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Pre-COSEWIC review of variation in the abundance, distribution and productivity of white hake (*Urophycis tenuis*) in the southern Gulf of St. Lawrence, 1971-2010

Revue pré-COSÉPAC des variations de l'abondance, de la distribution, et de la productivité de la merluche blanche (*Urophycis tenuis*) dans le sud du golfe du Saint-Laurent depuis 1971 à 2010

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ABSTRACT

White hake (*Urophycis tenuis*) is a demersal gadoid fish found in the southern Gulf of St. Lawrence where it was historically the third or fourth most important groundfish resource in the region. The directed fishery for white hake in the southern Gulf (NAFO Div. 4T) was closed in 1995 and has remained under moratorium since then. COSEWIC (the Committee on the Status of Endangered Wildlife in Canada) will be conducting an assessment of the status of white hake in Canadian waters in terms of its risk of extinction. This paper compiles and presents information possessed by DFO on life history traits, trends in the abundance and distribution of this species, and threats to its persistence in the southern Gulf of St. Lawrence for the development of a status report for COSEWIC. The available data, including the results of a recent molecular genetic study, indicate that white hake in the southern Gulf of St. Lawrence approximate a designatable unit (DU). There was an 80-90% decline in the abundance of mature fish in this DU over the last three generations. Despite the moratorium on the directed fishery since 1995, and very low reported landings since then, there has been no recovery of this resource. Natural mortality increased to very high levels in the 1990s and 2000s; few white hake now live more than 5 years. The white hake population is being maintained by unusually high survival at early life stages. Fishing mortality is now negligible and high natural mortality is the main threat to population persistence. The high natural mortality is hypothesized to result from predation by grey seals.

RÉSUMÉ

La merluche blanche (*Urophycis tenuis*) est un poisson de fond de la famille des gadidés que l'on retrouve dans le sud du golfe du Saint Laurent. Cette espèce représentait anciennement la troisième ou quatrième plus importante ressource de poissons de fond dans la région. La pêche dirigée à la merluche blanche dans le sud du golfe du Saint Laurent (la division 4T de l'OPANO) a été fermée en 1995 et demeure sous un moratoire depuis ce temps. Le Comité sur la situation des espèces en péril au Canada (COSEPAC) entreprendra une évaluation du statut de la merluche blanche dans les eaux canadiennes dans le contexte de son risque d'extinction. Le présent document résume l'information que possède le MPO concernant les caractéristiques du cycle vie, les tendances dans l'abondance et la distribution de cette espèce et les menaces à sa continuité dans le sud du golfe du Saint Laurent. Ces informations aideront le COSEPAC dans l'élaboration d'un rapport sur le statut de l'espèce. Les données disponibles, incluant les résultats d'une récente étude basée sur la génétique moléculaire, indiquent que la merluche blanche du le sud du golfe du Saint Laurent constitue une unité désignable (UD). Il y a eu un déclin de 80 à 90% dans l'abondance des individus matures de cette UD au cours des trois dernières générations. Malgré le moratoire sur la pêche dirigée, en place depuis 1995, et le peu de débarquements rapportés depuis, il n'y a eu aucun rétablissement de cette ressource. La mortalité naturelle a augmenté à des niveaux très élevés dans les années 1990 et 2000 et, actuellement, peu de merluches blanches vivent plus de 5 ans. La population de merluche blanche est présentement maintenue par un taux de survie anormalement élevé à des stades de vie précoces. La mortalité par pêche est présentement à un niveau négligeable et la mortalité naturelle élevée représente la principale menace à la survie de cette population. Une hypothèse visant à expliquer le haut taux de mortalité naturelle est que ce dernier soit le résultat de la prédation par les phoques gris.

INTRODUCTION

COSEWIC (the Committee on the Status of Endangered Wildlife in Canada) has chosen to evaluate the status of white hake (*Urophycis tenuis*) in Canadian waters in terms of risk of extinction. The purpose of this paper is to provide information on life history traits, trends in the abundance and distribution of this species, and threats to its persistence in the southern Gulf of St. Lawrence. This paper was presented at the November 2011 Zonal Advisory Process Pre-COSEWIC peer review of white hake.

BACKGROUND INFORMATION

The southern Gulf of St. Lawrence consists of a shallow shelf area, the Magdalen Shallows, with depths mostly less than 100 m, bordered by a 450-m trench, the Laurentian Channel. In summer and early autumn, three water layers are present in the southern Gulf: a warm surface layer, a cold intermediate layer (the CIL, extending from about 30 to 150 m), and a warm deep layer (Gilbert and Pettigrew 1997). The CIL covers the bottom over most of the Magdalen Shallows. In winter, the southern Gulf is typically ice-covered with water temperatures near the freezing point from the surface to the bottom, except along the slope of the Laurentian Channel where the warm deep-water layer covers the bottom.

White hake is a demersal gadoid fish found in the southern Gulf of St. Lawrence where fisheries targeting it were historically the third or fourth most important groundfish fisheries in the region, with annual landings that averaged 5,675 t from 1960-1994 (Hurlbut and Poirier 2001).

During the summer and early autumn, white hake in the southern Gulf typically exhibit a bimodal distribution with respect to depth, with concentrations occurring in warmer waters, either in shallow (<50 m) inshore areas in the Northumberland Strait and off the coasts of Prince Edward Island or in deep water (>100 m) along the Laurentian Channel and in the Cape Breton Trough (Clay and Hurlbut 1989; Clay 1991; Morin and Hurlbut 1994; Swain and Benoît 2001; Benoît et al. 2003). The constancy of this bimodal distribution pattern was the basis of the hypothesis that the shallow- and deep-water areas of the southern Gulf are inhabited by separate stock components in the summer and early autumn (Clay and Hurlbut 1989; Clay 1991; Hurlbut and Clay 1998). 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.

The annual migration pattern of southern Gulf white hake was inferred from two series of seasonal surveys conducted from 1986-1987 in the southeastern Gulf and from 1989-1991 in the southwest (Clay 1991; Hurlbut and Poirier 2001; Darbyson and Benoît 2003). In the fall, white hake from inshore areas migrate into the deep (>200 m), relatively warm (4-5˚C) water of the Laurentian Channel and Cabot Strait. This is the probable overwintering area for three groups of white hake: those from both the shallow- and deep-water components of the southern Gulf, and those from the northern Gulf (Clay 1991), however it is uncertain whether these groups mix or remain geographically separated while in this area. 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. 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 estuaries in the southern Gulf during the autumn (e.g. Miramichi R. estuary smelt fishery as described by Bradford et al. 1997) prompted speculation that juvenile white hake may over-winter in or near some estuaries.

FISHERIES

Landings in Commercial Fisheries

White hake was historically the third or fourth most important groundfish resource in the southern Gulf of St. Lawrence (NAFO Div. 4T), with annual landings that averaged 5,675 t from 1960-1994 (Table 1 and Figs. 1a and b). The hake fishery was carried out mainly by small inshore vessels using both fixed and mobile gears, and was concentrated in the Northumberland Strait, on the western end of P.E.I., and between P.E.I. and Cape Breton Island. Landings were fairly stable and averaged 4,684 t from 1971-1978, rose sharply to 14,039 t in 1981, and then declined rapidly to an average of 5,023 t from 1985-1992 (Table 1 and Figs. 1a and b).

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 (Table 1 and Fig. 1 a). Following consultations with industry in 1994, the Fisheries Resource Conservation Council (F.R.C.C.) 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 Minister of the Department of Fisheries and Oceans (D.F.O.) announced (Dec. 21, 1994) the closure of the fishery for white hake in NAFO Div. 4T in 1995.

The white hake fishery in NAFO Div. 4T has remained under moratorium since 1995, and a variety of management measures have been implemented to minimize the bycatch of white hake. As a result, the only removals that have occurred since the moratorium have been as bycatch or landings in the sentinel survey, and have ranged in magnitude from 15 t in 2010 to 399 t in 1999 (Table 1). In addition to the bycatch limits, a small fish protocol was enforced. If a fleet sector exceeded 15% in numbers of "small" fish (<45 cm), the groundfish fishery would be closed. To further minimize the bycatch of white hake, restrictive fishing seasons for both the fixed and mobile gear sectors directed at other species were implemented. The purpose of this management measure was to permit hake migration to be completed before opening the area to any other 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. Furthermore, aside from the sentinel survey, 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. DFO has also enforced a licensing condition since 1995 that requires fishers directing for smelts in the fall and winter fisheries to sort and release all groundfish (e.g. primarily white hake and winter flounder) from their fishing gear.

Unreported Catches (Bycatch of White Hake in Estuarine Fisheries)

Bradford et al. (1997) described the results of a bycatch monitoring program for white hake, winter flounder (*Pleuronectes americanus*), and striped bass (*Morone saxatilis*) conducted in the Miramichi, NB open-water smelt (*Osmerus mordax*) fishery between mid-October and the end of

November, 1994 and 1995. The purpose of the study was to: 1) estimate magnitude of the bycatch for these three species in absolute terms and relative to the commercial catch, 2) document size composition of the bycatch and 3) assess the possibility of remedial action to reduce the bycatch.

In 1994 and 1995, white hake were intercepted at an average rate of 23 kg.net^{-1}.day^{-1} (256.7 fish.net^{-1}.day^{-1}). The rate of white hake bycatch was comparable to the catch rate of both smelt and the permitted, saleable bycatch of tomcod (*Microgadus tomcod*). The estimated bycatch magnitude of white hake 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. Miramichi open-water smelt fishers were adamant that the high bycatch of white hake >25 cm TL reported in 1994 was an unusual occurrence (Bradford et al. 1997). Fish of this size were not common during a 1993 survey of this fishery (R.G. Bradford personal observation) and open-water fishers who operate in other estuaries throughout the southern Gulf also commented on the unusually high number of white hake >25 cm TL in their catches during 1994. The substantial reduction in the tonnage of the bycatch in 1995 was probably due to the smaller size of the fish intercepted.

In terms of remedial actions to reduce the bycatch, Bradford et al. (1997) recommended that a numerical reduction of the white hake bycatch of about 50% could be achieved by eliminating the interception of fish <20 cm in length, which could be accomplished by increased gear selectivity (via increased mesh size), but the landings of saleable smelt would undoubtedly be severely reduced. Alternatively, delaying the opening date of the fishery to November 1st could moderately reduce the bycatch of white hake (-30%) and substantially reduce the bycatch of striped bass (>50%) if it was coupled with concentration of fishing activity within a 10-12 km stretch of the estuary (Bradford et al. 1997). If this remedial action was adopted, Bradford et al. (1997) suggested that the total seasonal landings per fisher would likely decline as a consequence of reduced fishing effort.

We submitted a request to Gulf Region Conservation and Protection staff to determine if any of the above-mentioned remedial actions were incorporated into the regulations governing smelt fisheries in the southern Gulf, and were told: There has not been an increase in the minimum allowable mesh size of 31 mm but the opening date of the fishery was delayed this year from Oct. 22 to Oct. 30 (J. Curwin, Chief of Regulations). DFO has also 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. We note that Bradford et al. (1997) questioned the efficacy of culling live hake because these fish have difficulty descending into the water column after being discarded, and that predation on discarded hake by gulls can be substantial.

At meetings with the fishing industry during the mid-1990s, there were anecdotal reports of the bycatch of many small white hake in fishing gear set for silversides and eels on P.E.I. in 1994 (Hurlbut et al. 1996). Subsequent attempts to confirm these reports were ineffective and Hurlbut et al. (1996) concluded that the magnitude of removals of white hake in these fisheries was probably much lower than in the Miramichi smelt fishery.

DATA SOURCES

SEPTEMBER RESEARCH VESSEL (RV) SURVEY

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. 2). During these surveys, trawling was conducted at 63-74 sites in each year from 1971-1983, 82-132 sites from 1984-1988, and at about 140-200 sites from 1989-2010 (except 2003, when only 83 stations were successfully fished). The target fishing procedure in all years was a 30-min 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. For example, in 1978, half the weight associated with stratum 424 was apportioned to stratum 423 and half was apportioned to stratum 422. 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 2002–2004 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 2005-2010. Tows conducted by the *E. E. Prince* used a *Yankee 36* trawl, while all other vessels used a *Western IIA* trawl. Except for the *Wilfred Templeman*, relative fishing efficiency for white hake between these vessels and gears was estimated from comparative fishing experiments conducted during or shortly before the September survey in 1985, 1992, and 2004/2005. Based on these experiments, fishing efficiency for white hake was estimated to be 1.32 times greater for the *Alfred Needler* than for the *Teloest*, but no other differences in fishing efficiency were detected (Benoît and Swain 2003 a and b; 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.

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 (2003a) 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 (2003a).

SENTINEL SURVEYS

Sentinel surveys have been conducted in the southern Gulf of St. Lawrence since 1994. These surveys consist of limited removals from the stock following a scientific protocol established in consultation with industry. The objective of the program is to provide additional abundance indices for stocks under moratoria such as southern Gulf of St. Lawrence cod (4T-Vn) and southern Gulf white hake (4T). Since 2003, the southern Gulf of St. Lawrence sentinel survey program has consisted of two gear components: 1. a longline (fixed gear) component and 2. a bottom-trawl (mobile gear) component.

Sentinel Longline Survey

Although sentinel surveys have been conducted in the southern Gulf of St. Lawrence since 1994, longlines have only been consistently used in the program since 1996. The survey protocol has required each vessel participating in the longline project to fish at two traditional fishing areas selected by the participating fishermen (or 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 (Note: New sites have been incorporated each year since 1996 and several have been discontinued). Each vessel fished it’s 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. The protocol required the vessels in the longline project to set a maximum of 1,250 hooks (size 12 circle, 1 fathom apart) at both of their sites. The soak time for longlines was a minimum of 4-6 hours and a maximum of 24 hours. On each fishing trip, detailed information was collected by fisheries observers on the catch composition, length frequency, as well as material for age determination.

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. Data cells (eg. monthly aggregates) where the catch was 0 or effort was less than one complete fishing day were eliminated from the analysis. Sites that have been fished in at least 4 years were included in the analysis. There are currently 39 fishing sites in the sentinel longline program, distributed throughout inshore areas of the southern Gulf. However, catch rates of white hake are 0 at all sites except four occurring in St. Georges Bay, NS. The index for hake is based on catch rates at these four sites.

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 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

Sentinel Bottom-Trawl (Mobile) Survey

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 (Sept.) RV survey of the southern Gulf. A total of 188 sampling stations were fished in the 2010 survey.

Since 2003, there have been four vessel changes: the first in 2004 (the Viking II replaced L'Alberto), the second in 2006 (the Cap Adèle replaced the Manon Yvon), the third in 2007 (the Atlantic Quest I replaced the Riding It Out) and the fourth in 2010 (the Atlantic Quest I was replaced by the Tamara Louise).

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.

July-August Bottom-Trawl Survey of the Northumberland Strait

A bottom-trawl survey was conducted in the Northumberland Strait during July and August of each year from 2000-2009 to evaluate American lobster abundance and recruitment (S. LeBlanc and T. Surette DFO Unpublished data). This is an area that is very poorly sampled by the annual (Sept.) RV survey because of the occurrence of a lobster fishery throughout a large part of this area during September, and it is also an area where there were directed fisheries for white hake in the past.

This survey was conducted aboard the C.C.G.S. *Opilio*, an 18 m inshore research vessel equipped with a stern ramp for bottom trawling, and used a #286 otter trawl with "rockhopper" footgear, 140 mm diamond mesh throughout the body of the trawl, and a 12 mm liner in the codend (for details see Bosman et al. 2011). The target fishing procedure in all years was a 15-min. tow at 2.5 knots. All catches were adjusted to a standard tow distance of 0.625 nautical miles. Biological sampling was performed following procedures similar to those used during the September RV survey, but there were inconsistencies in the length frequency sampling of white hake and other species in some years (i.e. not all white hake were measured in 2000-2004 and 2006).

The sampling locations were selected from a 3.7 km regular grid covering the whole area of the Northumberland Strait deeper than 4 m (Bosman et al. 2011, Voutier and Hanson 2008). In addition, ten blocks were created to delineate distinct areas of the Strait based on sediment type (Fig. 3). The area covered by the survey varied considerably between years. The analyses are restricted to blocks 1, 2, 3 and 5 (which were most consistently sampled throughout the time series) and abundance and biomass indices are calculated based on a stratified random survey design with the blocks treated as strata.

RESULTS AND DISCUSSION

AGE AND SIZE AT MATURITY

There is considerable uncertainty in the published literature regarding the spawning seasonality of white hake (Markle et al. 1982; Fahay and Able 1989), which likely occurs at different times of the year in different locations (Scott and Scott 1988). The most information on white hake spawning appears to have been collected in the southern Gulf of St. Lawrence, where the period is protracted, occurring between June and September, with mid-June appearing as the only obvious peak (Nepszy 1968; Markle et al. 1982). However, spent individuals have been captured in the northeastern Gulf in May, suggesting late winter-early spring spawning in Laurentian Channel white hake (Markle et al. 1982). Fahay and Able (1989) examined data from ichthyoplankton surveys conducted between the Gulf of St. Lawrence and the Gulf of Maine-Georges Bank area and suggested the existence of two stocks with separate spawning schedules: (1) a shallow-water, summer spawning population occurring in the southern Gulf of St. Lawrence and the Scotian Shelf and (2) a deep-water, early spring spawning population occurring in the northeast Gulf of St. Lawrence (possibly) and extending along the slopes of the Scotian Shelf, Georges Bank, southern New England and the Middle Atlantic Bight. The distribution of eggs, larvae and juveniles, and the location of spawning areas are generally not well known. 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.

Data on the maturity of sGSL white hake at length and age are available from fish collected during the annual bottom-trawl survey in September. There is a concern that maturity staging of fish collected at this time of year, when most fish are in post-spawning condition, may not be reliable due to difficulty distinguishing between immature fish (maturity code 1) and those in a resting or a post-spawning recovering stage (codes 7 and 8). The bias introduced by mis-staging will depend on the mis-staging process. If there is a general tendency to mis-stage immature fish as stage 7 or 8 mature fish, then the size and age at maturity will be under-estimated. If there is a tendency to stage small resting/recovering fish as immature (and vice versa), then the opposite bias will occur. A solution that is sometimes proposed is to base maturity evaluation on fish in stages 1-6 only. However, this approach will also likely introduce bias. For example, if a substantial proportion of fish are staged as 7 or 8, and a high proportion of these fish are indeed mature, omitting these fish would result in a substantial over-estimate of the length and age at 50% maturity.

This potential problem could be evaluated by comparing results between fish collected in September and those collected during the spawning period (e.g., Swain 2011). However, data are available for very few sGSL hake collected during or immediately prior to the main spawning period (June-July), and most of the data that are available are from years (1984-1986, see below) when maturity staging appeared to be unreliable, even in June-July. Thus an indirect approach was used to evaluate the extent of this problem.

Maturation schedules were summarized using the length and age at 50% maturity (L_{50}, A_{50}). These were estimated by fitting logistic regressions to the maturity data for single years or groups of years, with fish coded as immature (stage 1) or mature (stages 2-8). Data were available for 1971-2010 for length and 1978, 1979, 1981-2010 for age. Analyses were conducted including or excluding fish staged as 7 or 8 (Table 2, Fig. 4).

Estimates of L_{50} and A_{50} were clearly anomalously low in 1984-1986 (Fig. 4). The group conducting the September survey changed in 1984, and there appeared to initially be a strong tendency for the new group to mis-identify immature fish as stage 7 or 8 mature fish. This problem appeared to be largely corrected by 1987. However, estimates of L_{50} and A_{50} still tended to be lower in the 1987-2010 period than in the period prior to 1984. This could reflect earlier maturation and/or continued bias in the recent period. Omitting the fish staged as 7 or 8, estimates of L_{50} and A_{50} are generally considerably higher (particularly from the mid 1980s to the mid 1990s) and show less of a declining trend. However, these estimates are likely biased high due to the omission of a high proportion of the mature fish, particularly since the mid 1980s when the majority of "mature" fish were staged as 7 or 8.

Proportions at length by maturity stage are shown in Figure 5. In the 1987-1995 data, stages 7-8 first appear at considerably smaller lengths than those staged as 2-6, particularly for females. In contrast, in the 1971-1982 data, fish staged as 7-8 and those staged as 2-6 first appear at about the same lengths, particularly for males. In the 1987-1995 data, the proportion of fish staged 7-8 increases to a relatively high level over small lengths where fish staged 2-6 remain absent or very rare. In the 1971-1982 data, the proportions of fish staged 7-8 and of those staged 2-6 increase to relatively high levels over about the same length ranges. These observations suggest that 1) many of the small fish staged as 7-8 in the 1987-1995 data are actually immature (stage 1), whereas there appears to be little tendency to mis-classify immature fish as stage 7 or 8 in the 1971-1982 data. Results for the 2000-2010 period are intermediate, particularly for males, suggesting that the estimates for this period remain biased, but less strongly so than those for the 1987-1995 period.

Based on these analyses, the 1971-1982 data were used to estimate maturation schedules (Fig. 6; Age data were not available for 1971-1977 and 1980). Estimated lengths at 50% maturity were 40.7 and 48.2 cm for males and females, respectively. Estimated ages at 50% maturity were 3.2 and 3.9 years for males and females, respectively. These estimates are about equal to or slightly greater than the estimates of L_{50} and A_{50} for the 2000s excluding stages 7 and 8 (Table 2). Since the latter estimates are likely biased high, it is possible that age and size at maturity has declined somewhat since the 1970s.

GENERATION TIME

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. Values of 0.2 for M_v and 4 years for A_{mat} (the approximate age at 50% maturity for females) yield an estimate of 9 years for generation time. At the current estimated levels of M (1 or higher, see below), generation time is about 5 years.

MAXIMUM LENGTH AND AGE

The maximum length and age observed in the September RV survey were 115-cm TL and 15 years, observed in 1974 and 1985 respectively (Fig. 7). Because white hake in the southern Gulf 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. Maximum length and age in the survey catches have declined substantially since the early 1990s and mid 1980s, respectively (Fig. 7). Maximum lengths and ages observed in recent surveys have been as low as 60 cm and 5 years.

GEOGRAPHIC DISTRIBUTION

Methods

The geographic distribution of white hake was mapped using the data visualization software ACON (http://www.mar.dfo-mpo.gc.ca/science/acon). Shaded contours were drawn using Delaunay triangles. Distribution was mapped for September based on catches in the annual RV survey (1971-2010) and for August based on catches in the mobile sentinel survey (2003-2010).

Area of occupancy (A_t) was calculated for two size classes of hake (<45 cm, corresponding to juveniles; 45+ cm, corresponding to adults) in year t as follows:

$$A_t = \sum_{k=1}^{S} \sum_{j=1}^{N_k} \sum_{i=1}^{n_j} \frac{a_k}{N_k n_j} I \quad \text{where } I = \begin{cases} 1 \text{ if } Y_{ijkl} > 0 \\ 0 \ \text{ otherwise} \end{cases}$$

where a_k is the area of the stratum k, Y_{ijkl} is the number of white hake caught in tow i at site j in stratum k, N_k is the number of sites fished in stratum k, n_j is the number of tows fished at site j in stratum k, and S is the number of strata. Two time series of estimates were made, one including strata 401, 403 and 415-439 for 1984-2010, and a second for the 1971-2010 period with data restricted to strata 415-439.

Area of occupancy (as defined above) will decrease as population size decreases even if there is no increase in geographic concentration (Swain and Sinclair 1994). In order to describe changes in geographic concentration, for each size class of hake we also calculated the minimum area containing 95% of fish, following Swain and Sinclair (1994). First, we calculated catch-weighted cdf's of hake catch in each year:

$$F(c) = 100 \frac{\sum_{i=1}^{n} w_i y_i I}{\sum_{i=1}^{n} w_i y_i} \qquad \text{where} \quad I = \begin{cases} 1 & \text{if } \ y_i \le c \\ 0 & \text{otherwise} \end{cases}$$

where c is a level of hake catch (i.e., number per standard tow), w_i is the weighting factor for tow i (i.e., the proportion of the survey area in the stratum fished by tow i divided by the number of sites fished in that stratum and the number of tows made at the site fished by tow i), n is the number of trawl tows in the survey, and y_i is the number of hake caught in tow i. F(c) is an estimate of the percent of hake that occur at a local density of c or less. We also calculated cumulative area in relation to hake catch:

$$G(c) = \sum_{i=1}^{n} \alpha_i I \qquad \text{where} \quad I = \begin{cases} 1 & \text{if } y_i \le c \\ 0 & \text{otherwise} \end{cases}$$

where α_i is the area of the stratum fished by tow i divided by the number of sites fished in that stratum and the number of tows made at the site fished by tow i. We evaluated F at intervals of 0.01, and calculated the density c_{05} corresponding to F = 5. $G(c)$ is the estimated area containing the most sparsely distributed 5% of hake (including areas where no hake were caught). Thus, the minimum area containing 95% of hake (D_{95}) is given by:

$$D_{95} = A_S - G(c_{05})$$

where A_S is 70,080 km^2, the total area covered by strata 415-439, or 71,650 km^2, the total area when strata 401 and 403 are also included.

Results

The distribution of white hake catches in the September RV survey are shown in 5-yr blocks for juvenile sizes (<45 cm TL), adult sizes (≥45 cm TL) and all sizes combined in Figures 8a-8c. 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. In recent periods, there has been a shift in distribution to the east and out of the inshore areas. In the 1970s and early 1980s, hake (particularly large hake) occurred at relatively high densities in inshore areas both to the east and to the west of PEI. Beginning in the 1986-1990 period, densities declined more rapidly in inshore areas to the west of PEI than in those to the east of PEI. By the late 1990s, hake were nearly absent from the area to the west of PEI. A similar eastward shift is seen in the deep waters along the slope of the Laurentian Channel. A loss of hake from inshore areas is evident in the 2000s.

The area occupied by adult-sized hake tended to increase from the mid 1970s to the early 1980s and then declined (Fig. 9). 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. 10).

Sentinel Bottom-Trawl (Mobile) Survey

As observed in annual (Sept.) bottom-trawl surveys of the southern Gulf conducted since 2000, catches of white hake in this survey have been concentrated in the deep-water strata along the Laurentian Channel and off northwestern Cape Breton (strata 415, 425, 437 and 439) (Fig. 11). White hake were rarely caught in the shallow, central zone adjacent to the Magdalen Islands.

July-August Bottom-Trawl Survey of the Northumberland Strait

The inter-annual variability in the area sampled by this survey seriously limits any conclusions that can be drawn about patterns or changes in the geographic distribution of white hake over its history (2000-2009). However, over its time series, white hake were caught throughout the Northumberland Strait, including the area not sampled by the annual (Sept.) bottom-trawl survey (i.e. Most of stratum 421 and the southwestern half of stratum 402) (Fig. 12).

HABITAT ASSOCIATIONS

Methods

We examined variation in the depth and temperature associations of white hake in September using cumulative distribution functions (Perry and Smith 1994). Depth distribution was also examined using generalized additive models (GAMs; Hastie and Tibshirani, 1990). A Poisson error distribution was assumed in the GAMs, allowing for overdispersion. Models were of the form:

$$\mathrm{E}[Y_j] = \mu_j = \exp(\beta_0 + s(X_j))$$

$$\mathrm{Var}[Y_j] = \phi\mu_j$$

where Y_j is the catch of hake in tow j, and $s(X_j)$ is a cubic spline function of depth. We specified the degree of smoothing for the depth term by setting its degrees of freedom to 4.

Results

As previously noted, depth distribution of hake in the southern Gulf is bi-modal, with hake distributed in inshore waters at depths less than 50 m and in offshore waters at depths greater than 100 m (Figs. 13, 14 and 15). The distribution of hake between these shallow and deep zones differed dramatically between the 2000s and earlier decades. In the 1970s, the majority of hake (68% of adult-sized hake, 44% of juvenile-sized hake, 58% of all sizes) occurred at depths less than 50 m. In the 1980s and 1990s, the proportion in shallow water declined to 40-50%. In the 2000s, less than 10% of hake occurred in shallow waters.

