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Southern Gulf of St. Lawrence, NAFO Division 4T, White Hake (*Urophycis tenuis*): Stock Assessment to 2022 and Rebuilding Plan Scientific Requirements

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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

The White Hake (*Urophycis tenuis*) stock in the southern Gulf of St. Lawrence (sGSL) is below its limit reference point (LRP) and in the Critical Zone of the Precautionary Approach (PA). The new Fish Stocks Provisions and the amended *Fisheries Act* legally require Fisheries and Oceans Canada (DFO) to develop a rebuilding plan for this stock. The sGSL stock assessment was updated using data up to 2022. The spawning stock biomass (SSB) in 2022 was 6.1 kilotonnes and the stock was in the Critical Zone of the PA. Fishing mortality of sGSL Hake ages 6+ has been below 0.02 since 2018. A review of the biomass reference points generated a new LRP based on a proxy for B_{MSY} using the statistical catch-at-age model. With this new LRP, the stock is now estimated to have declined into the Critical Zone in 1992. Upper Stock and Target Reference points based on the proxy for B_{MSY} were also calculated. In addition to the stock having a 75% probability of being at or above the LRP, the rebuilding target should include that the stock must be at or above this level for 5 consecutive years, and population projections must show the stock is likely to continue its positive trajectory under harvest for 5 years after the rebuilt state has been achieved. Population projections showed that the stock is unlikely to rebuild to the rebuilding target under prevailing conditions, even in the absence of fishing mortality. For the stock to rebuild, simulations showed that important reductions in natural mortality where necessary. Simulations also showed that the stock is highly vulnerable to declines in recruitment rates. Projections showed that at 100 tonnes (t) and 1,000 t of bycatch, SSB in 10 years would be reduced by 3.3% and 17.6% compared to no fishing, respectively. Preliminary analyses suggests the stock structure should be further investigated as Hake life history parameters in the St. Lawrence Estuary are more similar to Hake outside the sGSL. Additional measurable objectives for the rebuilding plan should include to increase the proportion of larger Hake and Hake aged 5+ to averages observed historically, to observe a return of Hake to their inshore spawning grounds, as well as an overall return of Hake to the inshore waters of the sGSL during the summer where they were historically distributed, to maintain the high recruitment observed in recent years and making enhanced efforts to understand the causes of the current high recruitment rates and how to promote it until the age structure has recovered, and finally to monitor discards and bycatch in fisheries intercepting White Hake more closely. Rebuilding progress will be tracked using the interim indicator derived from an annual survey and from stock assessment models. The periodic review of the rebuilding plan should be set to the 5-year stock assessment cycle with an interim update at the halfway point.

1. INTRODUCTION

White Hake (*Urophycis tenuis*) was historically a commercially important groundfish in the southern Gulf of St. Lawrence (sGSL), ranking third or fourth in terms of annual landings. However, the directed fishery for White Hake was closed in 1995 due to low abundance, and its fishery has remained been under moratorium since. The management unit for the sGSL White Hake consists of the Northwest Atlantic Fisheries Organization (NAFO) Division 4T and the northern portion of Subdivision 4Vn (COSEWIC 2013; Figure 1.1). White Hake in the sGSL are genetically distinct from White Hake in other areas of Atlantic Canada (Roy et al. 2012), and a recent genetic study suggests that at least two Hake genetic populations co-exist in the sGSL (Sylvain, F.-E., Pers. comm.). In 2013, the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed the status of sGSL Designatable Unit as Endangered, whereas the Atlantic and Northern Gulf of St. Lawrence Designatable Unit was assessed as Threatened (COSEWIC 2013).

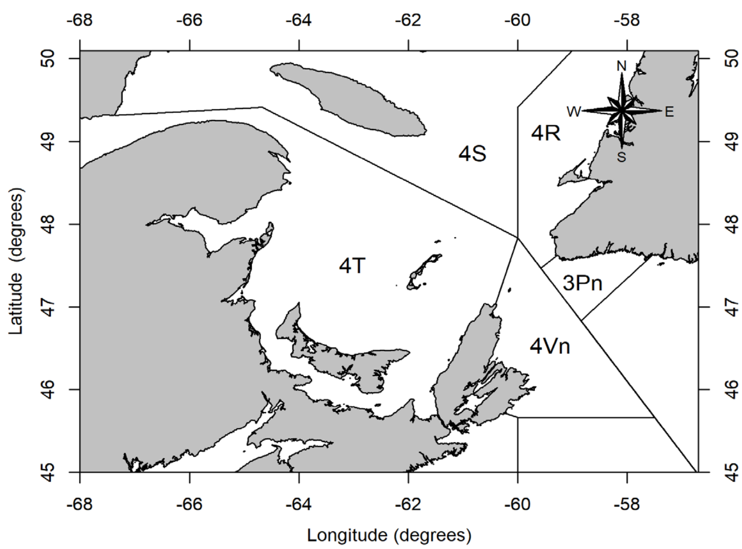

Figure 1.1: NAFO Divisions in the area of the Gulf of St. Lawrence. Unit areas are indicated for Division 4T.

As in previous assessments, it is assumed that the stock status and recovery potential of sGSL White Hake can be assessed based on analysis of the 4T management unit (Swain et al. 2016). The last update of the assessment of sGSL White Hake reported that the spawning stock biomass (SSB) had remained under the limit reference point (LRP) up to 2019, the stock assessment terminal year (Rolland et al. 2022a). Under the Fish Stocks Provisions s.6.2 in the amended Fisheries Act (2019) and amended Fishery General Regulations, a rebuilding plan for a prescribed major fish stock must be developed within 24 months of the day on which the Minister first has knowledge the stock has declined to or below its LRP. If a stock is already at or below its LRP when it is prescribed under the Fish Stocks Provisions, the 24-month timeline to develop a rebuilding plan for the stock starts the day the stock is prescribed in regulation, which occurred April 4 2022 for sGSL designatable unit White Hake (Hake hereafter).

The specific objectives of this document are i) to update commercial fishery landings, survey indices, population model inputs and results to 2022. ii) to review and update the current LRP and establish the stock status with respect to the recommended LRP, iii) to provide advice on the selection of a rebuilding target, iv) to calculate and evaluate the likelihood of achieving the rebuilding target in a specified timeline under various productivity and fishery management scenarios, v) to propose additional measurable objectives, vi) to identify indicators for tracking rebuilding progress, and vii) to provide guidance on the frequency of the periodic review of the rebuilding plan.

2. THE FISHERY

2.1. LANDINGS IN COMMERCIAL FISHERIES IN THE 4T MANAGEMENT AREA

Landings fluctuated between about 4,000 and 7,000 tonnes (t) between 1961 and 1978 (Table A1, Figure 2.1). Landings then rose sharply to a peak of 14,000 t in 1981, followed by a rapid decline to an average of 5,000 t from 1985-1992. The White Hake fishery was not managed by a TAC (Total Allowable Catch) until a precautionary quota of 12,000 t was established for the 1982 fishery. The TAC was subsequently reduced to 9,400 t in 1987, 5,500 t in 1988, 3,600 t in 1993, and 2,000 t in 1994. Following consultations with industry in 1994, the Fisheries Resource Conservation Council recommended that “there be no directed fishing for NAFO Div. 4T White Hake in 1995, and that bycatches be kept to the lowest possible level”. In response to these recommendations, the fishery for White Hake in NAFO Div. 4T was closed in January 1995, and has remained under moratorium since then. With the closure of directed Hake fishing, reported landings dropped from 1042 t in 1994 to 71 t in 1995, but then increased steadily to 400 t in 1999. Since then, reported annual landings declined to a level near 30 t in 2006-2016 and 15-20 t.

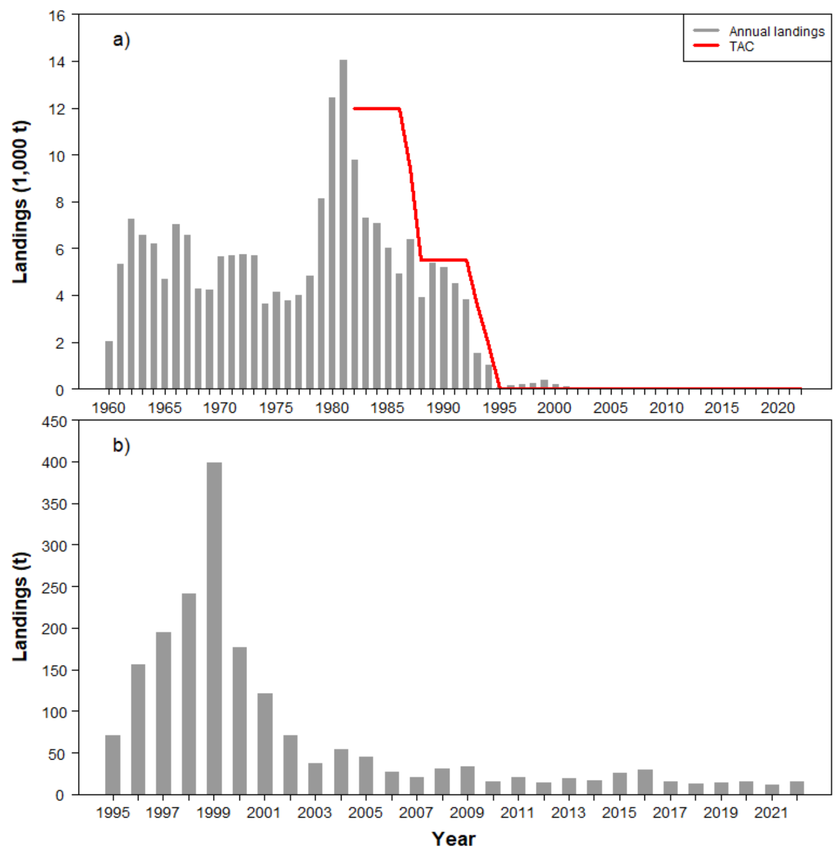

Figure 2.1: Landings and total allowable catch (TAC) for White Hake in NAFO Division 4T, 1960 to 2022 (upper panel a), landings in thousands of tons) and the bottom panel (b), landings in tons shows the landings of White Hake following the moratorium in 1995.

Prior to the moratorium, the Hake fishery was carried out mainly by small inshore vessels using both fixed and mobile gears, with each of the two gear types accounting for about 50% of the landings (Figure 2.2). For most of the time period since the moratorium, landings were predominantly from eastern regions of the sGSL, in unit areas 4Tf and 4Tg (Figure 2.2). Until recently, landings were predominantly from shallow inshore waters in 4Tg, in particular St. Georges Bay.

The importance of 4Tf has increased since the early 2000s, with most (> 70%) of landings coming from this area in 2010 to 2017. Regions of the western sGSL, in particular 4Tl, were also a source of landings prior to the moratorium but are now of negligible importance. Landings from areas of 4T west of the Magdalen Shallows (4Topq) were negligible prior to the moratorium, accounting for less than 1% of landings on average. The importance of unit areas 4Topq has recently increased to almost 50% of landings in years 2018 to 2022. Until recently, landings predominantly occurred in July to September while they now predominantly occur in June and July (Figure 2.2).

Since the closure of the directed fishery, the majority of White Hake have come from trips where White Hake, Atlantic Cod (*Gadus morhua*), Redfish (*Sebastes spp.*), Greenland Halibut (*Reinhardtius hippoglossoides*), and Atlantic Halibut (*Hippoglossus hippoglossus)* were the main species caught (bottom panel of Figure 2.3). "White Hake" trips were the most important source of White Hake landings from the mid-1990s to the early 2000s, Atlantic Cod and Witch Flounder (*Glyptocephalus cynoglossus*) trips the most important source in the mid-2000s and Redfish and Greenland Halibut trips the most important source since the late 2000s. In the last five years, the majority of White Hake catches have come from the Greenland Halibut, Redfish and Atlantic Halibut fisheries.

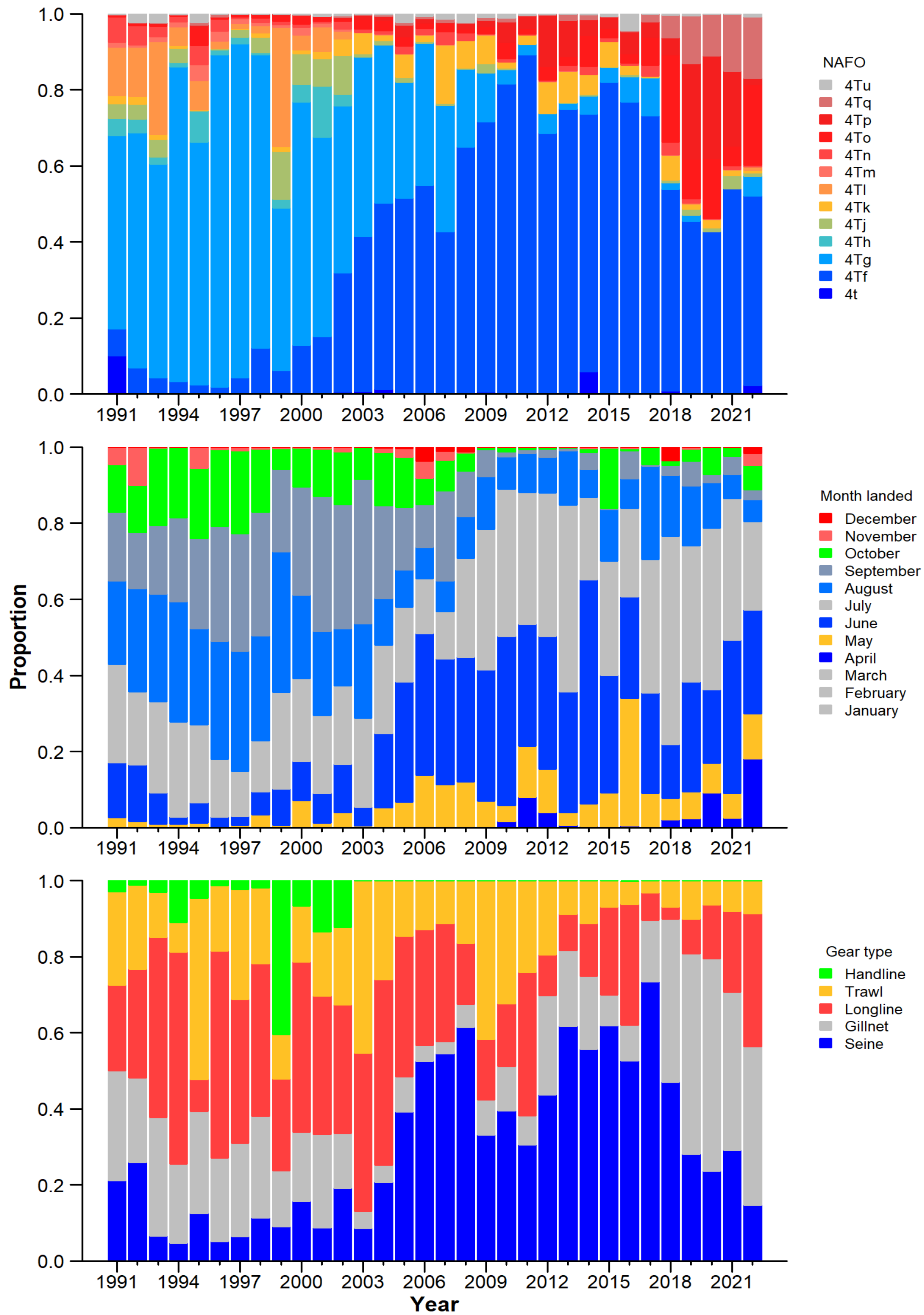

Figure 2.2: Proportion of annual White Hake landings in NAFO Divisions 4T by NAFO subdivision (top panel), by month (middle panel) and by type of fishing gear (lower panel), 1991 to 2022.

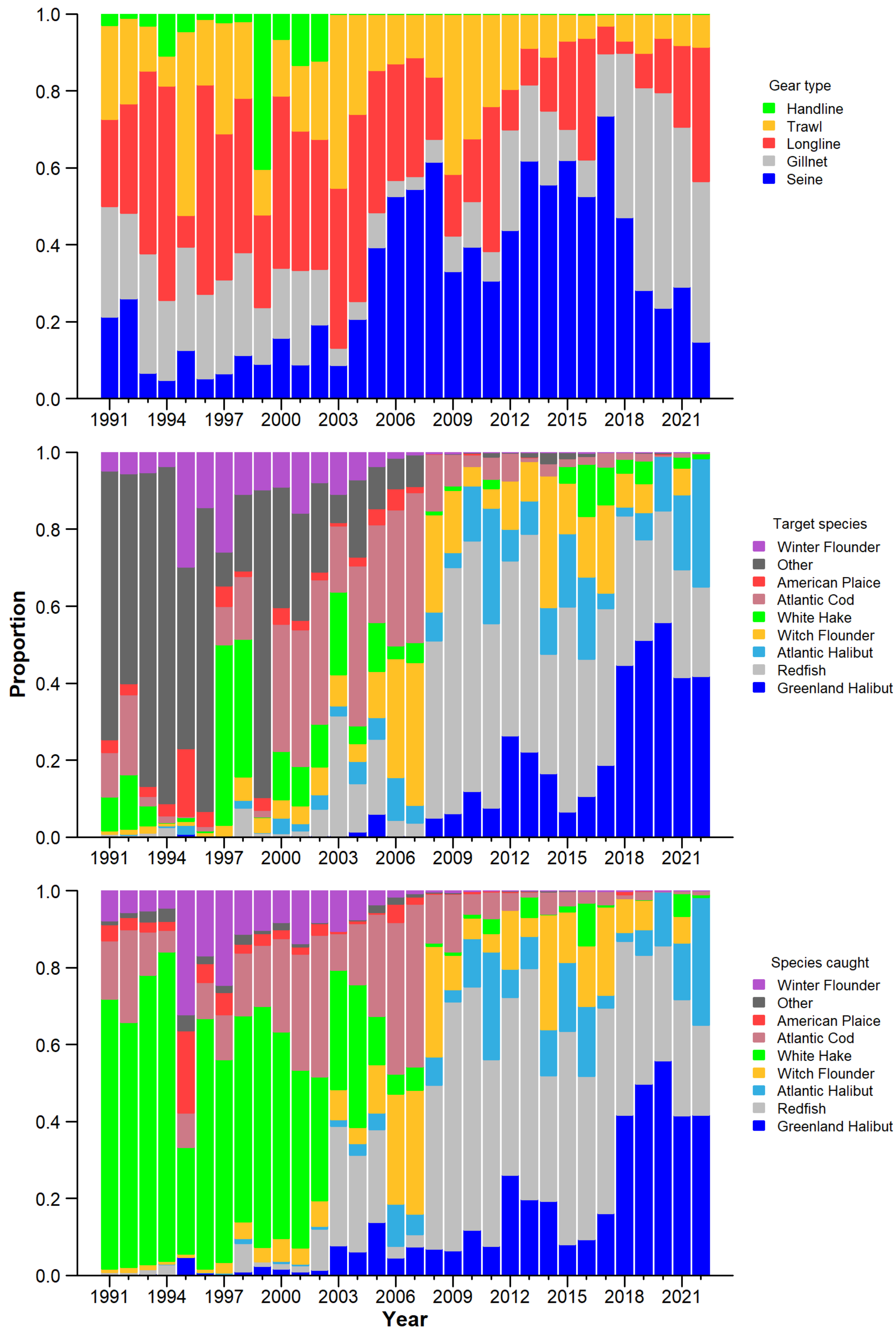

Figure 2.3: Proportion of annual White Hake landings in NAFO Divisions 4T by type of fishing gear (top panel), by target fishing species (middle panel), and by main fishing species caught (lower panel), 1991 to 2022.

2.2. RECREATIONAL FISHERY

A recreational fishery for groundfish remains open in 4T. Fishing is by angling or handline during a five-week season. Timing of the fishery is variable, with the season as early as July 12-August 17 in some areas and as late as August 30 to October 5 on PEI. No licenses are required for this fishery but there is a daily bag limit of 5 cod and/or White Hake. Landings by this fishery are unknown, but based on anecdotal information the estimated catch in St. Georges Bay (the area where Hake densities are highest in the inshore) is 500 kg (0.5 t) per year. There is also a groundfish charter-boat fishery in 4T with 5% observer coverage. No catches of White Hake have been reported for this fishery.

2.3. MANAGEMENT MEASURES

Since the closure of the directed fishery for White Hake, there has been a 30 t quota for bycatch in commercial fisheries, and catch in the recreational, scientific, and aboriginal fisheries in 4T. There is also a bycatch cap of 90 t for the fishery in 4Vn. A variety of management measures have been implemented to minimize the bycatch of White Hake. In the 4T management zone, the maximum allowable bycatch of White Hake is 15% of target species catch weight by fishing trip for Redfish and 10% for other species.

In addition to bycatch limits, a small fish protocol is enforced. The groundfish fishery is closed if small fish (i.e., fish < 45 cm in length) exceed 15% of the catch in numbers. To further minimize the bycatch of White Hake, restrictive fishing seasons for both the fixed and mobile gear sectors directed at other species have been implemented. The purpose of this management measure was to permit the spring Hake migration into inshore areas to be completed before opening the area to groundfish fishing activity. The fishing season for mobile gears in the eastern portion of the Northumberland Strait was adjusted to open on July 15 to allow Hake to spawn prior to any fishing activity. Furthermore, aside from sentinel fishing activity, there has not been a longline fishery in St. George's Bay since the establishment of the moratorium. An additional conservation measure enacted in 1995 to protect White Hake during their annual migration to and from over-wintering areas outside Div. 4T was the closure of directed fishing for White Hake in NAFO Div's./Sub-Div's. 4RS, 3Pn and 4Vn, from January to April. At present, no directed fisheries for White Hake are permitted in NAFO 4VWX5 at any time of the year.

2.4. LANDINGS IN 4VN

Although the population modelling for this assessment incorporates only the fishery and survey catches in the 4T area, the geographic area attributed to the sGSL DU includes a small region outside of this area, the northwest portion of NAFO Subdivision 4Vn (Roy et al. 2012; their Figure 3a). Landings in 4Vn were a small fraction of those in 4T prior to the moratorium on directed fishing but have been similar in magnitude to 4T catches since about 2000 (Table A3). Given the spatial distribution of the catches in 4Vn, more than half of the 4Vn catch is likely to be of fish in the sGSL DU. However, catches in 4Vn were a small fraction of total catches from the DU prior to the closure of the directed fishery and total catches including those from 4Vn have been very low since the moratorium in 1995. Hence, the effect of omitting 4Vn catches from population models, as in previous assessments, is expected to be small.

2.5. FISHERY CATCH-AT-AGE

The fishery catch-at-age, as well as mean lengths and weights at age in the landings, were updated from 2019 to 2022. Length frequencies of Hake caught by commercial fishing gear (trawl, seine, gillnet, longline) were obtained from years 2010 to 2019 and from port sampling and/or observers at sea programs, where available. The annual gear specific length-frequencies were weighted by annual landings by gear to produce annual length frequencies. The age-length keys used to update the catch-at-age were from the pooled years 2010 to 2014 RV survey data. Figure 2.4 shows the standardized proportions by age across years for ages 3 to 10 and years 1978 to 2022. The proportion of fish age 7+ in the catch steadily declined over the time series. The catch in years 2019 to 2022 consisted mostly of 3 to 5 year olds.

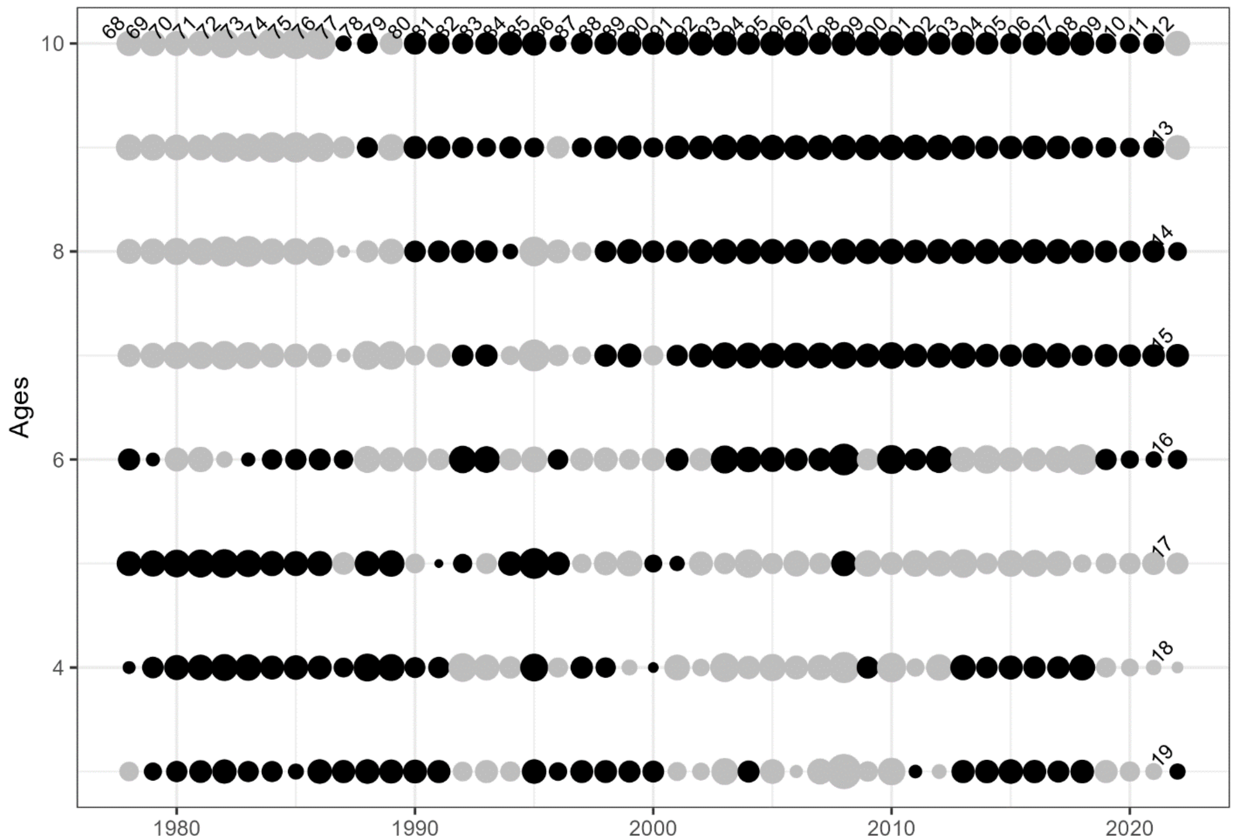

Figure 2.4: White Hake standardized proportions by age across years for ages 3 to 10 and years 1978 to 2022 from the commercial fishery.

3. SCIENTIFIC SURVEYS

3.1. RESEARCH VESSEL SURVEY

3.1.1. Methods

A multi-species bottom-trawl research vessel survey (RV) of the sGSL has been conducted each September since 1971 (for details see Hurlbut and Clay 1990 and Chadwick et al. 2007). This survey uses a stratified random design, with stratification based on depth and geographic region (Figure 3.1). A number of vessel and gear changes have occurred over the timespan of the survey (Figure 3.2), with *CCGS Teleost* using a Western IIA trawl being the reference survey platform for analyses. Conversion factors were applied to the September survey data so that all captures were adjusted to a standard 1.75 nautical miles daytime tow on *CCGS Teleost* using a Western IIA trawl. The conversion factors used are those estimated by Benoît and Swain 2003 and Benoît and Yin 2023.

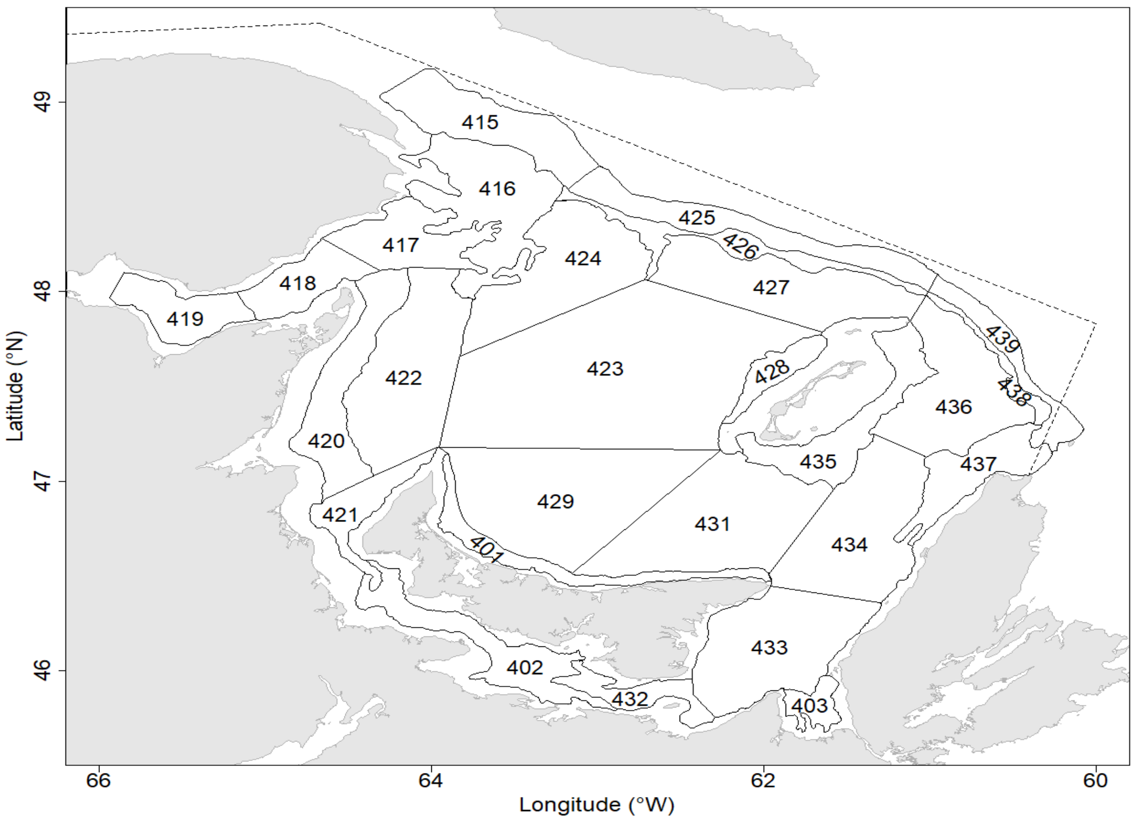

Figure 3.1: Stratification scheme used for the August sentinel and September research surveys of the southern Gulf of St. Lawrence.

