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Assessment of White Hake (*Urophycis tenuis*) in NAFO Divisions 4VWX and 5

Évaluation de l'état de la merluche blanche (*Urophycis tenuis*) dans les divisions 4VWX et 5

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ABSTRACT

White hake (*Urophycis tenuis*) are bottom dwelling fish whose distribution ranges from the southern Grand Banks to the mid-Atlantic Bight. Their depth range varies with life history stage, with age 2 and older fish occurring predominantly at depths between 50 to 400 m. They favour temperatures between 6 °C and 10 °C. The stock structure in NAFO Divisions 4VWX/5 may be complex, with several self-sustaining components. White hake in the Laurentian Channel slope waters (NAFO Sub-division 4Vn) are contiguous with NAFO Division 4T. Those in the Bay of Fundy and approaches are contiguous with NAFO Divisions 5Z and 5Y (i.e. the Gulf of Maine area). The central Scotian Shelf (parts of NAFO Divisions 4X and 4W) may be separate from those to the east and west. The present management units (NAFO Divisions 4T, 4VWX+5Zc, and USA 5+6) in the NW Atlantic, do not reflect clear discontinuities in adult distributions. On the Scotian Shelf white hake is assessed as three components, NAFO Divisions 4Vn, 4VsW and 4X/5. About 90 % of the white hake landed in NAFO Divisions 4VWX and 5Zc are currently from 4X and 5Zc.

The landings from all areas of NAFO Divisions 4VWX/5 have declined in recent years and total landings have declined since 1987. Canadian fishing effort for this species was unregulated in NAFO Divisions 4VWX/5 until 1996 when it was placed under quote regulations. Since 1999, the white hake fishery has been a by-catch fishery only. White hake are caught in longline, gillnet and otter trawl fisheries targeting halibut, redfish, cod, pollock and other groundfish. This has management implications in an ecosystem context. Several indicators were used to assess the health of white hake population: there are very few large white hake on the Scotian Shelf (NAFO Divisions 4VW) now compared to the 1980s, despite reduced catches in all areas and indications of good recruitment; in NAFO Divisions 4X/5, there has been a variable but general decrease in the abundance of white hake since the early 1990s; fishing mortality is relatively low in all areas since the introduction of catch limits; total mortality on the Scotian Shelf is high and its causes are unknown, whereas total mortality of white hake in the Bay of Fundy is variable. Overall, the status of white hake in NAFO Sub-division 4Vn and NAFO Division 4VsW is poor and requires rebuilding. In NAFO Divisions 4X/5, unless there is good recruitment over the next few years, catches at the current level may lead to further decreases in abundance.

RÉSUMÉ

La merluche blanche (*Urophycis tenuis*) est un poisson des grandes profondeurs dont l'aire de répartition s'étend du sud des Grands Bancs à la baie médio-atlantique. Elle est présente à des profondeurs qui varient selon le stade de son cycle biologique; les poissons d'âge 2 et plus abondent surtout dans les eaux de 50 à 400 m. L'espèce affectionne les températures qui oscillant entre 6 et 10 °C. Il se peut que la structure du stock dans les divisions 4VWX et la zone 5 de l'OPANO soit complexe et comporte plusieurs composantes autonomes. La merluche blanche des eaux de pente du chenal Laurentien dans 4Vn jouxte celle de 4T. Celle de la baie de Fundy et de ses approches jouxte celle de 5Z et de 5Y (golfe du Maine). La population du centre du plateau néo-écossais (parties de 4X et de 4W) peut être distincte de celle de l'est et de l'ouest. Les unités de gestion actuelles (4T, 4VWX+5Zc et 5+6 aux É.-U.) dans l'Atlantique N.-O. ne montrent pas de discontinuité nette dans la répartition des adultes. Sur le plateau néo-écossais, la merluche blanche est évaluée en trois composantes, soit celles de 4Vn, 4VsW et 4X/5. Environ 90 % des merluches blanches débarquées dans 4VWX et 5Zc proviennent de 4X et de *5Zc*.