In the shallow zone, predicted hake density increased as depth decreased to 20 m (near the shallowest waters surveyed), except in the 2000s when predicted densities were very low at all shallow depths (Figs. 14 and 15). In the deep water zone, predicted densities were highest between 200 and 300 m. For juvenile sizes (<45 cm), peak predicted densities were of similar magnitude in shallow and deep zones in the 1970s and 1980s, and higher in the deep zone in the 1990s and the 2000s. For these sizes, the peak predicted densities in the deep zone were much higher in the 2000s than in earlier decades (Fig. 14). Patterns were similar for the adult sizes (≥45 cm), except that peak predicted densities in the deep zone did not increase in the 2000s (Fig. 15).

In September, the majority of hake occurred at temperatures >4°C (>70-90%, depending on size class and decade; Fig. 16). The highest proportion occurred in the 4-6°C range. 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).

ABUNDANCE TRENDS

September RV Survey

Abundance trends were similar including or excluding strata 401 and 403 (Fig. 17 and Tables 3 and 4). Abundance indices for adult-sized hake (≥45 cm in length) fluctuated between medium and high levels in the 1970s and early 1980s. Abundance of this size class declined between the mid 1980s and mid 1990s, and has been at a low level since then. Abundance of small (<45 cm) juvenile-sized hake showed low-frequency variation between low and high levels in the 1970s and 1980s, and has varied around an intermediate level since the early 1990s.

The linear decline rate of adult hake over three generations was estimated by regressing log survey catch rate against year beginning in 1983 (or 1984 including strata 401 and 403). Results assuming that hake ≥45 cm in length represent the mature portion of the population are shown in Figure 18. Regression models were highly significant (*P*<0.0001), with a slope (*b*) of -0.087 (-0.095 including 401 and 403). Percent decline in abundance can be estimated as $100*(1-\exp(b*\Delta t))$ over a period of Δt years. Using this approach, mature abundance is estimated to have declined by 90% since 1983, a period corresponding to 3 generations. This decline occurred over the 1983-1995 period, with little change in abundance of hake 45+ cm in length since then.

Results were generally similar grouping hake into juveniles and adults based on age rather than length (Tables 5-7). The abundance index for juvenile hake (ages 1-3) fluctuated between low and high values in the 1970s and 1980s, and has generally been at an intermediate level since then (Fig. 19). The abundance index for mature hake (ages 4+) also varied widely in the 1970s and 1980s, though the average level during this period was relatively high. The 4+ index declined in the early 1990s and has been at a low level since then (Fig. 19). Based on this age-based index of mature abundance, the linear decline rate over the three-generation period beginning in 1983 was about 6% per year (Fig. 20), corresponding to a 79% decline since 1983. Most of this decline occurred between 1983 and 1995, with little change in 4+ abundance since then.

Abundance of older hake declined dramatically between the 1980s and the 2000s (Fig. 21). Hake aged 6 years and older were common in the 1980s but virtually absent in the 2000s. In contrast, hake aged 2 years and younger were much more abundant in the 2000s than in the 1980s.

A shift in the depth distribution of hake catches in the September survey, with the proportion of hake occurring in shallow inshore areas declining sharply in recent years, was described above. This could reflect altered habitat selection, with an increased preference for deep waters, as has been observed for thorny skate (Swain and Benoît 2006) and for cod (Swain et al. 2011) in the southern Gulf. Alternatively, it could reflect depletion of the inshore stock component hypothesized by Hurlbut and Clay (1998). To examine the implications of the second alternative, trends in abundance were examined separately for inshore areas (strata 401, 403, 417-424, 427-436) and for offshore areas (strata 415, 416, 425, 426, 437-439).

Abundance of the juvenile size class of white hake was relatively high in the inshore area in the mid 1970s and around 1990, but declined to a low level after 1995 (Fig's. 22 and 23 and Table 8). In contrast, abundance of juvenile white hake in deep strata increased to high levels throughout the 2000s. Abundance of the adult size class in the inshore strata tended to be relatively high in the 1970s, was at an intermediate level from the mid 1980s to the early 1990s, and then declined to the lowest levels observed throughout the 2000s. Abundance of the adult size class in the deep-water strata tended to increase from the early 1970s to the mid 1980s, and then declined sharply to a low level by the mid 1990s. Adult abundance in the deepwater strata has been at a low, but not a record-low level since then. The adult size class has declined by 99% in the inshore strata and 79% in the deepwater strata over the past 27 years (Fig. 24).

Results based on age classes are very similar to the results based on length groups (Fig's. 25 and 26 and Tables 9-11). Juvenile abundance (ages 0-3 yr) declined to low values in the 2000s in the inshore area but increased to relatively high values in the deeper offshore area. Adult abundance (ages 4+ yr) decreased to record low values in the 2000s in the inshore strata but did not decrease as drastically in the offshore strata (Fig. 25). The 4+ age group deceased by 99% over the last 3 generations in inshore strata but by only 55% in the deepwater strata (Fig. 26).

Sentinel Longline Survey

The model explained 67% of the variation in catch rates (Table 12). The residuals were normally distributed. Standardized catch rates were relatively high in 1996-1999 and then declined steadily to values less than 20% of those observed in the late 1990s (Fig. 27 and Table 13). A similar steep decline in biomass was not seen over this period in the RV survey covering the entire southern Gulf. This dramatic local depletion of hake in St. Georges Bay is consistent with the shift in distribution from shallow inshore areas to deeper waters seen in the RV survey in the 2000s.

Sentinel Bottom-Trawl (Mobile) Survey

Mean catch rates in the mobile sentinel survey (un-adjusted for vessel differences) tended to be higher in 2003-2005 than in recent years, though confidence intervals were wide and broadly overlapping (Fig. 28 and Table 14). Further details are given in Savoie (2011).

July-August Bottom-Trawl Survey of the Northumberland Strait

Abundance and biomass indices from the Northumberland Strait survey fluctuated without trend between 2000 and 2009 (Fig. 29 and Table 15). The majority (78%) of the white hake caught in this survey were less than the minimum commercial size of 45 cm.

POPULATION MODEL

Methods

A preliminary population model has been developed for white hake in the southern Gulf of St. Lawrence. The model is a sequential population analysis (SPA) calibrated using the RV survey catch rates at ages 2 to 7. Model inputs were the fishery catch at ages 2 to 10+ in 1971 to 2010 and the survey catch rates at ages 2 to 7 in 1971-2002 and 2004-1010. Survey catch rates of 0 were replaced by one-fifth the minimum catch rate at age. Fishery catches of 0 were replaced by a catch of 10 fish for ages 8 to 10+ yr. Parameters to be estimated were abundances at ages 3 to 10+ in 2011, the survey catchabilities, and the instantaneous rates of natural mortality for two ages classes, 2-3 yr (M_1) and 4+ yr (M_2). M_1 and M_2 were modeled as independent random walks. The instantaneous rate of fishing mortality F for ages 10+ was assumed to equal that of age 9 in the same year. Plus group calculations followed the FRATIO method described in Gavaris (1999). The model was fit using AD Model Builder (ADMB) (http://admb-project.org/).

The objective function minimized during the parameter estimation included the following components:

1. Fit to the RV data

$$\mathrm{f}_1 = 0.5 \cdot \sum_{a,y} (\log(I_{a,y} / (q_a N_{a,y})) / s_{a,y})^2 + \sum_{a,y} \log(s_{a,y})$$

where

$$s_{a,y} = (\log(1 + cv_{a,y}^2))^{0.5}$$

where *I* is the RV abundance index, *N* is estimated population abundance, *q* is catchability to the RV survey, *cv* is the coefficient of variation for the RV survey, *a* indexes age and *y* indexes year. *cv* was set to a constant value of 0.3, and thus had no effect on the minimization (beyond the relative weight of this component in the objective function).

2. Initial values for M_1 and M_2 (i.e., a penalty for departure from the prior values for *M* in 1971)

$$\mathrm{f}_2 = 0.5 \cdot \sum_j (((M_{j,1971} - M\mathrm{init}_j)/0.05)^2 + \log(0.05))$$

where $M_{j,1971}$ is the estimate for M_j in 1971, $M\mathrm{init}_j$ is the mean of the prior for M_j in 1971, and *j* indexes age group (2-3 or 4+). The prior means for *M* in 1971 were 0.3 for ages 2-3 yr and 0.2 for 4+ yr.

3. Random walks in *M*

$$\mathrm{f}_3 = 0.5 \cdot (\sum_{j,y} M\mathrm{dev}^2_{j,y}) / sd^2$$

where $M\mathrm{dev}_{j,y}$ is the *M* deviation for age class *j* (2-3 or 4+) in year *y* (1972-2010). This assumes that the *M* deviates are drawn from a normal distribution with mean 0 and standard deviation *sd*. The value of *sd* affects the degree to which the random walk is constrained. If it is too large, estimated *M* will tend to fluctuate erratically in response to year-effects. For these analyses, *sd* was set at 0.1.

Results

Model estimates fit the survey indices reasonably well (Fig. 30 and 31). The survey indices are quite noisy but the model captured the main trends in abundance, i.e. an increase in the abundance of young hake to relatively high levels in the 1990s and 2000s and a sharp decrease in the abundance of older hake in the early 1990s. Relative to the survey, the model tended to 1) overestimate abundance of ages 4 and 5 in years around 1980 and underestimate abundance of these ages in the 2000s, and 2) underestimate abundance of age 7 in the late 1980s and early 1990s.

Catchability to RV surveys might be expected to be flat-topped. However, in this case, estimated catchability was sharply domed, with a peak at ages 4-5 yr (Fig. 32). This suggests reduced availability to the survey at ages 6 and older. However, this dome might also be an artefact of the near absence of fish older than 5 years in the 2000s. If catchability were actually flat-topped rather than domed as estimated by the model, M of older hake would be underestimated by the model. Model runs were also conducted with a penalty on curvature in catchability as a function of age or with catchability of ages 6 and 7 set equal to that of age 5. Fit to the survey indices was poorer and changes in estimated M were minor.

Estimates of mature (4+) biomass and abundance dropped sharply in the early 1990s (Fig. 33). 4+ abundance peaked at about 20 million fish in 1980 and again in 1990, averaged 15 million in the 1980s and declined to a minimum of about 1.5 million in the mid 2000s. Estimated 6+ abundance averaged about 4 million from 1971 to 1990, declining to less than 400,000 since 2005.

Estimated M of both age classes of hake increased sharply beginning in the late 1980s (Fig. 34). For ages 2-3 yr, estimated M increased from 0.5-1.2 in the 1970s to a peak of 2.9 in 2001, declining to values near 1.7 in recent years. For ages 4+ yr, estimated M increased from about 0.1 in the 1970s to 1.4 in the mid 1990s, declining to a mean of 0.95 between 1997 and 2007 and then returning to values near 1.3-1.5.

Estimated F on ages 2-3 was near 0 in all years (Fig. 34). For ages 4+, estimated F averaged 0.34 from 1971 to 1994, falling to an average of 0.04 with the closure of the directed white hake fishery in 1995.

Exceptionally strong recruitment over the past two decades appears to allow this population to persist despite exceedingly high natural mortality on older fish. Estimated age-2 abundance averaged 34 million from 1971 to 1985, increasing to an average of 164 million from 1990 to 2010 (Fig. 35). The strong recruitment in the 1990s and 2000s was produced by a depleted spawning stock and reflected even more exceptional recruitment rates. Estimated recruitment rate (recruits per kg of SSB) averaged 2.8 for the1971 to 1985 yearclasses and 71.1 for the 1996 to 2008 yearclasses, an increase of more than an order of magnitude (Fig. 35). It is possible that the increase in the abundance of recruits has been overestimated due to an increase in their availability to the survey. As the abundance of older piscivorous hake became severely depleted, small juvenile hake may have dispersed from very shallow areas into the area covered by the survey. Nonetheless, it is apparent that this population is being maintained in the face of devastating adult natural mortality by much improved survival at very early life stages. A similar pattern of improved survival of small fish and reduced survival of large fish is seen throughout the southern Gulf ecosystem (Benoît and Swain 2008; Benoît and Swain 2011).

POPULATION SIZE

Estimates of trawlable abundance are available based on catch rates in the September RV survey. Trawlable abundance underestimates actual abundance, particularly for juveniles which have generally low catchability to the survey. Mean trawlable abundance of the juvenile size and age classes increased from 4 – 5 million fish in the 1970s to 6 – 6.5 million fish in the 2000s (Table16). Mean trawlable abundance of adults was highest in the 1980s, at 7 million fish for the 45+ cm length group and 10 million fish for the 4+ age group. Mean trawlable abundance of these size and age groups decreased to 1 and 3 million, respectively, in the 2000s.

Based on the population model, mean abundance of juveniles (ages 2-3 yr) increased from a mean of 57 million fish in the 1970s to 222 million in the 2000s. In contrast, the estimated mean adult abundance decreased from 15 million in the 1980s to about 3.4 million in the 2000s. For a marine fish population, 3 million is a small number; for example, even in its current severely depleted state, estimated mature abundance of the southern Gulf cod stock is over 60 million (DFO 2011).

CHANGES IN PRODUCTIVITY

Recruitment rate

Both the RV survey data (Fig. 36) and the population model (Fig. 35) indicate that recruitment rate has been exceptionally high since the mid 1990s. This indicates that survival of very small hake (less than about 20 cm in length) has been very high since the mid 1990s. A similar pattern of improved survival of small fish is seen throughout the marine fish community of the southern Gulf and may reflect a release from predation following the collapse of large demersal fish (Benoît and Swain 2008).

Size at age

Trends in the mean length-at-age (cm) of white hake (ages 3-7) sampled during the annual (Sept.) research vessel survey are shown in Figure 37. The mean length-at-age of age 3 fish fluctuated without trend over the time series. For ages 4-6, there is a decreasing trend from the mid-1980's to the end of the time series, whereas for age 7 fish there is a decreasing trend from the early-1990's onwards.

Natural mortality

The population model indicated a sharp rise in *M* for both age groups 1-3 and 4+ in the late 1980s and early 1990s (Fig. 34). Since then, model estimates of *M* have been at very high levels, about 1-2.5 for ages 1-3 yr and about 0.85 – 1.5 for ages 4+. Model independent analyses also indicate a sharp rise in adult *M* beginning in the late 1980s. Benoît and Swain (2011) estimated the total mortality ($Z = M + F$) of adult white hake (ages 5-7 years) using the modified catch-curve analysis of Sinclair (2001), with estimates based on a moving 7-year window. They also estimated the fishing mortality *F* for these fish using Baranov's catch equation (Ricker 1975), based on observed fishery catches and RV survey numbers-at-age adjusted for general length-dependent patterns in catchability (Harley and Myers, 2001). The analysis showed that in the 1970s and early 1980s, differences between the estimates of Z and F were relatively small, indicating that M was relatively low (Figure 38). Beginning in the mid 1980s the difference between Z and F increased, indicating increasing M. In the 2000s, estimated Z increased to levels near 2 while F declined to levels near 0, indicating exceedingly high M for hake aged 5-7 years. This very high M has resulted in the near disappearance of hake older than 5 years in the 2000s (Fig. 21).

THREATS

The main threat to white hake in the southern Gulf of St. Lawrence is the exceedingly high level of natural mortality experienced by hake in the 1-3 and 4+ age groups. Increasing M appears to be the main factor responsible for the decline in hake in the late 1980s and early 1990s, though the fishery at this time clearly contributed to the decline. Levels of fishing mortality that appeared sustainable in the 1970s and early 1980s became unsustainable when M increased in the late 1980s. Following the closure of the directed fishery in 1995, fishing mortality declined to a level near zero. The lack of recovery since the closure of the fishery 15 years ago is entirely due to high M. Only the exceptionally high recruitment rate observed since the late 1990s prevents the stock from declining further.

Benoît et al. (2011) examined possible causes of the elevated M of white hake in the southern Gulf. Factors that they considered included unreported catch, poor fish condition, life-history change, and predation by grey seals and other predators. The factor most strongly supported by the available evidence was predation by the increasing grey seal herd. The dramatic shift in the distribution of white hake to offshore areas in September is consistent with this conclusion. The inshore areas occupied by hake, in particular the Northumberland Strait and the area between Miramichi Bay and PEI are heavily used by foraging grey seals in summer, and the recent shifts in hake distribution represent shifts from areas of high to lower risk of predation by grey seals.

POPULATION STRUCTURE

<u>Possible disappearance of a white hake (Urophycis tenuis) spawning component in Baie Verte (Northumberland Strait): Evidence from fixed station sampling in July 1985, July 1986, June 1994 and July 2001.</u>

Throughout the 1980's there was a seasonal fishery that targeted spawning concentrations of white hake in Baie Verte (Northumberland Strait). Repeated sampling at eight fixed stations in Baie Verte in July 1985, July 1986 and June 1994 yielded similar catch rates of predominately commercial sized white hake. However, repeated sampling of the same fixed stations in July 2001 revealed that white hake had virtually disappeared from the area. There is additional evidence in support of the conclusion that white hake had disappeared from Baie Verte in 2001, and for the remainder of the decade, in the absence of catches in this area during the July-August 2001-2009 bottom-trawl survey of the Northumberland Strait (discussed above).

<u>Affinity to Designatable Units</u>

Roy et al. (2011) identified three genetically distinct populations of white hake in Atlantic Canada, which they termed the Southern Newfoundland – Grand Banks, Scotian Shelf – Bay of Fundy, and Southern Gulf of St. Lawrence populations, abbreviated here as the NFLD, Scotian and Gulf populations. The Gulf type occurred almost entirely in NAFO Division 4T and in the western portion of subdivision 4Vn. However, some individuals in 4T in deep water along the slope of the Laurentian Channel were of the Scotian type. In this section, the proportion of 4T individuals belonging to the Gulf type are described by depth zone and survey stratum, using data provided by Roy et al. (2011). These proportions are then weighted by the proportion of the survey population in each depth zone or stratum to obtain estimates of the proportion of white hake in the 4T area that are of the Gulf type.

The proportion of hake that were of the Gulf type was about 90% or more in all strata except the three deepest strata along the slope of the Laurentian Channel (strata 415, 425 and 439) (Table 17). In these three deep strata, only 60-75% of hake were of the Gulf type. Based on the distribution of hake (all sizes) among strata in the 2000s, 82% of hake in the survey area in September are estimated to be of the Gulf type.

Over 90% of hake sampled from depths less than 200 m were of the Gulf type (Table 18). This proportion declined with depth at depths greater than 200 m, from about 80% in the 200-250 m depth zone to 34% at depths greater than 350 m. The majority of samples in the deepest zone were collected on the August survey of the northern Gulf, which covers areas of 4T outside of the September survey area. Omitting the August survey samples from the analysis, the proportion of fish that were Gulf type increases to 70% at depths over 350 m, though sample size is small (Table 6). Weighting these proportions by the depth distribution of white hake within the 4T survey area in September in the 2000s (Fig's. 13-15), about 80% of white hake within the 4T survey area are estimated to be Gulf type (Table 19).

For practical management and assessment purposes, it seems reasonable to treat the white hake within the 4T survey area as a population, though recognizing that about 20% of these hake belong to the neighbouring Shelf population and that a portion of the Gulf population occurs outside of this survey area in western 4Vn. Using the 4T September survey to track trends in abundance of Gulf white hake assumes that there are no changes over time in the availability of the Gulf type to the survey and in the proportion of hake within the survey area that are of the Scotian type.

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Table 1. *Nominal landings (tonnes) of white hake from NAFO Div. 4T by gear, with yearly TAC's. All data from 1999 to present are preliminary statistics. N/S = Gear Type Not Specified.*

Year	Trawl	Seine	Gillnet	Longline	Handline	Other	Total	TAC
1960	479	21	3	1085	87	333	2008	
1961	1430	79	309	2834	664	7	5323	
1962	1141	97	889	3827	715	575	7244	
1963	1444	71	48	0	0	4987	6550	
1964	1508	82	N/S	1	0	4615	6206	
1965	N/S	N/S	N/S	N/S	N/S	N/S	4706	
1966	2267	205	375	1870	0	2307	7024	
1967	2295	128	809	841	107	2370	6550	
1968	795	84	1734	320	146	1182	4261	
1969	1030	50	1802	467	31	828	4208	
1970	1463	382	2149	310	75	1289	5668	
1971	1523	632	1622	599	103	1228	5707	
1972	1139	863	1190	1526	79	960	5757	
1973	2468	204	1265	962	83	720	5702	
1974	1454	305	1098	264	81	414	3616	
1975	1574	306	1279	241	83	642	4125	
1976	1429	398	1147	141	42	601	3758	
1977	1227	408	1300	185	46	818	3984	
1978	1303	737	1829	314	142	500	4825	
1979	2826	912	3189	305	174	704	8110	
1980	3430	1615	4831	604	228	1715	12423	
1981	4733	1922	6174	751	48	411	14039	
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	175	98	469	711	44	0	1497	3600
1994	79	45	218	580	114	0	1036	2000
1995	30	6	27	5	2	0	70	Moratorium
1996	24	6	41	84	0	0	155	Moratorium
1997	49	7	62	70	4	0	192	Moratorium
1998	44	25	62	102	5	0	238	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	27	0	0	55	Moratorium
2005*	6	17	4	16	0	0	44	Moratorium
2006*	3	14	1	8	0	0	26	Moratorium
2007*	2	11	1	6	0	0	20	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	15	Moratorium
			1960-1994					
Average	1518	622	1807	857	122	831	5675	
Percent	26	11	30	15	2	14	100	

Table 2. Estimated lengths and ages at 50% maturity of white hake in the southern Gulf of St. Lawrence based on September data including or excluding maturity codes 7 and 8.

	Length (cm)				Age (year)			
	Males		Females		Males		Females	
time period	include 7,8	exclude 7,8	include 7,8	exclude 7,8	include 7,8	exclude 7,8	include 7,8	exclude 7,8
1971 – 1979[1]	40.1	41.8	46.9	52.7	3.2	3.3	4.0	4.3
1980 – 1983	41.0	43.9	48.4	58.5	2.8	3.4	3.3	4.6
1987 – 1989	34.6	41.2	38.6	50.6	2.6	3.5	3.0	4.7
1990 – 1999	33.8	39.3	36.8	49.2	2.3	3.2	2.6	4.5
2000 – 2010	33.4	37.0	35.3	45.5	2.3	3.0	2.5	4.0

[1]1978-1979 for age.

Table 3. Stratified mean catch rates (fish/tow) of white hake and their CVs by length group in the September Research Vessel (RV) survey of the southern Gulf of St. Lawrence.

	Strata 415-439				Strata 401, 403, 415-439			
	<45 cm		≥45 cm		<45 cm		≥45 cm	
Year	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1971	1.2	0.48	0.9	0.41				
1972	0.4	0.36	1.0	0.36				
1973	0.6	0.39	3.9	0.80				
1974	3.0	0.34	5.3	0.57				
1975	4.6	0.67	1.8	0.17				
1976	4.2	0.52	1.4	0.20				
1977	2.0	0.32	1.5	0.28				
1978	2.8	0.46	4.2	0.30				
1979	2.0	0.47	4.4	0.31				
1980	0.9	0.36	4.7	0.16				
1981	1.4	0.44	7.8	0.33				
1982	0.7	0.29	2.3	0.39				
1983	1.0	0.37	1.7	0.14				
1984	1.4	0.23	2.9	0.18	1.4	0.23	3.0	0.17
1985	3.4	0.44	4.2	0.34	3.4	0.42	4.2	0.33
1986	5.3	0.23	6.4	0.20	5.3	0.22	6.4	0.19
1987	2.8	0.24	3.3	0.21	2.8	0.23	3.3	0.20
1988	4.3	0.29	4.2	0.19	4.3	0.28	4.6	0.17
1989	5.3	0.30	3.1	0.20	8.1	0.20	3.5	0.17
1990	5.1	0.31	3.5	0.19	5.4	0.29	3.7	0.18
1991	5.9	0.48	3.6	0.28	6.1	0.46	3.6	0.27
1992	5.0	0.41	1.7	0.27	5.4	0.37	2.2	0.25
1993	2.3	0.32	1.6	0.36	2.5	0.29	1.8	0.31
1994	1.8	0.42	1.5	0.29	1.9	0.41	1.5	0.28
1995	1.8	0.19	0.5	0.26	2.7	0.16	0.7	0.19
1996	2.4	0.23	0.6	0.21	2.5	0.22	0.7	0.18
1997	2.1	0.30	0.8	0.24	2.1	0.29	0.9	0.23
1998	2.3	0.23	0.6	0.24	2.7	0.20	0.9	0.23
1999	3.6	0.37	0.8	0.29	4.2	0.32	1.2	0.33
2000	8.0	0.35	0.8	0.19	8.1	0.34	0.9	0.16
2001	2.8	0.24	0.7	0.26	2.9	0.23	0.7	0.24
2002	2.4	0.32	0.5	0.29	2.5	0.31	0.5	0.27
2003	2.8	0.40	0.5	0.24	2.6	0.42	0.4	0.27
2004	1.1	0.27	0.4	0.23	1.2	0.24	0.5	0.21
2005	3.6	0.21	0.7	0.22	3.7	0.20	0.7	0.22
2006	1.4	0.20	0.3	0.28	1.4	0.19	0.3	0.27
2007	8.6	0.54	0.9	0.30	8.5	0.53	0.9	0.28
2008	2.7	0.25	0.6	0.26	2.7	0.25	0.6	0.25
2009	3.2	0.31	0.6	0.41	3.4	0.29	0.6	0.40
2010	3.2	0.23	0.7	0.21	3.1	0.23	0.7	0.21

Table 4. Trawlable abundance (thousands) of white hake by length group in the September Research Vessel (RV) survey of the southern Gulf of St. Lawrence.

	Strata 415-439		Strata 401, 403, 415-439	
Year	<45 cm	45+ cm	<45 cm	45+ cm
1971	2136.5	1585.1		
1972	661.8	1642.4		
1973	1085.5	6748.6		
1974	5131.8	9079.2		
1975	7878.7	3108.3		
1976	7243.9	2429.8		
1977	3387.1	2556.4		
1978	4802.6	7303.3		
1979	3424.9	7595.2		
1980	1625.9	8179.5		
1981	2380.4	13427.9		
1982	1163.0	4023.9		
1983	1799.1	2927.4		
1984	2461.9	5070.1	2461.9	5238.0
1985	5808.9	7212.8	6034.6	7470.0
1986	9146.9	11053.6	9359.3	11321.0
1987	4847.5	5677.0	4904.5	5855.8
1988	7350.2	7288.8	7643.7	8059.2
1989	9194.4	5336.2	14324.7	6218.8
1990	8849.7	5974.8	9604.6	6551.8
1991	10186.4	6159.2	10760.2	6387.5
1992	8570.7	3004.8	9561.6	3880.1
1993	3992.0	2784.3	4487.8	3245.8
1994	3144.7	2534.8	3275.2	2583.2
1995	3077.8	799.2	4739.7	1223.2
1996	4123.4	1007.0	4372.6	1231.2
1997	3594.2	1439.5	3728.0	1571.1
1998	4010.5	1119.9	4821.4	1614.6
1999	6156.4	1380.9	7463.5	2079.5
2000	13873.1	1324.0	14255.3	1621.6
2001	4769.8	1153.7	5044.3	1251.8
2002	4214.8	816.3	4395.2	871.7
2003	4797.1	855.9	4536.2	774.9
2004	1910.1	776.1	2152.8	921.1
2005	6287.0	1276.6	6511.5	1321.3
2006	2357.5	511.1	2476.7	538.5
2007	14887.1	1532.6	15106.9	1671.8
2008	4647.5	975.8	4785.0	985.5
2009	5592.2	1117.7	5955.3	1138.1
2010	5522.6	1181.4	5540.2	1181.5

Table 5. 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. Convert 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		0.018	0.727	0.691	0.788	0.346	0.142	0.038	0.005	0.005	0.012		0.027			
1972		0.017	0.206	0.217	0.365	0.317	0.365	0.140	0.023	0.015	0.031		0.008			
1973		0.017	0.448	0.471	2.143	1.833	0.643	0.216	0.033	0.013	0.049					
1974		0.140	1.993	1.529	2.614	2.055	1.382	0.588	0.178	0.044	0.111					
1975		0.080	3.422	2.133	1.481	0.728	0.267	0.072	0.012	0.012	0.031		0.020			
1976		0.067	3.086	1.980	1.304	0.550	0.187	0.058	0.006	0.006	0.014					
1977		0.020	0.874	1.236	1.456	0.558	0.180	0.067	0.022	0.006	0.020		0.008			
1978		0.058	2.154	1.499	2.516	2.006	0.982	0.300	0.030	0.021	0.066		0.042			
1979			0.278	2.042	2.077	1.822	1.279	0.484	0.132	0.015	0.025	0.037	0.061			
1980			0.108	1.110	1.895	2.106	1.308	0.456	0.138	0.008	0.049	0.064	0.046			
1981		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		0.059	0.265	0.613	0.960	0.786	0.716	0.310	0.137	0.019	0.036					
1983		0.093	0.809	0.824	0.809	0.447	0.285	0.142	0.070	0.067	0.009					
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			
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		
1987		0.039	0.464	2.020	2.581	1.723	0.739	0.214	0.053	0.028	0.026		0.025			
1988	0.007	0.146	1.557	2.713	3.232	2.378	0.761	0.297	0.050	0.011	0.013					
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		0.004		
1990	0.038	0.152	2.083	3.115	2.350	2.355	0.612	0.353	0.069	0.017						
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				
1992	0.043	0.279	1.499	3.386	2.557	0.770	0.134	0.028	0.006							
1993	0.015	0.138	0.826	1.281	1.691	0.856	0.199	0.071	0.002	0.015						
1994	0.061	0.140	0.977	1.068	1.258	0.587	0.144	0.016	0.018							
1995	0.105	0.271	1.058	0.673	0.570	0.147	0.066	0.019	0.006							
1996	0.066	0.345	1.174	1.123	0.835	0.236	0.057	0.010	0.007	0.002						
1997	0.130	0.420	0.832	0.671	1.039	0.514	0.143	0.029	0.006							
1998	0.009	0.382	1.451	0.792	0.678	0.374	0.140	0.021	0.011							
1999	0.325	1.037	1.781	1.022	0.933	0.449	0.099	0.020								
2000	0.068	0.387	4.426	3.406	2.630	0.449	0.050	0.008								
2001	0.014	0.257	1.218	1.231	1.251	0.443	0.036	0.002								
2002	0.012	0.588	1.712	0.599	0.601	0.250	0.015	0.006								
2004	0.009	0.074	0.555	0.547	0.530	0.280	0.038	0.006								
2005	0.002	0.262	2.508	0.979	1.370	0.364	0.039	0.016								
2006	0.057	0.136	0.731	0.605	0.573	0.088										
2007	0.111	0.441	5.705	3.281	2.450	0.503	0.032	0.010								
2008	0.058	0.133	1.067	1.249	1.400	0.352	0.025	0.008								
2009	0.072	0.708	1.601	0.907	1.304	0.501	0.029									
2010	0.004	0.330	2.191	1.062	1.211	0.288	0.032									

Table 6. Coefficients of variation (%) of the 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.