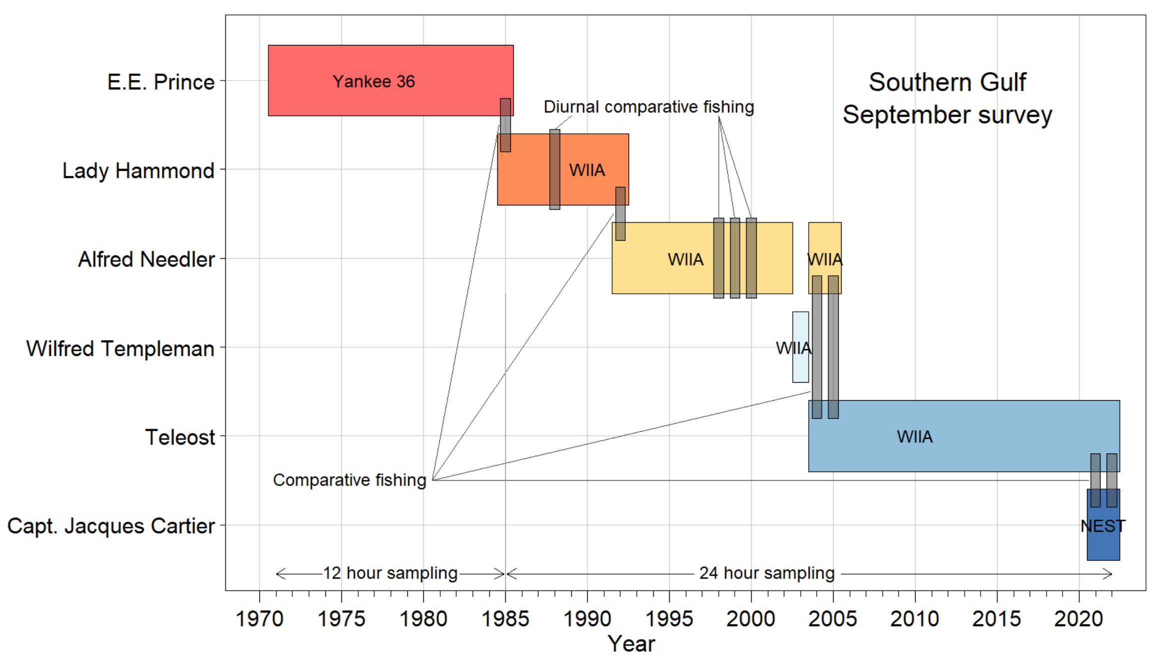

Figure 3.2: Timeline of the research vessels and gear types used in the southern Gulf of St. Lawrence survey. The x axis show years, the y axis shows the vessel names and the gear type used is written on each rectangle. Comparative fishing experiments are identified by gray polygons overlapping the survey platforms under comparison.

3.1.1.1. Abundance, distribution and inputs to the population model

Following Swain et al. 2012, fish 45 cm and longer and 4 years and older were considered mature in the construction of these indices. As such, indices for the 1971 to 2022 period are computed for strata 415 to 439, and are shown separately for juvenile and adult Hake.

Spatial interpolation of catch (kg/tow) was done using a weighting inversely proportional to the distance (inverse-distance weighted, IDW), using function "idw" of the gstat R package (Pebesma 2004; Gräler et al. 2016). To achieve a visually appropriate rendition of the available catch data, the IDW method uses a power parameter value of 10. The IDW predictions are over a fixed grid with a resolution of 200 by 200 on the bounding box of the georeferenced survey data. Distribution maps were generated for all individuals, and separately for juvenile and adult Hake.

These indices were calculated using the methods detailed in Swain and Sinclair 1994. Inputs to the population model from the RV survey are for years 1978 to 2022 (years 1971-1977 were excluded as 1978 is the first year with reliable fishery catch-at-age data). The abundance and biomass per tow for missing stratum-years were estimated from adjacent strata and the annual stratified means were then computed over strata 415-439. The details about the treatment of missing strata in the stratified calculations can be found in Appendix B. Coastal strata 401-403 were excluded as they were only added in 1984 to the RV survey coverage area. To obtain the annual mean trawlable abundance, the stratified mean abundance per tow was scaled by the number of trawlable units in the survey area.

The first input to the population model was annual proportions at age of the trawlable abundance for ages 2 to 7. Annual age length keys were derived for all years for which ageing data was available (1978, 1979 and 1981 to 2014). An age length key using data from years 1979 and 1981 was used for the year 1980. An age length key using data from 2010 to 2014 was used for years 2015 to 2022. The annual stratified mean trawlable abundance was then used to obtain annual stratified mean proportions at age of trawlable abundance.

The second input to the population model from the RV survey was the age aggregated trawlable biomass of ages 2 to 7. Annual mean weight-at-age vectors were calculated for all years for which ageing data was available (1978, 1979 and 1989 to 2014). Missing weight-at-age-year were predicted using a Gompertz growth model fit to age and weight data were a minimum of 3 observations were available for an age-year. The Gompertz growth function was as follows:

$$W_t = W_0\left[e^{G(1-e^{-}kt)}\right]$$

where W_t is weight at time t and W_0, G and k are model parameters. The annual stratified mean trawlable abundance and annual mean weight-at-age values were then used to obtain biomass at age. The third input to the population model from the RV survey was the weight-at-age matrix.

An index of condition, predicted weight at length, was calculated using annual estimates of the parameters of the length-weight relationship, obtained from individual measurements of length and weight made during the RV survey.

3.1.1.2. Diet

White Hake stomachs were collected in two sets of years; 2004 to 2006 and 2018 to 2020. Stomachs were thawed in the laboratory and the content was sorted and visually identified to the lowest possible taxonomic level (Darcy et al. 2024). For each stomach, prey were measured and weighed individually. Rare and small prey items such as algae and rocks were classified in the category "other". Fish remains that could not be identified were classified in the category "Unidentified teleostei remains". For each group of year (hereafter; periods), stomach contents were described by prey-specific percentage weight %W (weight of prey item/total weight of all prey items).

3.1.2. Results and discussion

3.1.2.1. Distribution

In September, White Hake are distributed in shallow inshore areas at depths less than 50 m and in deep water along the slope of the Laurentian Channel and in the Cape Breton Trough (Figure 3.3). However, distribution shifted out of inshore areas over the 1971 to 2010 period. In the 1970s and early 1980s, adult Hake tended to be most abundant in inshore areas (Figure 3.4). Abundance in inshore areas to the northwest of PEI declined in the 1990s, with Hake essentially absent from these waters in the 2000s. Abundance in eastern inshore areas began to decline in the late 1990s, with adult Hake nearly absent from the inshore in September by the end of the time series.

Unlike adults, juveniles were relatively rare in western regions of the inshore over the entire time period (Figure 3.5). In the 1970s, juveniles were distributed in eastern inshore areas and in deep water along the slope of the St. Lawrence Channel and in the Cape Breton Trough. Juvenile abundance was at a relatively high level in the 1980s and early 1990s, particularly in the Cape Breton Trough and in the inshore waters east of PEI. In the late 1990s and the 2000s, juvenile abundance declined in inshore waters but remained relatively high in the Cape Breton Trough and along the southern slope of the Laurentian Channel.

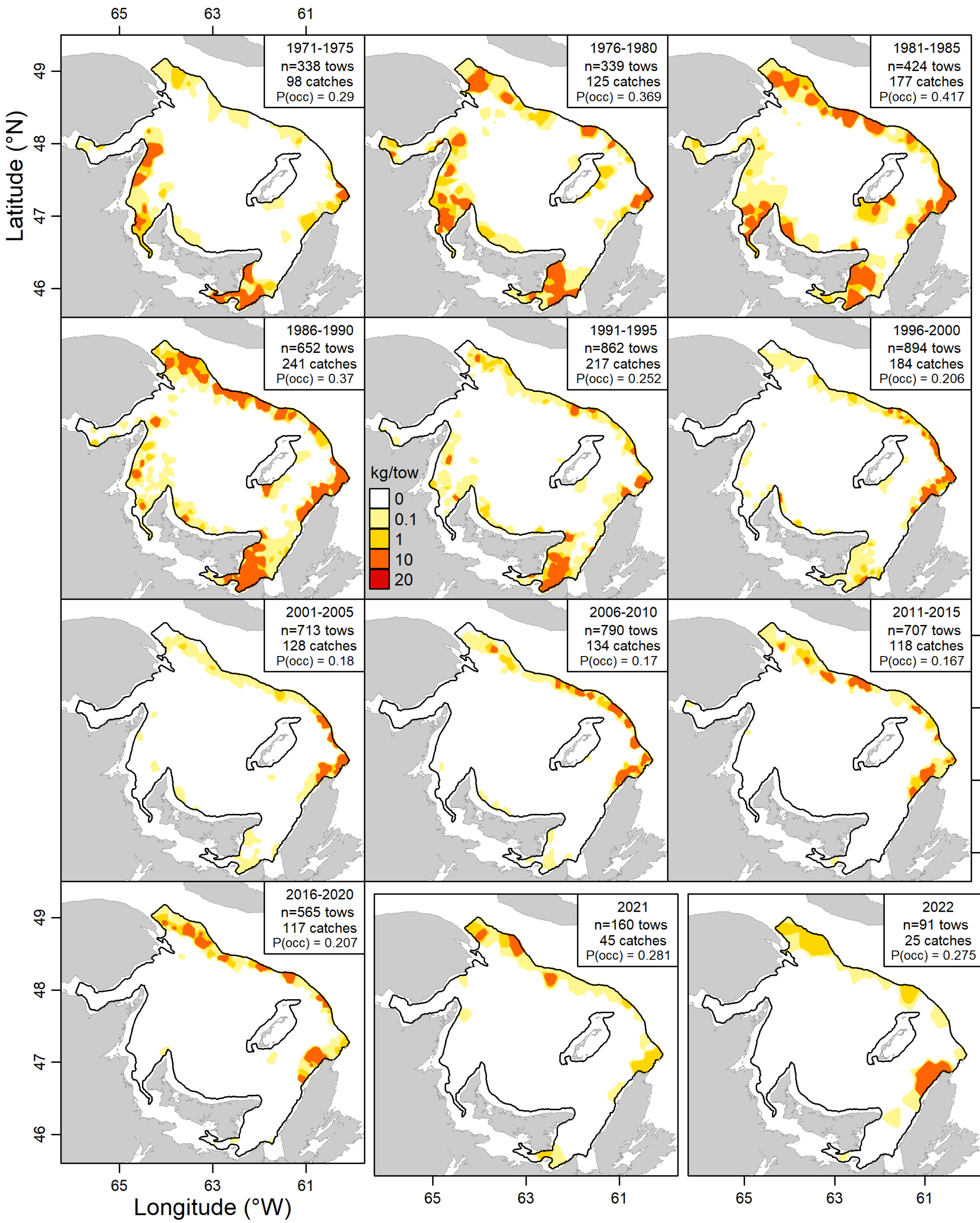

Figure 3.3: White Hake distribution (all fish lengths) derived from observation in the annual southern Gulf of St. Lawrence survey. Catch weights are spatially interpolated using Inverse Distance Weight (IDW). Individual maps are presented for 5-year blocks for the period 1971 to 2020, and the years 2021 and 2022 are shown separately. Shown in each map are the total number of tows used in the analyses for each panel, the number and proportion of tows where White Hake was captured.

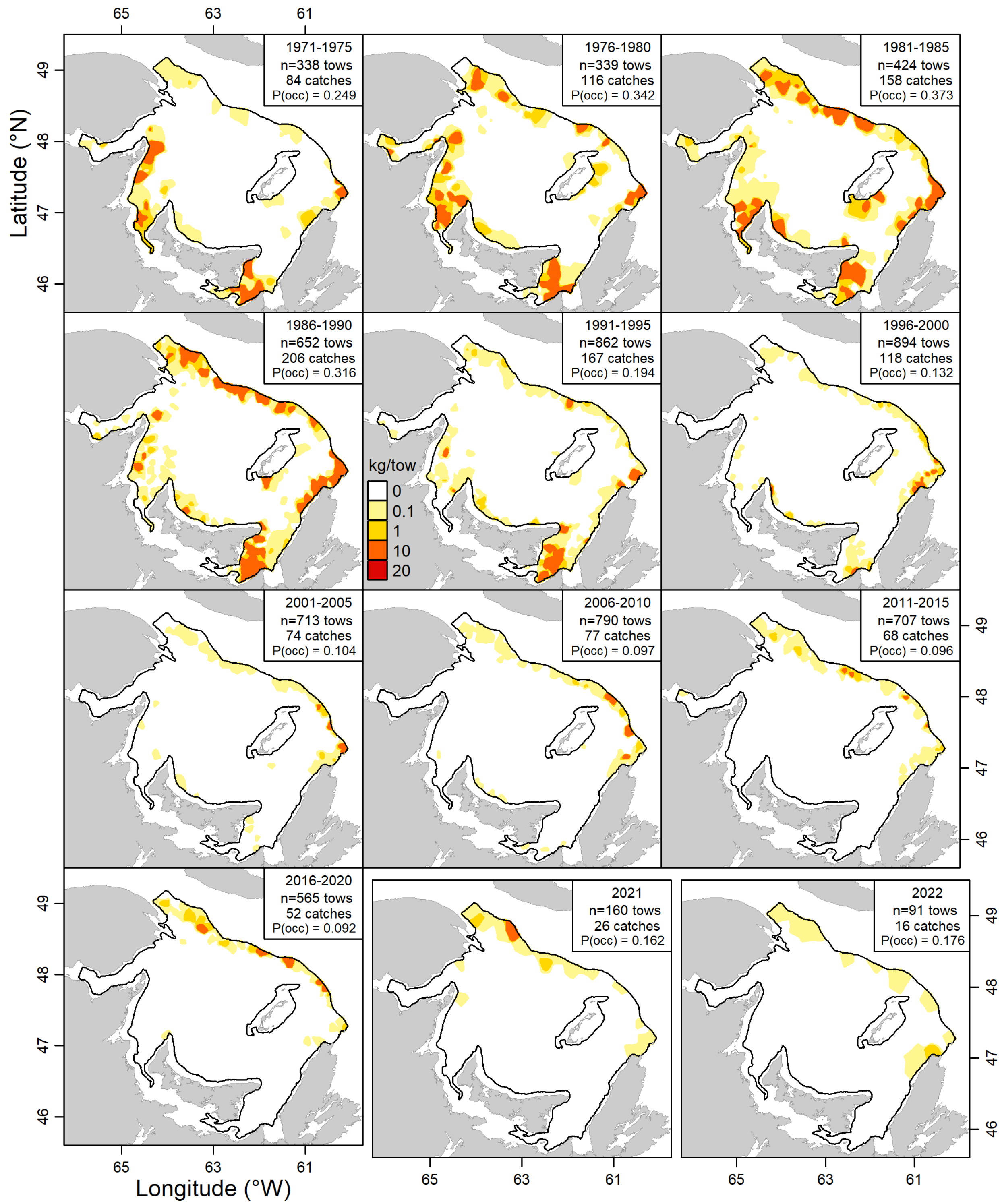

Figure 3.4: White Hake distribution (adults, lengths >=45 cm) derived from observation in the annual southern Gulf of St. Lawrence survey. Catch weights are spatially interpolated using Inverse Distance Weight (IDW). Individual maps are presented for 5-year blocks for the period 1971 to 2020, and the years 2021 and 2022 are shown separately. Shown in each map are the total number of tows used in the analyses for each panel, the number and proportion of tows where adult White Hake was captured.

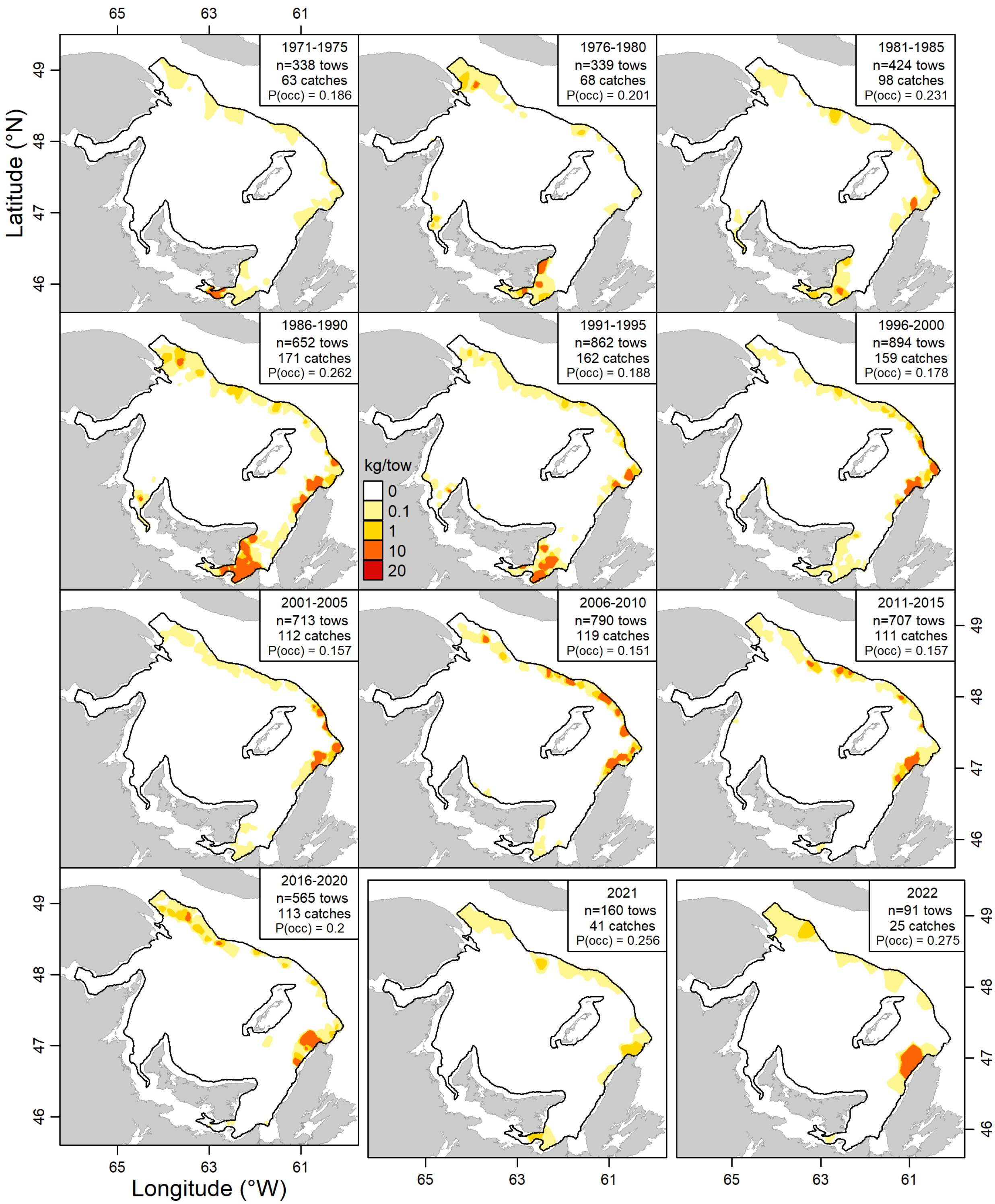

Figure 3.5: White Hake distribution (juveniles, lengths <45 cm) derived from observation in the annual southern Gulf of St. Lawrence survey. Catch weights are spatially interpolated using Inverse Distance Weight (IDW). Individual maps are presented for 5-year blocks for the period 1971 to 2020, and the years 2021 and 2022 are shown separately. Shown in each map are the total number of tows used in the analyses for each panel, the number and proportion of tows where juvenile White Hake was captured.

The area occupied by Hake tended to increase from the mid 1970s to the early 1980s and then declined (Figure 3.6). Area occupied peaked at values near 25,000 km² in the early 1980s, declining to values near 10,000 km² in recent years. Declines in area occupied were sharpest in the early 1990s but have been more gradual since then. Time trends in D95% and D75% were generally similar to those in area occupied (Figure 3.6).

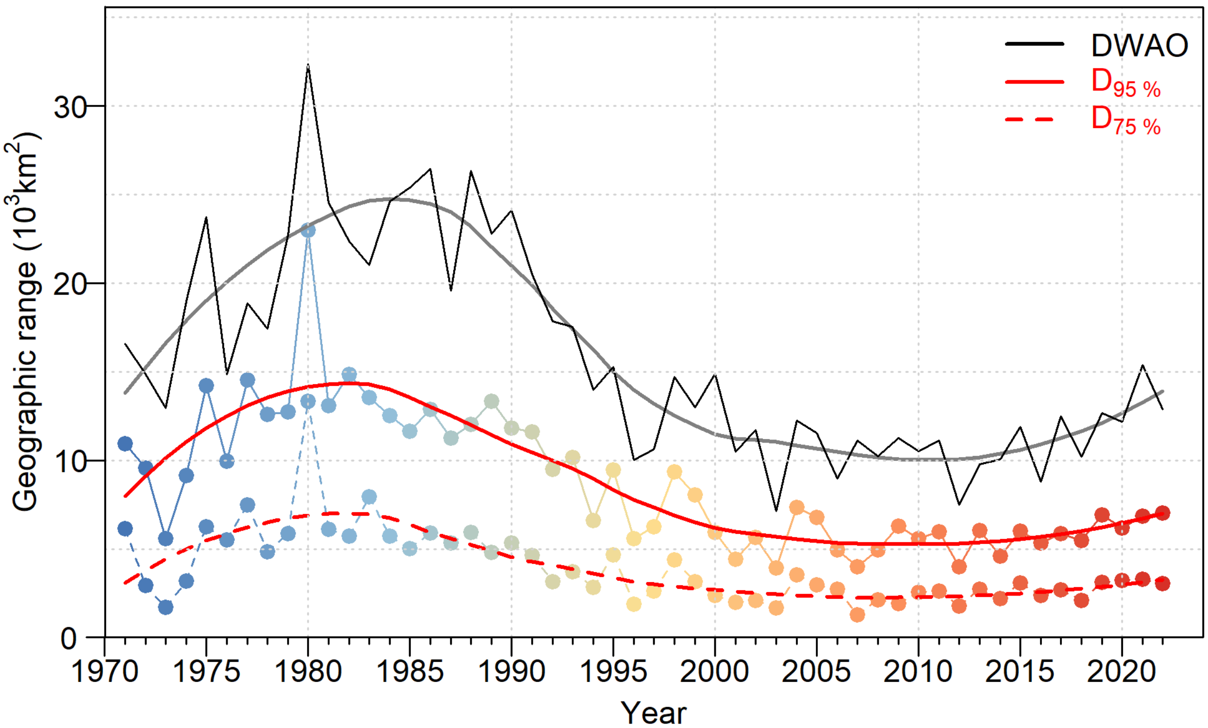

Figure 3.6: Yearly estimates of distribution indices (Distance-Weighted Area of Occupancy, DWAO, minimum area containing 75% of biomass, D75% and minimum area containing 95% of biomass, D95%) for White Hake, derived from the Southern Gulf of St. Lawrence research vessel survey 1971 to 2022. For D75% and D95%, the early years appear in blue and the recent years appear in red. The predictions from a loess estimator are overlaid on the distribution indices.

3.1.2.2. Abundance and inputs to the population model

Length-based indices of juvenile abundance and biomass fluctuated without clear trends between 1971 and 2022 (Figure 3.7). The juvenile indices tended to be higher between 1985 and 1992 than since 1993, though the indices in 2000, 2007, 2014, 2019 and 2020 were as high as or higher than those in the earlier period. The adult indices fluctuated widely between 1971 and 1984, perhaps reflecting the low sampling intensity during this period (Swain et al. 2012). The adult abundance and biomass indices both showed a sharp decline from 1986 to 1995, and have varied without trend at very low levels since then.

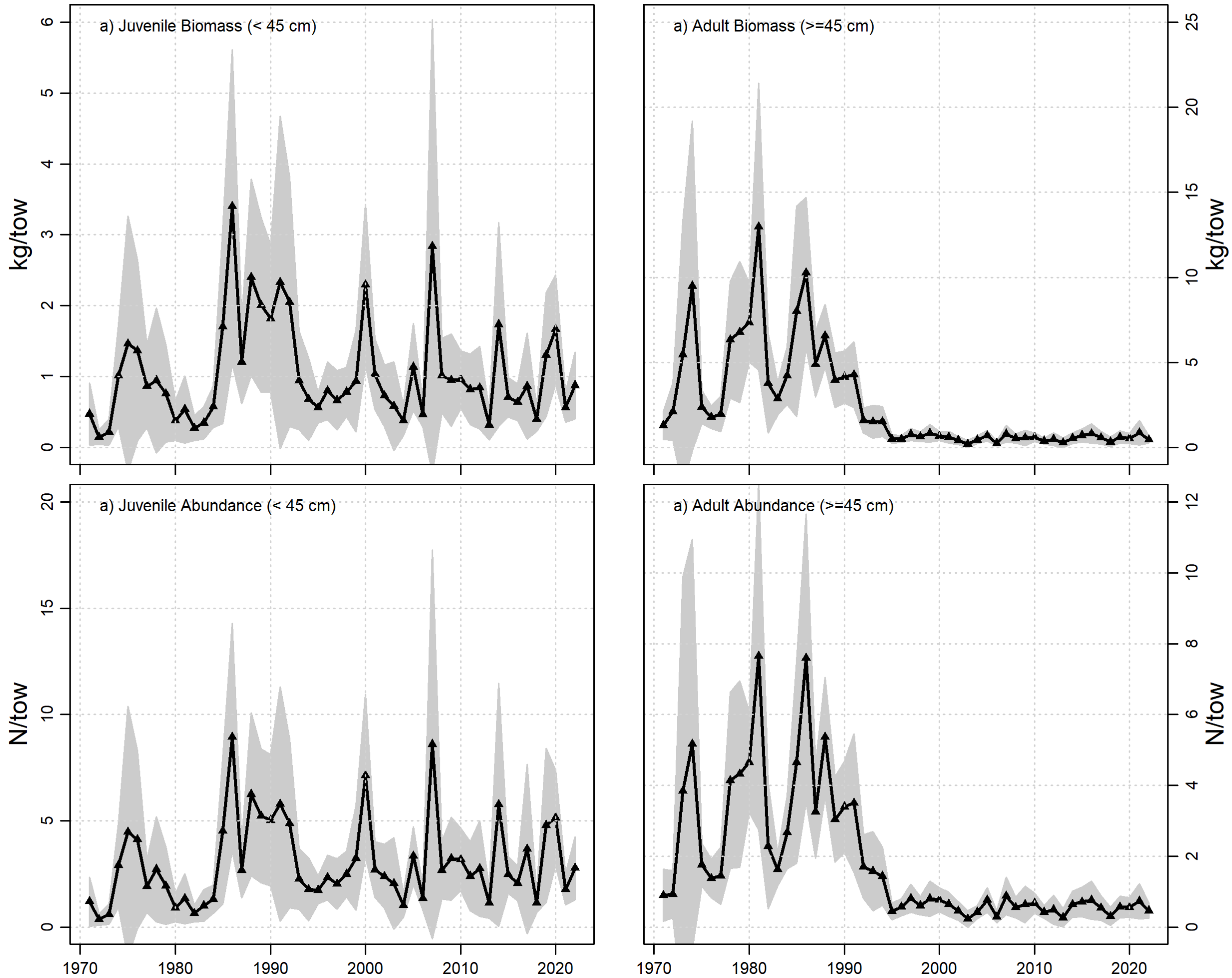

Figure 3.7: RV survey indices of abundance (number per tow) and biomass (kg per tow) for juvenile (< 45 cm) and adult (≥ 45 cm) White Hake, derived from the Southern Gulf of St. Lawrence research vessel survey 1971 to 2022. Grey shading shows the approximate 95% confidence intervals (+-2 SE) of the indices. All indices are based on strata 415-439.

Hake catches at all ages were generally higher in the 1980s (Figure 3.8; Table A5). Catches of Hake ages 3+ decreased during the late 1980s and early 1990s and remained low afterwards. Catches of age 2 Hake remained relatively stable on average over the time series, with occasional peaks. Catches of age 3 Hake also periodically showed peaks, reflecting the peaks in abundance of age 2 Hake. The tracking of the cohorts emerging post 1990 started to decline as catches of Hake ages 5+ remained low and did not reflect the peaks in abundance at younger ages.

The annual proportions at age showed greater proportions of older Hake from the beginning of the time series until the mid 1980s then later in the time series (Figure 3.9. The proportions at age of older fish gradually declined from the 1980s until the mid 1990s, where the population was mostly composed of Hake ages 2 to 5. Since the 2002-2007 period, the spawning population has been restricted to essentially ages 4 and 5, with age 4 comprising about 75% of the spawners.

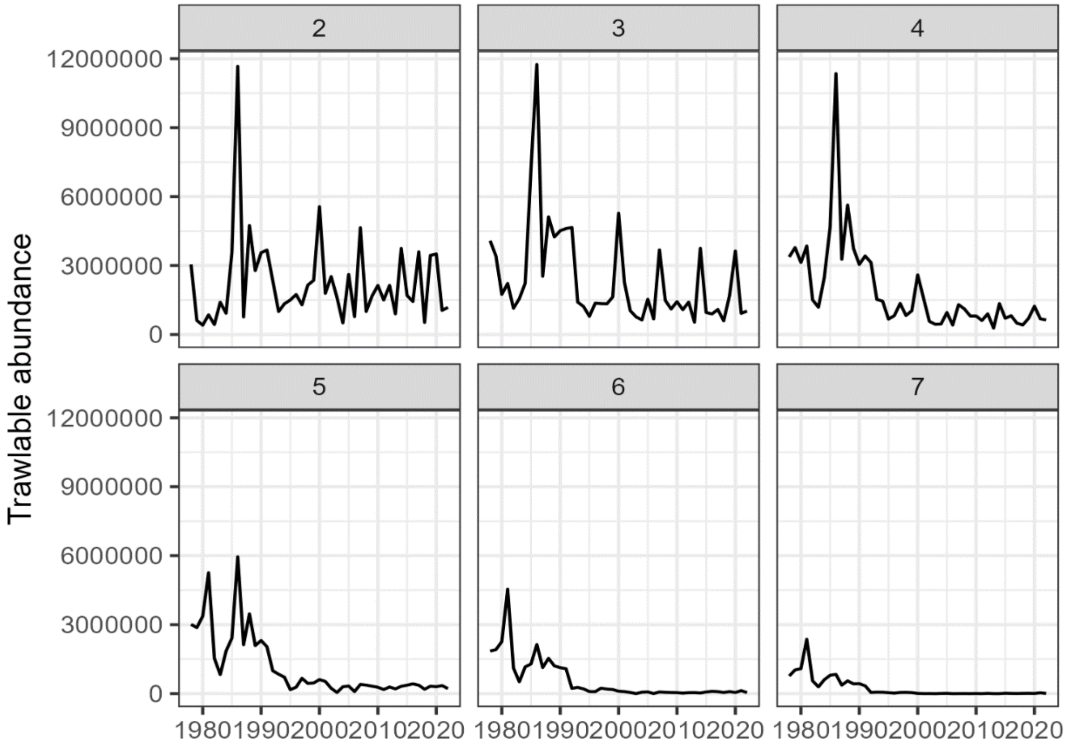

Figure 3.8: Catch at age in stratified mean trawlable abundance for ages 2 to 7 and years 1978 to 2022 from the southern Gulf of St. Lawrence research vessel survey.

