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Recovery potential assessment of the Southern Gulf of St. Lawrence Designatable Unit of White Hake (*Urophycis tenuis* Mitchill), January 2015

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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 Southern Gulf of St. Lawrence (SGSL) Designatable Unit (DU) of White Hake (*Urophycis tenuis*) was assessed as Endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) in November 2013. This DU consists primarily of white hake occurring in NAFO division 4T. Indices from the annual research vessel (RV) bottom-trawl survey of 4T indicate a 90% decline in adult abundance since 1985 (about three generations). Most of this decline occurred between 1985 and 1996, though the index continues to slowly decline. Sentinel indices available since 2003 (bottom-trawl survey) or 1995 (longline program) also indicate on-going declines, with recent values the lowest in the time series. The spawning stock biomass (SSB) estimated by population models declined from an average of 52,850 t in 1978-1982 to 3,850 t in 2013, a 93% decline. In contrast, juvenile abundance has fluctuated without trend since 1978. The area occupied by adult hake in the SGSL in September declined from about 25,000 km^2 in the early 1980s to 5,000 km^2 in recent years, but changed little over this period for juveniles. In summer and early fall, white hake in the SGSL occur either in shallow inshore waters or in deeper water along the slope of the Laurentian Channel and in the Cape Breton Trough. The proportion of hake occurring in inshore areas has declined over time, with hake virtually absent from these areas in recent years. This appears to result from increasing risk of predation by grey seals in inshore areas. These areas contain important spawning and feeding grounds for hake. The directed fishery for white hake has been closed since 1995, and fishing mortality has declined to negligible levels, F = 0.002 for ages 4-5 (0.2% annually) and F = 0.035 for ages 6 and older (3.4% annually) since 2006. In contrast, natural mortality has increased to very high levels, averaging 87% annually for ages 4-5 years and 78% annually for ages 6+ since 2000. Increasing predation by grey seals is considered to be an important cause of this increase in natural mortality. Recruitment remains strong in this population despite very low SSB. This reflects very high recruitment rates over the past 20 years.

SSB equal to 40% of the SSB producing the maximum surplus production of recruits is proposed as a recovery target. SSB has been below the target since 1995. The most recent estimate (for 2013) is 30% of the target with no chance of being at or above the target. Under current conditions, continued declines are projected, with no chance of achieving the recovery target and a 19-38% probability of extinction in 60 years, even with no fishing. Reductions in the instantaneous rate of natural mortality (*M*) would provide some possibility of recovery. Under the current condition of high recruitment productivity, the probability of recovery was estimated to be 27% 30 years after a 20% reduction in *M*, 95% 30 years after a 30% reduction in *M*, and 51% and 100% 6 and 20 years after a 40% reduction in *M*. At the lower level of recruitment productivity observed in 1978-1994, a 50% reduction in *M* would be insufficient to permit recovery, and the probability of recovery would be 77% 30 years after a 60% reduction in *M*. At recent levels of fishing effort, catches associated with commercial fisheries directing for groundfish result in instantaneous rates of fishing mortality for fully-recruited fish of 0.24 (1998-2002) to 0.04 (2009-2013), and consequently have a negligible impact on the population trajectory. The current high levels of natural mortality are the main threat and the most important factor limiting the recovery of this population.

Évaluation du potentiel de rétablissement de l'unité désignable du sud du golfe du Saint-Laurent (SGSL) pour la merluche blanche (*Urophycis tenuis* Mitchill), janvier 2015

RÉSUMÉ

L'unité désignable (UD) du sud du golfe du Saint-Laurent (SGSL) pour la merluche blanche (*Urophycis tenuis*) a été évaluée en voie de disparition par le comité sur la situation des espèces en péril au Canada (COSEPAC) en Novembre 2013. Cette UD consiste principalement de merluche blanche se retrouvant dans la division 4T de l'OPANO. Les indices du relevé au chalut de fond de navire de recherche de 4T indiquent une baisse de 90% dans l'abondance des adultes depuis 1985 (environ trois générations). La plupart de cette baisse a eu lieu entre 1985 et 1996, bien que l'indice continu à baisser lentement. Les indices sentinelles disponibles depuis 2003 (relevé au chalut de fond) ou 1996 (programme à la palangre) indiquent également une baisse continue, avec des valeurs récentes, les plus basses de la série chronologique. La biomasse du stock reproducteur (BSR) estimée par les modèles de population a diminué d'une moyenne de 52.850 t en 1978 à 1982 et à 3.850 t en 2013, soit une baisse de 93%. En revanche, l'abondance des juvéniles a fluctué sans tendance depuis 1978. La superficie occupée par les merluches adultes dans le SGSL en septembre a diminué d'environ 25 000 km^2 au début des années 1980 à 5000 km^2 au cours des dernières années, mais a peu changé au cours de cette période pour les juvéniles. En été et début de l'automne, la merluche blanche dans le SGSL provienne soit des eaux côtières peu profondes ou des eaux plus profondes le long de la pente du chenal Laurentien et de la cuvette du Cap- Breton. La proportion de merluche provenant des zones côtières a diminué au fil du temps, avec la merluche pratiquement absente de ces régions au cours des dernières années. Cela semble découler de l'augmentation du risque de prédation par les phoques gris dans les zones côtières. Ces régions contiennent des zones de frai et d'alimentation importantes pour la merluche. La pêche dirigée de la merluche blanche a été fermée depuis 1995, et la mortalité par pêche a diminué à des niveaux négligeables. Le taux instantané de mortalité par pêche est négligeable, étant en moyenne de F = 0,002 pour les âges de 4-5 (0,2% par an) et F = 0,035 pour les âges de 6 ans et plus (3,4% par an) depuis 2006. En revanche, la mortalité naturelle a augmenté à des niveaux très élevés, avec une moyenne de 87% par an pour les âges 4-5 et 78% par an pour les âges 6+ depuis 2000. L'augmentation de la prédation par les phoques gris est considérée comme une cause importante de cette augmentation de la mortalité naturelle. Le recrutement reste fort dans cette population, malgré une très faible BSR. Cela reflète des taux très élevés de recrutement au cours des 20 dernières années.

BSR égale à 40% de la BSR qui produit la production excédentaire maximale de recrutement est proposé en tant que cible de rétablissement. BSR a été inférieure à la cible depuis 1995. L'estimation la plus récente (2013) est de 30% de la cible, sans aucune chance d'être au niveau ou au-dessus de cette cible. Dans les conditions actuelles, des baisses sont projetées, sans aucune chance d'atteindre l'objectif de rétablissement et une probabilité de 19-38% d'extinction dans 60 ans, même sans pêche. Les réductions du taux instantané de mortalité naturelle (*M*) fourniraient une certaine possibilité de rétablissement. Sous l'état actuel de la productivité élevée du recrutement, la probabilité de rétablissement a été estimée à 27% 30 ans après une réduction de 20% en *M*, 95% 30 ans après une réduction de 30% en *M*, et 51% et 100% 6 et 20 ans après une réduction de 40% en *M*. Au niveau inférieur de la productivité du recrutement observée dans les années 1978-1994, une réduction de 50% en *M* seraient insuffisants pour permettre le rétablissement et la probabilité de rétablissement serait de 77% 30 ans après 60% de réduction en *M*. Aux niveaux actuels de l'effort de pêche, les prises accessoires de la merluche blanche dans les pêcheries commerciales diriger à d'autres poissons de fond ont un

effet négligeable sur la trajectoire de la population. Les niveaux élevés actuels de mortalité naturelle sont la principale menace et est le facteur le plus important limitant le rétablissement de cette population.

INTRODUCTION

White Hake (*Urophycis tenuis* Mitchill) was historically a commercially important groundfish in the southern Gulf of St. Lawrence, ranking third or fourth in terms of annual landings. However, the directed fishery for white hake was closed in 1995 due to low hake abundance, and this fishery has remained under moratorium since then. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) assessed the status of white hake in Canadian waters in November 2013 (COSEWIC 2013). The Southern Gulf of St. Lawrence Designatable Unit was assessed as Endangered.

The last full assessment of the southern Gulf of St. Lawrence (NAFO Div. 4T) White Hake stock was conducted in 2001 (DFO 2001), with an update in 2005 (DFO 2005). A review of information on the status of this stock was completed in 2011 in support of the COSEWIC assessment (Swain et al. 2012). Indices of abundance were updated to 2013 (DFO 2014). This Recovery Potential Assessment (RPA) provides information on the recent and current status of the Southern Gulf of St. Lawrence (SGSL) Designatable Unit of White Hake in terms of abundance, biomass and range, its life history and productivity, threats to its survival and recovery, and the feasibility of recovery. Results are summarized in relation to the RPA Terms of Reference in Appendix I.

BACKGROUND

During the summer and early autumn, white hake in the SGSL typically exhibit a bimodal distribution with respect to depth, occurring either in shallow (<50 m) inshore areas or in deep water (>100 m) along the slope of the Laurentian Channel and in the Cape Breton Trough (Fig. 1; see Swain et al. 2012 for details). White hake from the shallow- and deep-water areas differ in a number of morphometric and meristic traits, in particular snout length, consistent with the hypothesis that hake in these two areas represent different stock components (Hurlbut and Clay 1998). However, it is not known whether these differences reflect genetic and/or environmental differences.

Roy et al. (2012) reported that hake in the SGSL were genetically distinct from hake in other areas of Atlantic Canada, though the SGSL population overlapped with the neighbouring Scotian population in the deep waters of the Laurentian Channel. Based on the data in Roy et al. (2012), over 90% of hake collected in the SGSL (NAFO Division 4T) at depths less than 200 m were of the Gulf type, with this proportion declining as depth increased, from about 80% in the 200 – 250 m range to 34 % at depths greater than 350 m (Swain et al. 2012). The Gulf type also dominated in samples collected in the northwest portion of NAFO Subdivision 4Vn. COSEWIC (2013) defined the area occupied by the SGSL DU as all of NAFO Division 4T and the northern portion of Subdivision 4Vn. For the purposes of this report it is assumed that the status and recovery potential of the SGSL DU can be assessed based on analysis of the 4T management unit, which is dominated by the SGSL DU and comprises the bulk of the area occupied by this DU. While Division 4T includes the St. Lawrence Estuary, the genetic identity of hake occurring in this area (NAFO unit areas 4Topq, Fig. 2) is unknown as no samples were collected from this area. The contribution of this area to landings of 4T white hake is minor (1985-2010 average, 1.1%).

Following Swain et al. (2012), white hake 45 cm and longer and 4 years and older were considered mature in the analyses presented here. COSEWIC approximates generation time as Amat+1/*M*v where Amat is the age at maturation and *M*v is the historical (i.e., pre-fishing) instantaneous rate of natural mortality. If historical *M* is assumed to be 0.2, estimated generation time is 9 years.

FISHERIES

LANDINGS IN COMMERCIAL FISHERIES IN THE 4T MANAGEMENT AREA

Landings fluctuated between about 4,000 and 7,000 t between 1961 and 1978 (Table 1, Fig.3). 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 tonnes 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 (FRCC) 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 January1995, 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 2006-2009 and 15-20 t since then.

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 (Fig. 4). Landings were and continue to be predominantly from eastern regions of the SGSL, in unit areas 4Tf and 4Tg (Fig. 5). Until recently, landings were predominantly from shallow inshore waters in 4Tg, in particular St. Georges Bay. However, the importance of 4Tf has increased since the early 2000s, with most (>80%) of landings coming from this area in 2010. Regions of the western SGSL, in particular 4Tl, were also an important 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 increased to an average of 3.4% of landings from 1995-2010, but the quantity landed remains negligible, less than 1.5 t on average. Until recently, landings predominantly occurred in July to September (Fig. 6). Landings now predominantly occur in June and July.

Since the closure of the directed fishery, the majority of white hake landings have come from trips where white hake, cod or redfish were the main species caught (Fig. 7). “White hake” trips were the most important source of white hake landings from the mid-1990s to the early 2000s, cod trips the most important source in the mid-2000s and redfish trips the most important source since the late 2000s. Witch flounder trips were an important source of hake landings in 2006-2008, as were Atlantic halibut trips in 2011, turbot (Greenland halibut) trips in 2012 and winter flounder trips in 2013.

Fishery catch-at-age

The fishery catch-at-age, as well as mean lengths and weights at age in the landings, were updated from 2001 to 2013 (Table 2a-c). The age-length keys used to update the catch-at-age are described in Appendix 2. The proportion of older fish (ages 7+ yr) in the catch steadily declined between the 1978-1985 and 2005-2014 periods (Fig. 8).

DISCARDED BYCATCH IN COMMERCIAL FISHERIES

Marine fisheries

White hake are also incidentally captured in commercial fisheries for invertebrates in the SGSL. Since the introduction of the Nordmore grate in 1994, bycatch of white hake in the shrimp fishery has been less than 2 tonnes annually, and bycatch is restricted to juvenile fish (H.P. Benoît, unpublished analyses). Adult white hake are incidentally captured in SGSL scallop and lobster fisheries. Preliminary analyses suggest that catches in the scallop fishery are very small (Benoît 2011, Benoît et al. 2011a). The amount of white hake caught in the lobster fishery is unknown, though adult white hake are reported to be very rarely encountered in the traps (Benoît et al. 2011a). White hake catches in the fishery for snow crab have also not been recorded but are likely to be low because much of the effort in this fishery is restricted to areas where bottom temperatures are colder than those normally occupied by hake (see below for hake temperature associations).

Estuarine fisheries

Landing statistics for white hake do not include catches in the estuarine smelt fishery. Bycatch in this fishery in the Miramichi Estuary was monitored between mid-October and the end of November in 1994 and 1995 (Bradford et al. 1997). White hake were intercepted at an average rate of 23 kg per net per day (257 fish per net per day). The estimated magnitude of white hake bycatch was on the order of 40 t in 1994 (representing ~277,000 fish) and 20 t in 1995 (representing ~350,000 fish). In 1994, the sampled hake were mainly between 10-35 cm TL (1-3 year olds), but the length frequency had modes at 18 and 30 cm. In contrast, the hake sampled in 1995 were smaller (ranging from 10-25 cm; 1-2 year olds) with a modal size of 18 cm. Fish harvesters reported that bycatch of white hake >25 cm TL was normally lower than the high level observed in 1994, consistent with results of a survey of this fishery in 1993 (R.G. Bradford personal observation) and the monitoring results in 1995.

Suggested remedial action to reduce bycatch included increasing mesh size to reduce the catch of fish <20 cm in length (though this would severely reduce landings of commercial rainbow smelt), or delaying the opening date of the fishery to November 1 (Bradford et al. 1997). These suggestions have not been implemented, though the opening date of the fishery was delayed from Oct. 22 to Oct. 30 in 2011 (Swain et al. 2012). Instead, DFO has enforced a licensing condition that requires fishermen directing for smelts in the fall and winter fisheries to sort and release all groundfish from their fishing gear. This measure is not likely to substantially reduce bycatch mortality of hake because these fish have difficulty descending into the water column after being discarded, and predation on discarded hake by gulls can be substantial (Bradford et al. 1997).

In 1994, there were anecdotal reports from the fishing industry of the bycatch of many small white hake in fishing gear set for silversides and eels on P.E.I. (Hurlbut et al. 1996). Subsequently Hurlbut et al. (1996) were unable to confirm these reports, and concluded that the magnitude of removals of white hake in these fisheries was probably much lower than in the Miramichi smelt fishery.

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.

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.

LANDINGS IN 4VN

Although the population modelling for this RPA 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 Fig. 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 3).

In the 1985-1999 period, winter catches of white hake were mostly outside of the NW portion of 4Vn whereas summer catches were spread throughout 4Vn, with the highest catches in the NW portion of 4Vn (Fig. 9a). In 2000 to 2008, catches of white hake in 4Vn were largely confined to the May to October period (Fig. 9b). Although spread throughout 4Vn, the highest catches were again in the northwest portion of the subdivision. The small catches since 2009 have been mostly in the northwest portion of 4Vn in May to October (Fig. 9c). 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. Thus, the effect of omitting 4Vn catches from population models (see below) is expected to be small.

ABUNDANCE AND BIOMASS INDICES

RESEARCH VESSEL (RV) SURVEY

Methods

A bottom-trawl survey of the southern Gulf of St. Lawrence 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

(Fig. 10). The target fishing procedure in all years was a 30 minute tow at 3.5 knots. All catches were adjusted to a standard tow of 1.75 nautical miles.

Survey coverage was expanded in 1984 to include three inshore strata (401-403). Aside from the addition of these three strata, both the survey timing and survey area have remained constant since 1971. Analyses beginning in 1971 were restricted to the 24 strata fished since then (strata 415-439). Additional analyses restricted to the period after 1983 also included strata 401 and 403, inshore strata of potential importance to white hake. Of these 26 strata, two (424 and 428) were not fished in 1978, while stratum 421 was not fished in 1983 and 1988. In order to maintain a consistent survey area, in the years when these strata were not fished their weights were added to those of neighbouring strata in the same depth zone in calculations of stratified mean catch rates and distribution indices at length. In 2003, no stations were fished in strata 438 and 439. In length-based analyses, predicted values for the mean catch rate in these strata were obtained using generalized linear models with terms for year and stratum. Models used a log link and assumed a Poisson error distribution allowing for overdispersion. This analysis was restricted to the 2002 to 2004 period to avoid effects of changes in distribution. Predicted values were not obtained for these strata in 2003 in age-based analyses, which thus exclude this year.

The research vessels conducting the survey were the *E. E. Prince* from 1971 to 1985, the *Lady Hammond* from 1985 to 1991, the *Alfred Needler* from 1992 to 2002, the *Wilfred Templeman* in 2003, both the *Alfred Needler* and the *Teleost* in 2004 and 2005, and the *Teleost* from 2005-2013. Tows conducted by the *E. E. Prince* used a *Yankee 36* trawl, while all other vessels used a *Western IIA* trawl. Based on comparative fishing experiments, fishing efficiency for white hake was estimated to be 1.32 times greater for the *Alfred Needler* than for the *Teleost*, but no other differences in fishing efficiency were detected (Benoît and Swain 2003; Benoît 2006). Standardized time series were obtained by dividing catches by the *Alfred Needler*, *Lady Hammond* and *E. E. Prince* by 1.3 in length-based analyses or by multiplying *Teleost* catches by 1.3 in age-based analyses. This difference between length- and age-based analyses reflects the different approaches taken when these indices were last updated. The *Wilfred Templeman* was uncalibrated and assumed to have fishing efficiency similar to its sister ship, the *Alfred Needler*.

While comparative fishing in 1985 failed to detect a significant difference in fishing efficiency between the *E. E. Prince* / Yankee 36 and the *Lady Hammond* / Western IIA, the statistical power of this test was low (only 26 pairs of tows caught white hake). The non-significant estimate of relative efficiency suggested that the *E. E. Prince* / Yankee 36 was about 70% as efficient as the *Lady Hammond* / Western IIA at catching white hake (Benoît and Swain 2003b). Population models that assume no change in fishing efficiency in the RV survey in 1985 result in strong residual patterns between observed and predicted abundance indices (Appendix 3). Residuals are almost all negative, particularly at ages 4+, in 1978-1984 (i.e., predicted index > observed index). This pattern also suggests that fishing efficiency for white hake was greater for the *Lady Hammond* / Western IIA. We present both unadjusted indices for 1971-1984 and indices adjusted by dividing by 0.7.

Fishing was restricted to daylight hours (07:00-19:00) from 1971-1984 but was extended to 24-h per day since 1985. Benoît and Swain (2003) found important length dependencies in the diel variation in catchability of white hake: small individuals (<30 cm) were more catchable at night, whereas adult hake (40+ cm) were slightly more catchable during the day or showed no diel variation. Consequently, night catches were adjusted to be equivalent to day catches using the length-dependent correction factors recommended by Benoît and Swain (2003).

Indices are shown separately for juvenile and adult hake. Following Swain et al. (2012), fish 45 cm and longer and 4 years and older were considered mature in the construction of these indices. Indices are presented at the scale of mean number of fish or kg per tow (Fig. 11) or “trawlable” abundance and biomass (Table 4). The latter indices are the stratified mean catch rate multiplied by the number of trawlable units in the survey area; 1,729,346 for strata 415-439 and 1,768,089 including 401 and 403. A trawlable unit is the area swept by a standard tow (i.e., distance towed multiplied by the nominal wingspread of the trawl). Data are included up to 2013 for age-based analyses and 2014 for length-based analyses.

The linear decline rate of adult hake over approximately three generations was estimated by regression of the natural log of the survey catch rate against year beginning in 1985 (to maintain a consistent survey gear). Following Swain et al. (2012), generation time was taken to be 9 years. Percent change in abundance was estimated as $100*(\exp(b*\Delta t)-1)$ where b is the regression slope and Δt is the change in time (years). Piecewise regressions were also fit using the R package “segmented” (Muggeo 2008).

Results

Length-based indices of juvenile abundance and biomass fluctuated without clear trends between 1971 and 2014 (Fig. 11). Abundance and biomass tended to be slightly greater after than before 1985 if no adjustment for the change in gear in 1985 was applied. The juvenile indices tended to be higher between 1985 and 1992 than since 1993, though the indices in 2000, 2007 and 2014 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 1985 to 1995, and remained at a very low level since then. Differences between the indices based on strata 415-439 and those also including 401 and 403 were negligible.

For the juvenile length class, trawlable abundance and biomass in strata 401, 403 and 415-439 averaged 9 million fish and 3,500 t in 1985 to 1992 and 5.7 million fish and 1,875 t in 1993 to 2014 (Table 4a, 4b). For the adult length class trawlable abundance and biomass declined from an average of 7.4 million fish and 10,000 t in 1985 to 1991 to 1 million fish and 980 t in 2007 to 2014.

Regressions of the natural log of catch rates on year were highly statistically significant, accounting for 70% (415-439) or 77% (401,403,425-439) of the variation in catch rates (Fig. 12). Fit was substantially improved using piecewise regression (R^2 = 0.87). The estimated decline in the abundance of the adult length class from 1985 to 2014 (about 3 generations) was over 90%. However, most of the decline occurred from 1985 to 1996. Based on piecewise regression, adult abundance declined by 89% (415-439) or 86% (401,403,425-439) from 1985 to 1996, with a further decline of 38% (415-439; non-significant) or 53% (401,403,425-439; significant) from 1996 to 2014.

Age-based abundance indices and the mean weight at age in September are shown in Tables 5a and 5b. A dramatic contraction of the age composition of SGSL white hake has occurred since 1971 (Table 5a, Fig. 13). Fish 10 years and older were commonly observed in the survey catches in the 1970s and 1980s, but no hake over 7 years of age has been observed in the survey since 1998, with the oldest age observed at 5 years in 2006 and 6 years in 2009 to 2011 and 2013. The modal age declined from 4 years in the 1980 to 3 years in the 1990s and 2 years in the 2000s (Fig. 13).

Abundance of hake aged 3 years and younger (juveniles) fluctuated with little trend over the 1971 to 2013 period (Fig. 14a). Adult abundance (ages 4 years and older) declined sharply between the mid-1980s and mid-1990s and has remained at a low level since then (Fig. 14b). Linear regression of the natural log of catch rate of adult hake against year accounted for 56% of the variation in catch rates (Fig 14c), with a highly significant slope of -0.069, corresponding to an 85% decline over 28 years (about 3 generations). However, a piecewise regression with a break-point in 1995 fit the adult abundance indices better (R^2 = 0.72, Fig. 14d). The highly significant slope over the 1985-1995 period was -0.184, corresponding to an 84% decline over 10 years, whereas the non-significant slope since 1985 (-0.019) corresponded to a decline of 29% over 18 years.

MOBILE SENTINEL (MS) SURVEY

Methods

Since 2003, the mobile gear component of the southern Gulf of St. Lawrence sentinel survey program has consisted of a bottom-trawl survey conducted in August by four commercial fishing vessels using a standardized bottom trawl and standardized protocols. Data collection has been conducted by at-sea observers. This survey follows the same stratified-random survey design used for the annual (September) RV survey. There have been several vessel changes since 2003. In a number of cases the same captain operated the old and replacement vessels.

Although each vessel does not fish all strata, there is considerable overlap between vessels in the strata fished. Calibration of relative fishing efficiency between vessels is attempted annually using a catch rate model with terms for year, stratum and vessel. However, because of the restricted spatial distribution of white hake, stratum and vessel effects may be confounded in calibrations for this species. Thus, we report indices with no adjustment for possible vessel effects.

Results

Age-aggregated abundance and biomass indices from the mobile sentinel survey declined over the 2003 to 2013 period (Fig. 15). The abundance index was at the lowest levels observed in 2011 to 2013. Catch rates were lower at all lengths in 2008 to 2013 compared to 2003 to 2007 (Fig. 16). This difference (as a proportion) was greatest at the largest sizes. Almost no fish were caught over 62 cm in the earlier period and over 55 cm in the later period. Stratified mean catch rates at age and mean weights and lengths at age in the mobile sentinel survey are given in Tables 6a to 6c. The average length and weight of the fish caught decreased substantially in 2012 and 2013 due to a sharp decline in the abundance of fished aged 3 years and older.

LONGLINE SENTINEL (LL) SURVEY

Methods

Sentinel longlines have been fished with consistent protocols since 1996. Each participating vessel is required to fish in two traditional fishing areas selected by the participating fishermen (or their association). The fishing locations are 2.5 miles in radius and at least 5 miles apart. Once the locations were determined, they remained constant throughout the fishing season Two to five stations were added in 1997 to 1999, 2001 and 2002, and two stations were discontinued in each of five years between 2002 and 2014. Each vessel fished its gear a maximum of 18 times with a maximum frequency of twice per week, during the fishing season. The fishing days could be consecutive within each 7-day period. A maximum of 1,250 hooks (size 12 circle, one fathom apart) were set at each site. Soak time was a minimum of 4 to 6 hours and a maximum of 24 hours. During each fishing trip, detailed information was collected by fisheries observers on the catch composition and length frequencies, and material for age determination was collected.

Catch rates were standardized using a multiplicative analysis (Robson 1966; Gavaris 1980) with the SAS GLM procedure (SAS Institute Inc. 1989). The approach was similar to that used by Chouinard et al. (2000). Observations of catch and effort for each individual site were aggregated on a monthly basis. Months in which effort was less than one complete fishing day were eliminated from the analysis. Analyses were restricted to the July to October period, except for the Cape Breton Trough sites which were not fished in July. Sites that have been fished in at least four years were included in the analysis. There are currently 36 fishing sites in the sentinel longline program, distributed throughout inshore areas of the southern Gulf (Fig. 17). However, white hake have been very rarely caught in the program except at sites along the PEI and Nova Scotia coasts. Analyses were restricted to the 22 sites in these regions. Three analyses were conducted: one including all 22 sites, one restricted to the six sites in St. Georges Bay, and one restricted to the six sites in the Cape Breton Trough. Catch rate data were natural log (base e) transformed after adding a constant (1) to each catch rate to deal with zero catch rates.

The model was as follows: $\ln A_{ijk} = B_0 + B_1 I + B_2 J + B_3 K + \varepsilon$

where

A_{ijk} = the catch rate (+1) for year i during month j at site k

I = a matrix of 0 and 1 indicating year

J = a matrix of 0 and 1 indicating month

K = a matrix of 0 and 1 indicating site

Results

Results of the catch rate standardization are shown in Tables 7a to 7c. Models accounted for 56% to 87% of the variation in the catch rates aggregated by site, month and year. Effects of site, month and year were all highly statistically significant ($P < 0.0005$). For all three regions, catch rates dropped dramatically over the 1996 to 2013 period (Table 8; Figs. 18 and 19).

Considering the entire PEI and Nova Scotia region, catch rates declined at an annual rate of 0.28 (Fig. 19a), corresponding to a 99% decline over this 17 year period (about two generations). Allowing a break in the linear trend improves model fit slightly (from $R^2 = 0.92$ to $R^2 = 0.95$, Figs. 19a and 19b). The break-point is estimated to be in 2008, with a 98% decline between 1996 and 2008 and a non-significant change (slope) after 2008.

Considering only the St. Georges Bay area, the linear model fit the log transformed catch rate data well ($R^2 = 0.97$, Fig. 18c). The estimated annual rate of change (-0.48) corresponds to a 99.97% decline over two generations. In other words, white hake have been essentially eliminated from this region.

Declines were slightly less severe in the Cape Breton Trough (Fig. 19d). Model fit was poorer ($R^2 = 0.58$), though still highly statistically significant ($P = 0.0002$) with no serious residual patterns. The estimated annual rate of change was -0.16, corresponding to a decline of 93% over two generations.

MORTALITY

Methods

The instantaneous rate of total mortality (*Z*) was estimated from RV survey indices at age using a modified catch-curve analysis (Sinclair 2001). This is an analysis of covariance with log-transformed survey catch rate as the dependent variable, cohort as a factor (accounting for variation in cohort strength) and age as a covariate. If all ages in the analysis are equally catchable in the survey, the slope provides an estimate of *Z*. Analyses included ages 5 to 7 years and were conducted in moving 7-year windows.

Trends in *Z* were compared to trends in a survey-based index of fishing mortality, relative fishing mortality (*RF*, Sinclair 1998), in order to infer trends in natural mortality. *RF* is fishery catch in numbers divided by survey trawlable abundance. *RF* is proportional to *F* when the survey is conducted near the middle of the fishing year, as is the case here. We calculated *RF* over the same age ranges as *Z*, and averaged over the same moving blocks of years. Note that *RF* is an annual rate while *Z* is an instantaneous rate and that the level of *RF* will depend on catchability to the survey.

Results

RF averaged 0.55 prior to the moratorium, dropping to an average of 0.09 in 1995 to 2005 and 0.03 in 2006 to 2010 (Fig. 20). In contrast, Z increased sharply beginning in the late 1980s, with estimated *Z* exceeding a value of two in the 2000s. This corresponds to an annual mortality rate exceeding 85%. Because *RF* was declining as *Z* increased, this increase in *Z* must reflect an increase in natural mortality.

GROWTH, CONDITION AND FECUNDITY

White hake are relatively fast growing, with a life-history strategy that has been termed “get big quick” (Markle et al. 1982). A growth model was fit to the individual weight and age data collected during the RV survey (1971-2013). Due to difficulties fitting a von Bertalanffy model, a Gompertz growth function was used:

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

where W_t is weight at time *t* and W_0, G and k are model parameters. Predicted growth increments increased with age over the range of ages examined (2 to 12 years, Fig. 21). Based on the parameters of the Gompertz growth model, W_∞ was estimated to be 23 kg, far outside of the range of the observed data in the SGSL (though specimens near this size, 22 kg and 135 cm TL, have been caught elsewhere, e.g. Markle et al. 1982). Mean weight at age decreased in the mid to late 1980s for ages 4 to 6, but has fluctuated without trend since then (Fig. 22).

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. Temporal trends in predicted weight at 45 or 55 cm were relatively minor (Fig. 23). Predicted weight at length tended to be above the long-term average in the early to mid-1970s, below average in the late 1980s to mid-1990s, and fluctuated around the average since then.

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).

GEOGRAPHIC DISTRIBUTION AND HABITAT ASSOCIATIONS

SEASONAL DISTRIBUTION, SPAWNING AREAS AND NURSERY HABITAT

SGSL white hake overwinter in the Laurentian Channel in NAFO Division 4T and subdivision 4Vn (the Cabot Strait), occurring at depths greater than 200 m (Chouinard and Hurlbut 2011). In summer, SGSL hake either remain in relatively deep water (> 100 m) or move into shallow water (mostly < 50 m) along the Gulf coasts of New Brunswick, PEI, mainland Nova Scotia and southwestern Cape Breton Island. The inshore migration generally begins in April-May and proceeds rapidly until June, when most of the traditional summer habitats have been occupied. The return migration to the overwintering grounds in the Laurentian Channel occurs in November and December (Darbyson and Benoît 2003). While it is thought that most size classes of white hake undertake this migration to overwintering grounds in the Laurentian Channel, the bycatch of small juvenile hake in autumn smelt fisheries in some estuaries of the SGSL suggest that small juvenile hake may remain inshore in winter, overwintering near or in estuaries (Bradford et al. 1997).

Spawning by the inshore stock component is thought to occur from June to September (Markle et al. 1982) with a peak in mid-June (Nepszy 1968). The primary inshore spawning areas appear to be St. Georges Bay and the Northumberland Strait. A formerly important spawning area, Baie Verte in Northumberland Strait, supported a fishery targeting spawning aggregations throughout the 1980s, but this spawning component was lost at some point between 1994 and 2001 (Hurlbut 2012). The capture of spent individuals in the northeastern Gulf in May suggests that the deep water stock component may spawn in late winter – early spring in the Laurentian Channel (Markle et al. 1982).

Eelgrass beds are thought to be important habitats for demersal juveniles (Fahay and Able 1989) and McAllister (1960) described sand-hiding behaviour in young white hake (76-102 mm long) in depths of about one meter off Prince Edward Island.

GEOGRAPHIC RANGE

Two indices were used to describe changes in geographic range based on catches in the RV survey: 1) area of occupancy (A), the estimated area with hake density greater than zero, and 2) D_{95}, the minimum area containing 95% of fish. These indices were calculated based on the stratified-random survey design. Details are given in Swain et al. (2012).

Area of occupancy (as defined by Swain et al. 2012) will decrease as population size decreases even if there is no increase in geographic concentration (Swain and Sinclair 1994). In contrast, D_{95} describes changes in geographic concentration independent of changes in abundance. Indices were calculated for both juvenile and adult fish, lengths < 45 cm and ≥ 45 cm, respectively.

The area occupied by adult-sized hake tended to increase from the mid 1970s to the early 1980s and then declined (Fig. 24). Area occupied by this size group peaked at values near 25,000 km^2 in the early 1980s, declining to values near 5,000 km^2 in recent years. Trends were similar for all sizes combined. For both size groups, declines in area occupied were sharpest in the early 1990s. Declines have been more gradual since then, though they may still be on-going. Juvenile-sized hake showed a different time trend, with area occupied remaining relatively constant at values near 10,000 km^2, except for a temporary increase between the mid 1980s and early 1990s, and a slight decreasing trend in recent years. Time trends in D_{95} were generally similar to those in area occupied (Fig. 25). For adults, area occupied declined by about 75% from the early 1980s to recent years (415-439) or by about 70% from the late 1980s (401,403,415-439) while D_{95} declined by about 70% or 60% in these two cases. In contrast, for juveniles, declines in the indices of geographic range between these time periods were only 25% or 35% for *A* and about 35% for D_{95}.

CHANGES IN GEOGRAPHIC DISTRIBUTION AND HABITAT ASSOCIATIONS IN SUMMER

Geographic distribution

The geographic distribution of white hake was mapped using the data visualization software ACON. Shaded contours were drawn using Delaunay triangles. Distribution was mapped for September, based on catches in the annual RV survey (1971 to 2013), and for August, based on catches in the mobile sentinel survey (2003 to 2013).

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 (Figs. 26 and 27). However, distribution shifted out of inshore areas over the 1971 to 2013 period.

In the 1970s, adult hake tended to be most abundant in inshore areas. 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. 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.

Geographic distribution was similar in August based on catches in the MS survey (Fig. 28). Hake were already rare in inshore areas when this survey began in 2003. By 2012 to 2013, hake were nearly absent from inshore catches in this survey.

Habitat associations

Changes over time in the depth and temperature associations of white hake in the SGSL in September were described by Swain et al. (2012) and are reproduced here (Figs. 29 and 30). Associations of white hake with depth differed dramatically between the 2000s and earlier decades (Fig. 29). In the 1970s, the highest proportion of hake occurred at depths less than 50 m (68% of adult-sized hake, 44% of juvenile-sized hake, 58% of all sizes). In the 2000s, less than 10% of hake occurred in shallow waters. In contrast, the proportion occupying depths of 150 – 250 m increased from 29% in the 1970s to 67% in the 2000s for adults, and from 45% to 65% for juveniles.

In all years, the highest proportion of hake occurred in the 4-6°C depth bin (Fig. 30). However, the proportion of hake occurring at these temperatures increased from 21% in the 1970s to 86% in the 2000s for adults, and from 27% to 73% for juveniles. These increases were accompanied by sharp declines in the proportion of hake occurring at temperatures above 6°C. These changes in temperature associations reflect the shift in distribution out of shallow water and into depths greater than 100 m.

Given the broad distribution of waters suitable for white hake in the SGSL, habitat is not considered to be limiting for this population. SGSL white hake do not have any known dwelling-place similar to a den or nest during any part of their life.

POPULATION MODELS

METHODS

Several age-structured population models were fit to the white hake data. These models were of two types: Virtual Population Analysis (VPA) and Statistical Catch at Age (SCA). All models were implemented in AD Model Builder (Fournier et al. 2011). The main differences between VPA and SCA are as follows:

1) VPA assumes that the fishery catch-at-age is known without error; SCA assumes that there is observation error in the proportions at age in the fishery catches.

2) VPA fits to the abundance indices at age and assumes that indices at different ages in the same year are independent. SCA fits to the age-aggregated biomass indices and to the proportions at age in the fishery and survey catches; this accounts for the lack of independence between catches at different ages in the same year.

3) VPA is backward projecting from abundance at age in the terminal (most recent) year; terminal abundances at age are parameters estimated in the model. SCA is forward projecting from abundance at age in the first year and at the first age in all years; these are estimated in the model, either as parameters (the approach used here, except for some of the projections) or by fitting a stock-recruit relationship.

Models extended from 1978 (the first year with reliable fishery catch-at-age data) to 2013 and from age 2 to ages 10+ (i.e., 10 years and older). Data inputs for VPA models were fishery catches at ages 2 to 10+ (in numbers) and trawlable abundances at ages 2 to 7 in the RV survey (1978-2002, 2004-2013) and 2-6 in the mobile sentinel (MS) survey (2003-2013). Data inputs for SCA models were total annual fishery catch (tonnes), age-aggregated trawlable biomass in the RV (ages 2-7) and MS (ages 2-6) surveys, and proportions at age in the fishery, RV and MS catches. Indices from the sentinel longline program were not used for model fitting because these indices are thought to be hyperdepleting due to the movement of white hake out of nearshore areas.

Fu and Quinn (2000) and Jiao et al. (2012) have demonstrated that it is possible to estimate time-varying *M* using length- or age-structured population models. In both VPA and SCA models, independent time series of the instantaneous rate of natural mortality (*M*) were estimated for three age groups: ages 2-3, 4-5 and 6+. These time series were estimated as random walks:

$$M_{\mathrm{j},1} = M\mathrm{init}_j \tag{2}$$

$$M_{j,y} = M_{j,y-1} e^{M\mathrm{dev}_{j,y}} \quad \text{if } y>1 \tag{3}$$

where $M\mathrm{init}_j$ is *M* in year 1 (1978). $M\mathrm{init}_j$ and $M\mathrm{dev}_{j,y}$ are parameters estimated by the model. The *M*dev's were assumed to be normally distributed with a mean of 0 and a standard deviation set at 0.05. Priors were supplied for $M\mathrm{init}_j$. These priors were normally distributed with means of 0.55, 0.3 and 0.2 for hake aged 2-3, 4-5 and 6+ years, respectively. These values were selected based on empirical relationships between *M* and length and growth characteristics of marine fishes (Gislason et al. 2010). Standard deviations for the *M* priors were set at 0.05 for VPA models and 0.05, 0.03 and 0.03 for hake aged 2-3, 4-5 and 6+ years in SCA models. Simulation tests of VPA models for SGSL white hake indicate that they result in reliable conclusions about changes in *M* for ages 4+ (Swain and Benoit 2014).

In VPA models, parameters were estimated by minimizing an objective function with the following components: 1) a component for the discrepancy between observed and predicted values of the abundance indices at age, which were assumed to be log-normally distributed; 2) a normal prior for the log *M* deviations; and 3) a normal prior for the initial values of *M*.

The objective function for the SCA models 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 proportions 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 standard deviation of the log recruitment deviations was set at 0.5. The proportions 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 estimated by both types of models based on 200,000 MCMC samples, with every 40th sample saved.

Models differed in the following respects:

1) After adjustment for diel effects on catchability and the difference in catchability between the Teleost and the previous survey vessels, catchability to the RV survey was considered to be consistent over time (1RV models) or RV catchability/selectivity was allowed to change between the Yankee 36 and Western IIA trawls (2RV models). The 2RV models were implemented by splitting the RV data into separate series before and since 1985.
2) In VPA models, survey catchability was either constrained to be flat-topped by setting catchability-at-age to the product of logistic selectivity-at-age and fully-recruited catchability (*q*), or allowed to be dome-shaped by estimating independent *q*'s-at-age.

In SCA models, both fishery and survey selectivities were modelled as logistic functions, and thus survey catchability was constrained to be flat-topped. Fishery selectivity was allowed to change in 1995.

Model results are shown in Appendix 3. All models led to the same general conclusions about population status and trends in natural mortality. Patterns in the residuals between observed and predicted RV abundance indices at age suggested that the Yankee 36 was less efficient than the Western IIA trawl at catching white hake (Appendix 3). We present results from the 2RV SCA model here. We chose this model as the basis for advice for the reasons described in Appendix 3.