	Age (years)															
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1971		0	51	46	46	41	31	0	0	0	0		0			
1972		0	49	33	27	40	41	51	0	0	0		0			
1973		0	35	52	85	80	65	60	96	0	65					
1974		68	40	38	59	61	54	44	47	72	64					
1975		68	72	60	14	20	29	0	0	0	0		0			
1976		67	56	45	21	24	24	0	0	0	0					
1977		0	34	34	36	25	25	0	0	0	0		0			
1978		0	38	53	43	31	23	24	0	0	0		75			
1979			50	47	42	30	36	38	41	0	0	0	52			
1980			29	33	18	16	18	20	23	0	65	86	0			
1981		70	45	42	42	34	35	36	37	41	0	0	0	72	0	
1982		0	29	26	35	44	46	34	40	0	0					
1983		34	42	21	17	16	19	31	45	47	0					
1984	0	0	30	24	23	23	25	27	35	0	0	0	0			
1985	0	85	45	38	41	34	46	50	63	66	41	0	0	0	0	0
1986	0	25	25	22	26	22	17	21	29	27	77	0	90	0		
1987		0	26	24	22	22	19	33	60	0	0		0			
1988	0	38	29	31	27	20	19	15	63	0	0					
1989	76	41	31	33	29	19	24	29	0	0	0	0		0		
1990	0	36	39	34	23	22	19	25	46	0						
1991	0	42	49	55	49	27	21	30	49	0	0	0				
1992	0	30	38	44	38	23	24	0	0							
1993	0	32	24	37	42	36	28	0	0	0						
1994	73	39	49	42	29	32	49	0	0							
1995	52	42	24	24	30	22	48	0	0							
1996	0	29	24	28	26	23	0	0	0	0						
1997	54	36	33	34	30	25	22	0	0							
1998	0	36	25	26	21	24	32	0	0							
1999	95	71	35	35	34	29	32	0								
2000	47	32	43	34	28	17	0	0								
2001	0	28	27	24	24	29	0	0								
2002	0	40	36	33	32	31	0	0								
2004	0	43	30	28	23	28	0	0								
2005	0	24	20	40	33	29	0	0								
2006	55	33	27	21	23	36										
2007	40	51	54	67	45	33	0	0								
2008	55	48	27	26	24	25	0	0								
2009	44	69	30	39	39	40	0									
2010	0	33	29	22	22	25	0									

Table 7. 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 401, 403, and 415-439. Convert to trawlable abundance at age (in thousands) by multiplying by 1768.089.

	Age (years)															
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1984	0.007	0.053	0.467	1.118	1.422	1.141	0.535	0.268	0.165	0.057	0.062	0.010	0.010			
1985	0.011	0.100	0.669	2.583	3.299	1.231	0.816	0.577	0.315	0.270	0.106	0.028	0.041	0.024	0.018	0.005
1986	0.044	0.180	1.731	3.000	5.217	3.100	1.010	0.440	0.242	0.117	0.040	0.037	0.034	0.014		
1987		0.038	0.458	1.999	2.565	1.762	0.745	0.211	0.054	0.029	0.026		0.025			
1988	0.007	0.154	1.591	2.755	3.401	2.598	0.820	0.307	0.050	0.013	0.017					
1989	0.116	0.587	2.026	5.771	3.383	1.959	0.945	0.229	0.032	0.025	0.016	0.008		0.008		
1990	0.082	0.224	2.236	3.178	2.495	2.496	0.687	0.388	0.077	0.017						
1991	0.044	0.484	2.174	4.138	2.794	1.879	0.776	0.214	0.062	0.005	0.020	0.019				
1992	0.044	0.285	1.569	3.747	3.004	0.988	0.201	0.039	0.007							
1993	0.031	0.203	0.899	1.378	1.876	0.965	0.238	0.079	0.002	0.015						
1994	0.062	0.149	1.006	1.072	1.249	0.588	0.146	0.017	0.018							
1995	0.141	0.429	1.770	0.891	0.734	0.245	0.140	0.025	0.010							
1996	0.065	0.366	1.248	1.142	0.867	0.292	0.092	0.032	0.012	0.005						
1997	0.130	0.432	0.856	0.673	1.062	0.542	0.156	0.037	0.008							
1998	0.014	0.495	1.709	0.890	0.794	0.509	0.252	0.040	0.025	0.001	0.001					
1999	0.327	1.137	2.377	1.136	1.096	0.680	0.219	0.045								
2000	0.067	0.400	4.445	3.420	2.686	0.545	0.088	0.020	0.002		0.001					
2001	0.022	0.295	1.297	1.230	1.263	0.468	0.051	0.005								
2002	0.013	0.630	1.746	0.591	0.603	0.266	0.017	0.007								
2004	0.009	0.086	0.676	0.561	0.585	0.319	0.044	0.006								
2005	0.012	0.296	2.550	0.972	1.363	0.373	0.039	0.015								
2006	0.062	0.157	0.762	0.601	0.580	0.089										
2007	0.120	0.478	5.666	3.224	2.466	0.520	0.043	0.009								
2008	0.071	0.148	1.093	1.230	1.383	0.346	0.030	0.008								
2009	0.084	0.802	1.703	0.896	1.285	0.497	0.028									
2010	0.004	0.327	2.152	1.039	1.185	0.282	0.031									

Table 8. Stratified catch rates (fish/tow; mean and CV) of white hake by length group in shallow (strata 417-424, 427-436 ± 401 and 403) and deep-water strata (415, 416, 425, 426, 437-439) in the September RV survey of the southern Gulf of St. Lawrence. To convert to trawlable abundance in thousands multiply catch rates by 1401.687 (shallow strata – 401 and 403), 1440.430 (shallow strata + 401 and 403), or 327.659 (deep-water strata).

	401, 403, 417-424, 427-436				417-424, 427-436				415, 416, 425, 426, 437-439			
	<45 cm		≥45 cm		<45 cm		≥45 cm		<45 cm		≥45 cm	
Year	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1971					*0.3*	*0.69*	*0.7*	*0.56*	*5.3*	*0.57*	*1.8*	*0.6*
1972					0.0	0.35	1.0	0.4	1.9	0.38	0.6	0.58
1973					0.4	0.27	4.7	0.82	1.7	0.71	0.6	0.55
1974					2.5	0.47	5.9	0.62	5.1	0.43	2.5	0.22
1975					4.1	0.92	1.0	0.22	6.7	0.25	5.0	0.26
1976					3.7	0.7	1.3	0.22	6.2	0.41	1.8	0.46
1977					0.5	0.78	0.7	0.23	8.3	0.35	5.0	0.42
1978					3.3	0.48	3.8	0.4	0.7	0.43	6.2	0.38
1979					1.7	0.64	3.1	0.35	3.4	0.58	10.0	0.55
1980					0.9	0.47	4.3	0.19	1.2	0.23	6.8	0.23
1981					0.8	0.73	6.3	0.39	4.0	0.53	14.0	0.59
1982					0.3	0.4	1.6	0.63	2.5	0.39	5.4	0.4
1983					0.5	0.82	0.6	0.33	3.4	0.3	6.5	0.15
1984	0.6	0.42	1.5	0.3	0.6	0.42	1.4	0.32	5.0	0.27	9.6	0.21
1985	1.6	0.5	2.5	0.6	1.5	0.56	2.4	0.64	11.5	0.61	11.9	0.31
1986	2.3	0.34	2.9	0.32	2.2	0.36	2.8	0.34	18.5	0.29	21.8	0.24
1987	1.7	0.35	1.6	0.35	1.7	0.36	1.5	0.38	7.4	0.31	11.0	0.24
1988	1.4	0.42	1.6	0.41	1.2	0.48	1.1	0.59	17.2	0.34	17.6	0.18
1989	7.8	0.23	2.6	0.22	4.4	0.43	2.1	0.29	9.4	0.33	7.5	0.27
1990	4.8	0.39	2.0	0.24	4.4	0.44	1.6	0.3	8.3	0.26	11.2	0.25
1991	6.0	0.57	3.5	0.34	5.7	0.61	3.4	0.36	6.7	0.21	4.1	0.2
1992	5.2	0.47	2.0	0.32	4.6	0.54	1.4	0.37	6.3	0.24	3.0	0.27
1993	0.8	0.29	1.1	0.26	0.4	0.4	0.8	0.32	10.3	0.37	5.2	0.54
1994	1.6	0.57	1.5	0.33	1.5	0.6	1.5	0.34	3.2	0.36	1.3	0.34
1995	2.2	0.22	0.7	0.21	1.1	0.29	0.5	0.31	4.7	0.24	0.5	0.44
1996	0.5	0.17	0.2	0.16	0.4	0.22	0.0	0.43	11.0	0.26	2.9	0.22
1997	0.9	0.29	0.4	0.33	0.9	0.32	0.3	0.43	7.2	0.42	3.1	0.29
1998	1.0	0.29	0.7	0.32	0.4	0.48	0.3	0.34	10.5	0.26	2.0	0.33
1999	2.6	0.49	1.0	0.46	1.7	0.66	0.5	0.43	11.4	0.43	2.0	0.36
2000	0.7	0.18	0.3	0.31	0.5	0.27	0.1	0.62	40.3	0.37	3.5	0.19
2001	0.4	0.26	0.1	0.4	0.2	0.48	0.0	0.71	13.8	0.26	3.4	0.27
2002	0.2	0.27	0.1	0.38	0.1	0.41	0.0	0.5	12.4	0.33	2.3	0.31
2003	0.7	0.33	0.0	0.6	0.7	0.35	0.0	0	11.0	0.53	2.8	0.23
2004	0.4	0.3	0.2	0.43	0.3	0.39	0.1	0.48	4.7	0.32	2.1	0.25
2005	0.3	0.52	0.1	0.43	0.2	0.75	0.0	0.63	18.4	0.22	3.7	0.23
2006	0.3	0.48	0.0	0.61	0.2	0.65	0.0	0	6.3	0.21	1.6	0.28
2007	0.5	0.33	0.2	0.4	0.4	0.45	0.1	0.55	43.7	0.56	4.4	0.32
2008	0.3	0.33	0.0	0.6	0.2	0.43	0.0	0.73	13.1	0.27	2.9	0.26
2009	1.3	0.48	0.1	0.59	1.1	0.59	0.1	0.67	12.6	0.36	3.1	0.44
2010	0.1	0.41	0.0	0.85	0.1	0.45	0.0	0.85	16.5	0.24	3.5	0.22

Table 9. Stratified mean catch rates at age (fish/tow) of white hake in shallow strata (401, 403, 417-424, 427-436) in the September Research Vessel (RV) survey of the southern Gulf of St. Lawrence. Convert to trawlable abundance at age (in thousands) by multiplying by 1401.687.

	Age (years)															
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1984	0.008	0.048	0.238	0.298	0.424	0.493	0.299	0.164	0.132	0.040	0.057	0.007	0.009			
1985	0.013	0.120	0.537	1.083	0.630	0.636	0.648	0.515	0.330	0.303	0.107	0.033	0.050	0.030	0.022	0.006
1986	0.033	0.100	0.901	1.171	2.071	1.340	0.509	0.234	0.158	0.105	0.045	0.042	0.028	0.017		
1987		0.018	0.154	1.270	1.475	0.894	0.255	0.108	0.027	0.032	0.021		0.029			
1988	0.007	0.143	0.886	0.567	0.884	0.977	0.342	0.078	0.011	0.015	0.022					
1989	0.142	0.585	1.845	5.662	3.035	1.451	0.627	0.133	0.023	0.025	0.010	0.010		0.010		
1990	0.101	0.267	2.359	2.570	1.615	1.268	0.322	0.223	0.073	0.021						
1991	0.049	0.479	2.178	4.032	2.661	1.812	0.753	0.218	0.067	0.007	0.024	0.024				
1992	0.049	0.228	1.391	3.694	2.884	0.910	0.198	0.031	0.002							
1993	0.035	0.151	0.345	0.335	0.737	0.535	0.169	0.059		0.010						
1994	0.076	0.122	0.973	0.787	1.200	0.610	0.159	0.021	0.022							
1995	0.173	0.418	1.372	0.712	0.694	0.275	0.156	0.031	0.012							
1996	0.077	0.205	0.287	0.101	0.090	0.084	0.054	0.026	0.006	0.005						
1997	0.157	0.439	0.397	0.135	0.298	0.202	0.056	0.024	0.010							
1998	0.017	0.360	0.580	0.209	0.298	0.333	0.232	0.040	0.027	0.002	0.002					
1999	0.399	1.171	1.304	0.367	0.515	0.599	0.240	0.054								
2000	0.065	0.175	0.366	0.225	0.300	0.184	0.055	0.016	0.002		0.001					
2001	0.027	0.094	0.247	0.070	0.091	0.050	0.018	0.003								
2002	0.016	0.113	0.149	0.011	0.044	0.054	0.006	0.001								
2004	0.011	0.075	0.370	0.081	0.115	0.077	0.018									
2005	0.015	0.068	0.297	0.061	0.065	0.053	0.001	0.009								
2006	0.052	0.094	0.206	0.025	0.025	0.003										
2007	0.148	0.223	0.269	0.041	0.172	0.072	0.017									
2008	0.087	0.129	0.148	0.047	0.048	0.010	0.007	0.005								
2009	0.103	0.925	0.594	0.035	0.071	0.066	0.005									
2010		0.042	0.082	0.011	0.019	0.008	0.006									

Table 10. Stratified mean catch rates at age (fish/tow) of white hake in shallow strata (417-424, 427-436) in the September Research Vessel (RV) survey of the southern Gulf of St. Lawrence. Convert to trawlable abundance at age (in thousands) by multiplying by 1440.430.

	Age (years)															
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1971		0.003	0.145	0.196	0.458	0.288	0.121	0.035	0.006	0.006	0.013		0.033			
1972			0.011	0.037	0.226	0.357	0.451	0.172	0.028	0.018	0.038		0.010			
1973		0.017	0.314	0.377	2.497	2.196	0.773	0.262	0.041	0.017	0.060					
1974		0.148	1.648	1.308	2.640	2.360	1.605	0.698	0.219	0.053	0.134					
1975		0.069	3.197	1.774	0.794	0.467	0.198	0.054	0.012	0.012	0.027		0.025			
1976		0.068	2.977	1.623	0.994	0.557	0.207	0.067	0.007	0.007	0.016					
1977		0.013	0.356	0.225	0.256	0.319	0.140	0.066	0.025	0.005	0.017		0.009			
1978		0.072	2.616	1.678	2.210	1.788	0.986	0.319	0.034	0.022	0.065		0.053			
1979			0.244	1.777	1.539	1.228	0.818	0.301	0.086	0.009	0.019	0.046	0.037			
1980			0.086	1.025	1.585	1.880	1.244	0.434	0.141	0.007	0.057	0.079	0.038			
1981		0.055	0.288	0.571	1.280	2.449	2.251	1.439	0.506	0.249	0.011	0.018	0.011	0.055	0.018	
1982		0.073	0.138	0.174	0.472	0.574	0.597	0.245	0.100	0.018	0.033					
1983		0.072	0.442	0.176	0.111	0.185	0.137	0.112	0.067	0.060	0.011					
1984	0.009	0.049	0.245	0.304	0.410	0.459	0.274	0.150	0.120	0.035	0.055	0.006	0.009			
1985	0.001	0.043	0.513	1.051	0.508	0.605	0.634	0.517	0.321	0.309	0.109	0.034	0.052	0.030	0.023	0.007
1986	0.034	0.095	0.872	1.118	1.963	1.283	0.501	0.233	0.159	0.104	0.046	0.044	0.029	0.017		
1987		0.018	0.152	1.276	1.464	0.823	0.234	0.109	0.024	0.030	0.022		0.030			
1988	0.008	0.133	0.824	0.453	0.605	0.659	0.255	0.059	0.011	0.014	0.016					
1989	0.146	0.578	1.273	2.768	1.620	1.207	0.581	0.114	0.023	0.025	0.010	0.005		0.005		
1990	0.047	0.179	2.174	2.476	1.412	1.060	0.220	0.175	0.063	0.022						
1991	0.014	0.387	2.112	3.938	2.598	1.779	0.734	0.216	0.068	0.007	0.025	0.024				
1992	0.048	0.218	1.300	3.248	2.329	0.639	0.115	0.018								
1993	0.015	0.069	0.241	0.186	0.477	0.389	0.119	0.049		0.010						
1994	0.075	0.110	0.935	0.774	1.210	0.610	0.156	0.020	0.022							
1995	0.129	0.222	0.483	0.438	0.491	0.155	0.065	0.023	0.008							
1996	0.079	0.176	0.169	0.048	0.029	0.010	0.010			0.001						
1997	0.158	0.424	0.353	0.119	0.249	0.159	0.037	0.013	0.007							
1998	0.011	0.216	0.230	0.069	0.141	0.162	0.092	0.016	0.009							
1999	0.398	1.048	0.539	0.206	0.297	0.312	0.094	0.023								
2000	0.067	0.152	0.229	0.119	0.165	0.056	0.008									
2001	0.018	0.041	0.121	0.040	0.044	0.008										
2002	0.015	0.047	0.063	0.004	0.026	0.028	0.003									
2004	0.011	0.060	0.213	0.051	0.035	0.023	0.010									
2005	0.003	0.019	0.183	0.045	0.038	0.033		0.009								
2006	0.045	0.066	0.152	0.014												
2007	0.137	0.171	0.169	0.023	0.089	0.038	0.004									
2008	0.071	0.110	0.091	0.038	0.032	0.009		0.006								
2009	0.089	0.812	0.437	0.024	0.061	0.059	0.005									
2010		0.038	0.074	0.011	0.020	0.008	0.006									

Table 11. Stratified mean catch rates at age (fish/tow) of white hake in deep-water strata (415, 416, 425, 426, 437-439) in the September Research Vessel (RV) survey of the southern Gulf of St. Lawrence. Convert to trawlable abundance at age (in thousands) by multiplying by 327.659.

	Age (years)															
Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1971		0.083	3.217	2.809	2.197	0.592	0.231	0.050			0.006					
1972		0.088	1.042	0.985	0.961	0.143										
1973		0.017	1.019	0.875	0.626	0.276	0.086	0.016			0.002					
1974		0.109	3.470	2.478	2.504	0.748	0.428	0.119	0.004	0.004	0.017					
1975		0.127	4.385	3.666	4.420	1.844	0.566	0.151	0.013	0.013	0.047					
1976		0.062	3.556	3.509	2.634	0.517	0.100	0.020			0.005					
1977		0.049	3.091	5.558	6.591	1.579	0.347	0.068	0.008	0.008	0.030					
1978		0.003	0.327	0.792	3.723	2.868	0.965	0.225	0.017	0.017	0.071					
1979			0.420	3.178	4.380	4.363	3.250	1.269	0.330	0.040	0.049		0.164			
1980			0.199	1.472	3.221	3.072	1.583	0.552	0.125	0.014	0.018		0.076			
1981			0.196	3.426	7.572	6.155	2.993	1.480	0.331	0.162	0.018		0.018			
1982			0.805	2.487	3.049	1.692	1.224	0.589	0.291	0.021	0.046					
1983		0.185	2.348	3.545	3.736	1.549	0.905	0.266	0.085	0.096						
1984		0.074	1.472	4.723	5.811	3.990	1.570	0.723	0.309	0.130	0.083	0.024	0.015			
1985		0.014	1.250	9.178	15.030	3.844	1.554	0.852	0.250	0.122	0.103	0.005				
1986	0.090	0.534	5.379	11.040	19.046	10.835	3.211	1.348	0.613	0.168	0.017	0.014	0.061			
1987		0.128	1.797	5.204	7.359	5.575	2.900	0.663	0.176	0.016	0.046		0.008			
1988	0.005	0.201	4.629	12.188	14.250	9.585	2.882	1.296	0.216							
1989		0.597	2.821	6.250	4.913	4.192	2.344	0.652	0.074	0.026	0.041					
1990		0.034	1.694	5.848	6.362	7.895	2.288	1.114	0.095							
1991	0.021	0.504	2.159	4.601	3.377	2.169	0.874	0.195	0.043							
1992	0.022	0.538	2.350	3.977	3.530	1.331	0.217	0.072	0.030							
1993	0.014	0.435	3.331	5.963	6.884	2.855	0.543	0.165	0.013	0.034						
1994	0.003	0.269	1.153	2.325	1.465	0.492	0.090									
1995		0.478	3.517	1.680	0.906	0.112	0.071									
1996	0.011	1.071	5.475	5.721	4.283	1.205	0.260	0.055	0.037	0.008						
1997	0.014	0.404	2.877	3.035	4.419	2.034	0.593	0.096								
1998		1.089	6.672	3.884	2.976	1.283	0.342	0.042	0.018							
1999	0.010	0.990	7.093	4.514	3.650	1.038	0.123	0.010								
2000	0.076	1.389	22.380	17.467	13.177	2.131	0.233	0.041								
2001		1.177	5.912	6.325	6.417	2.303	0.192	0.013								
2002		2.901	8.766	3.143	3.060	1.199	0.065	0.031								
2004		0.134	2.020	2.671	2.648	1.380	0.159	0.030								
2005		1.300	12.450	4.974	7.069	1.780	0.206	0.043								
2006	0.109	0.433	3.207	3.133	3.022	0.465										
2007		1.597	29.390	17.220	12.552	2.490	0.155	0.050								
2008		0.234	5.243	6.429	7.254	1.820	0.130	0.019								
2009	0.001	0.263	6.580	4.681	6.623	2.392	0.130									
2010	0.020	1.578	11.250	5.555	6.307	1.487	0.142									

Table 12. General linear model results for the standardization of sentinel longline survey catch rates (1996-2009).

The GLM Procedure

Class Level Information

Class	Levels	Values
year	14	1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009
month	4	7 8 9 10
site	39	17 19 22 23 24 25 28 29 30 31 34 35 45 50 51 52 53 60 61 65 68 71 72 75 76 103 104 109 110 113 114 115 116 121 122 123 124 125 126

Number of Observations Read 844
Number of Observations Used 830

Dependent Variable: cat_eff

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	54	2739.375120	50.729169	28.84	<.0001
Error	775	1363.172309	1.758932		
Corrected Total	829	4102.547429			

R-Square	Coeff Var	Root MSE	cat_eff Mean
0.667725	60.30905	1.326247	2.199085

Source	DF	Type I SS	Mean Square	F Value	Pr > F
year	13	461.129699	35.471515	20.17	<.0001
month	3	49.125986	16.375329	9.31	<.0001
site	38	2229.119435	58.661038	33.35	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	13	579.076064	44.544313	25.32	<.0001
month	3	42.412168	14.137389	8.04	<.0001
site	38	2229.119435	58.661038	33.35	<.0001

Least Squares Means

year	cat_eff LSMEAN
1996	2.01397979
1997	2.50799905
1998	2.34653781
1999	2.50357919
2000	1.96794943
2001	1.50137616
2002	1.27561101
2003	0.81861132
2004	0.80983909
2005	0.64303858
2006	0.24464335
2007	0.13197119
2008	-0.46965368
2009	0.13002481

Table 13. Standardized catch rates (fish/tow) for ages 0+ white hake by longliners in the southern Gulf of St. Lawrence sentinel longline survey (1996-2009).

Year	Standardized Catch Rate	Standard Error
1996	17.3	0.20
1997	28.5	0.18
1998	24.3	0.17
1999	28.4	0.16
2000	16.6	0.17
2001	10.4	0.16
2002	8.3	0.18
2003	5.3	0.20
2004	5.2	0.18
2005	4.4	0.19
2006	3.0	0.19
2007	2.6	0.20
2008	1.4	0.24
2009	2.6	0.24

Table 14. Mean number and mean weight (kg) per tow for ages 0+ white hake in the southern Gulf of St. Lawrence sentinel bottom-trawl survey (2003-2010). Data were not adjusted for vessel differences. From Savoie (2011).

Year	Mean Catch/Tow (#'s)	Standard Error	Mean Catch/Tow (kg)	Standard Error
2003	2.4	0.90	1.103	0.328
2004	2.6	0.76	1.646	0.480
2005	3.0	0.99	1.567	0.523
2006	2.3	0.82	0.976	0.266
2007	1.6	0.52	0.722	0.220
2008	0.9	0.26	0.405	0.100
2009	1.8	0.67	1.205	0.401
2010	1.2	0.35	0.544	0.142

*Table 15. Mean number and mean weight (kg) per tow for ages 0+ white hake in the July-August bottom-trawl survey of the Northumberland Strait (2000-2009). Only data from blocks 1, 2, 3 and 5 were used for these calculations. * - The indices for 2002 and 2005 should be interpreted with caution because some blocks were not properly sampled in these years. (From S. LeBlanc and T. Surette DFO Unpublished data).*

Year	Mean Catch/Tow (#'s)	Standard Error	Mean Catch/Tow (kg)	Standard Error
2000	0.2	0.27	0.078	0.155
2001	0.6	1.80	0.141	0.333
2002	0.1	0.23	0.090	0.206
2003	0.1	0.16	0.062	0.147
2003	0.1	0.21	0.091	0.160
2004	0.1	0.22	0.048	0.099
2005	0.2	0.37	0.105	0.199
2006	0.2	0.37	0.058	0.121
2007	0.4	0.45	0.136	0.273
2008	0.1	0.17	0.045	0.113
2009	0.2	0.27	0.078	0.155

Table 16. Decadal variation in measures of abundance of white hake in the southern Gulf of St. Lawrence by age or size class. Trawlable abundance is based on catch rates in the September RV survey and likely underestimates abundance. Abundance estimates are beginning-of-year values from the population model. Values are the mean of the annual estimates for each decade.