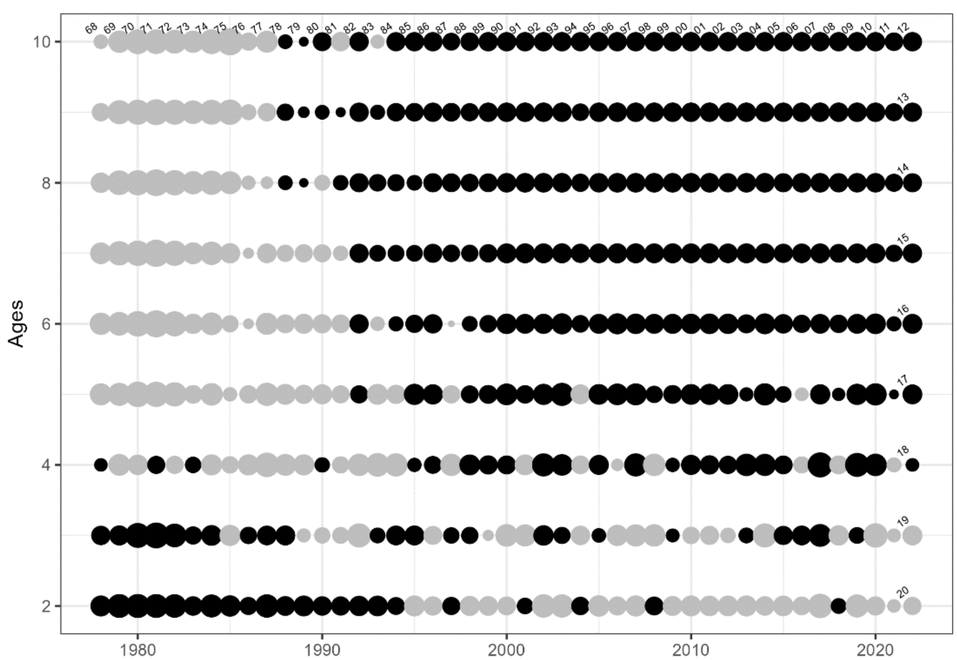

Figure 3.9: White Hake standardized proportions by age across years in stratified mean trawlable abundance for ages 2 to 10 and years 1978 to 2022 from the southern Gulf of St. Lawrence research vessel survey.

The annual age-aggregated (ages 2 to 7) stratified mean trawlable biomass was highest in the early period of the time series (Figure 3.10). Biomass started to decline in the late 1980s until the mid 1990s. Biomass varied without trend at low values to the end of the time series (2022).

Figure 3.10: Age-aggregated (ages 2 to 7) stratified mean trawlable biomass for years 1978 to 2022 from the southern Gulf of St. Lawrence research vessel survey.

The Gompertz growth model parameters were significant (p < 2e-16). The asymptotic weight was estimated to be 27 kg, far outside of the range of the observed data in the sGSL. Specimens near this size, 22 kg and 135 cm TL, have been caught elsewhere, e.g. Markle et al. 1982. However, the model fit to data within the range of the observations was good (Figure 3.11).

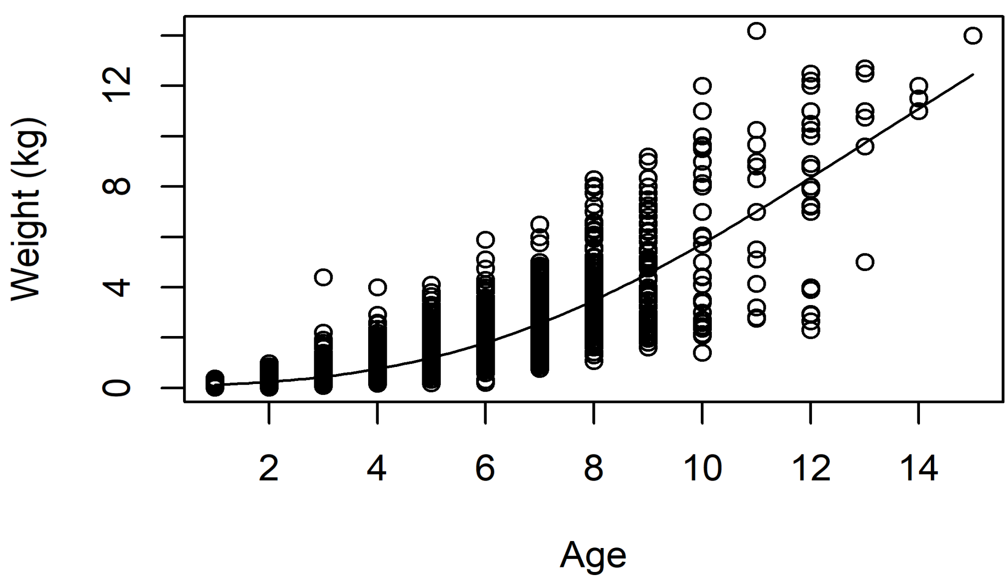

Figure 3.11: Weight (kg) at age relationship of White Hake in September in the southern Gulf of St. Lawrence research vessel survey. Circles show the weights at age using all the individual measurements collected on the RV surveys (1978-2014). Curve shows the Gompertz growth function fit to data for ages 2 to 15 years.

Weight-at-age was generally highest at the beginning of the time series and decreased gradually at most ages, until the early 1990s for younger ages and until the 2000s for older ages (Figure 3.12, Table A6). weight-at-age data of older fish (6+) was scarce as they were gradually less caught in the RV survey. Therefore, model predicted values were used for older Hake in most years post 2000. All weight-at-age values for years 2015 to 2022 were predicted, as no ageing data was available for these years.

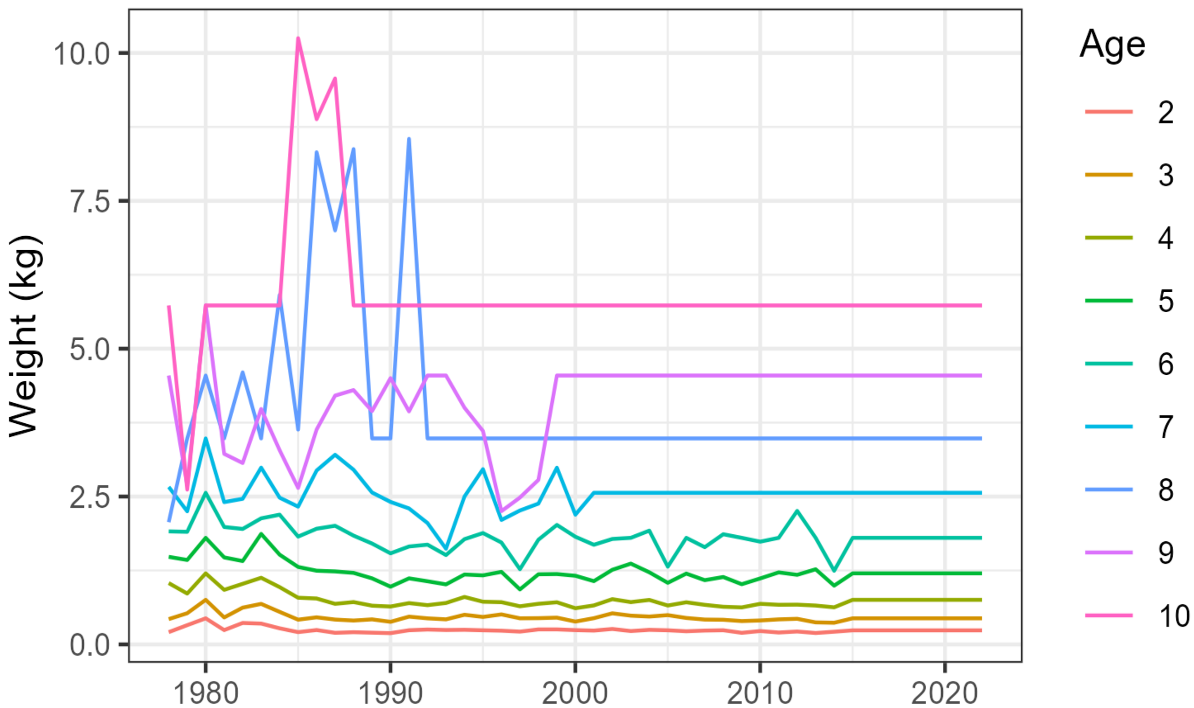

Figure 3.12: Annual mean weight-at-age of White Hake caught in the southern Gulf of St. Lawrence research vessel (RV) survey between 1978 and 2022.

The model predicted weight at length showed that Hake condition was relatively stable throughout the time series for Hake of length 35 cm (Figure 3.13). For Hake of length 45 and 55 cm, condition was slightly higher post 1995 although the scale of the directional change is small. The predicted weight in 2021 and 2022 for the three selected lengths were lower than the long term average and in the range of values observed prior to the mid 1990s.

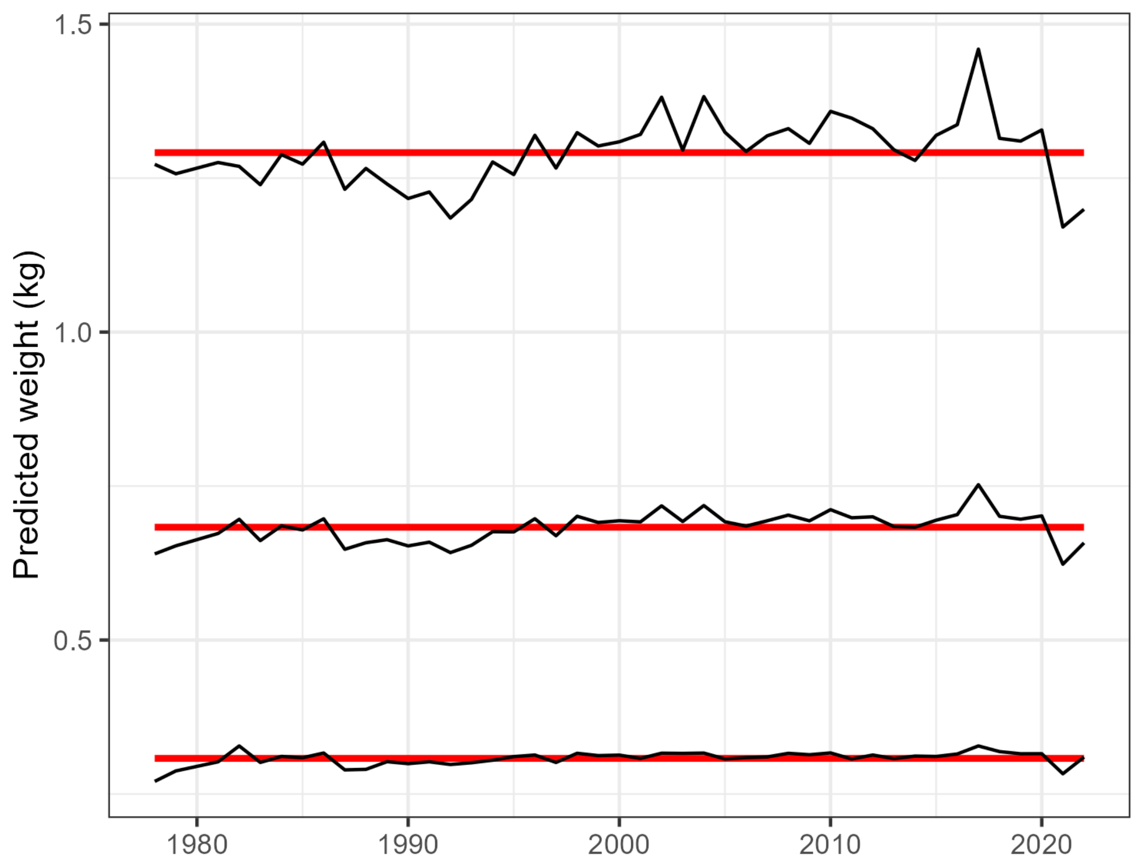

Figure 3.13: Indices of condition of southern Gulf od St. Lawrence White Hake. The indices are the predicted weight at lengths of 35, 45 and 55 cm (black solid line) White Hake, based on the parameters of the annual length-weight relationship. Red lines for each length show the long-term mean.

3.1.2.3. Diet

A total of 232 White Hake stomachs were sampled, 87 from the 2004 to 2006 period and 145 from the 2018 to 2020 period. The length of White Hake sampled for stomach contents had two modes at 32 and 42 cm in the 2004 to 2006 period whereas Hake length had one mode around 31 cm in the 2018 to 2020 period (Figure 3.14). White Hake < 45 cm was sampled from both shallow inshore and deep offshore regions in both periods (Figures 3.15 and 3.16). White Hake 45+ cm were sampled from both shallow inshore and deep offshore in the 2004 to 2006 period, whereas it was only caught in deep offshore regions in the Laurentian channel in the 2018 to 2020 period.

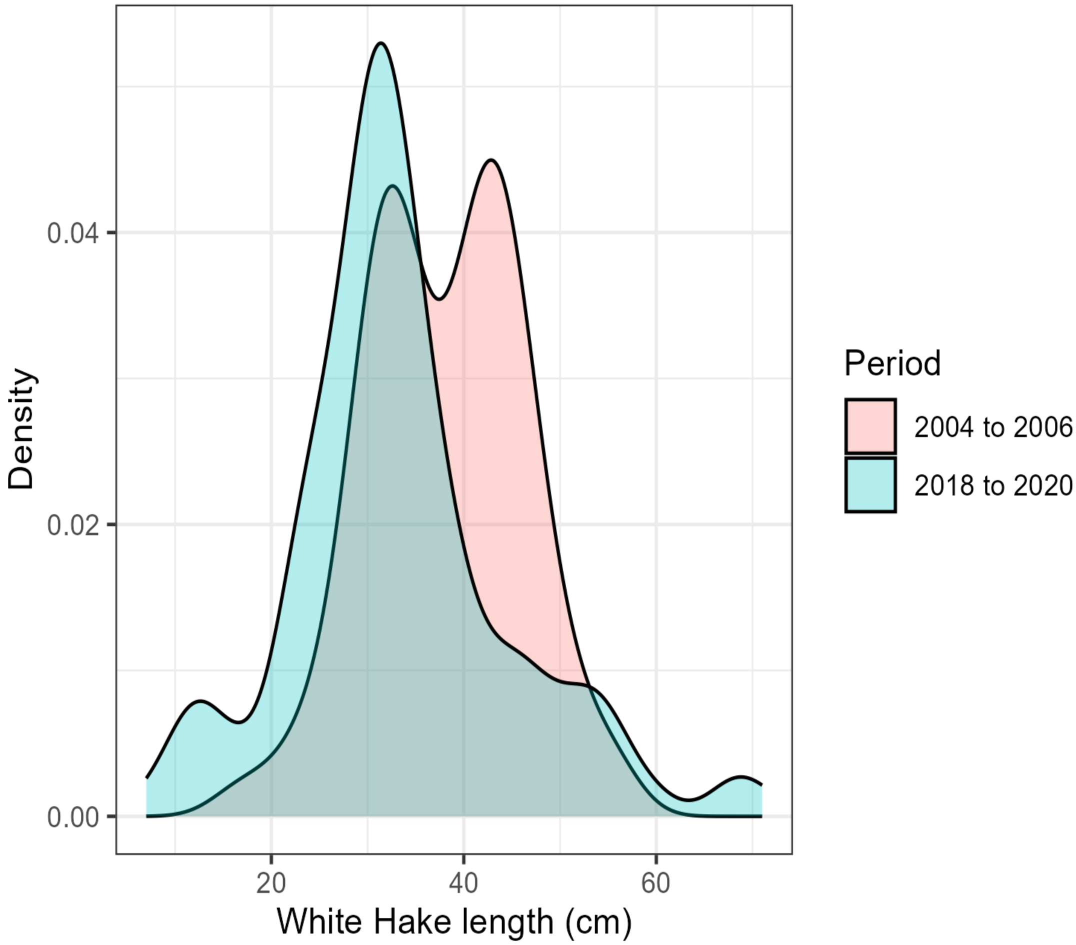

Figure 3.14: White Hake length (cm) density for two periods (2004 to 2006; red and 2018 to 2020; blue) for fish sampled for stomach contents.

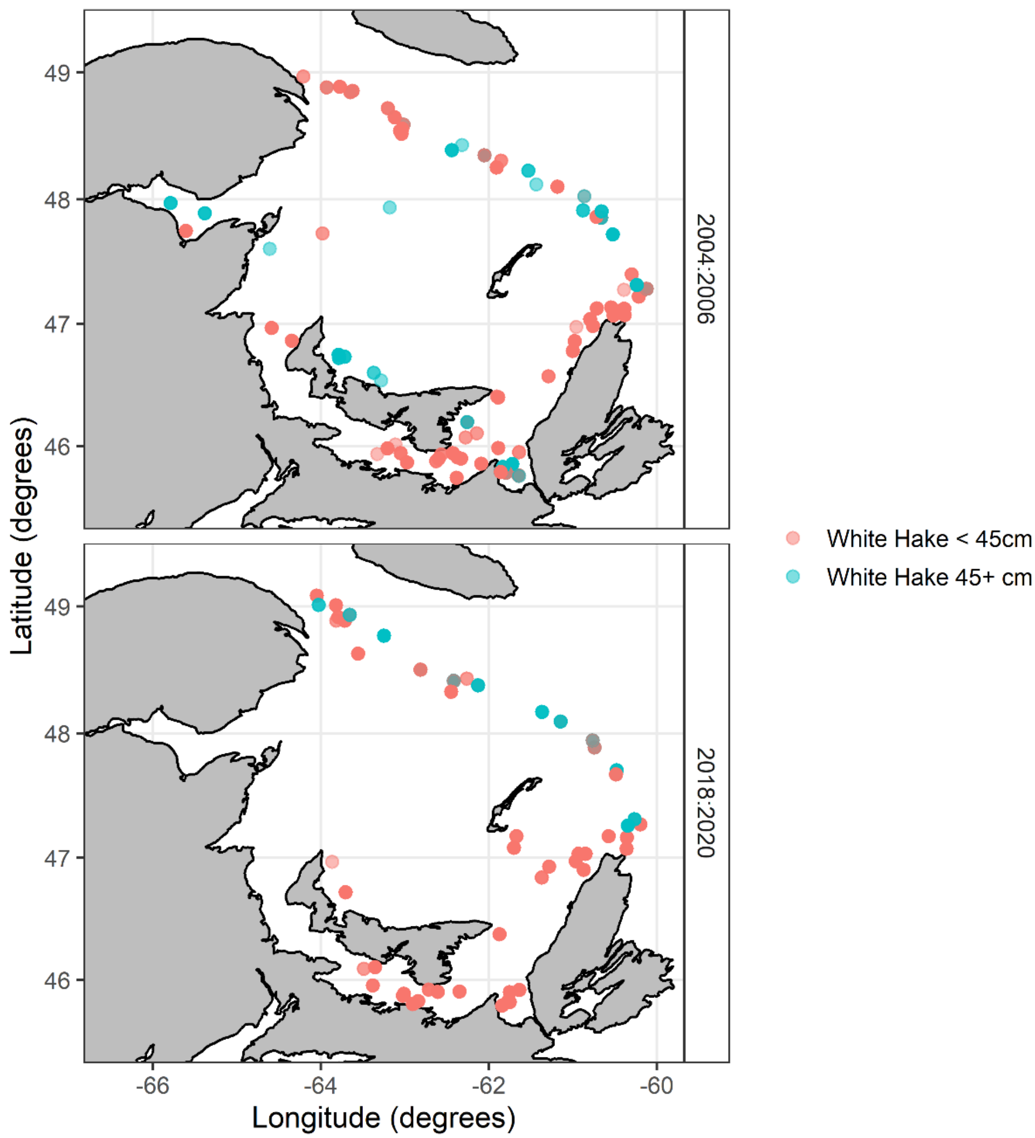

Figure 3.15: White Hake length (cm) spatial distribution for two periods (2004 to 2006; red and 2018 to 2020; blue) for fish sampled for stomach contents.

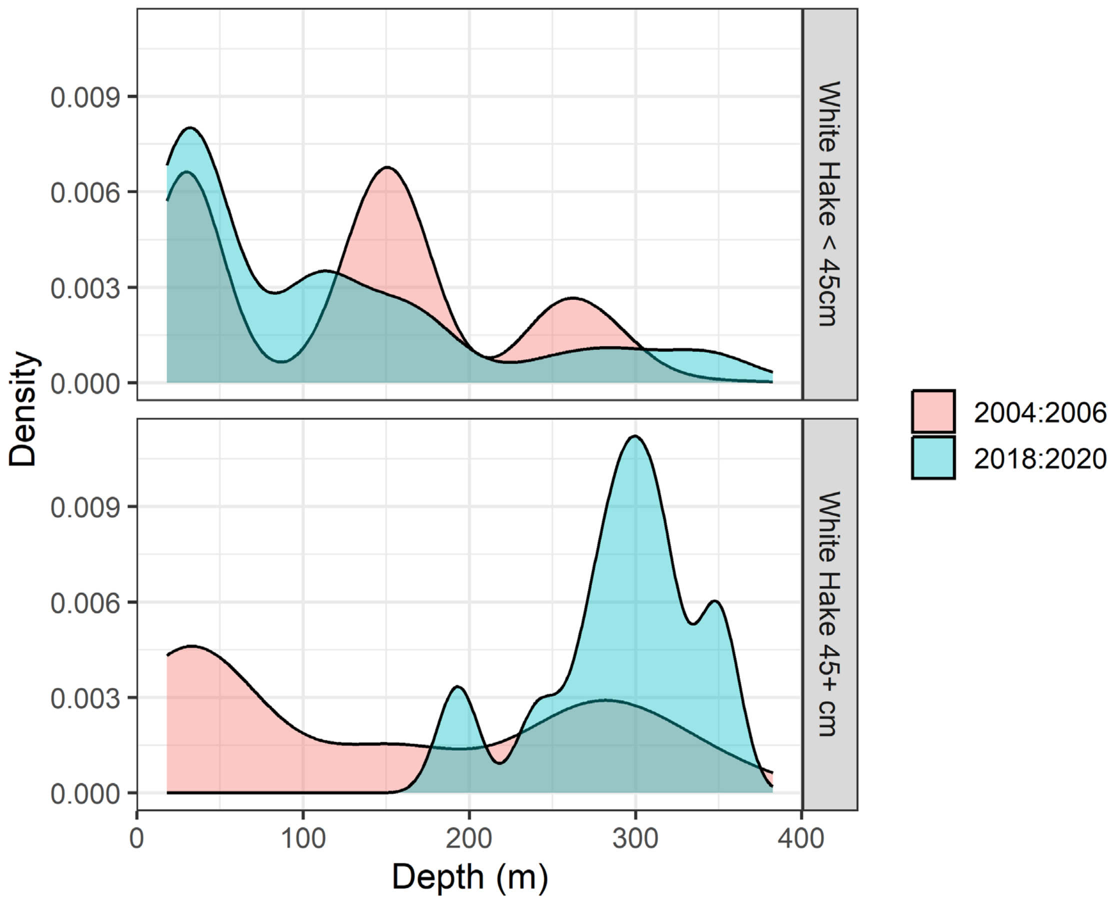

Figure 3.16: White Hake depth (m) density for two length groups and two periods (2004 to 2006; red and 2018 to 2020; blue) for fish sampled for stomach contents.

Shrimp and Capelin were the most important prey items by weight in White Hake < 45 cm stomach contents in years 2004 to 2006 (Figure 3.17). In years 2018 to 2020, the shrimp contribution to White Hake stomachs content was much less than in earlier years. No Capelin was found in the 2018 to 2020 period. Shrimp was still the most important (identifiable) prey item in Hake stomachs after digested remains. Krill and Sand Lance were prey items only found in the 2018 to 2020 period, whereas Atlantic Mackerel, squid and Atlantic Herring were only found in the 2004 to 2006 period. Crustaceans comprised 87–98% of prey biomass for fish up to 29.9 cm total length.

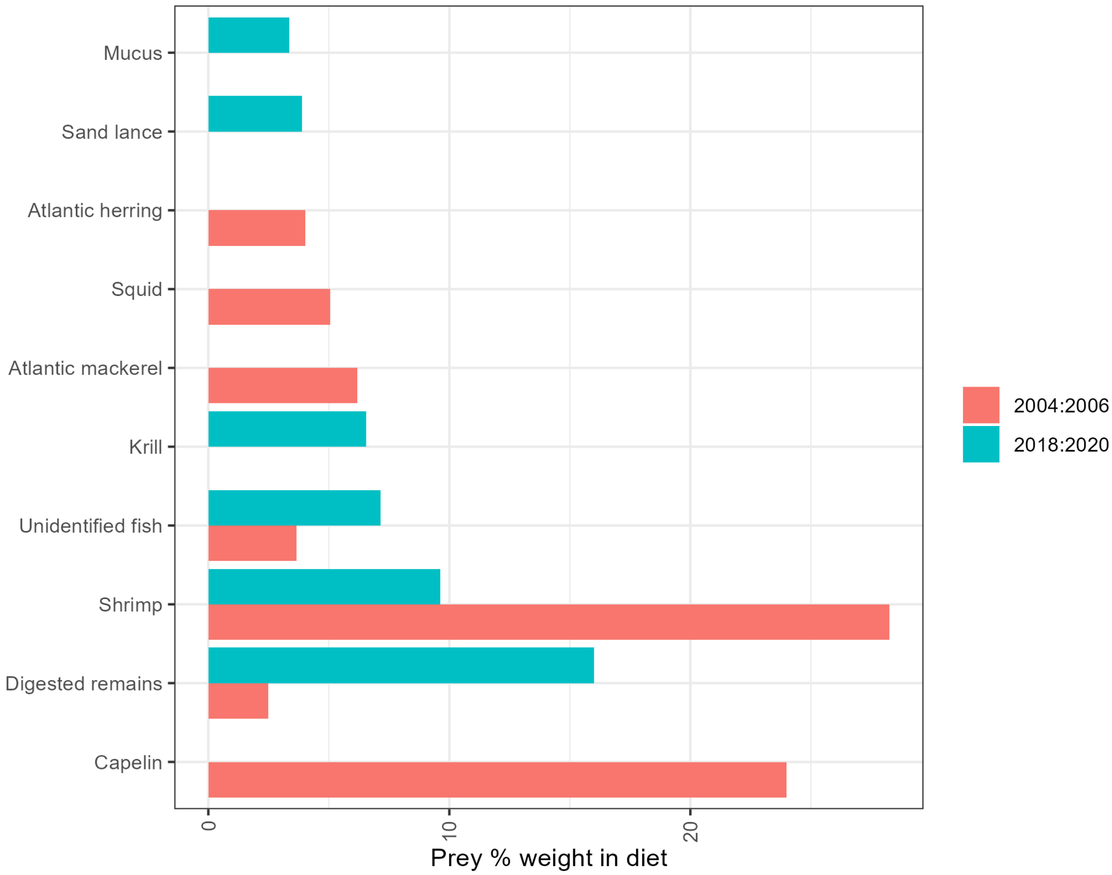

Figure 3.17: Prey items weight proportion in sGSL White Hake < 45 cm for two time periods.

Redfish was the most important prey item in White Hake 45+ cm in the 2018 to 2020 period, but was absent from stomach contents in the earlier period. Atlantic Herring was the most important prey item in the 2004 to 2006 period, but was not found in the recent period, potentially reflecting the contemporary absence of large White Hake in shallower parts of the sGSL. Shrimp, Atlantic Herring and Atlantic Cod were important components of the diet in the earlier period but almost absent (shrimp) or completely absent (Herring and Cod) in the recent period.

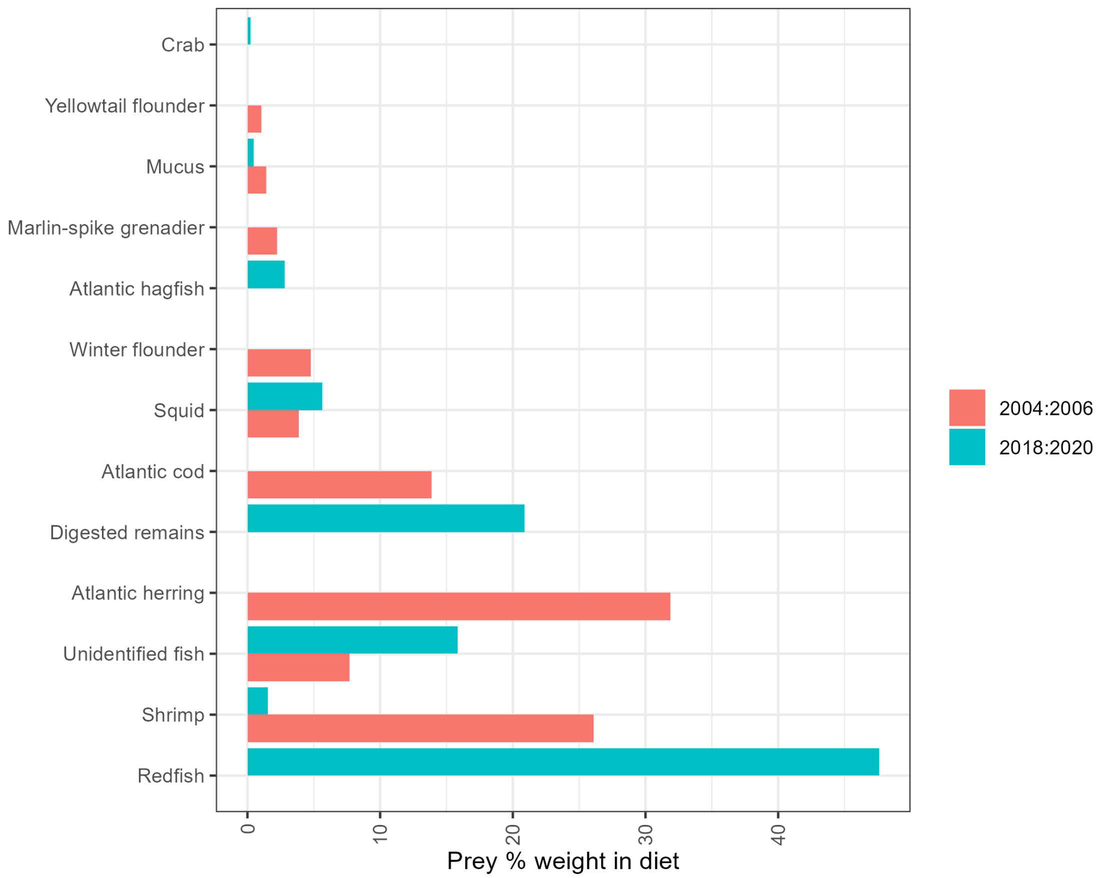

Figure 3.18: Prey items weight proportion in sGSL White Hake 45+ cm for two time periods.

