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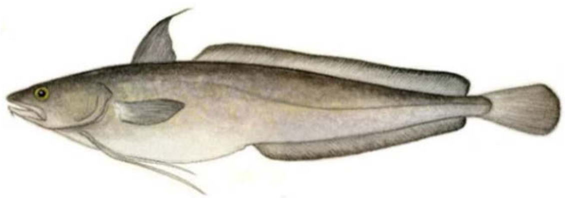
RECOVERY POTENTIAL ASSESSMENT FOR WHITE HAKE (*Urophycis tenuis*): POPULATION OF THE SOUTHERN GULF OF ST. LAWRENCE



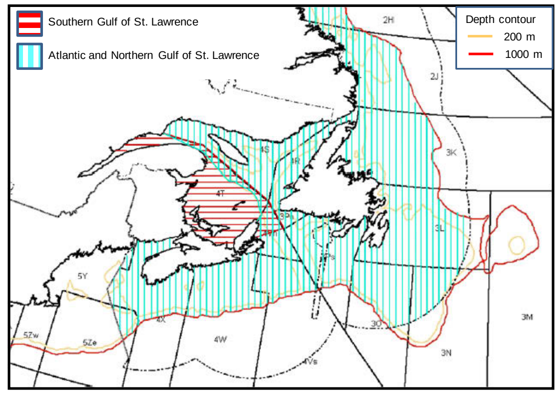


Figure 1. Geographic boundaries of the two Designatable Units of White Hake in eastern Canada as defined by COSEWIC (2013). The figure was extracted from COSEWIC (2013).

Context:

The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) conducted its first assessment of White Hake (Urophycis tenuis Mitchill 1815) in Canadian waters in November 2013. Two populations or Designatable Units (DU) were identified: the southern Gulf of St. Lawrence (sGSL) population and the Atlantic and northern Gulf of St. Lawrence (ANGSL) population. COSEWIC assessed the sGSL population as endangered and the ANGSL population as threatened. The sGSL DU consists of White Hake occurring in NAFO Div. 4T and the northwest portion of NAFO Subdiv. 4Vn.

When a species is assessed as Threatened or Endangered by COSEWIC, Fisheries and Oceans Canada (DFO) undertakes a number of actions required to support implementation of the Species at Risk Act (SARA). Many of these actions require scientific information on the current status of the wildlife species, threats to its survival and recovery, and the feasibility of recovery, and this advice has typically been developed through a Recovery Potential Assessment (RPA). In support of listing recommendations for White Hake by the Minister, DFO Science was asked to undertake an RPA, based on the national RPA Guidance. Advice in the RPA may be used to inform both scientific and socio-economic aspects of the listing decision, development of a recovery strategy and action plan, and to support decision-making regarding issuance of permits or agreements, and formulation of exemptions and related conditions, as per sections 73, 74, 75, 77, 78, and 83(4) of SARA. Advice in the RPA may also be used to prepare for the reporting requirements of SARA s.55. Advice generated through this process updates and consolidates any existing advice regarding White Hake in the sGSL DU.

This Science Advisory Report is from the January 14 to 16, 2015 science peer review meeting of the Recovery Potential Assessment of White Hake in eastern Canada. Participants at the review included personnel from DFO (Gulf, Maritimes, Newfoundland and Labrador, and Quebec Regions) Ecosystems and Science Branch, Fisheries and Aquaculture Management, Species at Risk, Policy and Economics, and invited experts from the COSEWIC Marine Fish Subcommittee and US National Marine Fisheries Service (NOAA).

SUMMARY

Biology, Abundance, Distribution and Life History Parameters

- Indices from research vessel (RV) bottom-trawl surveys indicate that adult abundance of White Hake declined by over 90% between 1985 and 2014 (about 3 generations). Although most of this decline occurred between 1985 and 1996, the index of adult abundance has continued to decline at a slower rate since then. RV indices of juvenile abundance tended to be higher between 1985 and 1992 than since 1993, though high indices occurred in several recent years.
- Age-aggregated indices from the sentinel bottom-trawl survey and the longline program both indicated substantial declines in biomass in the 2000s, with recent indices the lowest in the time series.
- Estimated spawning stock biomass (SSB) dropped sharply in the late 1980s and early 1990s, averaging 52,848 t during 1978 to 1982 and 6,516 t during 2009 to 2013, a decline of 88%. Estimated SSB in 2013 was 3,844 t, the lowest in the time series and a decline of 93% from the late 1970s and early 1980s. In contrast, estimated juvenile biomass and abundance fluctuated without trend over the 36-year time series.
- Area occupied by adults peaked at values near 25,000 km² in the early 1980s and declined to values near 5,000 km² in recent years, a reduction by about 70% from the late 1980s. Area occupied by juveniles remained fairly constant at 10,000 km² except for an increase to 10,000 km² in the late 1980s and early 1990s.
- In summer, White Hake are normally distributed in inshore waters at depths less than 50 m and offshore at depths greater than 100 m. The proportion of hake occurring in shallow inshore waters was 68% in the 1970s, 45% to 50% in the 1980s and 1990s, and 6% in the 2000s. This offshore shift in distribution is thought to result from increasing risk of predation by grey seals in the inshore.
- Spawning is known to occur in inshore areas in summer and thought to occur offshore in late winter and early spring. One inshore spawning area has not been utilized since the late 1990s. With adult hake now nearly absent in inshore waters, more losses of inshore spawning areas may be occurring.
- A dramatic contraction in the age composition of sGSL White Hake has occurred since 1971. Fish 10 years and older were commonly observed in the RV survey catches in the 1970s and 1980s, but no hake over 7 years of age have been observed in the survey since 1998.

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

- The directed fishery for White Hake has been closed since 1995. Bycatch in commercial fisheries targeting other groundfish species has declined to very low levels, averaging 18 t annually in NAFO Div. 4T during 2010 to 2013. Based on population modelling, the instantaneous rate of fishing mortality (*F*) was estimated to average 0.002 for ages 4 and 5 and 0.033 for ages 6+ during 2010 to 2013.
- In the past two decades, the dominant source of mortality for White Hake has been natural mortality (*M*). For juveniles (ages 2 and 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 and 5

(from 33 to 87% annually) and from 0.32 to 1.51 (from 27 to 78% annually) for ages 6 years and older.

- Natural mortality has also increased to extremely high levels in adults of other large demersal fishes in the sGSL ecosystem (e.g., Atlantic Cod, American Plaice, Thorny Skate, Winter Skate). Based on a review of evidence, increasing abundance of grey seals, an important predator of these fishes, is considered to be a major cause of these increases in *M*.
- Recruitment remains strong in this population of White Hake despite very low SSB. This reflects very high recruitment rates (recruits produced per unit of SSB) over the past 20 years.

Recovery Targets

- A sustained increase in SSB to or above 12,800 t, 40% of the SSB producing the maximum surplus production, is proposed as an abundance recovery target. Additionally, 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.
- Estimated SSB in the most recent year (2013) is about 30% of the abundance recovery target with no chance of being at or above this target. Estimated SSB has been below the abundance recovery target since 1995.
- The return of hake to inshore waters of the sGSL, the areas where they predominantly occurred in summer from the 1970s to the mid-1990s, is proposed as a distribution target for recovery.
- The main threat and most important limiting factor to recovery of this population is the exceedingly high level of non-fishing mortality (*M*).

Projections

- Projections indicated that the declines in SSB and adult abundance are expected to continue under current conditions. Under these conditions, there is no chance of reaching the recovery targets even with no fishing. There was a 5% probability of extinction at 45 to 50 years into the projection. After 60 years, the probability of extinction was 19% or 38%, depending on the method used to project recruitment. An increase in fully recruited (6+) *F* to 0.24, the highest level observed since 2000, had a negligible effect on the population trajectory.
- Recruitment productivity has been high for the past 20 years. Under this condition, the probability of achieving the biomass recovery target was estimated to be 27% in 30 years after a reduction in *M* by 20%, 95% in 30 years after a reduction by 30%, and 51% in 6 years after a reduction by 40%.
- If recruitment productivity were to return to the lower levels observed in the 1978 to 1994 period, a 60% reduction in *M* would be required to allow SSB to increase above the abundance recovery target. The probability of achieving this target would be 77% after 30 years.

Allowable Harm Assessment

- There continues to be mortality of White Hake due to fishing activities but current (6+ *F* = 0.04) and recent (6+ *F* = 0.24) fishing mortality rates have negligible effects on the population trajectory because of the extremely high natural mortality rates experienced by this population.

INTRODUCTION

In its first assessment of White Hake (*Urophycis tenuis* Mitchill 1815) in Canadian waters of November 2013, COSEWIC (2013) distinguished two populations or Designatable Units (DU): the southern Gulf of St. Lawrence population, and the Atlantic and Northern Gulf of St. Lawrence population (Fig. 1).

The southern Gulf of St. Lawrence (sGSL) population was assessed as endangered. Reasons for this designation included an overall decline rate of 91% over the past three generations, a similar though less dramatic decline in the area of occupancy and the apparent disappearance of one segment of the population. COSEWIC concluded that fisheries were the primary cause of the decline, but that high natural (i.e., non-fishing) mortality, perhaps due to predation by grey seals, may be preventing recovery.

The last full assessment of the sGSL White Hake stock (NAFO Div. 4T) 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). In 2014, indicators of abundance from the annual research vessel (RV) survey and sentinel fishery programs were updated to 2013 (DFO 2014).

Roy et al. (2012) identified three genetically distinct groups of White Hake in Atlantic Canada, one of which was the sGSL population. The sGSL population type occurred almost entirely in NAFO Div. 4T and in the western portion of NAFO Subdiv. 4Vn. Based on the distribution of hake (all sizes) among survey strata in the 2000s, 82% of hake in the NAFO Div. 4T RV survey area in September were estimated to belong to the sGSL population (Swain et al. 2012). For the purposes of this recovery potential assessment, it is assumed that the status and recovery potential of the sGSL DU can be assessed based on analysis of the information from the 4T management unit, which is dominated by the sGSL DU and comprises the bulk of the area occupied by this DU. While NAFO Div. 4T includes the St. Lawrence Estuary, the genetic identity of hake occurring in this area (NAFO unit areas 4Topq) is unknown. The contribution of this area to total landings of Div. 4T White Hake is small (1985 to 2010 average, 1.1%).

Biology and Distribution

White Hake is a demersal gadoid fish. The maximum length and age observed in the September RV survey (1971 to 2013) were 115 cm (total length) and 15 years, respectively. Because White Hake in the sGSL had been commercially exploited for many years at the time of these observations, historical maximum lengths and ages are likely greater than these values. Estimated lengths and ages at 50% maturity are 40.7 and 48.2 cm, and 3.2 and 3.9 years, for males and females, respectively. For the analyses presented here, hake 45 cm or longer and 4 years or older were considered mature.

Generation time can be approximated as $A_{mat} + 1/M_v$ where A_{mat} is the age at maturation and M_v is the historical (i.e., pre-fishing) instantaneous rate of natural mortality. With A_{mat} = 4 years and M_v = 0.2, estimated generation time is nine years. At current estimated levels of M (1 or higher, see below), generation time is about five years.

White Hake are pelagic spawners and have been considered to be among the most fecund of the commercial groundfish species. 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). 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 (Han and Kulka 2007).

In the sGSL, spawning occurs in shallow inshore areas, notably St. Georges Bay and the Northumberland Strait, in summer with a peak in mid-June. One inshore spawning component utilizing Baie Verte (Northumberland Strait) appears to have disappeared after being targeted by a seasonal fishery in the 1980s (Hurlbut 2012). Spawning is also thought to occur offshore in the Laurentian Channel in late winter and early spring.

During the summer and early autumn, White Hake in the sGSL typically exhibit a bimodal distribution with respect to depth, with concentrations occurring in warmer waters, either in shallow (<50 m) inshore areas or in deep water (>100 m) along the Laurentian Channel and in the Cape Breton Trough. In the fall, White Hake in inshore areas migrate into the deep (>200 m), relatively warm (4-5˚C) water of the Laurentian Channel and Cabot Strait to overwinter. The return migration to the waters of the southern Gulf generally begins in April-May and proceeds rapidly until June, by which time most of the traditional summer habitats are occupied. The observed by-catch of juvenile White Hake in fisheries in some estuaries of the sGSL during October and November suggests that some juvenile White Hake may over-winter in or near estuaries rather than migrating offshore.