	Trawlable Abundance (thousands)				Abundance (thousands)	
Decade	<45 cm	45+ cm	1-3 yr	4+ yr	1-3 yr	4+ yr
1970s	3,973	4,672	4,881	6,435	56,952	10,036
1980s	4,578	7,020	4,819	10,208	47,340	14,980
1990s	5,571	2,620	5,978	4,531	144,144	10,307
2000s	6,260	1,047	6,507	2,764	222,060	3,370

Table 17. Distribution of the survey population of white hake among strata in the 2000s, and the proportion of hake in each stratum that are of the Gulf type based on genetic sampling in the mid to late 2000s. Italics indicate assumed values, based on the values from neighbouring strata in the same depth zone.

Stratum	Proportion of Population	Proportion Gulf
401	0.008	0.875
403	0.038	0.960
415	0.057	0.739
416	0.000	1.000
417	0.000	0.000
418	0.000	*1.000*
419	0.001	1.000
420	0.004	1.000
421	0.001	*1.000*
422	0.000	*1.000*
423	0.000	0.000
424	0.000	0.000
425	0.137	0.614
426	0.000	1.000
427	0.000	0.000
428	0.000	0.000
429	0.012	1.000
431	0.000	*1.000*
432	0.011	1.000
433	0.048	1.000
434	0.003	*1.000*
435	0.001	1.000
436	0.000	1.000
437	0.420	0.929
438	0.000	*1.000*
439	0.259	0.701

Table 18. Proportion of 4T white hake that are of the Gulf type by depth zone. Results are shown including samples collected in 4T by the August RV survey of the northern Gulf or excluding this survey. The August survey includes deep areas of the Laurentian Channel not covered by the September RV survey of the southern Gulf.

	Include August survey		Exclude August survey	
Depth (m)	prop. Gulf	N	prop. Gulf	N
≤50	0.96	236	0.96	236
50-100	1.00	2	1.00	2
100-150	0.88	16	0.88	16
150-200	0.93	73	0.93	70
200-250	0.83	179	0.79	120
250-300	0.70	210	0.69	144
300-350	0.52	158	0.56	123
>350	0.34	38	0.70	10

Table 19. Proportion of white hake in the 4T survey area that are estimated to be Gulf type. Estimates are based on the proportion of Gulf type by depth zone (Table 6) and the depth distribution of white hake in the September survey (Figure 12).

		Include August survey		Exclude August survey	
Period for depth distribution	Depths	all sizes	≥45 cm	all sizes	≥45 cm
2005-2010	all	0.81	0.77		
2000-2010	all	0.81	0.76	0.80	0.76
2000-2010	≤300 m	0.85	0.82	0.83	0.81

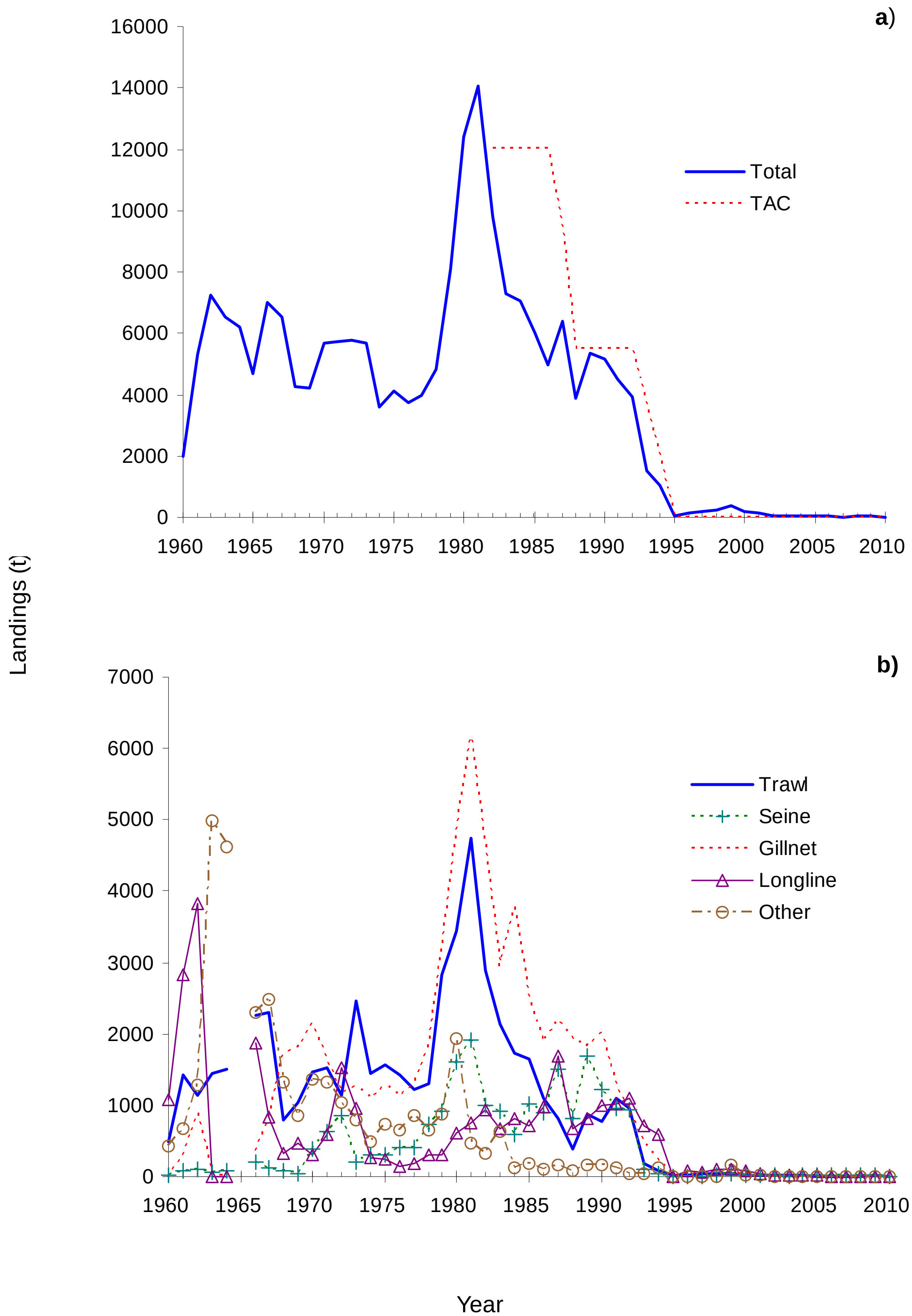


Figure 1. Nominal landings and total allowable catch (TAC) for white hake in NAFO Div. 4T (a) and nominal landings by gear category for white hake in NAFO Div. 4T (b).

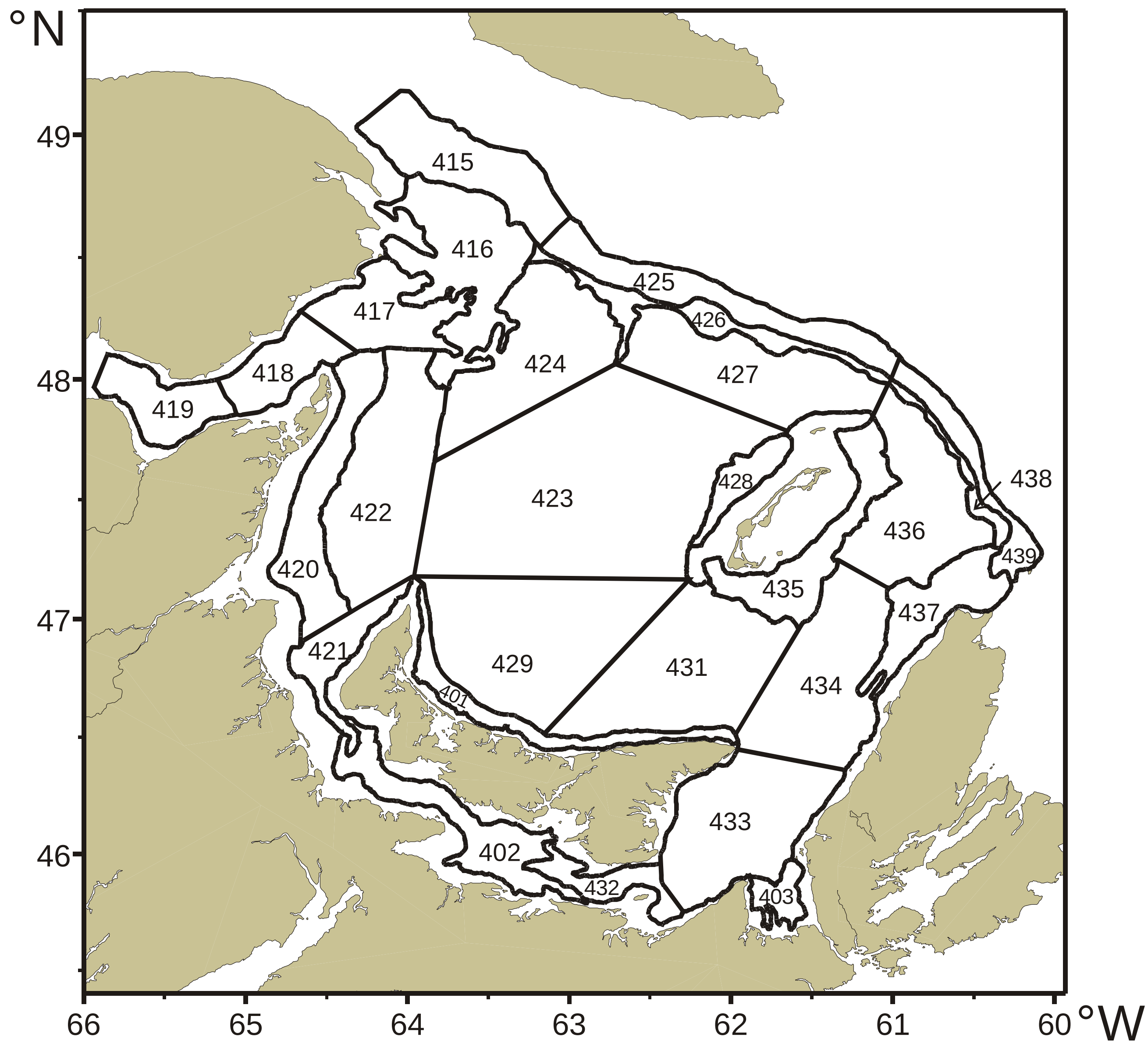


Figure 2. Strata used in the annual (September) bottom-trawl survey of the southern Gulf of St. Lawrence.

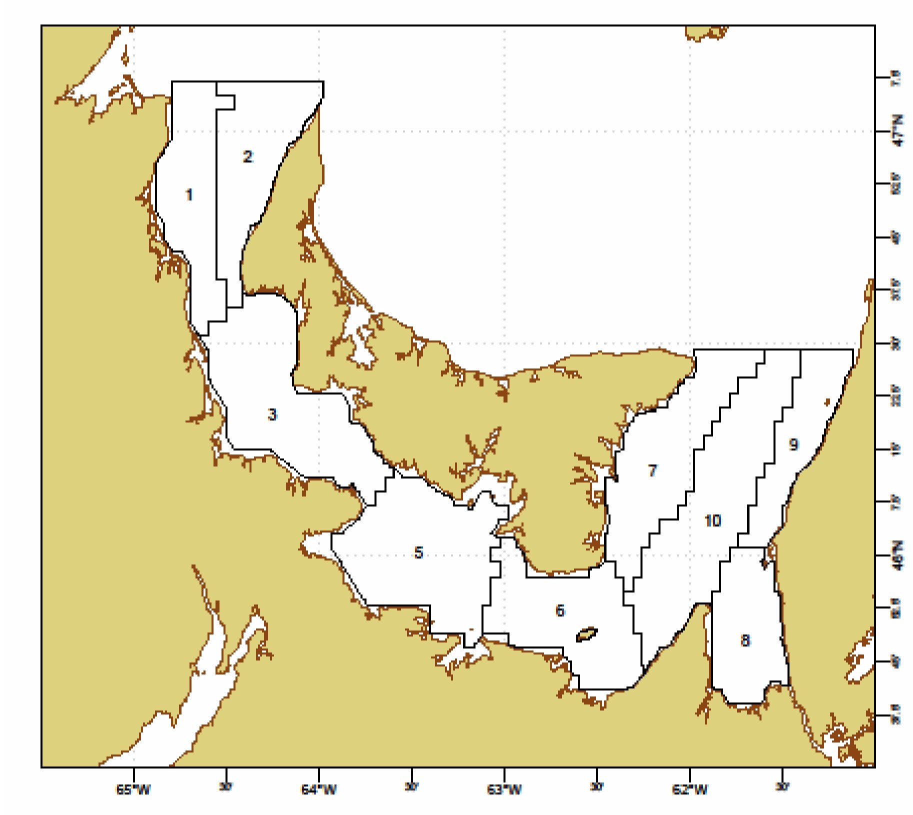


Figure 3. Blocking scheme used for the July-August bottom-trawl survey of the Northumberland Strait. (From S. LeBlanc and T. Surette DFO Unpublished data).

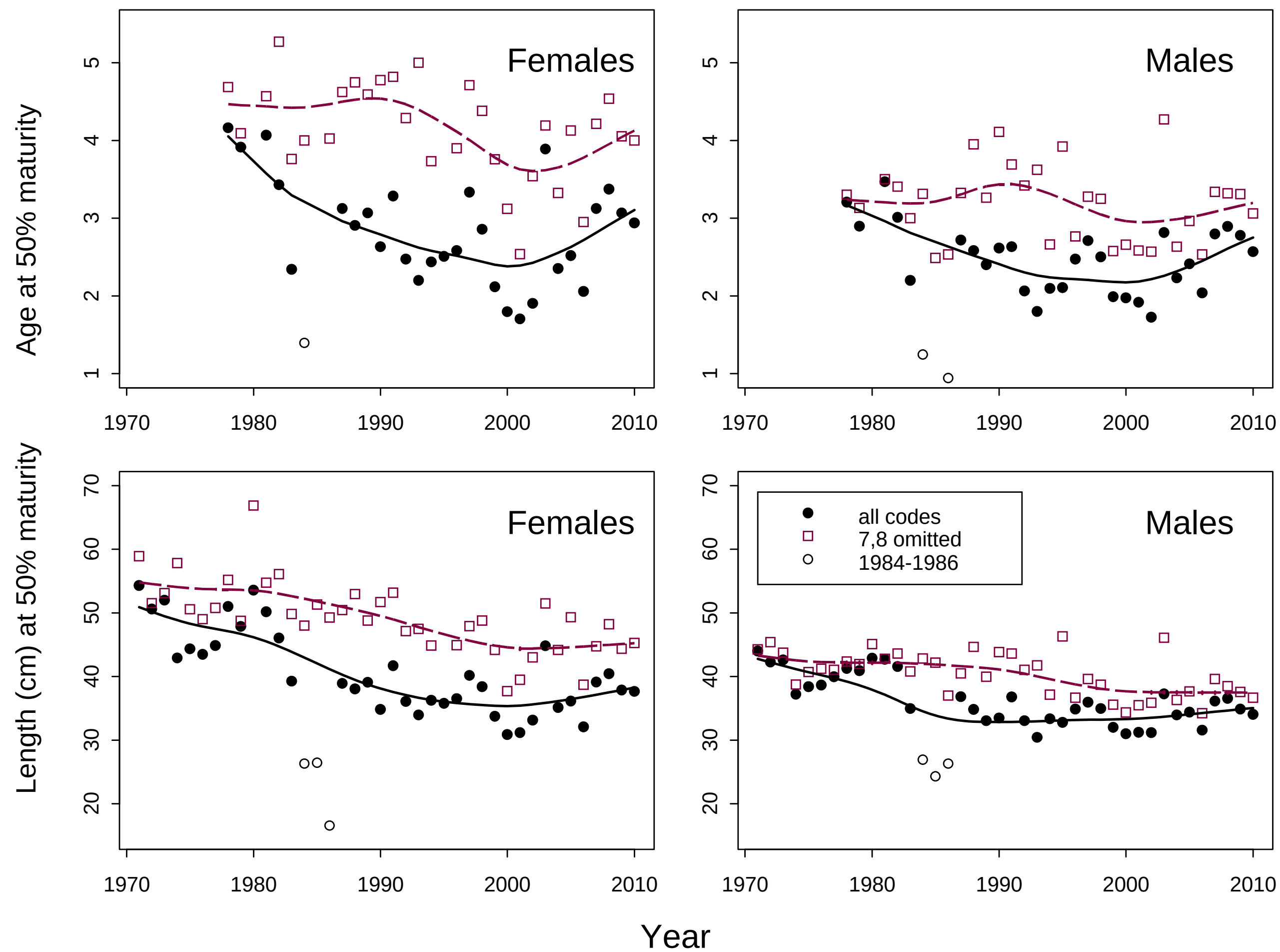


Figure 4. Lengths and ages at 50% maturity for white hake in the southern Gulf of St. Lawrence, including (circles) or excluding (squares) fish staged as maturity codes 7 and 8 (resting/recovering). Anomalously low estimates for the 1984-1986 period are shown as open circles. Lines are GAM (Generalized Additive Model) smooths to the time trends (with degrees of freedom set to 4). Based on data collected during the annual September survey.

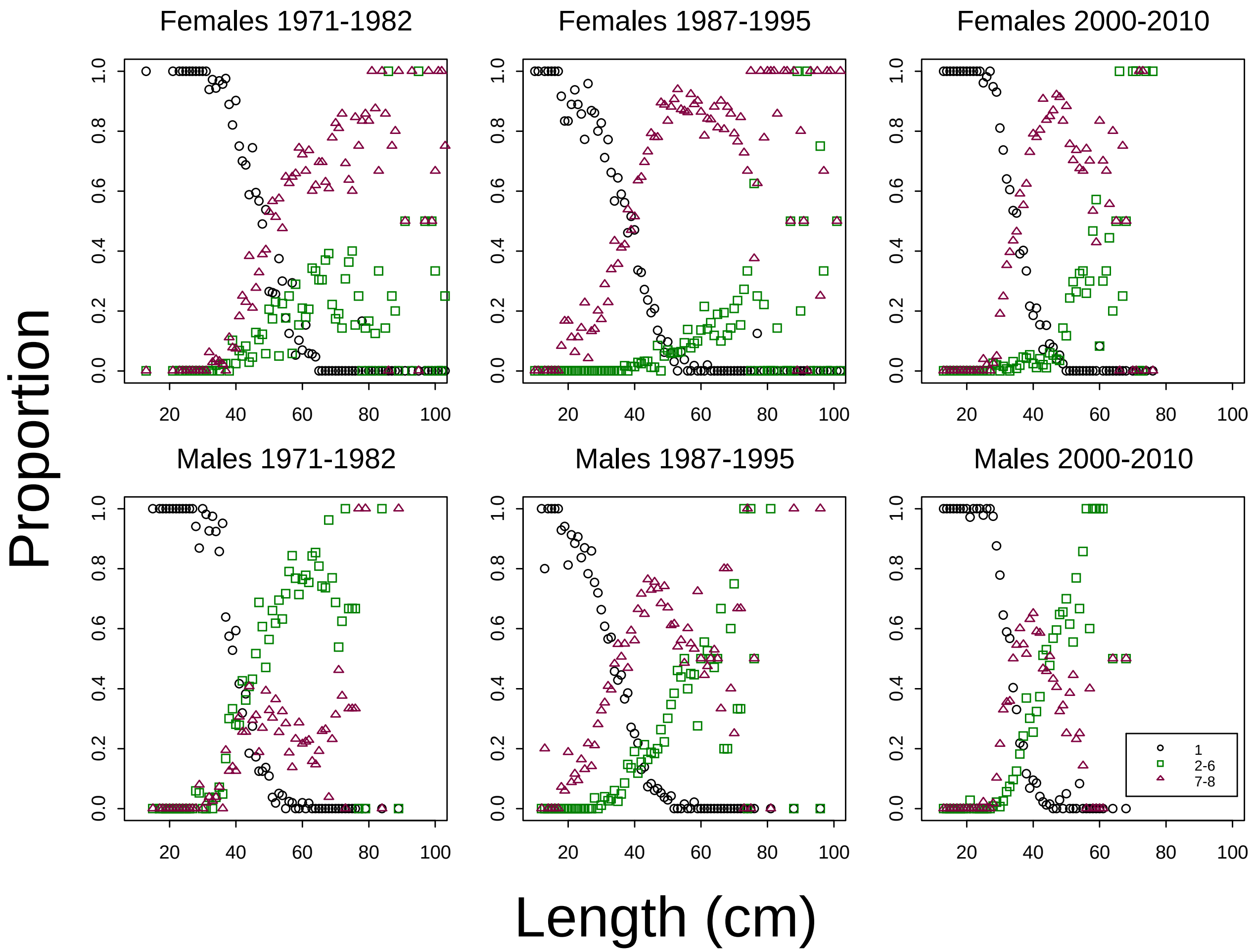


Figure 5. Maturity-stage proportions at length for white hake collected during annual September surveys of the southern Gulf of St. Lawrence. Maturity stages are 1: immature, 2-6: ripening – spent; 7-8: resting/recovering.

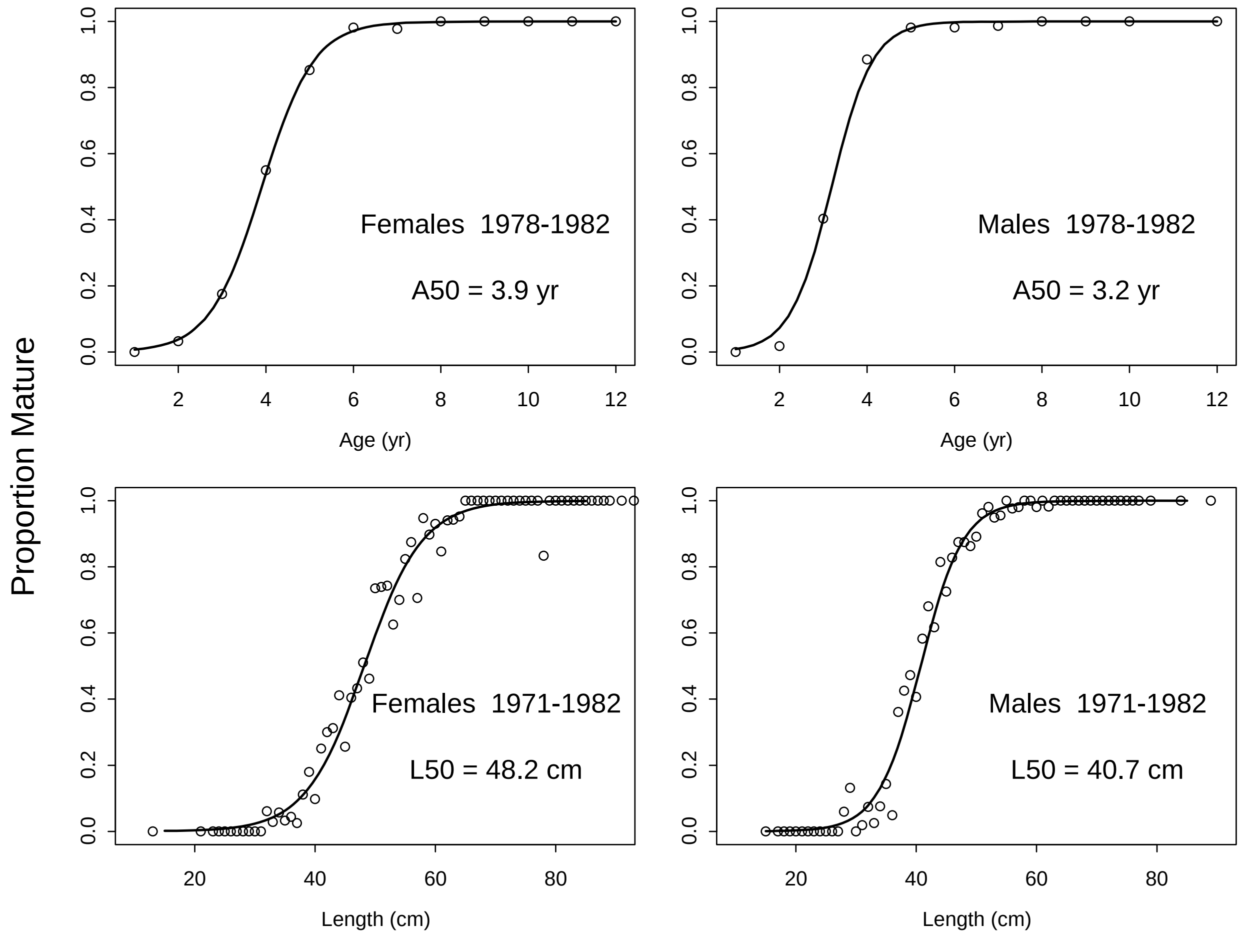
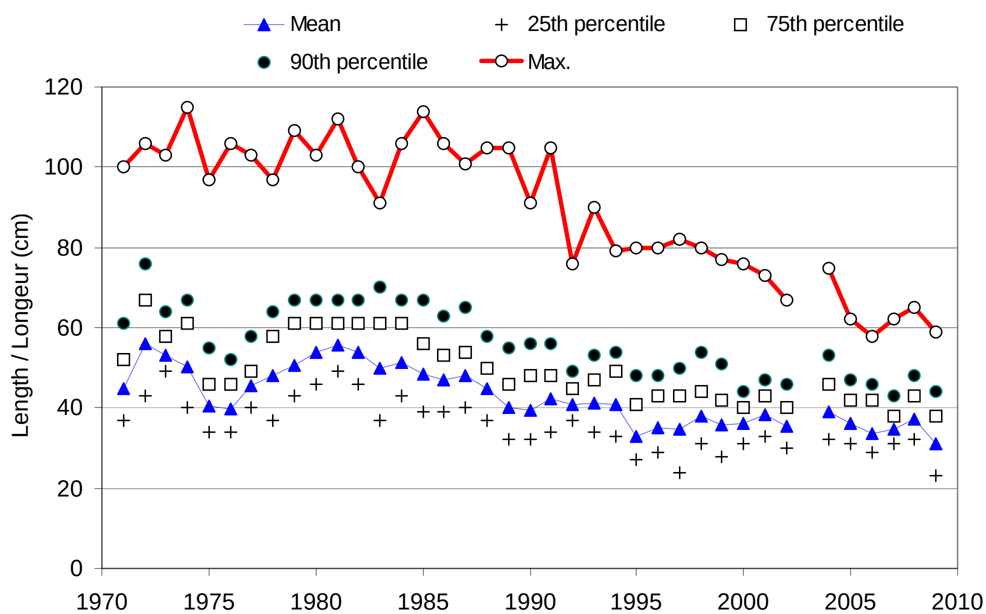


Figure 6. Maturity ogives for white hake collected during September surveys of the southern Gulf of St. Lawrence in 1971-1982 (maturity at length) or 1978-1982 (maturity at age). Circles show the observed proportions and lines the predicted values from logistic regression. Estimated lengths (L50) and ages (A50) at 50% maturity are based on the estimated parameters of the logistic regressions ($-\beta_1/\beta_2$).



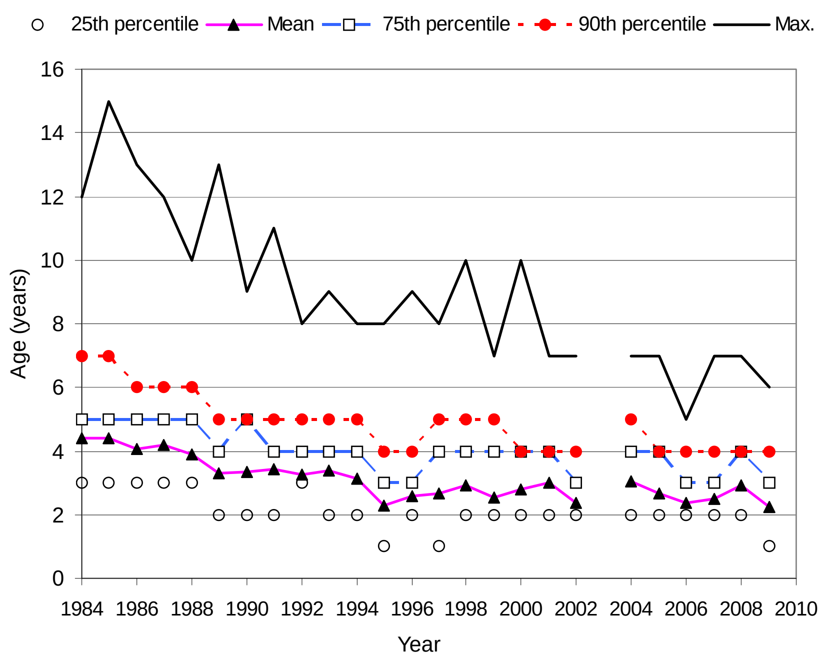


Figure 7. Length and age distributions of white hake in September RV surveys of the southern Gulf of St. Lawrence.