The most important difference in large White Hake diet between periods is the differential contribution of Redfish, Cod and Shrimp. Redfish was at low abundance in the GSL in years 2004 to 2006, while its abundance was high in the 2018 to 2020 period (Senay et al. 2023). Redfish and White Hake spatial distribution overlap in the deeper regions of the GSL in September (Sutton et al. In prep.[1]). Their co-occurrence is also linked to their diet as the primary item in the diet of White Hake is Redfish and both White Hake and Redfish feed on Shrimp. As Redfish continue to grow they may become too large for White Hake to consume and the abundance of smaller Redfish is dependent on the occurrence and size of future Redfish cohorts, which may have implications on the potential overlap of the species. Shrimp and Cod also co-occur with White Hake in the Laurentian Channel, but their relative contribution to White Hake 45+ cm diet decreased between the time periods, likely reflecting lower abundance of both Shrimp (DFO 2023a) and Cod (DFO 2024).

Atlantic Herring abundance also declined between the time periods but their distribution in September is almost exclusively inshore in the RV survey catch (Rolland et al. 2022b), and no large inshore White Hake was sampled (or caught) for stomach contents in the 2018-2022 period. Hanson 2011 also found that in 2001 and 2002 Atlantic herring was the most important

[1] Sutton, J.T., McDermid, J.L., Ricard, D. Turcotte, F. Mitigating bycatch of the southern Gulf of St. Lawrence Designatable Unit of White Hake (*Urophycis tenuis*). DFO Can. Sci. Advis. Sec. Res. Doc. In preparation.

prey item of large Hake (more than 70% of prey weight), although they only sampled Hake stomachs from 5-50 m waters bottom trawl catches of the RV survey and opportunistic gillnet sets in St George bay. The most important difference in small (< 45 cm) White Hake diet between periods is the decreased contribution of Shrimp and Capelin, even though Capelin abundance in the sGSL increased between time periods (RV survey, not shown). The differences in diet observed from RV survey samples do not appear to be problematic in terms of energetic considerations as both juveniles and adult fish condition were near average across the two time periods covered by the stomach content sampling. However, as the samples were only obtained from the RV survey, the diet and condition results are limited to the month of September, in the years sampled for stomach contents.

3.2. MOBILE SENTINEL SURVEY

Between 2003 and 2019, the mobile gear component of the sGSL Sentinel survey program (MS) has consisted of a bottom trawl survey conducted annually in August by three to four commercial fishing vessels using the same standardized bottom trawl and standardized fishing protocols (for details see Savoie 2012). Data collection has been conducted by at-sea observers. This survey follows the same stratified-random survey design used for the sGSL RV survey. There have been several vessel changes since 2003. Calibration of relative fishing efficiency between vessels is attempted annually using a negative binomial model with terms for year, stratum and vessel. However, because of the restricted spatial distribution of White Hake, stratum and vessel effects may confound in calibrations for this species. Thus, indices were not adjusted for potential vessel effects. The MS survey was not performed since the last White Hake assessment. Consequently, the inputs to the population model have not changed (see Rolland et al. 2022a)

Briefly, the MS index fluctuated without trend between 2003 and 2019. White Hake catches in the RV survey for that period were also at a low but relatively stable level. The proportions at age and age-aggregated biomass indices from the MS survey are consistent with the RV survey results (Rolland et al. 2022a).

4. POPULATION MODEL

4.1. METHODS

A Statistical catch-at-age (SCA) population model implemented in AD Model Builder (Fournier et al. 2011), was fit to the sGSL Hake data, as in previous assessments (Swain et al. 2016; Rolland et al. 2022a). The model ranged from 1978 (the first year with reliable fishery catch-at-age data) to 2022 and from age 2 to ages 10 and older (10+). Data inputs were: total annual fishery catch (t), stratified mean age-aggregated trawlable biomass in the sGSL RV (ages 2-7) and MS (ages 2-7) surveys, proportion-at-age in the fishery, sGSL RV and MS catches. Weight at age from the fishery catch, RV and MS surveys were also inputs to the model. A knife edge maturity schedule was assumed, where fish ages 2 and 3 are considered immature and all fish age 4 and over are considered fully mature.

Population abundance at age 2 (recruitment) was estimated as a random walk based on the log average recruitment, annual recruitment deviations and an autocorrelation term. Independent time series of natural mortality (M) were estimated for three age groups: ages 2-3, 4-5 and 6+. These time series were estimated on the log scale as random walks.

Fishery and survey selectivity were modelled as logistic functions. The fishery selectivity function was estimated independently for two time blocks, 1978–1995 and 1996–2022, to account for important changes in the fishery.

Previous assessments allowed RV catchability to change between the Yankee 36 and Western IIA trawls by splitting the RV data into separate series before and since 1985. In this assessment, the conversion factors calculated from comparative fishing experiments have been applied where necessary to maintain the consistency of the entire time series (Benoît and Swain 2003; Benoît 2006; Benoît and Yin 2023). Accordingly, the model estimated only one catchability parameter for the RV survey biomass index, instead of two as in previous assessments. The general results of the assessment are not modified by this difference in modelling. A model up to 2022 using the split RV survey time with all conversion factors applied and two q estimates generated q estimates very close to each other (0.40 and 0.43). Model were run using the split RV survey time series up to 2022 (2022_2q) or the continuous RV survey times series up to 2022 (2022_1q) with all conversion factors applied and the 2019 model, which used the split RV time series and two q estimates. Differences in SSB estimates from each model (2022_1q, 2022_2q and 2019_2q) were small (Figure 4.1). The biggest difference in SSB estimates between models was around the year where the split in the time series used to occur (1985).

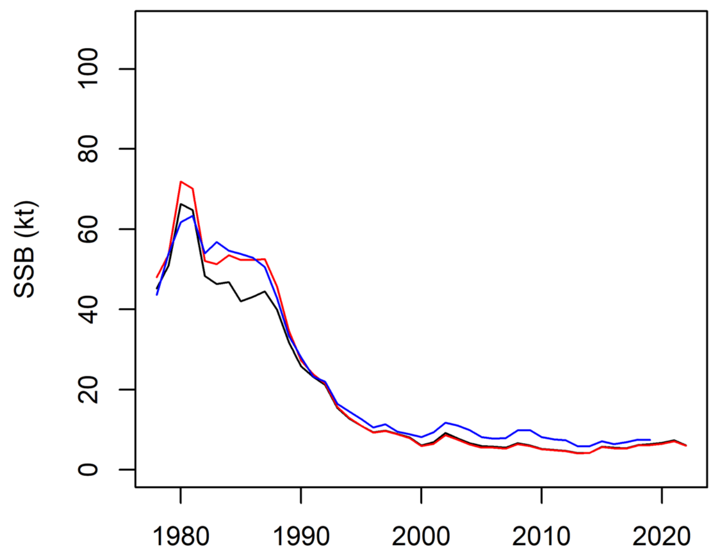

Figure 4.1: Estimated spawning stock biomass (SSB, kt) of White Hake in the southern Gulf of St. Lawrence (sGSL) for three different population models: $2022_1 q$ uses a non-split age aggregated sGSL research vessel (RV) survey time series and one catchability estimate (black line), $2022_2 q$ splits the RV survey time series and estimates 2 catchability parameters (red line), $2019_2 q$ is the assessment model from the last assessment, using a split RV survey time series and 2 catchability estimates (blue line). Solid lines are the median from the MCMC sampling.

The objective function included the following components: 1) components for the discrepancy between observed and predicted values of the age-aggregated biomass indices for the RV and MS surveys, 2) components for the discrepancy between observed and predicted proportion-at-age in the fishery, RV and MS catches, 3) a normal prior for the log M deviations; 4) a normal prior for the initial values of M and 5) a normal prior for the log recruitment deviations. The proportion-at-age were assumed to follow a multivariate logistic distribution. This avoids the need to specify effective sample sizes, which can have a large impact on model results. Approximate 95% confidence intervals were obtained for quantities based on 210,000 MCMC samples, with every 40th sample saved.

Goodness-of-fit to indices was assessed by visual examination of estimated and observed age-aggregated biomass plots. Discrepancies between predicted and observed proportion-at-age were assessed by plotting the residuals by year and age, and looking for blocking through ages or years. The sum of squares of the residuals were calculated for each index. Retrospective patterns in SSB, recruitment, M and F estimates were assessed by plotting time-series estimated by sequentially removing the terminal year of data, for 7 years (2016 to 2022). Mohn's rho values were calculated for every quantity evaluated in the retrospective patterns analysis.

4.2. RESULTS AND DISCUSSION

Model fit to both the sGSL RV and MS biomass indices was good, though there was little contrast in the MS index (Figure 4.2). Overall, the fit to the proportion-at-age in the sGSL RV and MS surveys and the fishery catches were adequate (Figure 4.3). There were no indications of year effects but there was some relatively weak blocking along age in indices. Minor blocking in RV survey proportion-at-age occurred. Residuals were mostly positive at age 2 between 1995 and 2017, while residuals at age 3 are all negative in 1993 and after. Residuals are also mostly positive at ages 5 and 6 in 1997 and after and negative at age 7 in 2009 and after. Residuals in ages 5 to 7 were more important in years 2001 to 2022, likely due to the low abundance of these fish in the survey catch. Residuals at age 2 were mostly positive while mostly negative at ages 3 and 4 in the MS survey proportion-at-age. Residuals in the fishery catch were more important for age 3 and ages 7 and 8+ after 1990. The distribution of negative and positive residuals appeared to be mostly random.

The retrospective analysis shows a negative bias in SSB estimates across peels where the terminal year estimate is consistently estimated higher as years of data are added (Figure 4.4). Even if Mohn's rho value for SSB is high (Table 4.1), this bias is negligible when considering the scale of SSB estimated over the assessment period versus in the 10 recent years. Retrospective patterns and high rho estimates were also present in fishing mortality (F) of both age groups. However, estimated F values in the 10 recent years are stable and low, making the bias also negligible. The biases in estimated M values in all age groups vary between positive and negative across peels and the magnitude of variation is moderate, generating low rho values (except for M6+, caused by one peel). The recruitment estimates show variation across peels, where the whole time series is shifted lower as years of data are removed from the analysis. The terminal year bias in the 10 recent years shows a negative bias with a rho value of -0.04, which is acceptable. However, the annual coefficient of variation across peels recruitment estimates between peels was between 0.06 and 0.19 which suggests the model estimation of recruitment is challenging but not problematic. This is consistent with the minor blocking of residuals at ages 2 and 3 in the age composition. Overall, the retrospective patterns are not concerning and the trends across peels are very similar, which suggest the stock dynamics are adequately estimated by the model over time.

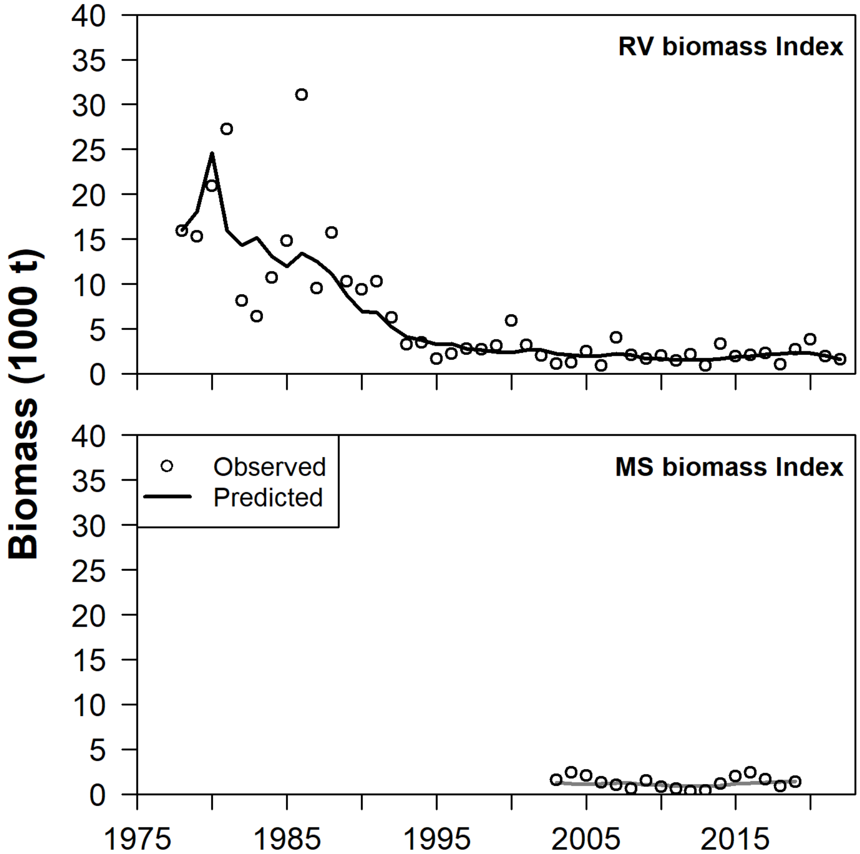

Figure 4.2: Fit of the predicted biomass indices (line) to those observed (circles) for the southern Gulf of St. Lawrence Research Vessel (RV) survey (upper panel) and Mobile Sentinel (MS) survey (lower panel).

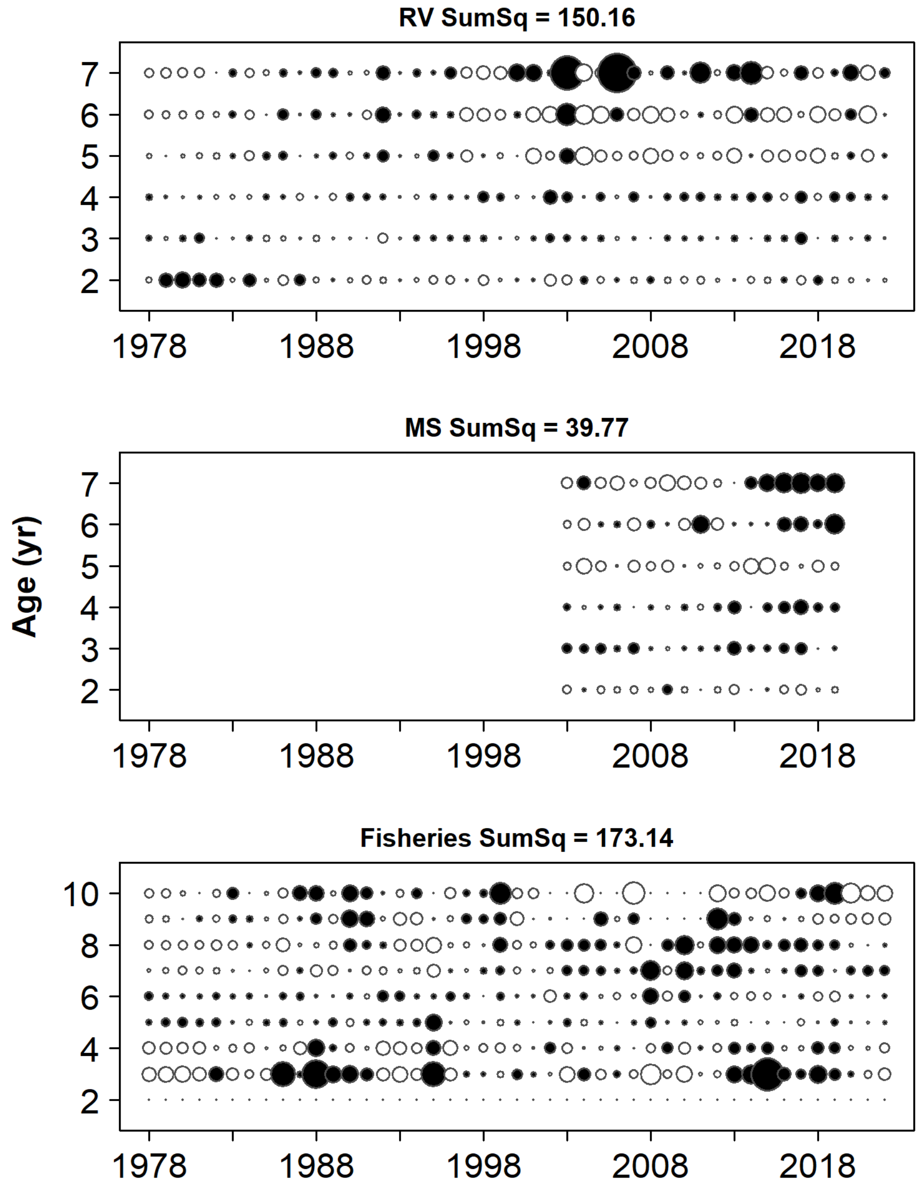

Figure 4.3: Residuals between the log of observed and and the log of predicted proportion-at-age in indices for White Hake in the southern Gulf of St. Lawrence. Rows are for ages and columns for years. Circle size is proportional to the magnitude of the residual. Black circles indicate negative residuals (observed < predicted) The upper panel shows residuals for the southern Gulf of St. Lawrence research vessel (RV) survey index, the middle panel for the Mobile Sentinel (MS) survey index and the lower panel shows residuals for the commercial fisheries.

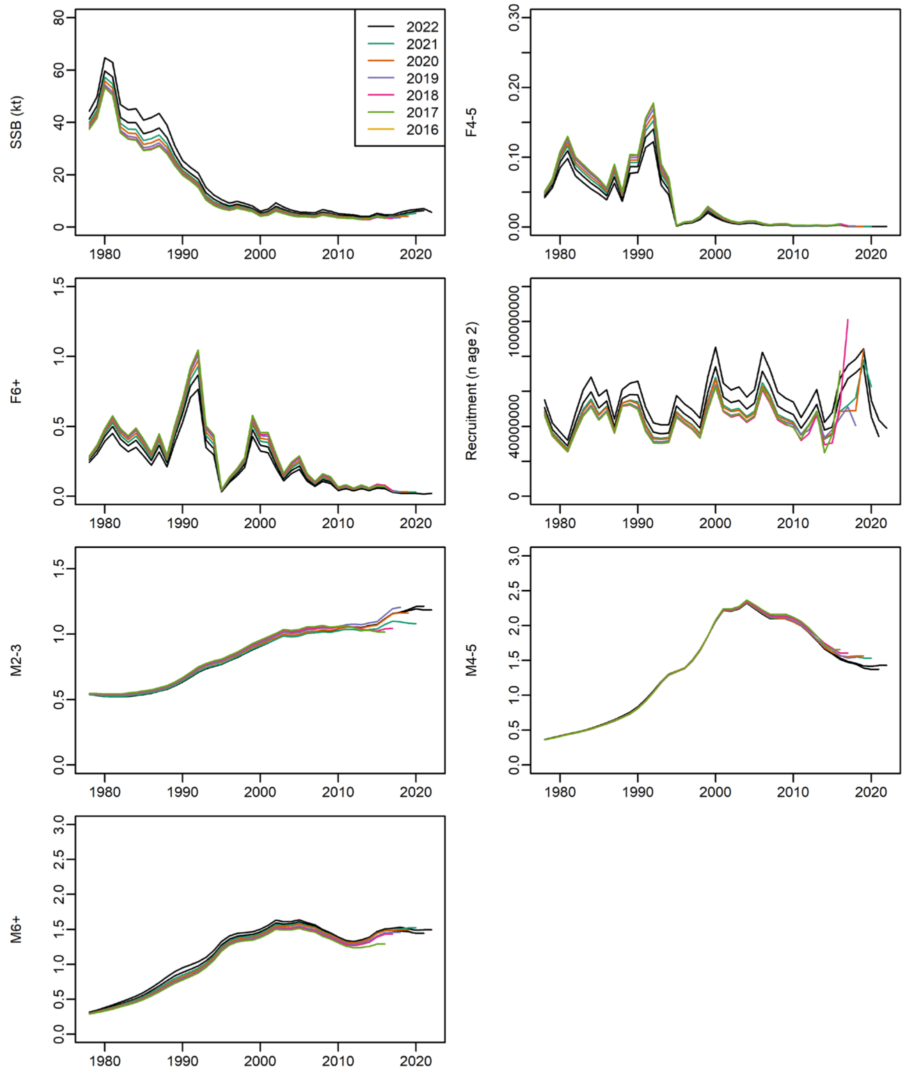

Figure 4.4: Retrospective patterns in estimated spawning stock biomass (SSB), fishing mortality for ages 4 to 5, and ages 6+, recruitment, natural mortality at ages 2 to 3, ages 4 to 5 and ages 6+ White Hake in the southern Gulf of St. Lawrence. Colored lines correspond to peels between years 2016 and the terminal year 2022.

Table 4.1: Mohn's rho values for every quantity evaluated in the retrospective patterns analysis.

Variable name	Mohn's rho
SSB	-0.2740495
Recruitment	-0.0432213
F4-5	0.5333702
F6+	0.4622162
M2-3	-0.0314403
M4-5	-0.0284311
M6+	0.1815344

SSB increased from 45 to 66 kt between 1978 and 1980 (Figure 4.5). SSB then decreased until 2000 when it reached 6.0 kt. SSB fluctuated without trend between 2001 and 2022. The estimated value in 2014, 4.2 kt, was the lowest of the time series. SSB in 2022 was 6.1 kt.

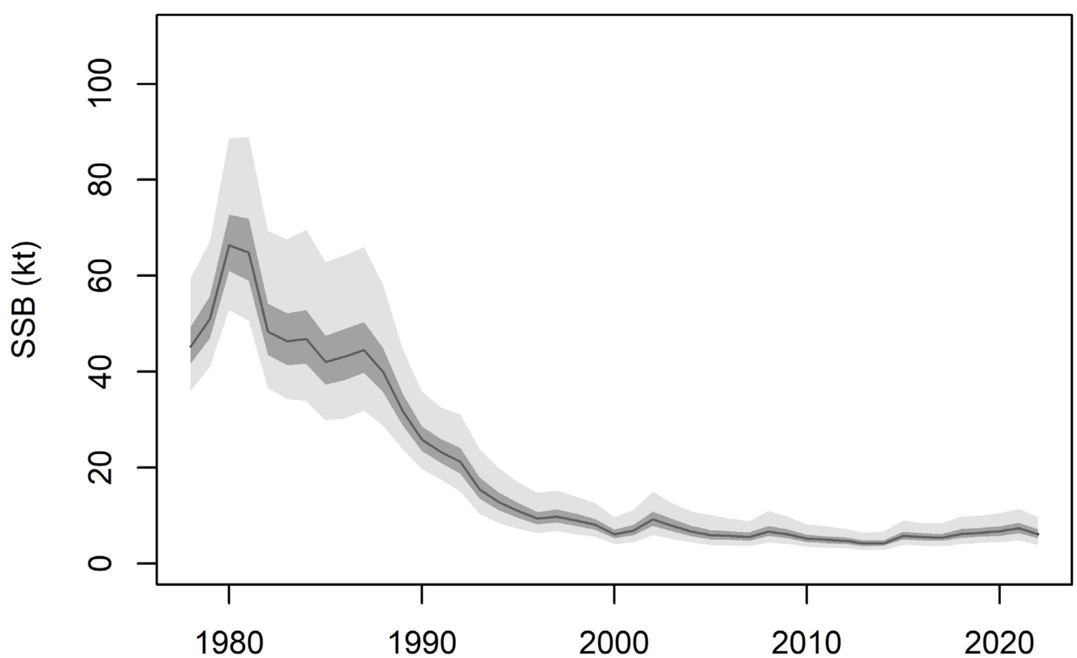

Figure 4.5: Estimated spawning stock biomass (SSB, kt) of White Hake in the southern Gulf of St. Lawrence. Solid line is the median and dark and light shading the 50% and 95% confidence interval from the MCMC sampling.

Average F for ages 2-3 was estimated to be negligible over the time series. Average F for ages 4-5 was low over the time series, peaking at 0.12 in 1992 (Figure 4.6). Average F for ages 4-5 is estimated to have been below 0.004 since 2006. Low F for ages 4-5 was expected has only age 5 is well recruited to the fishery (Figure 4.9). Average F for ages 6+ varied between 0.2 and 0.4 in the 1970s and 1980s before increasing to a peak at 0.72 in 1992. F then decreased to 0.03 in 1995 with the imposition of the moratorium on directed fishing for Hake and has remained low since then, except for a period in the late 1990s and early 2000s when F peaked at 0.39. F at all age ages has been under 0.1 since 2006, and under 0.02 since 2018.

In most years, the dominant source of mortality for sGSL White Hake has been natural mortality (Figure 4.6). Average M for ages 2-3 gradually increased over the time series, from 0.5 in 1978 to 1.1 in 2022 (39% to 67% annual mortality). Average M for ages 4-5 gradually increased from 0.36 to 2.3 between 1978 and 2004 (30% to 90% annual mortality). Average M then decreased to 1.68 in 2022 (81% annual mortality). Average M for ages 6+ followed a similar trend, gradually increasing from 0.31 to 1.62 between 1978 and 2005 (27% to 80% annual mortality). Average M then slowly declined until 2022 (1.05; 65% annual mortality). Natural mortality exceeded fishing mortality in all age groups and all years.

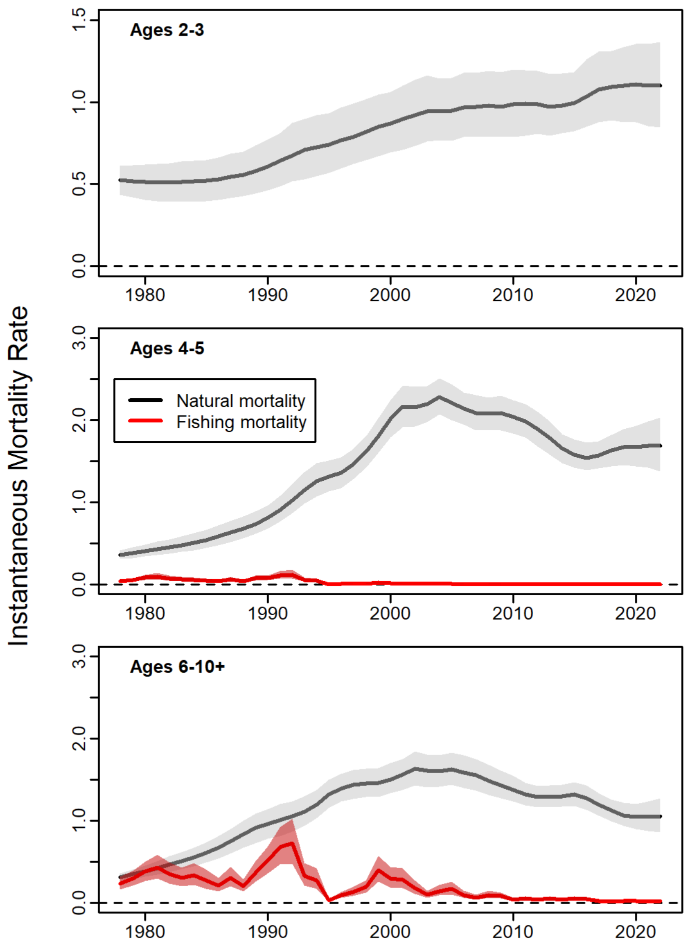

Figure 4.6: Estimated instantaneous rates of fishing and natural mortality (F in red and M in black, respectively) by age group (ages 2-3, ages 4-5, ages 6+). Solid lines are the median and shading are the 95% confidence intervals from the MCMC sampling.

Abundance of age-2 recruits fluctuated with little trend over time (Figure 4.7, though average recruit abundance was slightly higher in 1998-2022 (56.6 million fish) than in 1978-1997 (49.11 million fish). Recruitment rates (the number of recruits divided by the SSB that produced them) were low (1.2 thousand fish per ton of SSB) on average between 1980 and 1994. Rates increased until the early 2000s and the average recruitment rate between 1995 and 2022 was 8.6 thousand fish per unit of SSB. Rates varied almost periodically between 1995 and 2022, and rates were decreasing in the last years of the assessment (2019 to 2022). The recruitment rates in 2021 and 2022 were 6.8 and 5.5 thousand fish per ton of SSB, respectively, the lowest values estimated since the late 1990s to early 2000s.

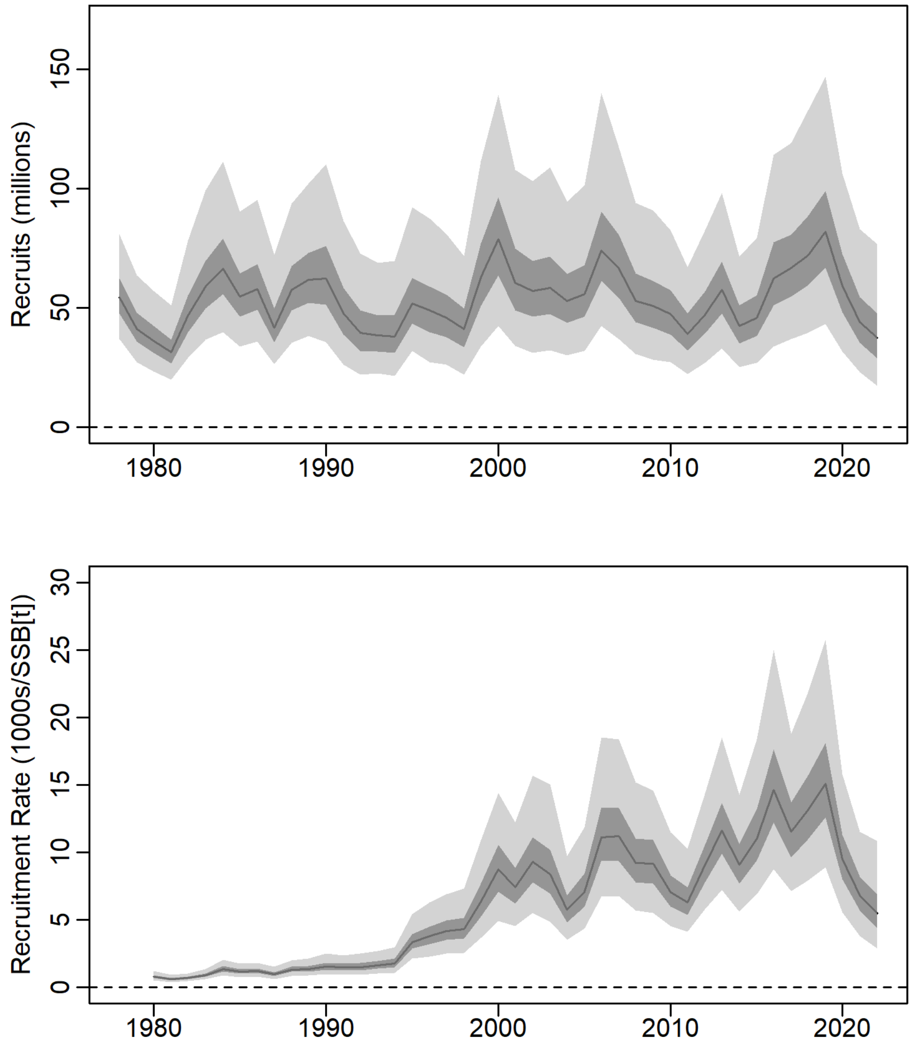

Figure 4.7: sGSL White Hake estimated abundance of age-2 recruits (upper panel) and recruitment rates (age-2 recruits/SSB) by year-class. Solid lines are the median and dark and light shading the 50% and 95% confidence interval from the MCMC sampling.