ASSESSMENT

Abundance and Life History Parameters

Recent species abundance

Indices of abundance and biomass are available from a research vessel (RV) survey conducted each September since 1971, a mobile sentinel (MS) survey conducted each August since 2003 and a sentinel longline (LL) program conducted since 1996. The RV and MS surveys are both bottom-trawl surveys using the same stratified-random design. Twenty-four strata (415-439) have been fished since 1971, with three inshore strata (401 to 403) added in 1984. The sentinel programs were conducted by commercial fishing vessels using standardized gear and protocols. For the LL program, analyses were restricted to sites off Prince Edward Island (PEI) and in St. Georges Bay and the Cape Breton Trough because White Hake were very rarely caught at sites in other areas.

The rate of change in abundance for adult hake over approximately three generations was estimated by regression of the natural logarithm of survey catch rate against year beginning in 1985. Percent change in abundance was calculated as $100*(\exp(b*\Delta t)-1)$ where b is the log-linear regression slope and Δt is the change in time (years).

Age-structured population models were fit to the White Hake data to estimate abundance and biomass for the years 1978 (the first year with reliable fishery catch-at-age data) to 2013 and for age 2 to ages 10+ (i.e., 10 years and older). Independent time series of the instantaneous rate of natural mortality (*M*) were estimated for three age groups: ages 2 and 3, ages 4 and 5 and ages 6+. Various models were examined and all led to the same general conclusions about population status and trends in natural mortality. The results from a Statistical Catch at Age (SCA) model fit to the age-aggregated RV and MS survey biomass indices and to the proportions at age in these surveys and in the fishery catch are presented here.

Research vessel indices (RV)

Length-based indices of juvenile abundance and biomass fluctuated without clear trends between 1971 and 2014 (Fig. 2). 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). Both the adult abundance and biomass indices showed a sharp decline from 1985 to 1995, and have remained at a very low level since then.

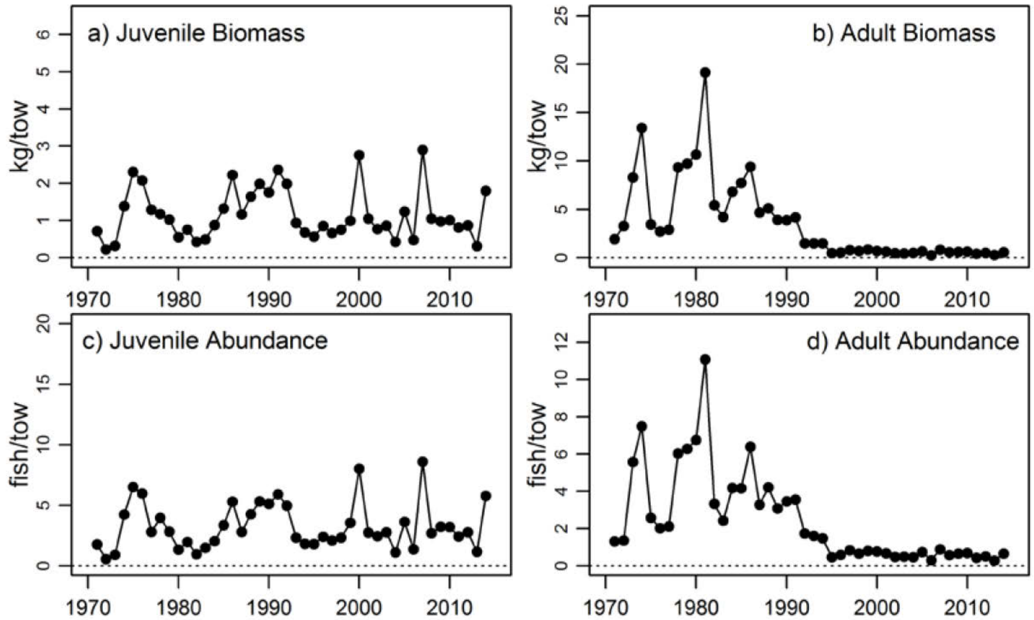


Figure 2. RV survey indices of biomass (kg per tow; top row) and abundance (fish per tow; bottom row) for juvenile (< 45 cm; left column) and adult (≥ 45 cm; right column) of White Hake from the southern Gulf of St. Lawrence, 1971 to 2014. Indices are based on the 24 strata fished since 1971.The 1971 to 1984 indices have been divided by 0.70 as an approximate adjustment for the difference in fishing efficiency between the vessel and gear used in this period and those used subsequently.

The estimated decline in the abundance of the adult length class from 1985 to 2014 (about three generations) was over 92% (Fig. 3a; Table 1). Most of the decline occurred from 1985 to 1996. Adult abundance declined by 86% from 1985 to 1996, with a further decline of 52% from 1996 to 2014 (Fig. 3b). Results were similar using age-based indices. The decline in the abundance of hake aged 4 years and older was estimated to be 84% from 1985 to 2013 (Fig. 3c). The greatest decline occurred from 1985 to 1995 (a decline of 84% over 10 years), whereas the statistically non-significant slope since 1995 (Fig. 3d) corresponds to a decline of 29% over 18 years (Table 1).

Mobile sentinel index (MS)

Age-aggregated abundance and biomass indices from the mobile sentinel survey declined over the 2003 to 2013 period (Fig. 4) with the lowest levels observed in 2011 to 2013. Catch rates were lower for all size groups in 2008 to 2013 compared to 2003 to 2007 with the greatest difference for the largest sizes.

Longline sentinel index (LL)

Catch rates in the sentinel longline program dropped dramatically over the 1996 to 2013 period. For the entire PEI and Nova Scotia region, catch rates declined at an annual rate of -0.28 (Fig. 5; Table 1), corresponding to a 99% decline over this 17-year period (about two generations). Considering only the St. Georges Bay area, the decline rate was 99.9% over two generations, with White Hake essentially now absent in this region. Declines were slightly less severe in the Cape Breton Trough area, at 93% over two generations.

Table 1. Estimated percent decline within periods of adult White Hake based on length (≥ 45 cm) and age (4+ years) indices from the September research vessel survey (RV) (1985 to 2014) and the fixed gear (longline) sentinel survey (1996 to 2013). The superscript “ns” means the slope is not statistically significant (p > 0.05) from zero.

Survey	Index type	Size/age group or area	1985 to 2013/2014	1985 to 1995/1996	1995/1996 to 2013 or 2014
RV survey (all strata)	length based	adult	92%	86%	52%
	age based	adult	84%	84%	29%^{ns}
Sentinel longline	length-based	PEI & Nova Scotia	na	na	99.2%
		St. Georges Bay			99.9%
		Cape Breton Trough			93.4%

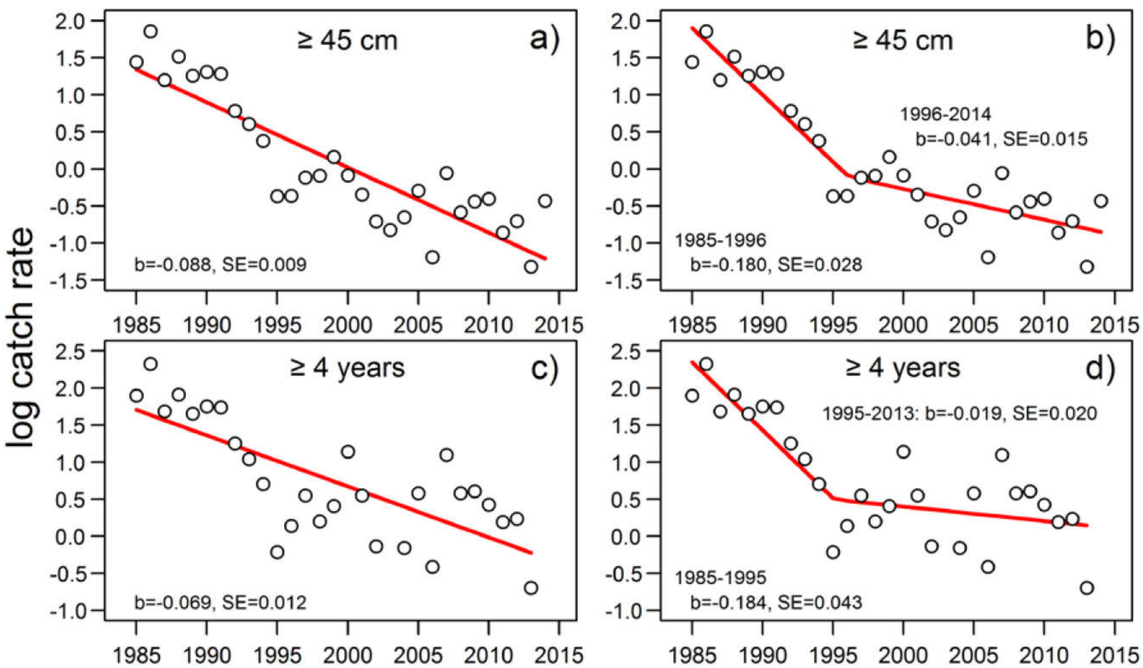


Figure 3. Log$_e$-transformed RV abundance indices for adult White Hake (≥ 45 cm or ≥4 years old). Lines show the regression (left) or piecewise regression (right) of log catch rate on year.

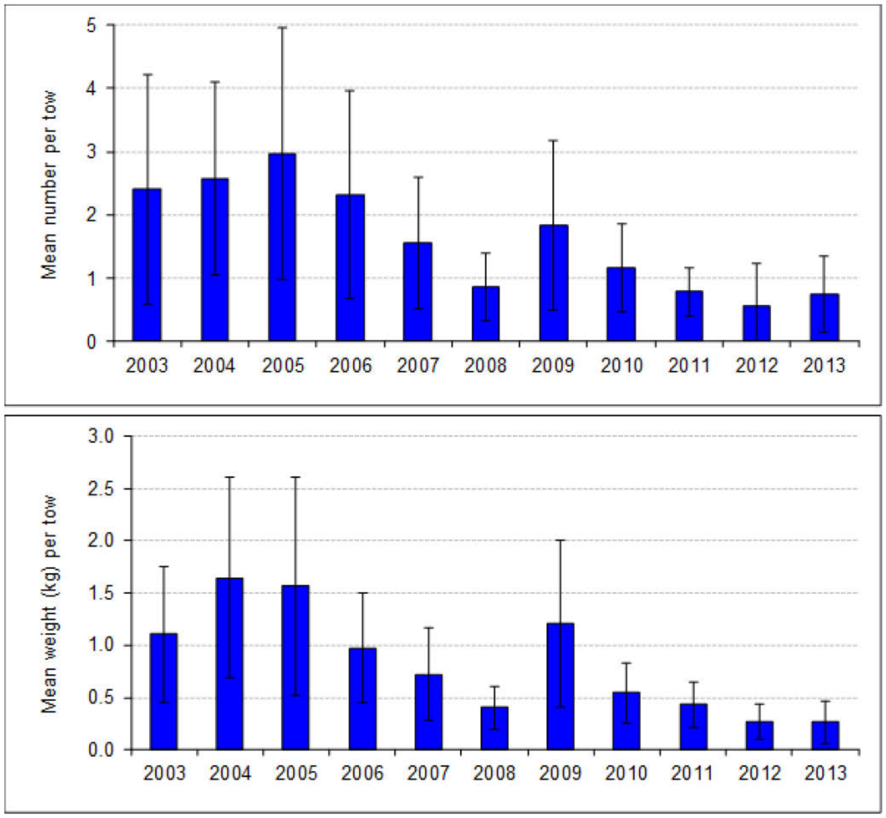


Figure 4. Mean numbers (top) and weight (bottom) per tow of White Hake in the sentinel bottom-trawl survey of the southern Gulf of St. Lawrence. Vertical lines denote approximate 95% confidence limits (± 2 standard errors).