RESULTS

Abundance and biomass

Adult biomass (i.e. Spawning Stock Biomass, SSB) and abundance dropped sharply in the late 1980s and early 1990s (Figs. 31a and 31b). The estimated values in 2013 were the lowest in the time series. Estimated SSB averaged about 52,900 t in 1978 to 1982 and 6,500 t in 2009 to 2013, a decline of 87.7% (see Table 9 for confidence intervals). Estimated biomass in 2013 was 3,844 t, a decline of 92.7% from the late 1970s and early 1980s. Estimated adult abundance averaged 46.32 million in 1978 to 1982 and 11.46 million in 2009 to 2013, a decline of 75,3%. Estimated abundance in 2013 averaged 6.17 million, a decline of 86.7% from the late 1970s and early 1980s. Estimated juvenile biomass and abundance fluctuated without trend over the 36-year time series (Figs. 31c and 31d).

Mortality

The instantaneous rate of fishing mortality *F* has been at a negligible level for several years (Fig. 32). Since 2006, average *F* is estimated to have been below 0.00004 for ages 2-3, 0.004

for ages 4-5 and 0.055 for ages 6+. Average *F* for ages 4-5 combined was low for the entire time series, peaking at 0.12 in 1992 (Fig. 32). However, the youngest age that is well-recruited to the fishery is age 5 (Fig. A3.10). For age 5 alone, *F* varied between 0.1 and 0.2 in the 1970s and 1980s, increasing to 0.4 in 1992 and then falling to 0.01 in 1995. Age-5 *F* has remained below 0.025 since then, except for a brief period in the late 1990s and early 2000s when *F* peaked at 0.09. *F* for ages 6+ shows a similar pattern (Fig. 32), varying between 0.2 and 0.4 in the 1970s and 1980s, then increasing to a peak at 0.86 in 1992. *F* for this age group fell to 0.03 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 0.36.

While *F* of white hake has been negligible since the mid -2000s, the population is now so low that very small landings can cause significant fishing mortality. Between 1978 and 1986, annual landings averaging 8,000 t resulted in an average 6+ *F* of 0.3. Between 1998 and 2001 annual landings averaging only 236 t resulted in an average 6+ *F* of 0.23. SSB is estimated to currently be less than half of its average value between 1998 and 2001, suggesting that landings as low as about 100 t could inflict non-negligible fishing mortality.

In most years, the dominant source of mortality for SGSL white hake has been natural mortality (Fig. 32). For juveniles (ages 2-3 years), estimated *M* increased from 0.60 in 1978 to 1.36 in 2013 (45% to 75% annual mortality). For older ages, increases in *M* were even more extreme, from 0.4 in 1978 to an average value of 2.05 since 2000 for ages 4-5 (from 33 to 87% annually, and from 0.32 to 1.51 (from 27 to 78% annually) for ages 6 years and older. For ages 2-3, *M* has been gradually increasing since the late 1980s and may be continuing to increase. For the older ages, *M* steadily increased from the start of the time series in 1978 to about 2000 and has changed little since then.

Recruitment

Abundance of age-2 recruits fluctuated with little trend over time, though recruit abundance tended to be slightly higher for year-classes produced after than before the mid-1990s (Fig. 33a). In contrast, recruitment rate (the number of recruits divided by the SSB that produced them) increased sharply in the mid-1990s, with recruitment rates of year-classes produced in the late 1990s and the 2000s much higher than those produced in earlier years (Fig. 33b). Recruit abundance appeared to be independent of SSB (Fig. 33c). However, though the relationship may be difficult to discern, recruitment cannot be entirely unrelated to SSB. As suggested by Figure 33b, log recruitment rate showed a strong inverse relationship with SSB (Fig. 33d). This can be indicative of 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.

However, the increase in recruitment rate at the low SSB seen since the mid-1990s seems to be too great to be attributed solely to compensation. For example, this is suggested by the curvilinear relationship in Fig. 33d. Increases in the survival of small fish appear to be widespread throughout this ecosystem since the mid-1990s (Benoît and Swain 2008, Swain et al. 2013, Swain and Benoît 2015), and this ecosystem change may contribute to the increased recruitment rate of white hake in recent years. Thus, two stock-recruit models were fit to the hake data. Model A, a classical Ricker function, assumes that increased recruitment rate since the mid-1990s is entirely due to compensation. Model B takes the apparent ecosystem-wide increase in productivity at small fish sizes into account by estimating separate α parameters (i.e. slope at the origin) between 1978 to 1994 and 1995 to 2011. Models were formulated as follows:

Model A: $R = \alpha S e^{-\beta S}$ (4)

Model B: $R = (\alpha_1 + \alpha_2 I) S e^{-\beta S}$ (5)

where R is age-2 recruit abundance (millions), S is SSB (X 1000 t), I is a vector of 0s and 1s (0s for 1978 to 1994, 1s for more recent year-classes), and α and β are parameters to be estimated. Parameter estimates for the two models are reported in Table 10. There is a fairly strong residual pattern in the fit of model A to the data, with residuals tending to be positive at small SSB, negative at intermediate SSB and positive at large SSB (Fig. 33e). Model B provides a better fit to the data, with negligible pattern in the residuals (Fig. 33f).

In summary, recruitment remains strong in this population despite very low SSB. This reflects very high recruitment rates over the past 20 years. These high recruitment rates may reflect strong compensation in the stock-recruit relationship, an ecosystem-wide increase in the survival of small fish, or a combination of the two.

RECOVERY TARGETS

BIOMASS TARGET

A target corresponding to a limit reference point is proposed. This target was defined as the SSB equal to 40% of the SSB producing the maximum surplus production (with no fishing mortality). This target was estimated using stock-recruit model B, based on the parameters for the 1978 to 1994 period. First, spawner biomass produced per recruit (SpR) was calculated based on average weight at age, maturity at age and survival at age in the late 1970s and early 1980s. The stock recruit relationship was then compared to a “replacement” line with slope equal to the inverse of SpR to find the SSB producing maximum surplus production (Fig. 34). This SSB was 32,000 t, corresponding to a recovery target of 12,800 t of SSB. Based on the population model, there is no chance that the SSB in 2013 is at or above this target. Estimated SSB has been below this level since 1995.

The recent period (1995-2013) was deemed to be inappropriate for deriving a recovery target. In this period, the spawner biomass produced per recruit was very low because of the extremely high natural mortality rates experienced during this period. Consequently, the replacement line intersects the stock-recruitment relationship at very low SSB (Fig. 33c). If natural mortality were to increase much further, the replacement line would no longer intersect the stock-recruit curve and the population would no longer be viable.

In addition to a sustained increase in biomass to or above this target, recovery would require an expansion in age structure to include substantial frequencies of fish older than 7 years, as observed in the mid-1980s and earlier.

DISTRIBUTION TARGET

In the 1970s and the 1980s, white hake were common in inshore waters of the SGSL in the summer and early fall. In September in the 1970s, the majority of SGSL hake occurred in these inshore waters (68% of adults, 58% of all sizes). By the 2000s, these proportions had dropped to 6% of adults and 8% of all sizes (Fig. 29). In the past, these inshore waters contained important spawning grounds for hake. In fact, it is only in these inshore areas that the spawning grounds and spawning timing of SGSL white hake are relatively well known. One of these spawning grounds (Baie Verte in the Northumberland Strait) was abandoned in the late 1990s (Hurlbut 2012). Hake now appear to be abandoning the remaining inshore spawning grounds (e.g., St. Georges Bay), judging from the near absence of adult hake in inshore waters in recent RV and MS surveys in September and August. Loss of spawning components severely compromises the productive potential of a stock. The return of hake to inshore waters of the SGSL, the areas where they predominantly occurred in summer in the past, should be a distribution target for recovery.

Animals typically balance the trade-off between foraging success and predation mortality by increasing their use of safer but less profitable habitats as predation risk increases. Risk of predation by grey seals increased dramatically in inshore areas of the SGSL in the 1990s and 2000s, particularly in the Northumberland Strait, along the north coast of PEI, and in the areas between Miramichi Bay and PEI and from PEI to St. Georges Bay. These are the areas where hake were formerly most abundant. The shift in distribution of white hake out of these inshore waters and into deeper water in the Cape Breton Trough and along the Laurentian Channel appears to be a response to increased risk of predation by grey seals (Swain et al. 2015). It is unlikely that hake will return to these inshore areas until predation risk in these areas is substantially reduced.

PROJECTED POPULATION TRAJECTORY AT CURRENT PRODUCTIVITY

As part of the population modelling, the population was projected forward 60 years in time during the MCMC sampling. In this way, the uncertainty in model estimates was taken into account in the projections. These projections assumed that the current productivity conditions will persist over the projection period. For each age group, *M* was set equal to the average of the last 5 years (2009-2013). For each projection year, the weight-at-age vector was randomly selected from those observed over the last 20 years (1994-2013). Fishing mortality was set at a constant level for each projection, either a fully-recruited *F* of 0, the 2009 to 2013 average (a median value of 0.04), or the 1998 to 2002 average (a median value of 0.24). Fishery selectivity-at-age was assumed to remain the same as the estimate for 1995 to 2013. Two approaches were used for obtaining projected recruitment. In one approach, a recruitment rate (age-2 recruits/SSB) was randomly selected for each projection year from those estimated for the period when recruitment productivity was high (1995 to 2013). Recruitment rates were then multiplied by SSB to obtain recruit abundance. In the second approach, Ricker Model B was estimated within the population model; this had a negligible effect on the recruitment estimates. Recruit abundance in each projection year was obtained with this model, using α for the current period of high recruitment productivity (i.e., $\alpha_1+\alpha_2$ in equation 5). A randomly selected residual from the *S-R* model in the 1995 to 2013 period was added (on the log scale) to the predicted recruitment in each year and iteration. The uncertainty in the projection was based on 200,000 MCMC samples with every 40th sample retained, yielding 5,000 retained samples.

Both approaches for obtaining recruitment yielded similar results (Fig. 35). The on-going declines in SSB and adult abundance persisted in the projection. Projected SSB and adult abundance approached 0 about 15 years into the future. Extinction was defined as an adult abundance of less than 1000 individuals. Extinction of MCMC iterations began in about 2045. The probability of reaching the recovery target under current conditions was 0 even with no fishing. There was a 5% probability of extinction 44 or 50 years into the projection (Fig. 36; 2057 using recruitment rates or 2063 using a Ricker stock-recruit relationship). At the end of the 60-yr projection with *F* = 0, the probability of extinction was 19% using a stock-recruit function and 38% using randomly-sampled recruitment rates. In the projection with *F* = 0.24, the corresponding probabilities of extinction were 21% and 40%, respectively.

At the *F*'s examined, the impact of fishing on the projected adult abundance was negligible (Fig. 36). This is a consequence of the extremely high level of natural mortality currently experienced by this stock. It is important to note that these projections are constant effort scenarios, not constant catch scenarios. As hake abundance declined in the projections, these levels of *F* would have resulted in steadily declining catches.

POPULATION PROJECTIONS AT HIGHER LEVELS OF PRODUCTIVITY

Projections were also conducted at reduced levels of *M*. Methods were the same as those described above, except *F* was set equal to 0 for all projections, and for each MCMC iteration, the average *M* at age in 2009 to 2013 was calculated and *M* for the projection was set to a specified percentage of this average. Initially, projections were conducted assuming that the current conditions of high recruitment productivity persisted over the projection period. Projections were conducted using Ricker Model B, with α set to the value for the period of high recruitment productivity.

Assuming that recruitment productivity was to remain high, a 20% reduction in *M* at all ages was sufficient to halt the decline in SSB (Fig. 37a). The probability that SSB exceeded the target in 30 years was 27% (Fig. 37d). A 30% reduction in *M* resulted in a rapid increase in SSB, with the probability of exceeding the target 41% in 10 years and 95% in 30 years (Figs. 37b and 37d). With a 40% reduction in *M*, the probability that SSB would exceed the target level was 51% in six years and 100% in 20 years (Figs. 37c and 37d).

It is possible that changes in *M* and recruitment productivity are not independent. Profound changes in the SGSL ecosystem have occurred over the past 25 years. These changes have involved increases in the abundance of small demersal fish, which appear to reflect reduced mortality at small sizes, coincident with increases in the natural mortality of large demersal fish (Benoît and Swain 2008; Swain et al. 2013; Swain and Benoît 2015). It has been hypothesized that these changes in the SGSL ecosystem result from linked changes in the species composition of the top predators in this ecosystem (i.e., large demersal fishes versus grey seals). That is, productivity of demersal fishes increased at early life-history changes 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. Thus, recruitment productivity might be expected to decline from its current high level as natural mortality at older ages declines and the abundance of large demersal fish increases, increasing predation on early life stages. The consequences of this possibility were explored by conducting projections that assumed a return to lower recruitment productivity. In these projections, the Ricker α parameter was set to the value for the period of low recruitment productivity.

Under conditions of low recruitment productivity, 40% and 50% reductions in *M* at age were both insufficient to halt the decline in SSB (Figs. 38a and 38b). The probability that SSB would exceed the recovery target after 30 years was 0.025 and 0.11 with *M* reductions of 40% and 50%, respectively. The probability of extinction after 60 years was 0.38 and <0.0002, respectively. A 60% reduction in *M* was sufficient to allow SSB and adult abundance to increase in the low-productivity scenario (Fig. 38c). With this reduction in *M*, there was a 77% probability that SSB would exceed the recovery target in 30 years and the probability of extinction after 60 years was less than 0.02%.

If recruitment productivity and *M* at older ages are linked, results of *M* reductions would presumably be somewhere intermediate between the results at low recruitment productivity and those assuming high recruitment productivity. Neither changes in *M* nor in recruitment productivity would be instantaneous in projection year 1 as assumed in these projections. Instead, changes in *M* would be gradual and there would likely be a delayed response in the change in recruitment productivity.

Projections were also made assuming a stationary stock-recruit relationship (i.e., Model A). Under this assumption, a 20% reduction in *M* at all ages was sufficient to halt the decline in SSB, with a 10% probability of exceeding the biomass target in 30 years (Figs. 39a and 39d). This probability increased to 67% with a 30% reduction in *M* and to 99% with a 40% reduction in *M* (Figs. 39b to 39d).

THREATS AND LIMITING FACTORS

FISHING

The directed commercial fishery for white hake has been closed in NAFO Div. 4T since 1995. Reported landings as bycatch in commercial fishing activity directed at other species is low in Div. 4T (Table 1; 20 t or less since 2010). At recent levels of fishing effort, the bycatch of white hake in Div. 4T groundfish fisheries is estimated to have a negligible impact on population trajectory (Fig. 36).

The distribution of the SGSL DU of white hake extends into the northwest portion of NAFO Subdivision 4Vn. No directed fishing for white hake is permitted in this region. Reported bycatch in this area is low, averaging 44 t annually since 2000 and 23 t annually since 2010 (Table 3). Based on the projection at an *F* of 0.24, fishing effort has a negligible impact on the population trajectory even including the 4Vn catch.

There is also bycatch of white hake in estuarine fisheries for smelt in the SGSL. The hake caught in this fishery are normally <25 cm in length. This corresponds to hake that are mostly 1 year of age or less. Thus, this fishery catches primarily pre-recruits. Because recruitment rates are currently unusually high for hake, the impact of this fishery on pre-recruit abundance appears to be small. Juvenile hake are also caught in the shrimp fishery, but the estimated bycatch is small, at <2 t annually.

Adult white hake are also incidentally captured in sGSL scallop and lobster fisheries. Analyses based on data from a two year at-sea sampling program during the mid 2000s suggest that catches in the scallop fishery are very small (Benoît et al. 2011a). White hake bycatch amounts in the lobster fishery are unknown, though adult white hake are reported to be very rarely encountered in the traps (Benoît et al. 2011a).

White hake are also caught by the recreational fishery for groundfish in Div. 4T. Catches in this fishery are unknown, though anecdotal information suggests that the catch of white hake is negligible. Based on charter boat logs and 5% observer coverage, no catches of white hake have been recorded by the charter-boat fishery in Div. 4T.

OFFSHORE OIL DEVELOPMENT

The possibility of oil and gas development is being explored at the Old Harry site in the Laurentian Channel. Spills or blow-outs from any such development are a risk to SGSL hake, which occupy waters adjacent to this site.

NATURAL MORTALITY

The lack of recovery (and continued decline) of SGSL white hake is due to high natural mortality of hake two years and older. In contrast to the 2+ age group, productivity at earlier life-history stages is unusually high. At the current level of 2+ *M*, SGSL white hake would rapidly decline to extinction if recruitment rates were not at their current high level. Even given the current strong recruitment rates, SGSL white hake are projected to gradually decline to extinction at current levels of 2+ *M*.

The unusual productivity regime currently exhibited by SGSL white hake (productivity that is unusually high at early life stages and unusually low at later stages) is widespread throughout the SGSL demersal fish community. The high productivity at early life stages has been attributed to a release from predation following the collapse of large demersal fish (Benoît and Swain 2008). The extremely high natural mortality afflicting older large demersal fish (i.e., white hake, Atlantic cod, American plaice, thorny skate, winter skate, and others in the SGSL) has been hypothesized to reflect a “predator pit” or predation-driven Allee effect, resulting from the depleted abundance of these fishes and the high and increasing abundance of grey seals, an important predator of these fishes (Swain and Benoît 2015).

Grey seal abundance has increased in the SGSL by more than an order of magnitude since the 1970s (Fig. 40). The link between grey seal abundance and *M* of large demersal fish in the SGSL has been examined in most detail for Atlantic cod. Swain et al. (2011) examined a suite of hypotheses for causes of the elevated *M* of adult cod in the SGSL and concluded that the most likely cause was predation by grey seals. Benoît et al. (2011a) came to a similar conclusion for white hake. White hake are an important prey of grey seals in the SGSL (Hammill et al. 2007, 2014), but it is difficult to estimate the average annual consumption of hake due to wide spatial, seasonal and individual variation in the diet of grey seals. Nonetheless, based on the energy requirements of grey seals and their spatial overlap with SGSL white hake, Benoît et al. (2011b) concluded that predation by grey seals could explain all of the increase in *M* of hake if they comprised 12% of the diet of overlapping seals and 4% of the diet of the entire Gulf herd. In recent decades, the distribution of SGSL white hake has shifted out of areas where risk of predation by grey seals is high and into areas where this risk is low, consistent with a strong impact by grey seals on these fish (Swain et al. 2015).

LOSS OF ACCESS TO SPAWNING HABITAT

Although a component of the SGSL white hake population is thought to spawn in deep waters offshore, the best known spawning areas are in shallow inshore areas. In the 1970s, the majority of SGSL hake occupied these inshore areas in summer. However, over time, the distribution of adult hake has shifted out of these areas into deeper water. In recent years, the inshore areas appear to be virtually abandoned based on catches in the RV and MS surveys. White hake appear to have abandoned these inshore areas due to the extremely high risk of predation by grey seals in these areas in recent years (Swain et al. 2015). This may represent a loss of access to important spawning grounds, with negative consequences for population productivity. On the other hand, there has not yet been any indication of a decline in recruitment productivity from its recent high level, and very small white hake (<33 cm in length) appear to remain relatively common in these inshore areas (Fig. 41). Possibly, white hake continue to spawn in these inshore areas in late spring or early summer but move offshore by August. Alternatively, there may now be little spawning inshore, with the inshore juveniles produced by offshore spawning. For example, in the waters off New England, white hake spawn offshore in the Slope Sea and pelagic juveniles actively swim across the shelf/slope front and move into nearshore juvenile habitats (Hare et al. 2001).

MITIGATION MEASURES

With the directed commercial fishery closed over the past 20 years, and negligible bycatch in other groundfish fisheries at recent levels of fishing effort in NAFO Div. 4T and Subdiv. 4Vn, no additional measures in terms of fishery restrictions appear to be available to promote the recovery of this white hake DU. The amounts of hake caught in the recreational fishery and the lobster fishery are unknown, and monitoring of these fisheries to obtain estimates of hake bycatch is recommended. However, catches of hake in the recreational fishery and of adult hake in the lobster fishery are thought to be negligible.

The only additional action that can be taken to improve the chances for recovery of this stock would appear to be action to reduce the unusually high rate of natural mortality currently experienced by hake two years and older. This high natural mortality is the factor preventing the recovery of this DU of white hake. The most likely cause of this high natural mortality is predation by grey seals. Thus, one action that could be taken to promote the recovery of this stock is to reduce the abundance of grey seals foraging in the SGSL. This should also benefit other collapsed SGSL stocks whose recoveries are also prevented by elevated natural mortality of large individuals (e.g., Atlantic cod, American plaice, winter skate and thorny skate; Swain and Benoît 2015). However, additional analyses are required to determine the reductions in seal abundance that would be likely to allow recovery.

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TABLES

Table 1. Nominal landings (tonnes) of white hake from NAFO Division 4T by gear, with the yearly TAC's. (N/S = gear type not specified and na = not applicable).

Year	Trawl	Seines	Gillnet	Longline	Handline	Other	Total	TAC
1960	479	21	3	1085	87	333	2008	na
1961	1430	79	309	2834	664	7	5323	na
1962	1141	97	889	3827	715	575	7244	na
1963	1444	71	48	0	0	4987	6550	na
1964	1508	82	N/S	1	0	4615	6206	na
1965	N/S	N/S	N/S	N/S	N/S	N/S	4706	na
1966	2267	205	375	1870	0	2307	7024	na
1967	2295	128	809	841	107	2370	6550	na
1968	795	84	1734	320	146	1182	4261	na
1969	1030	50	1802	467	31	828	4208	na
1970	1463	382	2149	310	75	1289	5668	na
1971	1523	632	1622	599	103	1228	5707	na
1972	1139	863	1190	1526	79	960	5757	na
1973	2468	204	1265	962	83	720	5702	na
1974	1454	305	1098	264	81	414	3616	na
1975	1574	306	1279	241	83	642	4125	na
1976	1429	398	1147	141	42	601	3758	na
1977	1227	408	1300	185	46	818	3984	na
1978	1303	737	1829	314	142	500	4825	na
1979	2826	912	3189	305	174	704	8110	na
1980	3430	1615	4831	604	228	1715	12423	na
1981	4733	1922	6174	751	48	411	14039	na
1982	2885	994	4625	937	90	245	9776	12000
1983	2141	906	2959	662	91	546	7305	12000
1984	1734	588	3789	808	57	74	7050	12000
1985	1639	1008	2480	714	85	88	6014	12000
1986	1094	898	1884	979	89	4	4948	12000
1987	820	1505	2200	1692	155	0	6372	9400
1988	388	817	1923	672	76	11	3887	5500
1989	868	1689	1830	806	137	24	5354	5500
1990	771	1216	2022	1003	115	48	5175	5500
1991	1094	959	1292	1027	129	0	4501	5500
1992	955	926	914	1096	40	0	3931	5500
1993	177	99	467	713	45	0	1501	3600
1994	81	50	217	581	113	0	1042	2000
1995	34	9	19	6	3	0	71	Moratorium
1996	27	8	34	85	2	0	157	Moratorium
1997	56	13	48	74	4	0	195	Moratorium
1998	48	27	64	97	5	0	241	Moratorium
1999	47	36	59	96	161	0	399	Moratorium
2000	26	28	32	79	12	0	177	Moratorium
2001	21	11	30	44	16	0	121	Moratorium
2002	14	14	10	24	9	0	70	Moratorium
2003	17	3	2	15	0	0	37	Moratorium
2004	14	11	2	35	0	0	64	Moratorium
2005	7	17	4	16	0	0	45	Moratorium
2006	4	14	1	8	0	0	27	Moratorium
2007	3	11	1	6	0	0	21	Moratorium
2008	5	19	2	5	0	0	31	Moratorium
2009	14	11	3	5	0	0	33	Moratorium
2010	5	6	2	3	0	0	16	Moratorium
2011	5	6	2	7	0	0	20	Moratorium
2012	3	6	4	1	0	0	14	Moratorium
2013	2	12	4	2	0	0	20	Moratorium

Table 2a. Commercial fishery catch-at-age (by 1000) for white hake in NAFO Division 4T from 1982 to 2013. na means no catch and 0.00 indicates a non-zero number less than 0.005.

Age	0-2	3	4	5	6	7	8	9	10	11	12	13+	Total
1978	na	79.00	354.00	579.00	545.00	345.00	172.00	61.00	26.00	4.00	8.00	2.00	2175.00
1979	na	90.00	470.00	833.00	972.00	672.00	315.00	101.00	47.00	8.00	11.00	4.00	3523.00
1980	na	91.00	452.00	1028.00	1661.00	1196.00	540.00	137.00	75.00	7.00	6.00	5.00	5198.00
1981	na	66.00	427.00	1075.00	1976.00	1391.00	604.00	154.00	94.00	4.00	1.00	8.00	5800.00
1982	na	7.60	184.38	658.33	1156.11	1169.35	628.58	184.42	81.92	22.76	14.75	14.75	4122.94
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	3300.23
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	3118.37
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	2391.41
1986	na	1.37	206.63	511.34	489.74	332.24	236.08	78.91	46.67	22.00	13.94	8.49	1947.40
1987	na	29.74	513.68	1377.85	936.06	417.46	153.50	64.19	17.97	3.51	2.35	3.56	3519.87
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	1795.97
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	2562.95
1990	na	14.84	454.01	1197.71	1047.61	437.92	91.43	18.98	6.47	2.87	0.97	0.53	3273.32
1991	na	27.22	400.29	1027.54	891.51	503.22	79.11	17.17	5.59	1.87	1.05	4.78	2959.37
1992	0.17	112.32	1010.98	1017.50	553.60	271.75	61.46	25.95	10.05	3.47	0.50	0.84	3068.74
1993	na	55.18	286.88	415.77	217.46	91.41	26.55	11.77	1.27	1.84	0.44	0.08	1108.65
1994	na	25.18	133.74	184.15	201.21	86.04	27.70	4.90	0.69	na	na	0.17	663.76
1995	na	0.01	0.63	2.15	9.85	11.20	3.99	0.29	na	na	na	na	28.12
1996	0.73	2.26	16.60	26.41	23.74	13.14	6.41	1.72	0.46	0.06	0.17	na	92.44
1997	0.19	1.11	13.71	39.73	33.97	13.88	5.43	1.10	0.39	0.07	na	na	109.77
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	140.36
1999	0.51	3.72	42.57	114.54	74.88	15.82	2.12	0.73	0.07	0.02		na	255.50
2000	0.61	1.77	18.63	38.45	35.36	15.43	2.93	1.13	0.13	0.17	0.02	na	115.26
2001	0.12	2.89	20.97	28.47	20.29	7.48	2.12	0.31	0.17	0.00	na	na	82.82
2002	0.41	1.49	7.72	18.61	14.02	2.75	0.43	0.16	na	na	na	na	46.00
2003	0.54	2.58	11.19	12.27	5.44	0.63	0.14	na	na	na	na	na	33.33
2004	0.42	0.66	9.61	23.48	9.44	1.42	0.16	na	0.02	0.11	na	na	45.73
2005	2.14	2.23	10.82	14.10	8.32	1.70	0.22	0.02	na	na	na	na	41.68
2006	0.71	0.59	4.38	9.01	4.85	0.74	0.19	0.04	na	na	na	na	21.22
2007	0.53	0.99	3.55	5.48	3.48	0.46	0.36	0.02	0.04	0.01	na	na	15.43
2008	0.74	8.93	15.56	9.22	2.34	0.28	na	na	na	na	na	na	37.81
2009	0.25	0.86	2.81	10.28	6.69	1.38	0.10	na	na	na	na	na	22.62
2010	0.55	1.20	4.96	5.48	2.02	0.18	0.03	na	na	na	na	na	14.97
2011	0.13	0.39	2.31	6.22	3.33	0.85	0.22	na	na	na	na	na	13.58
2012	0.15	0.31	2.77	4.65	1.96	0.52	0.07	0.00	0.03	na	na	na	10.60
2013	0.16	0.12	1.10	7.15	4.55	0.41	0.10	0.04	0.03	na	na	na	13.80

Table 2b. Commercial fishery weight-at-age (kg) for white hake in NAFO Division 4T from 1982 to 2013.

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13+	Weighted average
1982	na	na	na	1.11	1.35	1.61	2.19	2.48	2.97	3.34	3.99	3.90	3.83	5.22	2.37
1983	na	0.39	0.63	0.91	1.41	1.79	2.06	2.55	2.51	3.54	4.36	5.98	6.26	10.39	2.23
1984	na	na	0.55	0.90	1.16	1.65	2.12	2.64	3.18	3.56	5.26	4.74	6.65	9.25	2.27
1985	na	na	0.95	1.37	1.50	1.95	2.27	2.73	3.57	3.89	4.79	6.37	6.60	8.18	2.52
1986	na	na	na	2.81	0.98	1.54	2.37	2.94	3.88	4.67	5.72	6.84	6.96	9.39	2.57
1987	na	na	na	0.62	0.80	1.29	2.04	2.89	3.77	4.35	5.61	8.42	9.70	10.72	1.81
1988	na	na	0.28	0.36	0.96	1.30	1.95	2.79	3.68	5.13	6.03	8.85	10.69	9.56	2.16
1989	na	0.11	0.21	0.41	0.89	1.25	1.79	2.51	3.51	4.19	5.98	6.25	9.46	10.41	2.10
1990	na	na	na	0.59	0.85	1.18	1.70	2.52	3.53	4.95	5.84	7.11	9.26	8.29	1.58
1991	na	na	na	0.53	0.80	1.13	1.59	2.34	2.89	4.30	6.90	5.95	7.19	10.04	1.52
1992	na	na	0.17	0.53	0.77	1.10	1.71	2.38	3.12	4.32	5.58	5.59	6.06	9.09	1.28
1993	na	na	na	0.58	0.92	1.21	1.74	2.12	3.10	2.99	3.38	4.36	4.23	10.19	1.35
1994	na	na	na	0.62	0.83	1.22	1.82	2.47	3.00	3.44	4.02	na	na	9.38	1.56
1995	na	na	na	0.79	0.92	1.37	1.99	2.75	3.62	5.42	na	na	na	na	2.49
1996	na	na	0.18	0.53	0.94	1.40	1.93	2.50	2.60	2.92	3.31	2.27	3.50	na	1.70
1997	na	0.11	0.22	0.51	0.87	1.41	2.02	2.58	2.95	3.72	3.29	5.95	na	na	1.78
1998	na	0.17	0.43	0.57	0.84	1.44	2.10	2.55	2.89	4.01	3.45	2.84	6.35	6.83	1.71
1999	na	0.16	0.25	0.58	0.86	1.38	2.07	2.75	3.32	3.36	4.79	6.97	na	na	1.59
2000	na	0.11	0.24	0.51	0.75	1.21	1.85	2.38	2.94	3.04	2.34	4.32	5.31	na	1.54
2001	0.08	0.14	0.27	0.58	0.76	1.24	1.99	2.64	3.23	3.42	3.94	7.37	na	na	1.47
2002	na	0.16	0.33	0.56	0.81	1.39	2.00	2.55	3.48	4.43	na	na	na	na	1.54
2003	na	0.13	0.23	0.55	0.79	1.20	1.80	2.42	2.98	na	na	na	na	na	1.12
2004	na	0.10	0.22	0.47	0.89	1.33	1.95	2.72	3.68	na	6.33	4.76	na	na	1.40
2005	na	0.13	0.23	0.45	0.73	1.20	1.70	2.17	3.01	3.79	na	na	na	na	1.13
2006	na	0.15	0.22	0.49	0.80	1.26	1.90	2.55	2.91	4.88	na	na	na	na	1.32
2007	na	0.13	0.24	0.51	0.82	1.39	2.05	2.93	2.74	5.22	4.51	5.38	na	na	1.40
2008	na	0.15	0.34	0.48	0.67	1.21	1.97	3.00	na	na	na	na	na	na	0.85
2009	na	0.14	0.22	0.48	0.79	1.39	1.85	2.44	3.24	na	na	na	na	na	1.48
2010	na	0.13	0.25	0.51	0.79	1.26	1.77	3.22	2.02	na	na	na	na	na	1.09
2011	na	0.15	0.28	0.50	0.95	1.42	1.95	2.33	2.13	na	na	na	na	na	1.50
2012	na	0.18	0.23	0.51	0.97	1.38	1.86	2.26	4.06	3.68	2.49	na	na	na	1.38
2013	na	0.14	0.22	0.49	0.90	1.30	1.71	2.48	4.25	4.87	6.35	na	na	na	1.46

Table 2c. *Commercial fishery length-at-age (cm) for white hake in NAFO Division 4T from 1982 to 2013.*

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13+	Weighted average
1982	na	na	na	52.2	55.7	59.1	65.4	68.0	72.1	74.8	79.3	78.0	77.1	84.8	66.6
1983	na	37.8	43.7	49.3	56.5	61.3	63.9	68.3	66.6	75.1	79.1	90.3	97.2	108.2	64.7
1984	na	na	41.9	48.3	52.5	58.9	63.7	68.3	72.2	74.6	84.3	81.6	91.4	101.8	63.9
1985	na	na	50.0	55.6	57.4	62.0	65.1	68.9	74.8	76.5	81.2	89.4	89.2	96.8	66.3
1986	na	na	na	67.7	49.7	57.3	66.1	70.7	77.1	81.4	86.4	92.6	92.0	102.4	65.9
1987	na	na	na	44.2	47.9	55.5	64.0	71.4	77.3	79.8	85.3	99.8	104.0	107.6	60.1
1988	na	na	34.2	37.1	50.5	55.3	62.6	70.2	76.5	84.5	89.2	100.5	106.7	103.5	63.8
1989	na	24.9	31.0	38.3	49.1	54.9	61.5	68.6	76.6	80.6	89.3	90.0	105.9	108.8	63.5
1990	na	na	na	43.5	48.9	54.2	61.0	69.3	77.6	86.6	91.0	97.8	107.0	102.6	58.6
1991	na	na	na	41.9	47.8	53.3	59.5	67.4	72.1	82.3	96.2	92.0	97.8	109.0	57.6
1992	na	na	29.0	42.2	47.6	53.4	61.8	69.0	75.2	83.9	91.0	91.6	94.6	107.8	54.9
1993	na	na	na	42.8	49.9	54.6	61.8	65.9	74.4	73.4	76.7	83.7	82.7	112.0	55.9
1994	na	na	na	43.6	48.0	54.3	61.9	68.4	72.8	76.1	80.4	na	na	106.0	57.7
1995	na	na	na	47.0	49.4	55.8	63.0	69.7	75.8	86.5	na	na	na	na	66.9
1996	na	na	28.8	41.0	49.2	55.9	62.1	67.7	68.4	70.9	74.8	67.0	75.7	na	58.7
1997	na	25.0	31.0	40.9	48.2	56.2	62.8	67.9	70.6	76.4	73.3	88.4	na	na	59.5
1998	na	28.3	37.7	42.1	47.2	56.0	63.3	67.2	70.0	77.6	74.5	69.9	90.6	92.8	58.4
1999	na	28.1	32.0	42.3	48.0	55.5	63.1	69.2	73.4	73.6	83.2	94.0		na	57.3
2000	na	24.8	31.7	40.5	46.1	53.7	61.5	66.8	71.7	72.4	66.6	82.4	86.4	na	57.1
2001	23.1	26.8	33.4	42.4	46.2	53.6	62.2	67.9	72.1	73.5	77.4	95.1		na	55.3
2002	na	28.2	35.3	41.4	46.5	55.1	61.8	66.4	73.5	78.9	na	na	na	na	56.0
2003	na	26.3	31.3	41.8	46.9	53.3	60.8	66.8	70.8	na	na	na	na	na	51.4
2004	na	24.6	30.7	39.2	48.0	54.5	61.5	68.4	75.7	na	91.0	83.0	na	na	54.7
2005	na	26.8	31.8	39.2	45.7	53.6	60.2	65.1	72.2	79.9	na	na	na	na	51.4
2006	na	27.4	31.1	40.4	47.1	54.7	62.5	68.8	71.6	85.7	na	na	na	na	54.4
2007	na	26.8	31.9	40.8	47.2	56.0	63.7	71.3	70.0	86.4	81.7	88.0	na	na	54.7
2008	na	27.4	35.6	39.9	44.1	53.2	62.5	71.3	na	na	na	na	na	na	46.5
2009	na	26.9	31.1	39.8	46.7	56.4	61.9	67.4	74.5	na	na	na	na	na	56.6
2010	na	26.0	32.3	40.3	46.6	54.3	60.8	73.7	64.0	na	na	na	na	na	50.8
2011	na	27.9	33.6	40.4	49.0	55.7	61.3	65.0	62.9	na	na	na	na	na	56.0
2012	na	29.3	31.1	40.8	49.4	55.7	61.1	65.2	78.3	77.0	67.9	na	na	na	54.9
2013	na	26.5	31.1	40.4	49.8	56.0	61.4	69.3	83.5	88.0	92.0	na	na	na	57.6

Table 3. Comparison of white hake landings (tonnes) in NAFO Division 4T and Subdivision 4Vn.

Year	4T	4Vn	4T/4Vn
1985	5406	346	15.6
1986	4952	373	13.3
1987	6389	554	11.5
1988	3861	323	12.0
1989	5125	291	17.6
1990	4742	190	24.9
1991	4510	170	26.5
1992	3813	158	24.1
1993	1501	136	11.0
1994	1042	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	0.4
2007	20	40	0.5
2008	31	27	1.2
2009	33	27	1.2
2010	16	24	0.6
2011	20	38	0.5
2012	14	15	0.9
2013	20	16	1.2

Table 4a. Abundance indices (trawlable abundance in thousands of fish) for white hake in the September RV survey of the southern Gulf of St. Lawrence for strata 415-439 or 401,403 and 415-439. Strata 401 and 403 were established in 1984. A Yankee 36 trawl was used in 1971-1984 and a Western IIA trawl since 1985. Indices adjusted by dividing by 0.7 are also shown for 1971-1984. Fishing efficiency for white hake by the Yankee 36 trawl is estimated to be 70% of that by the Western IIA trawl, though this estimate is not statistically significant (see text for details). Fish 45 cm and longer are considered to be adults in the construction of these indices.

Year	Juveniles			Adults		
	415-439	415-439 adj	401,403, 415-439	415-439	415-439 adj	401,403, 415-439
1971	2136.5	3052.1	na	1585.1	2264.4	na
1972	661.8	945.4	na	1642.4	2346.2	na
1973	1085.5	1550.8	na	6748.6	9640.8	na
1974	5131.8	7331.1	na	9079.2	12970.3	na
1975	7878.7	11255.2	na	3108.3	4440.4	na
1976	7243.9	10348.4	na	2429.8	3471.1	na
1977	3387.1	4838.8	na	2556.4	3651.9	na
1978	4802.6	6860.8	na	7303.3	10433.3	na
1979	3424.9	4892.8	na	7595.2	10850.3	na
1980	1625.9	2322.7	na	8179.5	11685.0	na
1981	2380.4	3400.6	na	13427.9	19182.8	na
1982	1163.0	1661.5	na	4023.9	5748.4	na
1983	1799.1	2570.1	na	2927.4	4181.9	na
1984	2461.9	3517.0	2461.9	5070.1	7243.0	5238.0
1985	5808.9	na	6034.6	7212.8	na	7470.0
1986	9146.9	na	9359.3	11053.6	na	11321.0
1987	4847.5	na	4904.5	5677.0	na	5855.8
1988	7350.2	na	7643.7	7288.8	na	8059.2
1989	9194.4	na	14324.7	5336.2	na	6218.8
1990	8849.7	na	9604.6	5974.8	na	6551.8
1991	10186.4	na	10760.2	6159.2	na	6387.5
1992	8570.7	na	9561.6	3004.8	na	3880.1
1993	3992.0	na	4487.8	2784.3	na	3245.8
1994	3144.7	na	3275.2	2534.8	na	2583.2
1995	3077.8	na	4739.7	799.2	na	1223.2
1996	4123.4	na	4372.6	1007.0	na	1231.2
1997	3594.2	na	3728.0	1439.5	na	1571.1
1998	4010.5	na	4821.4	1119.9	na	1614.6
1999	6156.4	na	7463.5	1380.9	na	2079.5
2000	13873.1	na	14255.3	1324.0	na	1621.6
2001	4769.8	na	5044.3	1153.7	na	1251.8
2002	4214.8	na	4395.2	816.3	na	871.7
2003	4797.1	na	4536.2	855.9	na	774.9
2004	1910.1	na	2152.8	776.1	na	921.1
2005	6287.0	na	6511.5	1276.6	na	1321.3
2006	2357.5	na	2476.7	511.1	na	538.5
2007	14887.1	na	15106.9	1532.6	na	1671.8
2008	4647.5	na	4785.0	975.8	na	985.5
2009	5592.2	na	5955.3	1117.7	na	1138.1
2010	5522.6	na	5540.2	1181.4	na	1181.4
2011	4162.9	na	4312.3	744.1	na	747.6
2012	4782.6	na	4935.8	865.2	na	875.6
2013	1977.8	na	2057.6	472.5	na	472.5
2014	9982.1	na	10127.8	1125.9	na	1147.5

Table 4b. Biomasss indices (trawlable biomass in tonnes) for white hake in the September RV survey of the southern Gulf of St. Lawrence for strata 415-439 or 401,403 and 415-439. Strata 401 and 403 were established in 1984. A Yankee 36 trawl was used in 1971-1984 and a Western IIA trawl since 1985. Indices adjusted by dividing by 0.7 are also shown for 1971-1984. Fishing efficiency for white hake by the Yankee 36 trawl is estimated to be 70% of that by the Western IIA trawl, though this estimate is not statistically significant (see text for details). Fish 45 cm and longer are considered to be adults in the construction of these indices.