The log recruitment rates showed a strong inverse relationship with SSB (Figure 4.8, which suggests strong recruitment compensation, i.e. improved recruitment success at low SSB due to a relaxation of density-dependent constraints on productivity. Hake are known to be cannibalistic (Davis et al. 2004; Benoît and Swain 2008), and cannibalism is one factor that may promote strong compensation in their stock-recruit relationship. White Hake have been considered to be among the most fecund of the commercial groundfish species (Beacham and Nepszy 1980). Fecundity is reported to be about 4 million eggs for a female 70 cm long and 15 million eggs for a female 90 cm in length (Scott and Scott 1988).

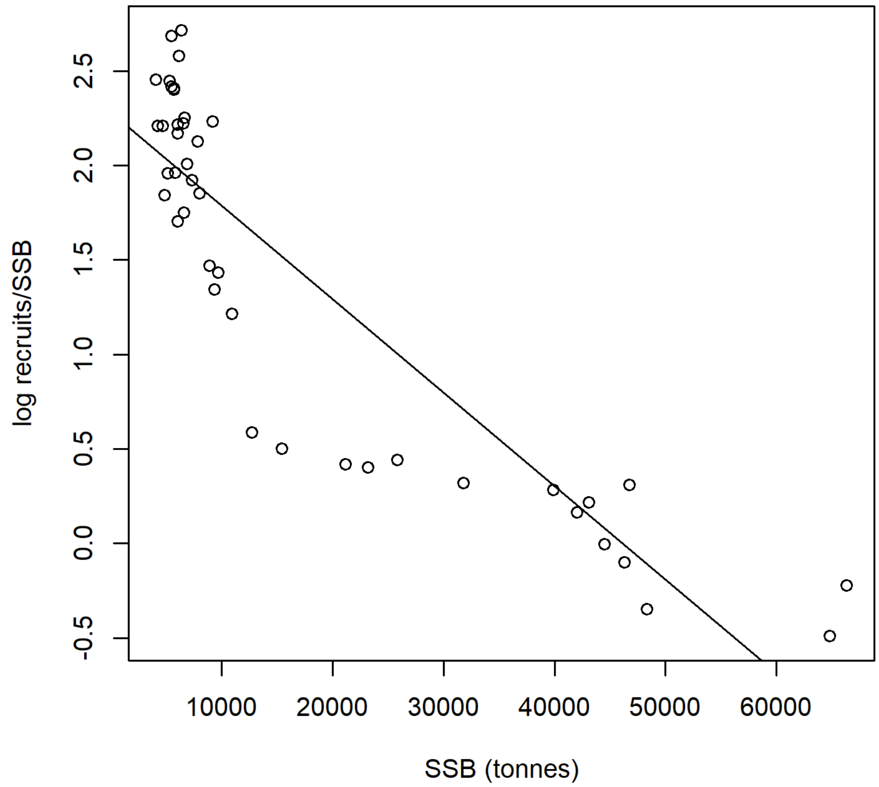

Figure 4.8: sGSL White Hake estimated log recruitment rates (age-2 recruits/SSB) in function of SSB. Solid line is a linear regression line.

Fishery selectivity was flat-topped with ages <5 being poorly recruited and ages 7-10+ estimated to be fully recruited (Figure 4.9). Selectivity at ages 4 to 7 was slightly higher in the 1978-1994 period. Fully-recruited q was estimated to be 0.48 for both the RV survey and the MS survey.

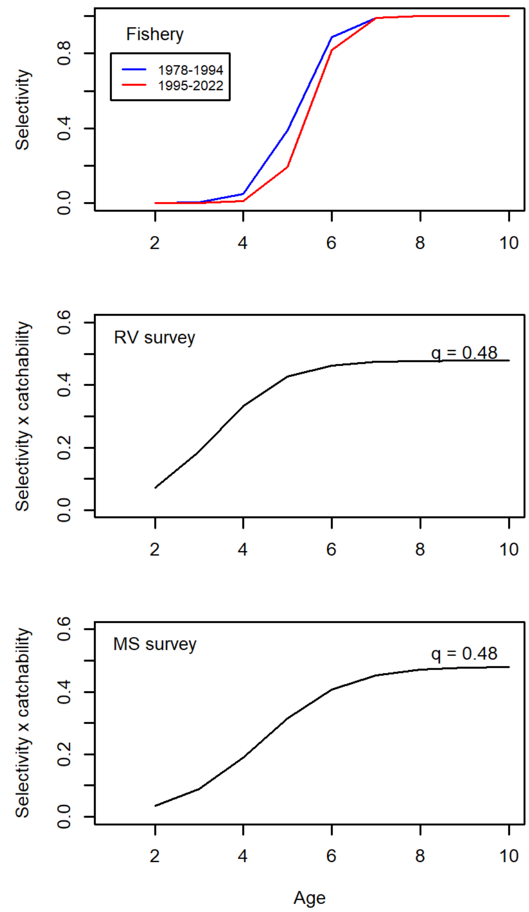

Figure 4.9: Southern Gulf of St. Lawrence (sGSL) White Hake estimated selectivity at age to the commercial fishery (upper panel) for years 1978-1994 (blue) and 1995-2022 (red), catchability and selectivity to the sGSL research vessel (RV) survey (middle panel) and to the Mobile Sentinel (MS) survey (lower panel).

Uncertainties related to the population model structure and data limitations remain. Unaccounted for fishing mortality (discards-at-sea, unreported catches) is likely a small component of the estimated natural mortality values (see sections 2.2 and 9.4). Efforts should be made to estimate these removals and integrate them into the total catch. However, the age composition of the catches would be difficult to estimate. In addition, there have been important changes in the fishery over time and the associated changes in gear selectivity may be more important than what the model currently allows for. Estimating natural mortality in any population model is demanding. Here, the pairing of ages 2 and 3 may not be ideal as these age groups may have different predators and sources of mortality. Given the inability to de-confound recruitment and mortality of those recruits, beginning of year abundance of age 2 is uncertain. The older Hake age group (6-10+) is only informed by the age 6 to age 7 information from surveys, as these age composition inputs only go up to age 7. Strong retrospective patterns were identified for key stock parameters. While this indicates issues with the potential accuracy of the assessment, this is very unlikely to affect the stock trajectory and status.

5. REFERENCE POINTS

The current LRP for this stock (12,800 t of SSB) was defined as the SSB equal to 40% of the SSB producing the maximum surplus production in a lower productivity period (without fishing mortality). It was established in 2016 as a recovery target in the Hake recovery potential assessment (Swain et al. 2016). As many years of data have been added to the assessment since this LRP was established, a review of its applicability was in order. There is no upper stock reference (USR), target reference point (TRP) or removal reference (RR) for this stock.

5.1. METHODS

5.1.1. Stock recruit relationships

Three parametric stock recruitment relationships (SRR) were used: Beverton-Holt, Ricker and Hockey Stick. The Beverton-Holt and Ricker models were fit to the data using the nls function in the R statistical software (R Core Team 2024). The Beverton-Holt (BH) model was of the form:

$$R = aS/(b + S)$$

where R is the number of recruits in a given year class, S is the spawning stock biomass that produced that year class, a is the maximum number of recruits produced, and b is the spawning stock biomass needed to produce, on average, recruitment equal to half of the maximum.

The Ricker (RK) model was of the form:

$$R = aSe^{-bS}$$

where a is the recruits per unit of spawner biomass at low stock levels and b relates to the rate of decline in the recruits per unit of spawner biomass as S increases.

The Hockey Stick (HS; also named segmented or change-point regression) models the SRR in two segments, one being a flat line at maximum recruitment and the other a straight line from the origin to a point intersecting the flat segment. The intersection of the two lines is determined by an iterative grid search method using Julious’s algorithm (Julious 2001; O’Brien et al. 2003) .

The LRP derived from SRRs will be dependent on the functional form of the relationship and the type of dynamics observed. Typically, the LRP is the SSB at 50% of the maximum recruitment estimated by the SRR.

5.1.2. MSY proxy from the DFO Precautionary Approach guidelines

Estimates of biomass that produce maximum sustainable yield (B_{MSY}) are typically used to derive LRPs from population models. However, they require stationarity in demographic productivity parameters. The absence of equilibrium in natural mortality precludes the use these methods for sGSL Hake.

In the absence of an estimate of B_{MSY} from an explicit model, the Precautionary Approach (PA) framework provides guidance to identify reference points and harvest rules (DFO 2009). The provisional estimate of B_{MSY} could be taken as follows (select the first feasible option): (1) the biomass corresponding to the biomass per recruit at $F_{0.1}$ multiplied by the average number of recruits; or (2) the average biomass over a productive period; or (3) the biomass corresponding to 50% of the maximum historical biomass (DFO 2009).

5.1.2.1. The biomass corresponding to the biomass per recruit at $F_{0.1}$ multiplied by the average number of recruits

To obtain the $F_{0.1}$ value, a yield per recruit analysis was performed using the *ypr* function of the fishmethods package (Gabriel et al. 1989) in the R statistical software. A gear selectivity vector and a natural mortality vector for ages 2-10+ in the initial assessment year (1978) were used as a proxy year for equilibrium conditions (higher weight at age, lower M at age). The mean weight at age in years 1978 to 1981 (to account for low sample size at older ages) was used. The survival per recruit at $F_{0.1}$ was calculated using a survivorship analysis:

$$lage_a = lage_{a-1}e^{-(M_{a-1}+Fsel_{a-1})}$$

and for the plus group:

$$lage_a = lage_{a-1}e^{-(M_{a-1}+Fsel_{a-1})}/1 - e^{-(M_a+Fsel_a)}$$

Where $lage_a$ is the survival at age of age a, M_a is natural mortality at age, F is fishing mortality and sel is selectivity at age. The F value was set to $F_{0.1}$.

To obtain the SSB per recruit at $F_{0.1}$, the survival per recruit multiplied by the weight at age and maturity at age vectors was summed over all ages. The SSB per recruit at $F_{0.1}$ was multiplied by the average number of recruits estimated by the random walk over the time series. The LRP derived from this $BMSY_{proxy}$ was calculated as 40% of its value (named $40\%PA1BMSY_{proxy}$).

5.1.2.2. The average biomass over a productive period.

Stock production was calculated as:

$$P_t = C_t + B_{t+1} - B_t$$

Where P_t is the stock production in year t, C_t is the fishery catch in year t, B_{t+1} is the stock biomass for ages 2+ in year $t+1$ and B_t is the stock biomass for ages 2+ in year t. Productive periods were identified by finding uninterrupted periods of 5 years during which stock production and stock biomass were simultaneously near or at their highest values. The $BMSY_{proxy}$ was calculated as the mean SSB in the identified years. The LRP derived from this $BMSY_{proxy}$ was calculated as 40% of its value (named $40\%PA2BMSY_{proxy}$).

5.1.2.3. The biomass corresponding to 50% of the maximum historical biomass.

50% of the highest SSB in a single year was used to derive a $BMSY_{proxy}$. A candidate LRP was calculated at 40% of its value ($40\%PA3BMSY_{proxy}$).

5.1.3. B_0

B_0 is the mean long-term equilibrium spawning stock biomass of the stock in the absence of fishing. The per-recruits methods require equilibrium to derive reference points, so that their outcome adequately represent the average state of the stock. However, these methods assume stationary productivity parameters. Over the years of the Hake assessment, M increased and weight- age-age declined, violating the assumption of equilibrium over time. Hence, a year where the stock was in its best productivity state over the assessment period was selected to perform the calculations.

The year 1978 was selected to represent a productive period (high weight at age and lowest M at age). A vector of unfished spawners per recruit was calculated using M at age in the year 1978. SSB per recruit (ϕ_0) was then calculated by multiplying the spawner per recruit, the mean weight at age in years 1978 to 1981 (to account for low sample size at older ages) and maturity at age vectors.

B_0 is usually calculated by multiplying ϕ_0 by the average expected equilibrium unfished recruitment from a stock-recruit relationship. However, the sGSL Hake stock recruit relationships estimated for this stock are not credible (see below). As recruitment fluctuated without trend over the time series and seems independent of SSB within the estimated SSB range, this level of recruitment is assumed here to be a proxy for equilibrium recruitment. Hence, B_0 was calculated using the average recruitment over the time series.

5.2. RESULTS

5.2.1. Stock recruit relationships

The BH SRR model did not produce an acceptable fit to the data. The RK SRR model did not fit the data well (Figure 5.1). The ascending part of the curve and the estimated maximum are not supported by data. The stock recruit pairs at low biomass do not exhibit decreasing recruitment with decreasing biomass. Instead, a wide range of recruits were estimated to be produced at low SSB. There is no stock recruit pairs at the estimated maximum of the curve. Most stock recruit pairs are within a range of recruit values that occur across the SSB range.

The HS model fit set the inflexion point of the regression at the lowest SSB point and the diagonal part of the regression is not supported by data. The horizontal part of the regression is credible as there is no discernible trend in the stock recruit pairs. However, as the inflexion point of the regression is not supported by the data, the HS SRR should not be used to derive a LRP based on the SSB at 50% maximum recruitment.

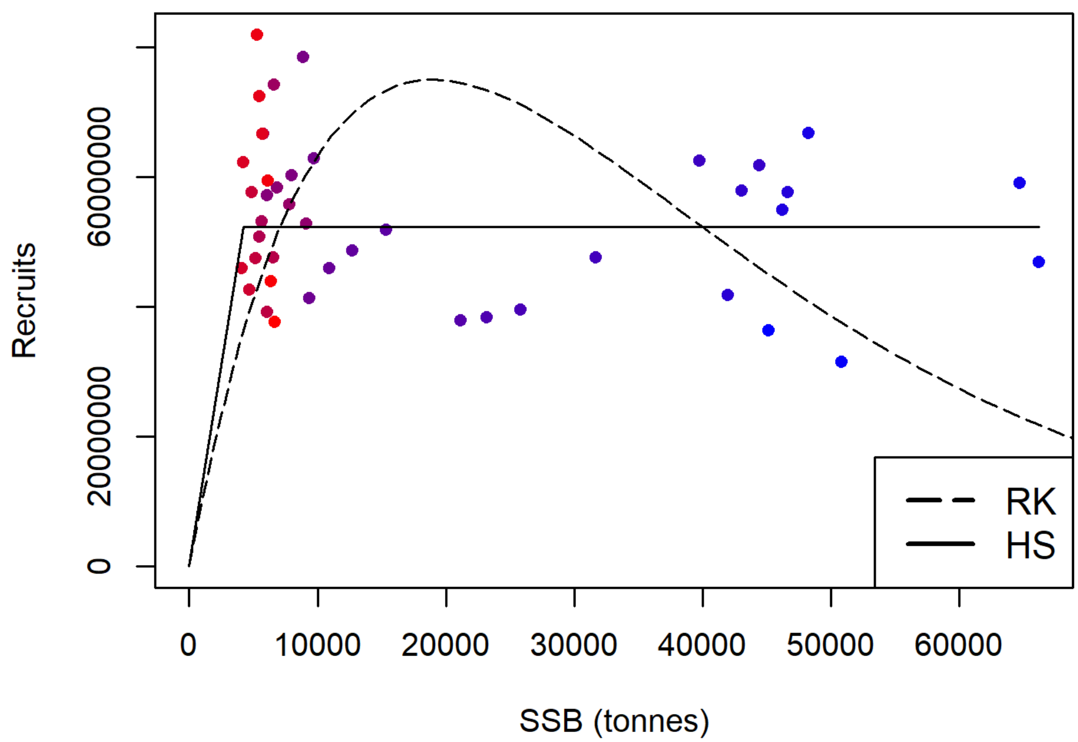

Figure 5.1: Ricker and segmented regression stock recruit relationships for southern Gulf of St. Lawrence White Hake.

5.2.2. MSY proxy from the DFO Precautionary Approach guidelines

5.2.2.1. The biomass corresponding to the biomass per recruit at $F_{0.1}$ multiplied by the average number of recruits:

$F_{0.1}$ was estimated at 1.0 for the initial year of the assessment period (1978). The SSB per recruit at $F_{0.1}$ was estimated at 0.000780797 t. The average number of recruit over the assessment period was 53,254,492. The SSB corresponding to the SSB per recruit at $F_{0.1}$ multiplied by the average number of recruits was 41,580 t. The associated LRP (40%PA1BMSY$_{proxy}$), was 16,632 t of SSB.

5.2.2.2. The average biomass over a productive period:

Hake production was highest between 1978 and 1982 and averaged 12,426 t of SSB annually (Figure 5.2). Production declined and reached consistently near zero or negative values by 1987. The average annual production over the 1987 to 2021 period was -325 t. A low production and low biomass state was persistent since the early 1990s.

The relationship between the rate of population production (Pt/Bt) and population biomass (Bt) has not exhibited positive density dependence over the time series as a whole (linear regression parameters not significant). A piecewise regression did find a break-point at 68,330 (SE: 9,226) tonnes of biomass. However, the data at medium to high biomass is scarce, making the results of this analysis difficult to support. Only four data points are to right of the break point to support its estimation. A linear regression over the data filtered for the biomass below the breakpoint was almost significant (p: 0.0523), and the positive slope suggests sGSL Hake could be experiencing an Allee effect (Figure 5.3). However, the wide range of production values at low biomass does not support the linear regression well, likely reflecting the wide range of recruitment values estimated at low biomass. When looking at production as a whole in this analysis, the high predation-driven mortality effect on sGSL Hake and the expected depensation associated with it is likely masked by the very high recruitment rates at low biomass. The high natural mortality in this stock acts as a direct effect on the reduction of the number of adults, that does not translate in a reduction of reproductive capacity and output that can be observed for other stocks in similar situations (e.g. sGSL Atlantic Cod; (Neuenhoff et al. 2019; Turcotte et al. 2024)). Overall, the breakpoint identified here is not supported to inform the position of an Allee threshold for this stock.

A proxy for B_{MSY} was defined as the average SSB in years 1978 to 1982, a high biomass high production period (Figure 5.4) and was estimated at 55,053 t. The chosen year period for productivity is consistent with DFO 2023 guidance for historical proxies for B_{msy}: “A historical proxy for B_{MSY} can be estimated as the mean or median value of an indicator or model estimate over a historical time period when the indicator is high (and assumed recruitment is stable) and catches are high; or the mean or median value of an indicator over a productive period. The associated USR, 80%BMSY$_{proxy}$, was estimated at 44,042 t. The LRP, 40%PA2BMSY$_{proxy}$, was estimated at 22,021 t.

5.2.2.3. The biomass corresponding to 50% of the maximum historical biomass:

The SSB corresponding to 50% of the maximum historical was 33,119 t of SSB (50%PA3BMSY$_{proxy}$).

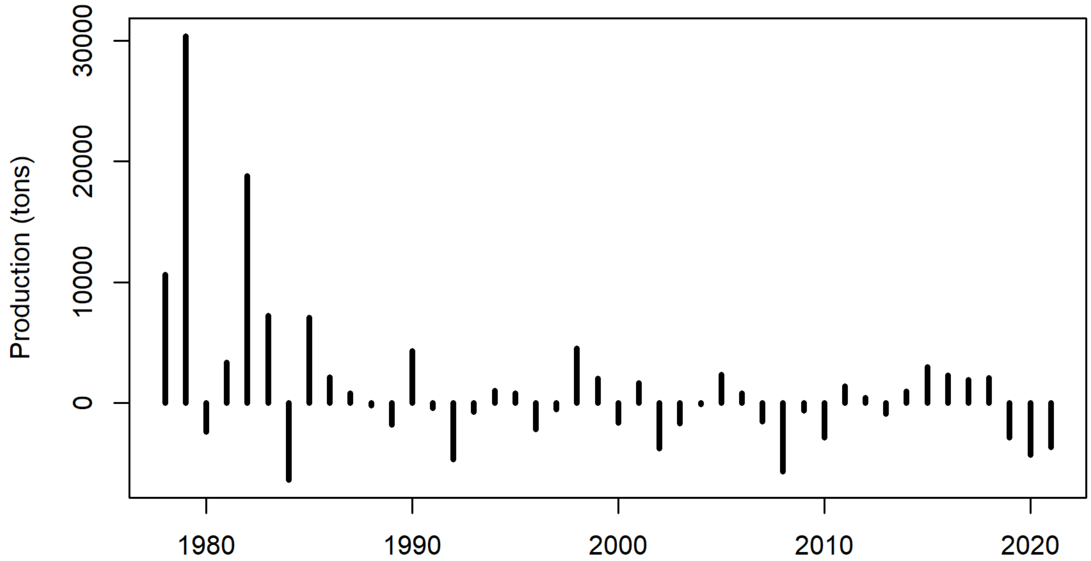

Figure 5.2: Southern Gulf of St. Lawrence White Hake annual production (tonnes; black bars) between 1978 and 2022.

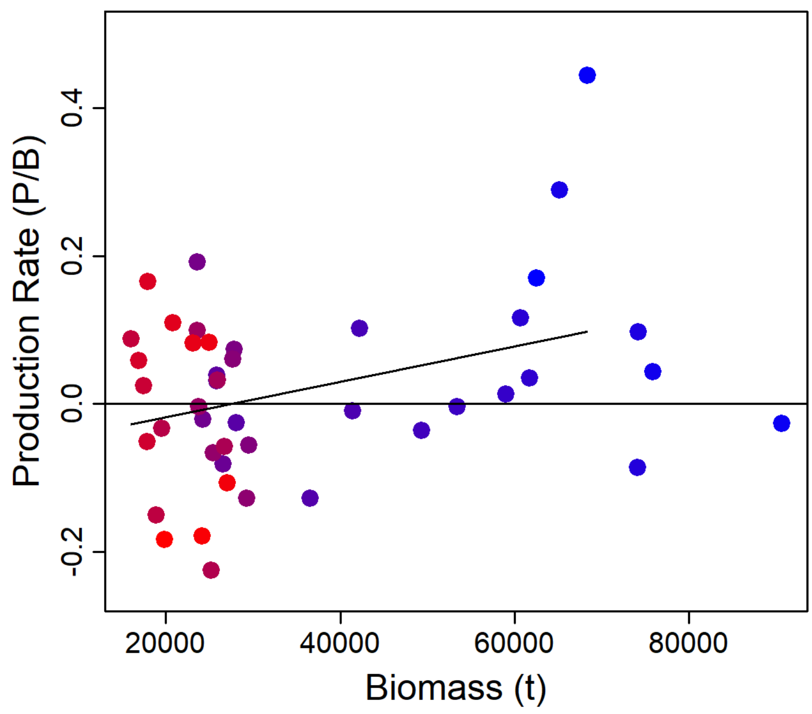

Figure 5.3: Annual production rate (P/B, population production of biomass per unit of population biomass) by southern Gulf of St. Lawrence White Hake, 1978 to 2022. Circle colour indicates year (1978–blue, 2022–red). Diagonal black line is linear regression for data below the breakpoint identified by a piecewise regression.

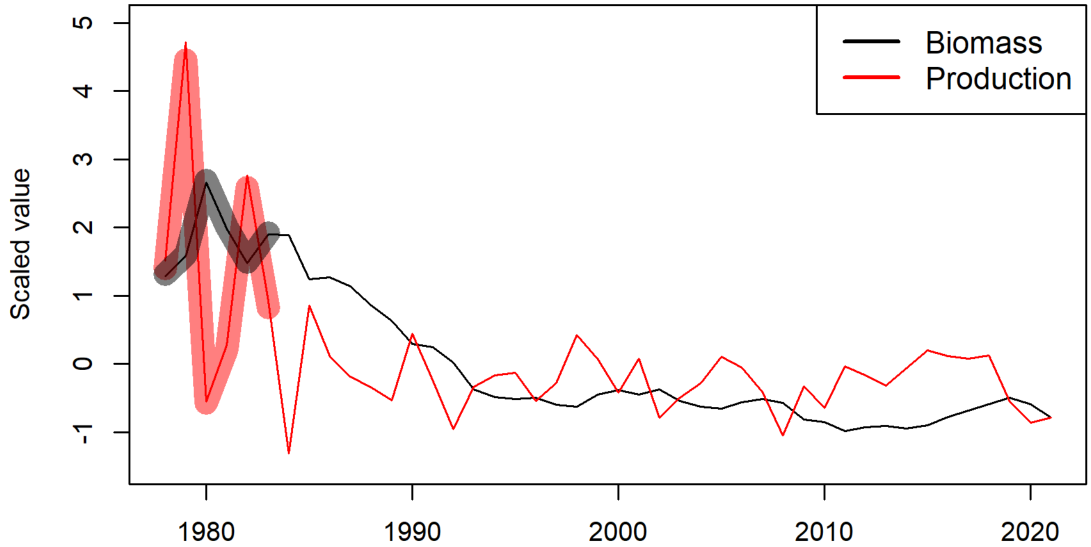

Figure 5.4: Scaled values of stock biomass (black line and shading) and production (red line and shading) between 1978 and 2022. The shaded areas indicate the selected high-biomass high-productivity years (1978-1982).

5.2.3. B_0

The estimated ϕ_0 value was 0.00201965 units of SSB per recruit. The corresponding initial B_0 value was 107,555 t. Initial $0.2B_0$ was estimated at 21,511 t of SSB.

5.2.4. Best LRP

In the context of fisheries, serious harm can be defined (DFO 2023) as an undesirable state that may be irreversible or only slowly reversible over the long-term. It may be directly or indirectly due to fishing, other human-induced impacts, or other natural causes, and occurs at states before extirpation is a concern. These states can be associated with impaired productivity or reproductive capacity, resulting from changes to biological processes such as recruitment, growth, maturation and survival, and may lead to a loss of resilience, defined as an impaired ability to rebuild, exceed replacement or to recover from perturbation. These states can be associated with an elevated risk of depensation or Allee effect (i.e., negative density dependence, in which the intrinsic rate of increase for a stock decreases, rather than increases, as abundance declines) and are states where population dynamics are generally poorly understood. When a stock is estimated to be at risk of serious harm, there may also be resultant impacts to the broader socio-ecological system, such as the ecosystem, associated or dependent species, or a long-term loss of fishing opportunities. However, economic inefficiencies such as growth overfishing or reduced yield do not in and of themselves constitute serious harm to the stock.

Hake biomass and production were highest between 1978 and 1982 but were low from the 1990s until 2022. The persistence of a low production-low biomass state since the early 1990s is an indicator of serious harm (Kronlund et al. 2018). The relationship between the rate of population production and population biomass did not suggest that an Allee effect is occurring for sGSL Hake. Production as a whole, mostly driven by high recruitment rates, remained sufficient to maintain the stock at a low level. Considering the truncated age composition, very high M and evidence of it being driven by grey seal predation (Benoît et al. 2011) this stock is likely in a predator pit (Bakun 2006).

The $0.2B_0$ candidate LRP was only partially supported because of the uncertainty in recruitment estimates. The stock recruit relationships for this stock are not credible, and the average recruitment over the time series was used as a proxy for equilibrium recruitment. The high CV in recruitment estimates from the retrospective analysis and blocking of residuals in the proportions at ages 2 and 3 in abundance indicators suggest that the recruitment estimated by the population model is uncertain. Hence, a candidate LRP generated using a method that does not directly use recruitment dynamics would be more appropriate for this stock. $0.4PA2BMSY_{proxy}$ is a simpler analysis that uses production and biomass as metrics to derive a proxy for B_{MSY}. Both series of estimates are credible and a good basis to derive an LRP, relying on the PA guidelines.

Two candidate LRPs received at least partial support, and both candidate LRPs are very close in estimated value. The fact that the two candidate LRP values are close gives support to the years selected for the proxy for B_{MSY}, but also to the proxy for equilibrium recruitment used in the B_0 calculation. As $0.2B_0$ is a proxy for $0.4B_{MSY}$ (DFO 2023), the proximity of the two LRP candidates further supports the results.

The supported LRPs both put the stock in the critical Zone of the PA in 1992. The year 1992 concurs with the LP-LB state occurring since the early 1990s, which is an indicator of serious harm for this stock. As $0.4PA2BMSY_{proxy}$ is fully supported, it is recommended as the LRP for the sGSL White Hake stock.

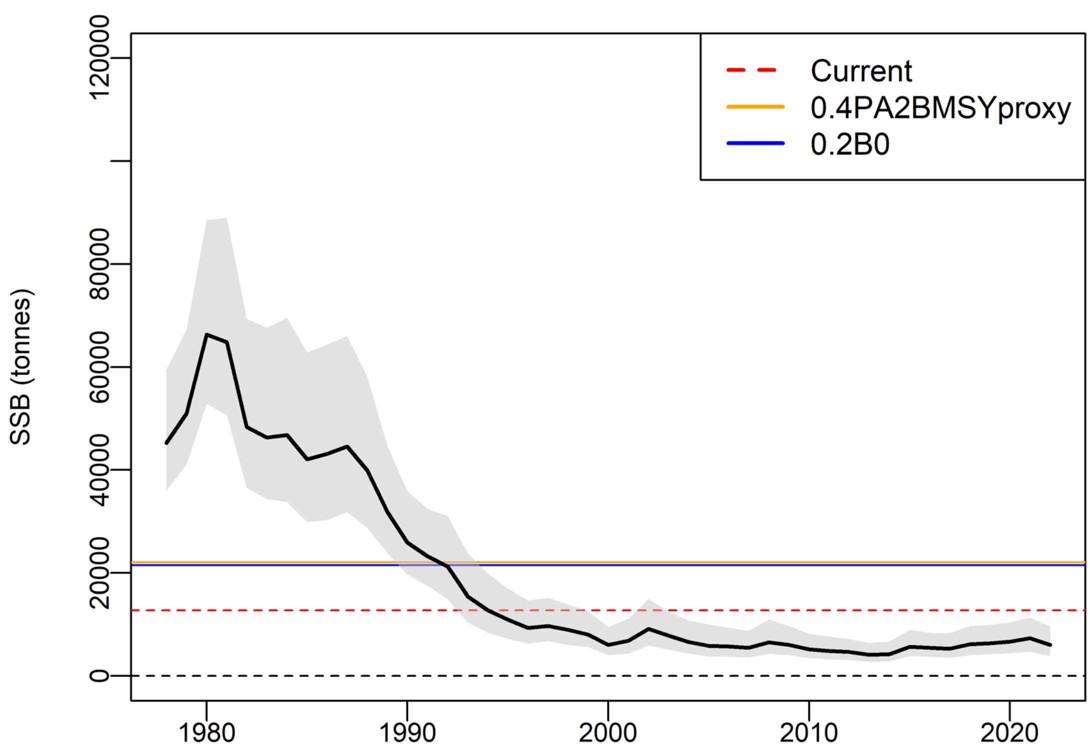

Figure 5.5: Candidate limit reference points for southern Gulf of St. Lawrence White Hake where at least partial support was received; $0.4PA2BMSY_{proxy}$ (full support, orange solid line) and $0.2B_0$ (partial support, blue solid line). Red dashed line is the current limit reference point. Black line is the median SSB estimate (kt) and grey shading is the 95% confidence interval.