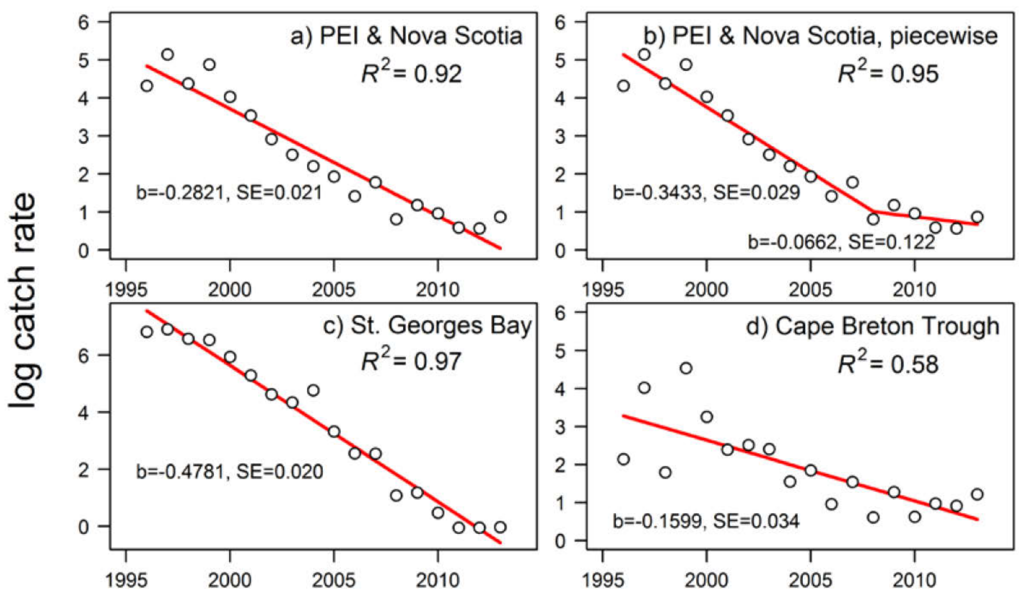


Figure 5. Decline rates in White Hake abundance indices in selected regions from the longline sentinel program, 1996 to 2013.

Population model estimates

Estimated adult biomass (or Spawning Stock Biomass, SSB) and abundance dropped sharply in the late 1980s and early 1990s (Fig. 6). Estimated SSB averaged 52,848 t during 1978 to 1982 and 6,516 t during 2009 to 2013, a decline of 88%. The estimated value of 3,844 t in 2013 was the lowest in the time series and represents a decline of 93% from the late 1970s and early 1980s. Estimated adult abundance averaged 46.32 million fish during 1978 to 1982 and 11.46 million fish during 2009 to 2013, a decline of 75%. Estimated abundance in 2013 averaged 6.17 million fish, a decline of 87% from the late 1970s and early 1980s. In contrast, estimated juvenile biomass and abundance fluctuated without trend over the 36-year time series (Fig. 6).

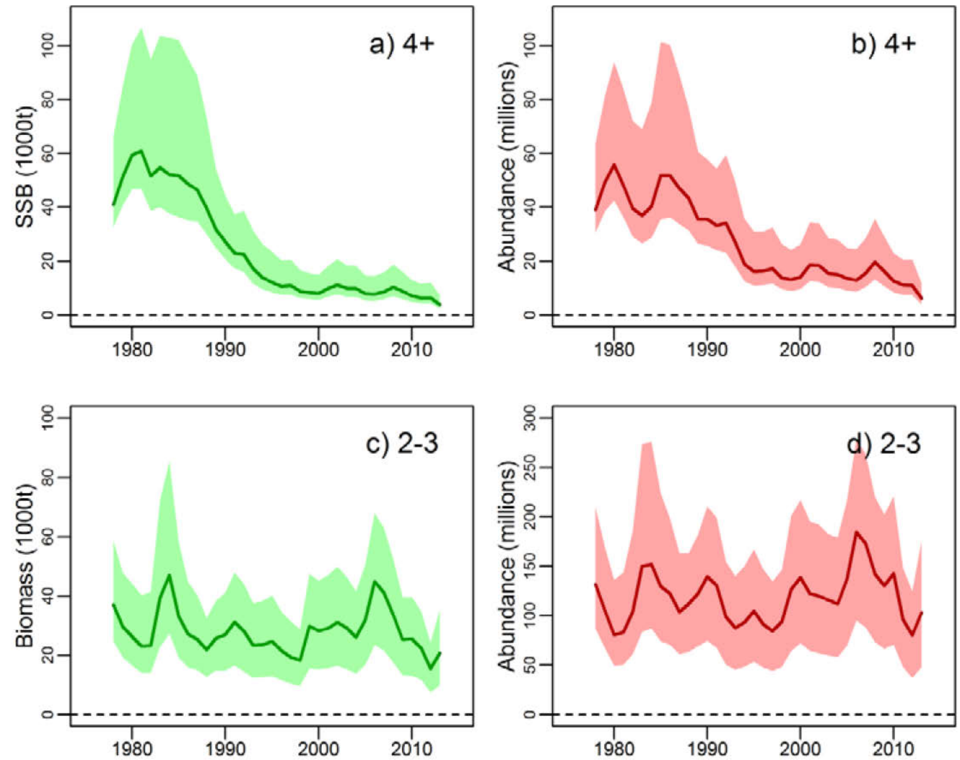


Figure 6. Estimated biomass (1,000 t; left column) and abundance (millions; right column) of adult (upper panels a and b) and juvenile (lower panels, c and d) White Hake in the southern Gulf of St. Lawrence. Lines show the maximum likelihood estimates and shading their 95% confidence intervals based on MCMC sampling.

Recent species distribution

White Hake from the sGSL overwinter at depths greater than 200 m in the Laurentian Channel in NAFO Div. 4T and Subdiv. 4Vn (the Cabot Strait). In summer, hake either remain in relatively deep water (> 100 m) or move into shallow water (mostly < 50 m) along the sGSL coasts of New Brunswick, PEI, mainland Nova Scotia and southwestern Cape Breton Island. The inshore migration generally begins in April and May and proceeds rapidly until June, by which time most of the traditional summer habitats are 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

Rainbow Smelt fisheries in some estuaries of the sGSL suggests that small juvenile hake may remain inshore in winter, overwintering near or in estuaries (Bradford et al. 1997).

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

Changes in distribution

The area occupied by adult-sized White Hake tended to increase in the 1970s to a peak in the early 1980s and then declined (Fig. 7). Area occupied peaked at values near 25,000 km^2, declining to values near 5,000 km^2 in recent years, an 80% reduction from the early 1980s. Juvenile-sized hake showed a different trend over time with the area occupied remaining relatively constant at values near 10,000 km^2, except for a temporary increase between the mid-1980s and early 1990s (Fig. 7).

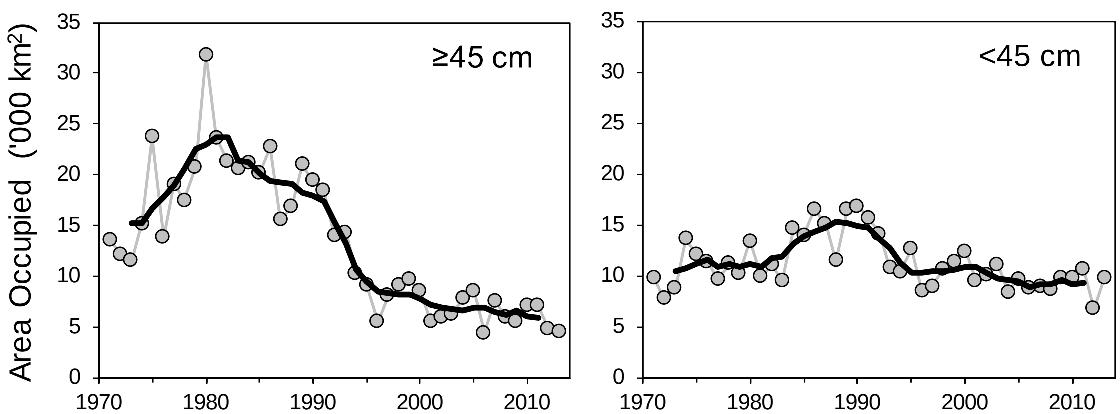


Figure 7. Area occupied (1,000 km,²) by two size classes of White Hake during September in the southern Gulf of St. Lawrence, 1971 to 2013. The size classes correspond roughly to adult (≥ 45 cm; left panel) and juvenile (< 45 cm; right panel) White Hake. The heavy lines are five-year moving averages.

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. 8 and 9). 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 (Fig. 8). This shift in distribution from shallow waters into deep waters has also been observed for other demersal fishes in the sGSL and appears to be a response to increased risk of predation by grey seals in inshore areas in summer (Swain et al. 2015).

Unlike adults, juveniles of White Hake were relatively rare in western regions of the inshore during the entire time period (Fig. 9). 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 areas but remained relatively high in the Cape Breton Trough and along the southern slope of the Laurentian Channel.

Based on catches in the MS survey, geographic distribution in August was similar to the distribution in September. Hake were already rare in inshore areas when this survey began in 2003. By 2012 to 3013, hake were nearly absent from inshore catches in this survey.

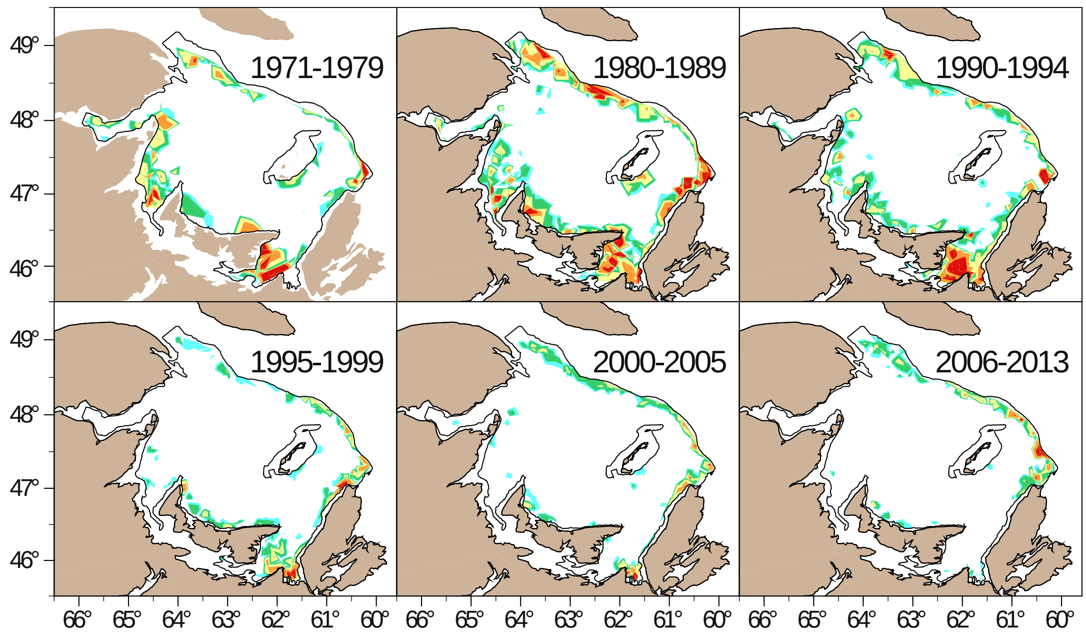


Figure 8. Geographic distribution of adult White Hake (≥ 45 cm) in the southern Gulf of St. Lawrence in September by time period. Contours intervals are the 10th (blue), 25th (green), 50th (yellow), 75th (orange) and 90th (red) percentiles of the non-zero catch rates. Inshore strata 401 to 403 covering the St. Georges Bay area and the inshore portion of northern PEI were not sampled in 1971 to 1983 which explains the absence of observations in those areas for those years.

These changes in spatial distribution are reflected in the depth and temperature associations of White Hake in the sGSL in September (Swain et al. 2012). In the 1970s, the highest proportion of hake occurred at depths less than 50 m (68% of adult-sized hake, 44% at juvenile sizes) (Fig. 10). In the 2000s, less than 10% of hake occurred in shallow waters. In contrast, the proportion occupying depths of 150 to 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 to 6°C temperature bin (Fig. 11). 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 reflected the shift in distribution out of shallow water and into depths greater than 100 m.