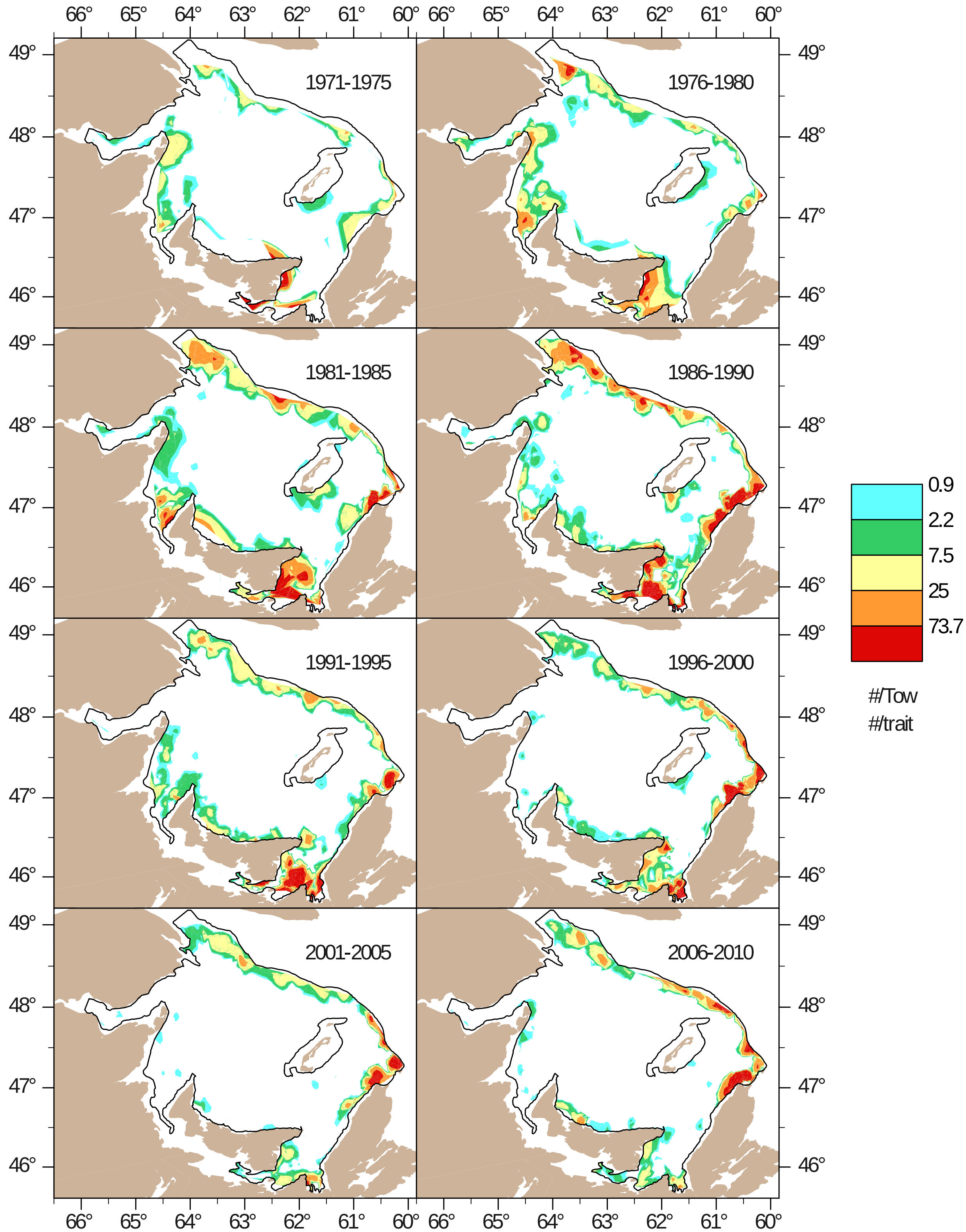


Figure 8a. Distribution of catches (numbers) of white hake (all sizes) in the southern Gulf of St. Lawrence September surveys.

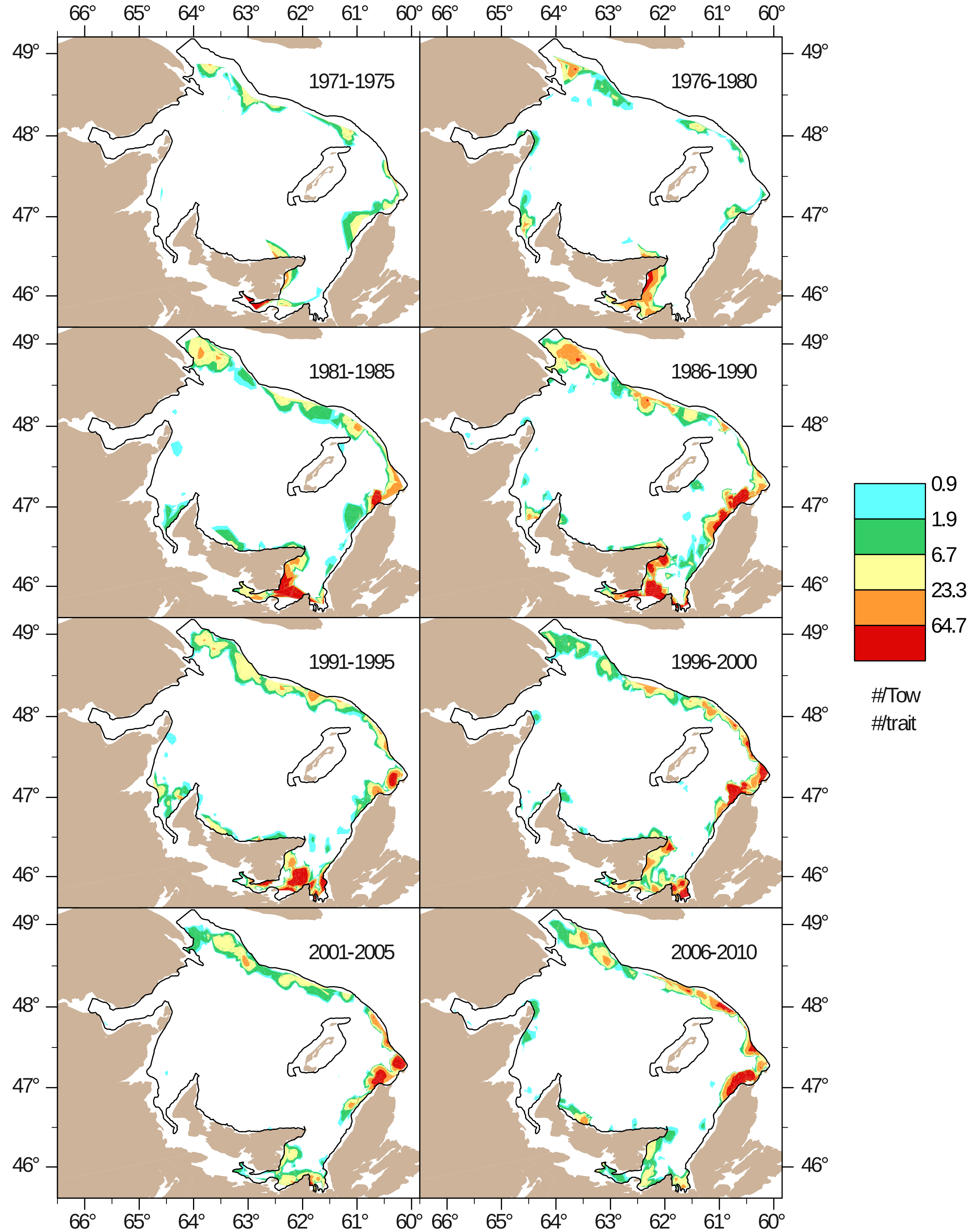


Figure 8b. Distribution of catches (numbers) of small white hake (<45 cm TL) in the southern Gulf of St. Lawrence September surveys.

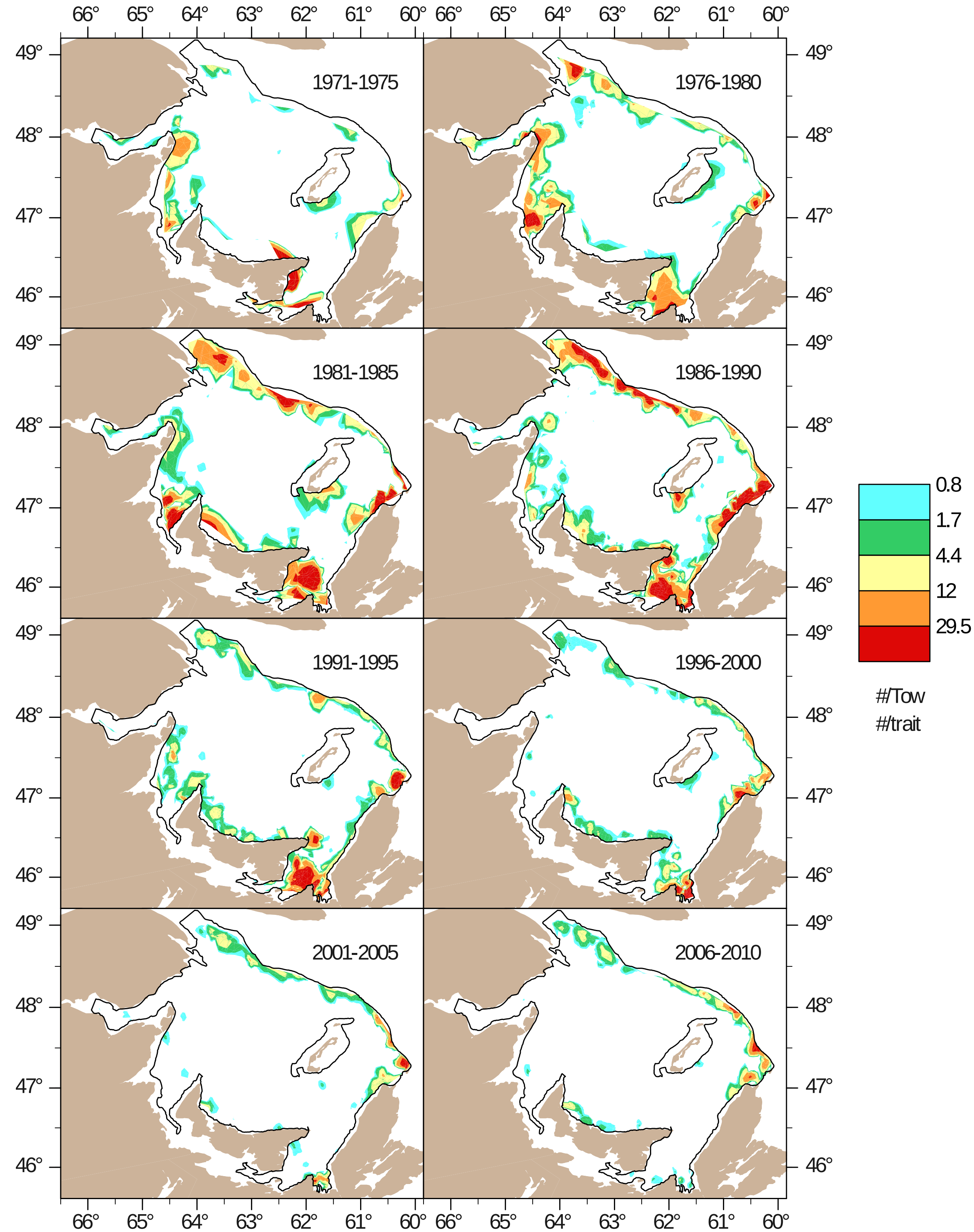


Figure 8c. Distribution of catches (numbers) of large white hake (≥45 cm TL) in the southern Gulf of St. Lawrence September surveys.

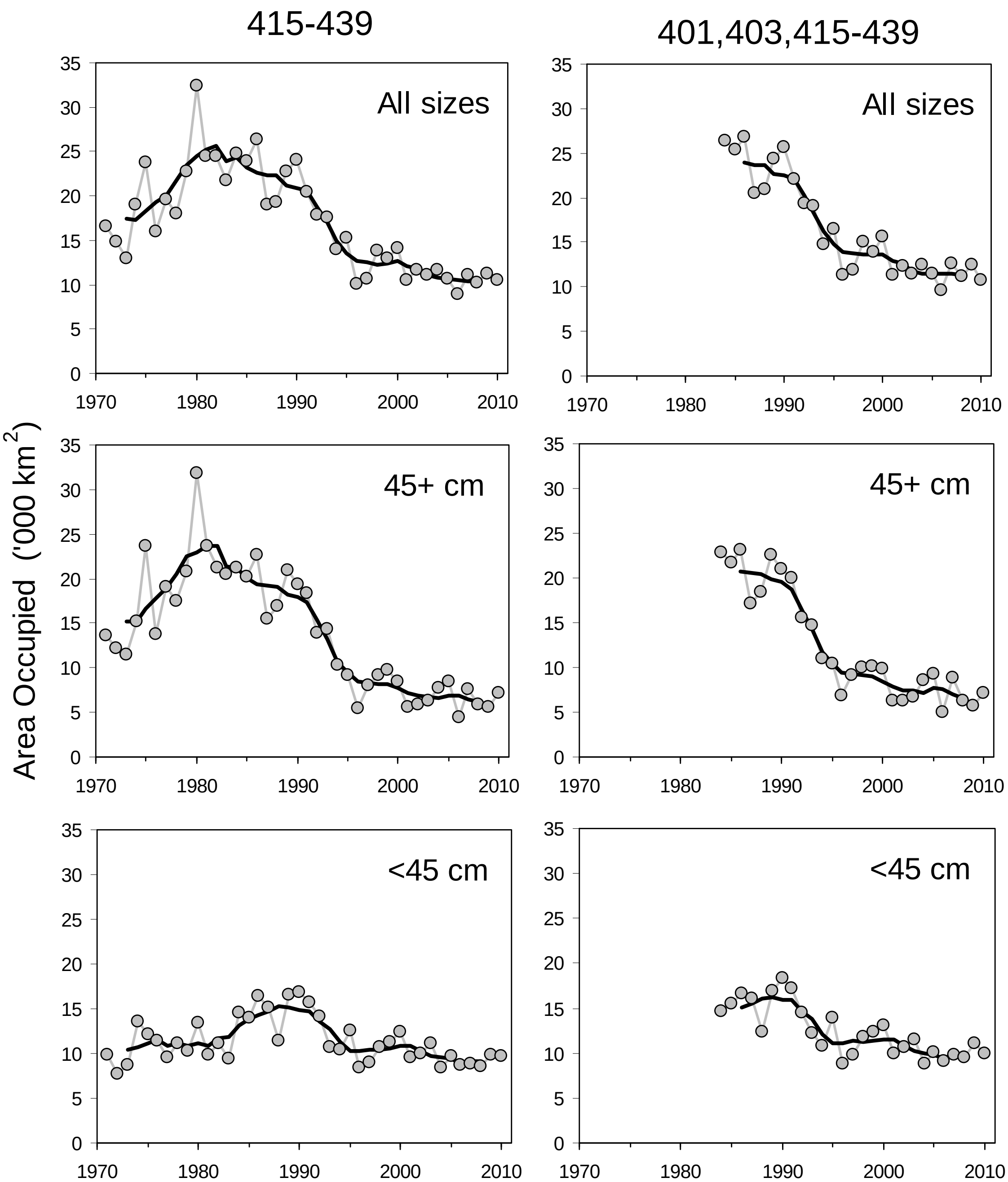


Figure 9. Area occupied by two size classes of white hake in September in the southern Gulf of St. Lawrence, 1971-2010. The size classes correspond roughly to juvenile (<45 cm) and adult (45+ cm) hake. Heavy line is a 5-yr moving average.

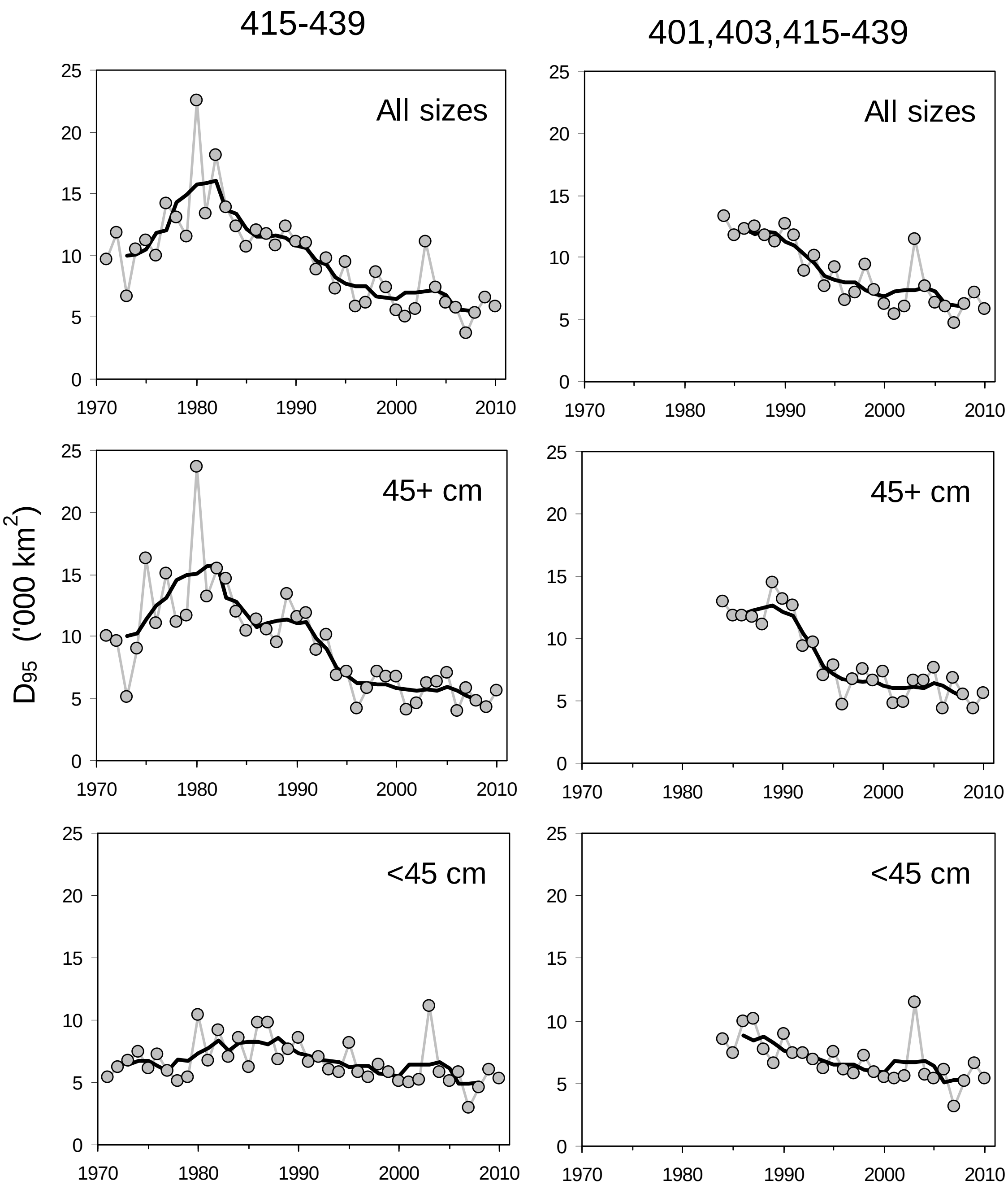


Figure 10. Time trend in an index of geographic range (D95) for two size classes of white hake in September in the southern Gulf of St. Lawrence, 1971-2010. The size classes correspond roughly to juvenile (<45 cm) and adult (45+ cm) hake. Heavy line is a 5-yr moving average.

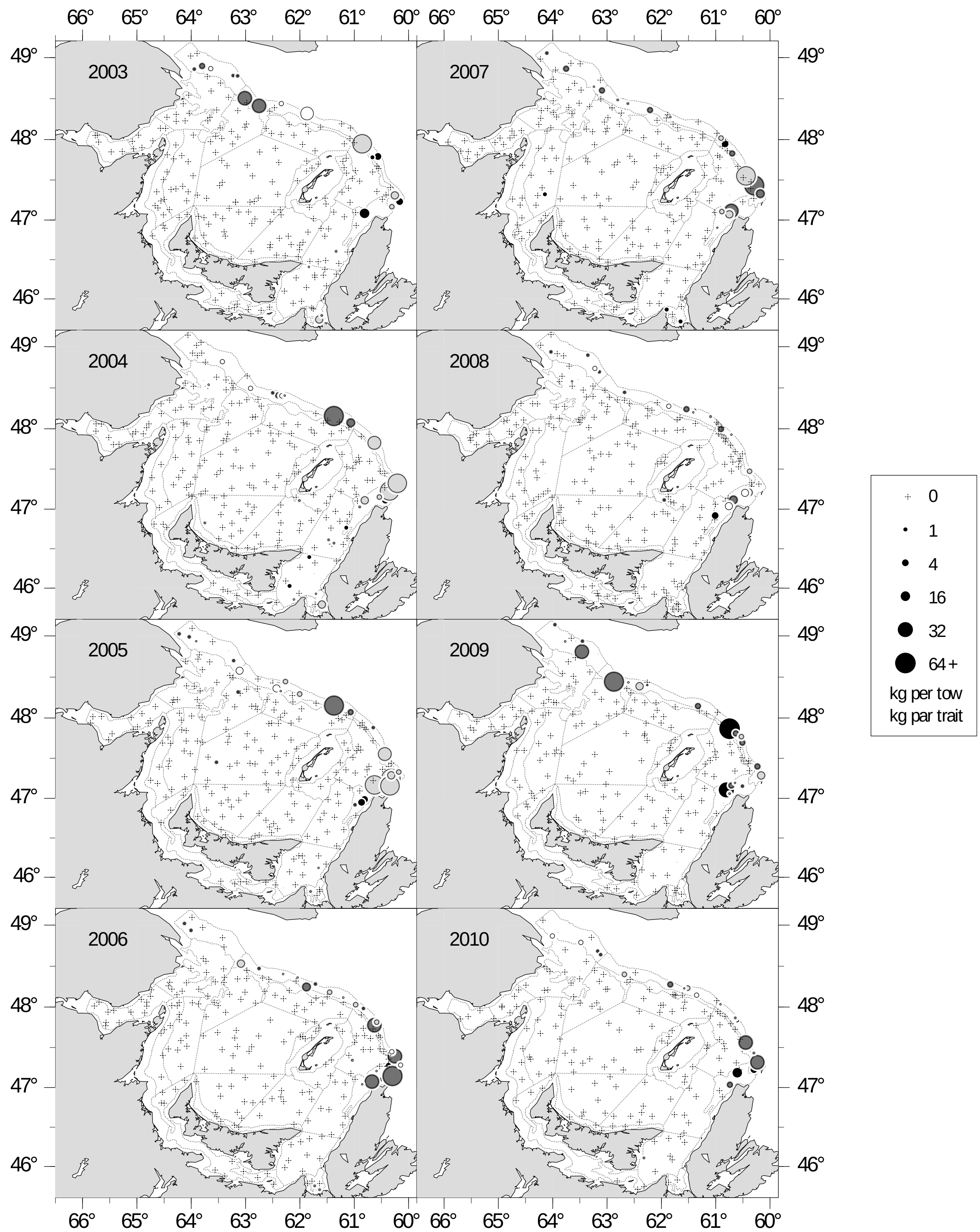


Figure 11. Catches (kg) of white hake in the Sentinel Bottom-Trawl Survey (2003-2010). Each participating vessel is color coded as follows: Riding It Out (2003-2006), Atlantic Quest I (2007-2009) and Tamara Louise (2010) as black, L'Alberto (2003) and Viking II (2004-2010) as dark grey, Manon Yvon (2003-2005) and Cap Adèle (2006-2010) as light grey, Miss Lamèque as white. From Savoie (2011.).

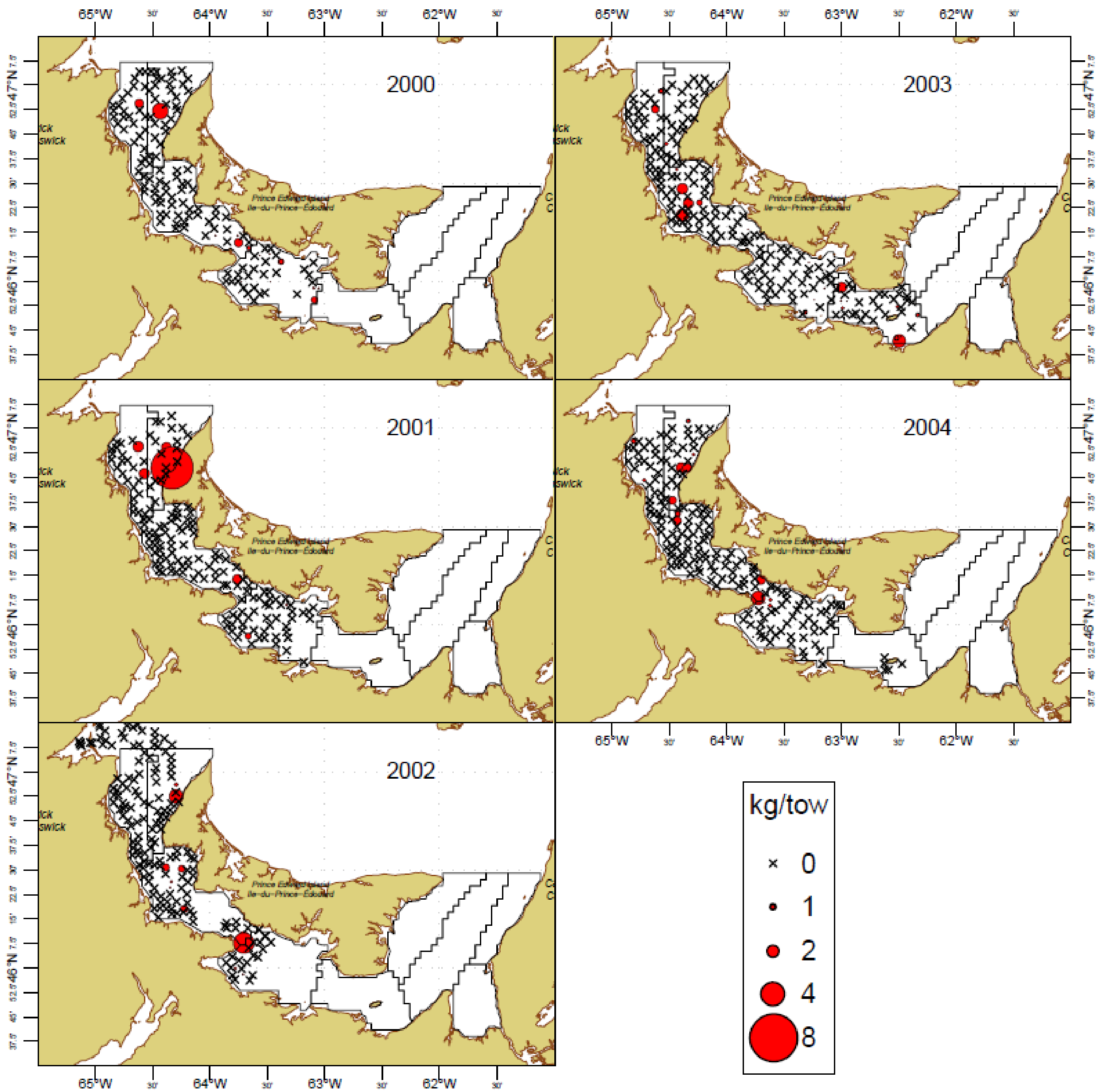


Figure 12. White hake catches (kg) during the July-August bottom-trawl survey of the Northumberland Strait. All sampling sites are shown, however only data from blocks 1, 2, 3 and 5 were included in the analyses. (From S. LeBlanc and T. Surette DFO Unpublished data).