Year	Juveniles			Adults		
	415-439	415-439 adj	401,403, 415-439	415-439	415-439 adj	401,403, 415-439
1971	861.5	1230.8	na	2323.6	3319.4	na
1972	270.9	387.0	na	3976.3	5680.4	na
1973	392.5	560.7	na	10040.5	14343.6	na
1974	1684.1	2405.8	na	16236.6	23195.1	na
1975	2791.8	3988.2	na	4187.5	5982.2	na
1976	2518.0	3597.1	na	3289.8	4699.7	na
1977	1561.8	2231.1	na	3524.0	5034.3	na
1978	1423.7	2033.9	na	11322.2	16174.6	na
1979	1239.4	1770.6	na	11762.2	16803.1	na
1980	667.9	954.2	na	12906.6	18437.9	na
1981	912.8	1304.0	na	23195.8	33136.8	na
1982	517.3	739.0	na	6592.0	9417.1	na
1983	596.0	851.4	na	5074.6	7249.4	na
1984	1067.5	1525.1	1067.5	8258.5	11797.9	8603.6
1985	2288.0	na	2336.7	13390.0	na	13738.4
1986	3847.1	na	3932.6	16285.9	na	16627.2
1987	2021.2	na	2045.8	8086.8	na	8332.1
1988	2836.8	na	2943.0	8847.3	na	9750.0
1989	3428.8	na	5638.8	6750.5	na	7639.3
1990	3042.1	na	3245.0	6726.8	na	7441.6
1991	4084.2	na	4261.6	7221.2	na	7470.4
1992	3431.3	na	3874.2	2592.9	na	3420.9
1993	1620.7	na	1788.7	2583.8	na	3007.7
1994	1172.6	na	1212.4	2565.0	na	2620.3
1995	980.8	na	1428.1	810.7	na	1298.6
1996	1479.7	na	1552.9	931.0	na	1240.1
1997	1148.6	na	1183.9	1358.0	na	1510.5
1998	1309.4	na	1543.3	1212.6	na	1938.5
1999	1716.6	na	2070.1	1467.0	na	2428.1
2000	4768.8	na	4896.6	1184.7	na	1555.2
2001	1811.5	na	1879.6	1097.1	na	1217.6
2002	1338.4	na	1374.2	815.6	na	886.9
2003	1484.6	na	1395.3	748.9	na	701.6
2004	739.5	na	802.7	898.8	na	1049.3
2005	2147.3	na	2194.3	1172.2	na	1214.1
2006	826.1	na	848.8	457.7	na	482.7
2007	5010.8	na	5053.1	1450.8	na	1583.2
2008	1820.0	na	1852.5	966.5	na	981.4
2009	1689.7	na	1737.5	1030.2	na	1048.3
2010	1747.5	na	1750.2	1108.5	na	1108.5
2011	1408.1	na	1443.8	691.7	na	696.8
2012	1502.6	na	1515.7	888.9	na	904.6
2013	536.1	na	550.4	498.6	na	498.6
2014	3104.3	na	3129.5	980.5	na	995.0

Table 5a. Stratified mean catch rates at age (fish/tow) of white hake in the September Research Vessel (RV) survey of the southern Gulf of St. Lawrence, based on strata 415-439. Values are converted to trawlable abundance at age (in thousands) by multiplying by 1729.346.

	Age (years)															
Year	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
1971	na	0.018	0.727	0.691	0.788	0.346	0.142	0.038	0.005	0.005	0.012	na	0.027	na	na	na
1972	na	0.017	0.206	0.217	0.365	0.317	0.365	0.140	0.023	0.015	0.031	na	0.008	na	na	na
1973	na	0.017	0.448	0.471	2.143	1.833	0.643	0.216	0.033	0.013	0.049	na	na	na	na	na
1974	na	0.140	1.993	1.529	2.614	2.055	1.382	0.588	0.178	0.044	0.111	na	na	na	na	na
1975	na	0.080	3.422	2.133	1.481	0.728	0.267	0.072	0.012	0.012	0.031	na	0.020	na	na	na
1976	na	0.067	3.086	1.980	1.304	0.550	0.187	0.058	0.006	0.006	0.014	na	na	na	na	na
1977	na	0.020	0.874	1.236	1.456	0.558	0.180	0.067	0.022	0.006	0.020	na	0.008	na	na	na
1978	na	0.058	2.154	1.499	2.516	2.006	0.982	0.300	0.030	0.021	0.066	na	0.042	na	na	na
1979	na	na	0.278	2.042	2.077	1.822	1.279	0.484	0.132	0.015	0.025	0.037	0.061	na	na	na
1980	na	na	0.108	1.110	1.895	2.106	1.308	0.456	0.138	0.008	0.049	0.064	0.046	na	na	na
1981	na	0.045	0.460	1.112	2.473	3.151	2.392	1.447	0.473	0.232	0.012	0.015	0.012	0.044	0.015	
1982	na	0.059	0.265	0.613	0.960	0.786	0.716	0.310	0.137	0.019	0.036	na	na	na	na	na
1983	na	0.093	0.809	0.824	0.809	0.447	0.285	0.142	0.070	0.067	0.009	na	na	na	na	na
1984	0.007	0.054	0.477	1.141	1.433	1.128	0.520	0.259	0.156	0.053	0.060	0.009	0.010	na	na	na
1985	0.001	0.037	0.652	2.591	3.259	1.218	0.809	0.581	0.307	0.273	0.108	0.028	0.042	0.025	0.018	0.005
1986	0.045	0.178	1.726	2.998	5.199	3.093	1.014	0.444	0.245	0.116	0.041	0.038	0.035	0.014	na	na
1987	na	0.039	0.464	2.020	2.581	1.723	0.739	0.214	0.053	0.028	0.026	na	0.025	na	na	na
1988	0.007	0.146	1.557	2.713	3.232	2.378	0.761	0.297	0.050	0.011	0.013	na	na	na	na	na
1989	0.118	0.581	1.566	3.428	2.244	1.772	0.915	0.216	0.033	0.026	0.016	0.004	na	0.004	na	na
1990	0.038	0.152	2.083	3.115	2.350	2.355	0.612	0.353	0.069	0.017	na	na	na	na	na	na
1991	0.015	0.409	2.120	4.063	2.746	1.853	0.761	0.212	0.064	0.006	0.020	0.020	na	na	na	na
1992	0.043	0.279	1.499	3.386	2.557	0.770	0.134	0.028	0.006	na	na	na	na	na	na	na
1993	0.015	0.138	0.826	1.281	1.691	0.856	0.199	0.071	0.002	0.015	na	na	na	na	na	na
1994	0.061	0.140	0.977	1.068	1.258	0.587	0.144	0.016	0.018	na	na	na	na	na	na	na
1995	0.105	0.271	1.058	0.673	0.570	0.147	0.066	0.019	0.006	na	na	na	na	na	na	na
1996	0.066	0.345	1.174	1.123	0.835	0.236	0.057	0.010	0.007	0.002	na	na	na	na	na	na
1997	0.130	0.420	0.832	0.671	1.039	0.514	0.143	0.029	0.006	na	na	na	na	na	na	na
1998	0.009	0.382	1.451	0.792	0.678	0.374	0.140	0.021	0.011	na	na	na	na	na	na	na
1999	0.325	1.037	1.781	1.022	0.933	0.449	0.099	0.020	na	na	na	na	na	na	na	na
2000	0.068	0.387	4.426	3.406	2.630	0.449	0.050	0.008	na	na	na	na	na	na	na	na
2001	0.014	0.257	1.218	1.231	1.251	0.443	0.036	0.002	na	na	na	na	na	na	na	na
2002	0.012	0.588	1.712	0.599	0.601	0.250	0.015	0.006	na	na	na	na	na	na	na	na
2004	0.009	0.074	0.555	0.547	0.530	0.280	0.038	0.006	na	na	na	na	na	na	na	na
2005	0.002	0.262	2.508	0.979	1.370	0.364	0.039	0.016	na	na	na	na	na	na	na	na
2006	0.057	0.136	0.731	0.605	0.573	0.088	na	na	na	na	na	na	na	na	na	na
2007	0.111	0.441	5.705	3.281	2.450	0.503	0.032	0.010	na	na	na	na	na	na	na	na
2008	0.058	0.133	1.067	1.249	1.400	0.352	0.025	0.008	na	na	na	na	na	na	na	na
2009	0.072	0.708	1.601	0.907	1.304	0.501	0.029	na	na	na	na	na	na	na	na	na
2010	0.004	0.330	2.191	1.062	1.211	0.288	0.032	na	na	na	na	na	na	na	na	na
2011	na	0.115	1.418	1.000	1.040	0.141	0.031	na	na	na	na	na	na	na	na	na
2012	0.021	0.280	1.855	0.888	0.994	0.241	0.025	0.008	na	na	na	na	na	na	na	na
2013	0.003	0.231	0.697	0.442	0.238	0.234	0.026	na	na	na	na	na	na	na	na	na

Table 5b. Mean weight (kg) at age of white hake in the September Research Vessel (RV) survey of the southern Gulf of St. Lawrence (strata 415-439).

	Age (years)															
Year	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*
1971	na	0.213	0.334	0.484	0.848	1.472	2.129	2.140	2.340	2.340	2.183	na	7.534	na	na	na
1972	na	0.064	0.314	0.524	1.111	2.094	2.760	2.890	3.684	2.514	2.481	na	7.278	na	na	na
1973	na	0.123	0.373	0.622	1.097	1.488	1.959	2.611	4.148	2.476	2.062	na		na	na	na
1974	na	0.084	0.257	0.484	0.957	1.701	2.080	2.806	4.712	2.395	2.208	na		na	na	na
1975	na	0.267	0.326	0.423	0.858	1.419	1.951	2.040	2.309	2.309	2.156	na	6.831	na	na	na
1976	na	0.249	0.310	0.419	0.838	1.421	2.009	2.262	2.462	2.462	2.288	na		na	na	na
1977	na	0.190	0.387	0.525	0.808	1.492	1.812	2.377	4.858	2.360	1.991	na	6.017	na	na	na
1978	na	0.175	0.255	0.416	0.955	1.532	2.096	2.510	3.398	2.471	2.121	na	8.288	na	na	na
1979	na	na	0.309	0.449	0.815	1.400	1.839	2.225	2.374	3.172	2.735	5.005	2.736	na	na	na
1980	na	na	0.437	0.647	0.960	1.378	1.764	2.167	2.829	3.115	4.128	4.688	2.667	na	na	na
1981	na	0.059	0.247	0.485	0.914	1.405	1.865	2.268	2.984	3.194	3.575	12.275	3.575	9.738	12.275	
1982	na	0.099	0.370	0.645	1.072	1.388	1.829	2.408	2.970	3.135	3.631	na	na	na	na	na
1983	na	0.161	0.337	0.620	1.108	1.907	2.136	3.138	3.876	4.031	5.964	na	na	na	na	na
1984	0.072	0.150	0.304	0.583	0.933	1.456	2.036	2.483	3.026	2.641	5.755	3.612	6.235	na	na	na
1985	0.006	0.099	0.234	0.430	0.761	1.258	1.838	2.440	3.298	4.592	3.225	4.250	9.308	8.269	10.060	10.821
1986	0.081	0.165	0.254	0.475	0.776	1.226	1.911	2.720	3.284	4.433	6.376	7.126	7.725	10.013	na	na
1987	na	0.103	0.197	0.432	0.680	1.184	1.982	2.907	3.680	6.485	6.445	na	7.974	na	na	na
1988	0.052	0.096	0.239	0.419	0.704	1.083	1.737	2.710	3.794	5.917	9.475	na	na	na	na	na
1989	0.047	0.101	0.224	0.447	0.631	1.064	1.583	2.402	3.435	5.355	6.856	9.162	na	9.162	na	na
1990	0.036	0.120	0.233	0.363	0.641	0.969	1.417	2.015	3.539	4.102	na	na	na	na	na	na
1991	0.065	0.201	0.269	0.477	0.674	1.033	1.504	2.120	3.694	4.338	6.550	7.223	na	na	na	na
1992	0.074	0.174	0.288	0.449	0.613	0.902	1.413	1.814	3.126	na	na	na	na	na	na	na
1993	0.084	0.154	0.276	0.462	0.666	0.888	1.173	1.381	2.576	4.713	na	na	na	na	na	na
1994	0.061	0.146	0.259	0.515	0.808	1.100	1.625	2.391	3.140	na	na	na	na	na	na	na
1995	0.015	0.109	0.249	0.483	0.716	1.078	1.752	3.046	3.698	na	na	na	na	na	na	na
1996	0.021	0.145	0.262	0.509	0.656	0.952	1.185	1.424	1.101	1.466	na	na	na	na	na	na
1997	0.044	0.086	0.234	0.440	0.626	0.888	1.254	1.807	1.908	na	na	na	na	na	na	na
1998	0.071	0.160	0.259	0.436	0.661	1.028	1.560	1.595	2.638	na	na	na	na	na	na	na
1999	0.049	0.098	0.257	0.460	0.669	1.085	1.727	3.120	na	na	na	na	na	na	na	na
2000	0.070	0.143	0.250	0.392	0.561	0.915	1.322	1.343	na	na	na	na	na	na	na	na
2001	0.064	0.185	0.252	0.450	0.617	1.016	1.399	1.308	na	na	na	na	na	na	na	na
2002	0.022	0.190	0.264	0.514	0.723	1.111	1.059	1.838	na	na	na	na	na	na	na	na
2004	0.043	0.136	0.227	0.492	0.670	1.078	na	na	na	na	na	na	na	na	na	na
2005	0.001	0.147	0.285	0.466	0.723	1.154	1.771	2.802	na	na	na	na	na	na	na	na
2006	0.029	0.188	0.260	0.460	0.615	0.946	1.169	1.509	na	na	na	na	na	na	na	na
2007	0.136	0.159	0.247	0.458	0.667	1.045	na	na	na	na	na	na	na	na	na	na
2008	0.025	0.143	0.269	0.391	0.592	0.982	1.367	1.259	na	na	na	na	na	na	na	na
2009	0.053	0.103	0.262	0.427	0.614	1.079	1.513	1.624	na	na	na	na	na	na	na	na
2010	0.013	0.087	0.215	0.405	0.593	0.933	0.986	na	na	na	na	na	na	na	na	na
2011	0.088	0.155	0.246	0.401	0.660	0.973	1.691	na	na	na	na	na	na	na	na	na
2012	na	0.120	0.214	0.427	0.636	1.112	1.103	na	na	na	na	na	na	na	na	na
2013	0.020	0.162	0.225	0.419	0.646	1.038	2.303	2.984	na	na	na	na	na	na	na	na

Table 6a. Mean number per tow by age for white hake in the August sentinel trawl surveys conducted in the southern Gulf of St. Lawrence from 2003 to 2013.

Age	1	2	3	4	5	6	7	8	Total
2003	0.497	0.904	0.376	0.415	0.181	0.021	0.004	0.006	2.417
2004	0.114	0.744	0.556	0.707	0.401	0.049	na	na	2.637
2005	0.143	1.350	0.542	0.702	0.209	0.017	0.010	na	2.975
2006	0.252	1.099	0.501	0.372	0.088	0.009	0.006	na	2.334
2007	0.123	0.689	0.309	0.317	0.108	0.019	na	na	1.567
2008	0.058	0.279	0.254	0.214	0.056	0.004	na	na	0.865
2009	0.025	0.371	0.610	0.581	0.231	0.014	0.010	na	1.842
2010	0.147	0.417	0.295	0.219	0.066	0.023	0.005	na	1.174
2011	0.059	0.222	0.214	0.236	0.051	0.002	0.005	na	0.789
2012	0.153	0.200	0.100	0.082	0.031	0.009	na	na	0.750
2013	0.049	0.463	0.098	0.063	0.059	0.007	na	na	0.745

Table 6b. Average weight (kg) at age for white hake in the August sentinel trawl surveys conducted in the southern Gulf of St. Lawrence from 2003 to 2013.

Age	1	2	3	4	5	6	7	8	Weighted average
2003	0.14	0.23	0.49	0.76	1.27	1.89	2.14	2.35	0.44
2004	0.11	0.24	0.42	0.73	1.19	1.71	na	na	0.57
2005	0.14	0.21	0.47	0.63	1.12	1.29	1.72	na	0.43
2006	0.15	0.23	0.44	0.63	1.02	1.33	2.47	na	0.37
2007	0.15	0.22	0.42	0.69	1.01	1.46	na	na	0.42
2008	0.15	0.22	0.44	0.65	1.11	2.20	na	na	0.45
2009	0.13	0.22	0.41	0.60	0.99	1.54	2.15	na	0.52
2010	0.14	0.23	0.40	0.69	1.08	1.83	2.77	na	0.44
2011	0.15	0.23	0.44	0.67	1.06	1.94	2.49	na	0.49
2012	0.14	0.21	0.49	0.81	1.13	2.40	na	na	0.31
2013	0.14	0.21	0.37	0.56	1.06	1.90	na	na	0.34

Table 6c. Average length (cm) at age for white hake in the August sentinel trawl surveys conducted in the southern Gulf of St. Lawrence from 2003 to 2013.

Age	1	2	3	4	5	6	7	8	Weighted average
2003	26.5	31.2	39.9	46.2	54.6	62.2	65.0	67.0	36.2
2004	24.7	31.4	37.9	44.9	52.7	59.4	na	na	39.1
2005	26.7	30.8	39.8	44.0	53.2	55.9	61.1	na	37.2
2006	27.8	31.4	39.1	43.6	51.2	56.2	68.6	na	35.5
2007	27.4	31.0	38.2	44.8	50.8	57.2	na	na	36.6
2008	27.5	30.8	38.7	43.7	51.9	65.0	na	na	37.6
2009	25.7	30.8	37.9	42.9	50.7	58.8	65.0	na	39.8
2010	26.6	31.3	37.4	44.8	51.7	61.7	71.0	na	36.6
2011	27.6	31.7	39.0	44.1	51.2	62.0	67.0	na	38.6
2012	26.9	30.4	40.2	47.0	52.6	66.0	na	na	27.1
2013	26.4	30.4	36.9	42.3	52.3	64.2	na	na	33.8

Table 7a. General linear model results for the standardization of longline sentinel survey catch rates (1996-2013) for sites from Nova Scotia and Prince Edward Island.

Factor	Levels	Values
Year	18	1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013
Month	4	7, 8, 9, 10
Site	22	22, 23, 24, 25, 28, 29, 30, 31, 34, 35, 65, 68, 71, 72, 75, 76, 115, 116, 121, 122, 123, 124
Number of observations	1091	

Source	DF	Sum of squares	Mean square	F-value	Pr > F
Model	41	4030.426665	98.303089	50.60	< 0.0001
Error	1049	2037.942725	1.942748		
Corrected total	1090	6068.369391			

R-square	Coeff. Var.	Root MSE	cat.eff Mean
0.664170	99.43283	1.393825	1.401775

Source	DF	Type I SS	Mean square	F-value	Pr > F
year	17	2512.969326	147.821725	76.09	< 0.0001
month	3	59.734521	19.911507	10.25	< 0.0001
site	21	1457.722819	69.415372	35.73	< 0.0001

Source	DF	Type III SS	Mean square	F-value	Pr > F
year	17	2243.681692	131.981276	67.94	< 0.0001
month	3	60.423429	20.141143	10.37	< 0.0001
site	21	1457.722819	69.415372	35.73	< 0.0001

year	LSMEAN (cat_eff)
1996	3.38663995
1997	4.20975692
1998	3.44150173
1999	3.94037170
2000	3.10013817
2001	2.59903142
2002	1.97972179
2003	1.57496795
2004	1.26607644
2005	0.99855883
2006	0.47539975
2007	0.84302624
2008	-0.1243115
2009	0.24157294
2010	0.02489418
2011	-0.3425486
2012	-0.3697597
2013	-0.0664614

Table 7b. General linear model results for the standardization of longline sentinel survey catch rates (1996-2013) from sites from St. Georges Bay (Nova Scotia).

Factor	Levels	Values
Year	18	1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013
Month	4	7, 8, 9, 10
Site	6	28, 29, 30, 31, 34, 35
Number of observations	322	

Source	DF	Sum of squares	Mean square	F-value	Pr > F
Model	25	1988.397216	79.535889	79.62	< 0.0001
Error	296	295.682786	0.998928		
Corrected total	321	2284.080002			

R-square	Coeff. Var.	Root MSE	cat.eff Mean
0.870546	32.44231	0.999464	3.080742

Source	DF	Type I SS	Mean square	F-value	Pr > F
year	17	1927.361887	113.374229	113.50	< 0.0001
month	3	37.764736	12.588245	12.60	< 0.0001
site	5	23.270593	4.654119	4.66	0.0004

Source	DF	Type III SS	Mean square	F-value	Pr > F
year	17	1949.772041	114.692473	114.82	< 0.0001
month	3	37.978702	12.659567	12.67	< 0.0001
site	5	23.270593	4.654119	4.66	0.0004

year	LSMEAN (cat_eff)
1996	6.36934610
1997	6.46129808
1998	6.11025024
1999	6.07484130
2000	5.47777888
2001	4.83492655
2002	4.16854922
2003	3.88140735
2004	4.30656421
2005	2.86247455
2006	2.09719862
2007	2.08410992
2008	0.62319972
2009	0.72464157
2010	0.02001746
2011	-0.5130316
2012	-0.5098533
2013	-0.4891368

Table 7c. General linear model results for the standardization of longline sentinel survey catch rates (1996-2013) from sites from Cape Breton Trough (Nova Scotia).

Factor	Levels	Values
Year	18	1996, 1997, 1998, 1999, 2000, 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013
Month	3	8, 9, 10
Site	6	22, 23, 24, 25, 121, 122
Number of observations	254	

Source	DF	Sum of squares	Mean square	F-value	Pr > F
Model	24	387.6286690	16.1511945	11.92	< 0.0001
Error	229	310.3452943	1.3552196		
Corrected total	253	697.9739632			

R-square	Coeff. Var.	Root MSE	cat.eff Mean
0.555363	111.1844	1.164139	1.047034

Source	DF	Type I SS	Mean square	F-value	Pr > F
year	17	209.2910740	12.3112396	9.08	< 0.0001
month	2	137.1334919	68.5667460	50.59	< 0.0001
site	5	41.2041031	8.2408206	6.08	< 0.0001

Source	DF	Type III SS	Mean square	F-value	Pr > F
year	17	246.5018085	14.5001064	10.70	< 0.0001
month	2	136.7954593	68.3977297	50.47	< 0.0001
site	5	41.2041031	8.2408206	6.08	< 0.0001

year	LSMEAN (cat_eff)
1996	1.53635515
1997	3.41371701
1998	1.18773373
1999	3.94093573
2000	2.67823924
2001	1.77393027
2002	1.91750142
2003	1.79891292
2004	0.93797149
2005	1.23132624
2006	0.34332894
2007	0.91865387
2008	-0.0104218
2009	0.65416971
2010	0.00361218
2011	0.35649678
2012	0.32586234
2013	0.61069156

Table 8. Standardized catch rates (fish/tow) for white hake by longliners in the southern Gulf of St. Lawrence sentinel longline survey (1996-2013).

	Nova Scotia and Prince Edward Island		St. Georges Bay (Nova Scotia)		Cape Breton Trough (Nova Scotia)	
Year	Catch rate	Standard Error	Catch rate	Standard Error	Catch rate	Standard Error
1996	74.86	0.22	917.59	0.27	8.51	0.34
1997	170.79	0.21	1005.96	0.27	55.61	0.34
1998	79.45	0.19	717.71	0.21	6.00	0.34
1999	130.87	0.19	691.11	0.22	93.39	0.37
2000	56.39	0.20	378.78	0.24	25.95	0.42
2001	34.29	0.18	199.27	0.24	10.94	0.29
2002	18.42	0.19	102.02	0.25	12.30	0.37
2003	12.31	0.18	76.85	0.24	11.06	0.34
2004	9.04	0.18	117.53	0.24	4.73	0.29
2005	6.92	0.17	27.80	0.23	6.35	0.29
2006	4.11	0.17	12.90	0.24	2.61	0.29
2007	5.93	0.17	12.73	0.24	4.67	0.27
2008	2.25	0.17	2.96	0.23	1.84	0.27
2009	3.25	0.17	3.27	0.24	3.58	0.27
2010	2.61	0.17	1.61	0.25	1.87	0.27
2011	1.81	0.18	0.95	0.24	2.66	0.27
2012	1.76	0.18	0.95	0.25	2.50	0.37
2013	2.39	0.17	0.97	0.24	3.39	0.31

Table 9. Estimated adult biomass (SSB) and abundance in selected years and decline rates based on the population model. Values in parentheses are 95% confidence intervals, based on MCMC sampling.

Indicator	Base period value (1978 to 1982)	Contemporary period	Contemporary period value	Decline (%)
SSB (t)	52,847 (41,107 – 90,710)	2009 to 2013	6,516 (4,387-12,041)	87.7 (83.2 – 91.4)
		2013	3,844 (2,545 – 7,392)	92.7 (89.4 – 95.1)
Abundance (millions)	46.32 (35.43 – 78.97)	2009 to 2013	11.46 (7.61 – 21.1)	75.3 (66.3 – 82.7)
		2013	6.17 (3.99 – 11.81)	86.7 (80.3 – 91.1)

Table 10. Parameter estimates for two Ricker stock-recruit relationships for SGSL white hake.

Model	Parameter	Estimate	SE	*t*	*P*
A	α	12.9808	1.3774	9.424	<0.0001
	β	0.04509	0.0038	11.372	<0.0001
B	α_1	5.2642	1.2578	4.185	0.0002
	α_2	6.9602	0.9971	6.980	<0.0001
	β	0.02441	0.005341	4.571	<0.0001

FIGURES

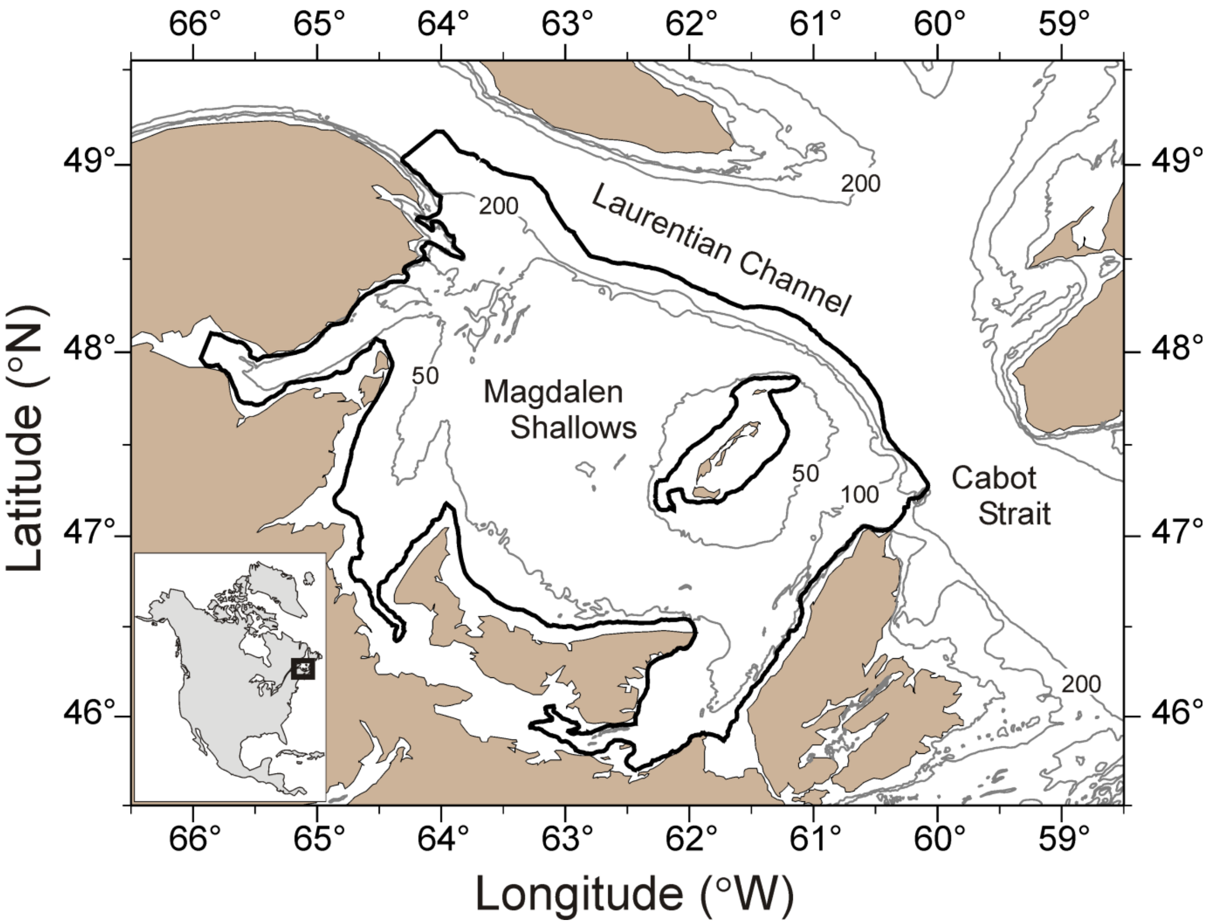

Figure 1. The southern Gulf of St. Lawrence, showing the 50, 100 and 200 m isobaths (grey lines). The heavy line shows the area covered by the September bottom-trawl survey, including only strata sampled since 1971. The inset map shows the study area within North America.

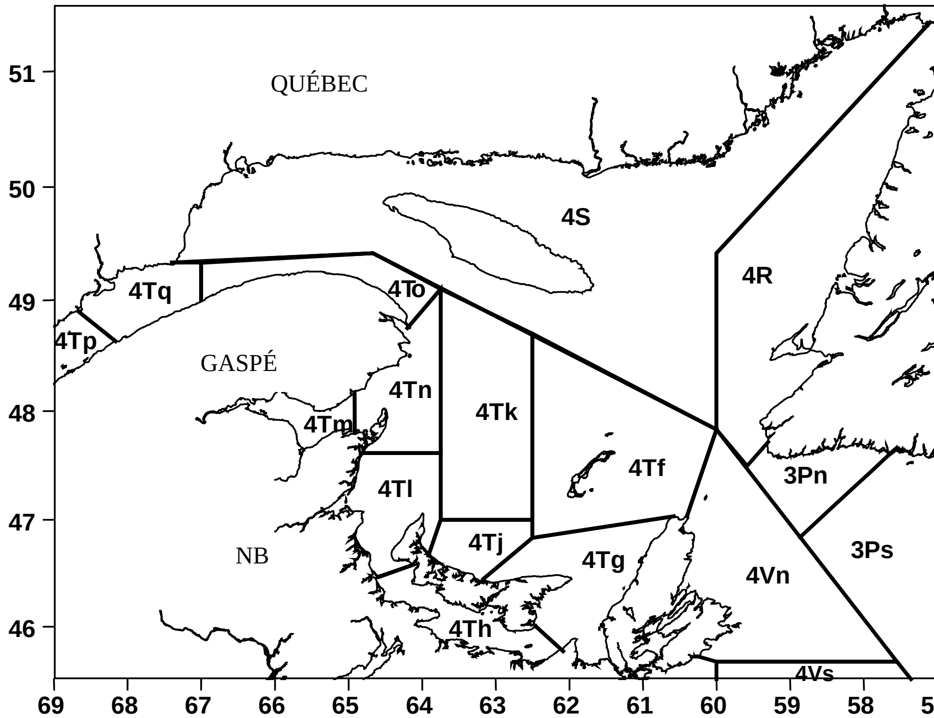

Figure 2. NAFO Divisions in the area of the Gulf of St. Lawrence. Unit areas are indicated for Division 4T.

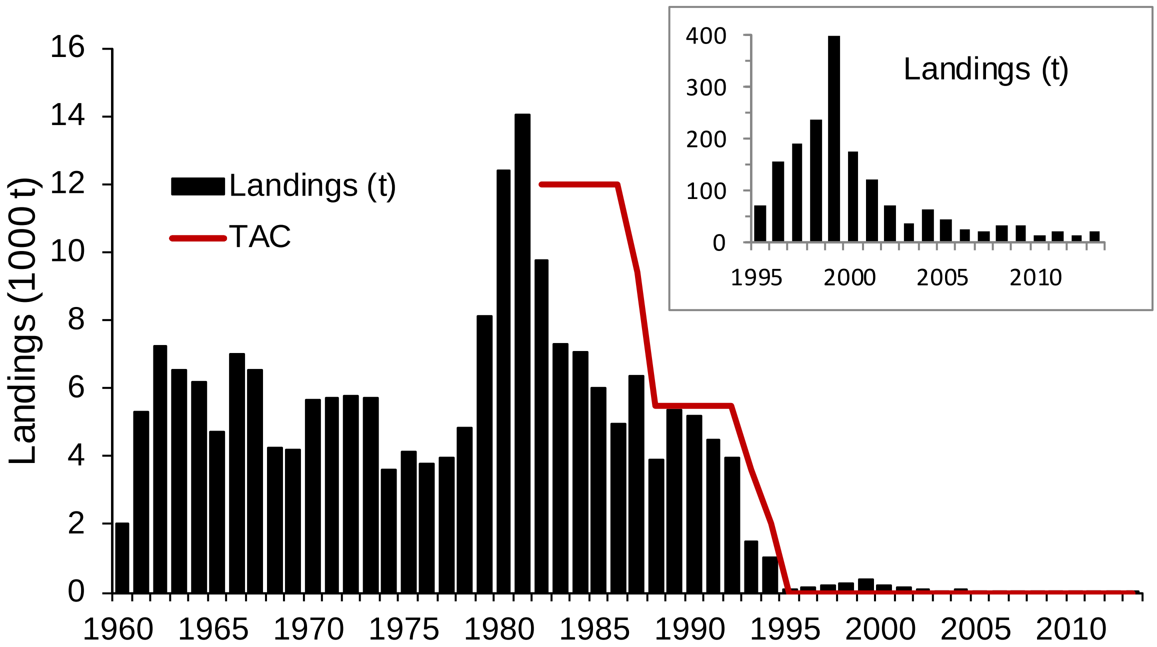

Figure 3. Landings and total allowable catch (TAC) for white hake in NAFO Div. 4T.

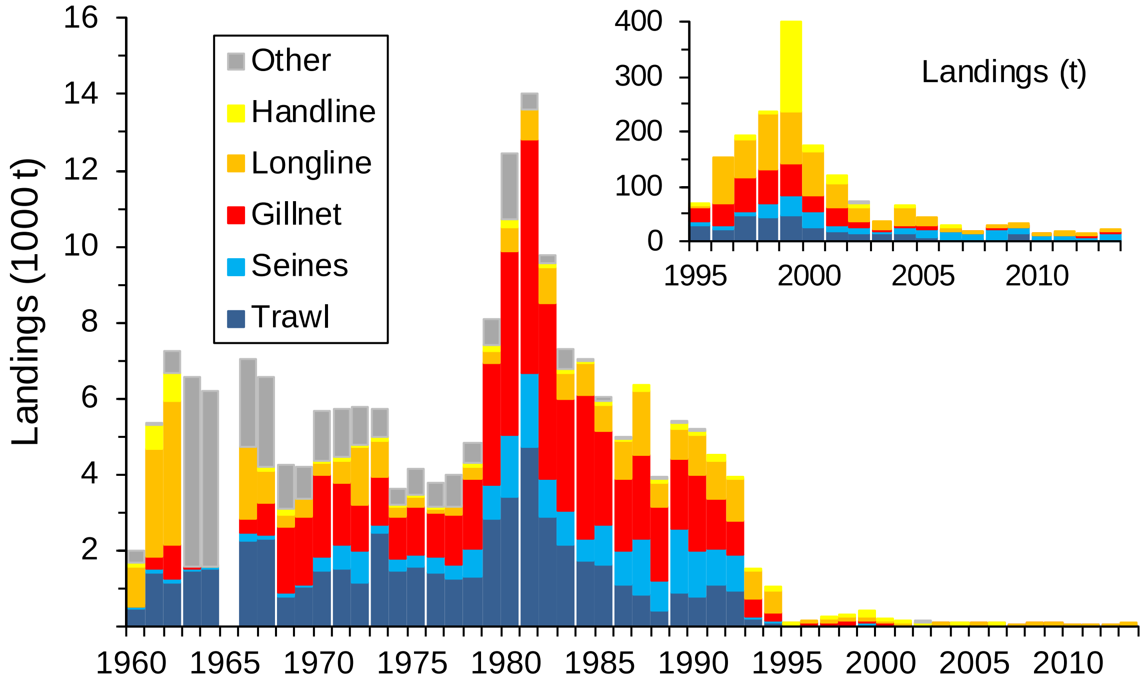

Figure 4. Landings by gear type for white hake in NAFO Div. 4T.

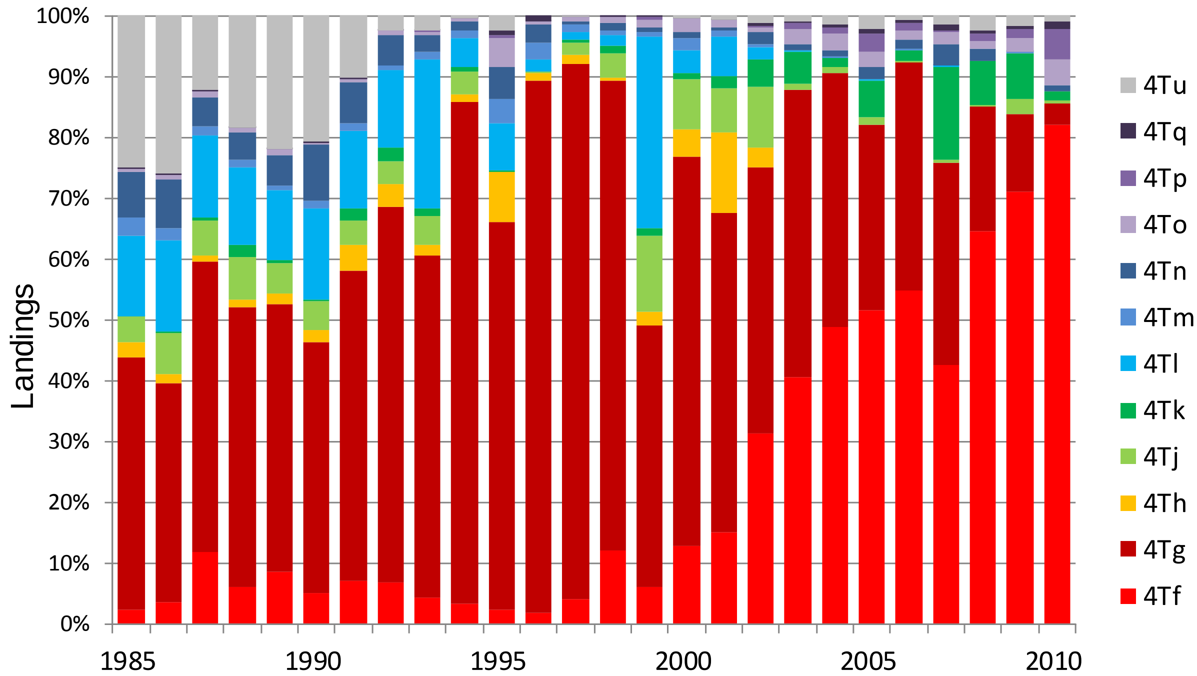

Figure 5. Landings of white hake in NAFO Division 4T by NAFO unit area.