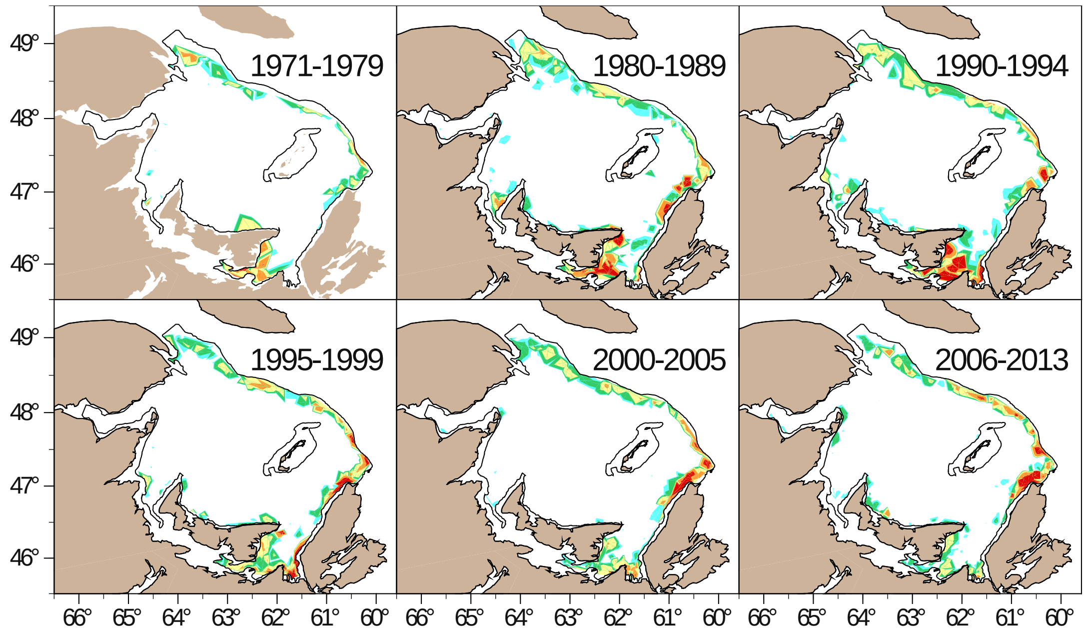


Figure 9. Geographic distribution of juvenile White Hake (< 45 cm) in the southern Gulf of St. Lawrence in September by time period. Contours intervals are the 10th (blue), 25th (green), 50th (yellow), 75th (orange) and 90th (red) percentiles of the non-zero catch rates. Inshore strata 401 to 403 covering the St. Georges Bay area and the inshore portion of northern PEI were not sampled in 1971 to 1983 which explains the absence of observations in those areas for those years.

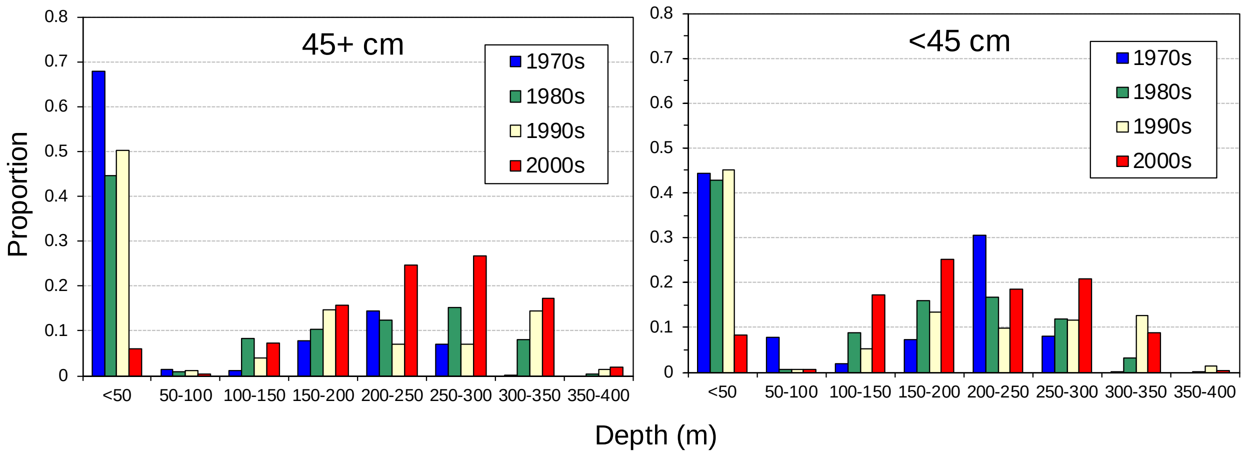


Figure 10. Proportions by depth category and approximate decades of White Hake catches from the September research vessel bottom trawl survey of the southern Gulf of St. Lawrence. The size classes correspond roughly to adult (45+ cm; left panel) and juvenile (<45 cm; right panel) White Hake.

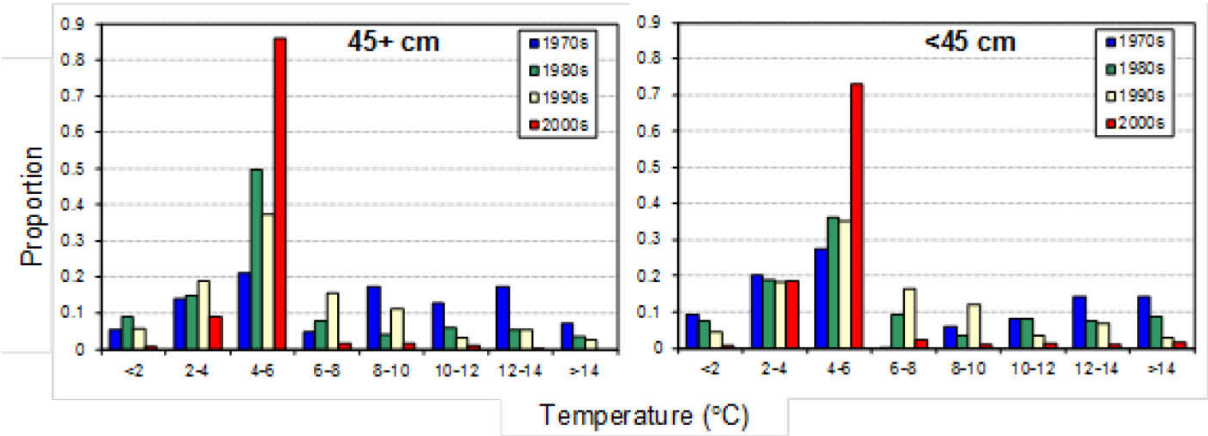


Figure 11. Proportions by temperature category and approximate decades of White Hake catches from the September research vessel bottom trawl survey of the southern Gulf of St. Lawrence. The size classes correspond roughly to adult (45+ cm; left panel) and juvenile (<45 cm; right panel) White Hake.

Current or recent life-history parameters

Age and size

The maximum length and age of White Hake observed in the September RV survey were 115 cm total length and 15 years, observed in 1974 and 1985, respectively. Because White Hake in the sGSL had been commercially exploited for many years at the time of these observations, historical maximum lengths and ages can be presumed to have been greater than these values. A dramatic contraction of the age composition of sGSL White Hake has occurred since 1971. Fish 10 years and older were commonly observed in the RV 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. 12).

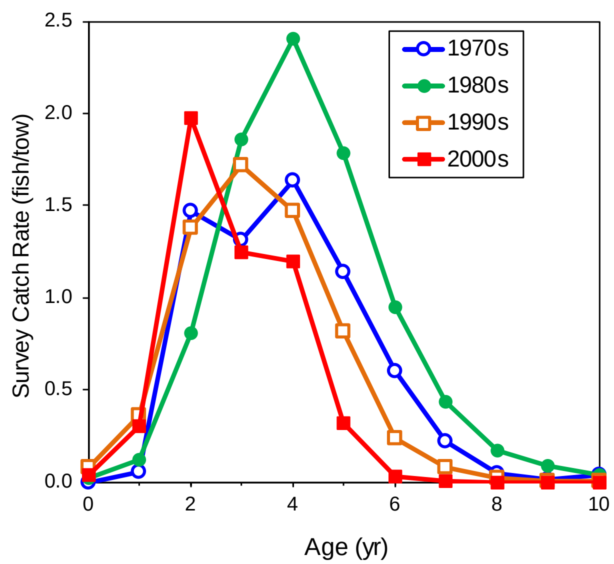


Figure 12. Catch rates (fish per tow) at age of White Hake in the September RV survey of the southern Gulf of St. Lawrence, averaged over approximate decade time periods, 1971 to 2013.

Age and length at maturity

Estimated lengths at 50% maturity were 40.7 and 48.2 cm for male and female White Hake, respectively, in the sGSL. Estimated ages at 50% maturity were 3.2 and 3.9 years for males and females, respectively. It is possible that age and size at maturity has declined somewhat since the 1970s.

Weight and condition at age

Mean weight at age of White Hake decreased in the mid to late 1980s for ages 4 to 6, but has fluctuated without trend since then (Fig. 13). Temporal trends in predicted weight at 45 or 55 cm (a measure of condition) were relatively minor (Fig. 13). 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.

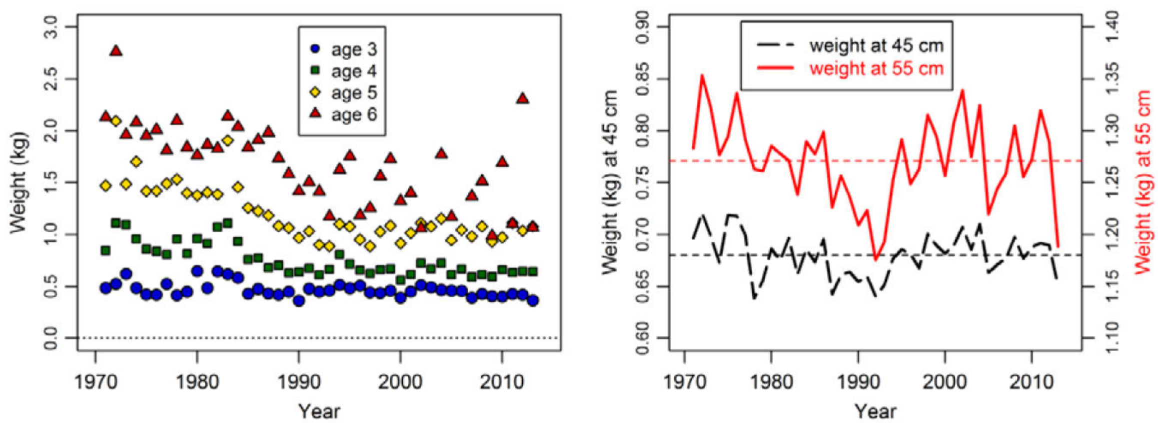


Figure 13. Stratified mean weights at ages 3 to 6 years (left panel) and condition indices (right panel; predicted weight at lengths of 45 cm (black dashed line) and 55 cm (red solid line)) of White Hake collected during the September RV survey of the southern Gulf of St. Lawrence.

Mortality rates

The instantaneous rate of total mortality (*Z*) was estimated from RV survey indices at age using a modified catch-curve analysis. Trends in *Z* were compared to trends in a survey-based index of fishing mortality, relative fishing mortality (*RF*, the ratio of fishery catch to the survey population), in order to infer trends in natural mortality. *RF* averaged 0.55 prior to the moratorium, dropping to an average of 0.09 during 1995 to 2005 and 0.03 during 2006 to 2010 (Fig. 14). In contrast, *Z* increased sharply beginning in the late 1980s, with estimated *Z* exceeding a value of 2 in the 2000s (Fig. 14). 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.

The instantaneous rate of fishing mortality (*F)* estimated from the population model has been negligible since the mid-2000s. In most years, the dominant source of mortality for sGSL White Hake has been natural mortality (*M*; Fig. 15). For juveniles (ages 2 to 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 to 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 and 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 (Fig. 15).

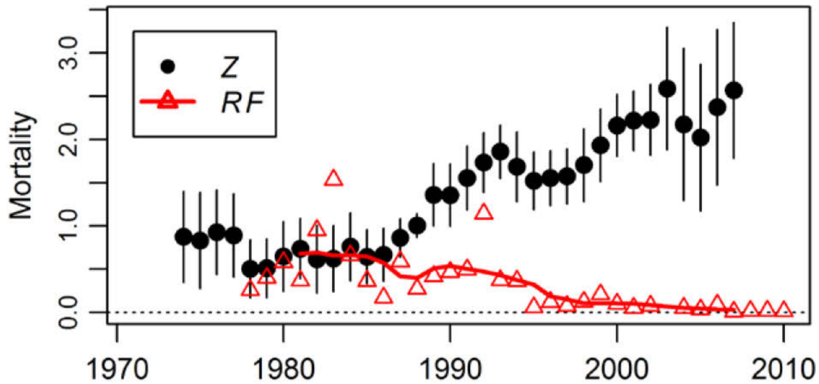


Figure 14. Relative fishing mortality (RF) and estimates of the instantaneous rate of total mortality (Z) for White Hake (ages 5 to 7 years) in the southern Gulf of St. Lawrence. Estimates of Z (closed circles) are derived from catch rates at age in the RV survey, calculated in moving 7-year blocks, 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).