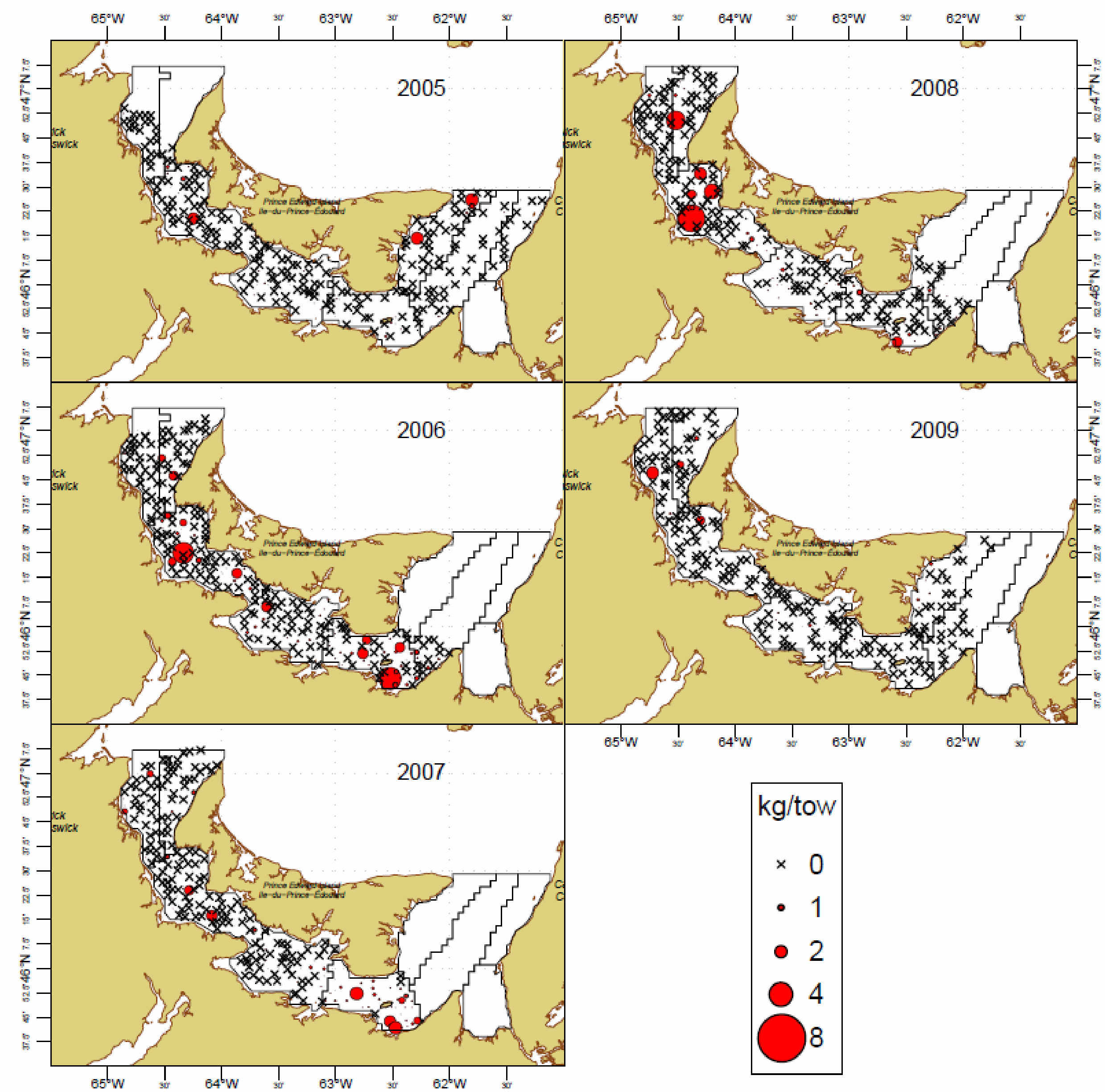


Figure 12 (continued). White hake catches (kg) during the July-August bottom-trawl survey of the Northumberland Strait. All sampling sites are shown, however only data from blocks 1, 2, 3 and 5 were included in the analyses. (From S. LeBlanc and T. Surette DFO Unpublished data).

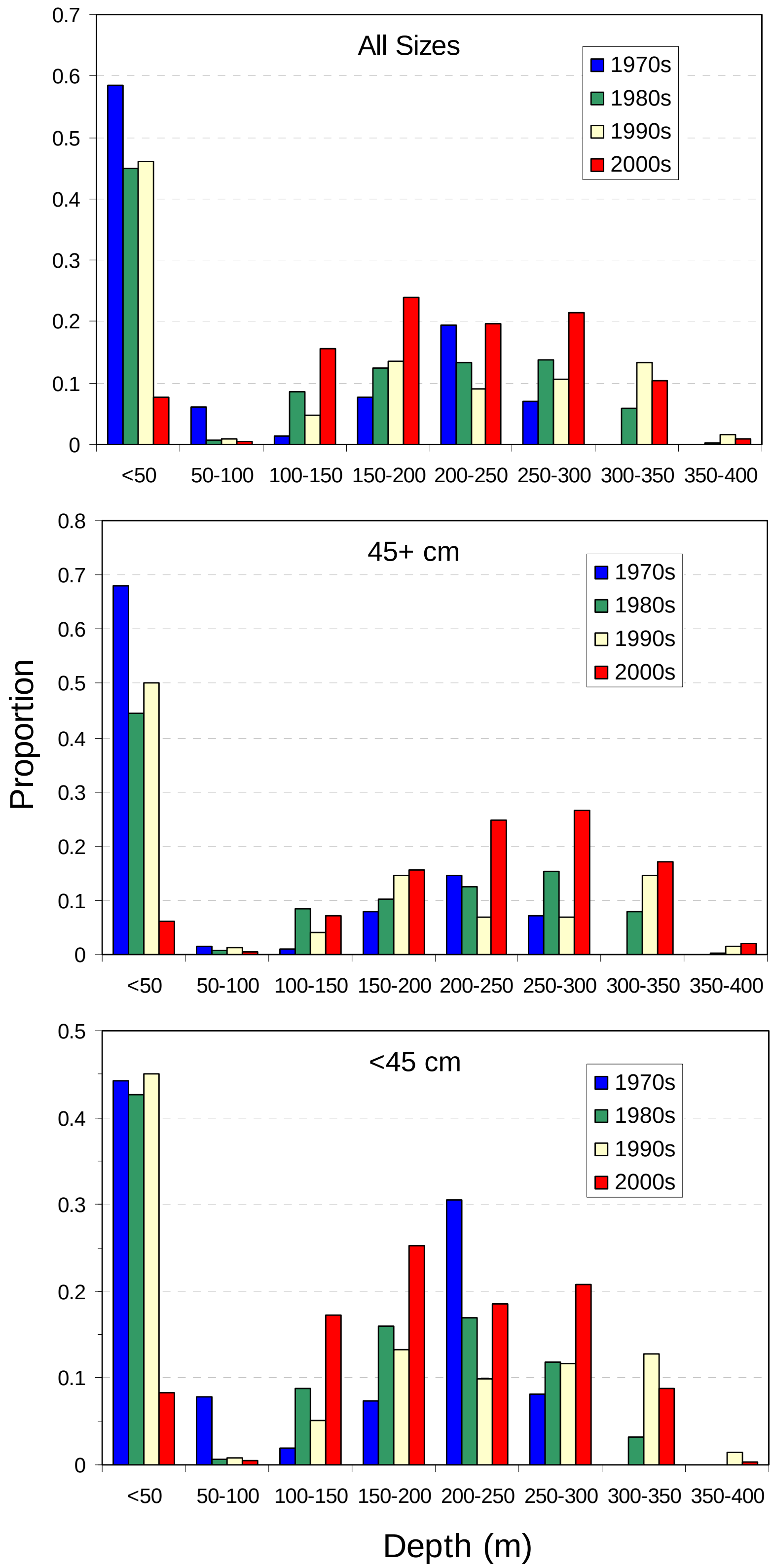


Figure 13. Proportion of southern Gulf of St. Lawrence white hake by depth zone in September.

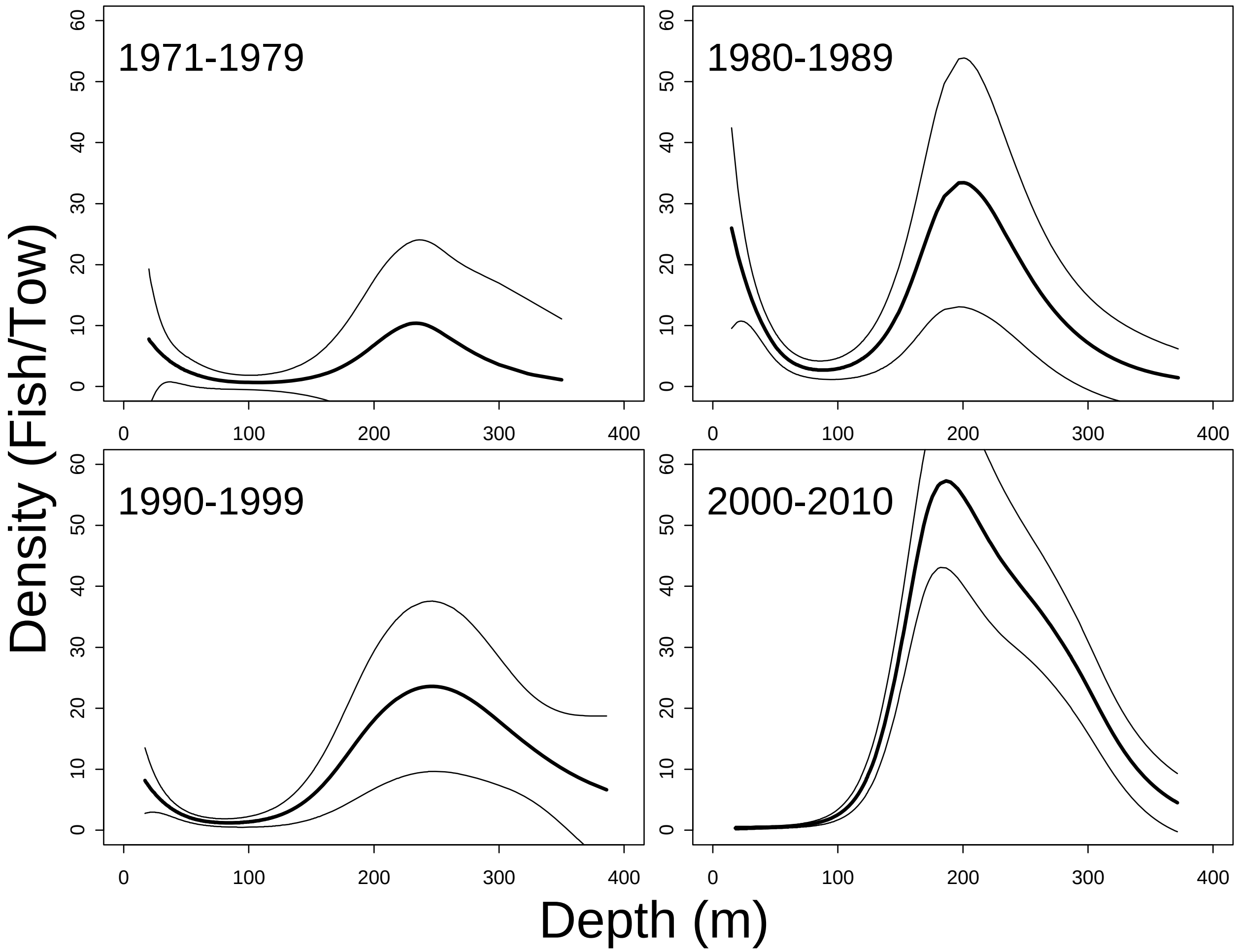


Figure 14. Effect of depth on the local density of white hake <45 cm in length (juvenile sizes) in the southern Gulf of St. Lawrence in September. Heavy line is the predicted density and light lines are ± 2SE.

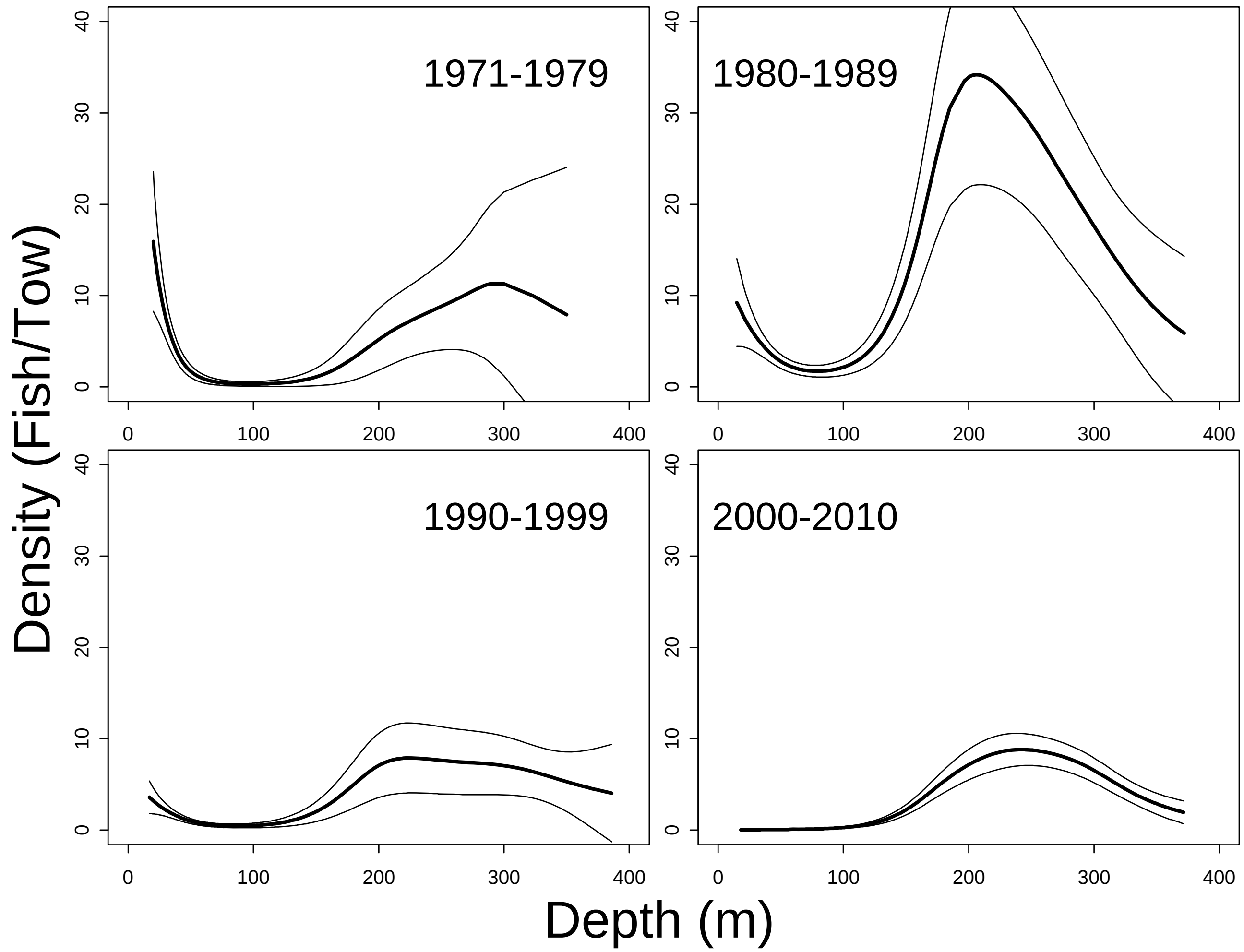


Figure 15. Effect of depth on the local density of white hake ≥45 cm in length (adult sizes) in the southern Gulf of St. Lawrence in September. Heavy line is the predicted density and light lines are ± 2SE.

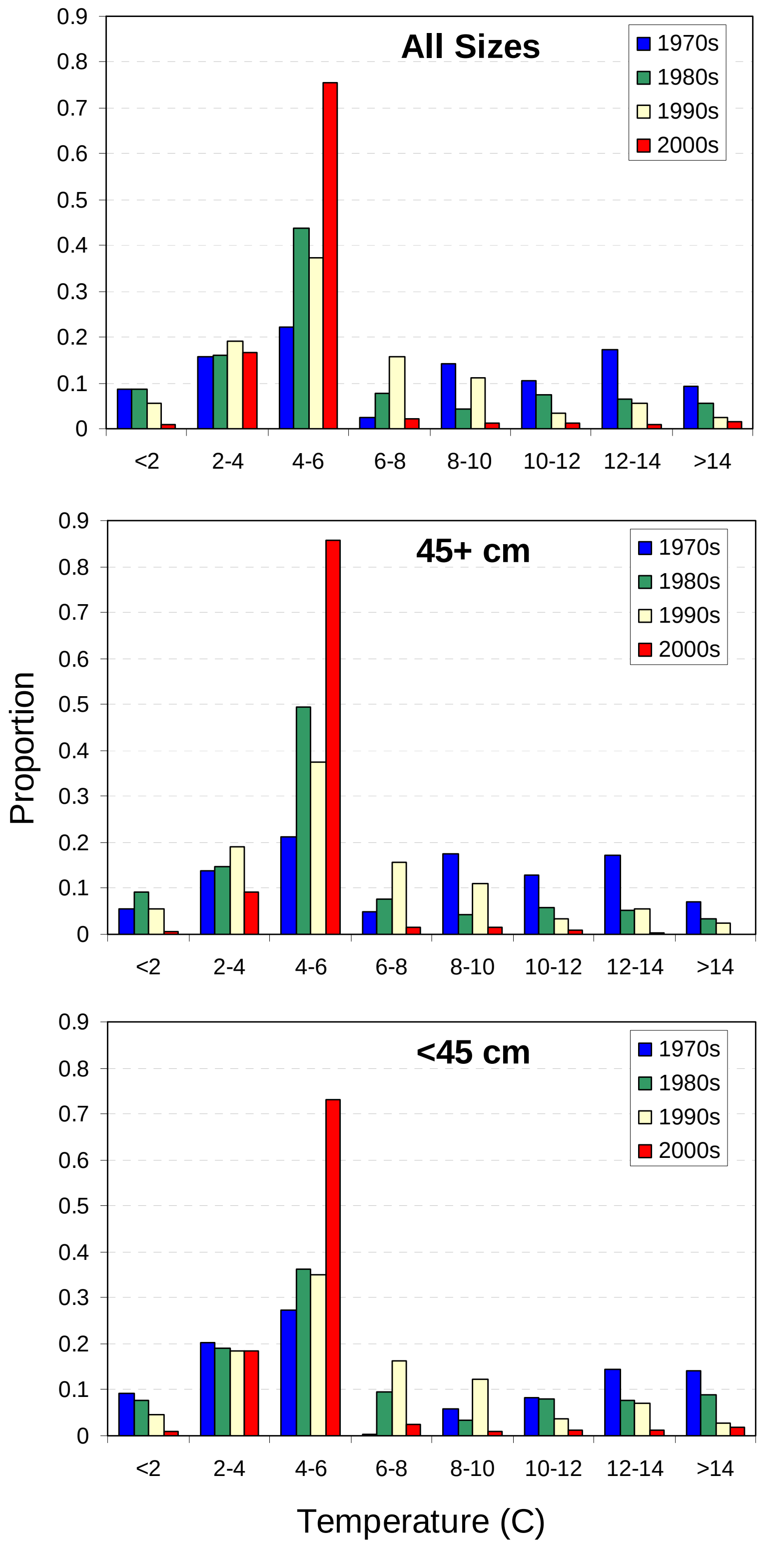


Figure 16. Proportion of southern Gulf of St. Lawrence white hake by temperature zone in September.

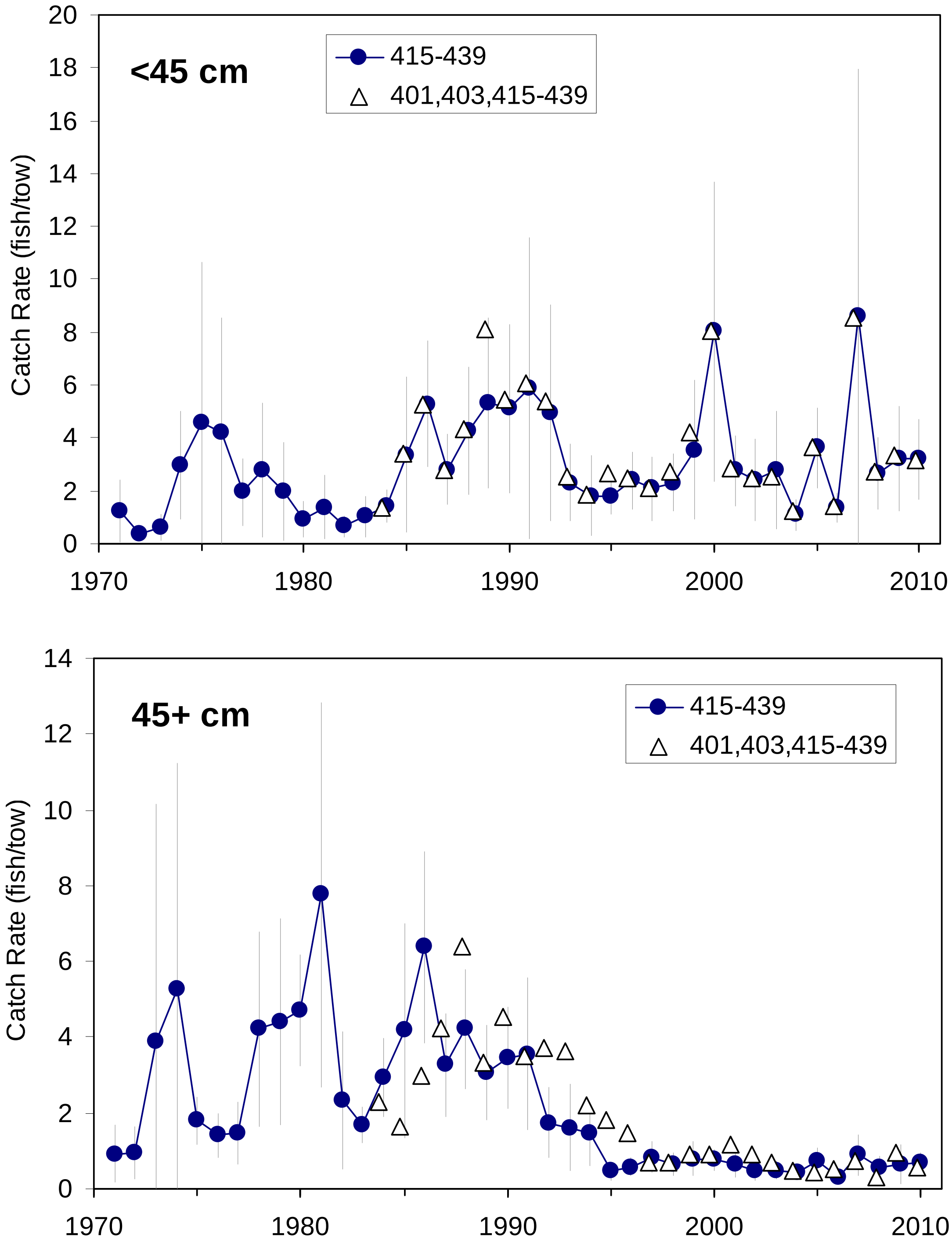


Figure 17. Stratified mean catch rates of two size classes of white hake in the September survey of the southern Gulf of St. Lawrence. Vertical lines are ±2SE. Catch rates are adjusted to daytime catchability by the Alfred Needler. Hake ≥45 cm in length correspond roughly to the adult portion of the population.

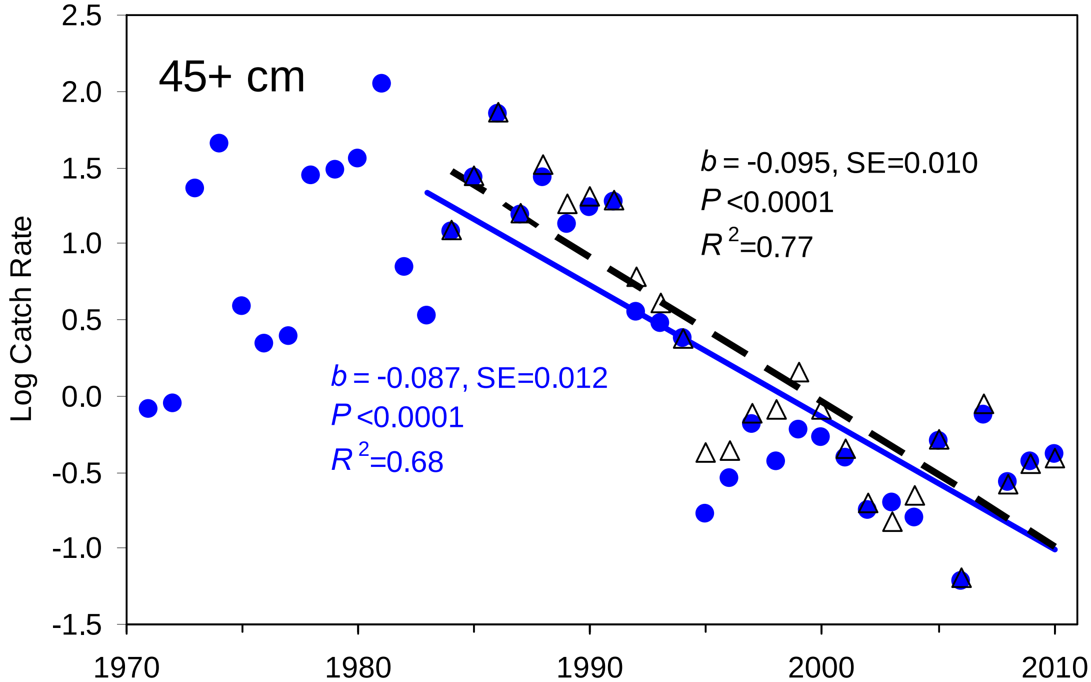


Figure 18. Log$_e$ – transformed catch rates of adult-sized white hake (≥45 cm in length) in September surveys of the southern Gulf of St. Lawrence. Lines show the regression of log$_e$ catch rate on year based on catches in strata 415-439 (circles, solid line, blue) or strata 401, 403 and 415-439 (triangles, dashed line, black). Regression lines are fit over the most recent 3-generation (27 yr) period.

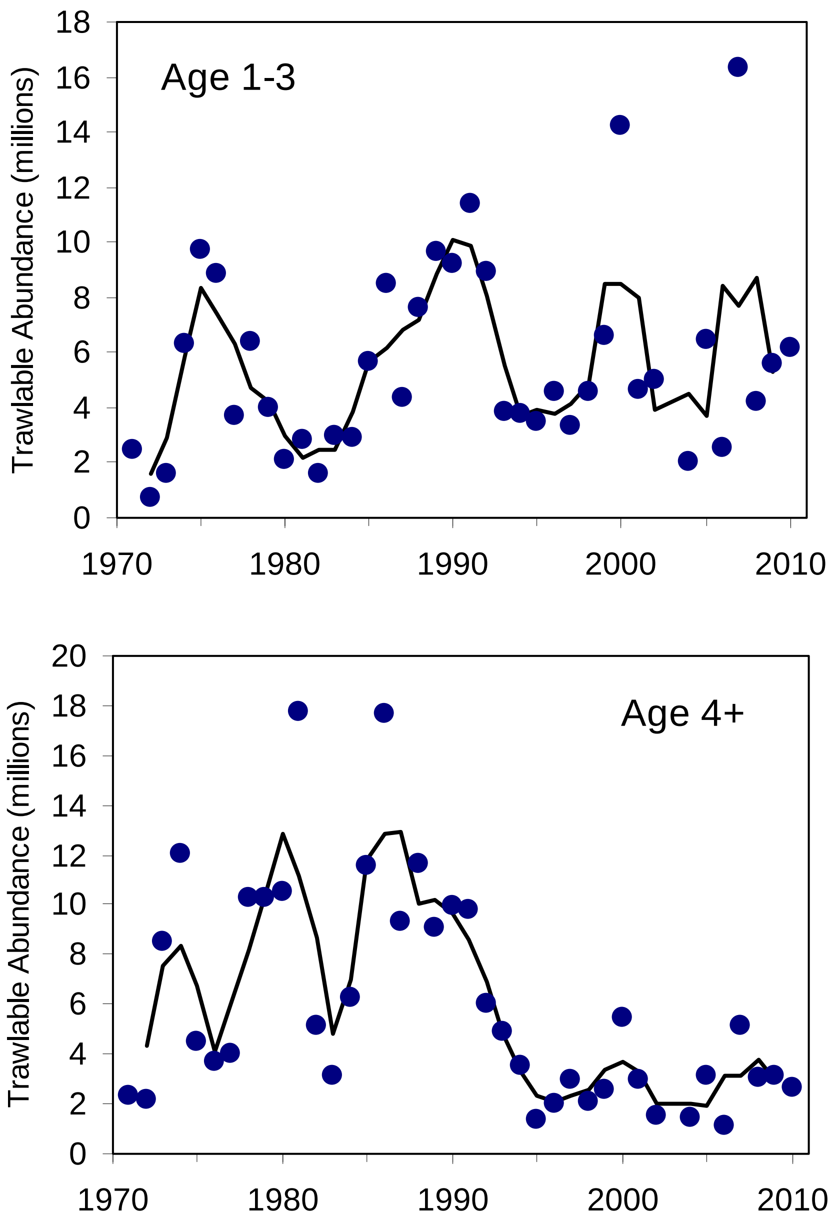


Figure 19. Trawlable abundance of two age groups of white hake in the September survey of the southern Gulf of St. Lawrence. Lines show three-year running averages. Hake 4 years and older correspond roughly to the adult portion of the population.