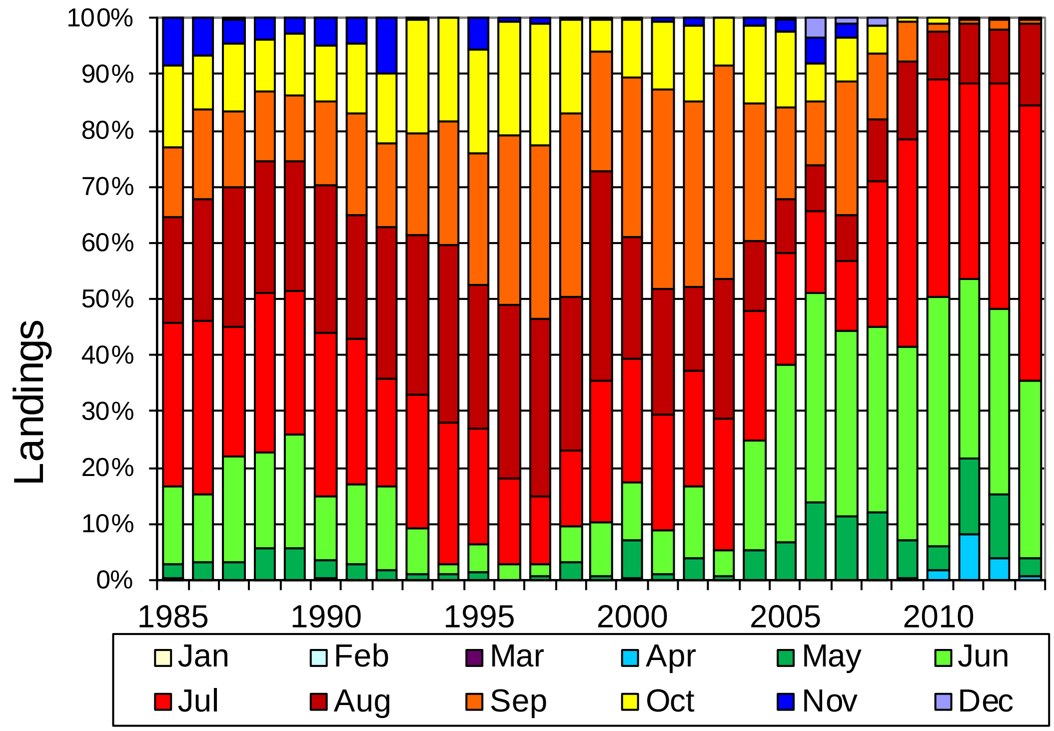

Figure 6. Landings of white hake in NAFO Division 4T by month.

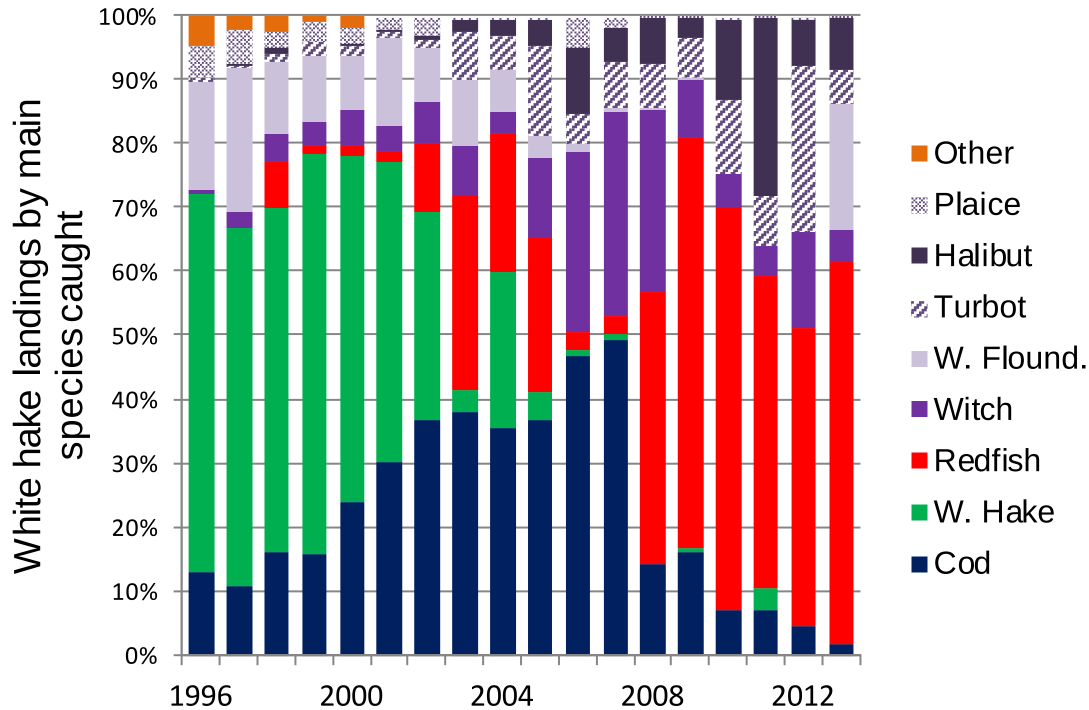

Figure 7. Landings of white hake in NAFO Division 4T by main species caught.

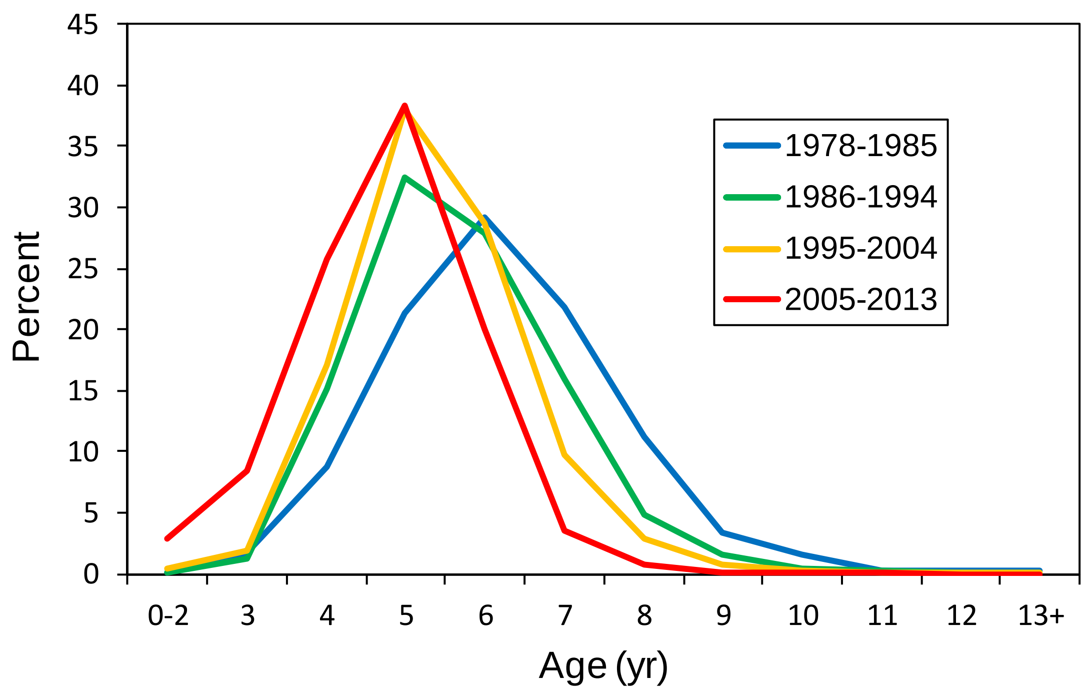

Figure 8. Age composition (% at age) of the landings of white hake in NAFO Division 4T.

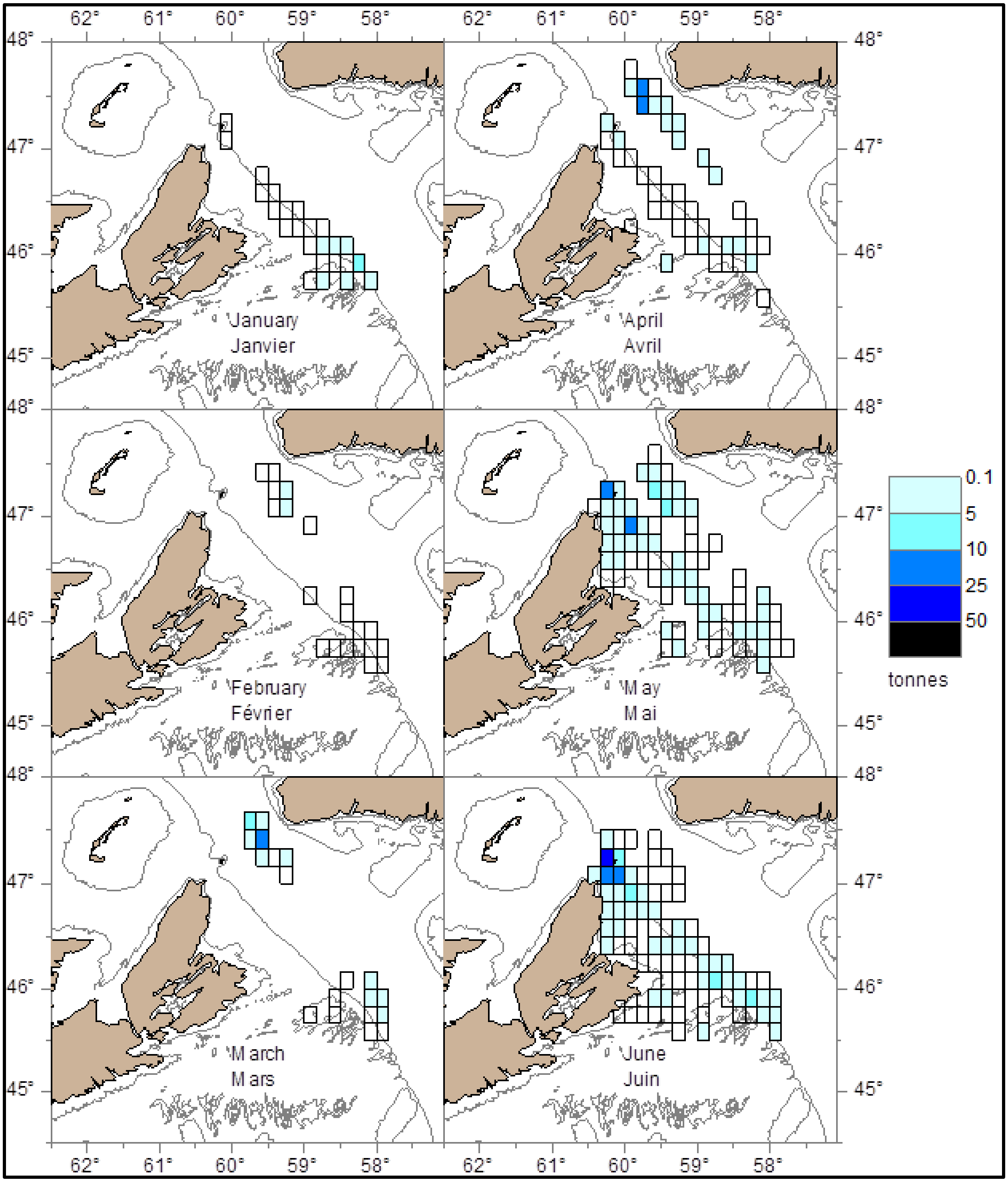

Figure 9a. Landings of white hake in NAFO Subdivision 4Vn by month in 1985-1999.Shading of the 10' grids indicates total catch in the time period.

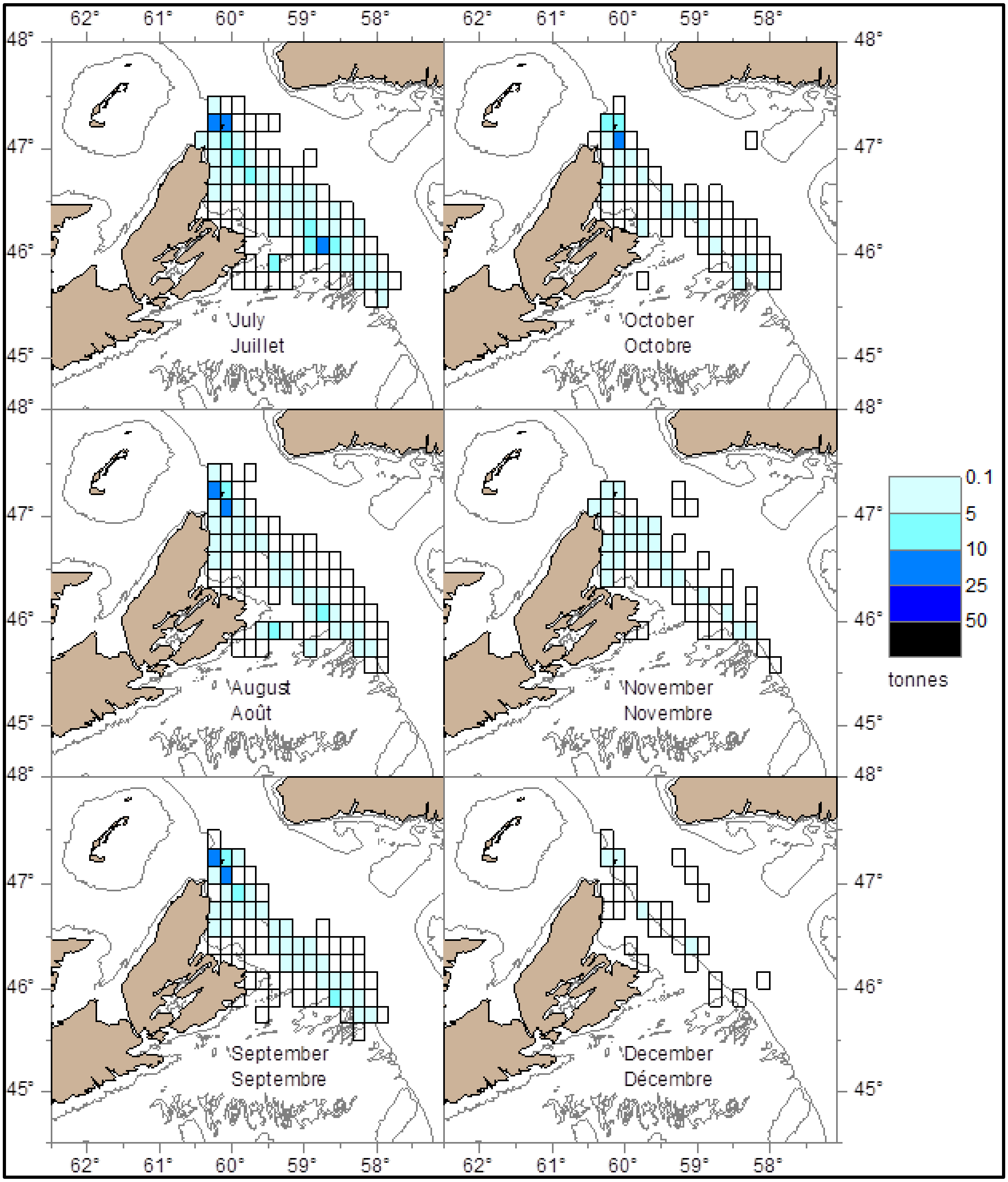

Figure 9a (continued).

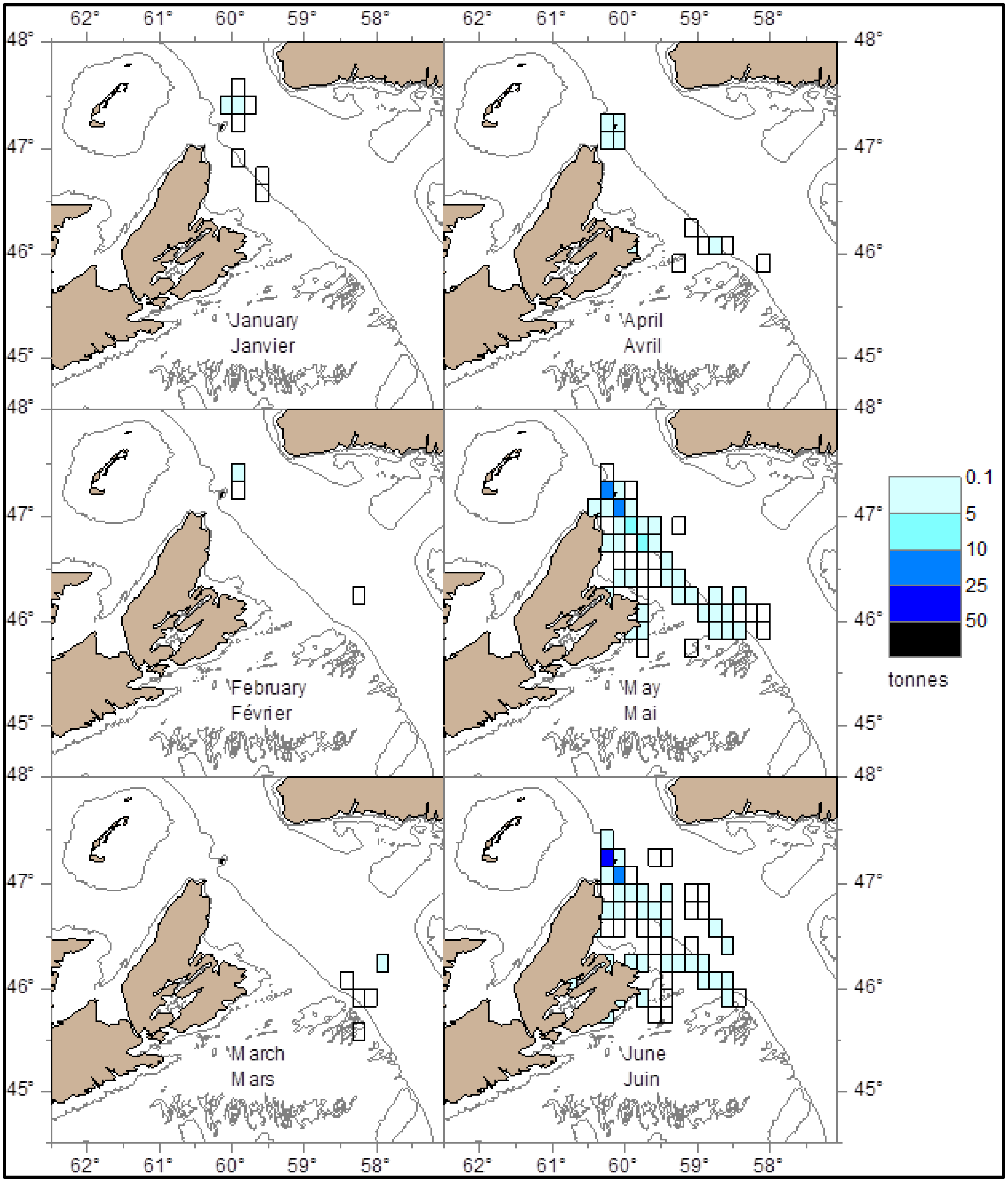

Figure 9b. Landings of white hake in NAFO Subdivision 4Vn by month in 2000-2008.Shading of the 10' grids indicates total catch in the time period.

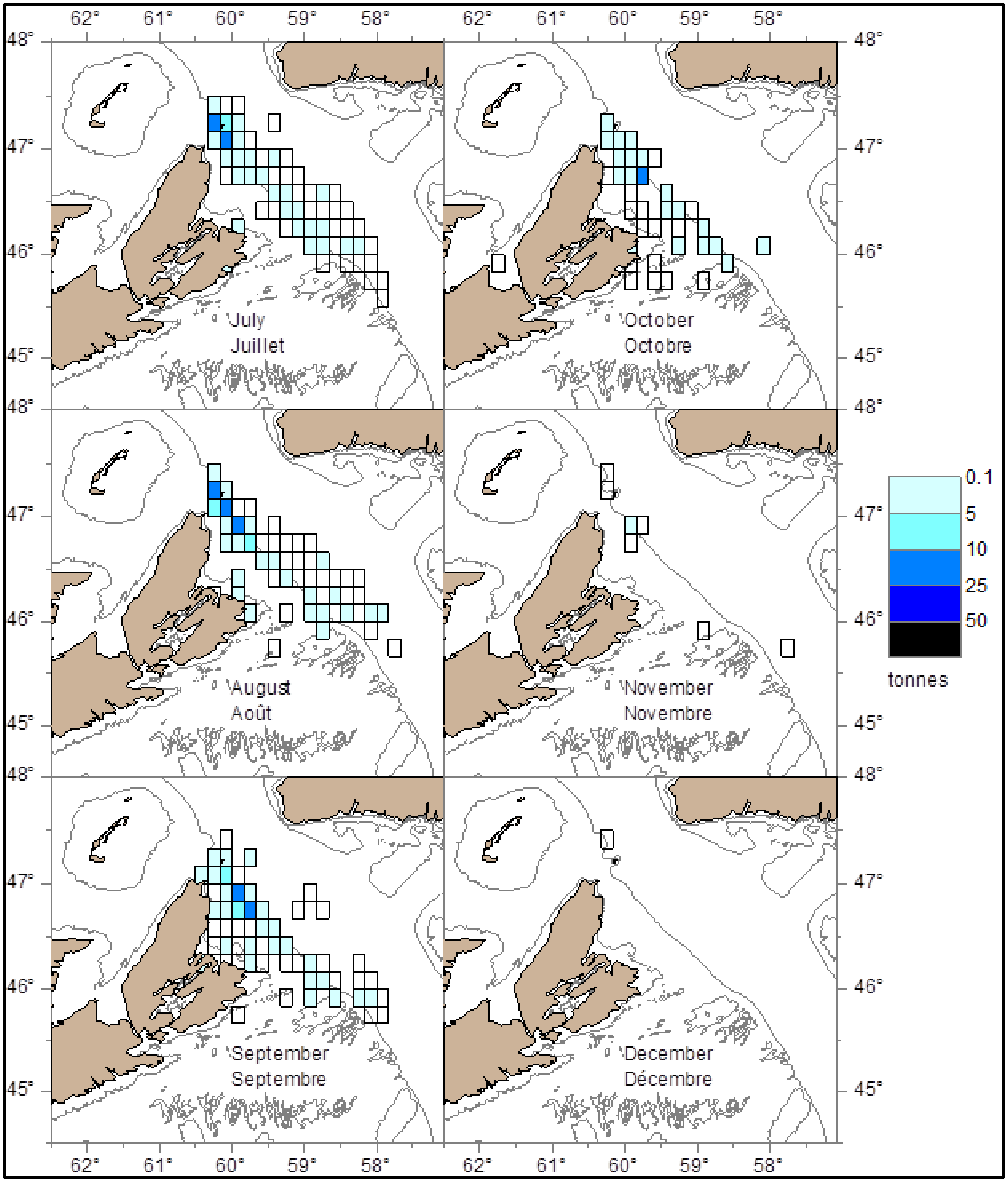

Figure 9b continued.

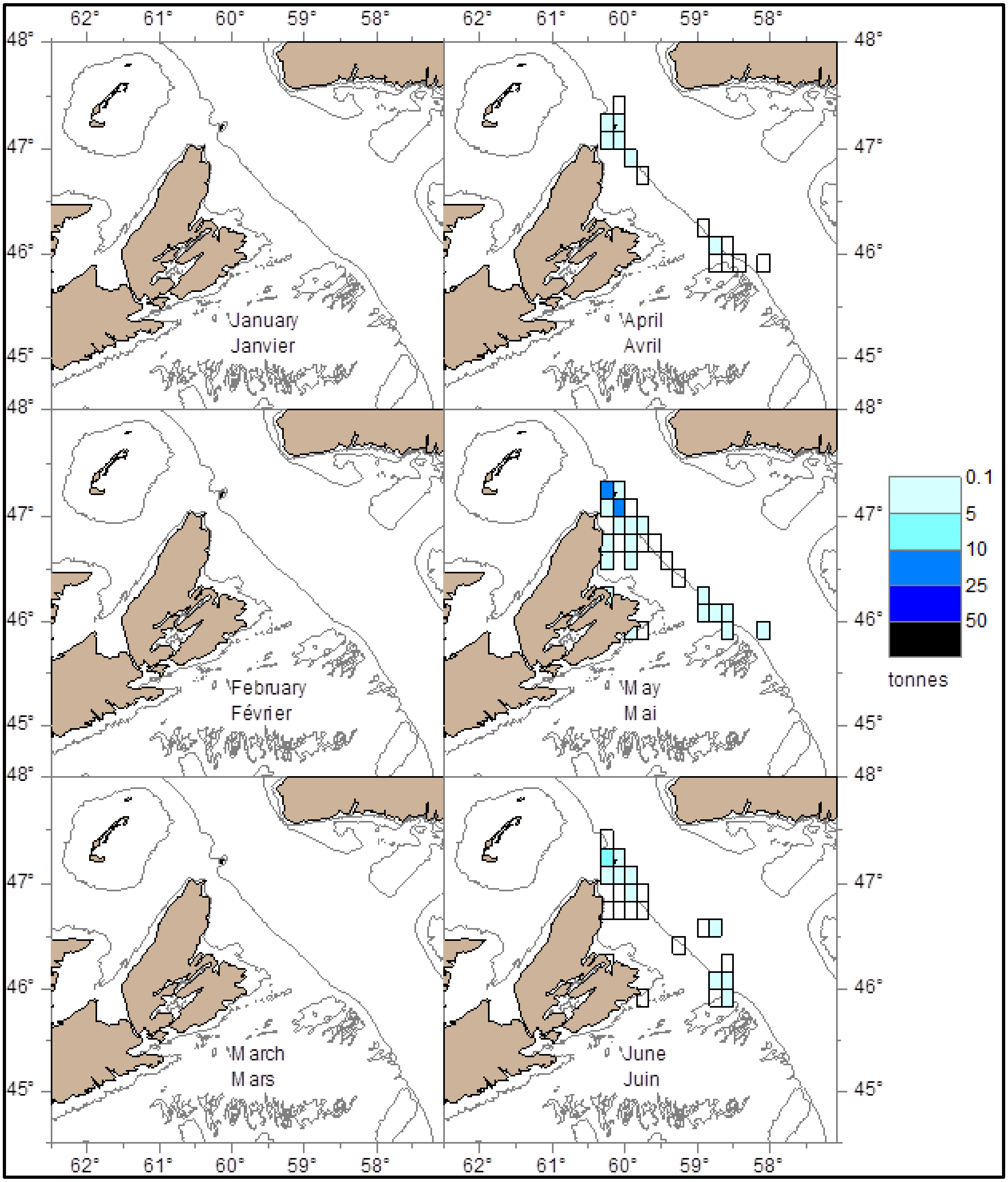

Figure 9c. Landings of white hake in NAFO Subdivision 4Vn by month in 2009-2013.Shading of the 10' grids indicates total catch in the time period.

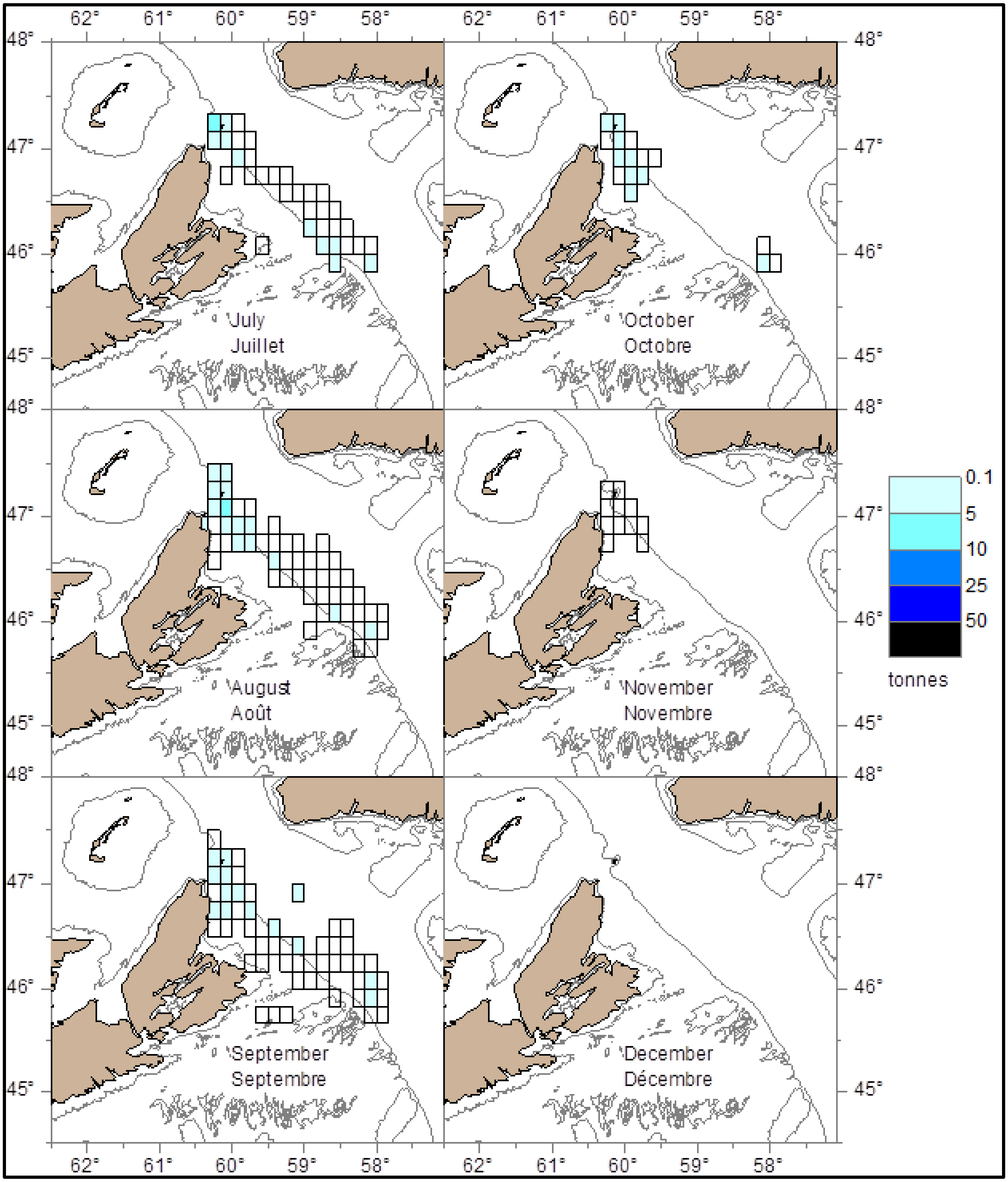

Figure 9c continued.

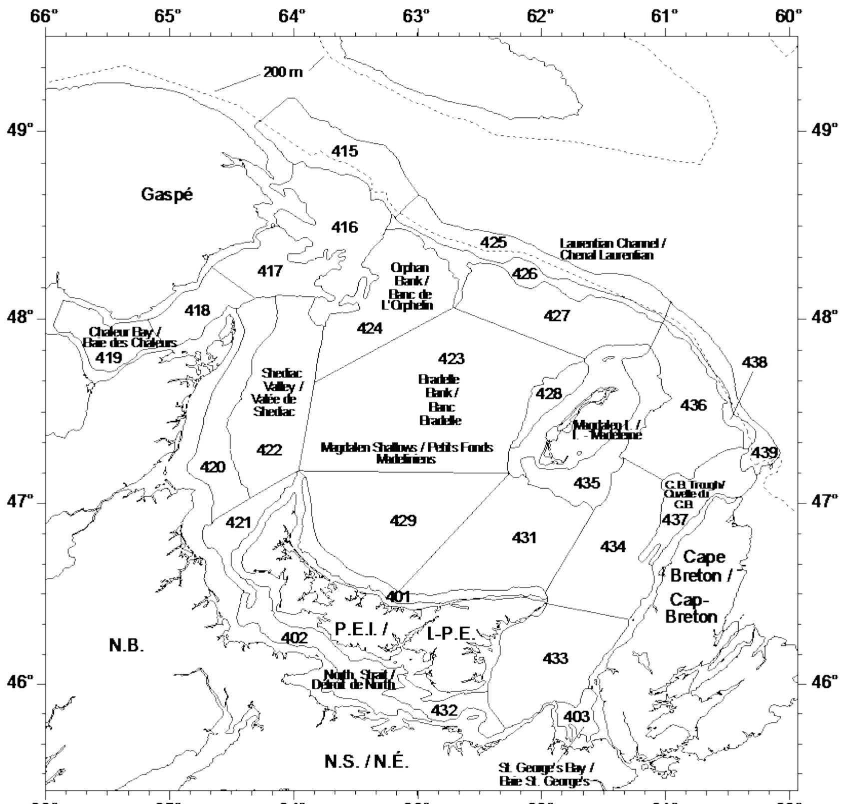

Figure 10. Stratification scheme used for the August sentinel and September research surveys of the southern Gulf of St. Lawrence.

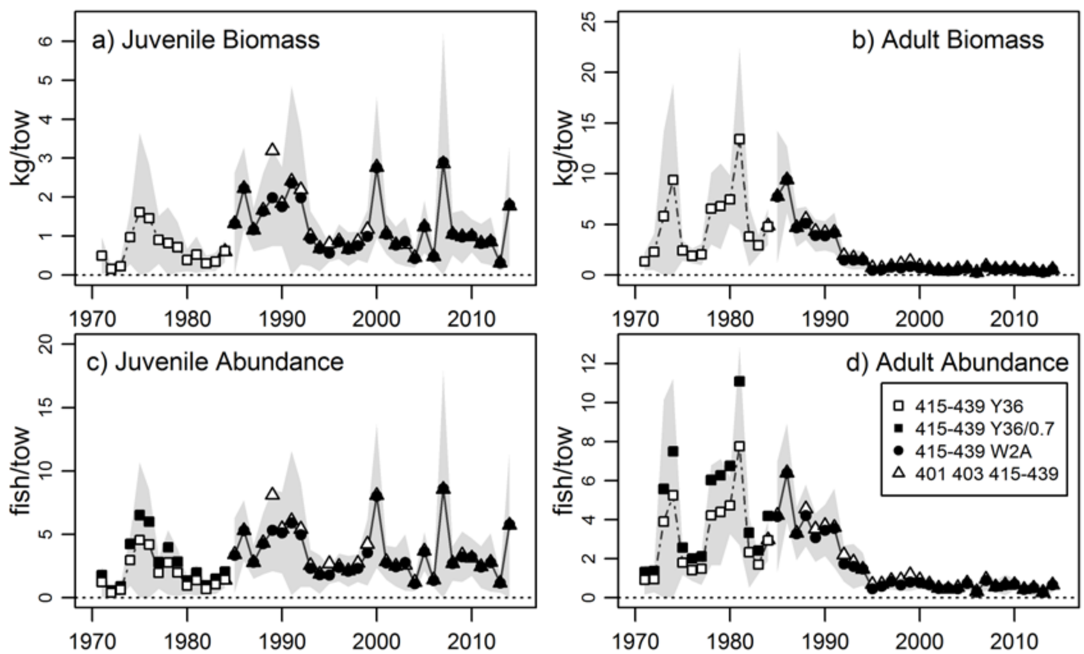

Figure 11. RV survey indices of abundance (number per tow) and biomass (kg per tow) for juvenile (< 45 cm) and adult (≥45 cm) white hake. Squares and circles denote indices based on strata 415-439 in years when a Yankee 36 (squares) or western IIA (circles) trawl was used .Grey shading shows the approximate 95% confidence intervals (±2 SE) for indices denoted by circles or open squares. Filled squares show Yankee-36 indices adjusted to be equivalent to western-IIA indices based on the non-significant factor estimated from paired fishing experiments (see text).Triangles show indices based on strata 401, 403 and 415-439.

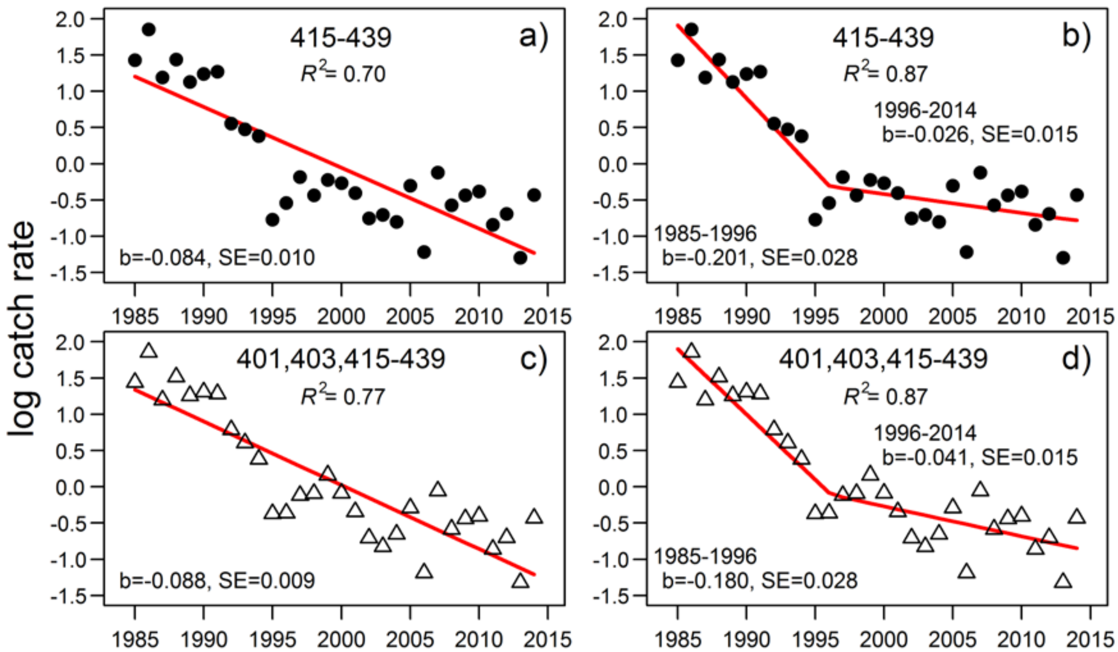

Figure 12. Natural log (base e) transformed RV abundance indices for adult-sized (≥45 cm) white hake, based on strata 415-439 (panels a and b) or 401, 403 and 415-439 (panels c and d). Lines show the regression (panels a and c) or piecewise regression (panels b and d) of log catch rate on year.

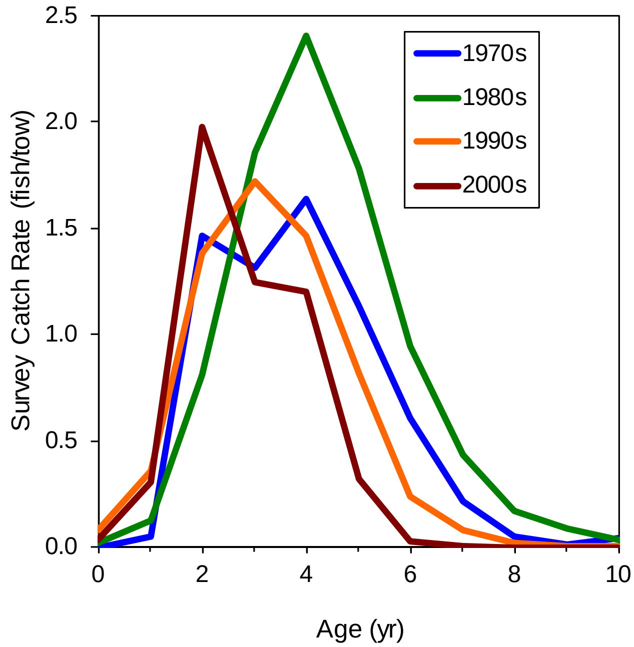

Figure 13. Catch rates at age (fish per tow) of white hake in the September RV survey of the SGSL, averaged over time periods (1970s, 1980s, 1990s, 2000s), 1971-2013.

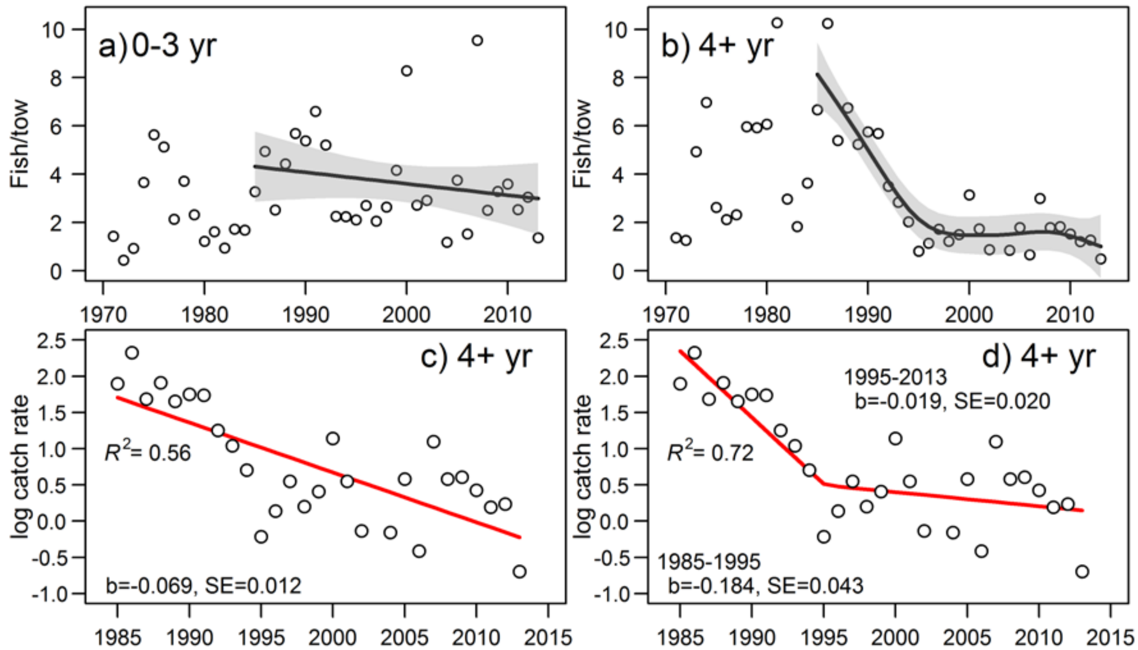

Figure 14. Age-based abundance indices from the September RV survey for juvenile (panel a, 3 years and younger) and adult (panel b, 4 years and older) white hake. Lines and shading in panels a and b show a GAM fit to the indices and its approximate 95% confidence band for the years when a western IIA trawl was used (1985-2013). Bottom panels (c and d) show the regression of natural log of catch rate (fish per tow) against year, either for the entire 1985-2013 period (panel c) or a piecewise regression with an estimated break-point at 1995 (panel d). Regressions are restricted to 1985-2013 period due to a possible change in survey catchability in 1985 when the gear changed.