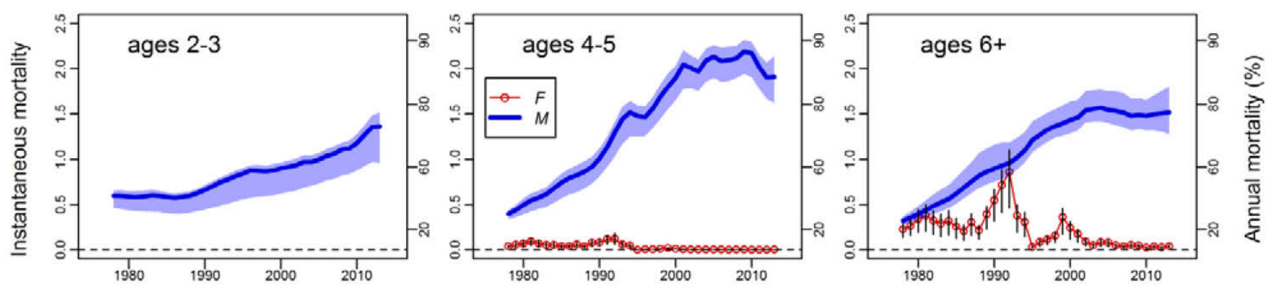


Figure 15. Estimated instantaneous rates of fishing (F) and natural mortality (M), from the population model, by age group of White Hake from the southern Gulf of St. Lawrence. Blue lines and red circles show the maximum likelihood estimates. Shading and vertical lines show their 95% confidence intervals 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).

The patterns of extremely high natural mortality seen in White Hake are also seen in other large demersal fish (i.e. adults of Atlantic Cod, American Plaice, Thorny Skate, Winter Skate, and other species) in the sGSL ecosystem. This high natural mortality rate 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). White Hake are an important component of grey seal diets (Hammill et al. 2014) and modelling has indicated that there is sufficient scope for predation by grey seals to explain the elevated levels of *M* (Benoit et al. 2011b).

Recruitment and recruitment rates

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.

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. 16a). 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. 16b). Hake are highly piscivorous, 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. Increases in the survival of small fish appear to be widespread throughout this ecosystem since the mid-1990s (Benoit and Swain 2008; Swain et al. 2012; Swain and Benoît 2015), and this ecosystem change may contribute to the increased recruitment rate of White Hake in recent years.

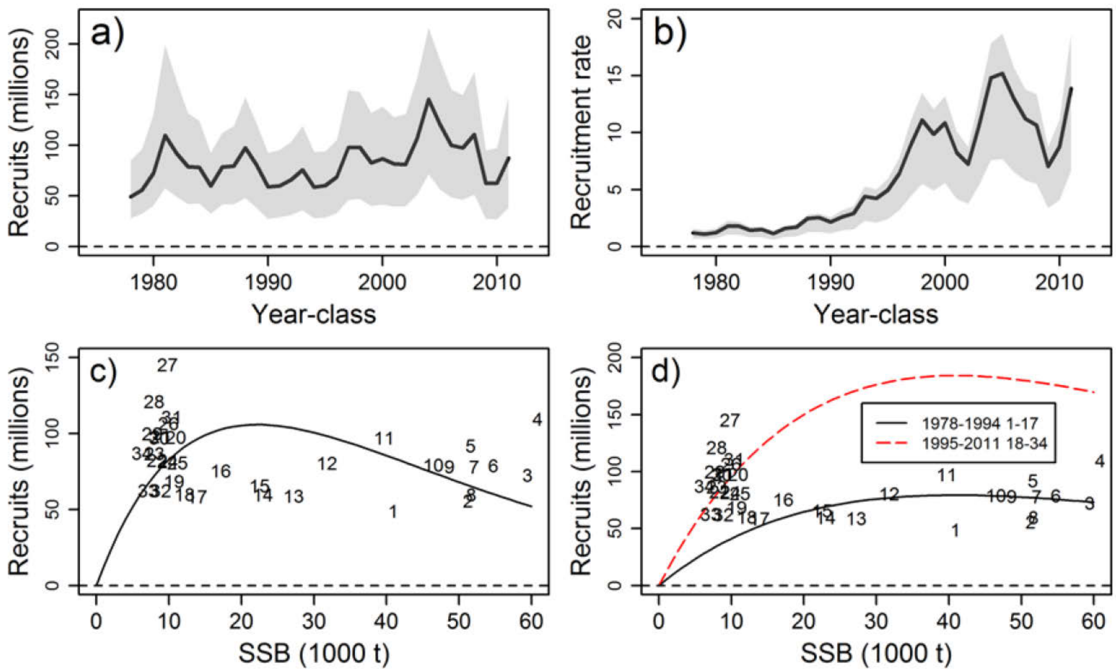


Figure 16. Stock and recruit relationship for White Hake from the southern Gulf of St. Lawrence. Panel a: the estimated abundance of age-2 recruits by year-class. Panel b: recruitment rate (age-2 recruits/SSB) by year-class. In panels a and b, lines show the maximum likelihood estimates and shading the 95% confidence interval. Panel c: fit of a Ricker model to the stock-recruit data (symbols indicate year-class). Panel d: fit of a Ricker model with a common β parameter and separate α parameters for the 1978 to 1994 and the 1995 to 2011 year-classes.

Habitat and Residence Requirements

Habitat properties

During the summer and early autumn, White Hake in the sGSL typically exhibit a bimodal distribution with respect to depth, with concentrations occurring in warm waters, either in shallow (<50 m) inshore areas or in deeper water (>100 m) further offshore. In the fall, White Hake from inshore areas migrate into the deep (>200 m) and relatively warm (4 and 5˚C) waters of the Laurentian Channel and Cabot Strait to overwinter. The return migration to the waters of the sGSL generally begins in April and May and proceeds rapidly until June, by which time most of the traditional summer habitats are occupied. It is thought that most sizes of White Hake undertake this inshore/shoreward movement in summer, and disperse to deeper waters in winter, but there is some uncertainty about the migration of juveniles. The significant bycatch of juvenile White Hake in some estuary fisheries in the sGSL during the autumn prompted speculation that juvenile White Hake may over-winter in or near some estuaries.

A striking shift has occurred in the summer habitat associations of White Hake (Figs. 8 and 9). In the 1970s, the majority (68%) of adult White Hake occurred in shallow inshore areas in September. In the 2000s, fewer than 10% of adults were distributed in these inshore areas. In recent years, adult hake have been nearly absent from the inshore in August and September. Juveniles exhibited a similar, but less dramatic, change in habitat associations.

White Hake are temperature keepers, showing a preference for water temperature above 4°C. In September, the majority of hake occurred at temperatures > 4°C (> 70-90%, depending on size class and decade). The highest proportion occurred in the 4 to 6°C range (Fig. 11). The proportion in this temperature range was much higher in the 2000s than in earlier decades, reflecting the shift in distribution into deep waters (where temperatures are mostly in this range). Over a short time period in the summer, juvenile White Hake have been found at low abundance within eelgrass habitat in a number of lagoons and estuaries in the sGSL (Joseph et al. 2013), leading the authors of that study to conclude that eelgrass habitats in numerous areas along the coast of the sGSL act as a network of habitat for hake juveniles to feed and take shelter.

Spatial extent of the habitat areas

White Hake were historically distributed in the shallow inshore areas of the sGSL and in the deeper waters along the slope and in the Laurentian Channel (Figs. 8 and 9). The physical characteristics of these habitats (temperature, salinity) are still available to White Hake and there has been no apparent change in the spatial extent of this suitable habitat.

Presence and extent of spatial configuration constraints

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 White Hake occupied these inshore areas in summer. However, over time, the distribution of adult hake has shifted out of these areas into deeper water. Based on catches in the RV and MS surveys in recent years, the inshore areas appear to be virtually abandoned. White Hake appear to have abandoned these inshore areas due to the extremely high risk of predation by grey seals that now occupy these areas (Swain et al. 2015). This high predation risk leads to 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 (Swain et al. 2016). The sustained presence of juvenile White Hake in the inshore areas could indicate that spawning continues in the inshore areas or alternatively, that the extended pelagic phase of White Hake juveniles allows the inshore areas to be colonized from spawning in offshore areas.

Concept of residence for White Hake

The SARA defines “residence” as:

> “a dwelling-place, such as a den, nest or other similar area or place, that is occupied or habitually occupied by one or more individuals during all or part of their life cycles, including breeding, rearing, staging, wintering, feeding or hibernating” (s.2(1)).

White Hake do not have any known dwelling-place similar to a den or nest during any part of their life cycle therefore, in accordance to the DFO June 2013 policy statement on the

"Application of Species at Risk Act Section 33 (Residence) to Aquatic Species at Risk" the concept of residence does not apply to White Hake.

Threats and Limiting Factors to the Survival and Recovery

Threats

COSEWIC (2013) indicated that the main threat to White Hake of the sGSL population is the exceedingly high level of non-fishing mortality (*M*) experienced by fish in the 1 to 3 and 4+ age groups (Swain et al. 2012). The source and consequence of exceedingly high non-fishing mortality are discussed in the section "Natural factors that limit the survival and recovery". The existing sources of mortality on White Hake resulting directly from human activities are presented below.

Fishing

Landings in commercial fisheries in NAFO Div. 4T fluctuated between about 4,000 and 7,000 t between 1961 and 1978, and 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 to 1992 (Fig. 17). The fishery for White Hake in NAFO Div. 4T was closed in January 1995, and has remained under moratorium since then. With the closure of directed hake fishing, reported landings dropped from 1,042 t in 1994 to 71 t in 1995, but then increased steadily to 400 t in 1999. Since then, reported annual landings, as bycatch in fisheries directing for other groundfish, declined to a level near 30 t in 2006 to 2009. Since 2010, reported bycatch in NAFO Div. 4T groundfish fisheries has been 20 t or less. The distribution of the sGSL DU of White Hake extends into the northwest portion of NAFO Subdiv. 4Vn. No directed fishing for White Hake is permitted in this region and reported bycatch in this area is low, averaging 44 t annually since 2000 and 23 t annually since 2010 for the entire subdivision.

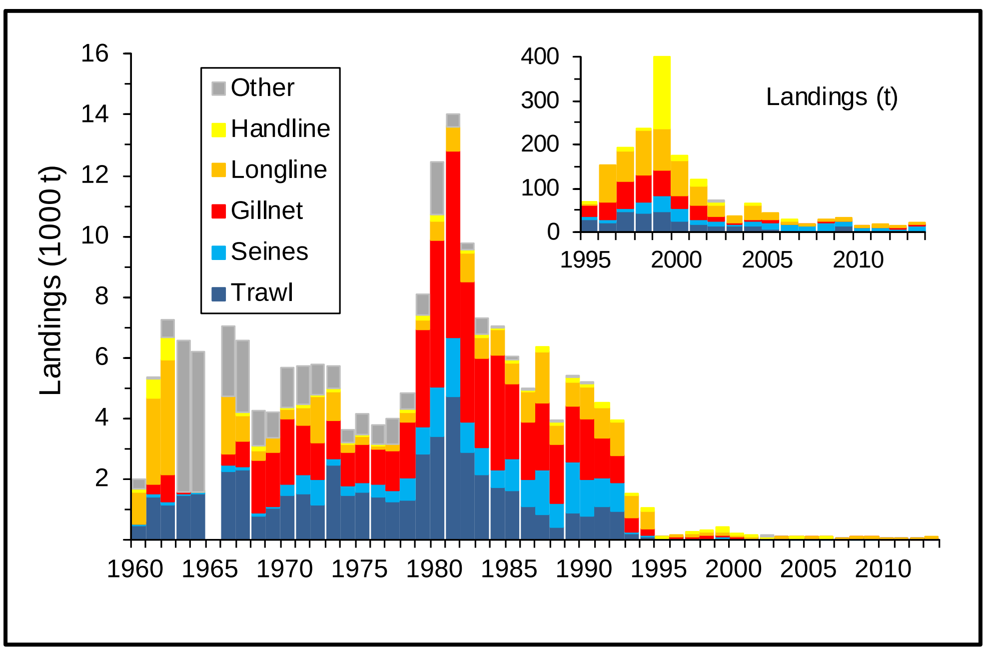


Figure 17. Landings (1,000 t) by gear type of White Hake in NAFO Div. 4T.

Adult White Hake are also incidentally captured in sGSL scallop and lobster fisheries. Preliminary analyses suggest that catches in the scallop fishery are very small (Benoît 2011).