As previously done for Hake, a stock status indicator based on the annual RV survey can be computed in the interim years (DFO 2020). The RV indicator for an interim update is the RV survey 3-year moving average catch in units of kg/tow for Hake 45 cm+ (Figure 5.6). An assessment would be triggered if the value of the RV index exceeds the re-scaled value of the LRP.

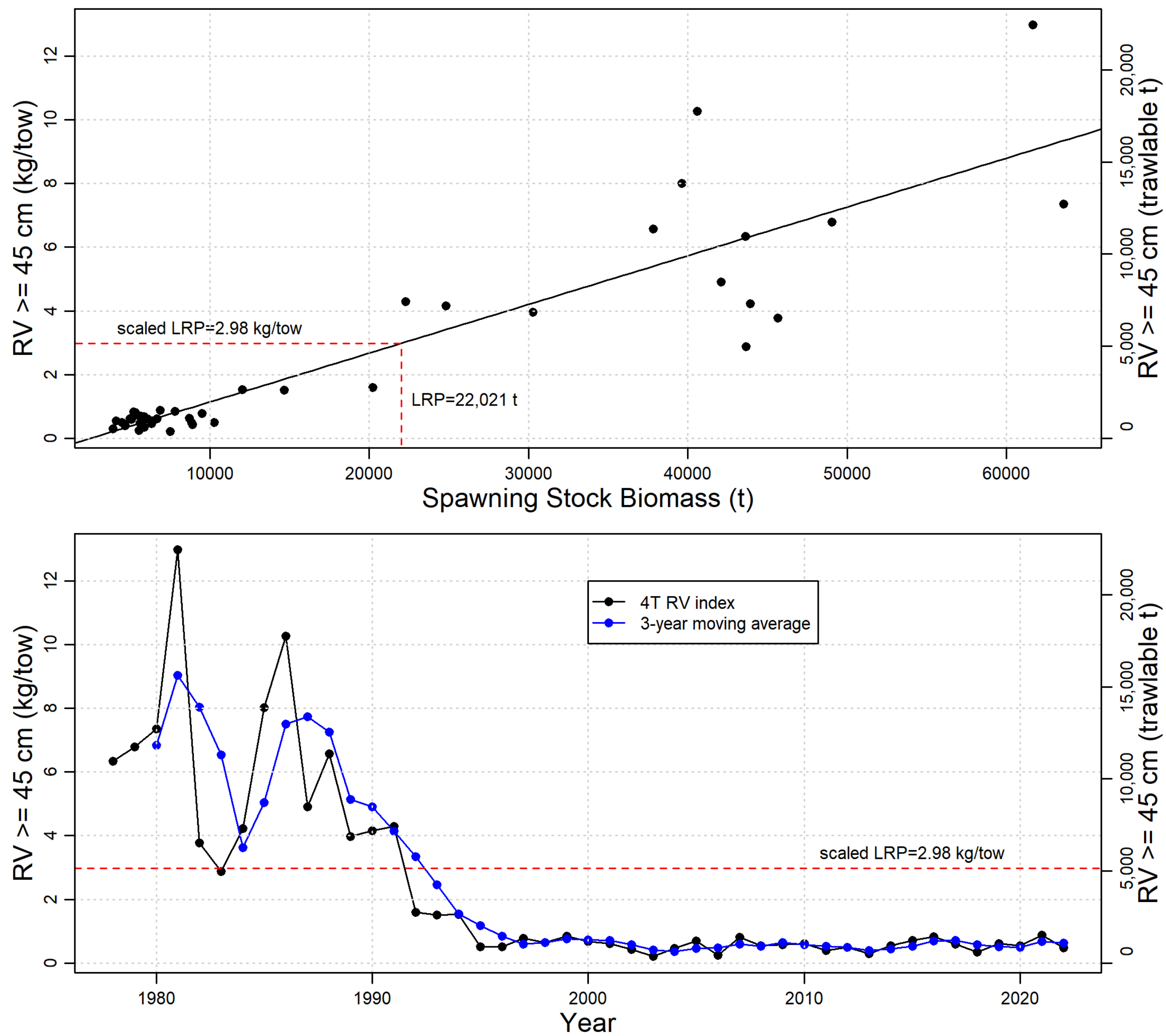

Figure 5.6:Top panel: linear regression (black line) between annual RV survey White Hake 45+ cm kg/tow (left axis) and stratified mean trawlable biomass (right axis) and estimated White Hake spawning stock biomass (black points). Vertical red dashed line is limit reference point value in units of spawning stock biomass. Horizontal red dashed line is re-scaled limit reference point value in units of kg/tow. Bottom panel: Annual RV survey White Hake 45+ cm kg/tow (left axis) and stratified mean trawlable biomass (right axis, black points and line) and its 3 year moving average (blue points and line). Red horizontal dashed line is the limit reference point scaled to the RV survey catch in kg/tow.

5.2.5. Other PA reference points

Using the default suggested by the PA, a USR and TRP can be calculated from a proxy for B_{MSY}. The USR ($0.8BMSY_{proxy}$) was estimated at 44,042 t of SSB and the TRP ($BMSY_{proxy}$) was estimated at 55,053 t of SSB (Figure 5.7). While determining the LRP is the role of the DFO Science Sector, the USR and TRP definitions are DFO Fisheries and Harbour Management's role. Here, the calculated default PA framework USR and TRP can be proposed as interim candidates for these reference points.

The average fishing mortality of sGSL Hake ages 6+ in the years selected as a proxy for B_{MSY} was 0.34. It could be argued that at this average removal rate, the stock did not immediately start declining in response to removals that would have been too important for the productivity of the stock, and could be considered a proxy for F_{MSY}. The stock did decline a few years later but at that time F and M were both higher than in the 1978 to 1982 period. Therefore, an interim removal reference of 0.32 could be used as a proxy for F_{MSY} for this stock. However, as natural mortality reached really high levels since that period, this stock should be managed with considerations on Z (the total mortality), if any commercial harvest was to resume. In the event that a science advice was requested to provide sustainable harvest levels of sGSL Hake in the future, populations projections at various F levels and at the M levels occurring at that time should be performed and the stock response should be evaluated to guide the risk management of TAC options.

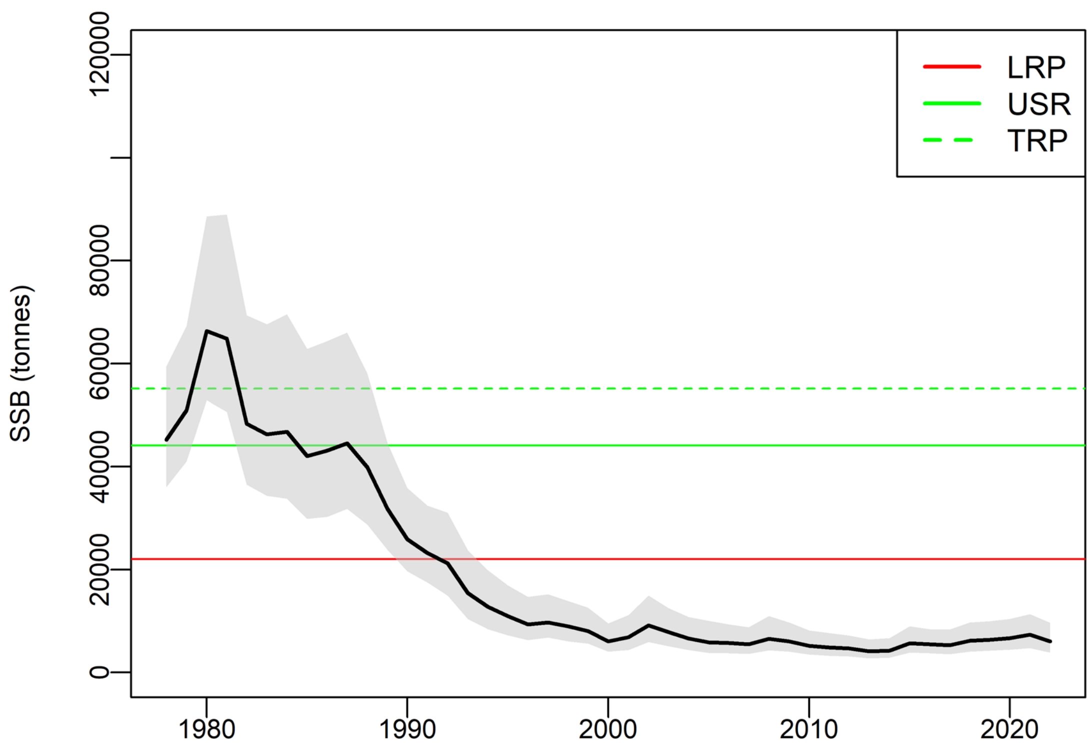

Figure 5.7: Reference points for southern Gulf of St. Lawrence White Hake (Limit reference point 0.4B_{MSY}, red line; Upper stock reference 0.8B_{MSY}, green full line; Target reference point B_{MSY}, green dashed line). Black line is the median SSB estimate (kt) and grey shading is the 95% confidence interval.

5.2.6. Stock status and trends

Using the newly defined LRP and interim USR from this study, the 2022 stock status is in the Critical Zone. The stock was in the Cautious Zone in 1978 and reached the Healthy Zone in 1979 where it stayed until 1988. The stock started to decline and reached the Cautious Zone in 1989. The stock kept declining and reached the Critical Zone in 1992, where it stayed until 2022. With the former LRP, the stock was estimated to have entered the Critical Zone in 1995.

The probable cause of the sGSL White Hake stock decline is high mortality. Fishing mortality for ages 6+ varied between 0.2 and 0.4 in the 1970s and 1980s. Natural mortality increased at all ages between 1978 and 2000, and fishing mortality rapidly increased from 0.35 to 0.69 between 1989 and 1992. SSB started to rapidly decline in 1989. This period of high mortality of older fish led to the age truncation that is estimated in the population the early 1990s. Predation-driven high natural mortality is now likely the main factor preventing the White Hake recovery.

6. REBUILDING TARGET AND TIMELINE

For a prescribed major fish stock subject to the FSP, the legal obligation of a rebuilding plan under section 6.2 only applies while the stock is at or below its LRP. However, to increase the likelihood that a stock will not decline back to or below its LRP and to be consistent with the 2009 PA Policy intent to grow depleted stocks to healthier levels (DFO 2009), a rebuilding plan will remain in effect until the stock reaches its rebuilding target. Once the stock reaches its rebuilding target, the rebuilding plan will come to an end and the stock will be subject to the Integrated Fisheries Management Plan (IFMP) or other management plan.

DFO guidelines on rebuilding plans state that the rebuilding target must be set at a level far enough above the LRP that there is a very low to low likelihood of the stock being below its LRP (< 5-25% probability; DFO 2022). Consequently, DFO Fisheries and Harbour Management defined the rebuilding target for this stock as having been reached when there is at least a 75% probability that the stock is at or above the LRP. The sGSL White Hake stock is assessed using a statistical catch at age model, therefore determining when the rebuilding target is achieved and monitoring the performance of the rebuilding plan should be accomplished using the accepted model and the estimated uncertainty from the model. As such, the value of the target is model-dependent and will change with every assessment as years of data are added and/or as model changes are implemented. Hence the target should be defined as “the SSB where there is a very low to low likelihood of the stock being below its LRP (< 5-25% probability)”, and not as a fixed number.

The science guidelines to support development of rebuilding plans for Canadian fish stocks states that the rebuilding target should be set far enough above the LRP that there is a low probability of falling below the LRP in the short to medium term (DFO 2021). The current rebuilding target proposed for this stock is being at or above the LRP with 75% certainty, and particularly as the uncertainty in SSB estimates for this stock are relatively small this means that the rebuilding target is very near the LRP (Figure 6.1). As such, this target theoretically offers a higher probability of the stock falling below the LRP than a target set closer to the USR or the TRP for example. If this rebuilding target is retained, it may be important to consider including additional considerations to the target such as; the stock must be at or above this level for 5 consecutive years, and population projections must show the stock is likely to continue its positive trajectory under harvest for 5 years after the rebuilt state has been achieved. Five years was selected since a rebuilding timeline could not be calculated or used to inform the choice of the number of years of growth that would minimize the probability of the stock falling below the LRP in the short to medium term. The number of years has consequently been set to the multi-year assessment cycle and projections timeline for advice for this stock. This is also the frequency of review of the rebuilding plan (see below).

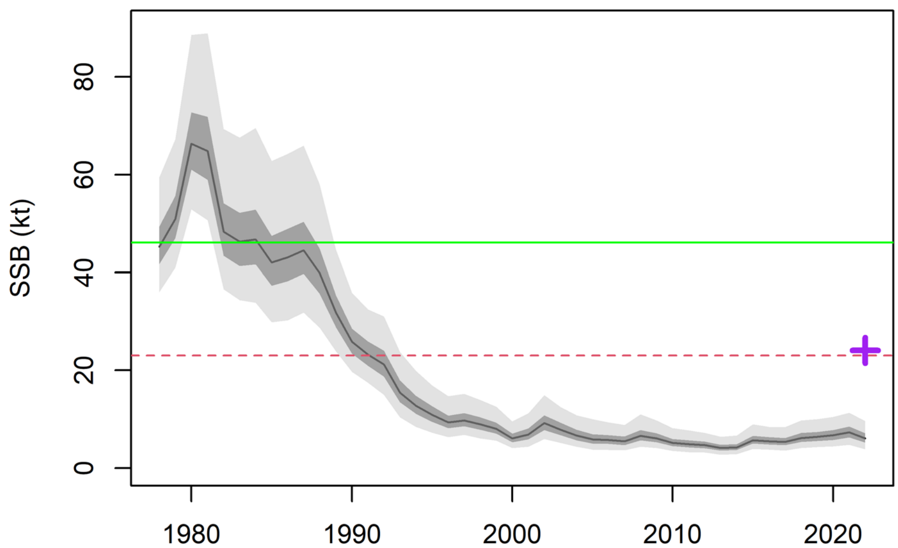

Figure 6.1: Southern Gulf of St. Lawrence White Hake rebuilding target at 75% certainty (purple cross) assuming the 2022 level of uncertainty around SSB estimates. Limit reference point $0.4B_{MSY}$, red line; Upper stock reference $0.8B_{MSY}$, green full line Black line is the median SSB estimate (kt), light grey shading is the 95% confidence interval and dark grey shading is the 50% confidence interval.

A rebuilding plan also requires that the timeline to rebuild be identified in order to track rebuilding progress with respect to the objectives and management measures. The international standard and the approach recommended by DFO 2021 is to estimate the time to reach the rebuilding target in the absence of all fishing (T_{min}). As seen in the last stock assessments, the stock was unlikely to rebuild to the previous LRP (Rolland et al. 2022a).

If T_{min} cannot be calculated, an estimate of an alternative such as generation time provided by DFO Science can be used by Fisheries and Harbour Management to define a rebuilding timeline. The generation time is estimated to be 9 years for sGSL Hake (DFO 2016). As the stock is unlikely to rebuild under prevailing conditions and a rebuilding timeline cannot be calculated (see below), the rebuilding timeline is instead set to correspond with the periodic review of the rebuilding plan. During each review, the factors limiting the stock's potential for growth will be re-assessed to determine if they are still influencing the stock and whether a rebuilding timeline can be calculated.

7. LIKELIHOOD OF ACHIEVING THE REBUILDING TARGET UNDER VARIOUS ENVIRONMENTAL AND/OR MANAGEMENT SCENARIOS

7.1. PRODUCTIVITY SCENARIOS

In the absence of fishing, natural mortality and recruitment are the two main drivers of the sGSL White Hake population. The objective of the following analysis was to identify the contribution of each process to the likelihood of stock rebuilding, and what levels of each process are necessary for rebuilding. Objectives of number of recruits and natural mortality levels to reach can then be set against potential management measures aiming to improve these processes. To estimate the minimum time for the stock to reach the rebuilding target (i.e. at or above the LRP with a 75% probability) in the absence of fishing (T_{min}), scenarios of future natural mortality and recruitment rates were simulated using the projection function of the assessment model.

The population was projected forward during the Markov chain Monte Carlo (MCMC) sampling by the population model, considering uncertainty in parameter estimates. The probability of SSB being above the LRP each year was calculated by finding the proportion of MCMC samples that were above the LRP in that year.

The future natural mortality scenarios were designed by examining historical natural mortality levels of the stock. Natural mortality gradually increased between 1978 and 2018 for the age group 2-3. For the age groups 4-5 and 6-10+, natural mortality increased between 1978 and the early 2000s before slowly decreasing for the age group 4-5, or varying without trend for the age group 6-10+.

Three future M scenarios were simulated:

1. Recent M: In this scenario, current estimates are assumed to be representative of futures estimates, which is the method used to project the population forward in the stock assessment. Projected M for all age groups were set as the average M values in the last 5 years of the assessment (2018 to 2022).
2. Short M decline: In this scenario, M was gradually decreased for 5 years by the historical rate of increase specific to each age group, then M was stable for remaining projection years. The realized M reduction in projections were of 6% for age group 2-3, 32% for age group 4-5 and 34% for age group 6+.
3. Long M decline: In this scenario, M was gradually decreased for 10 years by the historical rate of increase specific to each age group, then M was stable for remaining projection years. The realized M reduction in projections were of 12% for age group 2-3, 53% for age group 4-5 and 42% for age group 6+.

Recruitment rates for sGSL Hake varied over the assessment years, with low rates in the 1980 to mid 1990s, and higher rates from the early 2000s to 2022. Therefore, two scenarios of future recruitment rates were simulated:

1. Recent recruitment rates: recruitment rates were randomly selected from the last 20 years of the assessment, reflecting current conditions of high recruitment rates.
2. 1980-1990 recruitment rates: recruitment rates were randomly selected from the years 1980 to 1990, reflecting the low recruitment rates period.

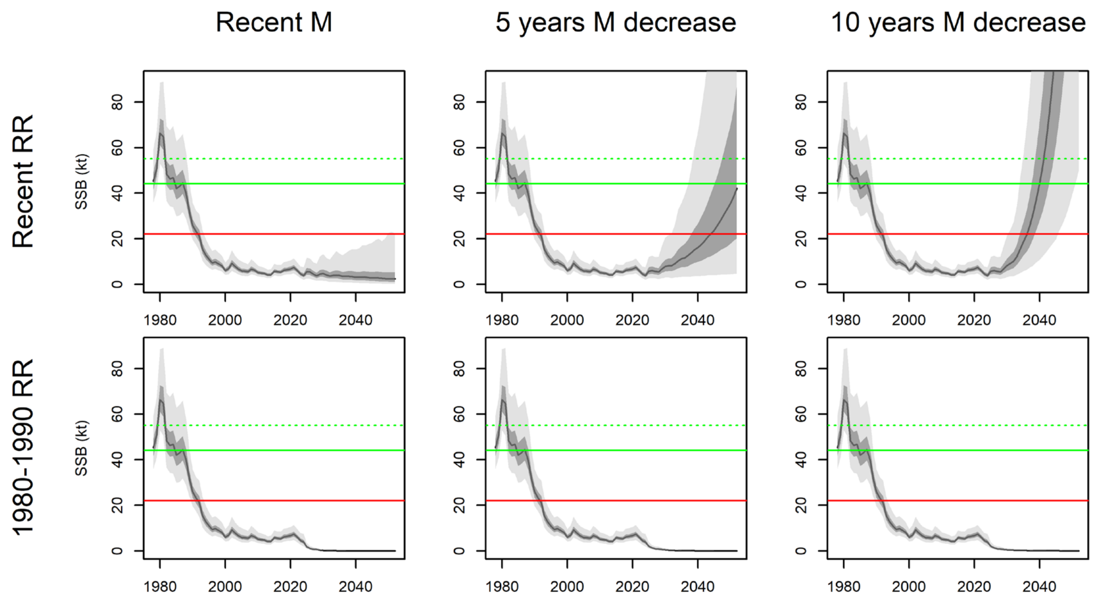

Figure 7.1: Estimated and projected southern Gulf of St. Lawrence White Hake spawning stock biomass (SSB, kt) for years 1978 to 2052, for two future recruitment rates scenarios: recruitment rates from the last 20 assessment years ("Recent RR", top row) and recruitment rates from years 1980 to 1990 ("1980-1990 RR", bottom row), for three natural mortality scenarios: average natural mortality from the last 5 assessment years ("Recent M", left column), a natural mortality decrease for 5 years ("5 years M decrease", middle column) and a natural mortality decrease for 10 years ("10 years M decrease", right column). The red horizontal line is the limit reference point, the green horizontal line is the upper stock reference, the green horizontal dashed line is the target reference point, the black line is the median estimate from the MCMC sampling, and dark and light grey shading indicate 50% and 90% confidence intervals, respectively.

At recent recruitment rates and recent natural mortality, SSB is projected to slowly decline (Figure 7.1). The probability of SSB declining below 2,000 t by 2052 was 45%. For the scenario with current recruitment rates and a 5 years decrease in natural mortality, SSB increased but did not cross the LRP with 75% probability over the projections time period. However, the median estimate (50% probability) crossed the LRP in 2045. For the scenario with current recruitment rates and a 10 years decrease in natural mortality, SSB increased rapidly and crossed the LRP with 75% probability in 2039. Uncertainty in projections is higher than in modeled assessment years, so the stock would likely be defined as rebuilt quicker if such scenarios were to occur, due to the reduced uncertainty in SSB estimates in assessment versus projections. On the other hand, the projections are likely optimistic as the recruitment rates would likely decrease as SSB increases due to density dependent effects. However, as stock recruit relationships for this stock are not credible and the drivers of recruitment are unknown, modelling a driver-dependent recruitment relationship for population projections of this stock is not feasible. The quick increase in SSB as M starts to decline reveals the influence of natural mortality on this stock and its role in preventing its recovery from the current low level. In scenarios using lower recruitment rates (1980-1990 values), the projected SSB declined under 1,000 t by 2027 across natural mortality scenarios.

Changes in M and recruitment productivity are likely not independent. The productivity of small demersal fishes increased due to release from predation following the collapse of large demersal fishes whereas large demersal fish remain depleted due to high predation mortality caused by high grey seal abundance (Benoît and Swain 2008; Swain et al. 2016). Therefore, recruitment productivity might be expected to decline from its current high level if natural mortality at older ages declines and the abundance of large demersal fish increases, increasing predation on early life stages (Swain et al. 2016). If recruitment productivity and M at older ages are linked, the SSB increases in M reductions scenarios presented here would presumably be slower and of a lesser magnitude.

Natural mortality in sGSL Hake is mostly driven by Grey seal predation (Benoît et al. 2011). The growth rate of the Grey seal population in Atlantic Canadian waters has slowed down, but it does not seem apparent that the population size would decline in the short term at current harvest levels (Hammill et al. 2023). Therefore, the grey seal predation on White Hake and associated natural mortality are not expected to decrease.

7.2. BYCATCH SCENARIOS

As outlined in the PA framework (DFO 2009), the primary objective of a rebuilding plan is to promote stock growth above the LRP by ensuring removals from all fishing sources are kept to the lowest possible level until the stock has cleared the Critical Zone. Rebuilding plans must also include additional restrictions on catches. The primary management measure proposed in the sGSL Hake rebuilding is to keep removals to the lowest level by continuing to implement and/or develop new management measures in all fisheries that intercept sGSL Hake. An analysis of spatial overlap and bycatch potential for fisheries that intercept sGSL Hake as well as the potential impact of the emerging commercial Redfish fishery is presented in Sutton et al. 2025.

Reducing bycatch of sGSL Hake is unlikely to rebuild the stock, as population projections without fishing mortality showed that the stock would remain in the Critical Zone in the long term under prevailing natural mortality levels. A White Hake bycatch TAC of 30 t was implemented in the mid 2000s. Between 2013 and 2022, bycatch varied between 13 and 29 t annually, for an average of 17.9 t annually. To evaluate the expected impact of bycatch on the long-term population status, the sGSL Hake population was projected forward for 10 years given annual catch levels of 0, 10, 30, 100 and 1000 t, as routinely performed in the stock assessment.

Projected SSB varied with a slight downward trend at all catch levels, including 0 catch (Figure 7.2). Based on median SSB estimates, annual bycatch levels of 10 t and 30 t reduced SSB 0.7 and 1.2% over ten years compared to no fishing. At 100 t and 1,000 t of bycatch, SSB in 10 years would be reduced by 3.3% and 17.6% compared to no fishing, respectively. The median estimates of all bycatch scenarios are all within the 50% confidence intervals of each other (not shown on the figure, for clarity).

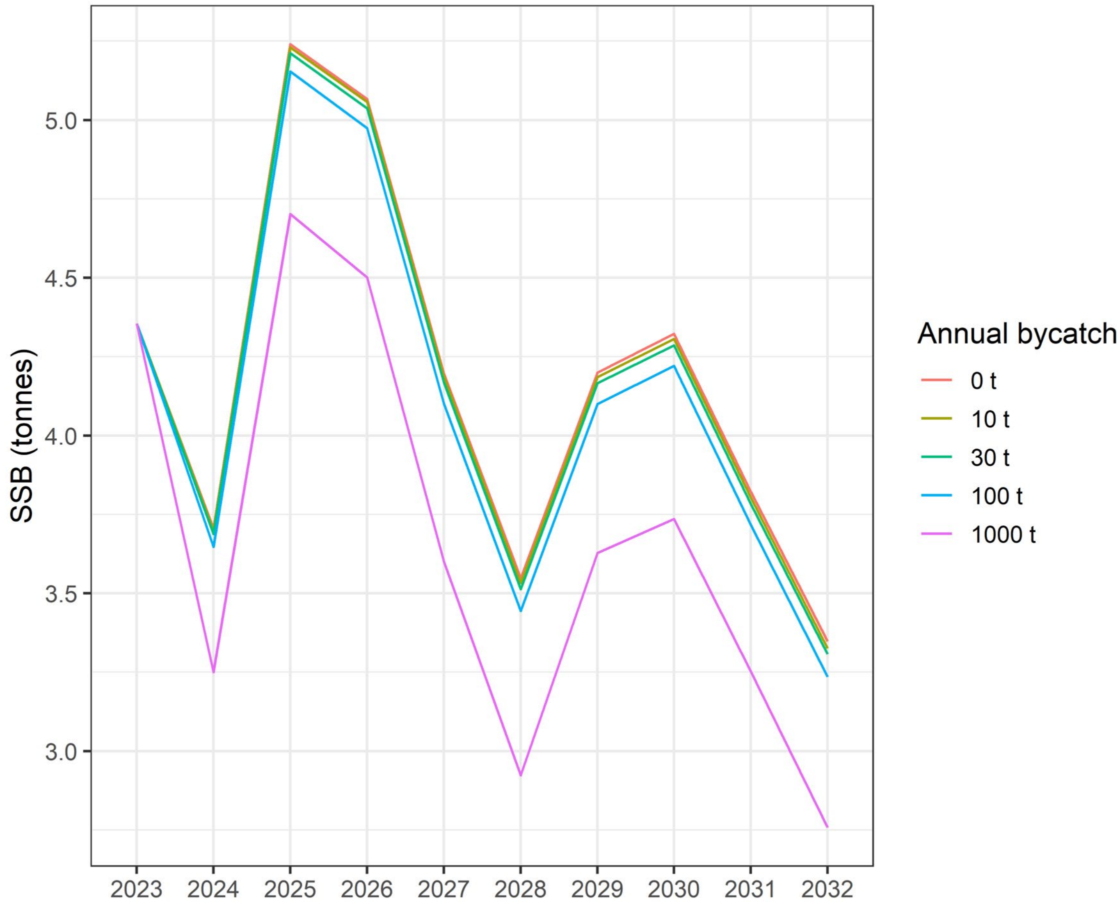

Figure 7.2: Projected southern Gulf of St. Lawrence White Hake spawning stock biomass (SSB) for years 2023 to 2032, with 0, 10, 30, 100 and 1000 tonnes of annual bycatch. Lines are median MCMC estimates.

As in previous assessments, the vulnerability of this stock to a decline in recruitment rates, irrespective of changes in natural mortality, is revealed by the population projections. As the recruitment rates have declined in the last 3 years of the assessment, combined with a potential increase in bycatch in the re-opened commercial Redfish fishery, the sGSL White Hake population should be monitored closely so that population declines can be detected in time to assess appropriate management measures.

8. STOCK STRUCTURE

Several studies have shown that sGSL Hake are genetically distinct from Hake in other areas of Atlantic Canada (Roy et al. 2012; Swain et al. 2012), though there is some overlap in the deep waters of the Laurentian Channel. In the rebuilding plan, the stock is considered to be NAFO Division 4T which includes the St. Lawrence Estuary. However the genetic identity of Hake in this area (NAFO unit areas 4Topq, Figure 1.1) is unknown as no samples were collected from this area in studies so far. It is unclear whether Hake in the Estuary belong to the sGSL stock or the Atlantic DU. Delineating between fish stocks is important for fisheries management, in particular for setting and monitoring bycatch limits in the case of sGSL White Hake. In the absence of genetic samples from the Estuary to determine the stock assignation of Hake in this area, life history parameters were examined. Differences in life history parameters can be used as evidence that stocks may be distinct and therefore discrete units for management purposes (Ihssen et al. 1981; Begg et al. 1999; Begg 2005; McBride 2014).

Hake biological data collected from RV surveys in the sGSL and northern GSL (nGSL) were combined. The nGSL RV occurs annually in August, while the sGSL occurs annually in September. The sGSL RV is conducted in NAFO Division 4T, covers a portion of 4Vn, but does not cover the St. Lawrence Estuary. The nGSL RV survey includes the St. Lawrence Estuary in NAFO Division 4T as well as NAFO 4RS, and portions of 4Vn and 3Pn. The data was filtered to exclude data from NAFO 3Pn and 4Vn. The samples were divided into four regions: (1) 4R, (2) 4S, (3) 4Tngsl, and (4) 4Tsgsl (Figure 8.1). All samples from 4R and 4S were retained. The samples in NAFO 4T were divided into two subgroups as follows: the 4Tngsl group consisted of the samples collected from the nGSL RV which were filtered to remove trawls east of the 64°W longitude such that samples did not overlap with sGSL RV data (both RVs surveys cover a common area). The 4Tsgsl group consisted of samples collected on the sGSL RV survey filtered to remove trawls that overlapped with the 4Tnsgl group. This group was further restricted to keep only trawl sets in waters shallower than 250 m. The 250 m cutoff was determined based on previous genetic work which found that the proportion of sGSL White Hake decreased with greater depths, whereas the proportion of the Scotian Shelf stock increased (Swain et al. 2012). At depths 250 m and shallower, 80% of samples represented the sGSL stock genetically.

