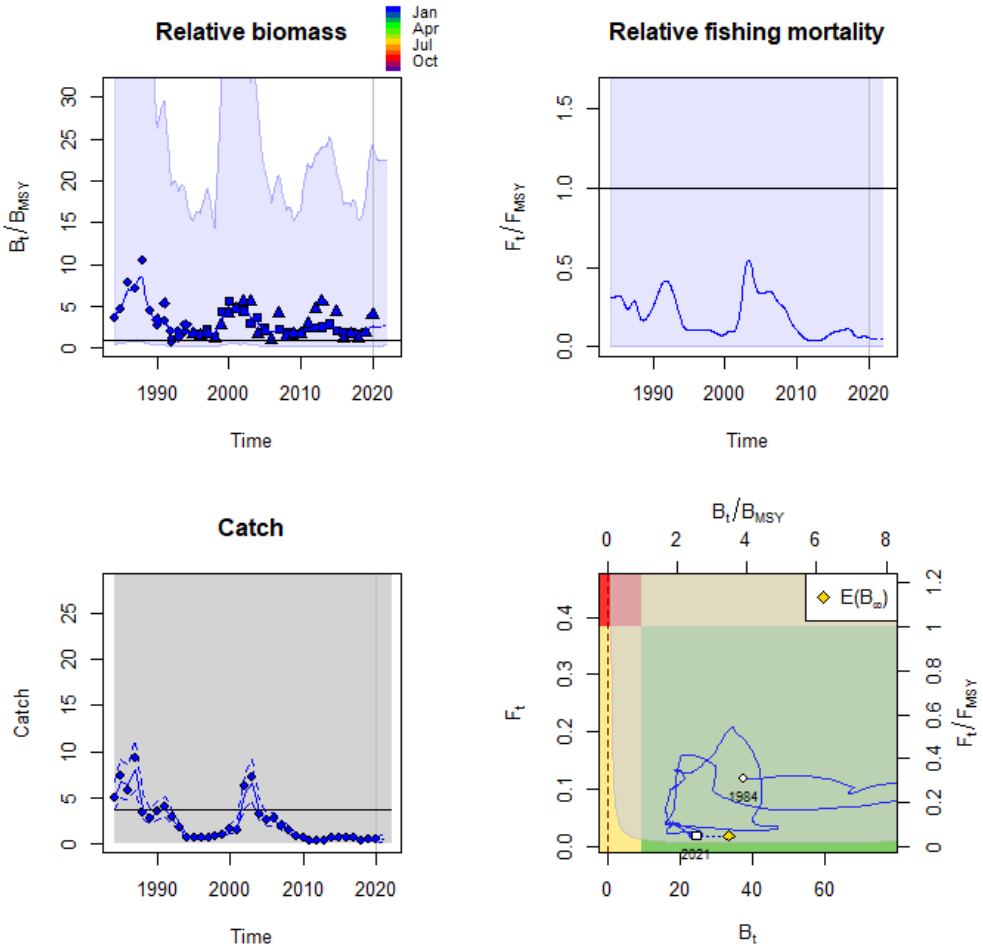


Figure 22. SPICT model output relative biomass(Top left) and relative mortality(Top right), Catch(Bottom left and Kobe plot(Bottom right).