White Hake catch amounts in the lobster fishery are unknown, though adult White Hake are reported to be very rarely encountered in the traps (Swain et al. 2016).

A recreational fishery for groundfish remains open in NAFO Div. 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 to August 17 in some areas and as late as August 30 to October 5 on PEI. No licences are required. There is a daily bag limit of five cod and/or White Hake. Landings by this fishery are unknown, but based on anecdotal information the estimated catch of White Hake 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 NAFO Div. 4T with 5% observer coverage. No catches of White Hake have been reported for this fishery.

There is a documented bycatch, but no retention, of White Hake in estuarine fisheries for Rainbow Smelt in the sGSL. The hake caught in this fishery are normally <25 cm in length (Bradford et al. 1997). 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 White Hake, the impact of this fishery on pre-recruit abundance appears to be small.

The instantaneous rate of fishing mortality (*F*) since 2006, estimated from the population model, has averaged less than 0.00004 for ages 2 to 3, 0.004 for ages 4 to 5, and 0.055 for ages 6+. Average *F* for ages 4 and 5 combined was low for the entire time series, peaking at 0.12 in 1992 (Fig. 15). While *F* on 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, indicating that landings as low as about 100 t would result in substantial fishing mortality (*F* = 0.23).

Offshore Oil Development

Oil and gas development has been proposed at the Old Harry site in the Laurentian Channel. Spills or blow-outs from any such development could pose a risk to sGSL hake, which occupy waters adjacent to this site. White Hake abundance in this DU is being supported by high recruitment rates and since adults only survive a year or two after maturing, the consequence of the loss of one year class to the population could be devastating, particularly for the offshore spawning component of White Hake and on the pelagic juvenile phase.

Activities most likely to damage or destroy the habitat properties

Spills or blow-outs from any offshore oil development could pose a risk to the habitat used by offshore spawning White Hake and to the habitat used by the pelagic juvenile phase of White Hake. No other activities were identified that could damage or destroy the habitat properties for White Hake.

Natural factors that limit the survival and recovery

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, productivity at earlier life-history stages (< 2 years old) 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 *M* for ages 2+.

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 adults of large demersal fish (i.e., White Hake, Atlantic Cod, American Plaice, Thorny Skate, Winter Skate, and other species 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. 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. (2011b) came to a similar conclusion for White Hake. White Hake are an important prey of grey seals in the sGSL (Hammill et al. 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). 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 shore 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.

Recovery Targets

Candidate abundance and distribution targets for recovery

Abundance Target

An abundance target corresponding to a sustained increase in Spawning Stock Biomass (SSB) to a level equal to or above 40% of the SSB producing the maximum surplus production is proposed. This target is considered to be an indicator of recovery from a high risk of extinction but it does not correspond to a reference point for sustainable fisheries exploitation under the Precautionary Approach (DFO 2009).

The recent period (1995 to 2013) was deemed to be inappropriate for deriving this target (Swain et al. 2016). Thus, this target was estimated using a stock-recruit model (solid line in Fig.16d) based on parameters (recruitment rates, mortality rates, weight at age) for the 1978 to 1994 period. SSB that produces maximum surplus production is 32,000 t and the corresponding recovery target is 12,800 t of SSB. Estimated SSB has been below the abundance target since 1995. Based on the population model, there is no chance that the SSB in 2013 is at or above this target. The SSB estimate for the most recent year (2013) is 3,844 t, about 30% of the abundance target.

High natural mortality has resulted in a contraction of the adult age structure. White Hake 10 years and older were common in the sGSL in the 1970s and 1980s, but no hake older than 7 years of age have been observed in the survey since 1998. In addition to the abundance target described above, recovery of the sGSL population of White Hake would be considered to have been attained when the age structure of the adult stock had expanded to that observed in the higher abundance period of the 1970s and 1980s.

Distribution target

The return of White Hake to inshore waters of the sSGL, the areas where they predominantly occurred in summer in the 1970s to 1990s, is proposed as a distribution target for recovery. Prior to the 2000s, approx. 50% of White Hake caught during the September RV survey were captured in the inshore area at depths <50 m (Fig. 10).

For adult White Hake, area occupied declined by about 75% from the early 1980s to recent years (Fig. 7). For juveniles, area occupied in recent years was about 40% of the peak values in the late 1980s and early 1990s, and was similar to the area occupied by juveniles in the 1970s.

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 White Hake occurred in these inshore waters (68% of adults, 58% of all sizes). By the 2000s, these proportions had dropped to 6% of adults (Fig. 10) and 8% of all sizes. In the past, these inshore waters contained important spawning grounds for White 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). White Hake now appear to be abandoning the remaining inshore spawning grounds (e.g. St. Georges Bay), judging from the near absence of adult White 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.

Expected population trajectories over three generations

Populations were projected forward 60 years assuming the current productivity conditions. For each age group, M was set equal to the average of the last 5 years (2009 to 2013). For each projection year, the weight-at-age vector was randomly selected from those observed over the last 20 years (1994 to 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) and was multiplied by SSB to obtain recruit abundance. The second approach used a Ricker stock and recruitment model with the density-independent recruitment rate parameter based on the recent productive period. A randomly selected residual from the Ricker model was added (on the log scale) to the predicted recruitment in each year. Uncertainty in the population model results was incorporated in the projections based on 5,000 Monte Carlo samples.

The on-going declines in SSB and adult abundance persisted in the projections (Fig. 18). Projected SSB and adult abundance approached 0 about 15 years into the future, with extinction beginning in about 2045. The probability of reaching the abundance recovery target under current conditions was 0 even with no fishing. There was a 5% probability of extinction about 45 years into the projection (Fig. 18). At the end of the 60-year 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 (Fig. 19).

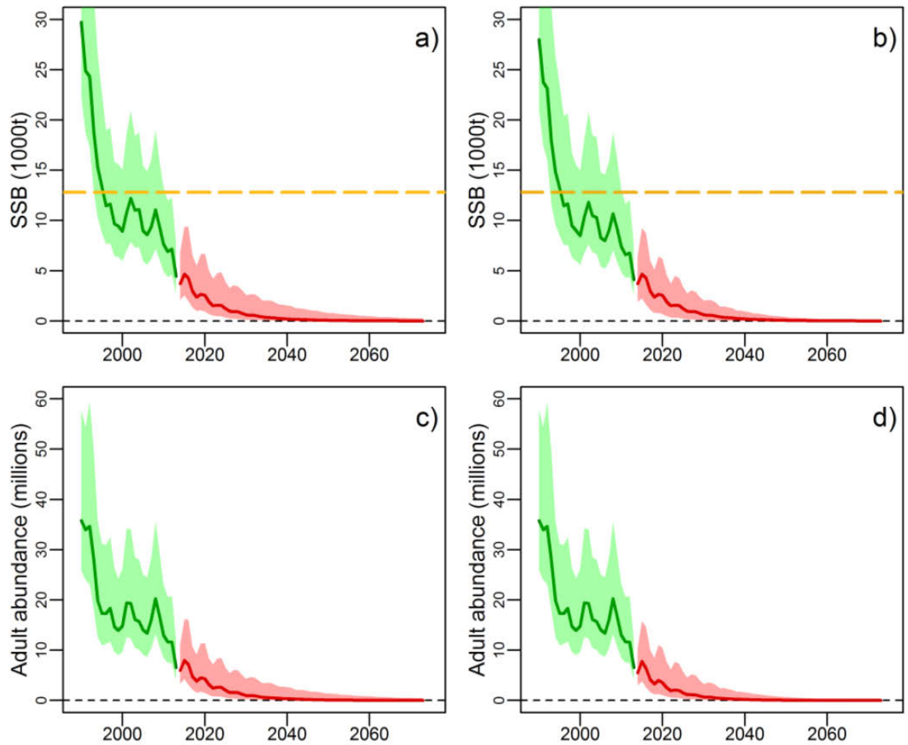


Figure 18. Projected spawning stock biomass (SSB in 1,000 t; upper row panels a and b) and adult abundance (millions; lower row panels c and d) of southern Gulf of St. Lawrence White Hake assuming current productivity and no fishing mortality. Projected recruitment was based on a stock-recruit relationship (left panels a and c) or based on randomly selected recruitment rates from the high productivity period (1995 to 2013) (right 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 dashes in the upper row of panels show the biomass recovery target (12,800 t).

At the fishing rates considered, the impact of fishing on the projected adult abundance was negligible (Fig. 19). This is a consequence of the extremely high level of natural mortality currently experienced by this population. 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.

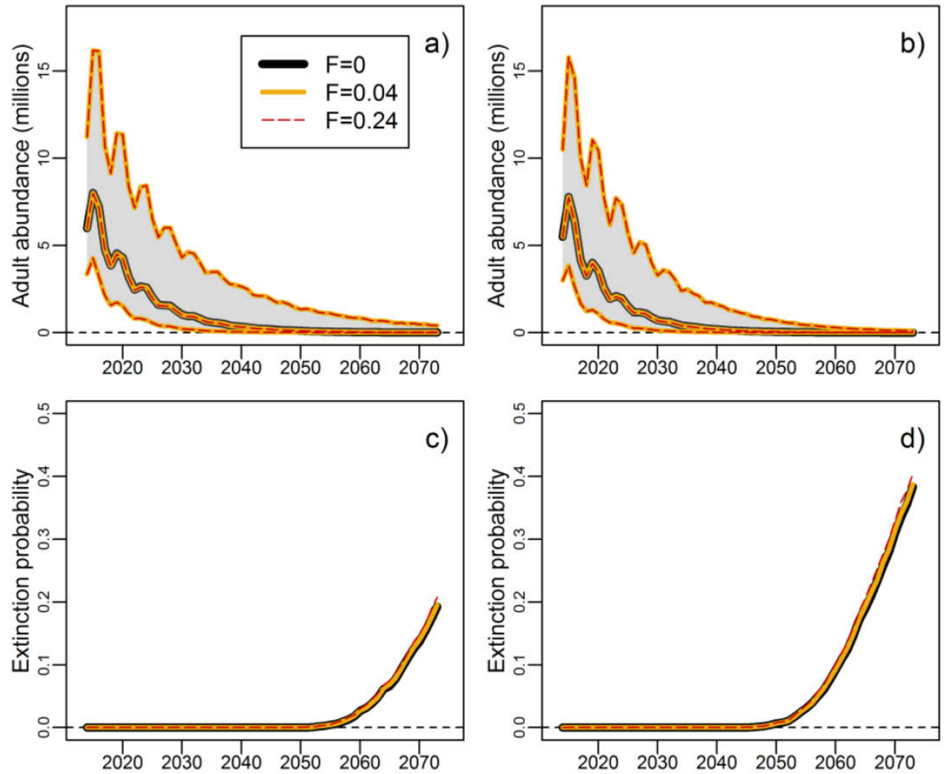


Figure 19. Projected adult abundance (millions; upper row panels a and b) and extinction probability (lower row panels c and d) of southern Gulf of St. Lawrence White Hake assuming current productivity and various levels of fishing mortality (F). Outcomes are based on projecting recruitment from a stock-recruit relationship (left column, panels a and c) or based on randomly selected recruitment rates from the high productivity period (1995 to 2013) (right column, panels b and d). In panels a and b, the median and 2.5th and 97.5th percentiles of the projected abundance is indicated by the thick black line and grey shading for F = 0, and by the coloured lines for higher F values.

Supply of suitable habitat at present and when the species reaches the potential recovery target(s)

In the past, the inshore waters contained important spawning grounds for White Hake. 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 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. There are no indications that the physical habitat characteristics of the inshore areas would not be suitable for spawning should White Hake return to the inshore areas.

Probability of achieving potential recovery target(s) with different mortality and productivity parameters

Projections were conducted at reduced levels of *M* using the same methods described above except for the following inputs. First, *F* was set equal to 0 for all projections. Second, for each iteration, *M* for the projection was set to a specified percentage of the average *M*-at-age from 2009 to 2013. Projections were conducted using a Ricker stock-recruit model assuming that the current conditions of high recruitment productivity persisted over the projection period.

Assuming that recruitment productivity remained high, a 20% reduction in *M* at all ages was sufficient to halt the decline in SSB (Fig. 20a). The probability that SSB exceeded the abundance recovery target in 30 years was 27% (Fig. 20d). A 30% reduction in *M* resulted in a rapid increase in SSB during the projection, with the probability of exceeding the abundance recovery target equal to 41% in 10 years and 95% in 30 years (Fig. 20b, 20d). With a 40% reduction in *M*, the probability that SSB would exceed the target level was 51% in 6 years and 100% in 20 years (Fig. 20c, 20d).