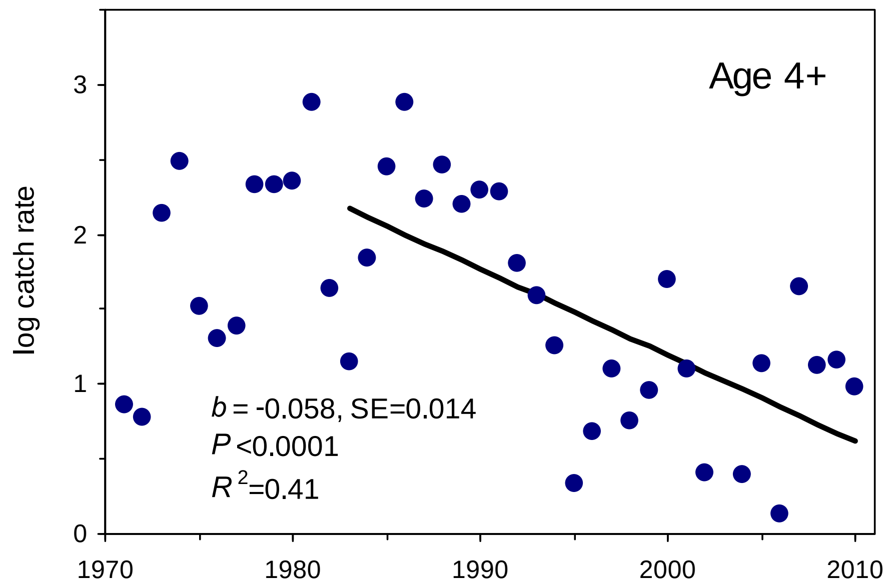


Figure 20. Log$_e$ – transformed catch rates (trawlable abundance) of white hake aged 4 years and older in strata 415 – 439 of the September surveys of the southern Gulf of St. Lawrence. The line shows the regression of log$_e$ catch rate on year fit over the most recent 3-generation (27 yr) period.

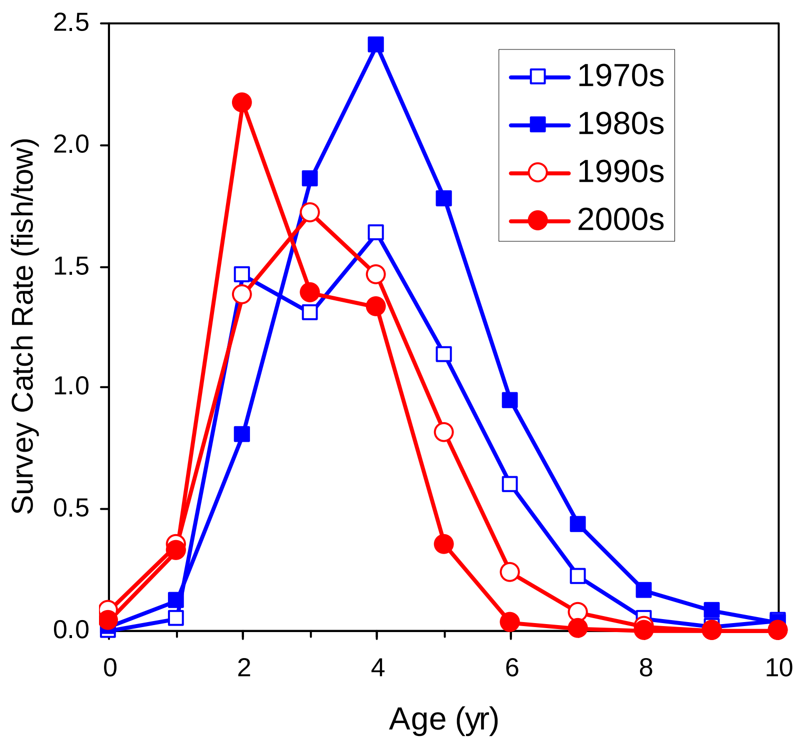


Figure 21. Decadal variation in mean catch rates at age of white hake in the September bottom-trawl survey of the southern Gulf of St. Lawrence.

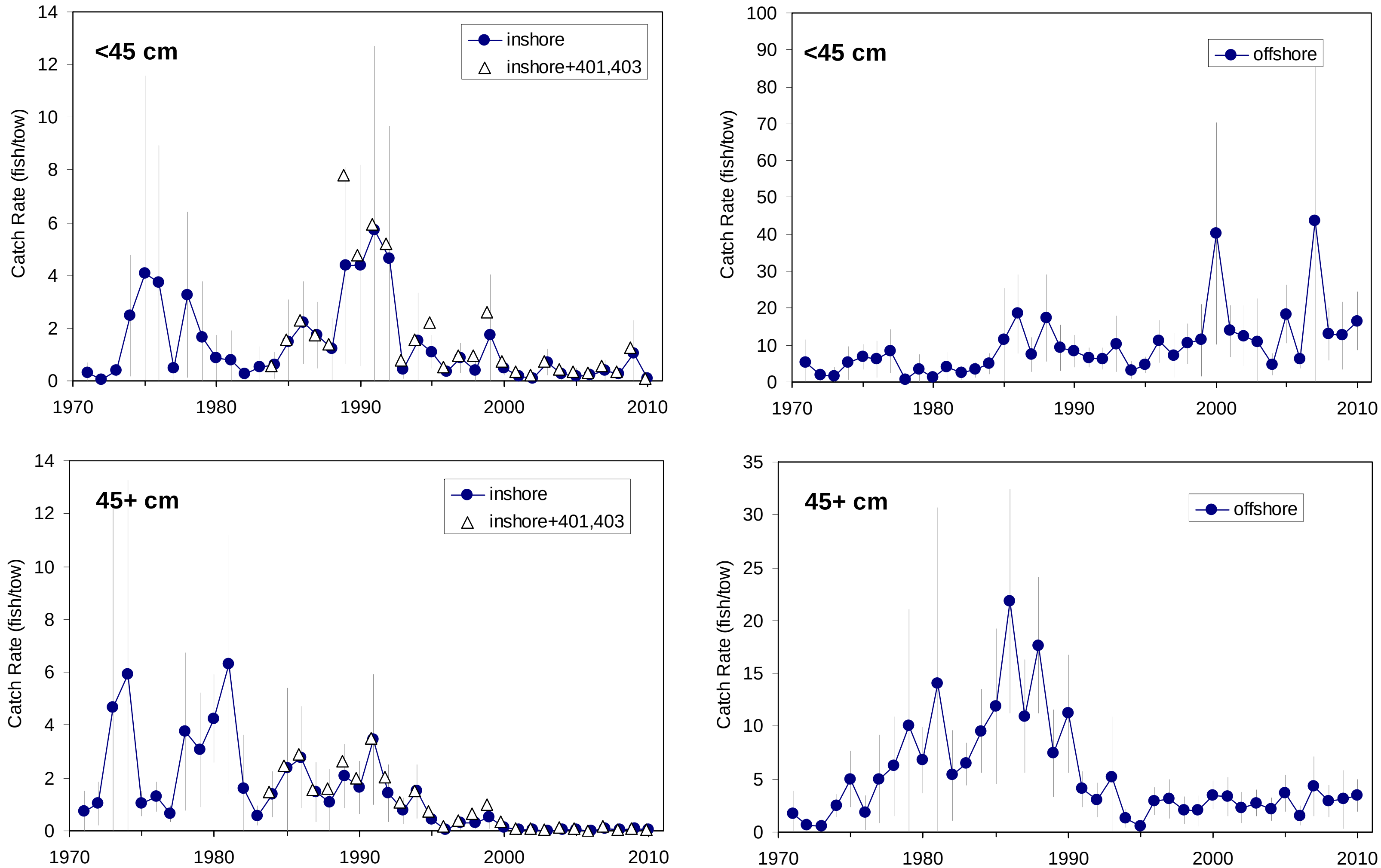


Figure 22. Stratified mean catch rates of juvenile and adult size classes of white hake (<45 and 45+ cm, respectively) in shallow- (417-424, 427-436 ± 401 and 403) and deep-water (415, 416, 425, 426, 437-439) strata of the September RV survey of the southern Gulf of St. Lawrence. Vertical bars show ±2SE.

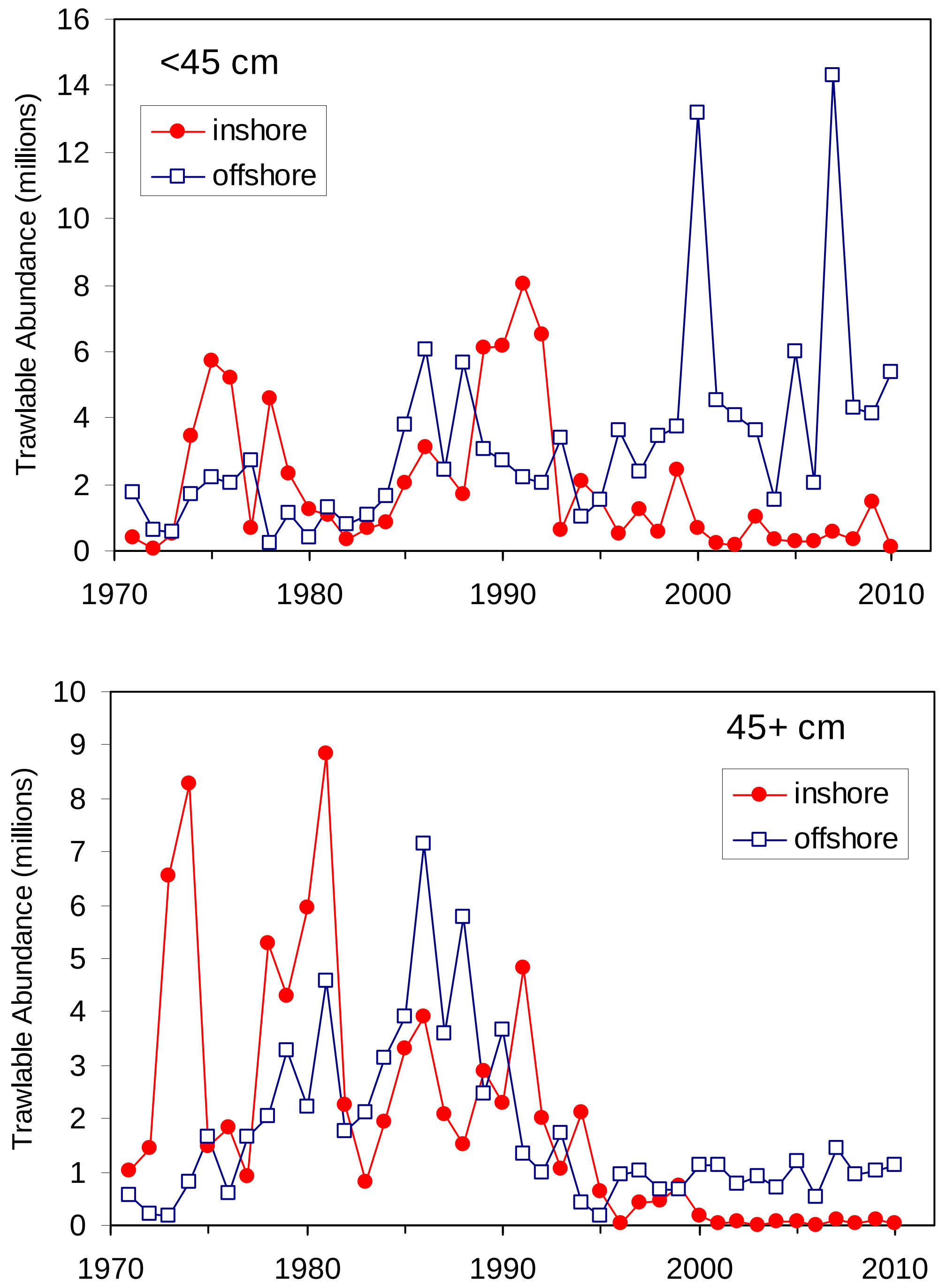


Figure 23. Trawlable abundance of juvenile and adult size classes (<45 and 45+ cm, respectively) of white hake in shallow-water (417-424, 427-436) and deepwater (415, 416, 425, 426, 437-439) strata of the September RV survey of the southern Gulf of St. Lawrence.

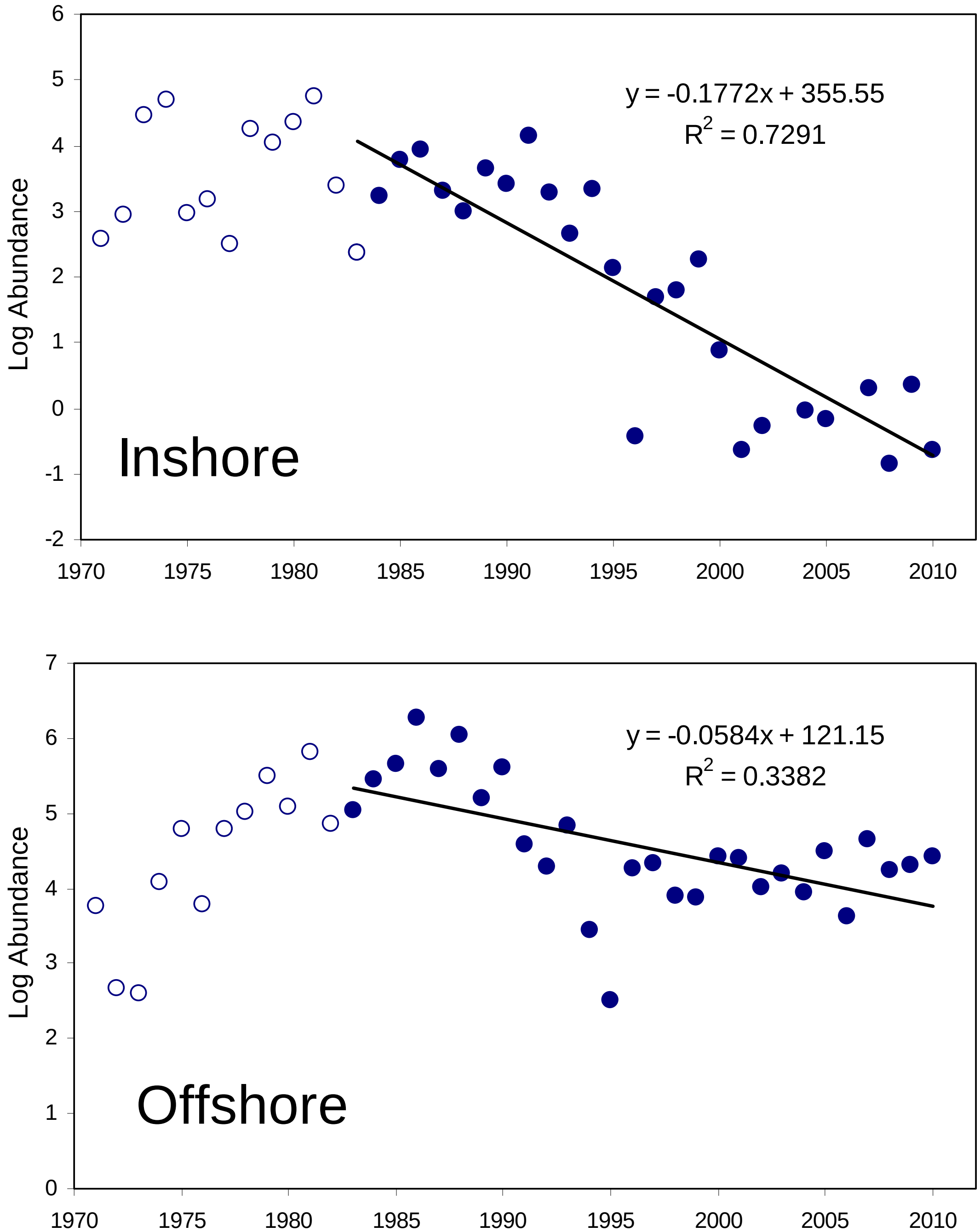


Figure 24. Log$_e$ – transformed catch rates of adult-sized white hake (≥45 cm in length) in inshore (417-424, 427-436) and offshore (415, 416, 425, 426, 437-439) strata of the September RV survey of the southern Gulf of St. Lawrence. Lines show the linear regression of log$_e$ catch rate against time over the past 27 years (3 generations). The estimated regression equation and its R^2 value are shown in each panel. Estimated slopes correspond to linear declines of 99% and 79% in inshore and offshore areas, respectively, over 3 generations (calculated as 100(1-exp(b*Δt)) over Δt years).*

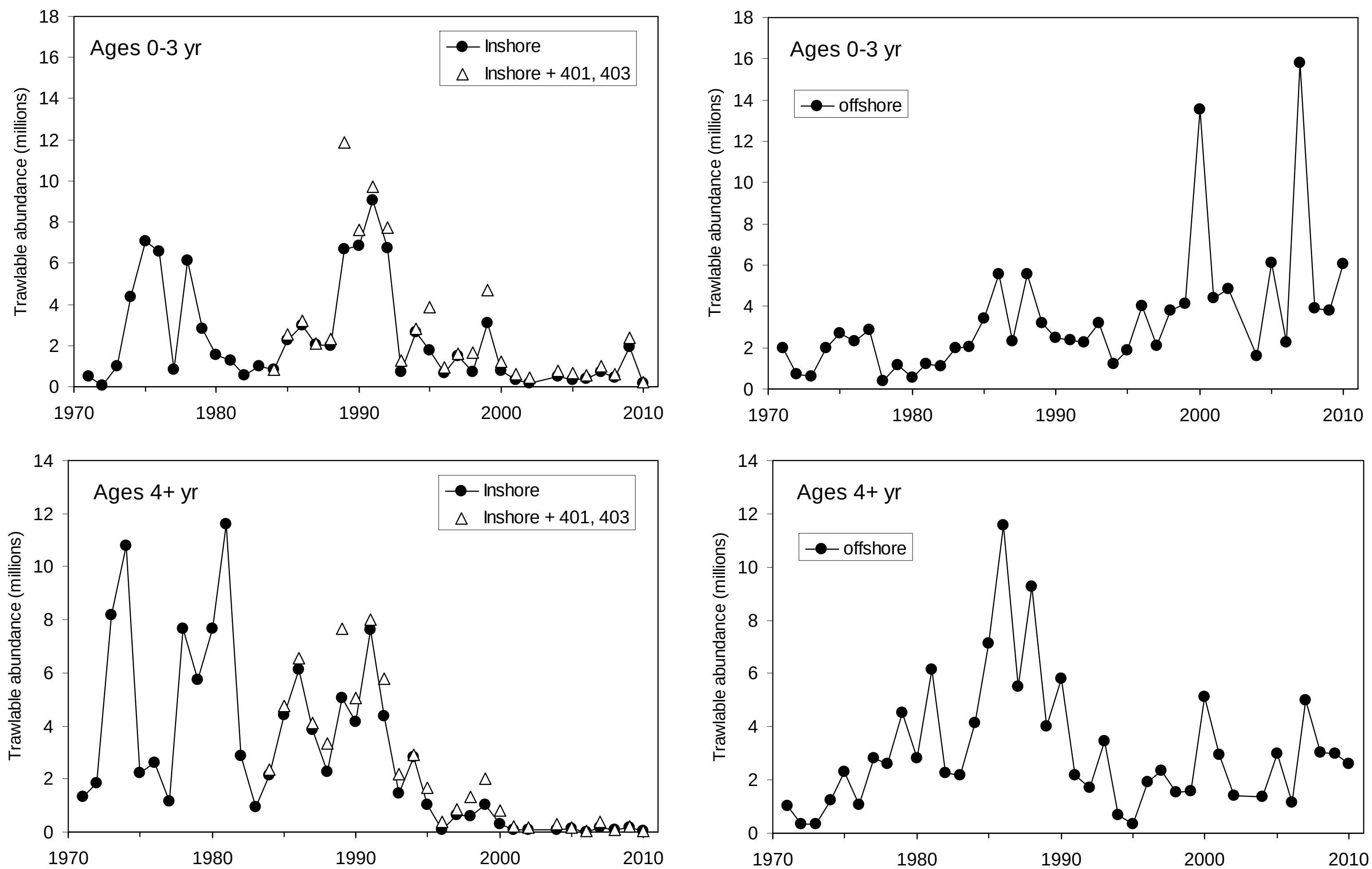
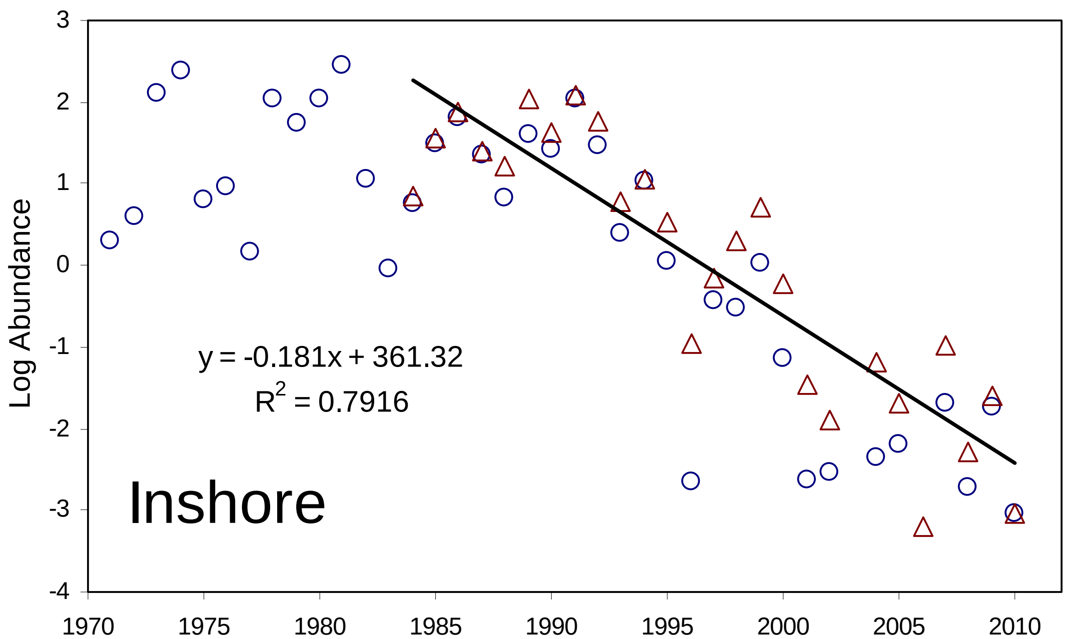


Figure 25. Trawlable abundance of juvenile and adult age classes of white hake (0-3 and 4+ years, respectively) in shallow-water (417-424, 427-436 ± 401 and 403) and deepwater (415, 416, 425, 426, 437-439) strata of the September RV survey of the southern Gulf of St. Lawrence.



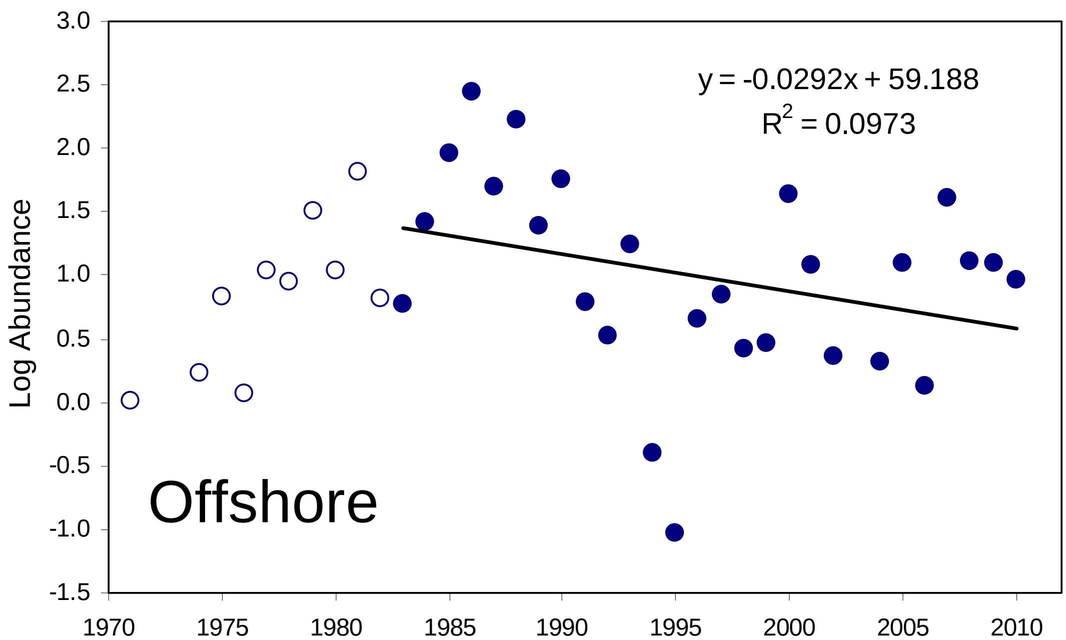


Figure 26. Log$_e$ – transformed trawlable abundance of adult white hake (ages 4+ yr) in inshore (417-424, 427-436± 401 and 403) and offshore (415, 416, 425, 426, 437-439) strata of the September RV survey of the southern Gulf of St. Lawrence. Lines show the linear regression of log$_e$ catch rate against time over the past 26-27 years (3 generations). The estimated regression equation and its R^2 value are shown in each panel. In the upper panel, circles are based on strata 417-424, and 427-436, and triangles and the regression line are based on these strata plus 401 and 403 (starting in 1984).

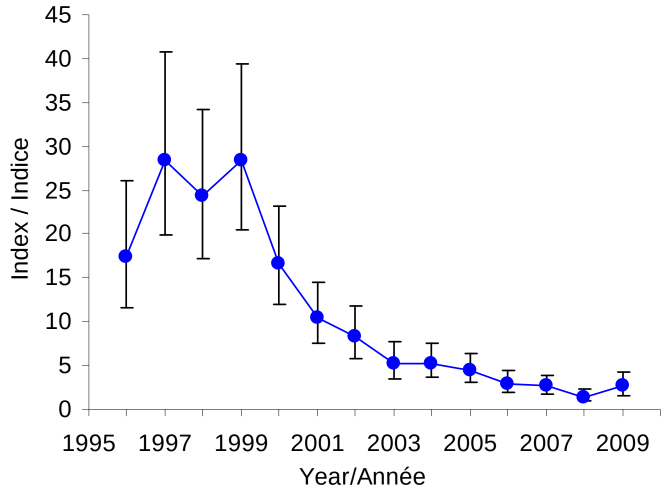


Figure 27. Standardized catch rates for longlines in the sentinel longline survey conducted from 1996-2009. Error bars indicate approximate 95% confidence intervals.