Les débarquements de toutes les zones de 4VWX/5 ont diminué ces dernières années et le total des débarquements fléchit depuis 1987. L'effort de pêche canadien de l'espèce ne faisait l'objet d'aucune restriction dans 4VWX/5 avant 1996, année au cours de laquelle il a été assujetti à un quota. Depuis 1999, la merluche blanche est gérée comme prise accessoire seulement. Elle est capturée à la palangre, au filet maillant et au chalut à panneaux dans le cadre des pêches du flétan, du sébaste, de la morue, de la goberge et d'autres poissons de fond. Cela a des conséquences sur la gestion dans un contexte écosystémique. Plusieurs indicateurs ont été utilisés pour évaluer la santé de la population de merluche blanche : il y a maintenant très peu de grandes merluches blanches sur le plateau néo-écossais (4VW) comparativement aux années 1980 et cela, malgré une réduction des prises dans toutes les zones et des indices de bon recrutement; dans 4X/5, l'abondance de la merluche blanche connaît un déclin variable mais général depuis le début des années 1990; la mortalité par pêche est relativement basse dans toutes les zones depuis l'adoption de limites de prises; la mortalité totale de la merluche blanche est élevée sur le plateau néo-écossais, sans qu'on sache pourquoi, tandis que dans la baie de Fundy, elle varie sans présenter de tendance. Dans l'ensemble, la ressource est en piètre état dans 4Vn et 4VsW et requiert des mesures de rétablissement. Dans 4X/5, à moins d'un bon recrutement au cours des quelques prochaines années, les prises au niveau actuel pourraient aboutir à d'autres baisses de l'abondance.

INTRODUCTION

White hake have been formally assessed in NAFO Divisions 4VWX/5 since 1996 (Fowler et al. 1996), and the last full assessment occurred in 2001 (Bundy et al. 2001) and an update in 2002 (DFO 2002).

Biological Background

White hake (*Urophycis tenuis*) are bottom dwelling fish found in areas with a mud bottom from the southern Grand Banks to the mid-Atlantic Bight. Their depth range varies with life history stage, with age 2 and older fish occurring predominantly at depths between 50 to 200m. They favour temperatures between 6° and 10°C.

White hake are highly fecund, having several million eggs per female. They are pelagic spawners, with the eggs and larvae drifting in the upper 50 meters for about a month. The larvae metamorphose into juveniles in the pelagic zone and subsequently migrate into the shallow coastal zone. At an age of about 2 months the small pelagic juveniles (approximately 4cm) move to the bottom in shallow water. They appear to stay in shallow water for a year and then migrate to the offshore adult distributional area at some time during their second year. In the Bay of Fundy they are about 10cm in length in August of the first year, and 30cm in length at age 1 (August). Growth rate varies with area. In the Gulf of Maine area, white hake begin maturation and reproduction at ages two and three, at lengths between 35 and 45cm. The age span is about 20 years, with fish potentially growing to lengths as large as 135 cm.

Adult white hake are pisicivores. On the Scotian Shelf their diet includes herring, silver hake, shrimp, krill, gadoids, shortfin squid, cod, haddock, redfish, and a wide variety of other prey species.

The stock structure in 4VWX and 5Zc may be complex, with several self-sustaining components. White hake in the 4Vn Laurentian Channel slope waters are contiguous with 4T. Those in the Bay of Fundy and approaches are contiguous with 5Z and 5Y (i.e. the Gulf of Maine area). The central Scotian Shelf (parts of 4X and 4W) may be separate from those to the east and west. The present management units (3NOPs, 4T, 4VWX+5Zc, and USA 5+6) in the Northwest Atlantic, do not reflect discontinuities in adult distributions (Figure 1). On the Scotian Shelf white hake is assessed as three components; 4Vn, 4VsW and 4X/5 in keeping with regional management areas. Currently, 90% of the white hake landed in 4VWX/5 are from 4X and 5Zc.