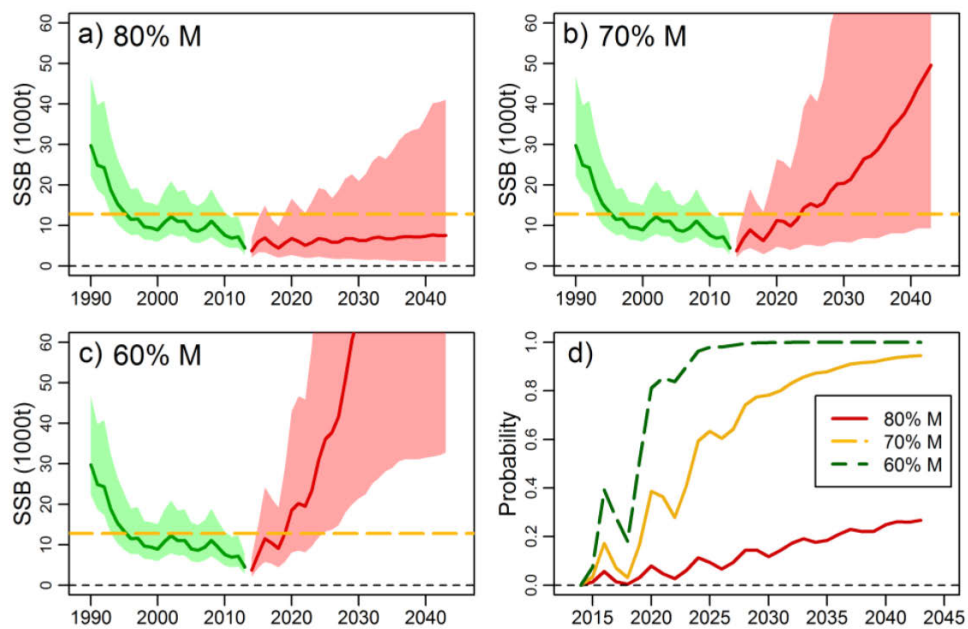


Figure 20. Projected spawning stock biomass (SSB in 1,000 t; panels a to c) of White Hake of the southern Gulf of St. Lawrence and the probability of exceeding the abundance recovery target at reduced levels of M (panel d), assuming that recruitment productivities were to remain at the current high level. In panels a to c, the long dashed horizontal line in each panel is the abundance recovery target value. Similarly in these panels, green lines and shading show the median estimates and 95% confidence bands for the recent period (1990 to 2013) and red lines and shading show the median values and 95% confidence bands for the projection.

The 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 (Benoît and Swain 2008; Swain et al. 2013; Swain and Benoît 2015). 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). If natural mortalities of adult White Hake and other large demersal fish were to decline, recruitment productivity might be expected to decline as a result of increased predation on small fish by an increasing abundance of large demersal fish. The consequences of this possibility were explored by conducting projections that assumed a return to lower recruitment productivity.

Under the conditions of low recruitment productivity, reductions of *M*-at-age by 40% and 50% were insufficient to halt the decline in SSB but a 60% decline in *M* allowed SSB to increase (Fig. 21). The probability that SSB would exceed the recovery target after 30 years was 0.025, 0.11, and 0.77 with *M* reductions of 40%, 50%, and 60%, respectively. The probability of extinction after 60 years was 38%, <0.02%, and <0.02%, respectively.

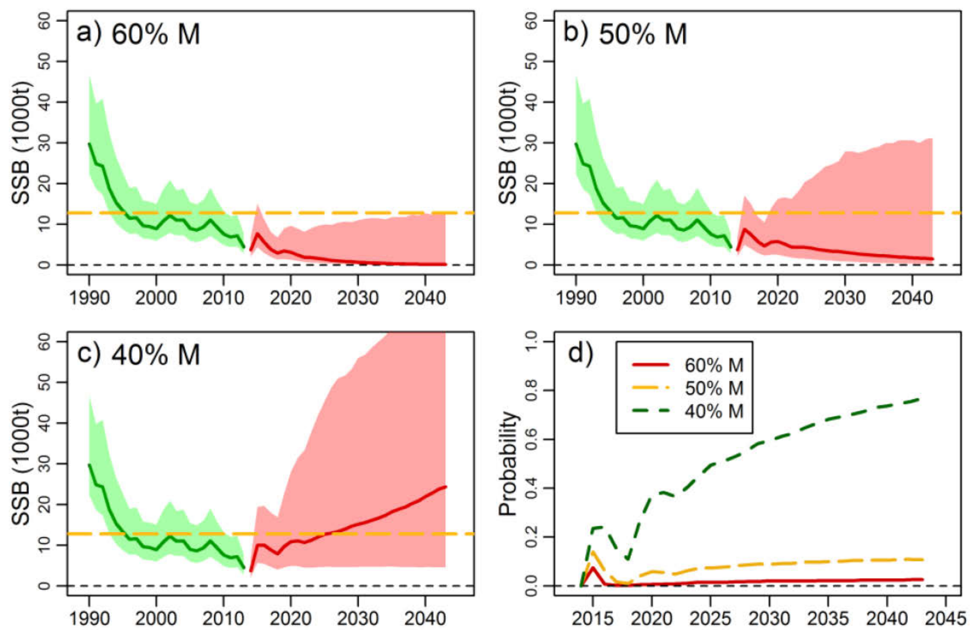


Figure 21. Projected spawning stock biomass of southern Gulf of St. Lawrence White Hake (1,000 t; panels a to c) and the probability of exceeding the abundance recovery target (panel d) at reduced levels of M, assuming that recruitment productivity were to return to its earlier low level. In panels a to c, 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 horizontal line in each of panels a to c is the abundance recovery target value.

Finally, projections were conducted under the hypothesis that the high recruitment rates over the past 20 years entirely reflect compensatory recruitment dynamics, as opposed to being partly due to ecosystem change. Under this assumption, a decline in *M* by 20% was sufficient to halt the decline in SSB, with a 10% probability of exceeding the abundance recovery target in 30 years (Fig. 22). With declines in *M* by 30% or 40%, this probability increased to 67% and 99% respectively. There was a 97% probability of exceeding the abundance recovery target in the seventh projection year with a 50% reduction in M.

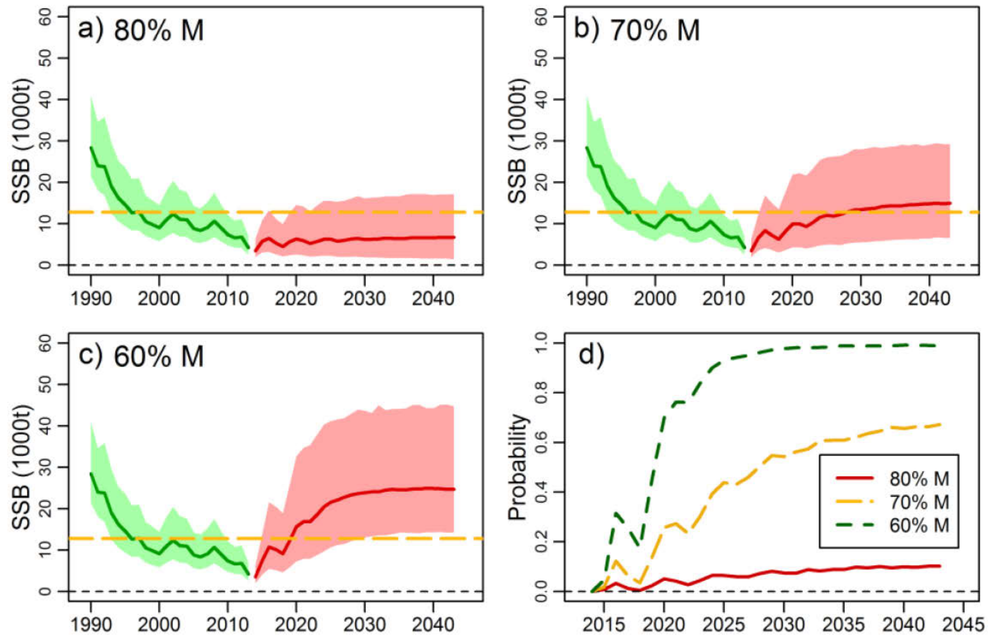


Figure 22. Projected spawning stock biomass of SGSL White Hake (1,000 t; panels a to c) and the probability of exceeding the abundance recovery target (panel d) at reduced levels of M, assuming that there has been no change in recruitment productivity over the assessment period. In panels a to c, green 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 horizontal line in each of panels a to c is the abundance recovery target value.

Scenarios for Mitigation of Threats and Alternatives to Activities

Inventory of feasible mitigation measures and reasonable alternatives to the activities that are threats to the species and its habitat

Fisheries

Although current (fully-recruited F = 0.04) and recent (fully-recruited F = 0.24) fishing mortality rates have a negligible impact on the population trajectory, there continues to be bycatch mortality on White Hake from fishing activities.

The majority of White Hake landings since the closure of the directed fishery in 1995 have come from trips where White Hake, cod or Redfish were the main species caught (Fig. 23). “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 White Hake landings in 2006 to 2008, as were Atlantic Halibut trips in 2011, turbot trips in 2012 and Winter Flounder trips in 2013.

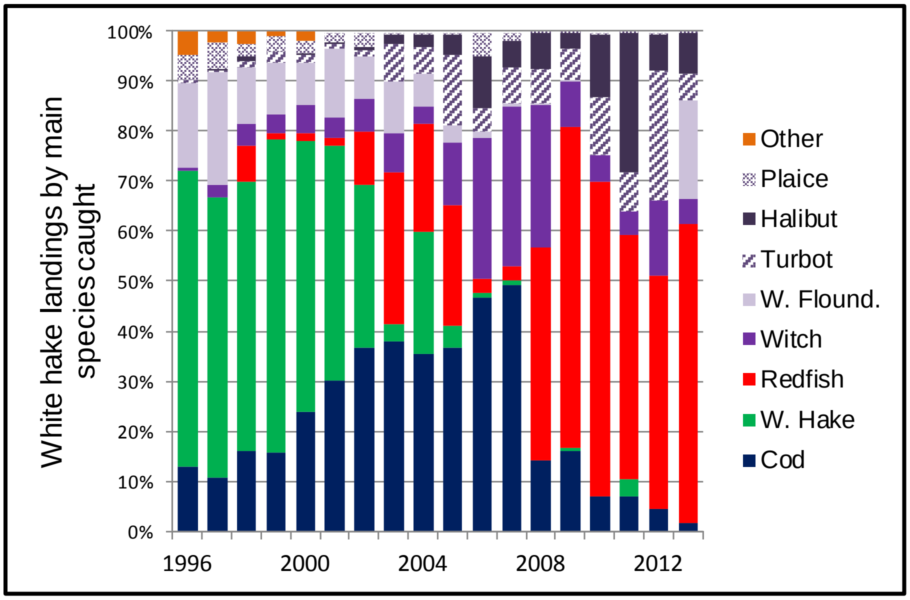


Figure 23. Proportion of total annual reported landings of White Hake by main species caught in NAFO Div. 4T, 1996 to 2013.

Reported landings in NAFO Div. 4T as bycatch in fisheries directing for other groundfish have been very low in recent years, ranging between 14 and 33 t from 2009 to 2013. These landings occurred primarily in June and July, and consisted predominantly of White Hake aged 4 to 6 years (Fig. 24). White Hake occurring in the northwest portion of NAFO Subdiv. 4Vn are also attributed to the sGSL DU. Reported landings of White Hake bycatch in NAFO Subdiv. 4Vn were also at very low levels in recent years, 15 and 16 t in 2012 and 2013, respectively, and less than 40 t since 2008.