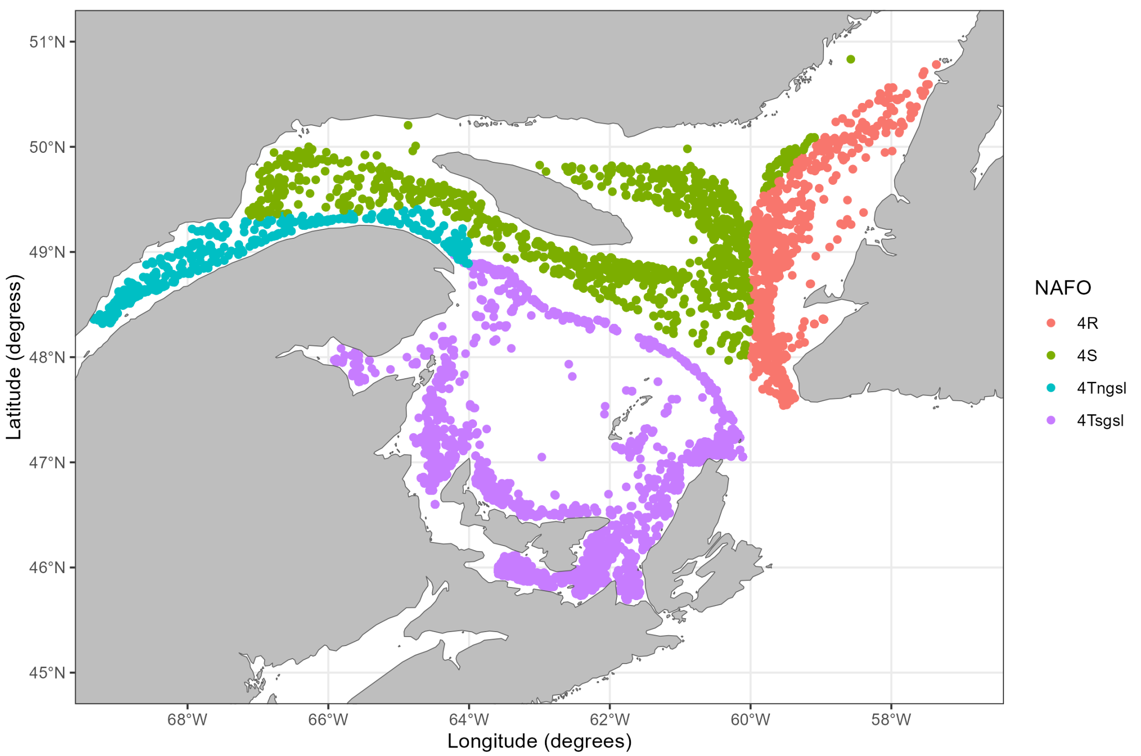

Figure 8.1: Location and region assignment for life history analysis: NAFO division 4R (red), 4S (green), Magdalen Shallows portion of 4T (4Tsgsl; purple), and the portion of 4T in the St. Lawrence Estuary (4Tngsl; blue).

Ageing is not conducted on Hake captured in the nGSL RV survey, therefore age-based life history parameters could not be examined. Consequently, only length-weight relationships and length at 50% maturity could be examined. Since Hake are sexually dimorphic, sex was included as a variable in the models and/or males and females were analyzed separately.

8.1. LENGHT-WEIGHT RELATIONSHIP

Linear regressions were fit on the log scale to length (cm) and weight (kg) data from NAFO Divisions 4R, 4S, and 4T. There are two caveats that need to be considered when analyzing the data. (1) Limited biological data is available outside the 4Tsgsl group prior to the early 2000s. (2) In the 4Tsgsl, Hake greater than 80 cm were only found prior to the early 2000s. Hence, length-weight regressions were first fit to all years of data (1970 to 2023), and then to recent years only (2004 to 2023). Results from both sets of analyses are reported and discussed.

Samples where unknown sex (coded 0 or 9) was recorded were removed from the data set so that sex could be included in the models. Length-weight regressions fit to all years of data (1970 to 2023) showed a significant effect of the interaction between length and region, and of the interaction between length and sex, ($p < 0.0001$). The interaction between region and sex was not strongly significant ($p = 0.02$). The interaction between length, sex, and region was not significant ($p = 0.36$).

The data set was subdivided into males and females. Length-weight regressions showed a significant interaction between region and length in both males ($p < 0.0001$) and females ($p < 0.0001$; Table 8.1; Figure 8.2). Again, post-hoc Tukey test showed that the interaction was not significant in males among 4R, 4S, and 4Tngsl regions (p-values ranged between 0.55 to 1), but all were significantly different that 4Tsgsl ($p < 0.0001$). For females, 4R, 4S, and 4Tngsl were also not significantly different ($0.82 < p < 0.99$) and again 4Tsgsl differed from all other regions ($p < 0.0001$; Table 8.2).

Table 8.1. Models for difference in slopes of the length-weight relationship between regions (NAFO divisions 4R, 4S, Magdalen Shallows portion of 4T (4Tsgsl), and the portion of 4T in the St. Lawrence Estuary (4Tngsl)) and sex for the full time series (1970-2023) and recent time series (2004-2023). Hake are sexually dimorphic, therefore length-weight relationships were also examined by sex.

Years	Model	Predictor	df	F	p
1970 - 2023	Sex only	L*sex	1, 27927	129.3	<0.0001
	Full model	L	1, 27915	1.90E+06	<0.0001
		Region	3	420.9	<0.0001
		sex	1	0.12	0.73
		L*Region	3	178.4	<0.0001
		L*sex	1	69.4	<0.0001
		Region*sex	3	3.07	0.03
		L*Region*sex	3	0.56	0.64
	Male	L	1, 15068	8.95E+05	<0.0001
		Region	3	164.9	<0.0001
		L*Region	3	62.7	<0.0001
	Female	L	1, 12847	9.85E+05	<0.0001
		Region	3	257.6	<0.0001
		L*Region	3	104.5	<0.0001
2004 - 2023	Sex only	L*sex	1, 11245	114.9	<0.0001
	Full model	L	1, 11233	8.11E+05	<0.0001
		Region	3	259.2	<0.0001
		sex	1	1.57	0.21
		L*Region	3	282.3	<0.0001
		L*sex	1	34.0	<0.0001
		Region*sex	3	9.26	0.03
		L*Region*sex	3	4.75	0.003
	Male	L	1, 5747	3.26E+05	<0.0001
		Region	3	128.4	<0.0001
		L*Region	3	138.3	<0.0001
	Female	L	1, 5486	4.53E+05	<0.0001
		Region	3	131.5	<0.0001
		L*Region	3	123.3	<0.0001

Table 8.2. Significance (p-values) of Tukey post-hoc test for pairwise comparison of length-weight relationship between regions (NAFO divisions 4R, 4S, Magdalen Shallows portion of 4T (4Tsgsl), and the portion of 4T in the St. Lawrence Estuary (4Tngsl)) Hake are sexually dimorphic, therefore length-weight relationships were also examined separately by sex Above the diagonal is the pairwise values for the full time series (1970-2023) and below the diagonal is the results for the recent time period (2004-2023).

Full model

Region	4R	4S	4Tngsl	4Tsgsl
4R	-	0.80	0.57	<0.0001**
4S	0.84	-	0.95	<0.0001**
4Tngsl	0.03*	0.12	-	<0.0001**
4Tsgsl	<0.0001**	<0.0001**	<0.0001**	-

Male

Region	4R	4S	4Tngsl	4Tsgsl
4R	-	0.55	0.64	<0.0001**
4S	0.83	-	1.00	<0.0001**
4Tngsl	0.08	0.3	-	<0.0001**
4Tsgsl	<0.0001**	<0.0001**	<0.0001**	-

Female

Region	4R	4S	4Tngsl	4Tsgsl
4R	-	0.99	0.94	<0.0001**
4S	1.00	-	0.82	<0.0001**
4Tngsl	0.46	0.52	-	<0.0001**
4Tsgsl	<0.0001**	<0.0001**	<0.0001**	-

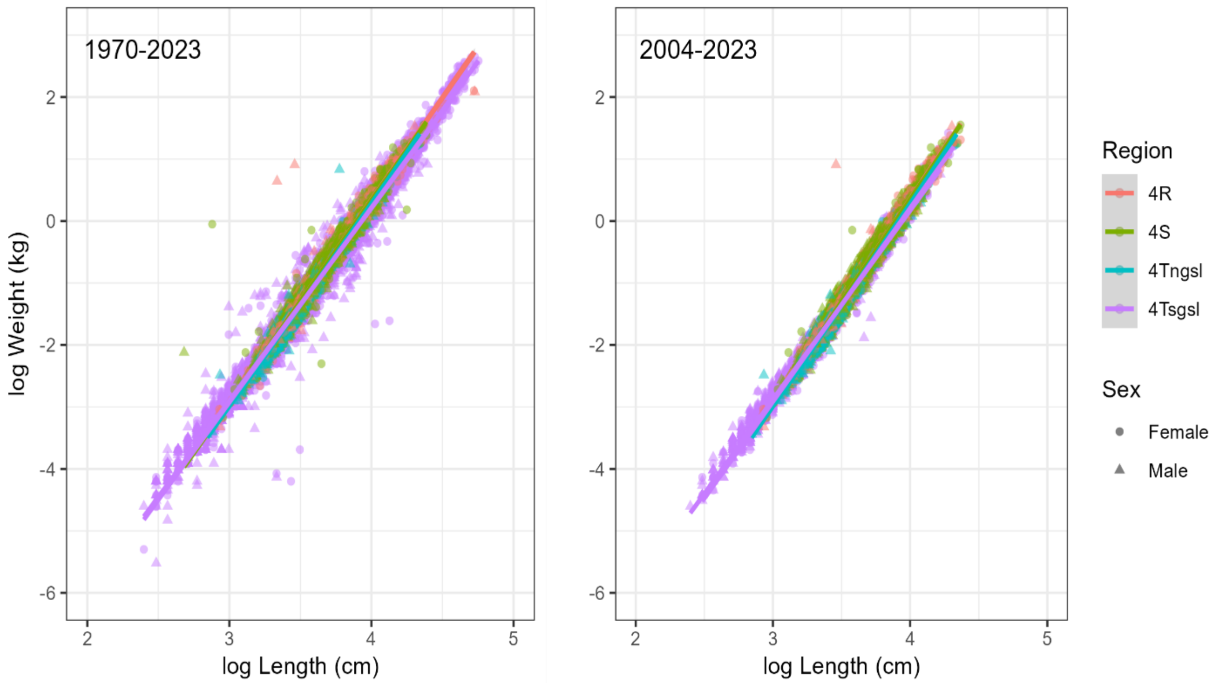

Figure 8.2: Length-weight relationships for the full time series (1970-2023; upper panel) and recent time series (2004-2023; bottom panel) by region NAFO division 4R (red), 4S (green), Magdalen Shallows portion of 4T (4Tsgsl; purple), and the portion of 4T in the St. Lawrence Estuary (4Tngsl; blue). Males are represented by circles and females by triangles.

Similar to the full time series, the length-weight regressions in recent years for males and females showed a significant effect of the interaction between length and region (both $p < 0.0001$). A post-hoc Tukey test showed the regression slopes of regions 4R, 4S, and 4Tngsl were not significantly different from one another (males: $0.08 < p < 0.82$ and females: $0.46 < p < 1.0$), whereas the regression slope of region 4Tsgsl was significantly different from all other regions in both sexes ($p < 0.0001$).

Annual length-weight regressions were fit for all regions to compare the temporal changes in weight at length between regions. For 35 cm Hake, the predicted weight at length was higher in regions 4R, 4S, and 4Tngsl, but declined through time to values similar to 4Tsgsl by the end of the time series (Figure 8.3). Temporal differences were small for fish 45 and 55 cm, but the predicted weight in regions 4R, 4S, and 4Tngsl were higher than the predicted weights at length in region 4Tsgsl.

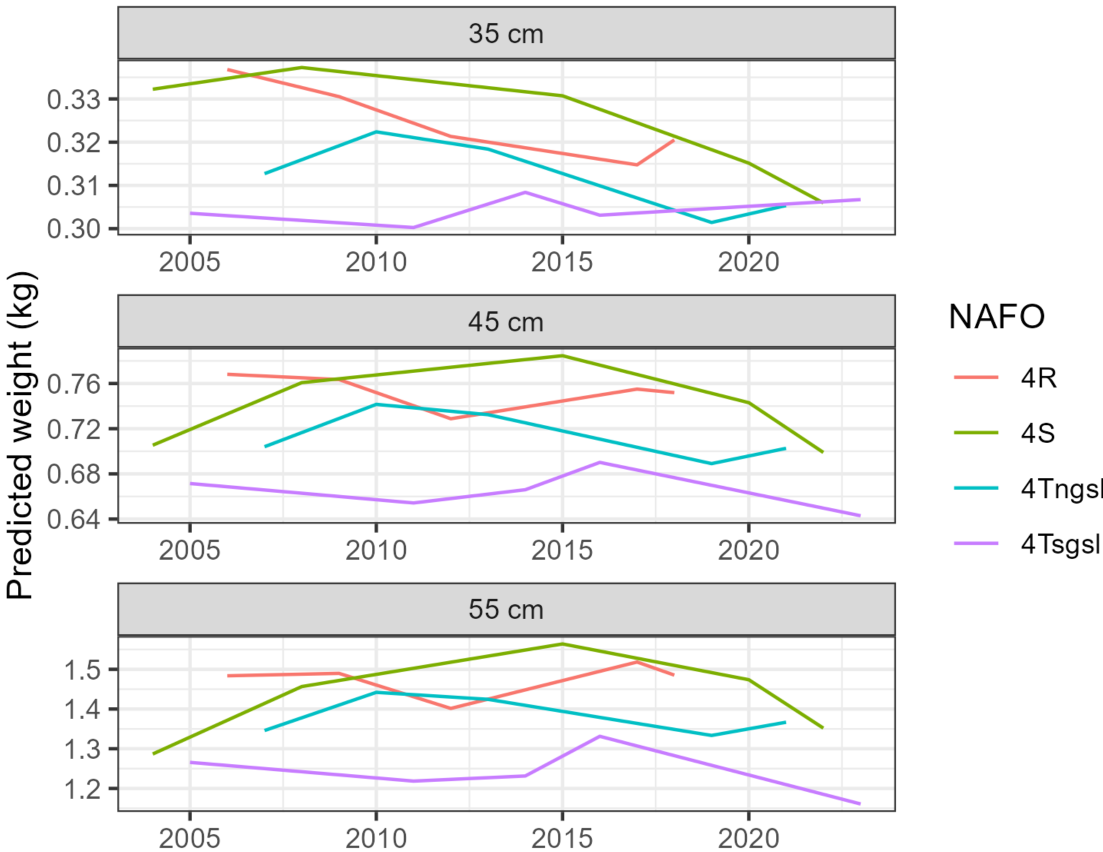

Figure 8.3: Temporal change in annual predicted weight at length for the recent time series (2004-2023) for regions NAFO divisions 4R (red), 4S (green), Magdalen Shallows portion of 4T (4Tsgsl; purple), and the portion of 4T in the St. Lawrence Estuary (4Tngsl; blue) and for three fish length (35 cm; upper panel, 45 cm; middle panel, 55 cm; lower panel).

8.2. LENGTH AT MATURITY

Despite the difficulties in determining the maturity stages of White Hake (Swain et al. 2012), length at 50% maturity was assessed for fish from RV surveys in the GSL. White Hake maturity stages were summarized in two maturity categories; immature and mature. Fewer Hake were assigned maturity stages on the nGSL RV survey than on the sGSL RV survey. The length and maturity data for males and females were fitted to logistic regression models by region using the glm R function with a binomial error distribution and confidence intervals were determined using the sizeMat R package. Length at 50% maturity (L50) in each region were nearly identical when using the full time series (1970 to 2023) or the recent time series (2004 to 2023; data not shown). However, the number of samples with maturity stages assigned in 4Tsgsl (n = 22,359) was over 28 times greater than all three regions covered by the nGSL RV combined (n = 818) in the full time series. Consequently, data from each region was sampled with replacement for a sample size of n=90 for each region.

Overall, males reached L50 at smaller sizes than females (Table 8.3). For males, the shape of the maturity ogives were similar among the 4 regions and L50 did not differ significantly among the regions (4R = 32.9 cm, 4S = 35.6 cm, 4Tngsl = 33.5 cm, 4Tsgsl = 33.7 cm; Figure 8.4; and parameters in Table 8.3). Females from the 4Tsgsl region reached L50 at smaller sizes

(38.4 cm) that did not fall within the confidence intervals of other regions. Whereas the confidence intervals of all the other regions overlapped (4R = 46.5 cm, 4S = 46.9 cm, 4Tngsl = 51.7 cm; Figure 8.4; and parameters in Table 8.3). In both males and females, the maturity ogive for 4Tsgsl was also less steep than in the other regions (Figure 8.4).

Table 8.3. Length at 50% maturity (L_{50}, cm) and 95% confidence intervals (CI) of female and male White Hake from the regions NAFO divisions 4R, 4S, Magdalen Shallows portion of 4T (4Tsgsl), and the portion of 4T in the St. Lawrence Estuary (4Tngsl) for the full data set and the subsampled data set. α and β are estimated parameters defining the shape and location of the fitted sigmoid curves.

Sex	Region	L_{50}	95% CI	R^2	α	β
Full 1970:2023						
Female	4R	48.0	46.5-49.8	0.59	-11.8	0.25
	4S	47.1	44.7-49.4	0.52	-9.6	0.20
	4Tngsl	51.2	43.9-59.6	0.75	-13.9	0.27
	4Tsgsl	37.9	37.6-38.2	0.55	-6.37	0.17
Male	4R	34.0	32.9-35.1	0.43	-11.5	0.34
	4S	34.2	32.8-35.6	0.49	-10.6	0.31
	4Tngsl	31.7	29.6-35.0	0.74	-12.6	0.39
	4Tsgsl	34.0	33.7-34.2	0.62	-7.7	0.23
Subset n = 90/region						
Female	4R	46.5	44.6-48.7	0.68	-14.6	0.32
	4S	46.9	44.2-49.5	0.53	-11.1	0.24
	4Tngsl	51.7	48.0-55.9	0.70	-15.6	0.30
	4Tsgsl	38.4	34.6-42.1	0.47	-5.4	0.13
Male	4R	32.9	31.4-34.2	0.44	-13.0	0.39
	4S	35.6	33.7-37.7	0.46	-10.0	0.28
	4Tngsl	33.5	30.7-36.0	0.79	-12.8	0.38
	4Tsgsl	33.7	31.0-36.7	0.66	-7.4	0.22

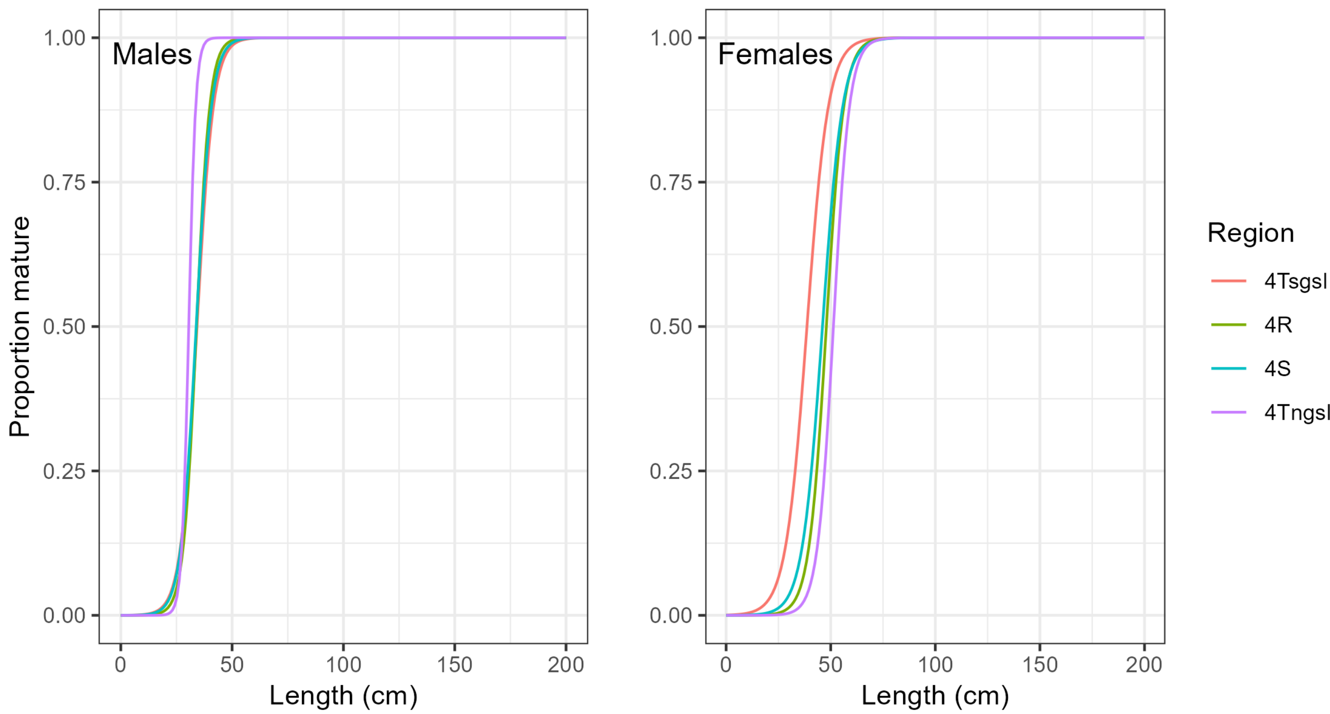

Figure 8.4: Comparison of maturity ogive fit to maturity data of female (upper panel) and male (lower panel) White Hake for the regions NAFO divisions 4R (red), 4S (green), Magdalen Shallows portion of 4T (4Tsgsl; purple), and the portion of 4T in the St. Lawrence Estuary (4Tngsl; blue) for the subsampled dataset (n = 90/region).

8.3. GENETICS

Life history data alone are typically not sufficient for characterizing stock structure. In 2022, a total of 164 Hake were sampled at 23 stations in the sGSL RV survey. Whole genome sequencing was performed on fin tissue samples and the Genotyping-By-Sequencing approach was used. 21,494 single nucleotide polymorphisms were identified, which enabled a high definition characterization of the Hake genotypes. The preliminary results from an Admixture analysis and Principal Components Analyses suggest that at least two Hake genetic populations co-exist in the region (Sylvain, F.-E., Pers. Comm) separated by an F_{ST} of approximately 0.028. A third genetic group was also detected, but with a low abundance. The spatial distribution of the populations did not appear to be depth or temperature dependent. A few genetic samples have been collected in the St. Lawrence Estuary on the ngsl RV survey and are currently being processed, however further samples have been requested from the 2024 nGSL RV survey.

8.4. STOCK STRUCTURE CONCLUSION

Based on these preliminary analyses, there is some doubt as to whether Hake in the St. Lawrence Estuary belong to the sGSL stock. Life history evidence supports the idea that they are more similar to the stock outside the sGSL and preliminary genetics results suggests three genetic groups could occur in the sGSL RV survey area. Life history variations may also be driven by variations in environmental productivity (Keller et al. 2012; Stark 2012), such that population segments are ecophenotypes and may not be discrete genotype. It is entirely plausible that environments are more similar outside of 4Tsgsl in this case, for example depth in 4R (269.9 m, range 45.0 - 525.0 m) and 4S (277.6 m, range 143.0 - 492.0 m) are quire similar, 4Tngsl is on average less deep (238.5 m, range 76.0 - 393.0 m), whereas 4Tsgsl is shallower

(87.7 m, range 13.0 - 250.0 m). However, 4Tsgsl Hake data was filtered to retain only fish caught at depths shallower than 250 m to minimize the chance of including the Atlantic DU. Therefore, this is not an accurate comparison. Collections of otoliths, maturity, and genetic tissues should help clarify this issue of stock structure in the estuary. This could be an important consideration in future iterations of the rebuilding plans as bycatch limits are managed on a stock basis.

9. ADDITIONAL OTHER MEASURABLE OBJECTIVES

Rebuilding objectives may include other metrics beyond biomass-based measures (DFO 2021). While setting measurable objectives for these metrics can be challenging, several targets were identified in the White Hake recovery potential assessment that could be incorporated into the rebuilding plan (Swain et al. 2016).

9.1. AGE AND SIZE STRUCTURE

Truncation of the age structure of sGSL Hake has occurred throughout the time series (Swain et al. 2016; Rolland et al. 2022a; this paper). Fish over 10 year of age were consistently observed in the 1970s and 1980s, by the end of the 1990s maximum age declined to 7 years old, and in the late 2000s the spawning stock consisted mostly 4 year olds. This represents a high risk to the stock as it is reliant on only a single reproductive cohort. In the period 1970-1980, Hake aged 5+ averaged 37% of the age composition from the RV survey, while from 2000 onward the percentage has decreased to 8% (Rolland et al. 2022a). A recovery target was identified in the recovery potential assessment to increase the proportion of Hake older than 7 years to the levels observed prior to the mid-1980s (Swain et al. 2016). Along with truncation of the age structure, a truncation in the size composition has also been observed. In the early time series, Hake reached sizes up to 116 cm, however fish larger than 84 cm have not been observed since 1993 on the RV survey. Given that the age and size structure has continued to contract, a rebuilding plan objective could be included to increase the proportion of larger Hake and Hake aged 5+ to averages observed historically (37% in the 1970-1980s).

9.2. SPATIAL DISTRIBUTION

A rebuilding objective could be included to restore the presence of Hake greater than or equal to 45 cm in the inshore waters of the sGSL during September according to their historical distribution prior to the late 1990s. The recovery potential assessment identified a distribution target that would see the return of Hake to their inshore spawning grounds, as well as an overall return of Hake to the inshore waters of the sGSL during the summer where they were historically distributed (Swain et al. 2016). Hake abandoned these inshore areas due to the high risk of predation by Grey Seals in coastal areas (Swain et al. 2015). This shift in distribution resulted in sGSL Hake distribution now overlapping with other active and emerging fisheries occurring in the Laurentian Channel. sGSL Hake had an offshore and inshore spawning component, this shift offshore may also have led to the loss of access to the inshore spawning grounds which could have negative consequences for population productivity. Nevertheless, juvenile biomass and abundance have fluctuated without trend over the time series despite low levels of adult biomass and significant truncation in age structure. The ability to maintain this level of juvenile abundance likely occurs as a result of strong recruitment over the past twenty plus years.

9.3. MAINTAINING HIGH RECRUITMENT

A rebuilding objective could be to maintain the high recruitment observed in recent years so that the stock does not decline further and maintains its ability to rebuild. Even in the absence of fishery removals the stock is expected to decline, yet if recruitment rates decline the stock would decline much more rapidly (Section 6 - Rebuilding targets). As described above, the sGSL Hake stock is now reliant on a single reproductive age group, however recruitment has been extremely high over the past 20 years. The causes of the unusually high recruitment rates are not known and it is not known whether they will persist. The rebuilding plan objective to "advance current scientific knowledge in the fields of monitoring stock status, recruitment, environmental conditions, and those ecosystem factors that are likely to impact the stock's recruitment, growth, habitat and health" should include making enhanced efforts to understand the causes of this high recruitment and how to promote it until the age structure has recovered.

9.4. DISCARD MORTALITY

The At-Sea Observer Program (ASO) collects detailed information on fishing activities at sea, including data on the target species, bycatch, and discards. ASO data on fishing activities that occurred between 2013 and 2022 in NAFO 4T where Hake were recorded as bycatch was extracted and validated. Data where only the total weight of Hake caught was reported were removed as the information on weight kept and weight discarded were absent. Fishing trips undertaken as part of DFO's Sentinel Fisheries Program were removed as this activity is not representative of commercial fisheries. Analysis of this data showed that bycatch of sGSL Hake most commonly occurs in fisheries targeting Greenland Halibut, Redfish, Atlantic Halibut, and Witch Flounder. This is consistent with the ZIFF landings data where 99% of White Hake is caught as bycatch in these four fisheries.

ASO only covers a certain percentage of fishing trips and therefore provides only partial information on bycatch, but is the only source of data on discards at sea. The targeted minimum coverage for commercial groundfish fisheries ranges from 5 to 20% of all fishing trips and depends on the fishery and fleet (Table 9.1). The realized coverage often differs from the targeted coverage and varies substantially over the years (Table 9.1). Discarding has been prohibited for White Hake since 1993 (Benoît et al. 2010) and both the conservation harvesting plans and licence conditions for the fisheries prohibit the discarding of White Hake. The ASO data, however, shows that discarding at sea does occur and the percentage of Hake discarded differs across the targeted fisheries (Figure 9.1). Of the 347 kg of Hake observed to be caught in the Witch Flounder fishery, no Hake were discarded. However, observers were only onboard in 2014 and 2016 less than 2% of trips between 2013 and 2022 (Table 9.1). Discarding of Hake occurred in the Atlantic Halibut, Redfish, and Greenland Halibut fisheries (Table 9.1). The Atlantic Halibut fishery was observed to have caught 1,572 kg of Hake from 2013-2022 with 29 kg discarded at sea (1.8% discards). The Redfish fishery captured 5,350 kg of Hake while ASO were onboard, discarding 606 kg at sea (11.3%). The Greenland Halibut fishery was observed to have caught 2,504 kg of Hake, discarding 1,283 kg at sea (51.2%; Figure 9.1). Studies of discard mortality have shown that in part due to their gas bladder Hake suffer from high discard mortality that increases with depth and size of fish (Benoît et al. 2010, 2013). The gear used in these fisheries and the depths at which the fisheries are prosecuted suggest that discard mortality would be quite high. Total removals of Hake from the stock may be significantly higher than reported.

Table 9.1: Fisheries and gear where 99% of White Hake bycatch occurred over the 2013-2022 period, with the target level of at-sea observer coverage (%), number of trips observed (At-Sea Observer Program database), the total number of trips (ZIFF database), mean (and range) realized observer coverage (%), and number of different vessels observed. Mean proportion of White Hake caught in observed fishing trip (i.e., bycatch) and mean (and range) of White Hake discarded in observed fishing trips.