The spawning patterns and behaviour of white hake on the Scotian Shelf and in the Bay of Fundy are also not well understood, as outlined by Fowler et al. (1996) and Bundy et al. 2001). Fahay and Able (1989) suggested that there may be two stocks of white hake with separate spawning schedules: one occurring in the late spring/early summer in shelf slope waters from the Scotian Shelf and Georges Bank down to New England; and the second a late summer/early autumn spawning population occurring in the Gulf of St. Lawrence and on the Scotian Shelf. White hake on the eastern Scotian Shelf may be derived from 4T/Laurentian Channel early summer spawning (Markle et al. 1982). Thus in total there may be three spawning origins for white hake on the Scotian Shelf.

Hare et al.(2001) have shown that white hake off the north-eastern US spawn offshore. They found small white hake larvae (< 5mm) in Slope Sea off the Middle Atlantic Bight in May and June. Such small larvae were not caught on the shelf. The authors hypothesised that white hake larvae actively cross the shelf/slope front to reach nearshore estuarine juvenile habitats. A similar mechanism may occur for the spring/early summer offshore spawning of white hake to the Scotian Shelf.

Data from the Scotian Shelf Icthyoplankton Surveys (SSIP) data (1977-1982) support the studies above. Juveniles occurred from May to November, with June to September being the peak months. Major concentrations occur around the northeast edge of Georges Bank from June through August, and just north of the slope in 4Wl from August to October (Figure 2). A northerly trend in the timing of spawning as waters warm up might be inferred. Secondary concentrations more inshore on the western shelf in July are characterized by larger fish than were caught near Georges Bank in June.

There is some evidence of nursery areas for juvenile white hake in the inshore areas of the Scotian Shelf. Simon and Campana (1987) observed 0 or 1 age group white hake in the inshore areas of 4X during an inshore trawl survey of southwest Nova Scotia. Some small fish are caught inshore in the Bay of Fundy in July and August, and a recent DFO-FSRS Inshore Ecosystem Study observed white hake less than 7 cm in inshore areas off Cape Breton and the southern shore of Nova Scotia (A. Bundy, pers. Comm). There are also anecdotal reports that the Bra D'ors Lakes in Cape Breton are a nursery area (T. Lambert, DFO, pers. Comm.). Markle et al.(1982), on the basis of SSIP data on the distribution of pelagic juveniles around the coast of Cape Breton from May to July (and the lack of pelagic juveniles inshore on the southern half of Nova Scotia), have suggested that these fish may originate in the southern Gulf of St. Lawrence.

Research into population genetics of white hake is required to determine how many distinct spawning populations of white hake there are on the Scotian Shelf and the north west Atlantic. In the absence of this data, white hake on the Scotian Shelf are treated here by (4Vn, 4Vs, 4W, 4X), by management area (4Vn, 4VsW, 4X/5) and by Scotian Shelf and Bay of Fundy, all reflecting possible different spawning components or sub-populations.

The Fishery

The fishery for white hake is essentially a Canadian fishery, with minimal foreign fishing activity (Table 1). The main foreign fishing has been by the USA. These landings came from 4X/5 and have been minimal since the revision of the Maritime Boundary between Canada and the USA in 4X, 5Y and 5Z in 1984 (Table 2).

Reported landings throughout 4VWX/5 peaked in 1987, then declined until the late 1990s since when they have been relatively stable (Figure 3). Until 1996, there were no restrictions on fishing effort for white hake in 4VWX/5, when the first catch limit (TAC) was introduced and allocated to the fixed gear sector. In addition, other fleet sectors were regulated through by-catch restrictions (20% for the ITQ fleet, 10% for large trawlers). The TAC was restrictive to fishing until 1998, when the TAC was not reached. In 1999, the FRCC recommended that white hake be caught as by-catch only, and a quota cap was placed on the catch of the fixed gear fleet <45 ft. In 1999, the quota cap was 1692 t. for 4VWX/5, and transfers between Community Management Boards were not permitted. The quota cap was reduced again in 2000 to 1429 t., increased to 2168 t. in 2001-2003 and in