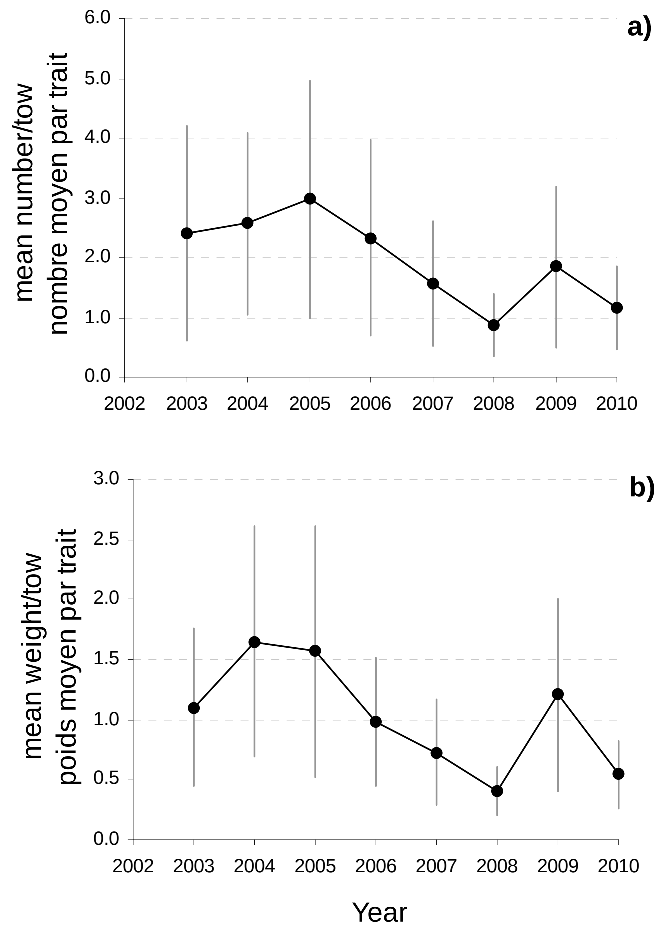


Figure 28. Mean number (a) and mean weight (kg) per tow (b) for ages 0+ white hake in the southern Gulf of St. Lawrence sentinel bottom-trawl survey (2003-2010). Data have not been adjusted for vessel differences. Error bars indicate approximate 95% confidence intervals. From Savoie (2011).

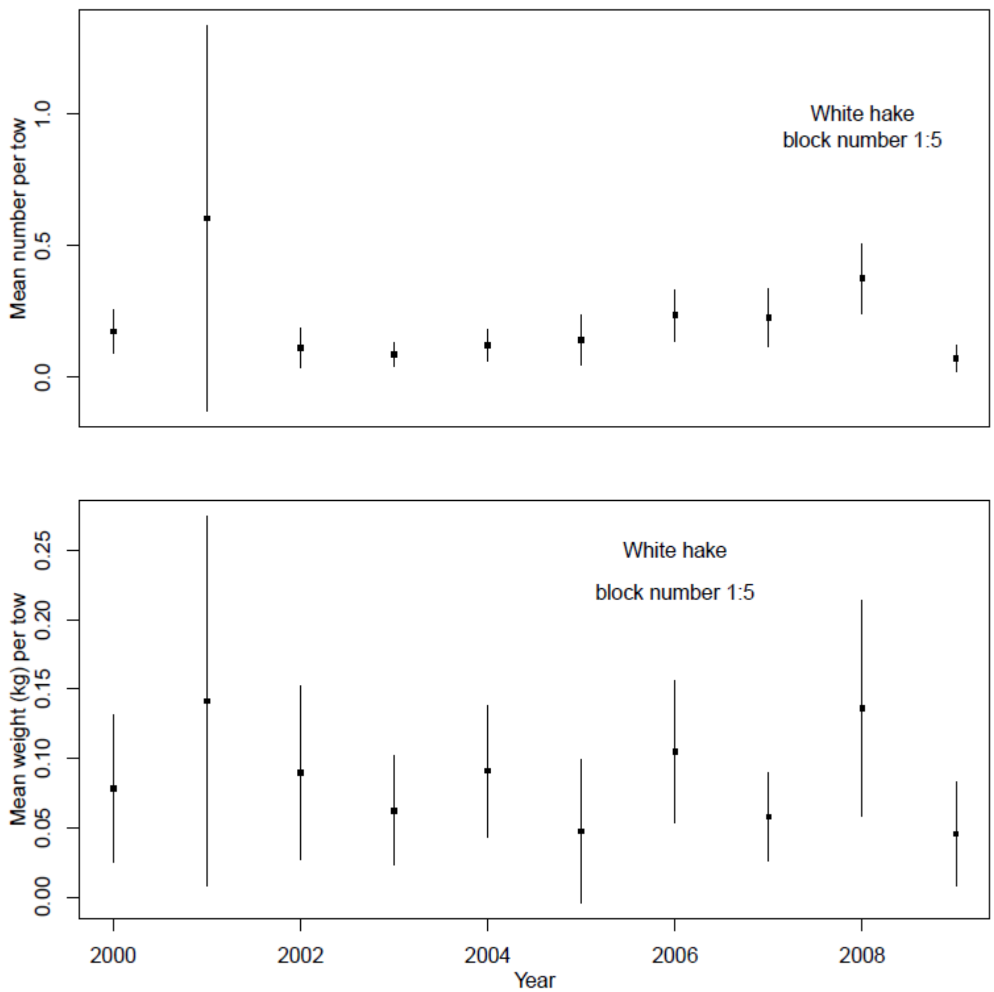


*Figure 29. Mean number per tow (top) and mean weight per tow in kg (bottom) of white hake caught during the July-August bottom-trawl survey of the Northumberland Strait. Error bars indicate approximately 95% confidence intervals. Only data from blocks 1, 2, 3 and 5 were used for these calculations. * - The indices for 2002 and 2005 should be interpreted with caution because some blocks were not properly sampled in these years. (From S. LeBlanc and T. Surette DFO Unpublished data).*

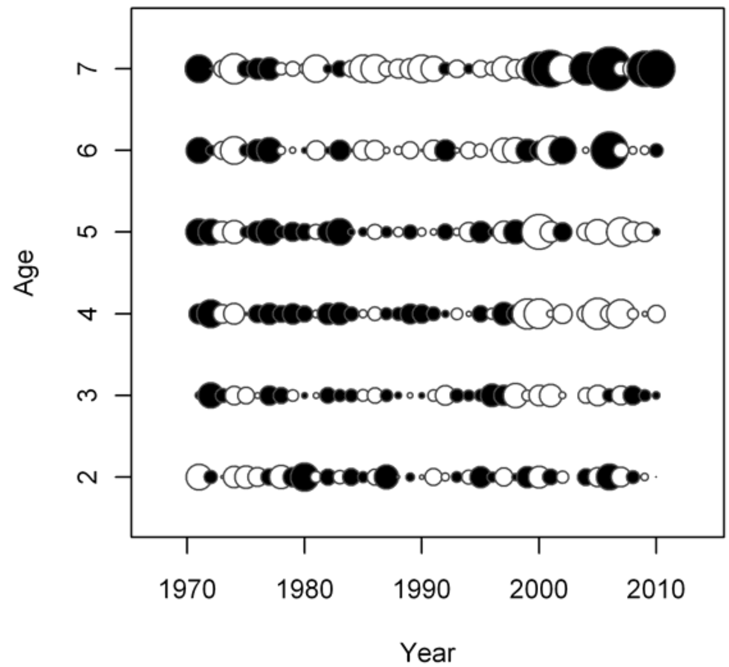


Figure 30. Residuals between the observed RV survey indices and those predicted by the population model. Circle radii are proportional to residual magnitude; black circles indicate negative residuals (i.e., observed < predicted).

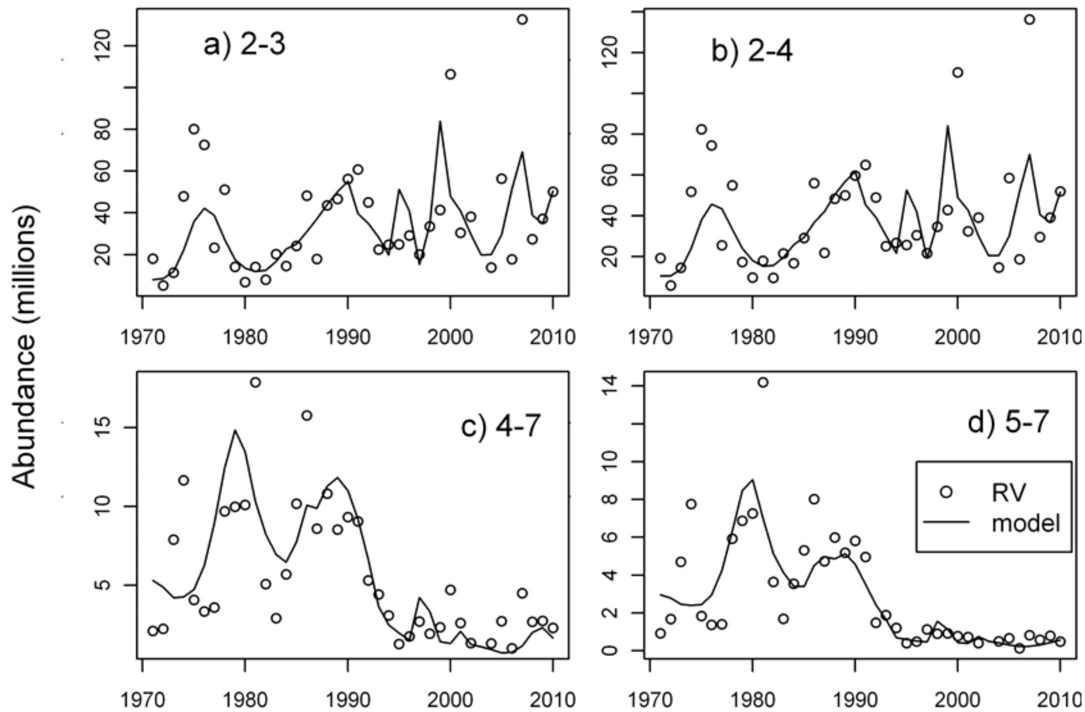


Figure 31. Comparison of catchability-corrected RV survey abundance indices and model estimates of abundance projected forward to September. Comparisons are shown for 4 age groupings.

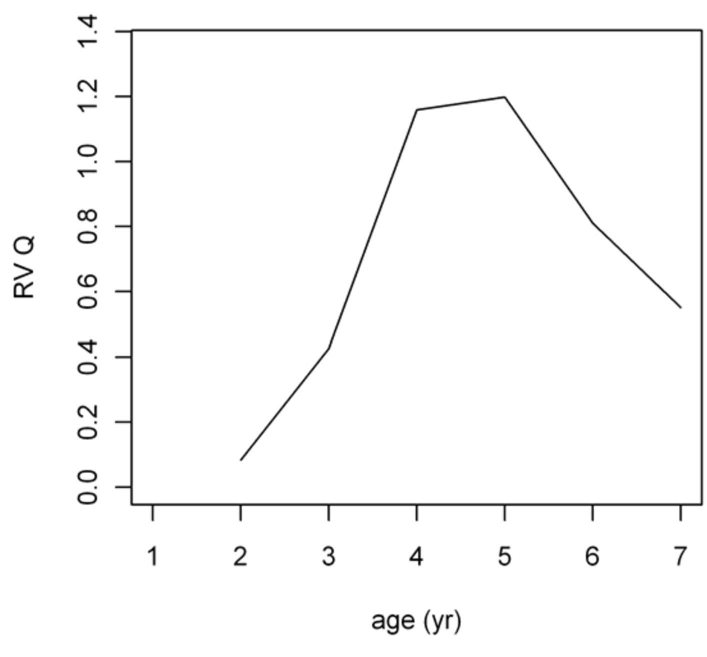


Figure 32. Estimated catchability of white hake to the September RV survey.

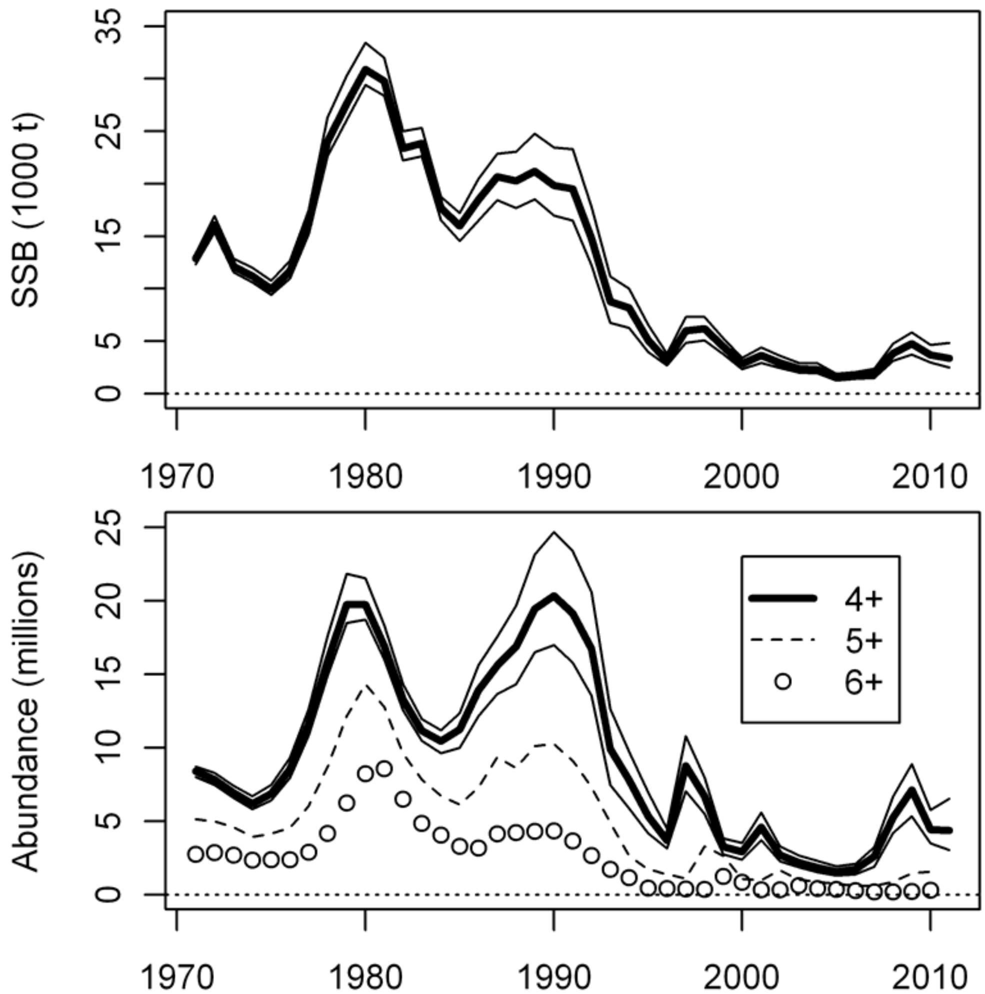


Figure 33. Model estimates of mature biomass (Spawning Stock Biomass, SSB) and abundance for white hake in the southern Gulf of St. Lawrence. Hake aged 4 years and older are assumed to represent the mature portion of the population. For SSB and 4+ abundance heavy lines indicate the median estimate and light solid lines the 2.5th and 97.5th percentiles. Abundance is also shown for ages 5+ and 6+.

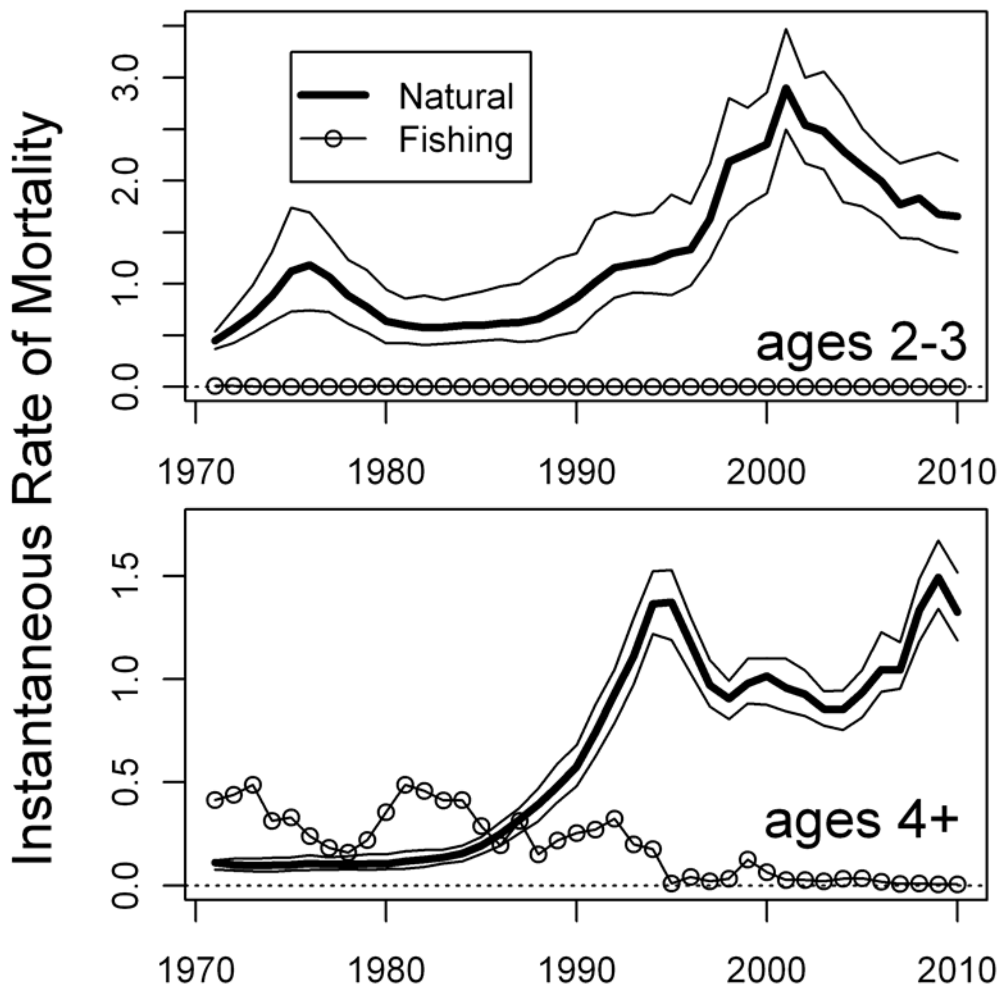


Figure 34. Estimated rates of natural and fishing mortality of southern Gulf of St. Lawrence white hake aged 1-3 or 4+ years. For natural mortality, the heavy line shows the median estimate and the light lines the 2.5th and 97.5th percentiles.

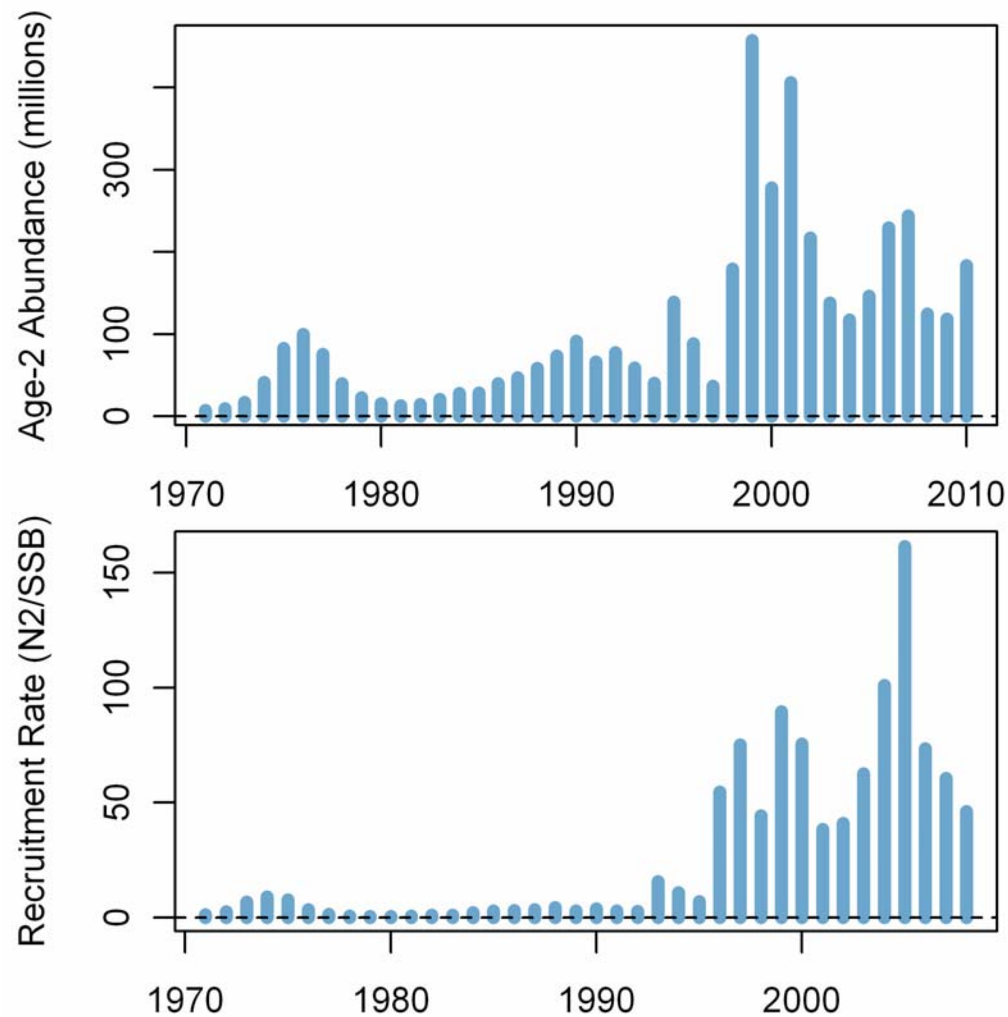


Figure 35. Model estimates of recruitment (age-2 abundance) and recruitment rate for white hake in the southern Gulf of St. Lawrence.

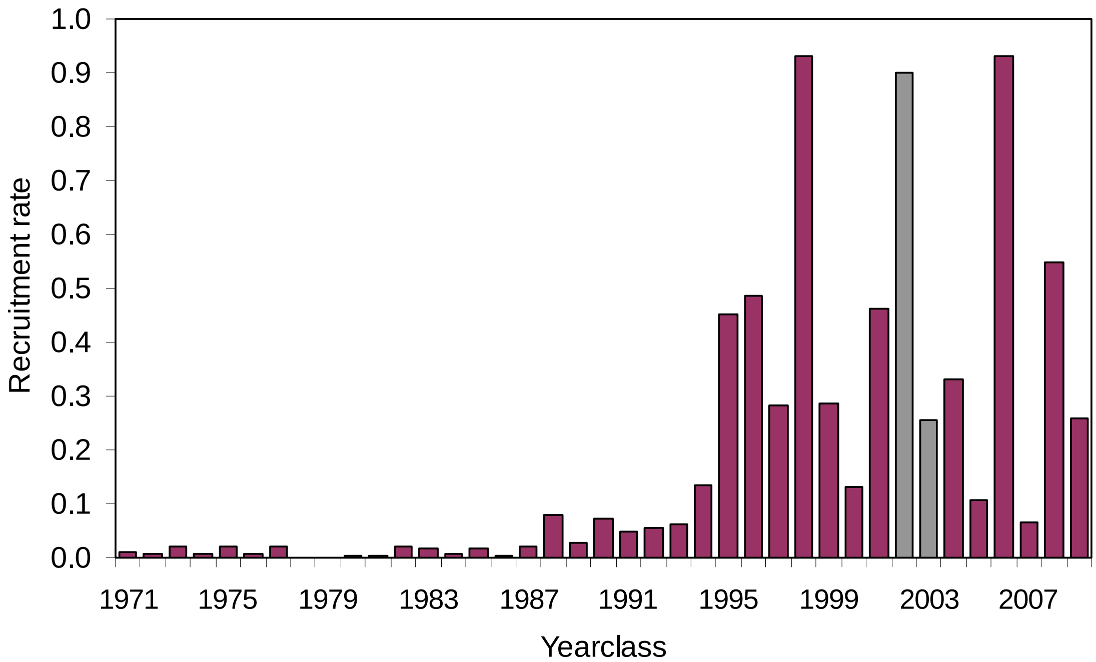


Figure 36. Recruitment rate (age-1 recruits per kg of SSB) of white hake in the southern Gulf of St. Lawrence based on survey catch rates (fish/tow). Grey bars are based on data from the 2003 survey without adjustment for incomplete coverage.

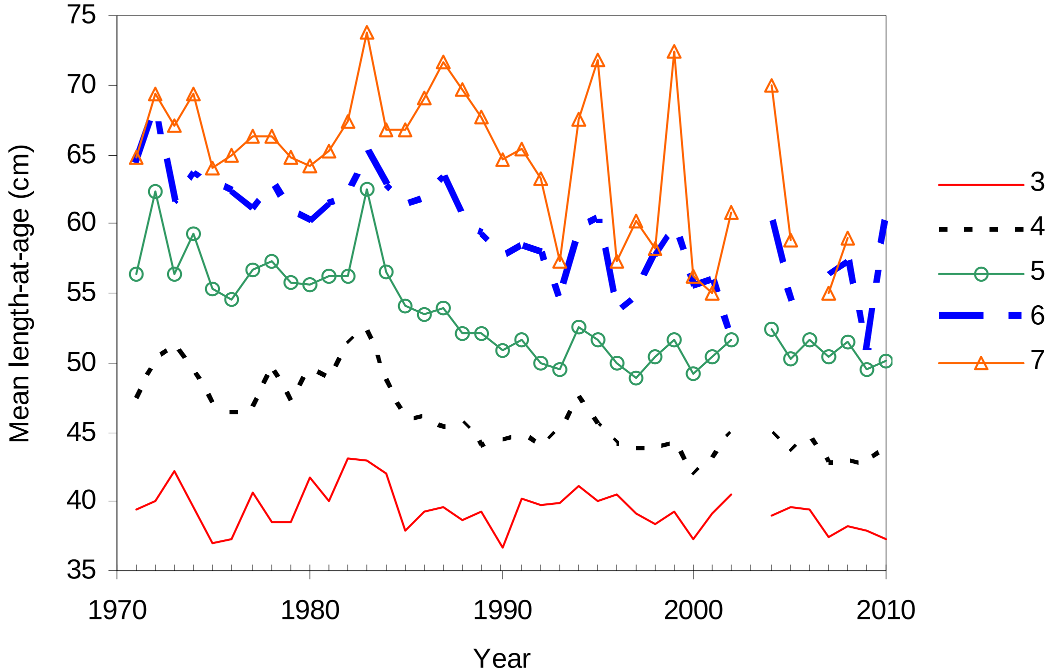


Figure 37. Trends in mean length-at-age (cm) of white hake (Ages 3-7) in the annual (Sept.) research vessel survey.

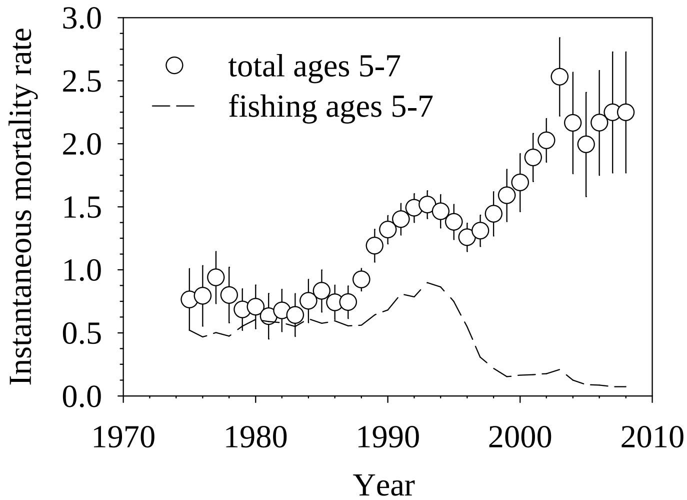


Figure 38. Total mortality (circles: mean ± 2SE) and fishing mortality (dashed line) for white hake ages 5-7 years. Total mortality was estimated using the modified catch-curve analysis of Sinclair (2001) and fishing mortality was estimated using Baranov's equation based on age-disaggregated commercial catches and survey numbers adjusted using a general size-dependent catchability relationship (Harley and Myers 2001).