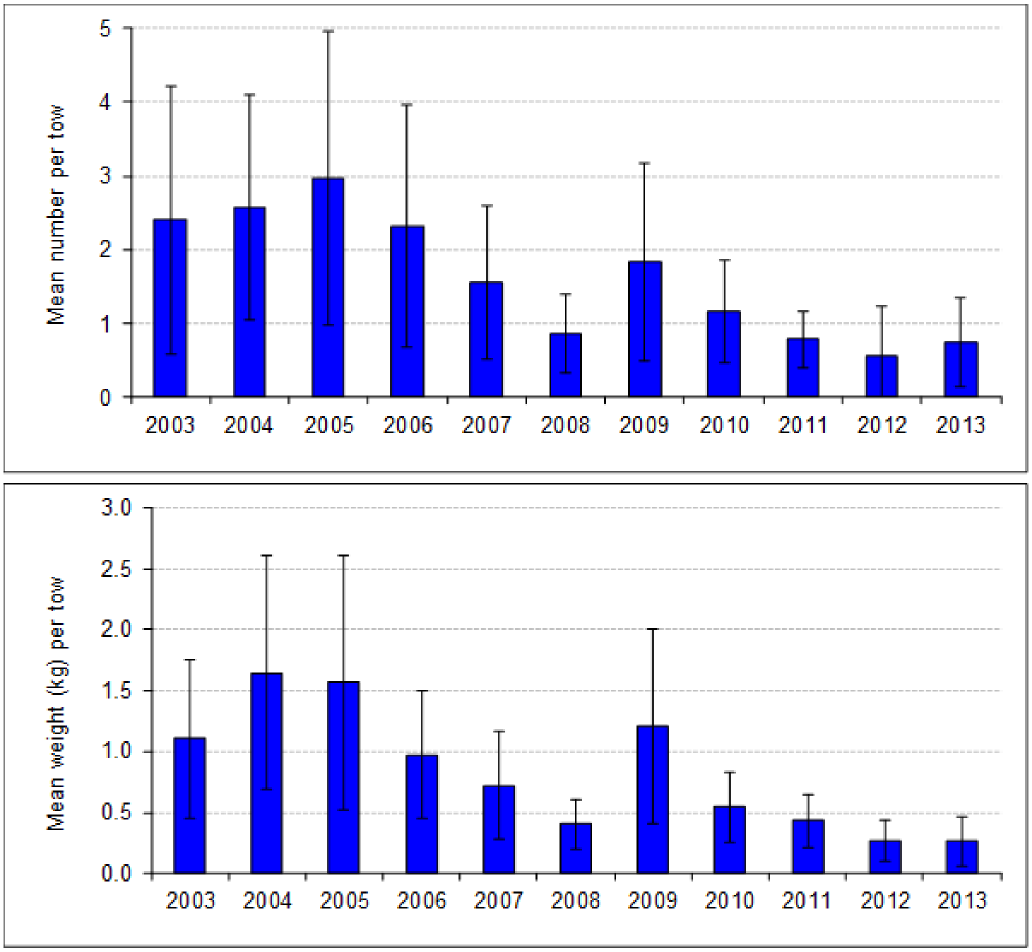

Figure 15. Mean number (top) and mean weight (kg; bottom) per tow of white hake in the sentinel bottom-trawl survey of the SGSL. Vertical lines denote approximate 95% confidence limits (± 2 standard errors).

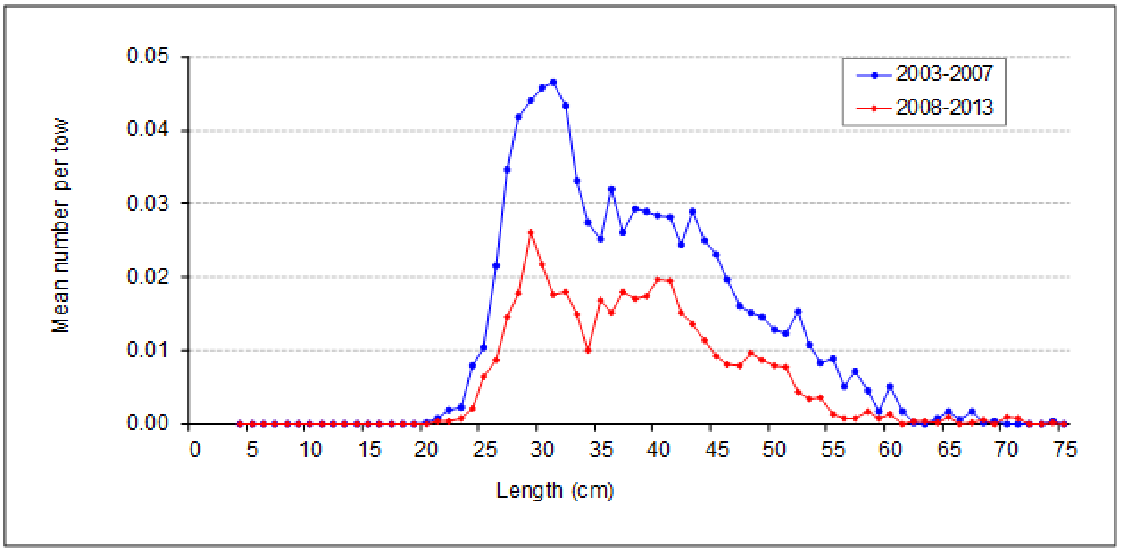

Figure 16. Average length frequency (expressed as number per tow) of white hake caught in the sentinel bottom-trawl survey in two periods, 2003 to 2007 and 2008 to 2013.

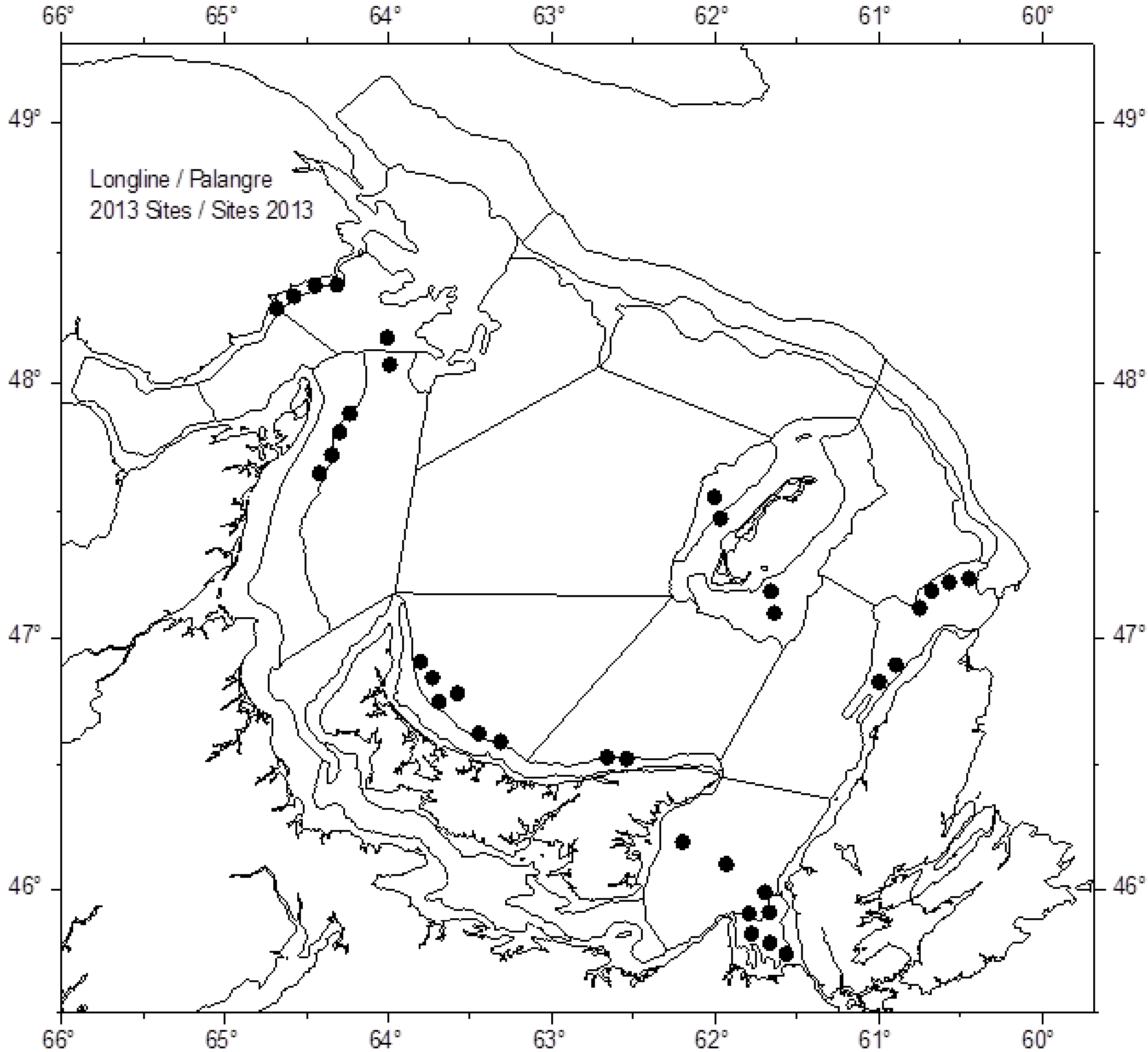

Figure 17. Location of the sentinel longline sites in 2013.

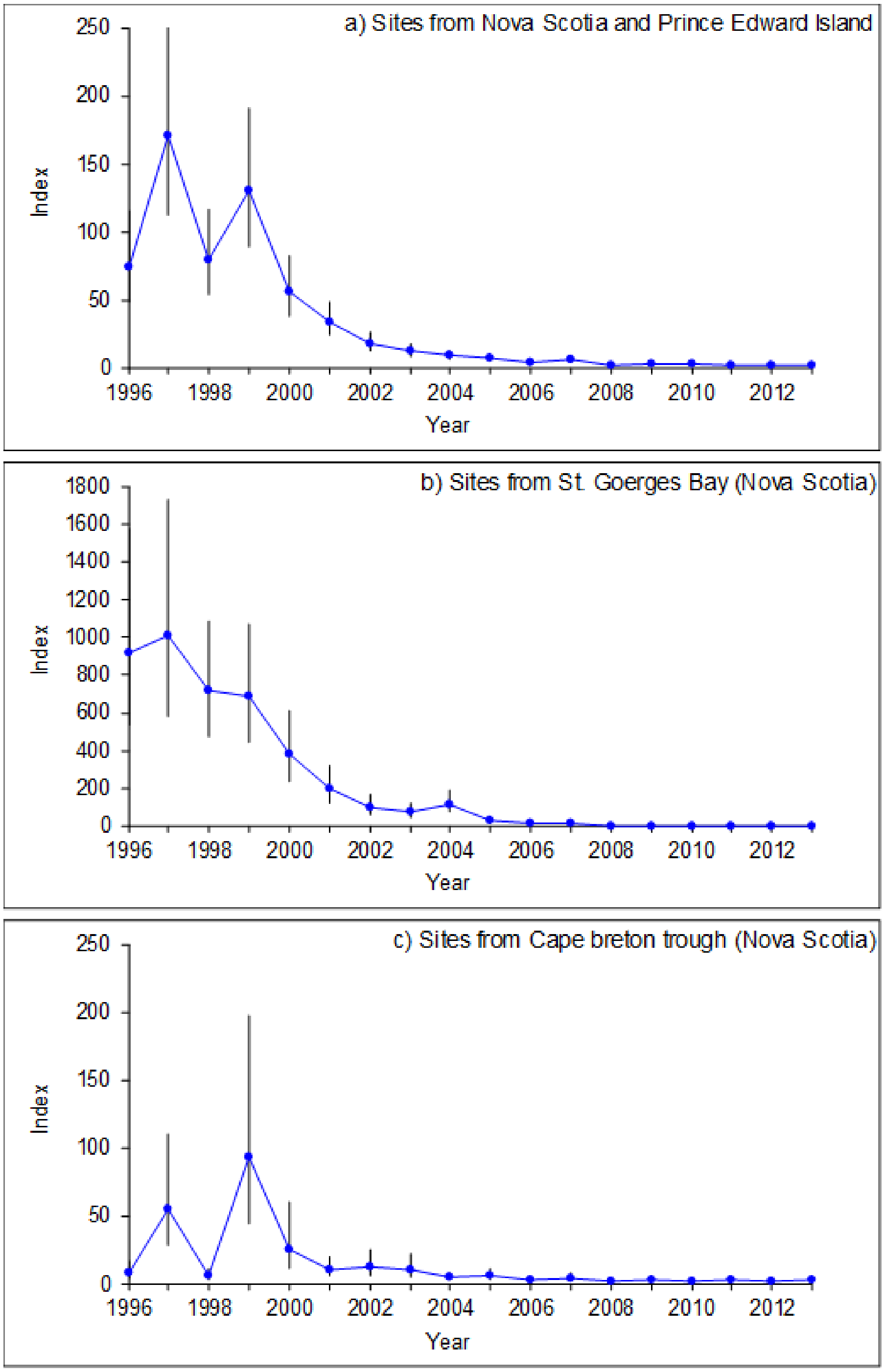

Figure 18. Standardized catch rate indices for longlines in the southern Gulf sentinel survey program (1996-2013) for three locations in the southern Gulf: a) sites from Nova Scotia and Prince Edward Island, b) sites from St. Georges Bay Nova Scotia, and c) sites from the cape Breton trough Nova Scotia. Vertical lines denote approximate 95% confidence limits (± 2 standard errors).

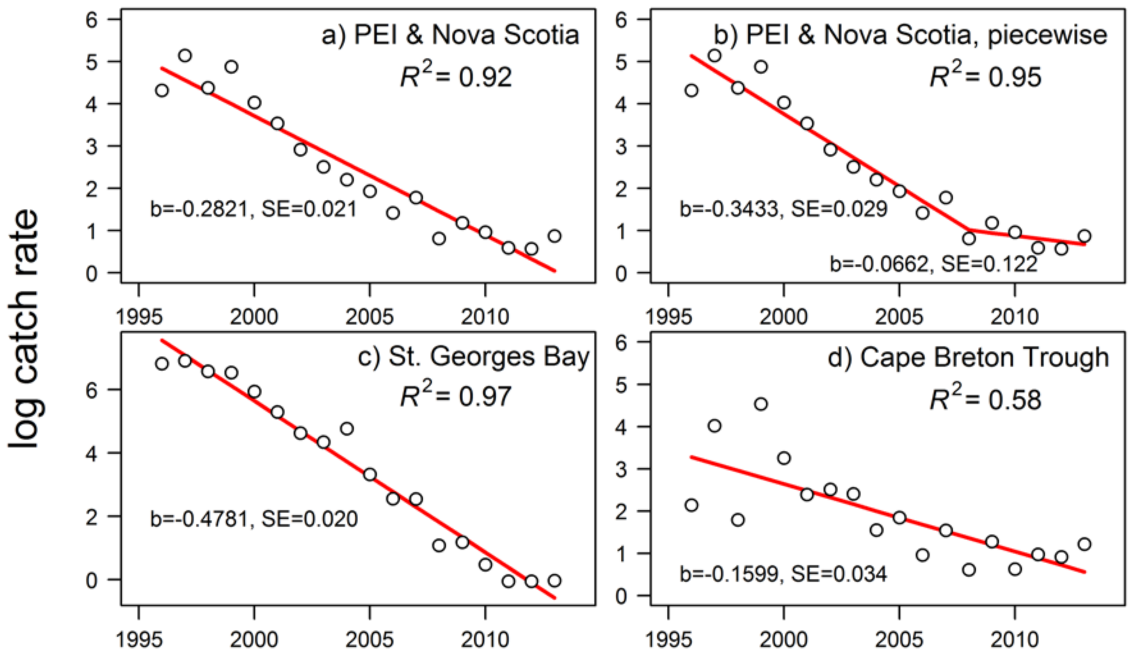

Figure 19. Decline rates in white hake abundance indices in selected regions fished by the longline sentinel program.

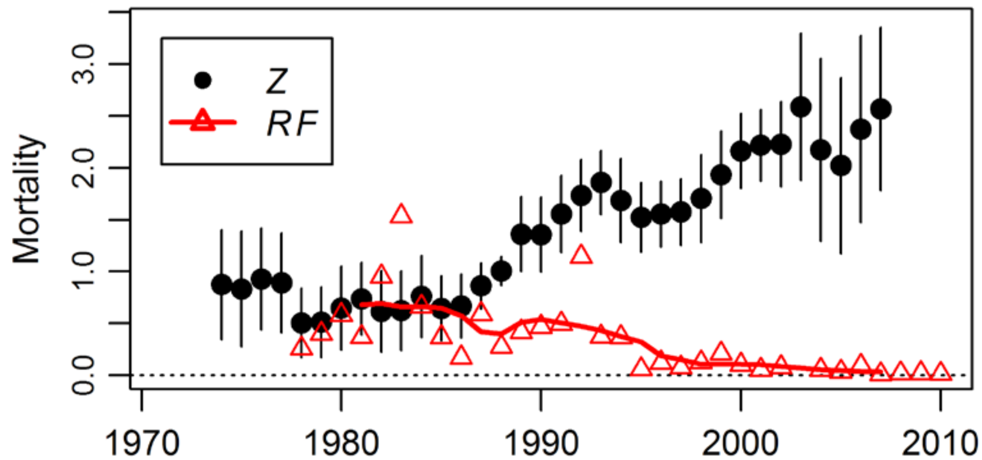

Figure 20. Relative fishing mortality (RF) and estimates of the instantaneous rate of total mortality (Z) for white hake (ages 5-7 years) in the southern Gulf of St. Lawrence. Estimates of Z are derived from catch rates at age in the RV survey (RV, closed circles), calculated in moving 7-year blocks, plotted at the center of each block. Vertical lines are ±2SE. RF is shown for individual years (red triangles) or averaged over the same blocks of years as Z (red line).

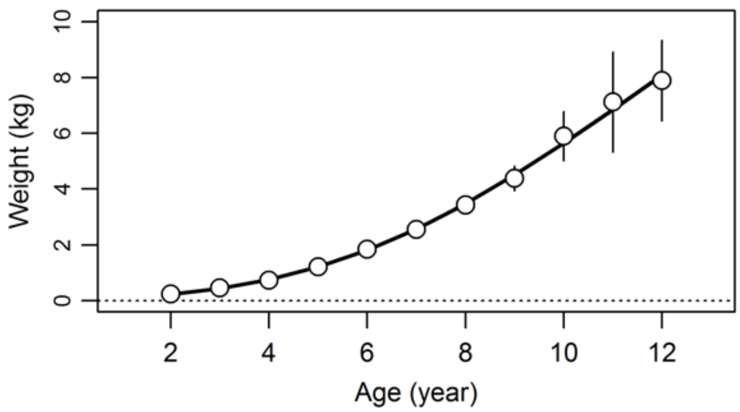

Figure 21. Age to weight (kg) relationship of white hake in September in the SGSL. Circles show the mean weights at age using all the individual measurements collected on the RV surveys (1971-2013). Vertical lines show ±2SE. Curve shows the Gompertz growth function fitted to data for ages 2 to 12 years.

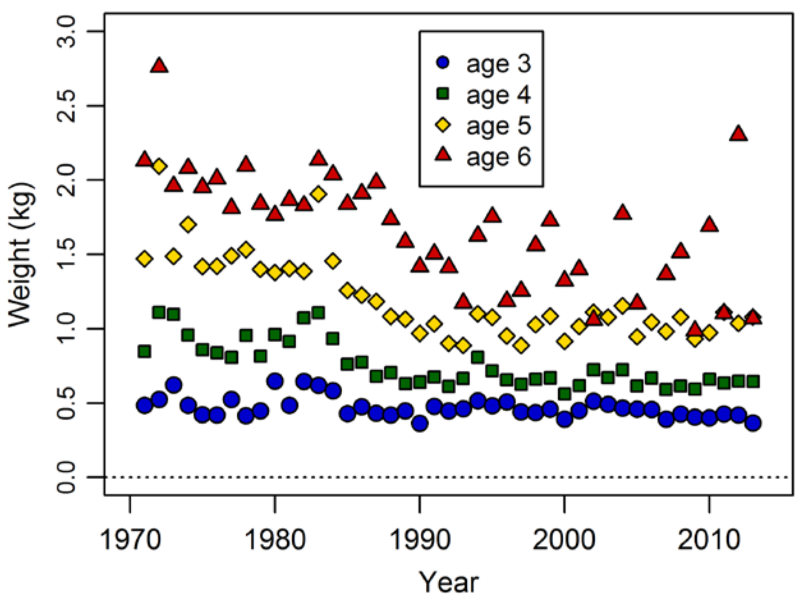

Figure 22. Stratified annual mean weights (kg) at ages 3 to 6 years of white hake collected during the September RV survey of the SGSL, 1971 to 2013.

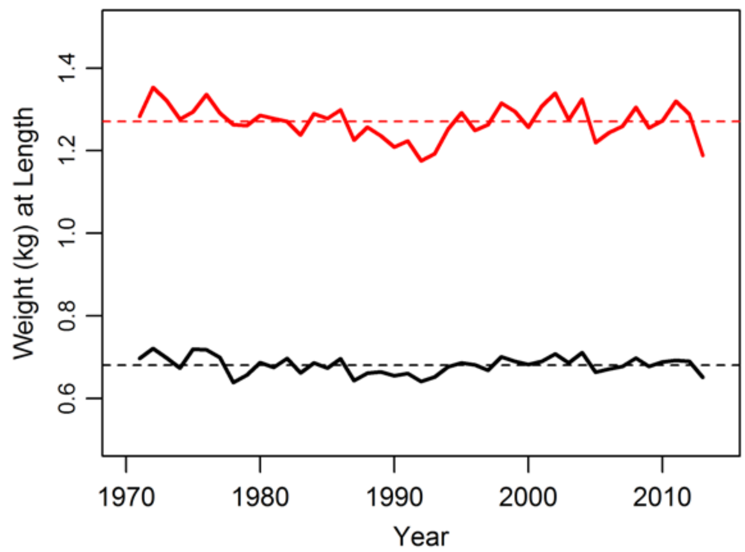

Figure 23. Indices of condition of SGSL white hake. The indices are the predicted weight at lengths of 45 cm (black solid line) and 55 cm (red solid line) long white hake, based on the parameters of the annual length-weight relationship. Dashed lines for each show the long-term mean.

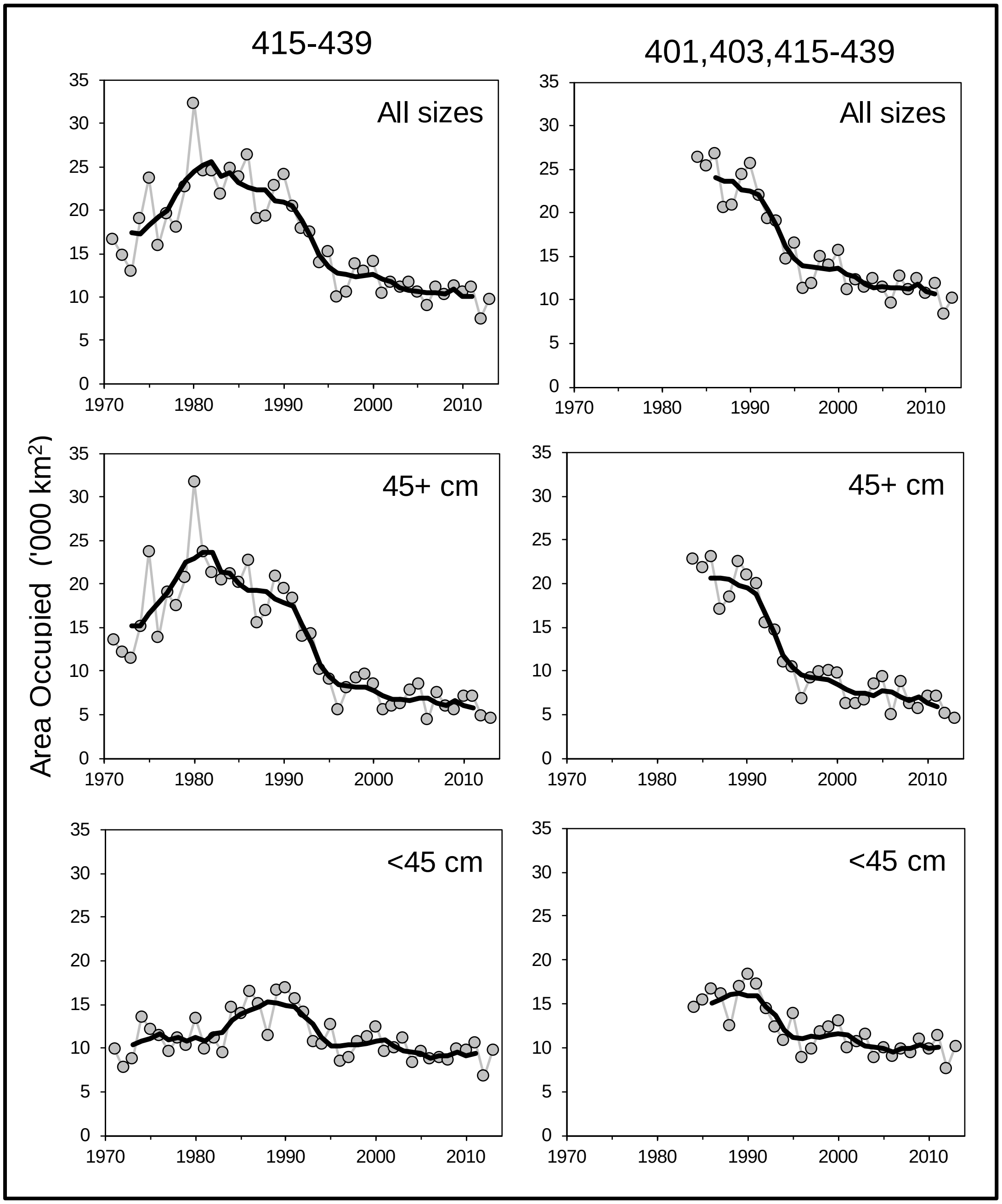

Figure 24. Area occupied by all sizes of white hake (upper row), by adult (45+ cm; middle row) white hake, and by juvenile (<45 cm) white hake based on catches in the September RV survey, 1971-2013. The left column shows area occupied for strata 415 to 439, surveyed since 1971 and the right column shows area occupied for strata 415 to 439 plus strata 401 and 403 surveyed since 1984. The heavy line is a 5-year moving average.

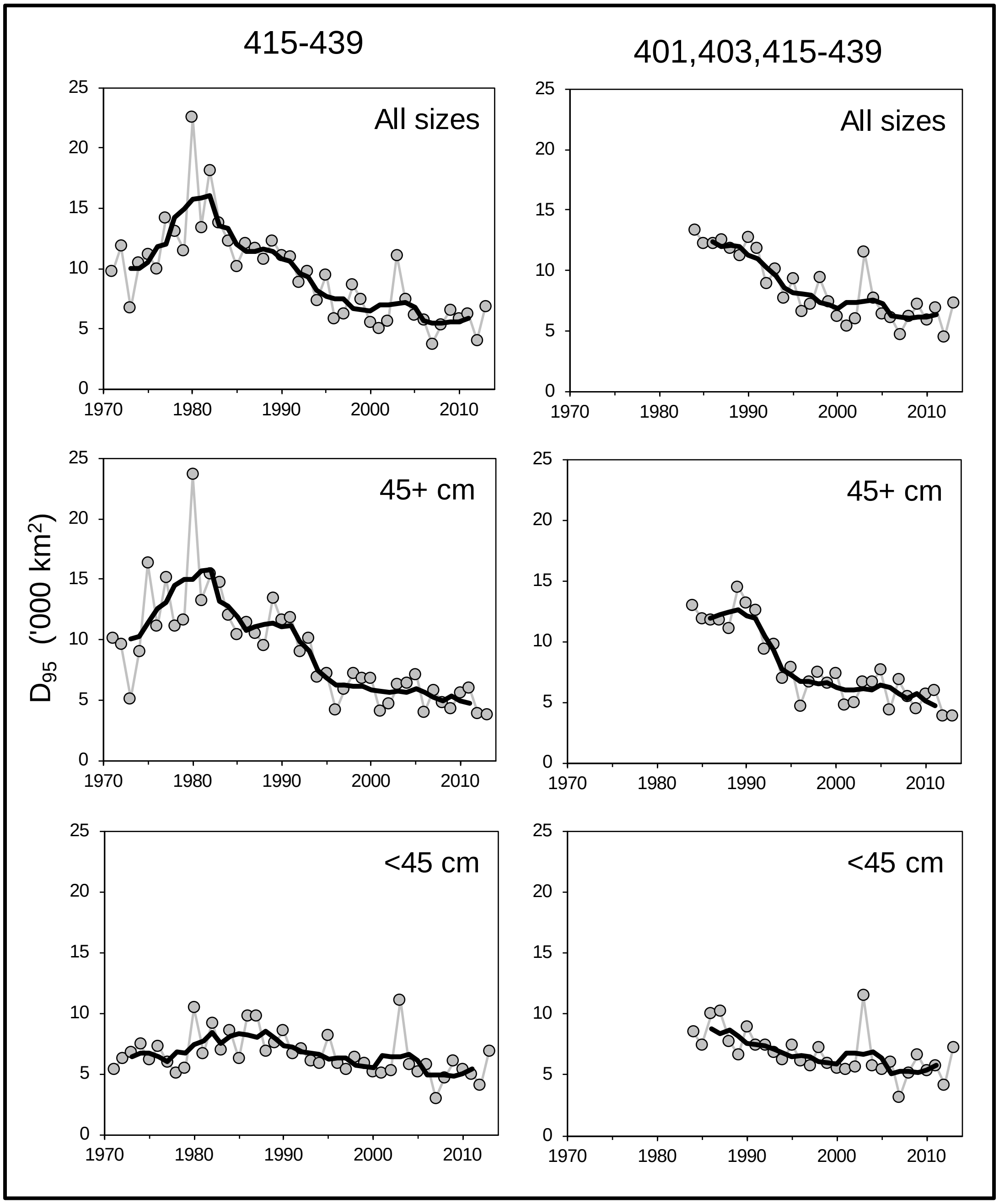

Figure 25. Time trend in the index of geographic range (D95) by all sizes of white hake (upper row), by adult (45+ cm; middle row) white hake, and by juvenile (<45 cm) white hake based on catches in the September RV survey, 1971-2013. The left column shows the index for strata 415 to 439, surveyed since 1971 and the right column shows the index for strata 415 to 439 plus strata 401 and 403 surveyed since 1984. The heavy line is a 5-year moving average.

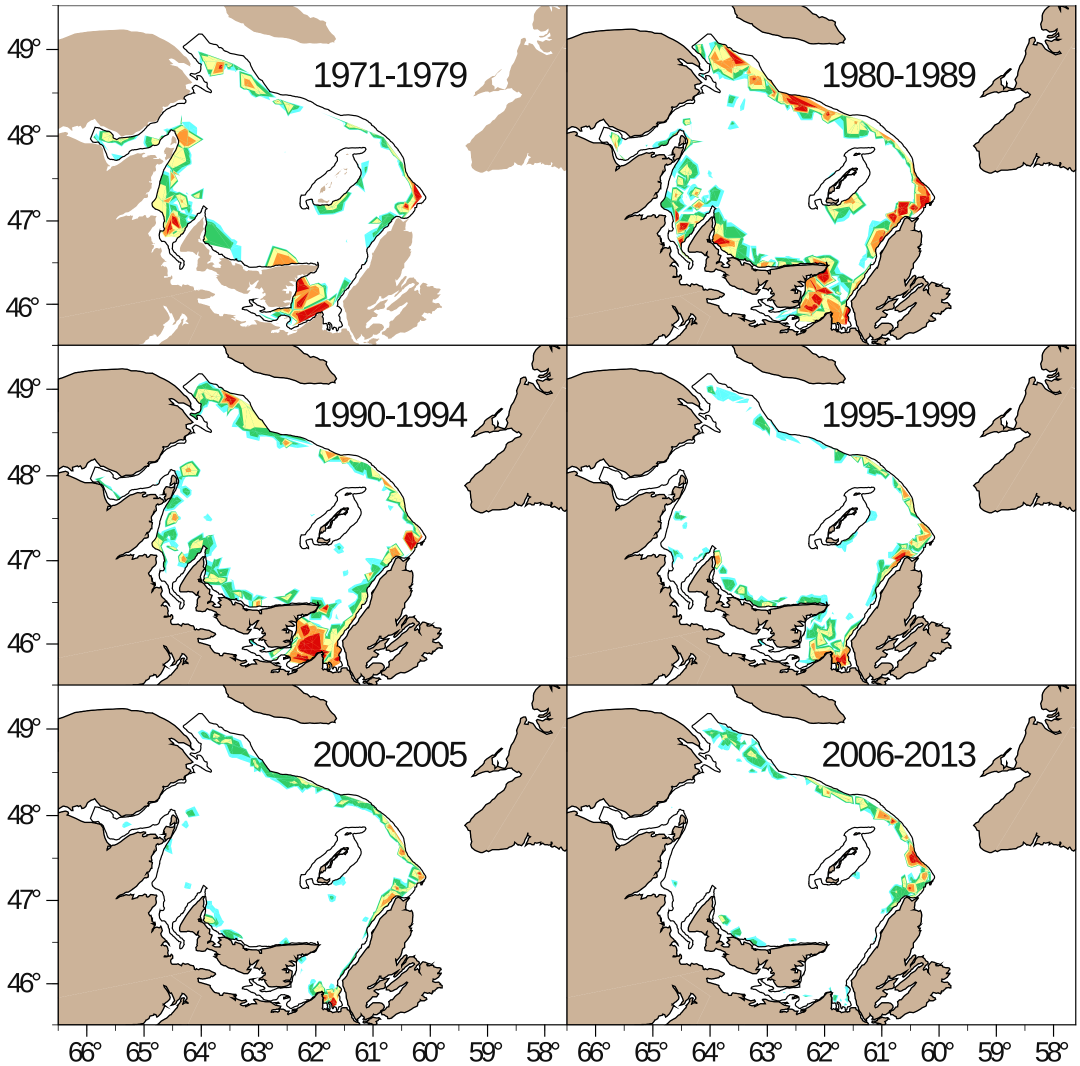

Figure 26. Geographic distribution of adult white hake (≥ 45 cm) in the southern Gulf of St. Lawrence in September by time period. Contour intervals are the 10th (blue), 25th (green), 50th (yellow), 75th (orange) and 90th (red) percentiles of the non-zero catch rates. Stratum 402 was excluded and strata 401 and 403 were not sampled in 1971-1983.

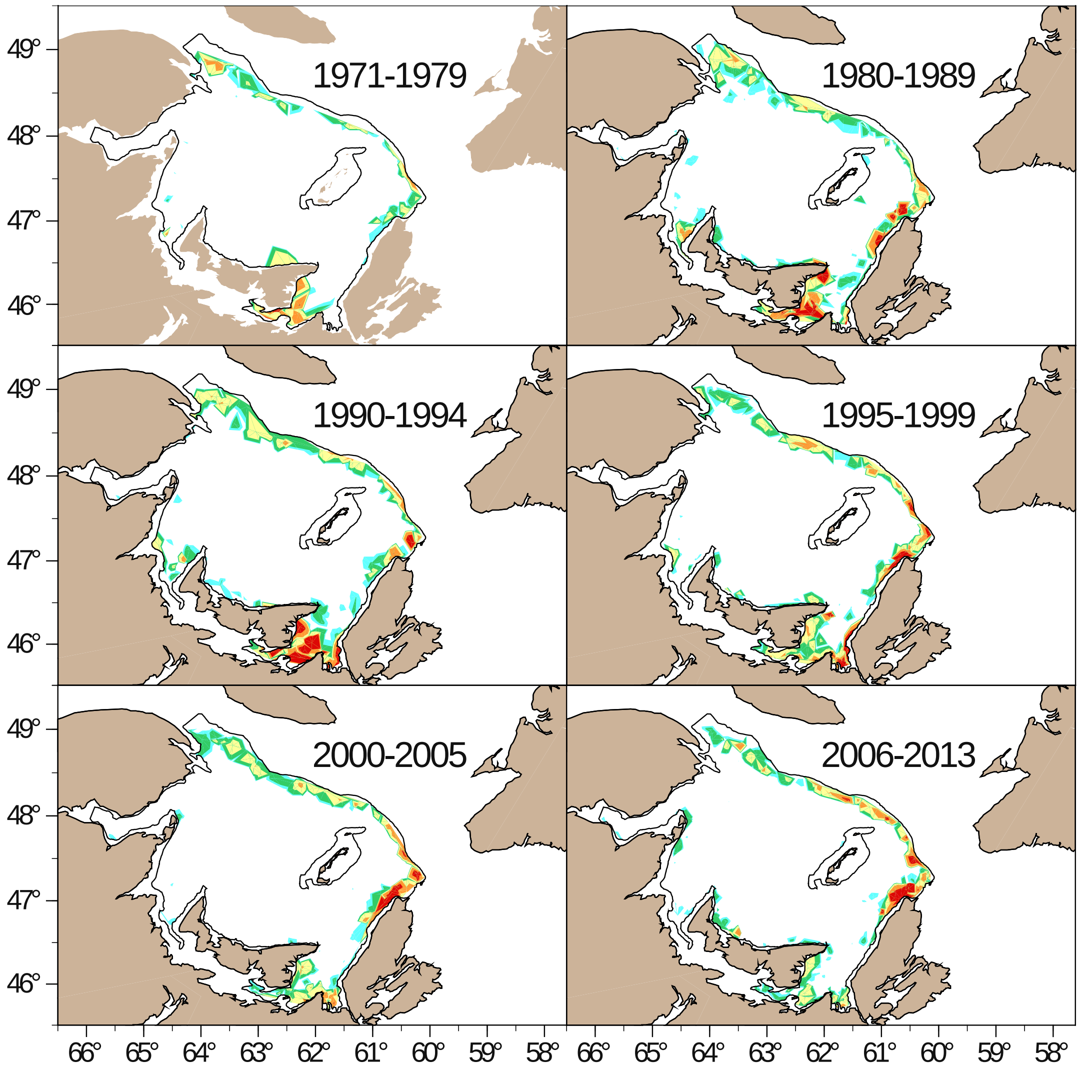

Figure 27. Geographic distribution of juvenile white hake (< 45 cm) in the southern Gulf of St. Lawrence in September by time period. Contour intervals are the 10th (blue), 25th (green), 50th (yellow), 75th (orange) and 90th (red) percentiles of the non-zero catch rates. Stratum 402 was excluded and strata 401 and 403 were not sampled in 1971-1983.