2004 decreased to 1768 t. where it remained for 2005. In addition, the mobile fleet and fixed gear >45 ft has been managed under a separate quota cap since 2001, initially at 650 t, but since 2004 at 555 t. In recent years, the fixed gear industry has reported difficulties staying within white hake catch restrictions while fishing for other species and in 2002, the otter trawl fleet in 4X reported similar difficulties. This appears to be less of a problem this year (2005).

Until the early 1990s, about 70 % of the catch was taken from 4X/5; since then, as total catch has decreased, a greater proportion of the catch has been taken from 4X/5 and since 2002 this has amounted to 90 % of the total catch (Table 3, Figure 4).

Longline, gillnet and otter trawl < 65 ft catch almost all the white hake from 4VWX/5. The distribution of catch by gear in 4VWX/5 has changed over time, with a decrease in the amount of catch taken by longline gear, and an increase by gillnets and otter trawl. These changes mirror the change in distribution of the catch noted above, with the shift to 4X/5. In this area, the catch is distributed between the gear types, whereas in 4VW, longline gear accounts for most of the catch (Bundy et al. 2001).

Proportion of total catch by gear type in 4VWX/5

	Otter Trawl	Longline	Gillnets	Misc
1970s	0.15	0.75	0.04	0.07
1980s	0.27	0.63	0.09	0.02
1990s	0.16	0.62	0.22	0.00
2000s	0.26	0.41	0.33	0.00

By-catch Considerations

White hake is caught as by-catch in longline, gillnet and otter trawl fisheries targeting halibut, redfish, cod, pollock, haddock and other groundfish. Any changes in these fisheries will have consequences for mortality on white hake.

Resource Distribution

Within 4VWX/5, white hake are distributed over the entire management area, but are concentrated along the Laurentian Channel, the shelf edge, around Emerald and LaHave basins and the Bay of Fundy (Figure 5). There are differences between these areas in several key indices such as abundance, catch per tow and size of white hake estimated from the summer RV survey. The largest fish are found in 4X, the highest mean number per tow is in 4Vn, whilst the highest mean weight per tow is in 4X. On average, 65% of the biomass is in 4X, 15% in 4W, 11% in 4Vs and 9% in 4Vn.

Indices averaged over the DFO Summer RV survey time series, 1970-2005

NAFO Area	Mean Nos/tow	Mean Wt/tow (Kg)	Mean proportion of biomass in 4VWX	Mean Wt of fish (Kg)	Mean length of fish (cm)
4Vn	16.0	10.6	0.09	0.69	42.1
4Vs	6.3	3.8	0.11	0.69	40.3
4W	3.2	3.2	0.15	1.02	44.2
4X	10.9	13.1	0.65	1.28	48.6

Resource Status

There are several sampling platforms from which data are available to assess the status of white hake. Traditionally, DFO research vessel (RV) otter trawl surveys have been used exclusively for this purpose. All the DFO surveys have stratified random design with standardised sampling protocols. The Summer (July) RV survey has the longest time series (1970 to present) and encompasses Scotian Shelf waters in 4VWX. The Spring (March) RV survey began in 1979 and ran until 1984. Originally it covered the Scotian Shelf (4VWX), but when it was re-instituted in 1986 as the 4VsW Cod Survey, it only covered 4VsW. There were no surveys in 1998 and 2004. The Fall Survey, which again covered 4VWX shelf waters, was only conducted from 1978-1985. Finally, there is the February George's Bank Survey which has been conducted since 1987 and covers 5Z.