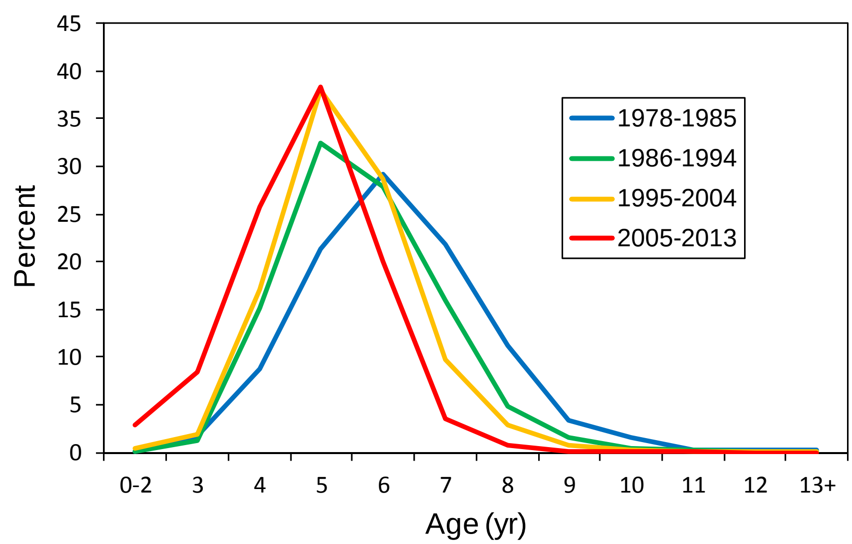


Figure 24. Age composition (%) of the landings of White Hake in NAFO Div. 4T.

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 this bycatch is comprised of juvenile fish.

Adult White Hake are incidentally captured in sGSL scallop and lobster fisheries. Analyses suggest that catches in the scallop fishery are very small (Benoît 2011). 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. 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.

The amount of hake caught in the recreational fishery for groundfish is unknown but anecdotal information suggests that it is negligible, at no more than 0.5 t.

Juvenile White Hake are captured in the Miramichi estuary fall open-water bagnet and boxnet Rainbow Smelt fishery. A remedial action to reduce bycatch of juvenile Striped Bass and White Hake delayed the opening date of the fishery to November 1 for the Miramichi River in 1999 (DFO 2011b). There is also a license condition that requires the sorting and release of all groundfish captured in smelt fishing gear. This measure is not likely to 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 was reported to be substantial (Bradford et al. 1997).

Since the closure of the directed commercial fishery for White Hake in 1995, a variety of management measures have been implemented to minimize the bycatch of White Hake (Table 2).

Potential additional measures to further reduce direct mortality from fishing on White Hake and their expected effectiveness include:

- Elimination of the retention of bycatch of White Hake in commercial fisheries and in recreational groundfish fisheries. Given the high post-release mortality of White Hake due to swim bladder distention, the benefits of this measure to reducing direct mortality are considered negligible.
- Reduced bycatch quota and closure of the fisheries when the bycatch quota has been attained. At present, the closure of marine fisheries when the bycatch quota for White Hake has been attained is discretionary. Since mandatory release of White Hake is not expected to result in any reduced mortality, reducing mortality on White Hake when the bycatch quota is exceeded could only be achieved by closing fisheries.
- Closure of the groundfish recreational fishery in St. Georges Bay. This is considered to be the most important area for recreational catches of White Hake. Closure of this fishing area would eliminate this source of mortality but the catches are thought to be low (no more than 0.5 t annually). If correct, the impact of this measure would not be measurable.
- Inseason closure of areas where White Hake bycatch in individual trips exceeds an identified percentage of the retained groundfish catch.
- Closure of the estuarine Rainbow Smelt fisheries. Juvenile White Hake are captured in the estuary fall open-water bagnet and boxnet smelt fisheries in 4T. There is no retention of any groundfish species at present but post-release survival of hake bycatch is considered to be very poor. The recruitment rates for White Hake are currently exceptionally high and the potential benefits of closing this fishery on pre-recruit abundance are likely inconsequential.

Table 2. Current fisheries management measures for White Hake.

Management measure	Area	Specific
Quota for total bycatch (including recreational, scientific, aboriginal FSC fisheries)	4T	30 t
	4Vn	90 t
Maximum allowable bycatch by fishing expedition		15% in Redfish 10% when directing for American Plaice, Witch Flounder, Winter Flounder and Atlantic Halibut
Small fish protocol	By fleet sector	<15% in numbers of hake < 45 cm
Fishing seasons		Deferred openings of groundfish fisheries to allow spring hake migration into inshore spawning areas
		Delayed opening of the fall open-water boxnet / bagnet estuary fisheries to November 1 to reduce bycatch of juvenile hake
Area closures	St. Georges Bay	Moratorium on longline fishery (except sentinel)
	4Vn and 4T	No directed fishing for White Hake

Other potential measures associated with improved information and monitoring of White Hake catches include:

- Increased at-sea observer coverage in the groundfish fisheries in NAFO Division 4T.
- Mandatory logbooks for reporting effort and catches in the recreational groundfish fisheries.
- Mandatory recording of White Hake bycatch in lobster fishery logbooks.

Inventory of activities that could increase the productivity or survivorship parameters

The lack of recovery and on-going decline of sGSL White Hake is due to the exceedingly high natural mortality of adult hake. If this high natural mortality persists, any additional measures to further reduce the already low fishing mortality will be ineffective in promoting recovery. Elevated levels of adult natural mortality are widespread among large-bodied demersal fish in the sGSL (Swain and Benoît 2015), and are thought to be due to the high and increasing abundance of grey seals, an important predator of these fishes, combined with the depleted abundance of these fishes (see above). If so, activities to reduce the abundance of grey seals foraging in the sGSL may increase the survivorship of White Hake, though other unexpected ecosystem changes resulting from these activities could prevent this result from being realized.

Feasibility of restoring the habitat to higher values

Physical habitat characteristics are not considered to have been degraded and be limiting to White Hake recovery. On the other hand, access to much of this habitat appears to be restricted by the very high risk of predation by grey seals that now exists in inshore areas in summer (Swain et al. 2015). Historically, the majority of adult White Hake utilized these inshore areas in summer, but it is unlikely that they will resume use of these areas until predation risk is reduced.

Reduction in mortality rate expected by each of the mitigation measures or alternatives and the increase in productivity or survivorship associated with each measure

Depending upon future recruitment productivity, a reduction of 50% or more in the natural mortality of adult White Hake may be required to recover populations above the recovery targets. The population size of grey seals that would correspond to these reduced levels has not been determined (Benoît et al. 2011a; DFO 2011a). 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 White Hake if they comprised 12% of the diet of overlapping seals and 4% of the diet of the entire Gulf herd.

Expected population trajectory (and uncertainties) and time to reach recovery targets, given reduced mortality rates and increased productivities

It is possible that changes in natural mortality (*M*) and recruitment productivity are not independent. Recent increases in productivity at early life-history stages have been associated with increased *M* and reduced abundance of adult demersal fish (Swain and Benoît 2015). Thus, the current high recruitment productivity may be due in part to a release of small fish from predation following the collapse in the biomass of large demersal fish (Benoît and Swain 2008). If so, recruitment productivity would be expected to decline from its current high level as *M* at older ages declines and the abundance of large demersal fish increases, increasing predation on early life stages. The effect of recruitment productivity on the reduction in *M* required to permit recovery and the associated time to recovery is described above.

Parameter values for population models for additional scenarios analyses

Models for assessing trajectories for White Hake from the sGSL population have been described, reviewed and accepted as appropriate for assessing management scenarios associated with recovery (see section Expected population trajectories over three generations).

Allowable Harm Assessment

Reported landings as bycatch in groundfish commercial fisheries in NAFO Div. 4T averaged 21 t (annual range of 14 to 33 t) during 2009 to 2013. Harvests of White Hake in all other fisheries are unknown but assumed individually to be less than the groundfish bycatch (Table 3). Losses of White Hake in the DFO research vessel scientific survey are less than 0.5 t per year. Reported bycatch of White Hake in Subdiv. 4Vn averaged 24 t since 2009; White Hake from the sGSL population may be included in these landings. Since 2006, the fishing mortality rate (*F)* is estimated to have been below 0.00004 for ages 2 to 3, 0.004 for ages 4 to 5 and 0.055 for ages 6+. While *F* on White Hake has been negligible since the mid-2000s, the population is now so low that very small landings can cause significant fishing mortality.

The population trajectories in projections using the 2009 to 2013 fully-recruited average *F* of 0.04 (median value), the 1998-2002 average *F* of 0.24, or *F* = 0 were indistinguishable, indicating the impact of fishing at these rates on probabilities of recovery can be considered negligible (Fig. 19, above). This is a consequence of the extremely high level of natural mortality currently experienced by this stock. 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.

Table 3. Fishery related losses (t) of White Hake in commercial and recreational fisheries, and scientific activities in NAFO Div. 4T.

Fishery	Gear	Age / size group	Mean (t; range) losses 2009 to 2013
Groundfish commercial	Trawl (including sentinel fisheries	Adult	5.8 (2 to 14)
	Seines	Adult	8.2 (6 to 12)
	Gillnet	Adult	3.0 (2 to 4)
	Longline (including sentinel fisheries	Adult	3.6 (1 to 7)
	Handline	Adult	0
	All gears 4T	Adult	20.6 (14 to 33)
	All gears 4Vn	Adult	24.1 (15 to 38)
Groundfish recreational	Handline	Adult	~ 0.5
Smelt commercial	Boxnet and bagnets	Juvenile	Unknown (20 t in the Miramichi estuary in 1995)
Silverside commercial	Bagnets	Juvenile	Unknown
Aboriginal Food, Social and Ceremonial	Unspecified	Unknown	Unknown
Scientific (DFO Research Vessel)	Trawl	All stages	< 0.5 t

The majority of White Hake captured in estuarine smelt and silverside fisheries in the sGSL are <25 cm in length, corresponding to hake that are mostly one year of age or less. Thus, these fisheries catch primarily pre-recruits. Recruitment rates are currently exceptionally high for White Hake and the impact of this fishery on pre-recruit abundance thus appears to be inconsequential.

Sources of Uncertainty

COSEWIC (2013) defined the area occupied by the sGSL DU as all of NAFO Div. 4T and the northern portion of NAFO Subdiv. 4Vn. For the purposes of this assessment, it is assumed that the status and recovery potential of the sGSL DU can be assessed based on analysis of the Div. 4T management unit. Based on RV survey data, about 80% of the White Hake in the NAFO Div. 4T area are of the sGSL type and the 4T area contains the bulk of the White Hake of the sGSL DU (Swain et al. 2012). The genetic identity of White Hake in the St. Lawrence Estuary (NAFO unit areas 4Topq) is unknown but the contribution of this area to landings of NAFO Div. 4T White Hake is minor (1985 to 2010 average, 1.1%). Thus, NAFO Div. 4T is considered here to be an adequate representation of the geographic area for the sGSL DU of White Hake.

The interpretation that the formerly important spawning area in the Baie Verte area in Northumberland Strait has been lost comes from sampling at fixed stations in Baie Verte conducted on July 2 1985, July 7 1986, June 29 1994 and July 5 2001. Catches were similar between 1985, 1986 and 1994 but White Hake were virtually absent in 2001. The uncertainty is whether the loss of this component was due to overfishing associated with a fishery targeting a spawning component or some other factor such as seal predation or risk of predation. The exact time and location of spawning in this area was not known as no plankton surveys were conducted to sample hake eggs or larvae. Plankton surveys in that area during the expected spawning period of White Hake could answer this knowledge gap regarding the disappearance of this previously known and important spawning component.

White Hake are captured in directed recreational groundfish fisheries in the sGSL for which catch and harvest data are not available. The extent of the total catch of White Hake in these fisheries has been reported by area fishery managers as small (i.e. less than 500 kg annually) but this cannot be confirmed. Similarly, White Hake bycatch occurs in some other fisheries including lobster and scallop, and the extent of this bycatch is not known due to lack of monitoring and reporting.

The recovery of the sGSL White Hake population is currently prevented by elevated levels of natural mortality of adult fish. Based on the weight of evidence, predation by grey seals is the most likely cause of a major component of this mortality. Further work on diet studies to fill spatial and seasonal gaps in diet sampling is needed to improve understanding of effects of predation by grey seals on White Hake.

Elevated risk of predation by grey seals is proposed to be the principal cause of the observed shift of adult White Hake away from the inshore to the offshore areas. It is uncertain whether White Hake will return to inshore areas even if abundance increases or the cause of the offshore shift is removed.

SOURCES OF INFORMATION

This Science Advisory Report is from the January 14 to 16, 2015 meeting on the Recovery Potential Assessment – White Hake (*Urophycis tenuis*), population of the southern Gulf of St. Lawrence and population of the Atlantic and northern Gulf of St. Lawrence. Additional publications from this meeting will be posted on the Fisheries and Oceans Canada (DFO) Science Advisory Schedule as they become available.

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