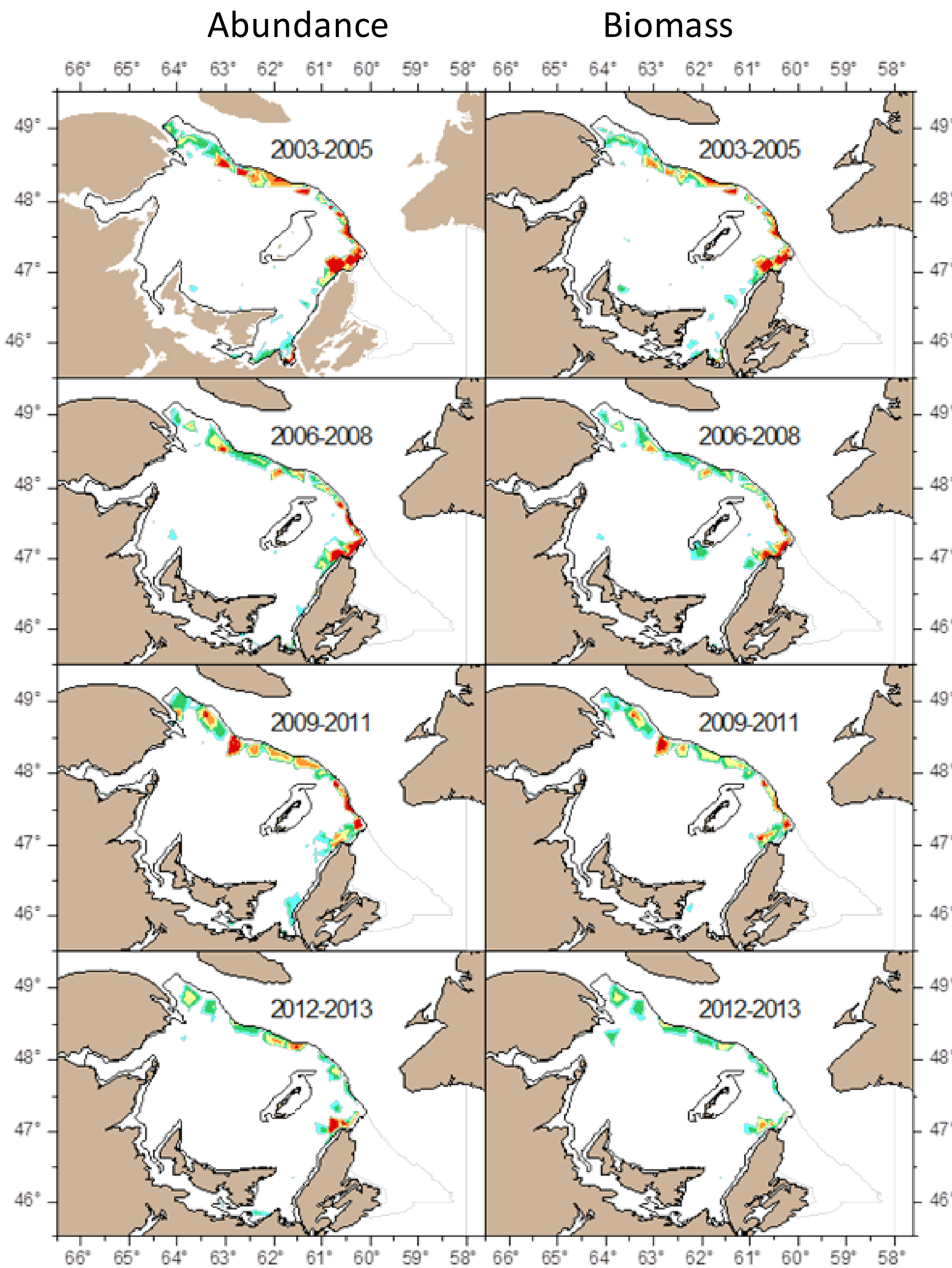

Figure 28. Geographic distribution of white hake (all sizes) in the southern Gulf of St. Lawrence in August by time period. Contour intervals are the 10th (blue), 25th (green), 50th (yellow), 75th (orange) and 90th (red) percentiles of the non-zero catch rates (fish per tow on left column and kg per tow on right column).

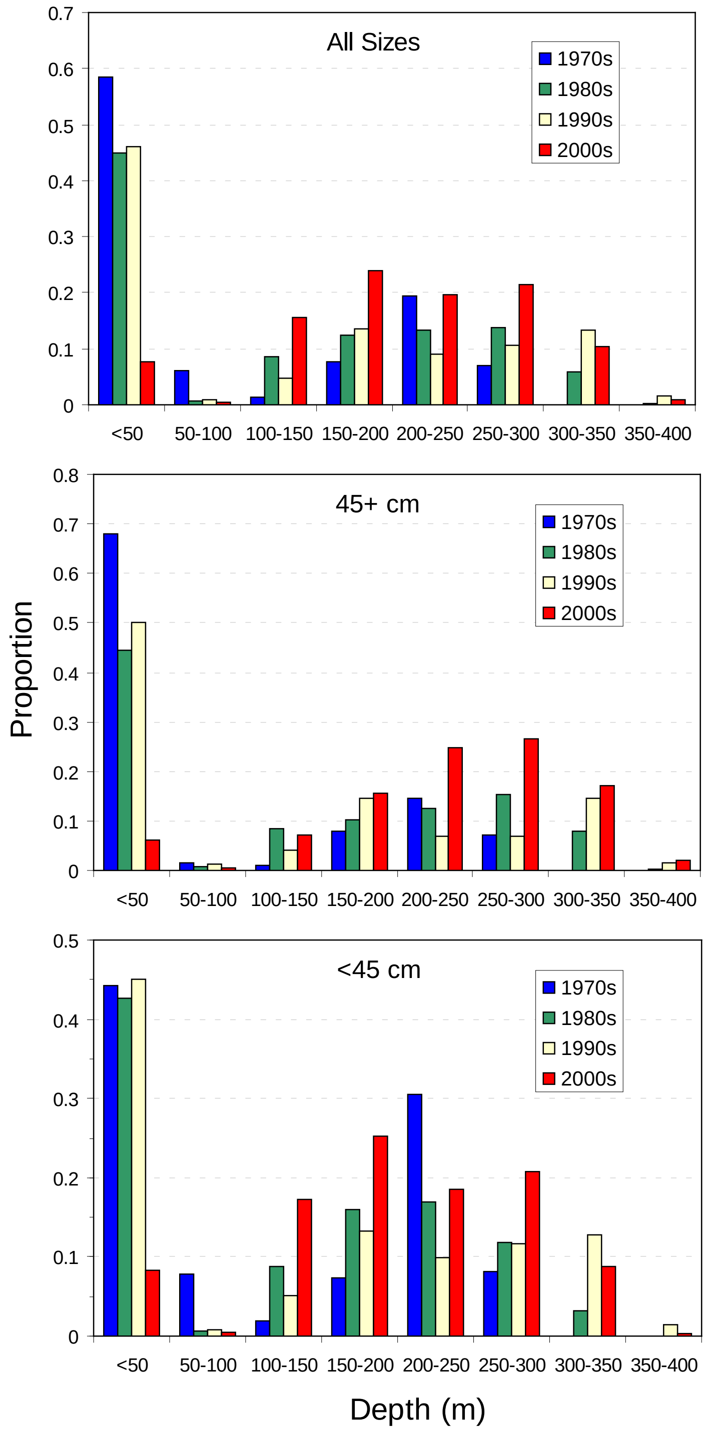

Figure 29. Proportion of catches of white hake in the September RV survey from the southern Gulf of St. Lawrence by depth interval, all sizes upper panel, adult white hake (>= 45 cm) in middle panel, and juvenile white hake (< 45 cm) in lower panel.

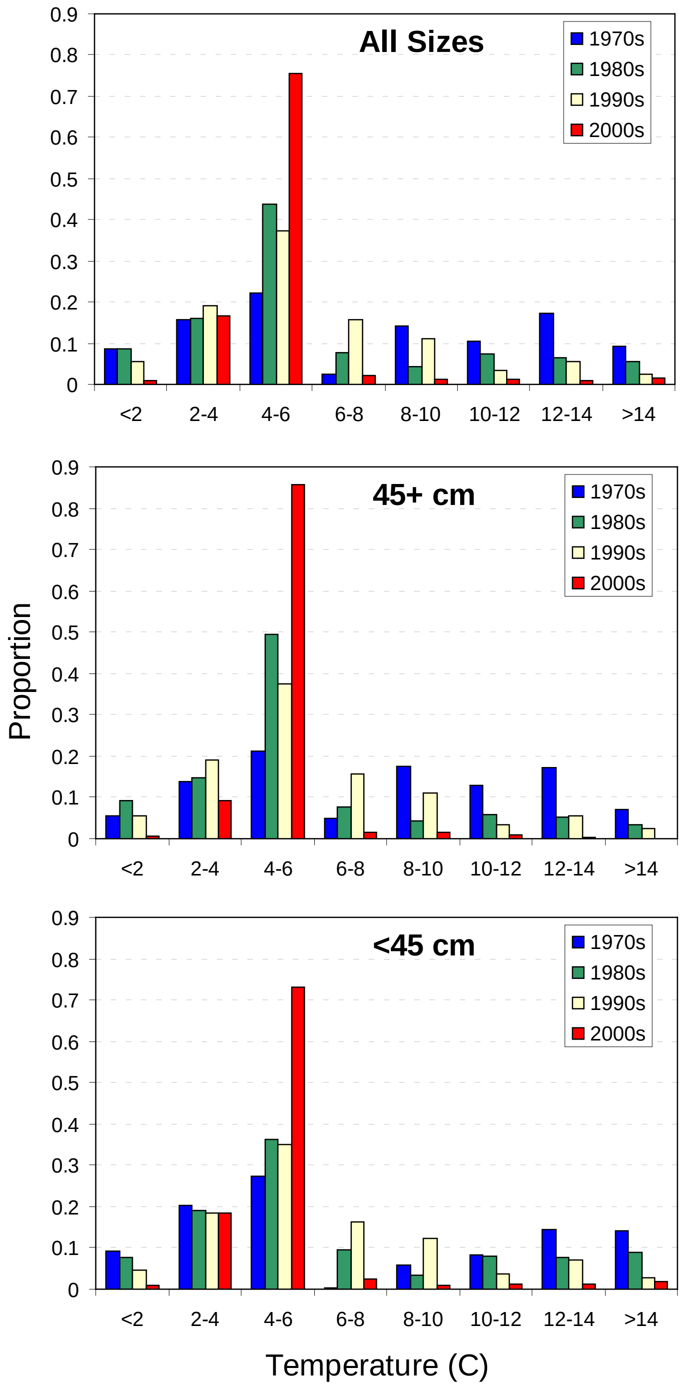

Figure 30. Proportion of catches of white hake in the September RV survey from the southern Gulf of St. Lawrence by temperature interval, all sizes upper panel, adult white hake (>= 45 cm) in middle panel, and juvenile white hake (< 45 cm) in lower panel.

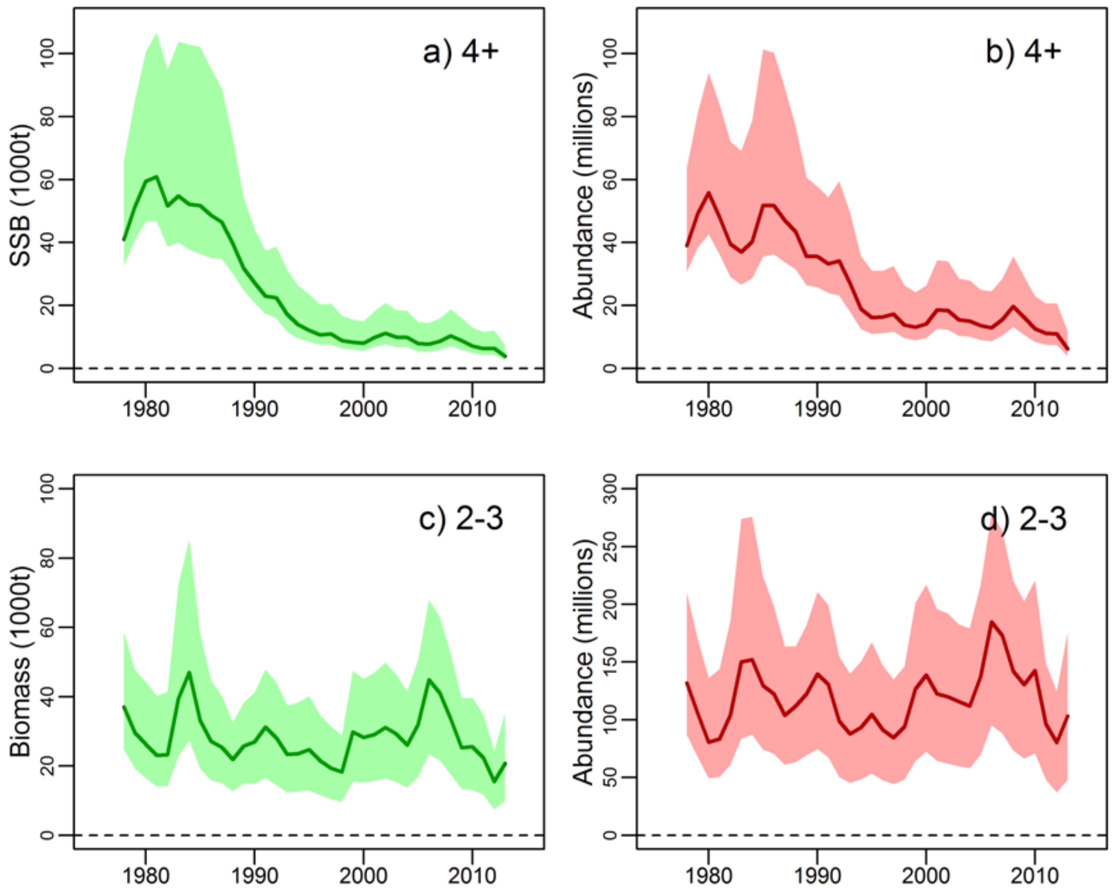

Figure 31. Estimated biomass (1000 t, left column) and abundance (millions, right column) of adult (panels a and b) and juvenile (panels c and d) white hake in the southern Gulf of St. Lawrence. Lines show the maximum likelihood estimates and shading their 95% confidence intervals based on MCMC sampling.

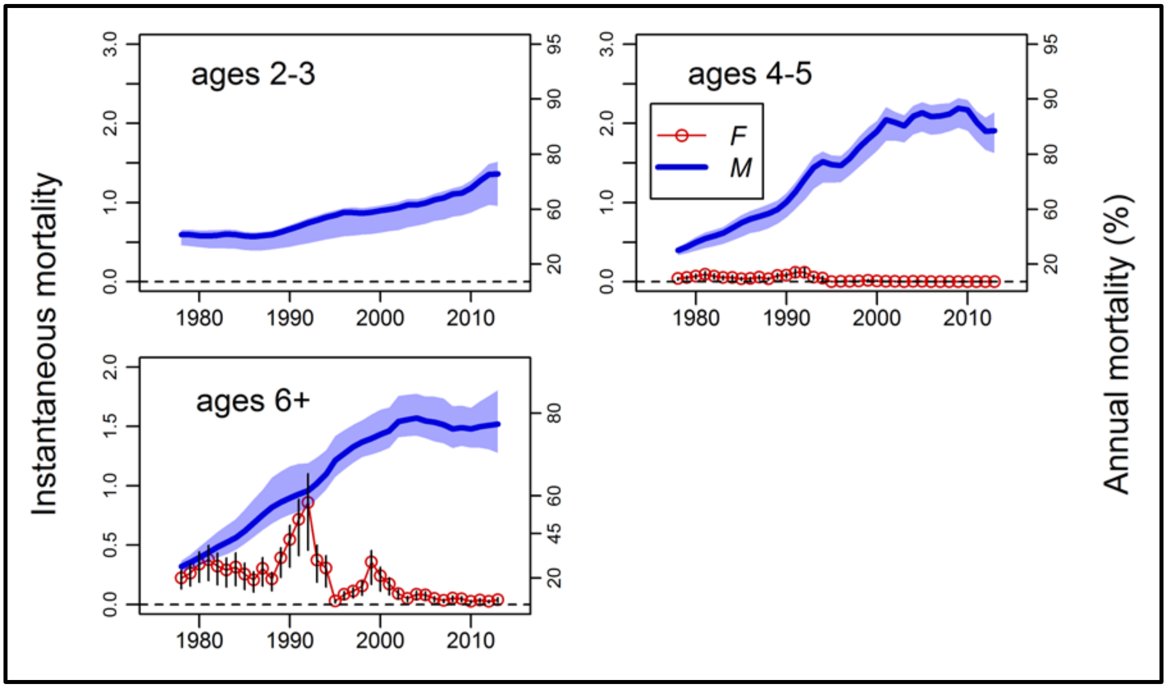

Figure 32. Estimated instantaneous rates of fishing and natural mortality (F and M, respectively) by age group (aages 2-3, ages 4-5, ages 6+). Blue lines and red circles show the maximum likelihood estimates. Shading and vertical lines show their 95% confidence intervals based on MCMC sampling. The right-hand axis shows the corresponding annual mortality. Average Fs for ages 2 and 3 are not shown since they were negligible (<0.001 in all years, < 0.00005 since 2000).

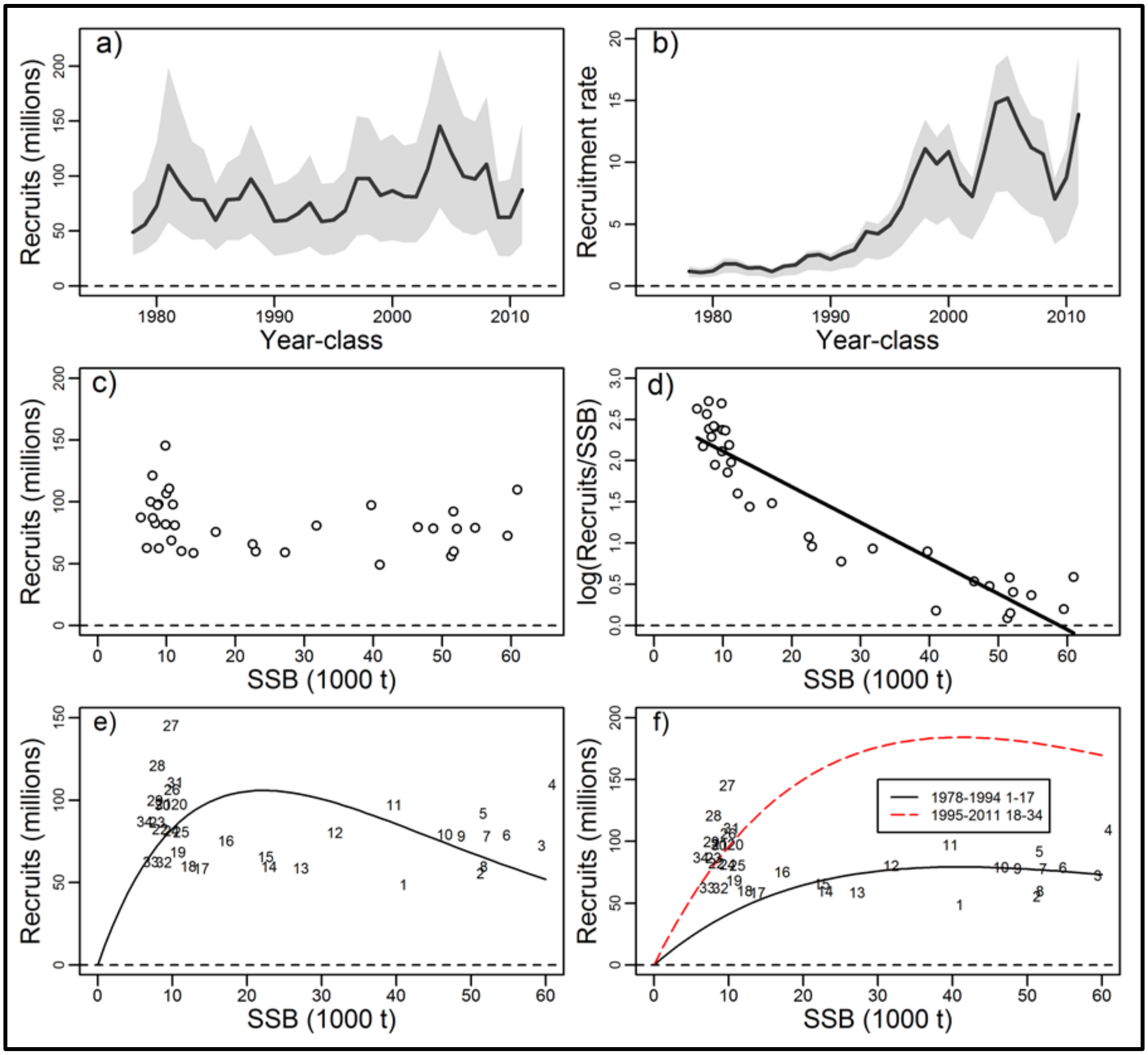

Figure 33. Stock and recruit relationship for SGSL white hake. Panel a) the estimated abundance of age-2 recruits by year-class. The line shows the maximum likelihood estimate and shading its 95% confidence interval. Panel b) recruitment rate (age-2 recruits/SSB) by year-class. Panel c) recruit abundance in relation to SSB.Panel d) log recruitment rate in relation to SSB. Line shows the fit of a "linearized" Ricker relationship to these data. Panel e) fit of a Ricker model to the stock-recruit data (symbols indicate year-class). Panel f) fit of a Ricker model with a common β parameter and separate α parameters corresponding to the 1978-1994 and 1995-2011 year-classes.

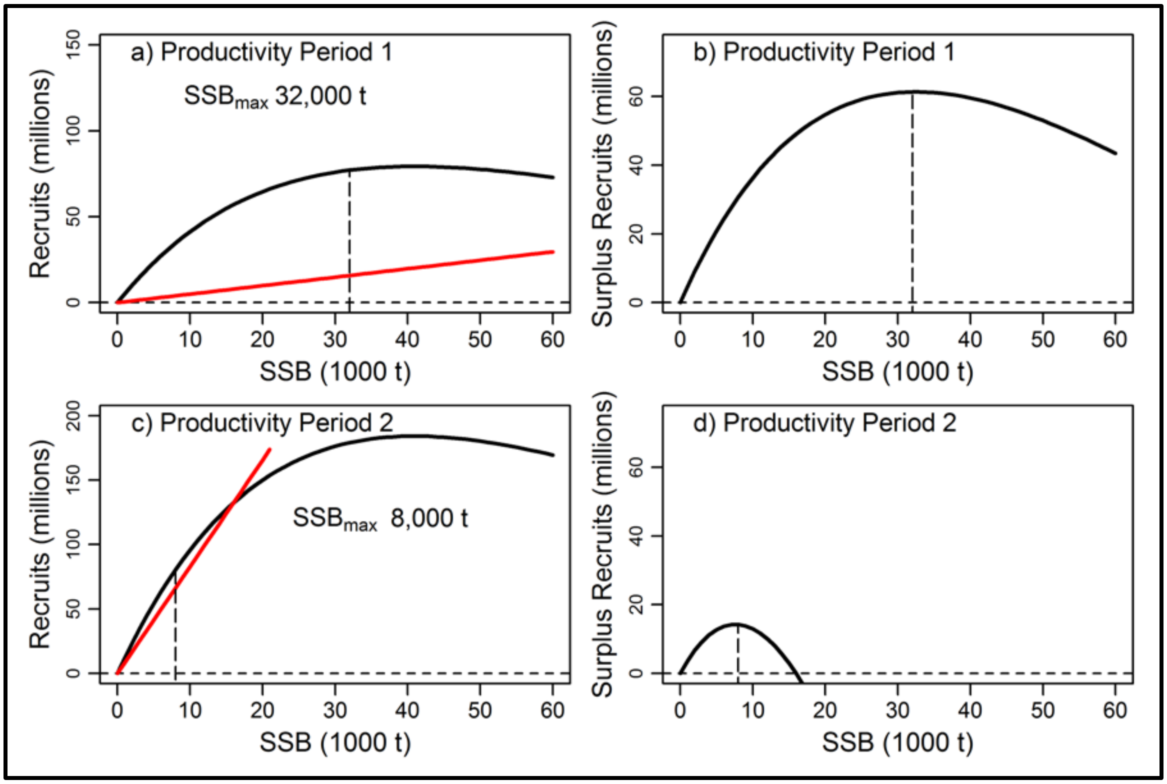

Figure 34. Surplus production of age-2 recruits in two productivity periods (period 1: 1978-1994, period 2: 1995-2013). In panels a and c, the black line is the stock-recruit relationship (model B) and the red line is the replacement line corresponding to the number of recruits required to replace the SSB given prevailing productivity conditions. In panels b and d, the black line is the surplus recruits produced at various levels of SSB. The vertical dashed lines denote the SSB producing the maximum number of surplus recruits.

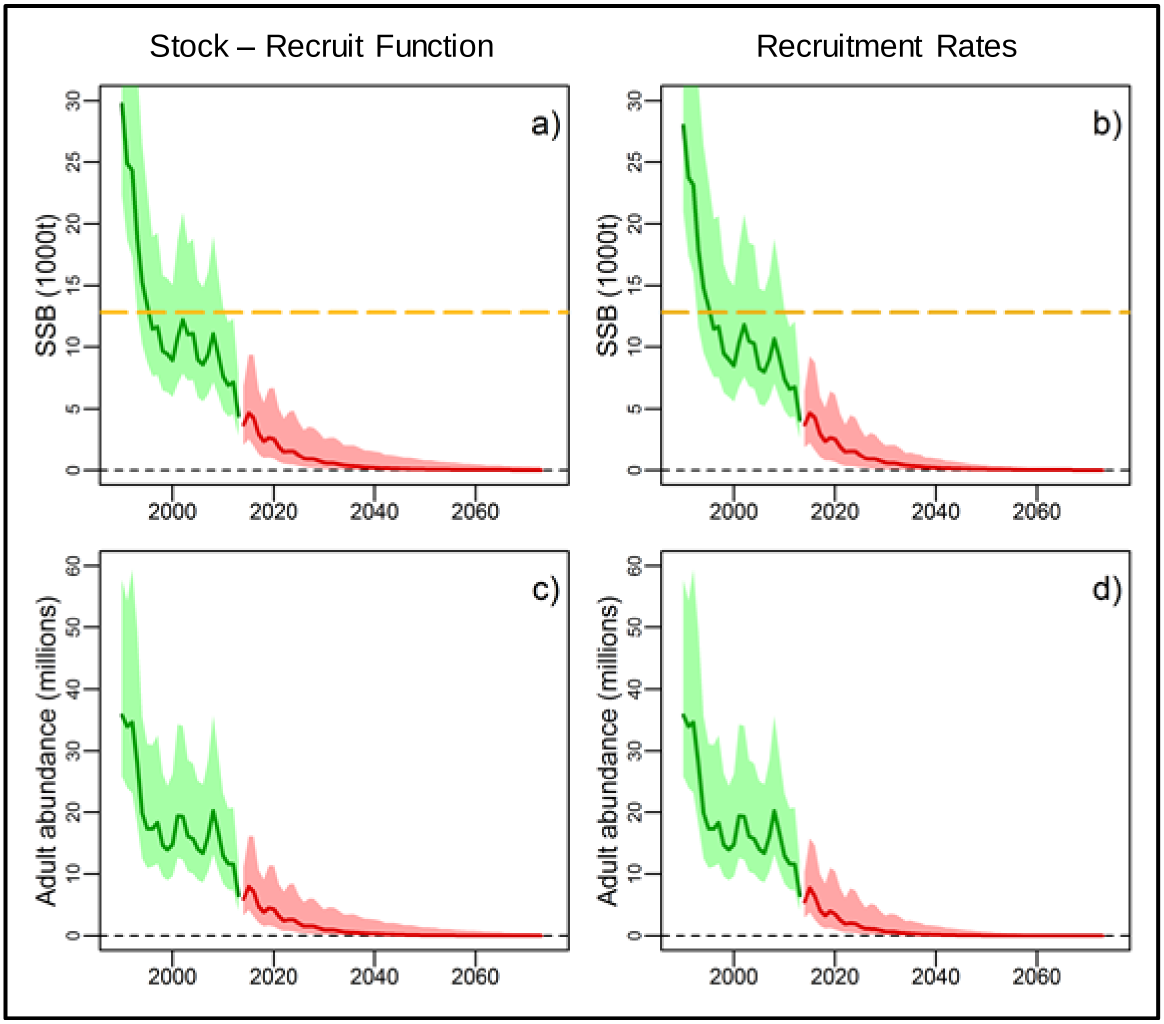

Figure 35. Projected spawning stock biomass (SSB; panels a and b) and adult abundance (millions, panels c and d) of southern Gulf of St. Lawrence white hake assuming current productivity and no fishing mortality. Projected recruitment was based on a stock-recruit relationship (panels a and c) or based on randomly selected recruitment rates from the high productivity period (1995-2013) (panels b and d). Green lines and shading show the median estimates and 95% confidence bands for the recent past, and red lines and shading show the median values and 95% confidence bands for the projection. The long dashed lines show the biomass recovery target (12,800 t).

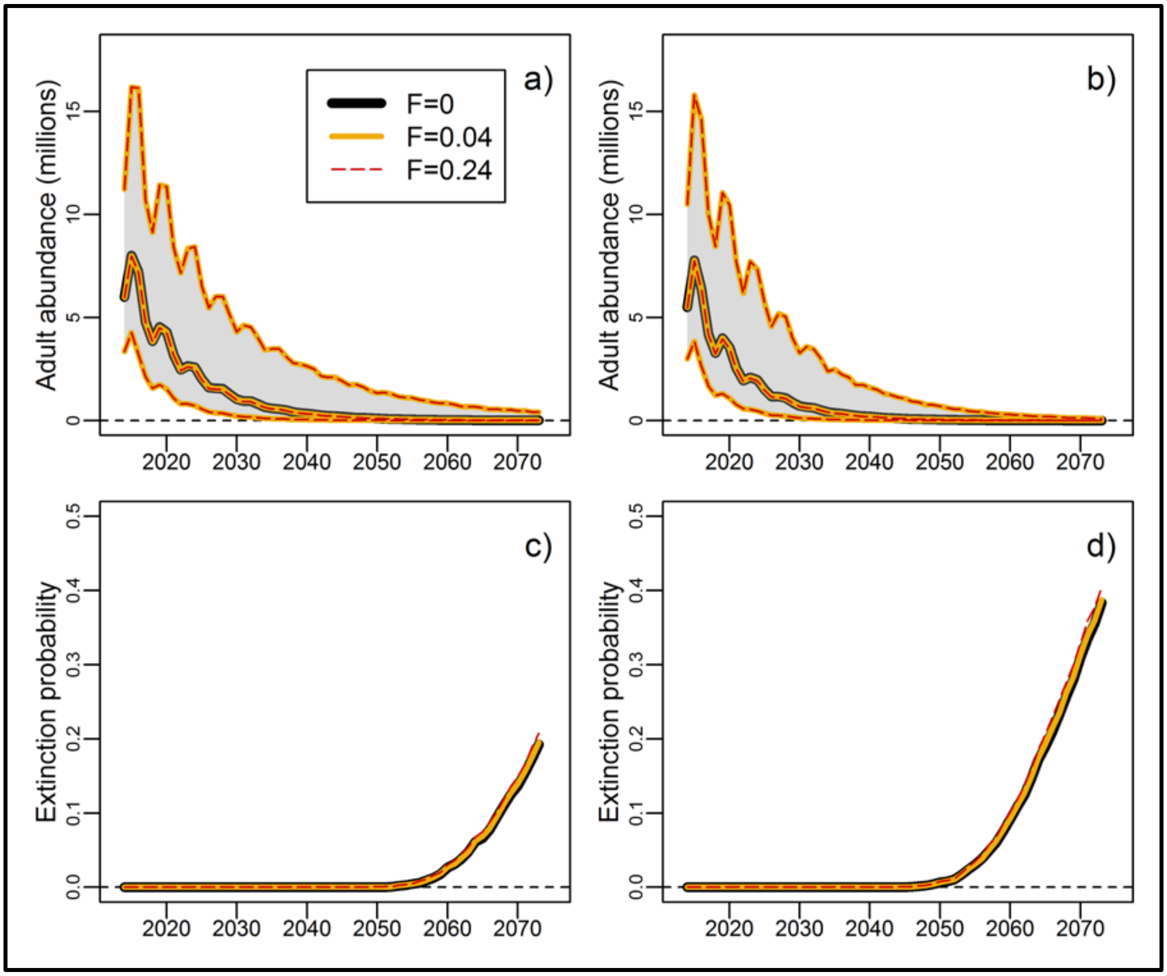

Figure 36. Projected adult abundance (millions; panels a and b) and extinction probability (panels c and d) of southern Gulf of St. Lawrence white hake assuming current productivity and various levels of fishing mortality (F). Projected recruitment was based on a stock-recruit relationship (panels a and c) or based on randomly selected recruitment rates from the high productivity period (1995-2013) (panels b and d).In panels a and b, the median and 2.5th and 97.5th percentiles of the projected abundance are indicated by the thick black line and grey shading for F=0,and by the colored lines for higher F.

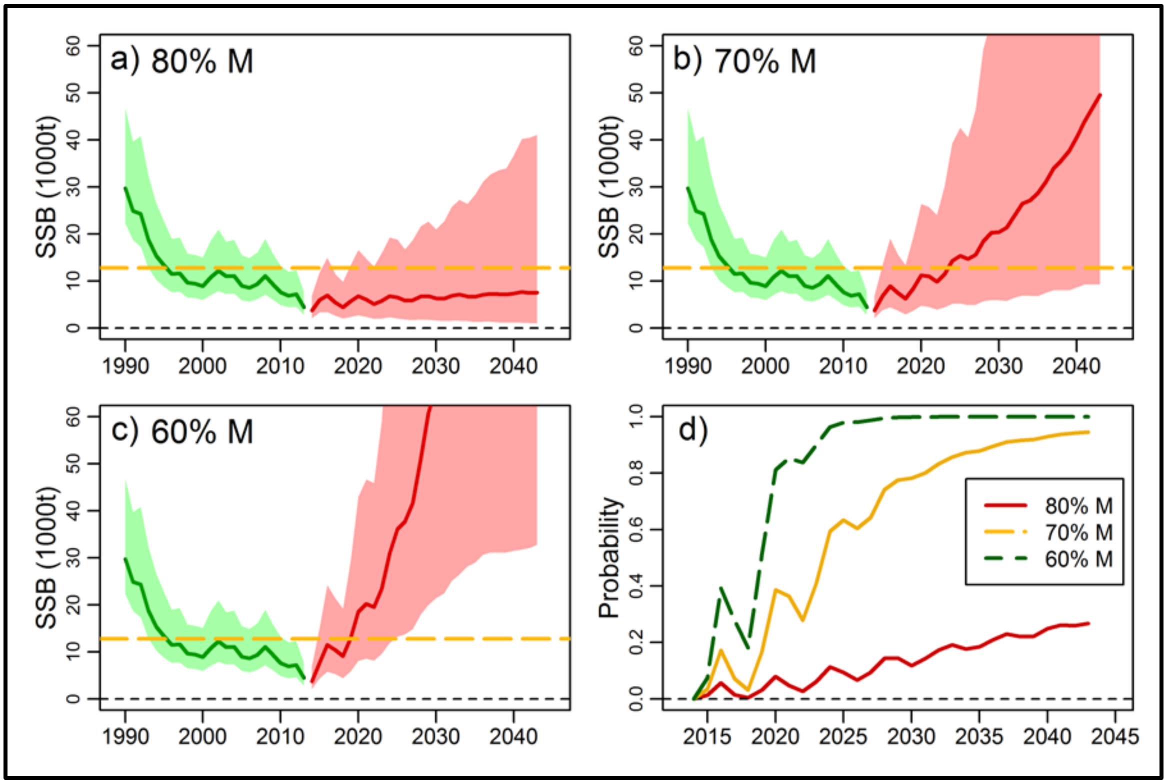

Figure 37. Projected spawning stock biomass of southern Gulf of St. Lawrence white hake (SSB in 1000 t; panels a to c) and the probability (panel d) of exceeding the recovery target (the long dashes in panels a to c) at reduced levels of M, assuming that recruitment productivity was to remain at the current high level. Green lines and shading show the median estimates and 95% confidence bands for the recent past, and red lines and shading show the median values and 95% confidence bands for the projection.

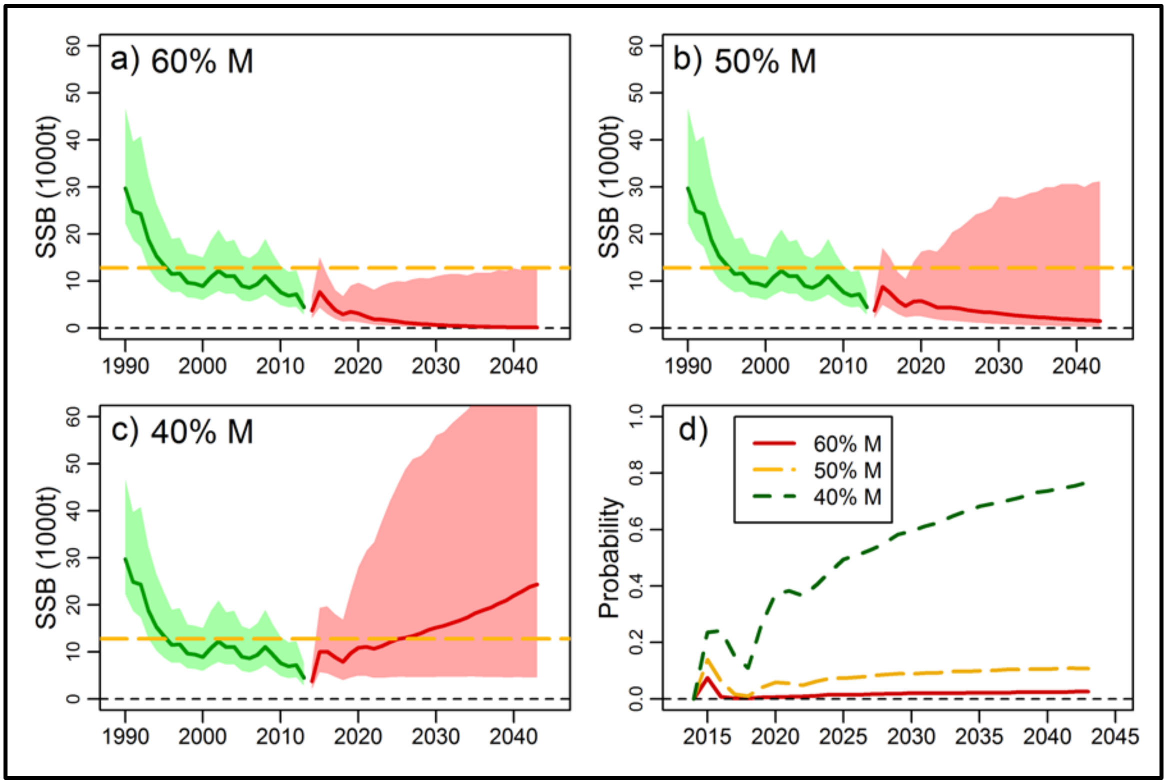

Figure 38. Projected spawning stock biomass (by 1,000 t) of SGSL white hake at differing levels of M (panels a to c) and the probability of exceeding the recovery target for differing levels of M (panel d) assuming that recruitment productivity were to return to its earlier low level. In panels a to c, the long dashed horizontal line is the abundance recovery target, the green lines and shading show the median estimates and 95% confidence bands for the recent past, and the red lines and shading show the median values and 95% confidence bands for the projection.

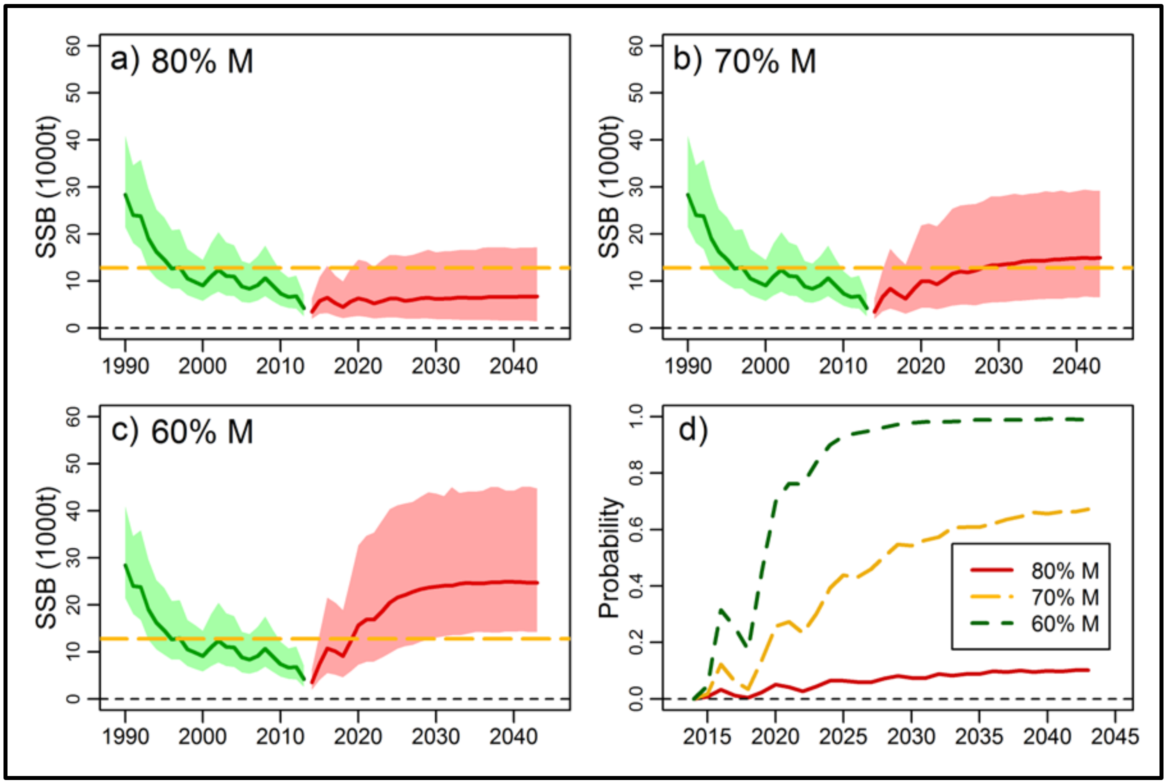

Figure 39. Projected spawning stock biomass (by 1,000 t) of SGSL white hake at differing levels of M (panels a to c) and the probability of exceeding the recovery target for differing levels of M (panel d) assuming a stationary stock-recruit relationship. In panels a to c, the long dashed horizontal line is the abundance recovery target, the green lines and shading show the median estimates and 95% confidence bands for the recent past, and the red lines and shading show the median values and 95% confidence bands for the projection.