In addition to the DFO research vessel surveys, there are a number of industry surveys that also provide data on white hake. The 4Vn Sentinel and 4VsW Sentinel Surveys each include stratified random sets with standardised sampling protocols which include detail sampling of white hake from 1995 to 2004. These two surveys are similar in design to the DFO summer RV survey although they use longline rather than trawl gear, and the 4VsW Sentinel includes additional strata inshore of the standard DFO survey area. The 4VsW Sentinel Survey was changed in 2004 and the 2004 data is not used here. The Halibut Survey has been running since 1998 and uses halibut longline gear. The survey was initially stratified based on commercial catches of halibut and stations were selected in the first year by the skippers and have been fixed since then. The Halibut Survey samples deeper areas than any of the other surveys. The 4X Mobile (ITQ) Survey has operated since 1996 using <65' otter trawlers. The design is fixed stations, selected by the skippers in the first year but fixed since then. The ITQ Survey includes considerable inshore area, not sampled by the RV surveys, but this seems to be of little significance for white hake. The Longline Survey on Georges Bank has a fixed set design for years 1999 to 2004.

The stock status is based on evaluation of abundance and distribution estimates from these various sampling platforms. Mortality is estimated from the summer groundfish research vessel survey and the commercial fishery.

Abundance Trends

Summer research vessel trends in abundance and weight are shown in Figure 6 for 4Vs, 4Vn, 4W and 4X. In 4Vn, mean numbers and weight per tow were low in the 1970s, then increased to a peak in 1986. They then declined until 1992 and have remained variable but low. Mean abundance since the 1990s is at a comparable level to mean abundance during the 1970s. The peak in 2001 is due to several large catches of fish between 30 and 45 cm in length (see below, Figure 9) which may be due to white hake from 4T. In 2000, four very large sets of small white hake (30-45 cm) were made in the Cape Breton Trough in 4T (Hurlbut and Poirier 2001). In 2001, these fish were not observed in the 4T survey and may be the fish observed in 4Vn in 2001. The 2005 point is higher than both the 2002 and 2003 points.

Abundance in 4Vs was low in the 1970s, peaked in the mid-1980s, peaked in 1997, but has otherwise been low since 1987. Similarly in 4W, abundance was low in the 1970s, peaked throughout the 1980s, and has been low since 1992. The mean weight per tow and mean numbers per tow in the 2002 and 2003 and 2005 are all time lows. Abundance in 4X in terms of both mean number and weight per tow was lower in the 1970s and 1990s than in the 1980s, although the point in 2005 is higher than in most recent years. There has been a declining trend of peaks since the early 1980s, and it is likely that the 2005 point is one more in this series. When discussing 4X white hake, it is useful to consider the abundance of white hake in the Gulf of Maine and George's Bank, since 4X white hake might be contiguous with this stock. Abundance and biomass of white hake in the Gulf of Maine and George's Bank (as measured by the Northeast Fisheries Science Centre spring and fall surveys, Northeast Fisheries Science Center 2001) were variable with no overall trend until around 1990, since when both decreased. There has been an increase in abundance from 1997 to 2002, but biomass and abundance have since decreased. The current value of biomass is ½ of B_{MSY}, and F (relative) is greater than the F_{MSY} (Sosebee, 2005). This stock is considered overfished.

In general, all RV series show low abundance during the 1970s, increased abundance during the 1980s, and low abundance in the 1990s and 2000s. This pattern is especially pronounced in 4VW and is seen in other gadid species such as 4Vn cod (Mohn et al. 2001) and 4VsW cod (Mohn et al. 1998). Since 1990, mean abundance in 4Vn and 4WX, has been comparable (4Vn) or lower (4WX) than the average abundance during the 1970s.

Industry surveys

In general there is good consistency between the RV survey trends and industry survey trends (Figure 7). There are a couple of exceptions: in 4Vn, the Sentinel Survey did not increase in 2001 and in 5Z the Fixed Survey and the RV Surveys show opposite trends in 2003 and 2004. There has been no Fixed Survey since 2004. In 4VsW and 4X all surveys decreased in the last 3 to 5 years and in general, all these different indices indicate low abundance of white hake.