Target species	Gear	Year	Total trips	Observed trips	Vessels observed	Target coverage[1]	Realized coverage	White Hake bycatch	White Hake discarded
Atlantic Halibut	Longline	2013-2022	12,689	617	349	10-20%	4.9% (1.7-24.7)	0.005	1.8% (0-66.7)
Greenland Halibut	Gillnet	2013-2022	4,822	246	58	5-20%	5.1% (2.3-8.0)	0.007	51.2% (23.1-83.0)
Redfish	Trawl, Seine	2013-2022	167	33	16	10-25%	19.8% (0-62.5)	0.032	11.3% (0-100)
Witch Flounder	Seine	2013-2022	303	5	5	0.25	1.7% (0-6.8)	0.035	0

[1]Target coverage differs by fleet, vessel length class, fishing area, and year.

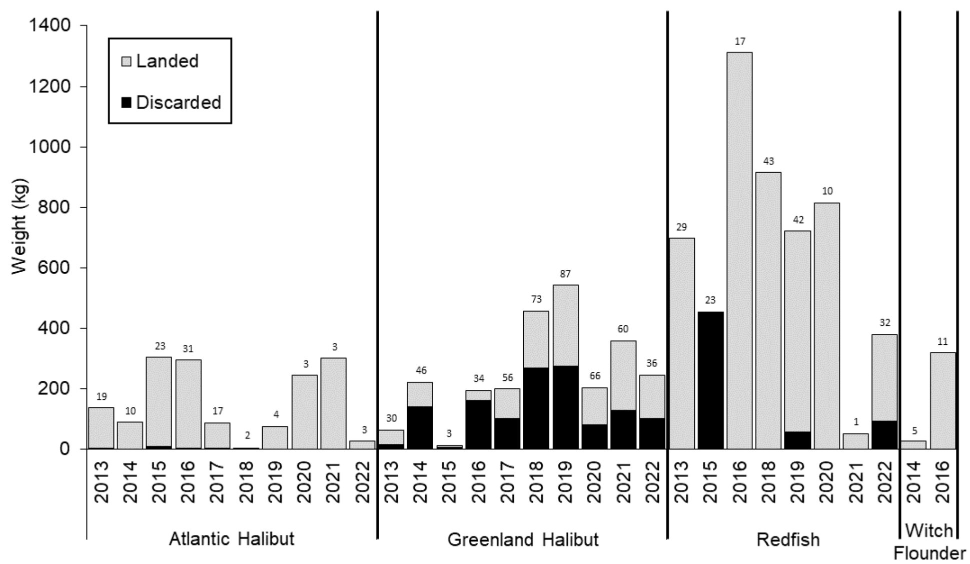

Figure 9.1: Weight (kg) of White Hake kept and discarded in the four fisheries where 99% of the White Hake bycatch occurred from 2013 to 2022. The number above each bar indicates the number of trips where at-sea observers were onboard.

By adding the estimated amount of Hake discarded at sea to the reported landings, an estimated lower bound for total removals could be calculated (Table 9.2). Removals of White Hake may be underestimated by an average of 30%, with removals underestimated by a range of 7-53% depending on the year (Table 9.2).

Table 9.2: Fisheries-specific and overall total removals of White Hake in tonnes from the four fisheries where 99% of the White Hake bycatch occurred from 2013 to 2022. Total removals was estimated by adjusting the reported landed of White Hake by the mean annual percentage discarded at sea in a given fishery.

Year	Atlantic Halibut	Greenland Halibut	Redfish	Witch Flounder	Overall removals	Reported landings
2013	1.74	5.66	11.13	2.01	20.53	19.18
2014	1.98	7.2	5.01[a]	5.54	19.73	15.18
2015	5.07	3.37	14.06[b]	3.37	25.87	23.54
2016	6.37	18.21	10.43	4.6	39.6*	24.39
2017	0.67	6.09	6.48[a]	3.66	16.91	13.75
2018	0.87	13.62	4.85	1.09	20.43	11.82
2019	0.97	14.19	3.87	1.03	20.06	12.55
2020	2.19	14.57	4.52	0	21.28	15.38
2021	2.56	8.49	3.69	0.92	15.67	12.63
2022	5.8	12.46	5.4	0	23.65	17.14

[a] No observer data available, thus total removals were equal to the reported landings.
[b] Only 1 trip was and all Hake was discarded, thus total removals was amount discarded from that trip added to the reported landings.
* Denotes when overall removals exceed the 30 tonnes bycatch limit for White Hake.

Previous studies have indicated that the presence of ASO onboard fishing vessels alters the behavior of fish harvesters. Changes included harvesters landing more non targeted fish when an observer was aboard, despite landing less of target species. This is consistent with a greater adherence to certain discarding bans (Benoît and Allard 2009). In future, discards and bycatch in these fisheries should be examined more closely using weighting methods outlined in Savard et al. 2012 and applied in Chamberland and Benoît 2024.

10. HABITAT

Section 2(1) of the Fisheries Act, defines fish habitat as “water frequented by fish and any other areas on which fish depend directly or indirectly to carry out their life processes, including spawning grounds and nursery, rearing, food supply and migration areas”. For some stocks, the availability and quality of habitat may be important for rebuilding the stock when tightly linked to stock declines or rebuilding potential. With respect to this definition, habitat loss or degradation is unlikely to have contributed to the stock decline or play a role in preventing the recovery of the stock. sGSL White Hake overwinter in the relatively warm water deep waters along the Laurentian Channel and in NAFO 4Vn. In summer they historically showed a bimodal distribution with an offshore component in deep waters > 100 m and an inshore component < 50 m. While the inshore component of adults population is now absent this is due to avoidance of predation risk, not because habitat is considered to be limiting for this population. Juveniles are still often captured on surveys inshore. Information on habitat uses of earlier stages of White Hake is limited. McAllister 1960 described sand-hiding behavior in young White Hake (76-102 mm long) in depths of about one meter off Prince Edward Island. Limited sampling have found juvenile White Hake in eelgrass beds in the sGSL (Joseph et al. 2006), and enclosure experiments in Newfoundland have shown that feeding and growth of young Cod and Hake can be higher in eelgrass beds than in nearby non-eelgrass habitats (Renkawitz et al. 2011). Drastic contemporary declines in eelgrass coverage have been reported in the sGSL (DFO 2023b). The declines have been linked to a multitude of factors including invasive species, human alterations to drainage basins, eutrophication, and coastal landscape alteration. Other factors potentially limiting eelgrass abundance include high summer temperatures and suspended shellfish aquaculture. As sGSL White Hake have been very high in recent decades, it is assumed that, if that habitat use is significant, the declines in eelgrass beds did not cause a loss of habitat that would translate in a decreases in recruitment success. However, information on this ecosystem interaction is scarce and should be investigated further. Overall, the sGSL has experienced a trend towards warmer waters, shorter duration of ice season, and lower ice volume (Galbraith et al. 2021), however this has likely not decreased the habitat potential for Hake (Swain et al. 2016).

11. HOW TO TRACK REBUILDING PROGRESS

Rebuilding progress will be tracked using the sGSL White Hake stock assessment model and monitoring of productivity parameters (natural mortality, recruitment, and growth) and the associated uncertainty of the model results. Projections and decision tables will be provided to monitor the progress towards attaining objectives of the rebuilding plan. Rebuilding plan progress should be tracked as part of the multi-year assessment cycle which we propose to be every 5 years. Objectives should be revised and models should be updated if stock productivity or external factors influencing the stock dynamics change.

12. FREQUENCY OF PERIODIC REVIEW OF THE REBUILDING PLAN

The periodic review of the rebuilding plan was set to 5 years, this should also be established as the multi-year assessment cycle for sGSL Hake with an interim update at the halfway point. The interim update will consist of an updated indicator of stock status from the RV survey. A full stock assessment would be triggered during the interim update if the stock indicator is above the LRP-proxy. Regardless of when a new stock assessment is to be initiated, at least 6-12 months lead time is required before the new stock assessment is initiated to allow for analyses of other indicators and biological sampling that will be needed for the interpretation of the population trajectory.

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APPENDIX A. TABLES

Table A1: Nominal landings (tons) of White Hake from NAFO Division 4T, with yearly total allowable catch (TAC) between 1960 and 2022.

Year	Landings (tonnes)	TAC	Year	Landings (tonnes)	TAC
1960	2,008.00	-	1993	1,501.09	3,600
1961	5,323.00	-	1994	1,041.84	2,000
1962	7,244.00	-	1995	71.08	0
1963	6,550.00	-	1996	156.52	0
1964	6,206.00	-	1997	194.82	0
1965	4,706.00	-	1998	241.20	0
1966	7,024.00	-	1999	398.96	0
1967	6,550.00	-	2000	176.51	0
1968	4,261.00	-	2001	121.23	0
1969	4,208.00	-	2002	70.17	0
1970	5,668.00	-	2003	36.80	0
1971	5,707.00	-	2004	54.55	0
1972	5,757.00	-	2005	44.39	0
1973	5,702.00	-	2006	26.50	0
1974	3,616.00	-	2007	20.33	0
1975	4,125.00	-	2008	31.29	0
1976	3,758.00	-	2009	32.78	0
1977	3,984.00	-	2010	15.56	0
1978	4,825.00	-	2011	20.22	0
1979	8,110.00	-	2012	14.27	0
1980	12,423.00	-	2013	19.63	0
1981	14,039.00	-	2014	16.16	0
1982	9,776.00	12,000	2015	25.56	0
1983	7,305.00	12,000	2016	29.24	0
1984	7,050.00	12,000	2017	15.90	0
1985	6,014.00	12,000	2018	12.50	0
1986	4,895.00	12,000	2019	13.65	0
1987	6,372.00	9,400	2020	15.55	0
1988	3,887.00	5,500	2021	13.15	0
1989	5,354.00	5,500	2022	17.41	0
1990	5,175.00	5,500	-	-	-
1991	4,510.17	5,500	-	-	-
1992	3,813.43	5,500	-	-	-

Table A2: Nominal landings (tons) of White Hake from NAFO Division 4T by gear type between 1960 and 2022.

Year	Trawl	Seine	Gillnet	Longline	Handline	Other	Total
1960	479	21	3	1,085	87	333	2,008
1961	1,430	79	309	2,834	664	7	5,323
1962	1,141	97	889	3,827	715	575	7,244
1963	1,444	71	48	0	0	4,987	6,550
1964	1,508	82	0	1	0	4,615	6,206
1965	-	-	-	-	-	-	4,706
1966	2,267	205	375	1,870	0	2,307	7,024
1967	2,295	128	809	841	107	2,370	6,550
1968	795	84	1,734	320	146	1,182	4,261
1969	1,030	50	1,802	467	31	828	4,208
1970	1,463	382	2,149	310	75	1,289	5,668
1971	1,523	632	1,622	599	103	1,228	5,707
1972	1,139	863	1,190	1,526	79	960	5,757
1973	2,468	211	1,265	962	83	713	5,702
1974	1,454	305	1,098	264	81	414	3,616
1975	1,574	306	1,279	241	83	642	4,125
1976	1,429	398	1,147	141	42	601	3,758
1977	1,227	408	1,300	185	46	818	3,984
1978	1,303	737	1,829	314	142	500	4,825
1979	2,826	912	3,189	305	174	704	8,110
1980	3,430	1,615	4,831	604	228	1,715	12,423
1981	4,733	1,922	6,174	751	48	411	14,039
1982	2,885	994	4,625	937	90	245	9,776
1983	2,141	906	2,959	662	91	546	7,305
1984	1,734	588	3,789	808	57	74	7,050
1985	1,639	1,008	2,480	714	85	88	6,014
1986	1,094	898	1,831	979	89	4	4,895
1987	820	1,505	2,200	1,692	155	0	6,372
1988	388	817	1,923	672	76	11	3,887
1989	868	1,689	1,830	806	137	24	5,354
1990	771	1,216	2,022	1,003	115	48	5,175
1991	1,104	957	1,299	1,020	131	0	4,510
1992	845	992	846	1,089	41	0	3,813
1993	177	99	467	713	45	0	1,501
1994	81	50	217	581	113	0	1,042
1995	34	9	19	6	3	0	71
1996	27	8	34	85	2	0	157
1997	56	13	48	74	4	0	195
1998	48	27	64	97	5	0	241
1999	47	36	59	96	161	0	399

Year	Trawl	Seine	Gillnet	Longline	Handline	Other	Total
2000	26	28	32	79	12	0	177
2001	21	11	30	44	16	0	121
2002	14	14	10	24	9	0	70
2003	17	3	2	15	0	0	37
2004	14	11	2	27	0	0	55
2005	6	17	4	16	0	0	44
2006	3	14	1	8	0	0	26
2007	2	11	1	6	0	0	20
2008	5	19	2	5	0	0	31
2009	14	11	3	5	0	0	33
2010	5	6	2	3	0	0	16
2011	5	6	2	8	0	0	20
2012	3	6	4	2	0	0	14
2013	2	12	4	2	0	0	20
2014	2	9	3	2	0	0	16
2015	2	16	2	6	0	0	26
2016	2	15	3	9	0	0	29
2017	0	12	3	1	0	0	16
2018	1	6	5	0	0	0	12
2019	1	4	7	1	0	0	14
2020	1	4	9	2	0	0	16
2021	1	4	5	3	0	0	13
2022	1	3	7	6	0	0	17

Table A3: Comparison of White Hake landings (tonnes) in NAFO Division 4T and Subdivision 4Vn between 1985 and 2022.

Year	Landings 4T (tonnes)	Landings 4Vn (tonnes)	Ratio 4T/4Vn
1985	6,014	346	17.4
1986	4,895	397	12.3
1987	6,372	587	10.9
1988	3,887	333	11.7
1989	5,354	293	18.3
1990	5,175	191	27.1
1991	4,510	170	26.5
1992	3,813	158	24.1
1993	1,501	136	11.0
1994	1,042	224	4.7
1995	71	32	2.2
1996	157	68	2.3
1997	195	141	1.4
1998	241	138	1.7
1999	399	108	3.7
2000	177	74	2.4
2001	121	51	2.4
2002	70	70	1.0
2003	37	42	0.9
2004	55	60	0.9
2005	44	54	0.8
2006	26	75	0.3
2007	20	40	0.5
2008	31	27	1.1
2009	33	27	1.2
2010	16	24	0.7
2011	20	38	0.5
2012	14	15	0.9
2013	20	17	1.2
2014	16	22	0.7
2015	26	36	0.7
2016	29	30	1.0
2017	16	9	1.8
2018	12	7	1.7
2019	14	8	1.8
2020	16	10	1.6
2021	13	12	1.1
2022	17	14	1.2

Table A4: Commercial fishery catch-at-age (in thousands) for White Hake in NAFO Division 4T from 1978 to 2022.

Year	0-2	3	4	5	6	7	8	9	10	11	12	13+
1978	-	79.00	354.00	579.00	545.00	345.00	172.00	61.00	26.00	4.00	8.00	2.00
1979	-	90.00	470.00	833.00	972.00	672.00	315.00	101.00	47.00	8.00	11.00	4.00
1980	-	91.00	452.00	1,028.00	1,661.00	1,196.00	540.00	137.00	75.00	7.00	6.00	5.00
1981	-	66.00	427.00	1,075.00	1,976.00	1,391.00	604.00	154.00	94.00	4.00	1.00	8.00
1982	-	7.60	184.38	658.33	1,156.11	1,169.35	628.58	184.42	81.92	22.76	14.75	14.75
1983	13.01	59.52	179.10	693.71	902.98	720.87	546.78	117.18	36.81	8.73	5.94	2.59
1984	1.47	57.21	327.71	807.03	813.95	558.30	286.09	147.01	71.25	22.91	17.03	6.94
1985	2.99	66.29	224.99	631.63	610.42	404.26	233.38	112.82	52.94	17.50	19.02	12.18
1986	-	1.37	206.63	511.34	489.74	332.24	236.08	78.91	46.67	22.00	13.94	8.49
1987	-	29.74	513.68	1,377.85	936.06	417.46	153.50	64.19	17.97	3.51	2.35	3.56
1988	0.22	0.40	35.61	462.40	648.91	513.32	109.48	15.78	5.91	2.03	0.86	0.84
1989	5.01	8.93	116.81	585.01	830.99	685.56	213.80	76.72	11.25	12.99	5.45	5.45
1990	-	14.84	454.01	1,197.71	1,047.61	437.92	91.43	18.98	6.47	2.87	0.97	0.53
1991	-	27.22	400.29	1,027.54	891.51	503.22	79.11	17.17	5.59	1.87	1.05	4.78
1992	0.17	112.32	1,010.98	1,017.50	553.60	271.75	61.46	25.95	10.05	3.47	0.50	0.84
1993	-	55.18	286.88	415.77	217.46	91.41	26.55	11.77	1.27	1.84	0.44	0.08
1994	-	25.18	133.74	184.15	201.21	86.04	27.70	4.90	0.69	-	-	0.17
1995	-	0.01	0.63	2.15	9.85	11.20	3.99	0.29	-	-	-	-
1996	0.73	2.26	16.60	26.41	23.74	13.14	6.41	1.72	0.46	0.06	0.17	-
1997	0.19	1.11	13.71	39.73	33.97	13.88	5.43	1.10	0.39	0.07	-	-
1998	0.27	1.45	19.94	57.07	45.03	11.16	3.86	0.84	0.34	0.11	0.01	0.02
1999	0.51	3.72	42.57	114.54	74.88	15.82	2.12	0.73	0.07	0.02	-	-
2000	0.61	1.77	18.63	38.45	35.36	15.43	2.93	1.13	0.13	0.17	0.02	-
2001	0.12	2.89	20.97	28.47	20.29	7.48	2.12	0.31	0.17	0.00	-	-
2002	0.41	1.49	7.72	18.61	14.02	2.75	0.43	0.16	-	-	-	-
2003	0.54	2.58	11.19	12.27	5.44	0.63	0.14	-	-	-	-	-
2004	0.42	0.66	9.61	23.48	9.44	1.42	0.16	-	0.02	0.11	-	-
2005	2.14	2.23	10.82	14.10	8.32	1.70	0.22	0.02	-	-	-	-

Year	0-2	3	4	5	6	7	8	9	10	11	12	13+
2006	0.71	0.59	4.38	9.01	4.85	0.74	0.19	0.04	-	-	-	-
2007	0.53	0.99	3.55	5.48	3.48	0.46	0.36	0.02	0.04	0.01	-	-
2008	0.74	8.93	15.56	9.22	2.34	0.28	-	-	-	-	-	-
2009	0.25	0.86	2.81	10.28	6.69	1.38	0.10	-	-	-	-	-
2010	0.55	1.20	4.96	5.48	2.02	0.18	0.03	-	-	-	-	-
2011	0.13	0.39	2.31	6.22	3.33	0.85	0.22	-	-	-	-	-
2012	0.15	0.31	2.77	4.65	1.96	0.52	0.07	0.00	0.03	-	-	-
2013	0.16	0.12	1.10	7.15	4.55	0.41	0.10	0.04	0.03	-	-	-
2014	0.00	0.07	1.37	3.91	4.08	0.71	0.06	0.06	0.03	-	-	-
2015	0.00	0.00	1.65	7.54	5.19	1.33	0.20	0.08	0.08	-	-	-
2016	0.00	0.16	2.46	9.44	6.33	1.08	0.17	0.07	0.04	-	-	-
2017	0.00	0.16	1.32	4.62	3.84	0.54	0.08	0.05	0.01	-	-	-
2018	0.00	0.04	0.51	2.60	3.25	0.68	0.13	0.06	0.00	-	-	-
2019	0.00	0.10	0.61	2.42	3.55	0.94	0.23	0.10	0.00	-	-	-
2020	0.01	0.13	0.34	1.59	3.49	2.22	0.57	0.27	0.16	0.06	0.03	0.03
2021	0.01	0.14	0.34	1.49	3.20	1.90	0.47	0.20	0.11	0.04	0.02	0.02
2022	0.01	0.19	0.51	2.11	4.21	2.45	0.62	0.26	0.15	0.06	0.03	0.03

Table A5: Stratified mean catch rates at age (fish/tow) of White Hake in the September Research Vessel survey of the southern Gulf of St. Lawrence, in strata 415-439 between 1978 and 2022.

Year	2	3	4	5	6	7	8	9	10	11	12	13	14
1978	1.762	2.358	1.954	1.740	1.071	0.444	0.138	0.038	0.012	0.005	0.005	0.005	0.006
1979	0.354	1.973	2.186	1.661	1.108	0.596	0.244	0.083	0.028	0.011	0.005	0.004	0.003
1980	0.236	1.009	1.812	1.948	1.309	0.627	0.239	0.088	0.038	0.019	0.010	0.006	0.003
1981	0.495	1.285	2.228	3.041	2.630	1.368	0.497	0.163	0.058	0.025	0.014	0.010	0.008
1982	0.252	0.661	0.872	0.888	0.641	0.321	0.126	0.045	0.017	0.006	0.002	0.001	0.000
1983	0.812	0.903	0.686	0.479	0.297	0.170	0.081	0.032	0.012	0.004	0.001	0.000	0.000
1984	0.535	1.290	1.432	1.070	0.671	0.349	0.155	0.065	0.028	0.013	0.007	0.004	0.002
1985	2.066	4.173	2.700	1.397	0.747	0.461	0.267	0.151	0.093	0.061	0.041	0.026	0.015
1986	6.749	6.795	6.564	3.443	1.236	0.484	0.189	0.080	0.044	0.027	0.017	0.009	0.005
1987	0.443	1.467	1.892	1.230	0.655	0.213	0.041	0.025	0.019	0.015	0.009	0.005	0.002
1988	2.742	2.960	3.257	2.006	0.887	0.321	0.064	0.014	0.010	0.008	0.003	0.000	0.000
1989	1.609	2.452	2.168	1.208	0.697	0.245	0.054	0.019	0.009	0.004	0.004	0.002	0.000
1990	2.058	2.611	1.762	1.336	0.653	0.249	0.073	0.017	0.001	0.000	0.000	0.000	0.000
1991	2.126	2.666	1.977	1.179	0.626	0.198	0.042	0.021	0.018	0.011	0.003	0.000	0.000
1992	1.352	2.692	1.812	0.575	0.132	0.029	0.005	0.000	0.000	0.000	0.000	0.000	0.000
1993	0.579	0.815	0.884	0.488	0.156	0.036	0.009	0.006	0.004	0.001	0.000	0.000	0.000
1994	0.774	0.704	0.837	0.413	0.119	0.034	0.010	0.002	0.000	0.000	0.000	0.000	0.000
1995	0.869	0.459	0.387	0.099	0.052	0.023	0.009	0.001	0.000	0.000	0.000	0.000	0.000
1996	1.007	0.789	0.476	0.162	0.049	0.012	0.002	0.000	0.000	0.000	0.000	0.000	0.000
1997	0.749	0.776	0.782	0.386	0.137	0.028	0.004	0.001	0.001	0.001	0.000	0.000	0.000
1998	1.244	0.773	0.477	0.257	0.114	0.031	0.007	0.002	0.001	0.000	0.000	0.000	0.000
1999	1.363	0.945	0.600	0.268	0.102	0.024	0.004	0.000	0.000	0.000	0.000	0.000	0.000
2000	3.217	3.051	1.501	0.352	0.061	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2001	1.035	1.310	0.915	0.306	0.051	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2002	1.458	0.600	0.332	0.134	0.028	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2003	0.931	0.444	0.258	0.028	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2004	0.292	0.367	0.264	0.172	0.035	0.004	0.002	0.001	0.000	0.000	0.000	0.000	0.000
2005	1.511	0.889	0.555	0.191	0.042	0.007	0.001	0.000	0.000	0.000	0.000	0.000	0.000

Year	2	3	4	5	6	7	8	9	10	11	12	13	14
2006	0.451	0.393	0.239	0.051	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2007	2.687	2.130	0.753	0.231	0.040	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2008	0.580	0.859	0.645	0.215	0.032	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2009	0.968	0.641	0.467	0.186	0.027	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2010	1.234	0.828	0.468	0.159	0.024	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2011	0.868	0.624	0.353	0.103	0.012	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2012	1.236	0.815	0.522	0.166	0.023	0.006	0.001	0.000	0.000	0.000	0.000	0.000	0.000
2013	0.520	0.311	0.161	0.119	0.025	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2014	2.166	2.169	0.777	0.184	0.015	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2015	0.983	0.554	0.408	0.214	0.040	0.008	0.002	0.000	0.000	0.000	0.000	0.000	0.000
2016	0.829	0.518	0.474	0.244	0.059	0.005	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2017	2.082	0.630	0.285	0.213	0.049	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2018	0.305	0.344	0.241	0.110	0.027	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000
2019	1.993	0.978	0.410	0.187	0.050	0.007	0.001	0.000	0.000	0.000	0.000	0.000	0.000
2020	2.026	2.100	0.713	0.174	0.027	0.005	0.001	0.000	0.000	0.000	0.000	0.000	0.000
2021	0.608	0.533	0.396	0.202	0.076	0.020	0.004	0.002	0.000	0.000	0.000	0.000	0.000
2022	0.683	0.591	0.369	0.126	0.024	0.005	0.001	0.000	0.000	0.000	0.000	0.000	0.000

Table A6: Mean weight (kg) at age of White Hake in the September Research Vessel survey of the southern Gulf of St. Lawrence (strata 415-439) between 1978 and 2022.

Year	2	3	4	5	6	7	8	9	10	12	11	13	14
1978	0.207	0.427	1.036	1.480	1.911	2.663	3.625	2.000	2.067	7.200	-	-	-
1979	0.325	0.527	0.860	1.427	1.903	2.250	2.686	3.200	3.925	2.617	5.100	-	-
1980	0.325	0.527	0.860	1.427	1.903	2.250	2.686	3.200	3.925	2.617	5.100	-	-
1981	0.242	0.456	0.922	1.471	1.985	2.406	3.222	3.458	3.400	3.900	14.200	10.067	11.500
1982	0.363	0.621	1.024	1.409	1.952	2.462	3.067	3.800	4.600	-	-	-	-
1983	0.352	0.685	1.126	1.868	2.131	2.989	3.980	3.900	6.000	-	-	-	-
1984	0.272	0.550	0.968	1.517	2.193	2.481	3.284	3.055	5.909	5.475	3.468	-	-
1985	0.207	0.418	0.789	1.310	1.823	2.329	2.646	3.543	3.632	10.250	4.125	9.600	12.000
1986	0.243	0.455	0.773	1.246	1.924	2.939	3.526	5.039	8.321	8.880	5.900	10.750	-
1987	0.195	0.417	0.686	1.234	1.977	3.206	4.206	6.479	7.000	9.570	-	-	11.000
1988	0.202	0.403	0.716	1.192	1.839	2.953	4.300	6.583	8.375	10.500	-	-	-
1989	0.198	0.423	0.654	1.116	1.705	2.568	3.945	5.316	7.840	-	9.660	11.000	-
1990	0.190	0.382	0.641	0.976	1.539	2.409	4.502	4.780	-	-	-	-	-
1991	0.240	0.469	0.698	1.117	1.655	2.298	3.940	4.840	8.548	-	8.683	-	-
1992	0.251	0.440	0.663	1.067	1.686	2.052	3.768	-	-	-	-	-	-
1993	0.243	0.423	0.700	1.015	1.510	1.618	2.645	4.995	-	-	-	-	-
1994	0.247	0.501	0.802	1.182	1.779	2.500	4.003	-	-	-	-	-	-
1995	0.239	0.464	0.721	1.167	1.883	2.963	3.609	-	-	-	-	-	-
1996	0.232	0.507	0.714	1.227	1.722	2.104	2.253	1.980	-	-	-	-	-
1997	0.216	0.441	0.644	0.930	1.271	2.264	2.483	-	-	-	-	-	-
1998	0.253	0.435	0.682	1.175	1.770	2.380	2.781	2.210	4.425	-	-	-	-
1999	0.253	0.452	0.712	1.189	1.999	2.988	-	-	-	-	-	-	-
2000	0.239	0.386	0.613	1.160	1.838	2.359	2.823	-	2.720	-	-	-	-
2001	0.234	0.443	0.659	1.069	1.685	2.110	-	-	-	-	-	-	-
2002	0.261	0.525	0.765	1.261	1.783	1.888	-	-	-	-	-	-	-
2003	0.225	0.486	0.715	1.366	-	-	-	-	-	-	-	-	-
2004	0.246	0.471	0.752	1.186	1.709	3.080	-	-	-	-	-	-	-
2005	0.239	0.495	0.657	1.041	1.314	1.677	-	-	-	-	-	-	-

Year	2	3	4	5	6	7	8	9	10	12	11	13	14
2006	0.222	0.446	0.712	1.197	-	-	-	-	-	-	-	-	-
2007	0.231	0.414	0.669	1.086	1.644	1.240	-	-	-	-	-	-	-
2008	0.239	0.417	0.632	1.113	1.862	1.715	-	-	-	-	-	-	-
2009	0.195	0.394	0.626	1.017	1.051	-	-	-	-	-	-	-	-
2010	0.226	0.404	0.686	1.115	1.737	-	-	-	-	-	-	-	-
2011	0.201	0.423	0.669	1.218	1.180	-	-	-	-	-	-	-	-
2012	0.218	0.432	0.672	1.176	2.257	3.620	-	-	-	-	-	-	-
2013	0.192	0.372	0.657	1.270	1.389	-	-	-	-	-	-	-	-
2014	0.214	0.366	0.627	0.993	1.245	-	-	-	-	-	-	-	-
2015	0.210	0.399	0.662	1.154	1.562	-	-	-	-	-	-	-	-
2016	0.210	0.399	0.662	1.154	1.562	-	-	-	-	-	-	-	-
2017	0.210	0.399	0.662	1.154	1.562	-	-	-	-	-	-	-	-
2018	0.210	0.399	0.662	1.154	1.562	-	-	-	-	-	-	-	-
2019	0.210	0.399	0.662	1.154	1.562	-	-	-	-	-	-	-	-
2020	0.210	0.399	0.662	1.154	1.562	-	-	-	-	-	-	-	-
2021	0.210	0.399	0.662	1.154	1.562	-	-	-	-	-	-	-	-
2022	0.210	0.399	0.662	1.154	1.562	-	-	-	-	-	-	-	-

APPENDIX B. PROCEDURES TO DEAL WITH MISSING YEAR-STRATUM COMBINATIONS

Years with missing strata are 1978 (strata 424 and 428 are missing), 1983 (stratum 421 is missing), 1988 (stratum 421 is missing), 2003 (strata 438 and 439 are missing, only one set in strata 425 and 436), 2020 (stratum 421 is missing) and 2021 (stratum 421 is missing).

For 1978, the weight of missing stratum 428 is assigned to stratum 435, and the weight of missing stratum 424 is assigned 1/3 to stratum 422 and 2/3 to stratum 423 prior to the stratified calculations.

For 1983, 1988, 2020 and 2021, where stratum 421 is missing, the stratum weight in the stratified calculations is assigned to the adjacent stratum 420 prior to the stratified calculations.

For 2003, a multiplicative model is used to predict the catches in strata 425, 436, 438 and 439 prior to the stratified calculations.