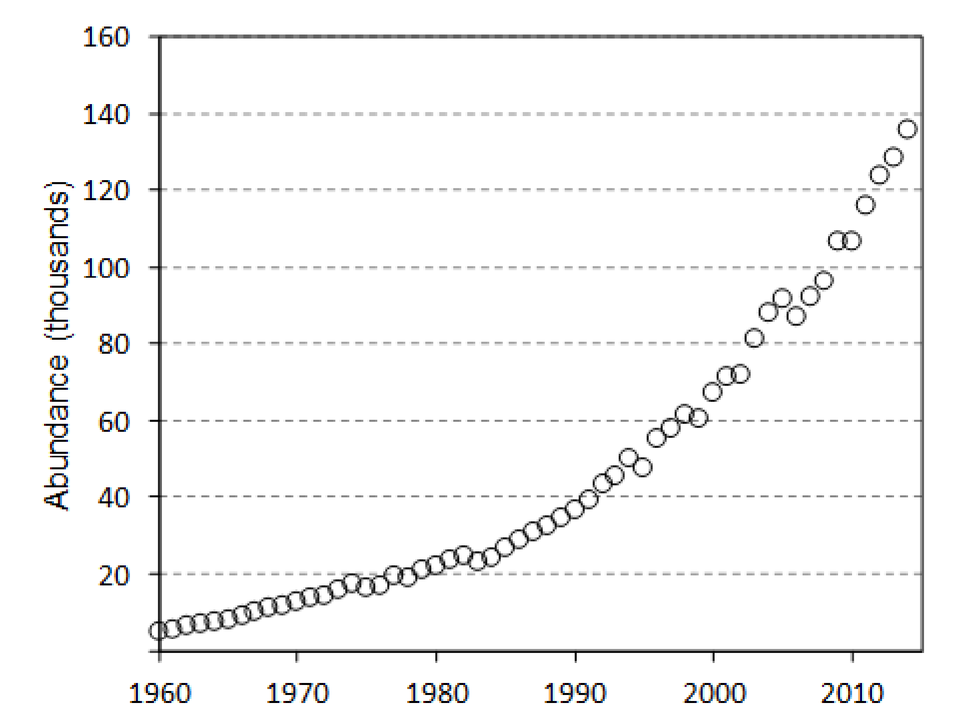

Figure 40. Estimated abundance (in thousands) of grey seals foraging in the southern Gulf of St. Lawrence.

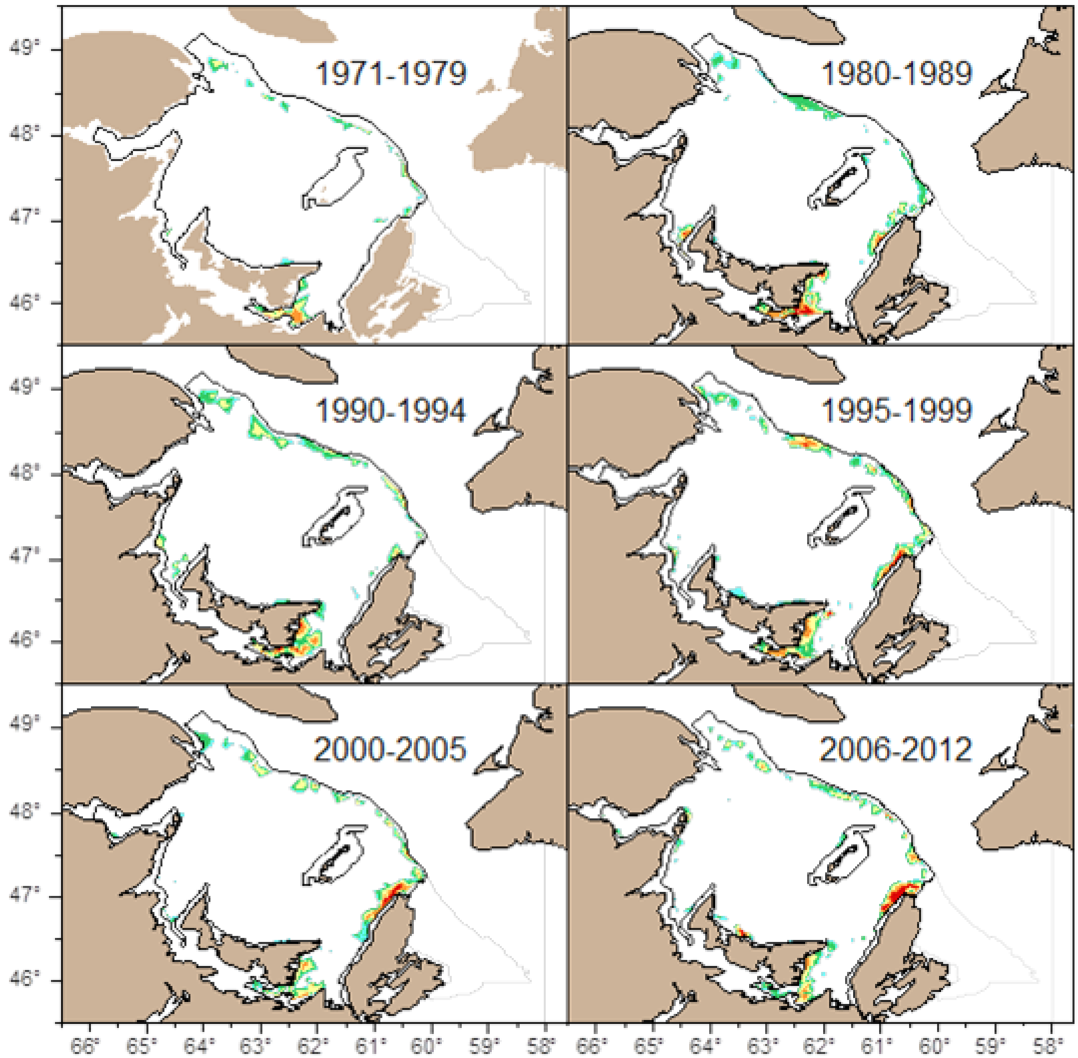

Figure 41. Spatial distributions of small (< 33 cm) juvenile white hake in the southern Gulf of St. Lawrence in September by time period. Contours intervals are the 10th (blue), 25th (green), 50th (yellow), 75th (orange) and 90th (red) percentiles of the non-zero natural log transformed catch rates.

APPENDICES

APPENDIX 1. RESULTS IN RELATION TO THE TERMS OF REFERENCE

Biology, Abundance, Distribution and Life History Parameters

Element 1: Summarize the biology of White Hake (*Urophycius tenuis*).

White hake are highly fecund (Beacham and Nepszy 1980). Their eggs are buoyant and generally occur in the upper water layer. They have an extended pelagic stage, with their eggs, larvae and pelagic juveniles remaining in the upper water layer for two to three months (e.g., Han and Kulka 2007).

In summer in the southern Gulf of St. Lawrence (SGSL), white hake have a bimodal distribution with respect to depth, occurring in shallow water in inshore areas and deep water offshore. In late fall, hake move into deep water in the Laurentian Channel, where they overwinter. Spawning in inshore areas occurs in summer, with a peak in June. Spawning is also thought to occur in deeper water in the Laurentian Channel in late winter and early spring. White hake in the SGSL are mature at lengths of 45 cm and greater and ages of 4 years and older. Assuming that the instantaneous rate of natural mortality (M) of adult hake is normally 0.2, generation time is estimated to be 9 years in the SGSL.

Element 2: Evaluate the recent species trajectory for abundance, distribution and number of populations.

<u>Abundance and biomass</u>

Abundance and biomass indices are available from a Research Vessel (RV) survey conducted each September since 1971. Adult abundance and biomass indices declined sharply between 1985 and 1995 and have remained at a low level since then. Based on the RV indices, the estimated decline in adult abundance from 1985 to 2014 (about 3 generations) was over 90%. Although most of this decline occurred between the mid-1980s and the mid-1990s, indices of adult abundance have tended to decline further since then. Abundance indices for juveniles have fluctuated without trend over the 1971-2014 period.

A sentinel bottom-trawl survey has been conducted in August in the SGSL since 2003. Age-aggregated abundance indices were at the lowest levels observed in 2011-2013. Standardized catch rates are available from a sentinel longline program since 1995. The estimated annual decline rate in this index corresponded to a 99% decline between 1995 and 2013. The estimated decline was greater in inshore areas (99.97% decline) than in offshore areas (93% decline).

Based on population models covering the 1978-2013 period, spawning stock biomass (SSB) and adult abundance declined by 93% and 87% respectively between 1978-1982 and 2013. Juvenile abundance and biomass fluctuated without trend over this period.

<u>Distribution</u>

Based on the September RV survey, the area occupied by adult hake increased from about 15,000 km^2 in the early 1970s to 25,000 km^2 in the early 1980s, declining to 5000 km^2 in recent years. The area occupied juvenile hake was near 10,000 km^2 in most years, except in the late 1980s and early 1990s when it was about 15,000 km^2.

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. Adult hake were most abundant in the inshore areas in the 1970s but their distribution has shifted out of these areas over time. In recent years, adult hake have been nearly absent from inshore areas. This change in distribution is thought to be due to increased risk of predation by grey seals in inshore areas.

Number of populations

White hake in the SGSL DU are genetically distinct from hake elsewhere in Atlantic Canada. In summer, white hake in the SGSL are separated into two groups, one occurring in waters shallower than 50 m and the second occurring at depths greater than 100 m. These two groups may reflect different spawning groups. Spawning occurs in inshore areas, most notably the St. Georges Bay area, in summer but also appears to occur in deeper water in the Laurentian Channel in late winter and early spring. At least one important inshore spawning ground, Baie Verte in the Northumberland Strait, has been abandoned since the late 1990s. With very few adult hake now occurring in inshore areas during the August and September surveys, it is possible that inshore spawning no longer persists in the SGSL.

Element 3: Estimate the current or recent life-history parameters for White Hake.

Growth and Condition

White hake are fast-growing. Mean weight at age decreased in the mid to late 1980s, fluctuating without trend since then. It is not known whether this change reflects decreases in growth rate or changes in size-selective mortality, or both.

Recruitment rate

Recruitment remains strong in this population despite very low SSB. This reflects very high recruitment rates over the past 20 years. These high recruitment rates may reflect strong compensation in the stock-recruit relationship (e.g., due to cannibalism), an ecosystem-wide increase in the survival of small fish (Benoît and Swain 2008), or a combination of the two.

Natural mortality

In most years, the dominant source of mortality for SGSL white hake has been natural (i.e., non-fishing) mortality. Estimated natural mortality increased from the late 1970s to the early 2000s. Since 2000, estimated natural mortality has averaged 87% annually for hake aged 4-5 years and 78% annually for hake aged 6+ years, about 2.5 to 3 times the estimated level in 1978. This unusually high natural mortality is the reason for the lack of recovery of this population despite negligible fishing mortality.

Habitat and Residence Requirements

Element 4: Describe the habitat properties that White Hake needs for successful completion of all life-history stages.

In summer in the SGSL, white hake occur in inshore areas with depths less than 50 m or offshore areas with depths greater than 100 m. The proportion of adult hake occurring in inshore waters decreased from an average of 68% in the 1970s to about 5% since 2000. The temperatures most frequently occupied by white hake in August and September are 4-6°C. The proportion of adult hake occupying this temperature bin increased from 20% in the 1970s to 85% in the 2000s. This reflected the shift in distribution out of warmer inshore waters and into deep water in the Cape Breton Trough and along the slope of the Laurentian Channel. Hake appear to consistently avoid waters with temperatures < 2°C.

The known spawning grounds of white hake in the SGSL are in inshore areas in summer, most notably the St. Georges Bay area. Other inshore spawning grounds occur in the Northumberland Strait, in particular the now abandoned Baie Verte spawning ground. However, spawning is thought to also occur over deep water in the Laurentian Channel in late winter or early spring.

Element 5: Provide information on the spatial extent of the areas of the distribution of White Hake that are likely to have these habitat properties.

Suitable habitat for hake is widespread in the SGSL at depths less than 50 m and greater than 100m. Given the broad distribution of waters suitable for white hake in the SGSL, habitat is not considered to be limiting for this population.

Element 6: Quantify the presence and extent of spatial configuration constraints, if any, such as connectivity, barriers to access, etc.

Although access to suitable habitat does not appear to be constrained by physical barriers, there may be biological barriers to access. Historically the majority of the population occupied shallow inshore waters in summer. These areas now appear to be largely abandoned, at least in August and September. This is thought to result from the very high risk of predation by grey seals that now exists in these inshore areas.

Element 7: Evaluate to what extent the concept of residence applies to the species, and if so, describe the species' residence.

SGSL white hake do not have any known dwelling-place similar to a den or nest during any part of their life.

Threats and Limiting Factors to the Survival and Recovery of White Hake

Element 8: Assess and prioritize the threats to the survival and recovery of White Hake.

At recent levels of effort, fishing no longer appears to pose an important threat to the survival and recovery of white hake in the SGSL DU. The directed commercial fishery has been closed since 1995. Bycatch in commercial fisheries for other groundfish species has declined to very low levels, averaging 18 t annually in 4T and 23 t in 4Vn in 2010-2013. (Only a portion of the 4Vn catch is of fish belonging to the SGSL DU.) Based on projections, the impact of recent levels of commercial fishing effort for groundfish on the white hake population trajectory is negligible at recent levels of population productivity.

Juvenile white hake (mostly less than or equal to 1 year of age) are caught in estuarine fisheries for smelt in the SGSL. Because recruitment rates are currently unusually high for hake, the impact of this fishery on pre-recruit abundance appears to be small.

Juvenile hake are also caught in the shrimp fishery, but the estimated bycatch is small (<2 t annually). Adult white hake are also incidentally captured in sGSL scallop and lobster fisheries. Catches are estimated to be very small in the scallop fishery and are thought to be small in the lobster fishery.

White hake are also caught by the recreational fishery for groundfish in 4T. Catches in this fishery are unknown, though anecdotal reports suggest negligible catches. Based on charter boat logs and 5% observer coverage, no catches of white hake have been recorded by the charter-boat fishery in 4T.

Oil and gas development is being considered at the Old Harry site in the Laurentian Channel. Spills or blow-outs from any such development are a risk to SGSL hake, which occupy waters adjacent to this site.

The main threat to the survival and recovery of the SGSL DU of white hake is unusually high natural mortality of adult hake. Predation by grey seals is considered an important cause of this high mortality.

Element 9: Identify the activities most likely to threaten (i.e., damage or destroy) the habitat properties identified in elements 4-5 and provide information on the extent and consequences of these activities.

Possible oil and gas development at the Old Harry site has the potential to damage or destroy overwintering habitat and offshore spawning grounds of SGSL white hake. The latter could have serious consequences for this population, particularly given the severely reduced use of the inshore areas where other spawning grounds occur.

Element 10: Assess any natural factors that will limit the survival and recovery of White Hake.

Unusually high natural mortality of adult hake is limiting the survival and preventing the recovery of this population. Predation by grey seals is considered to be a major cause of this mortality.

Element 11: Discuss the potential ecological impacts of the threats identified in element 8 to the target species and other co-occurring species. Identify existing monitoring efforts for the target species and other co-occurring species associated with each of the threats, and identify any knowledge gaps.

The main threat to this population is elevated natural mortality of adult hake, considered to be largely due to predation by grey seals. Predation by grey seals is also considered to be an important cause of elevated adult mortality of other large demersal fishes in the SGSL.

Fishing mortality is not considered to be an important threat at current levels of fishing effort. However, catches of hake in some invertebrate fisheries (i.e. lobster) and in the recreational fishery are unknown and constitute an important knowledge gap. Improved monitoring of bycatch of hake in the lobster fishery and hake catches in the recreational fishery is needed.

Recovery Targets

Element 12: Propose candidate abundance and distribution target(s) for recovery.

The proposed recovery target is the spawning stock biomass (SSB) equal to 40% of the SSB producing the maximum surplus production of recruits (i.e., recruits in excess of those needed to replace SSB under prevailing productivity conditions and in the absence of fishing). The recent period was considered inappropriate for deriving a recovery target due to the very high natural mortality of adults. Thus, calculations were based on productivity conditions in 1978-1994. The estimated target is 12,800 t of SSB.

In addition to a sustained increase in biomass to or above this target, recovery would require an expansion in age structure to include substantial frequencies of fish older than 7 years, as observed in the mid-1980s and earlier.

The return of hake to inshore waters of the SGSL, the areas where they predominantly occurred in summer in the past, is proposed as a distribution target for recovery. These inshore areas contain important spawning and feeding grounds for hake. It is not known whether the near absence of adult hake from these areas in August and September reflects a loss of this spawning component or hake continue to spawn in the inshore in June but move offshore to feed in later in the summer. If it is the former, the productive potential of this stock has been seriously compromised. The shift in summer distribution out of inshore areas appears to reflect large increases in the risk of predation by grey seals in these areas in the 1990s and 2000s. It is unlikely that hake will return to these inshore areas until predation risk in these areas is substantially reduced.

Element 13: Project expected population trajectories over a scientifically reasonable time frame (minimum of 10 years), and trajectories over time to the potential recovery target(s), given current White Hake population dynamics parameters.

The population was projected forward 60 years given current population dynamics parameters and no fishing mortality. Under these conditions, the population steadily declines over time, with no chance of achieving the potential recovery target (Fig. 35). By the end of the 60-yr projection, the probability of population extinction was 19% or 38%, depending on the stock-recruit relationship used in the projections.

Element 14: Provide advice on the degree to which supply of suitable habitat meets the demands of the species both at present and when the species reaches the potential recovery target(s) identified in element 12.

Given the broad distribution of waters suitable for white hake in the SGSL, the extent of habitat is not considered to be limiting for this population. On the other hand, much of this suitable habitat may no longer be available to white hake due to the high risk of predation by grey seals in inshore waters in summer and fall.

Element 15: Assess the probability that the potential recovery target(s) can be achieved under current rates of population dynamics parameters, and how that probability would vary with different mortality (especially lower) and productivity (especially higher) parameters.

The probability that the potential biomass recovery target can be achieved under the current high rate of natural mortality is essentially 0, even in the absence of any fishing mortality (Fig. 35).

Recruitment productivity has been high for SGSL white hake for the past 20 years (Fig. 33). Under this condition, the probability of achieving the biomass recovery target was estimated to be 27% 30 years after a reduction in natural mortality by 20% (Fig. 37). If natural mortality were reduced by 30%, this probability would be 41% in 10 years and 95% in 30 years. With a 40% reduction in natural mortality, this probability would be 51% in 6 years and 100% in 20 years.

If recruitment productivity were to return to the lower levels observed in the 1978-1994 period, even 50% reductions in natural mortality would be insufficient to halt the decline in the biomass of the adult population (Fig. 38). If natural mortality were reduced by 60%, the estimated probability of achieving the biomass target is 77% after 30 years at the reduced mortality level.

Assuming that the stock-recruit relationship is stationary (i.e., that there has been no extrinsic change in recruitment productivity over the past 36 years), the estimated probability of achieving the biomass target after 30 years at reduced M is 10% with a 20% reduction in M, 67% with a 30% reduction in M, and 99% with a 40% reduction in M.

Scenarios for Mitigation of Threats and Alternatives to Activities

Element 16: Develop an inventory of feasible mitigation measures and reasonable alternatives to the activities that are threats to the species and its habitat (as identified in elements 8 and 10).

The directed fishery for SGSL white hake has been closed since 1995. At current levels of fishing effort, bycatch of white hake in fisheries directing for other groundfish has a negligible impact on the population trajectory (Fig. 36). Thus, this activity now poses a negligible threat and no further mitigation is required as long as fishing effort remains at current levels.

White hake are caught in the recreational groundfish fishery and in the commercial fisheries for shrimp, lobster, scallop and possibly snow crab. Except for shrimp, catch in these fisheries is unknown but thought to be low. In particular, there is little overlap between the snow crab fishery and habitat that is suitable for white hake. Monitoring of bycatch in these fisheries is required in order to assess the level of threat posed by these activities and to develop mitigation scenarios if necessary. Bycatch in the shrimp fishery is restricted to juveniles, is very small (<2 t annually), and is considered to represent a negligible threat.

No mitigation measure for the threat posed by potential oil and gas development was identified.

Element 17: Develop an inventory of activities that could increase the productivity or survivorship parameters (as identified in elements 3 and 15).

The main current threat to the SGSL DU of white hake is unusually high natural mortality of adult hake. Predation by grey seals is considered an important cause of this high mortality. Reduction in the number of grey seals foraging in the SGSL would be expected to reduce the natural mortality rate of hake.

Element 18: If current habitat supply may be insufficient to achieve recovery targets (see element 14), provide advice on the feasibility of restoring the habitat to higher values. Advice must be provided in the context of all available options for achieving abundance and distribution targets.

Much of the suitable habitat for white hake appears to be unavailable due to the high risk of predation by grey seals in inshore areas in summer and fall. Reduction in the number of seals in these areas in these seasons may make these areas more available and may be required to achieve the distribution target.

Element 19: Estimate the reduction in mortality rate expected by each of the mitigation measures or alternatives in element 16 and the increase in productivity or survivorship associated with each measure in element 17.

Under current conditions (i.e., no directed fishing for white hake and low effort in other commercial fisheries for groundfish), the effects of further reductions in commercial fishing effort for groundfish are estimated to be negligible.

Bycatch of white hake in the recreational groundfish fishery and in commercial fisheries for scallop, lobster and snow crab is unknown. Given this knowledge gap, it is not possible to determine the impact of any mitigation measures involving these fisheries.

There is wide spatial, seasonal and individual variation in grey seal diets. It is not yet possible to obtain a reliable estimate of the average annual diet of grey seals. Thus, it is currently not possible to estimate the reduction in mortality expected to result from a given reduction in the number of seals foraging in the SGSL.

Element 20: Project expected population trajectory (and uncertainties) over a scientifically reasonable time frame and to the time of reaching recovery targets, given mortality rates and productivities associated with the specific measures identified for exploration in element 19. Include those that provide as high a probability of survivorship and recovery as possible for biologically realistic parameter values.

Reductions in known fishing mortality (i.e., that associated with landings in fisheries for groundfish) have a negligible impact on the population trajectory at current levels of fishing effort (Fig. 36).

Insufficient information currently exists to provide quantitative evaluations of other potential mitigation measures.

Element 21: Recommend parameter values for population productivity and starting mortality rates and, where necessary, specialized features of population models that would be required to allow exploration of additional scenarios as part of the assessment of economic, social, and cultural impacts in support of the listing process.

The statistical catch at age model accepted in the review of this RPA is recommended for exploration of additional scenarios. Uncertainty needs to be incorporated in the exploration.

Recommended population dynamics parameters are:

- starting values for the instantaneous rate of natural mortality:
    - ages 2-3: 1.21 (95% CI: 0.96 – 152),
    - ages 4-5: 1.87 (95% CI: 1.62 – 2.14), and
    - ages 6+: 1.52 (95% CI: 1.28 – 1.81).
- stock-recruit relationship: Model B in Table 10.

Allowable Harm Assessment

Element 22: Evaluate maximum human-induced mortality and habitat destruction that the species can sustain without jeopardizing its survival or recovery.

Catches associated with commercial fisheries directing for groundfish have a negligible impact on the population trajectory at recent levels of fishing effort. Recent levels of fishing effort result in instantaneous rates of fishing mortality for fully-recruited fish of 0.24 (1998-2002) to 0.04 (2009-2013).

APPENDIX 2. AGE-LENGTH KEYS USED TO UPDATE THE FISHERY CATCH-AT-AGE

Table A2.1. Specifics of the age-length keys that were used in the calculation of the catch-at-age for white hake in NAFO Division 4T, 2001 to . Gear type abbreviations are as follows: OTB = Otter Trawl, SNU = Seine, GN = Gillnet, LL = Longline, LHP = Handline. For each year, the corresponding research vessel mission the length / weight coefficients (a and b) for the sexes combined used to translate lengths to weight and are shown.

Year	Key	Fishery and period	Samples	Total samples	Landings (t)
2001 N045 a = 0.003667 b = 3.190280	1	GN - Bycatch & Sentinel Survey Jan. - Dec.	GN - Bycatch & Sentinel Survey Jan. - Dec. Lengths	1,595	29.692
			GN & LL - Bycatch & Sentinel Survey Jan. - Dec. Ages	1,039	
	2	LL & Handline – Bycatch Jan. - Dec.	LL – Bycatch Jan. - Dec. Lengths	335	32.655
			LL - Bycatch & Sentinel Survey Jan. - Dec. Ages	823	
	3	LL - Sentinel Survey Jan. - Dec.	LL - Sentinel Survey Jan. - Dec. Lengths	19,815	27.581
			LL - Bycatch & Sentinel Survey Jan. - Dec. Ages	823	
	4	OTB/SNU - Bycatch & Sentinel Survey Jan. - Dec. (No Liners)	OTB/SNU - Bycatch & Sentinel Survey Jan. - Dec. Lengths (No Liners)	614	31.072
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages (No Liners)	1,283	
	5	OTB/SNU - Sentinel Survey Jan. - Dec. (Liners)	OTB/SNU - Sentinel Survey Jan. - Dec. Lengths (Liners)	376	0.228
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages (No Liners)	1,283	
2002 N251 a = 0.003896 b = 3.181022	1	GN - Bycatch & Sentinel Survey Jan. - Dec. (Large Mesh)	GN - Bycatch & Sentinel Survey Jan. - Dec. Lengths (Large Mesh)	1,406	9.775
			GN & LL - Bycatch & Sentinel Survey Jan. - Dec. Ages	598	

Year	Key	Fishery and period	Samples	Total samples	Landings (t)
	2	GN - Bycatch & Sentinel Survey Jan. - Dec. (Small Mesh)	GN - Bycatch & Sentinel Survey Jan. - Dec. Lengths (Small Mesh)	319	0.338
			GN & LL - Bycatch & Sentinel Survey Jan. - Dec. Ages	598	
	3	LL & Handline – Bycatch Jan. - Dec.	LL – Bycatch Jan. - Dec. Lengths	341	18.376
			LL - Bycatch & Sentinel Survey Jan. - Dec. Ages	466	
	4	LL - Sentinel Survey Jan. - Dec.	LL - Sentinel Survey Jan. - Dec. Lengths	9,844	13.892
			LL - Bycatch & Sentinel Survey Jan. - Dec. Ages	466	
	5	OTB/SNU – Bycatch Jan. - Dec. (No Liners)	OTB/SNU - Bycatch Jan. - Dec. Lengths (No Liners)	249	26.710
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	705	
	6	OTB/SNU - Bycatch & Sentinel Survey Jan. - Dec. (No Liners)	OTB/SNU - Bycatch & Sentinel Survey Jan. - Dec. Lengths (No Liners)	397	0.798
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	705	
	7	OTB/SNU - Sentinel Survey Jan. - Dec. (Liners)	OTB/SNU - Sentinel Survey Jan. - Dec. Lengths (Liners)	724	0.280
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	705	
2003 T352 a = 0.005327 b = 3.090703	1	LL, GN, & Misc. – Bycatch & Sentinel Survey Jan. - Dec.	LL, GN, & Misc. – Bycatch & Sentinel Survey Jan. - Dec. Lengths	9,228	17.088
			LL - Bycatch & Sentinel Survey Jan. - Dec. Ages	391	
	2	OTB/SNU – Bycatch Jan. - Dec. (No Liners)	OTB/SNU - Bycatch Jan. - Dec. Lengths (No Liners)	857	19.641

Year	Key	Fishery and period	Samples	Total samples	Landings (t)
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	810	
	3	OTB - Sentinel Survey Jan. - Dec. (Liners)	OTB - Sentinel Survey Jan. - Dec. Lengths (Liners)	641	0.379
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	810	
2004 T434 & N446 a = 0.005196 b = 3.106523	1	LL, GN, & Misc. – Bycatch Jan. - Dec.	LL, GN, & Misc. – Bycatch Jan. - Dec. Lengths	890	22.835
			LL - Bycatch & Sentinel Survey Jan. - Dec. Ages	546	
	2	LL Sentinel Survey Jan. – Dec.	LL. – Sentinel Survey Jan. - Dec. Lengths	11,135	15.153
			LL - Bycatch & Sentinel Survey Jan. - Dec. Ages	546	
	3	OTB/SNU – Bycatch Jan. - Dec. (No Liners)	OTB/SNU - Bycatch Jan. - Dec. Lengths (No Liners)	162	25.004
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	825	
	4	OTB - Sentinel Survey Jan. - Dec. (Liners)	OTB - Sentinel Survey Jan. - Dec. Lengths (Liners)	722	0.467
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	825	
2005 T507 & N542 a = 0.006387 b = 3.034420	1	LL, GN, & Misc. – Bycatch & Sentinel Survey Jan. - Dec.	LL, GN, & Misc. – Bycatch & Sentinel Survey Jan. - Dec. Lengths	5,207	20.094
			LL - Bycatch & Sentinel Survey Jan. - Dec. Ages	443	
	2	OTB/SNU – Bycatch Jan. - Dec. (No Liners)	OTB/SNU - Bycatch Jan. - Dec. Lengths (No Liners)	1,480	23.910
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	841	
	3	OTB - Sentinel Survey Jan. - Dec. (Liners)	OTB - Sentinel Survey Jan. - Dec. Lengths (Liners)	851	0.619

Year	Key	Fishery and period	Samples	Total samples	Landings (t)
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	841	
2006 T678 a = 0.005500 b = 3.076648	1	LL, GN, & Misc. – Bycatch & Sentinel Survey Jan. - Dec.	LL, GN, & Misc. – Bycatch & Sentinel Survey Jan. - Dec. Lengths	2,236	9.310
			LL - Bycatch & Sentinel Survey Jan. - Dec. Ages	397	
	2	OTB/SNU – Bycatch Jan. - Dec. (No Liners)	OTB/SNU - Bycatch Jan. - Dec. Lengths (No Liners)	692	17.282
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	784	
	3	OTB - Sentinel Survey Jan. - Dec. (Liners)	OTB - Sentinel Survey Jan. - Dec. Lengths (Liners)	615	0.419
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	784	
2007 T749 a = 0.005270 b = 3.090270	1	LL, GN, & Misc. – Bycatch & Sentinel Survey Jan. - Dec.	LL, GN, & Misc. – Bycatch & Sentinel Survey Jan. - Dec. Lengths	2,194	7.034
			LL - Bycatch & Sentinel Survey Jan. - Dec. Ages	420	
	2	OTB/SNU – Bycatch Jan. - Dec. (No Liners)	OTB/SNU - Bycatch Jan. - Dec. Lengths (No Liners)	963	13.347
			OTB/SNU (Bycatch + Sentinel) Jan. - Dec. Ages	441	
	3	OTB - Sentinel Survey Jan. - Dec. (Liners)	OTB - Sentinel Survey Jan. - Dec. Lengths (Liners)	682	0.364
			OTB/SNU (Bycatch + Sentinel) Jan. - Dec. Ages	441	
2008 T815 a = 0.004841 b = 3.12038	1	LL, GN, & Misc. – Bycatch & Sentinel Survey Jan. - Dec.	LL, GN, & Misc. – Bycatch & Sentinel Survey Jan. - Dec. Lengths	638	6.986
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	440	

Year	Key	Fishery and period	Samples	Total samples	Landings (t)
	2	OTB/SNU – Bycatch Jan. - Dec. (No Liners)	OTB/SNU - Bycatch Jan. - Dec. Lengths (No Liners)	449	24.360
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	440	
	3	OTB - Sentinel Survey Jan. - Dec. (Liners)	OTB - Sentinel Survey Jan. - Dec. Lengths (Liners)	325	0.148
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	440	
2009 T992 a = 0.005510 b = 3.078501	1	LL, GN, & Misc. – Bycatch & Sentinel Survey Jan. - Dec.	LL, GN, & Misc. – Bycatch & Sentinel Survey Jan. - Dec. Lengths	932	8.159
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	479	
	2	OTB/SNU – Bycatch Jan. - Dec. (No Liners)	OTB/SNU - Bycatch Jan. - Dec. Lengths (No Liners)	532	24.435
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	479	
	3	OTB - Sentinel Survey Jan. - Dec. (Liners)	OTB - Sentinel Survey Jan. - Dec. Lengths (Liners)	608	0.414
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	479	
2010 T074 a = 0.005944 b = 3.062167	1	LL, GN, & Misc. – Bycatch & Sentinel Survey Jan. - Dec.	LL, GN, & Misc. – Bycatch & Sentinel Survey Jan. - Dec. Lengths	243	4.365
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	302	
	2	OTB/SNU – Bycatch Jan. - Dec. (No Liners)	OTB/SNU - Bycatch Jan. - Dec. Lengths (No Liners)	516	11.133
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	302	
	3	OTB - Sentinel Survey Jan. - Dec. (Liners)	OTB - Sentinel Survey Jan. - Dec. Lengths (Liners)	305	0.205
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	302	

Year	Key	Fishery and period	Samples	Total samples	Landings (t)
2011 T194 a = 0.003285 b = 3.220009	1	LL, GN, & Misc. – Bycatch & Sentinel Survey Jan. - Dec.	LL, GN, & Misc. – Bycatch & Sentinel Survey Jan. - Dec. Lengths	389	9.016
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	422	
	2	OTB/SNU – Bycatch Jan. - Dec. (No Liners)	OTB/SNU - Bycatch Jan. - Dec. Lengths (No Liners)	352	11.034
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	422	
	3	OTB - Sentinel Survey Jan. - Dec. (Liners)	OTB - Sentinel Survey Jan. - Dec. Lengths (Liners)	219	0.126
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	422	
2012 T205 a = 0.004839 b = 3.117382	1	LL, GN, & Misc. –Bycatch & Sentinel Survey Jan. - Dec.	LL, GN, & Misc. – Bycatch & Sentinel Survey Jan. - Dec. Lengths	141	5.172
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	280	
	2	OTB/SNU – Bycatch Jan. - Dec. (No Liners)	OTB/SNU - Bycatch Jan. - Dec. Lengths (No Liners)	575	9.092
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	280	
	3	OTB - Sentinel Survey Jan. - Dec. (Liners)	OTB - Sentinel Survey Jan. - Dec. Lengths (Liners)	170	0.087
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	280	
2013 T318 a = 0.007148 b = 2.999851	1	LL, GN, & Misc. – Bycatch & Sentinel Survey Jan. - Dec.	LL, GN, & Misc. – Bycatch & Sentinel Survey Jan. - Dec. Lengths	149	5.819
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	288	
	2	OTB/SNU – Bycatch Jan. - Dec. (No Liners)	OTB/SNU - Bycatch Jan. - Dec. Lengths (No Liners)	300	13.833

Year	Key	Fishery and period	Samples	Total samples	Landings (t)
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	288	
	3	OTB - Sentinel Survey Jan. - Dec. (Liners)	OTB - Sentinel Survey Jan. - Dec. Lengths (Liners)	182	0.066
			All Gears (Bycatch + Sentinel) Jan. - Dec. Ages	288	

Table A2.2. Landings (numbers) at age by gear in 2001 (a) to 2013 (m). Numbers are rounded to the nearest integer and "na" means there were no fish of that age in the age-length key. The age-key numbers correspond to those in Table A2.1 and the source is noted as: Comm. = Commercial, Sent. = Sentinel, Comb. = Commercial & Sentinel, L=Liner, NoL=No Liner.

a) 2001

	Key - Gear - Source					
	1	2	3	4	5	
	GN	LL/LHP	LL	OTB/SNU	OTB/SNU	
Age	Comb.	Comm.	Sent.	Comb. (NoL)	Sent. (L)	Total
0	na	na	na	na	3	3
1	na	na	na	na	65	65
2	na	na	19	na	31	50
3	1	823	1,664	294	108	2,891
4	142	10,111	8,669	1,891	157	20,970
5	2,237	12,610	7,853	5,728	45	28,471
6	6,198	4,061	3,845	6,181	9	20,293
7	3,117	1,014	1,052	2,293	1	7,477
8	1,043	94	287	696	0	2,120
9	101	45	37	121	2	306
10	37	0	5	128	na	169
11	0	na	2	0	na	3
Total	12,876	28,757	23,431	17,331	423	82,818

b) 2002

	Key - Gear - Source							
	1	2	3	4	5	6	7	
	GN (Lm)	GN (Sm)	LL/LHP	LL	OTB/SNU	OTB/SNU	OTB/SNU	
Age	Comb.	Comb.	Comm.	Sent.	Comm. (NoL)	Comb. (NoL)	Sent. (L)	Total
1	na	na	na	na	na	na	131	131
2	na	na	14	210	na	0	56	280
3	115	37	491	786	na	2	57	1,488
4	687	200	3,112	3,396	191	21	118	7,724
5	1,186	105	4,988	4,061	8,031	173	68	18,612
6	2,162	26	3,112	1,944	6,594	161	22	14,021
7	695	4	752	415	843	32	6	2,749
8	52	0	167	36	170	3	1	428
9	39	na	70	41	na	7	na	157
Total	4,937	371	12,705	10,889	15,828	399	458	45,587

c) 2003

	Key - Gear - Source			
	1	2	3	
	LL/GN/Misc.	OTB/SNU	OTB	
Age	Comb.	Comm. (NoL)	Sent. (L)	Total
1	na	na	200	200
2	34	na	307	341
3	518	1,929	130	2,577
4	4,437	6,589	163	11,189
5	5,050	7,149	72	12,271
6	2,912	2,511	14	5,437
7	539	92	1	632
8	120	24	na	145
Total	13611	18294	885	32790

d) 2004

	Key - Gear - Source				
	1	2	3	4	
	LL/GN/Misc.	LL	OTB/SNU	OTB	
Age	Comb.	Sent.	Comm. (NoL)	Sent. (L)	Total
1	na	na	na	68	68
2	6	35	na	309	350
3	50	427	12	173	662
4	1,971	3,842	3,583	216	9,612
5	8,440	4,875	10,045	116	23,476
6	3,780	1,945	3,691	19	9,435
7	662	343	417	na	1,423
8	81	25	54	na	160
9	na	na	na	na	na
10	17	na	na	na	17
11	na	na	111	na	111
Total	15,007	11,493	17,913	901	45,312

e) 2005

	Key - Gear - Source			
	1	2	3	
	LL/GN/Misc.	OTB/SNU	OTB	
Age	Comb.	Comm. (NoL)	Sent. (L)	Total
1	3	113	80	196
2	85	1,300	556	1,941
3	395	1,658	174	2,227
4	5,669	4,749	399	10,817
5	6,131	7,845	126	14,102
6	3,495	4,812	17	8,324
7	669	1,024	2	1,695
8	95	130	na	225
9	na	20	na	20
Total	16,542	21,651	1354	39,547

f) 2006

	Key - Gear - Source			
	1	2	3	
	LL/GN/Misc.	OTB/SNU	OTB	
Age	Comb.	Comm. (NoL)	Sent. (L)	Total
1	na	na	155	155
2	33	na	523	556
3	414	15	163	592
4	3,284	887	212	4,383
5	3,311	5,637	65	9,013
6	1,314	3,527	7	4,847
7	195	546	1	742
8	29	157	na	186
9	na	39	na	39
Total	8,580	10,808	1,124	20,512

g) 2007

	Key - Gear - Source			
	1	2	3	
	LL/GN/Misc.	OTB/SNU	OTB	
Age	Comb.	Comm. (NoL)	Sent. (L)	Total
1	na	na	70	70
2	83	na	376	460
3	787	41	164	992
4	2,532	841	180	3,552
5	2,296	3,118	63	5,478
6	845	2,631	5	3,481
7	70	385	0	455
8	9	347	na	356
9	na	16	na	16
10	na	37	na	37
11	na	7	na	7
Total	6,621	7,424	858	14,904

h) 2008

	Key - Gear - Source			
	1	2	3	
	LL/GN/Misc.	OTB/SNU	OTB	
Age	Comb.	Comm. (NoL)	Sent. (L)	Total
1	6	na	20	26
2	194	411	111	717
3	477	8,360	89	8,926
4	1,582	13,889	87	15,558
5	2,475	6,725	20	9,220
6	951	1,390	2	2,343
7	125	157	na	282
Total	5,810	30,932	329	37,071

i) 2009

	Key - Gear - Source			
	1	2	3	
	LL/GN/Misc.	OTB/SNU	OTB	
Age	Comb.	Comm. (NoL)	Sent. (L)	Total
1	1	na	14	15
2	42	na	188	230
3	589	2	270	861
4	2,116	437	260	2,813
5	2,563	7,629	89	10,281
6	1,189	5,498	4	6,691
7	321	1,060	3	1,384
8	8	91	na	100
Total	6,830	14,716	828	22,374

j) 2010

	Key - Gear - Source			
	1	2	3	
	LL/GN/Misc.	OTB/SNU	OTB	
Age	Comb.	Comm. (NoL)	Sent. (L)	Total
1	na	na	70	70
2	252	24	201	477
3	756	351	97	1,204
4	2,037	2,842	79	4,958
5	1,038	4,408	34	5,480
6	547	1,468	8	2,023
7	65	114	1	181
8	na	27	na	27
Total	4,695	9,234	489	14,419

k) 2011

	Key - Gear - Source			
	1	2	3	
	LL/GN/Misc.	OTB/SNU	OTB	
Age	Comb.	Comm. (NoL)	Sent. (L)	Total
1	na	na	20	20
2	47	na	67	114
3	303	14	70	386
4	1,576	654	79	2,309
5	2,596	3,599	20	6,215
6	1,479	1,850	2	3,332
7	390	461	1	851
8	79	144	na	223
Total	6,469	6,722	259	13,450

l) 2012

	Key - Gear - Source			
	1	2	3	
	LL/GN/Misc	OTB/SNU	OTB	
Age	Comb.	Comm. (NoL)	Sent. (L)	Total
1	na	na	47	47
2	na	na	101	101
3	282	na	31	313
4	1,880	856	29	2,766
5	1,739	2,892	17	4,648
6	431	1,528	3	1,962
7	98	420	na	518
8	29	37	na	66
9	na	5	na	5
10	na	32	na	32
Total	4,459	5,770	228	10,457

m) 2013

	Key - Gear - Source			
	1	2	3	
	LL/GN/Misc.	OTB/SNU	OTB	
Age	Comb.	Comm. (NoL)	Sent. (L)	Total
1	na	na	14	14
2	19	na	125	143
3	91	na	25	116
4	459	629	16	1104
5	1614	5528	12	7154
6	1449	3093	3	4545
7	134	276	0	411
8	2	94	na	95
9	na	37	na	37
10	26	na	na	26
Total	3793	9657	196	13646

APPENDIX 3. ALTERNATIVE POPULATION MODELS

Models

The following alternative models were examined:

- Model 1: VPA, RV not split, survey catchability constrained to be flat-topped
- Model 2: VPA, RV not split, survey catchability allowed to be dome-shaped
- Model 3: VPA, RV split 1984 / 1985, survey catchability constrained to be flat-topped
    - fully recruited RV *q* for the Yankee 36 trawl was modelled as a constant times the fully recruited *q* for the Western IIA trawl. This constant was given a normal prior (on the log scale) equal to the estimate of relative fishing efficiency from comparative fishing (0.715). Selectivity at age was freely estimated for each of the two trawls.
- Model 4: VPA, RV split 1984 / 1985, survey catchability allowed to be dome-shaped
    - *q*-at-age was freely estimate for the Western IIA trawl. For the Yankee 36 trawl, *q*-at-age equaled the estimate for the Western IIA trawl multiplied by the same constant for all ages. This constant was given a normal prior (on the log scale) equal to the estimate of relative fishing efficiency from comparative fishing (0.715).
- Model 5: SCA, RV not split, survey catchability constrained to be flat-topped
- Model 6: SCA, RV split 1984 / 1985, survey catchability constrained to be flat-topped
    - Fully recruited *q* and selectivity at age were freely estimated for both trawls.

Residuals

A block of negative residuals between observed and predicted RV abundance indices at age occurred in the 1978 to 1984 period in all models that assumed that the RV data represented a consistent time series over the entire 1978 – 2013 period (Fig. A3.1ab and A3.6a). This tendency for model predictions to be greater than the observed data prior to 1985 is also evident for age groups 4-5 and 6-7 in Fig. A3.2ab and for the age-aggregated biomass index in Fig. A3.8a. This is consistent with the results of comparative fishing experiments, which suggested that fishing efficiency for white hake was lower for the Yankee 36 than for the Western IIA trawl (though the difference was not statistically significant).

This problem in model fit was alleviated by splitting the RV time series between 1984 and 1985 (Fig. A3.1cd, A3.2cd, A3.6b, and A3.8b). In the models with a split in the RV series, catchability was estimated to be greater for the Western IIA trawl than for the Yankee 36 trawl (Fig. A3.5 and A3.10). The estimated difference in catchability was greater than suggested by the limited comparative fishing, but was in the same direction. Relative fishing efficiency (Yankee/Western) was estimated to be 0.715 in the comparative fishing, and 0.686 in Model 3 (for fully recruited *q*, lower for *q*-at-age), 0.544 in Model 4 and 0.564 in Model 6. Fit to the RV data was better (i.e., lower residual sum of squares, RSS) when the RV data were divided into separate time series for the Yankee 36 years (1978-1984) and Western IIA years (1985-2013) (Fig. A3.1, A3.6). Fit to the RV data (i.e., the abundance indices at age) was considerably better for the SCA models (RSS 69 or 76) than for the VPA models (RSS 98-116), even though the SCA models were not fit directly to the abundance indices at age. Fits to the MS data were similar between models (RSS 28-30), except when catchability was allowed to be domed (RSS 16-17).

Catchability

In VPA models with flat-topped survey catchability, fully-recruited *q* was 1.35 for the RV survey and 1.01 for the MS survey when the RV survey was not split and 0.92 for the RV survey in Yankee 36 years, 2.15 in Western IIA years and 1.61 for the MS survey when the RV survey was split (Fig. A3.4ab and A3.5ab). When domed catchability was allowed, catchability at age was estimated to be very sharply domed with a peak at age 5. Maximum catchability was as high as 2.27 (for the Western IIA years when the RV survey was split). The increase in catchability from age-4 to the peak at age 5 was large, up to 3-fold for the RV survey and 6-fold for the MS survey. Such a large increase is surprising given that hake already average 45 – 50 cm in length at age 4. The drop in catchability from age 5 to the oldest calibrated age was also large, 40-50% for age 7 in the RV survey and 55-60% for age 6 in the MS survey.

In SCA models (in which selectivity was constrained to be flat-topped), fully-recruited *q* was estimated to be 0.72 for the RV survey (except 0.41 for the Yankee years when the survey was split) and 0.56 in the MS survey (Fig. A3.9ab and A3.10ab). Unlike in the VPA models, the level of *q* did not depend on whether the RV series was split (except for *q* in the Yankee years).

It is possible for *q* to be greater than 1 when indices are expressed as trawlable abundance and trawlable abundance is calculated based on wingspread rather than door spread. In this case, the area fished by the trawl is underestimated if there is herding of fish into the path of the trawl by the doors. If fishing efficiency of the trawl is high and herding is substantial, then estimated *q* could be greater than 1. However, estimated *q*'s that greatly exceed 1 are not expected except under special circumstances that do not apply here.

In the SCA models, fishery selectivity was flat-topped with ages 7-10+ estimated to be fully recruited. This is consistent with the estimates of partial recruitment (PR) in the VPA models. In the 1978 to 1994 period, the average PR was approximately flat-topped beginning at age 7.

Model Estimates

Estimates of stock status were generally similar between all models (Fig. A3.3, A3.11, A3.12). In all cases SSB was estimated to be severely depleted in 2013 relative to the 1980s. In all cases except Model 2, this severe depletion extended back to the mid-1990s. In Model 2, estimated SSB was higher from 1995 to 2009, about half the level in the early 1980s. In all cases, estimated *M* of 4-5 year old hake was exceedingly high in the 2000s, 85% - 95% annually. Estimated *M* of 6+ hake was also estimated to be high in all the models, over 50% annually in the 2000s in VPA models and nearly 80% annually in SCA models. VPA models estimate that *M* of 2-3 year olds increased sharply to 90% annually in the 2000s if catchability was flat-topped but not if it was domed. Simulation tests indicate that VPA models applied to data with characteristics of the SGSL hake data perform poorly in estimation of *M* of 2-3 year old hake, but well in estimation of *M* for ages 4-5 and reasonably well for ages 6+ (Swain and Benoît 2014). SCA models estimated that *M* of 2-3 year olds increased to about 75-80% annually in the 2000s. All models estimated that recruitment rate was high and fishing mortality negligible in the 2000s.

Preferred Model

The SCA model with the RV time series split between 1984 and 1985 was chosen as the preferred model on which to base advice. Both the comparative fishing experiment and the population modelling suggested that fishing efficiency for white hake differed between the Yankee 36 and the Western IIA trawls. This SCA model also provided the best fit to the survey abundance indices at age. The statistical assumptions of SCA models are more reasonable than those of VPA. Simulation tests indicate that VPA models can be strongly influenced by error in the proportions at age in the fishery catch (Deroba et al. 2014).

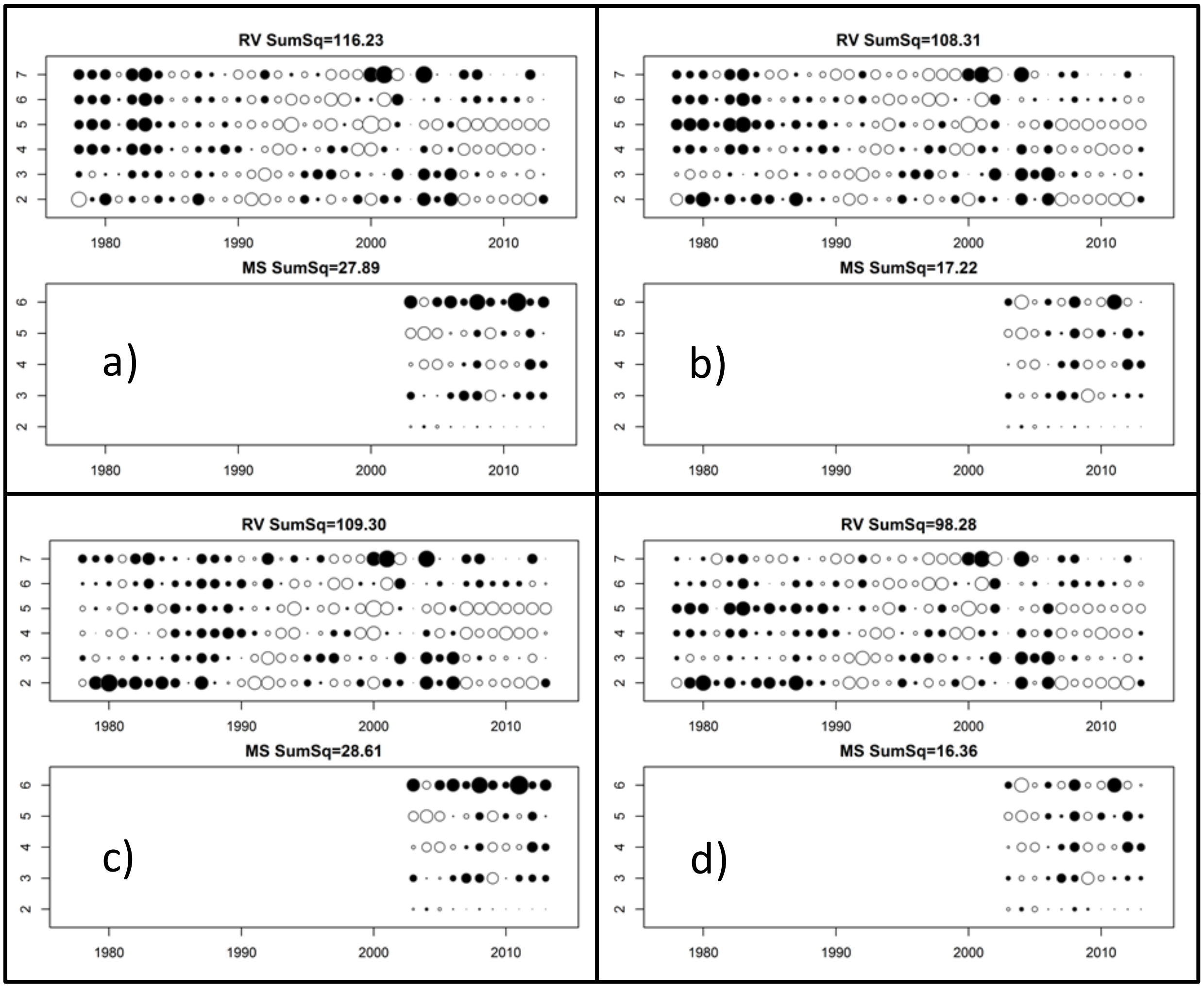

Figure A3.1. Residuals between observed and predicted log abundance indices at age for VPA models assuming a single consistent RV series (panels a, b) or splitting the RV series between 1984 and 1985 (panels c, d) with flat-topped (panels a, c) or dome-shaped (panels b, d) catchability to the RV and MS surveys. Circle size is proportional to the magnitude of the residual. Black circles indicate negative residuals (observed < predicted).

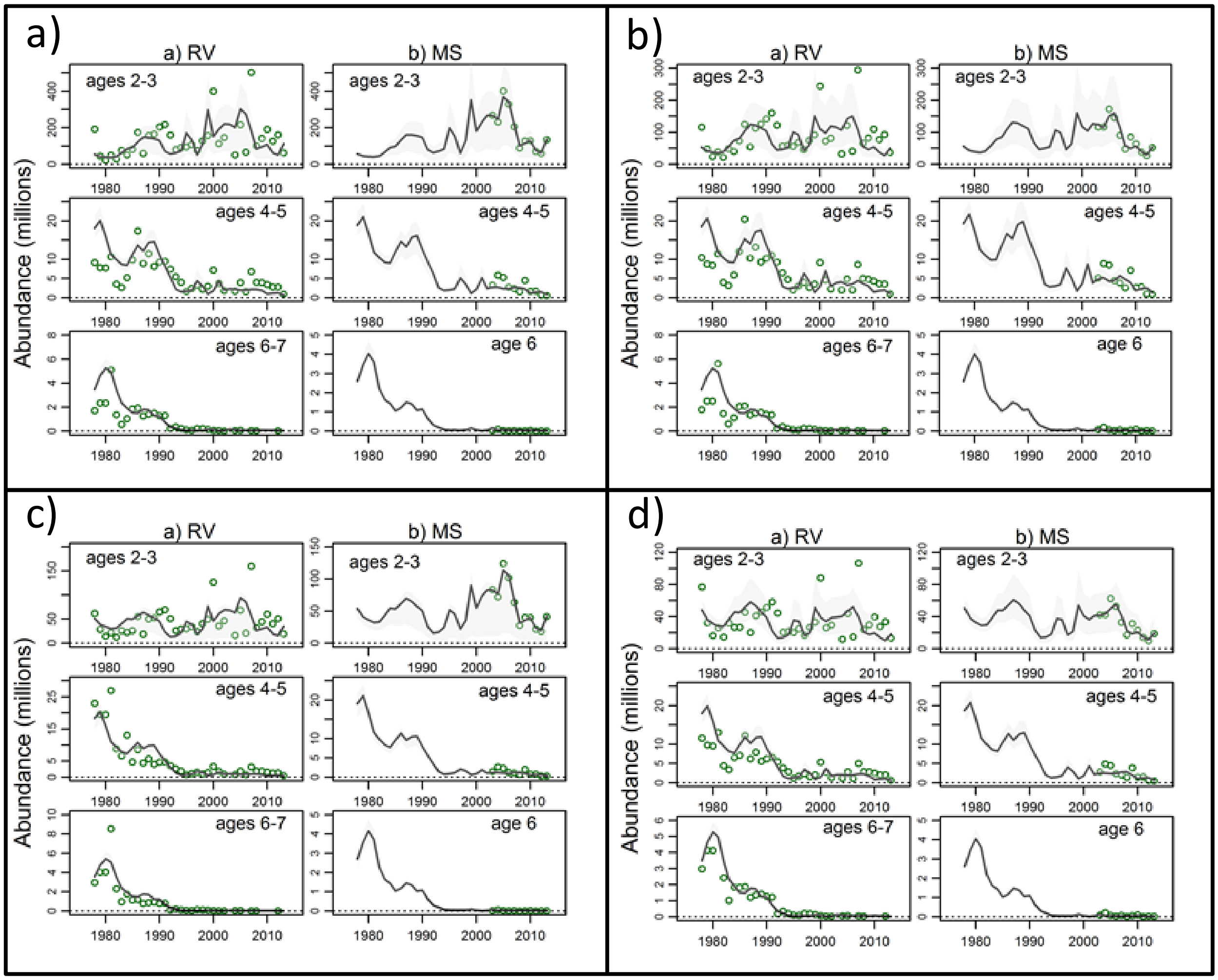

Figure A3.2. Comparison between observed (circles) and predicted (lines) abundance indices for groups of ages for VPA models assuming a single consistent RV series (panels a, b) or splitting the RV series between 1984 and 1985 (panels c, d) with flat-topped (panels a, c) or dome-shaped (panels b, d) catchability to the RV and MS surveys. Light grey shading shows the 95% confidence interval for the predicted indices.

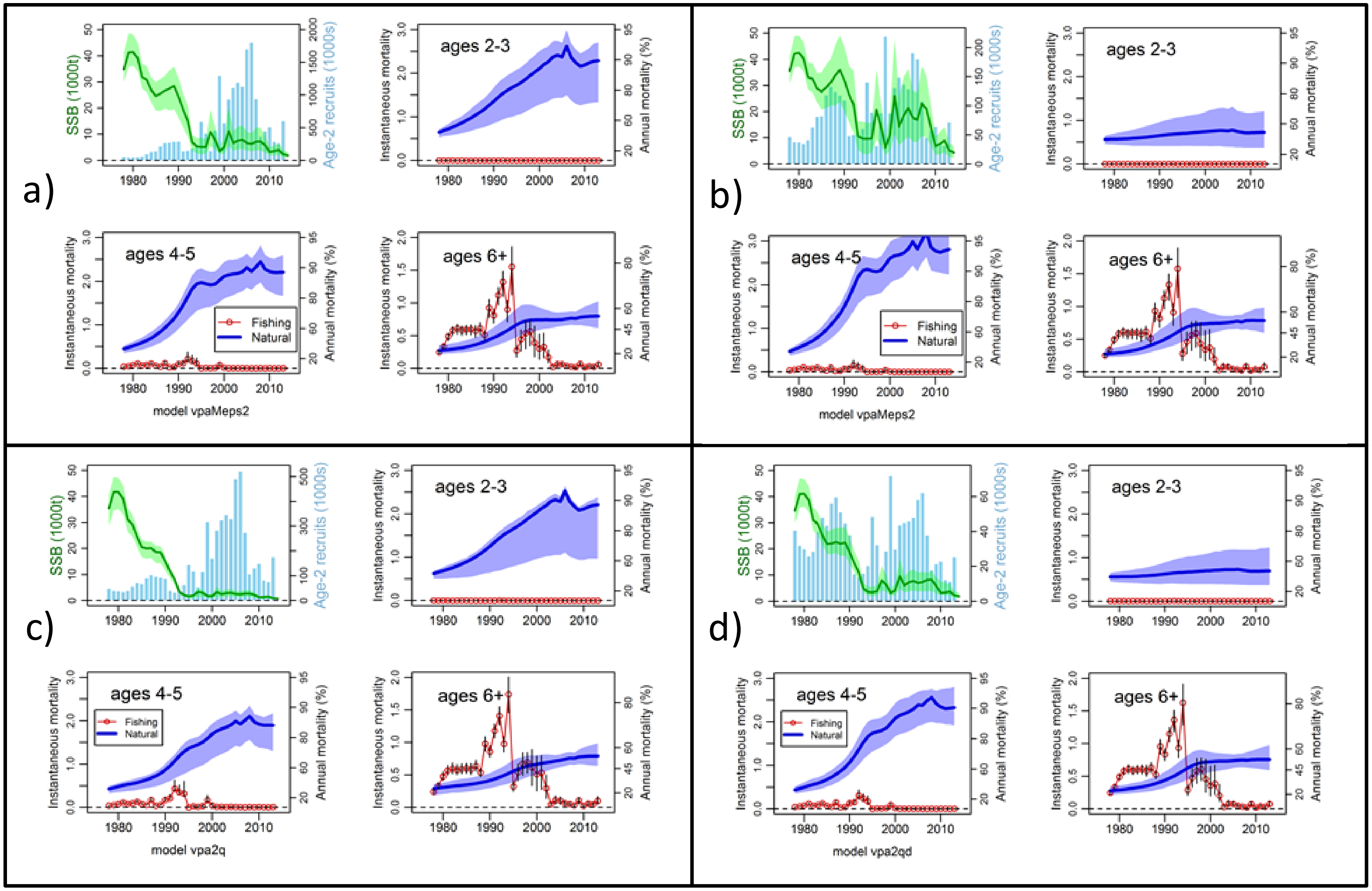

Figure A3.3. Model predictions of SSB (by 1,000 t), recruitment at age 2 (number in 1000s) and estimated natural mortality and fishing mortality for three age groups (ages 2-3, 4-5, 6+) of White Hake based on VPA models assuming a single consistent RV series (panels a, b) or splitting the RV series between 1984 and 1985 (panels c, d) with flat-topped (panels a, c) or dome-shaped (panels b, d) catchability to the surveys. Shading and vertical lines show 95% confidence intervals.

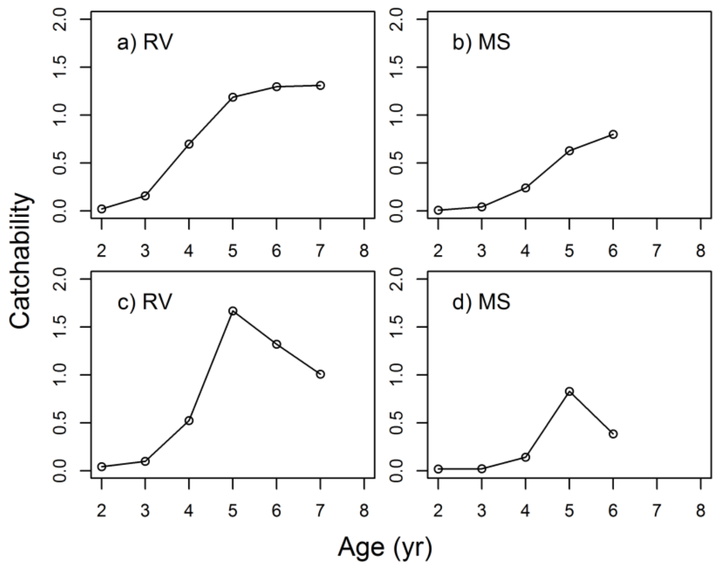

Figure A3.4. Estimated catchability at age in VPA models assuming a single consistent RV series (1978-2013) with logistic selectivity at age (panels a, b) or with independent estimates of catchability at each age (panels c, d).

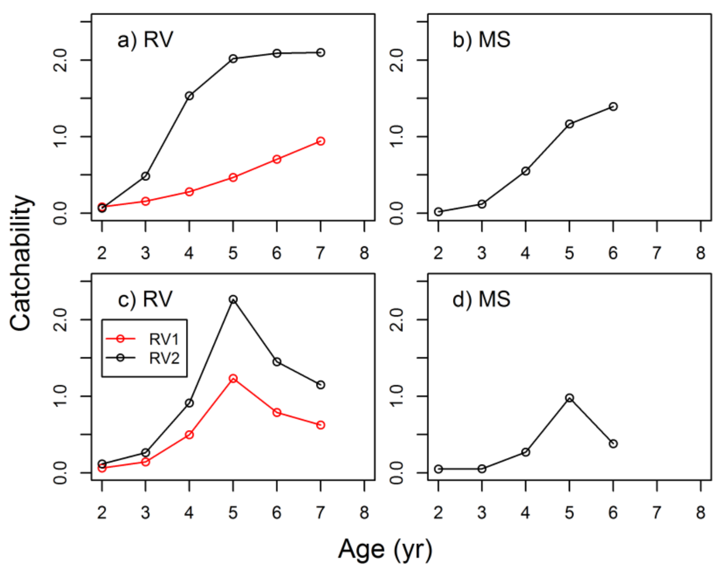

Figure A3.5. Estimated catchability at age in VPA models with a split in the RV series between 1984 and 1985 and with logistic selectivity at age (panels a, b) or with independent estimates of catchability at each age (panels c, d). In panel c, RV1 is for the period 1978-1984, and RV2 is for the period 1985-2013.

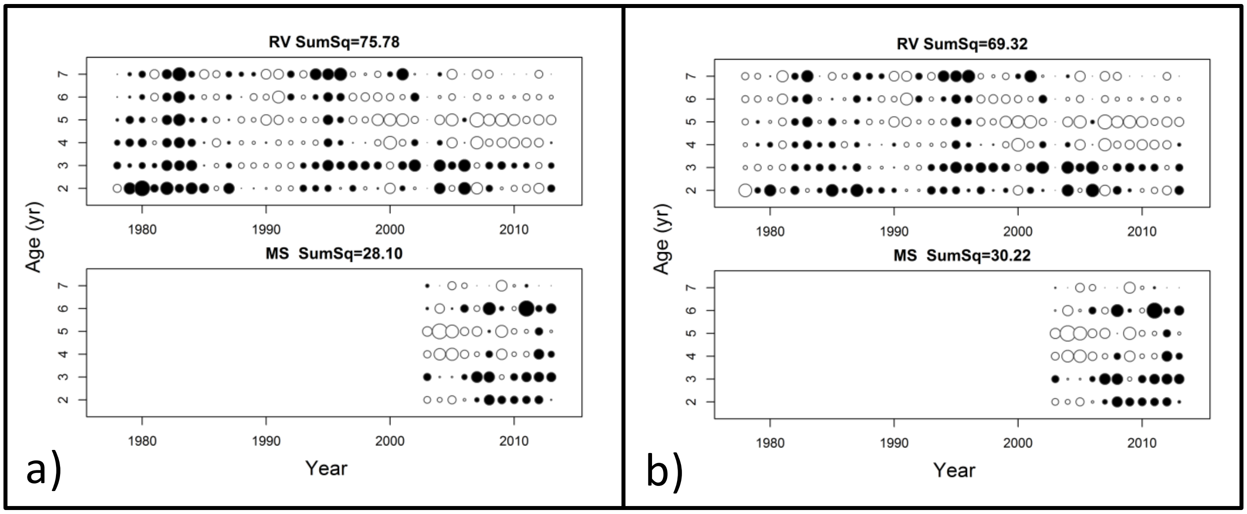

Figure A3.6. Residuals between observed and predicted log abundance indices at age for SCA models assuming a single consistent RV series (panel a) or splitting the RV series between 1984 and 1985 (panel b). These models did not fit to abundance indices at age but the residuals were calculated for comparison with VPA models.

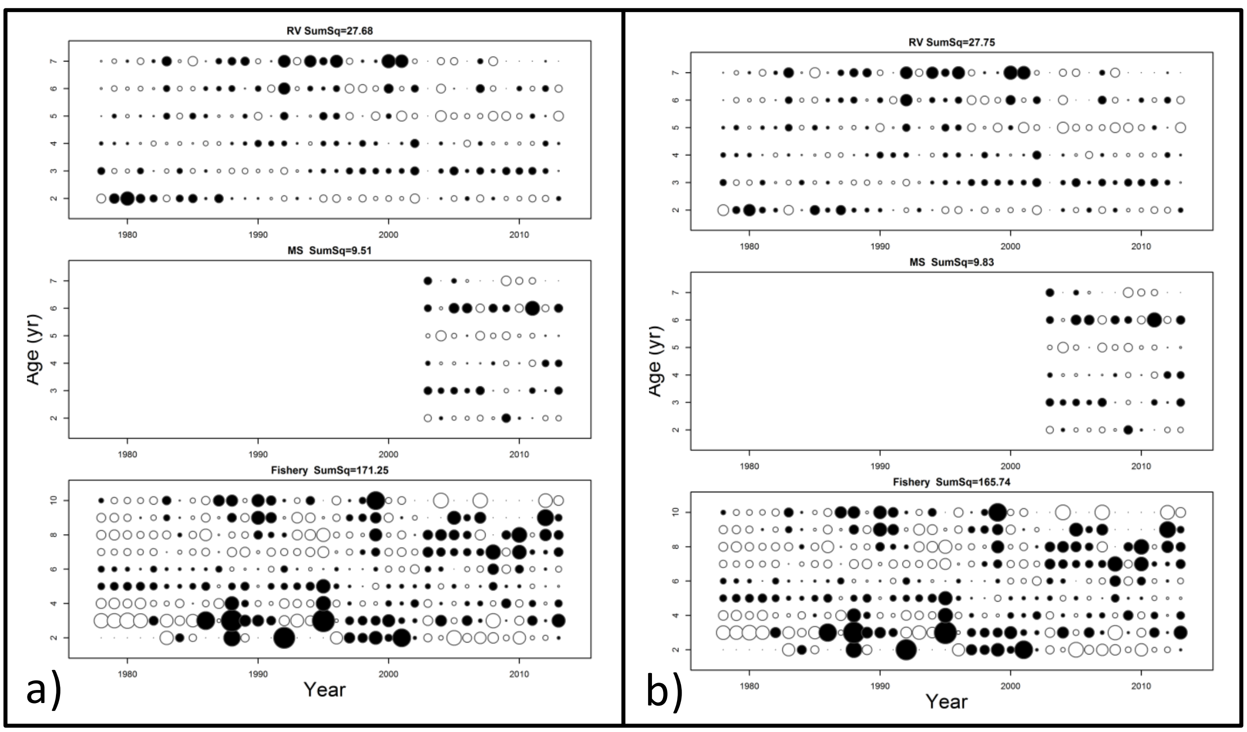

Figure A3.7. Residuals between observed and predicted proportions at age in catches in the RV and MS surveys and in the fishery for SCA models assuming a single consistent RV series (panel a) or splitting the RV series between 1984 and 1985 (panel b).

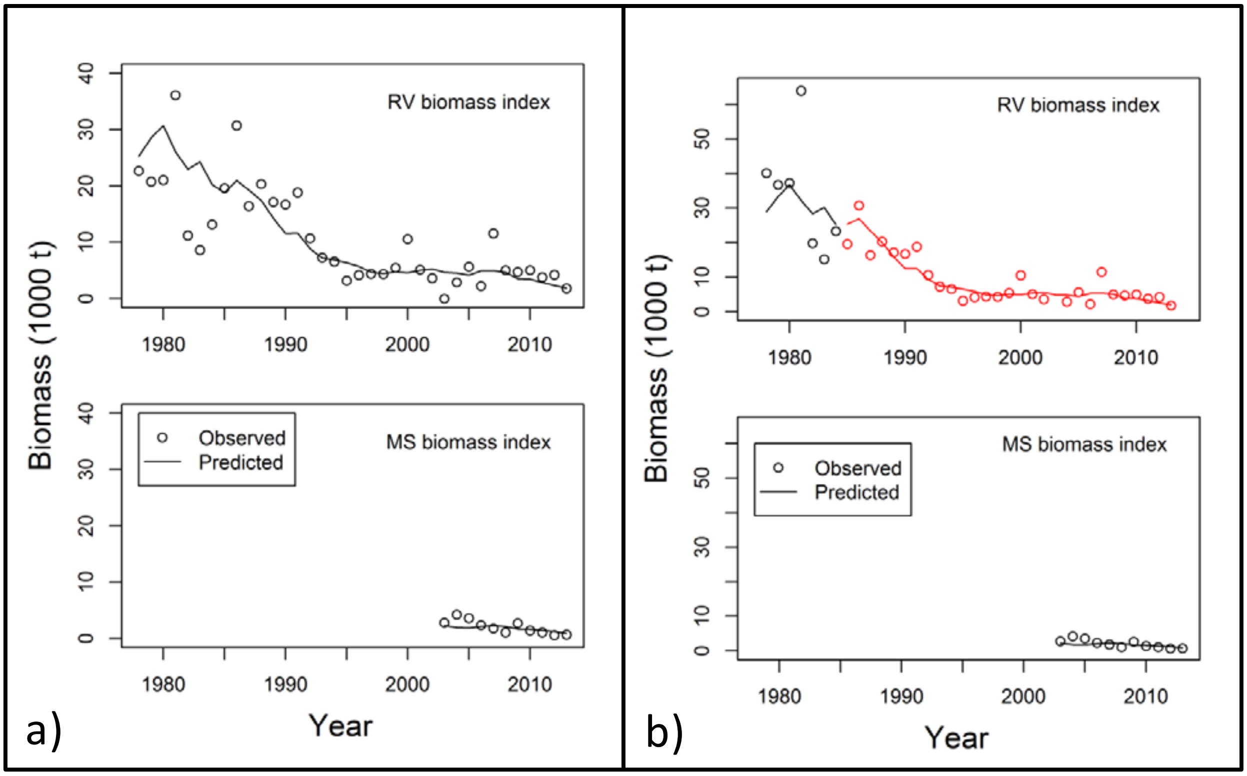

Figure A3.8. Observed (circles) and predicted (lines) biomass indices for SCA models assuming a single consistent RV series (panel a) or splitting the RV series between 1984 and 1985 (panel b).

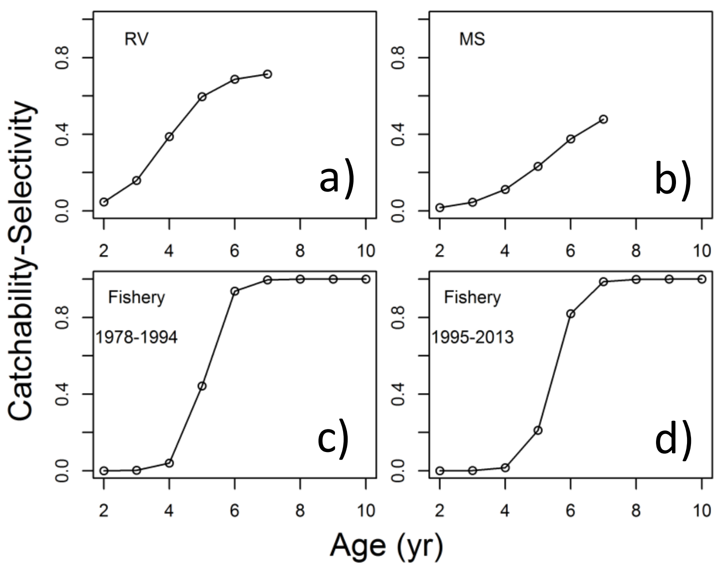

Figure A3.9. Estimated catchability and selectivity in the SCA model assuming a single consistent RV series (1978-2013) and logistic selectivity. Panels show the following: a, catchability to the RV survey; b, catchability to the MS survey; c, fishery selectivity in 1978-1994; and d, fishery selectivity in 1995-2013.

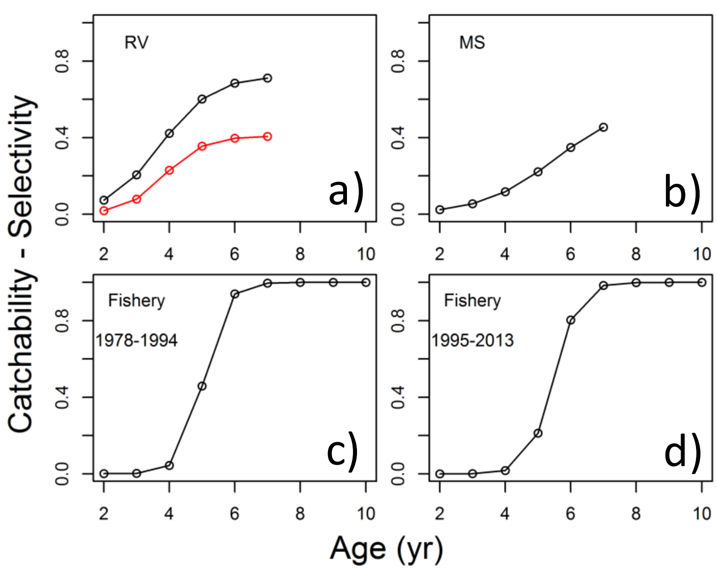

Figure A3.10. Estimated catchability and selectivity in the SCA model with a split in the RV series between 1984 and 1985 and logistic selectivity. Panels show the following: a, catchability to the RV survey; b, catchability to the MS survey; c, fishery selectivity in 1978-1994; and d, fishery selectivity in 1995-2013. In panel a, red denotes the RV series in 1978-1984, and black the series in 1985-2013.

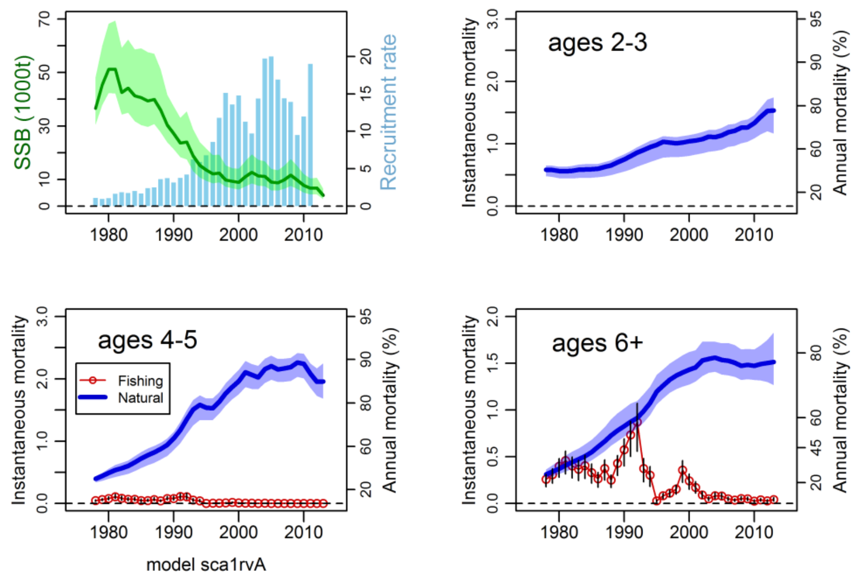

Figure A3.11. Model predictions of SSB (X 1000 t) and recruitment rate and estimated fishing mortality and natural mortality for three age groups (ages 2-3, 4-5, 6+) from the SCA assuming a single consistent RV series (1978-2013) and logistic selectivity. Bars in the upper left panel show the recruitment rate (age-2 recruits / SSB). Green lines show estimated SSB, blue lines estimated natural mortality M, and red circles estimated fishing mortality F. Shading and vertical lines show 95% confidence intervals based on MCMC sampling.

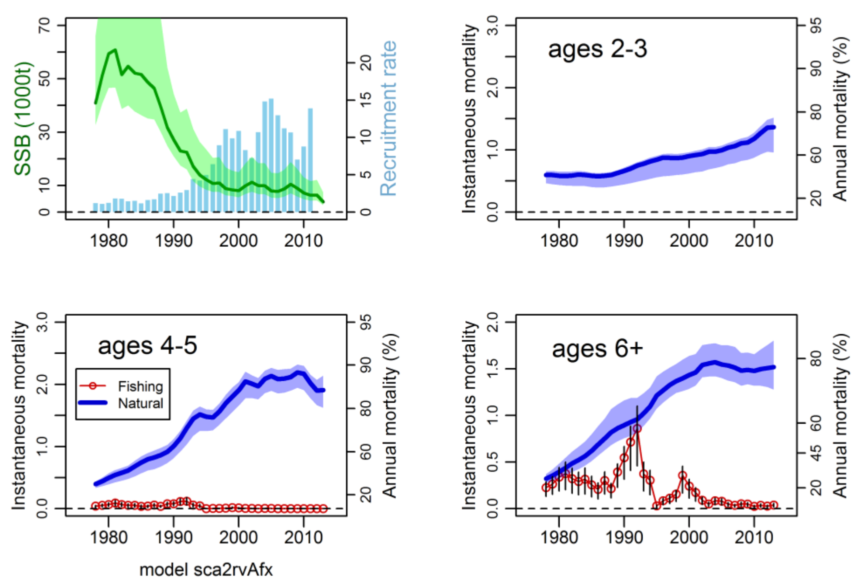

Figure A3.12. Model predictions of SSB (X 1000 t) and recruitment rate and estimated fishing mortality and natural mortality for three age groups (ages 2-3, 4-5, 6+) from the SCA assuming a split in the RV series between 1984 and 1985 and logistic selectivity. Bars in the upper left panel show the recruitment rate (age-2 recruits / SSB). Green lines show estimated SSB, blue lines estimated natural mortality M, and red circles estimated fishing mortality F. Shading and vertical lines show 95% confidence intervals based on MCMC sampling.