Maturity

Length at 50% maturity varies spatially and temporally. Estimates range between 39 cm for males on the Scotian Shelf in 1979 (Beacham 1983), to 48 cm for females in the northwestern Atlantic (Cohen et al. 1990). On the Scotian Shelf, for the time period 1970-1985, the length of maturity is 42.5 cm and in the Bay of Fundy is 45.5 cm, including both sexes (Figure 8). These lengths correspond to age of 3.2 and 3.5 respectively (see below for aging and growth). More recent data on the maturity of white hake from the Scotian Shelf is not available. In the analysis below, a cut-off point of 45 cm was used to demarcate mature fish from immature fish.

Abundance of Large and Small Fish

An analysis of mean numbers of large fish (greater or equal to 45 cm) and small fish (less than 45 cm) in the Summer RV survey shows that the relative numbers of large and small fish in 4VW has changed over time. Both large and small fish have decreased since the 1980s, but the relative number of small fish has increased (Figure 9). In 2005, large and small fish in 4Vn and 4W increased (from 2003), whereas change was minimal in 4Vs. The 4VsW Cod RV survey is consistent with the summer RV index of abundance for 4VsW: the number of large fish represented in the survey area has been extremely low since 1987 (Figure 10).

The trends in small fish are used as proxies for direct recruitment estimates. In 4Vn, abundance of small fish has been variable, with a peak in 2001 due to fish between 30-45 cm. This high abundance may have been due to white hake from 4T (Bundy et. al., 2001), but they have not been seen since. In 4Vs and 4W, the number of small fish has been low since 2001. Although small fish greatly outnumbered large fish in the 1990s and 2000s, the number of large fish is low. There are several reasons why this may be occurring:

(a) small fish are not surviving to become large fish,
(b) the distribution of large fish has changed,
(c) growth rate has decreased and thus fish are smaller at age (this has been seen in 4TVW Haddock (Frank et al.2001), 4Vn cod (Mohn et al.2001), 4VsW cod (Mohn et al.1998)). However, this does not seem to be the case for white hake (see growth section below).

In 4X, which typically contains about 65% of the biomass for the 4VWX/5 stock unit, the small and large fish track each other well. On average, there are more large fish than small fish. There has been an overall decrease in abundance of large and small fish since the 1980s and the average abundance of both is less in the 2000s than in earlier decades. Both large and small fish increased in 2005, but their numbers are still very low.

Proportion of large fish in the population.

In 4Vn, 4Vs and 4W there has been a decrease in the proportion of large fish in the population from the 1970s to the mid-1990s, since then the proportion has remained below the long term mean (Figure 11). In 4X, there is no trend, but since 1990, most points have been below the long term mean. These data indicate that in 4VW there has been a sustained loss of large fish in the population to a point where they constitute only 20-30 % of the population. In 4X, large fish comprise around 50% of the population. Over the time series, there is a higher proportion of large fish in 4X than in 4VW.

Condition of white hake.

The condition factor, the predicted weight at size 45 cm has varied over time but has shown no pattern (Figure 12).

Distributional indices

Area occupied is the proportion of the area where 75% of white hake are caught, and may be related to the stock status. It was estimated here for small and large white hake (Figure 13).

In 4Vn, little pattern is evident in the area occupied by large or small fish until the late 1980s when both fell below average for a few years. Since then, the area occupied by large and small fish has increased to fluctuate around the mean. The large interannual variation in abundance of small fish (see above) coupled with the relative consistency in area occupied, supports the view that 4T fish are mixing with 4Vn fish.

In 4VsW, the area occupied by small fish has fluctuated around the mean throughout the time series. Area occupied by large fish was reasonably constant until 1984 and then declined and remains below the long term mean. This decrease may be due to mortality, distributional changes, or both. A regression of area occupied on relative fishing mortality indicates that there is a significant negative relationship between area occupied and fishing mortality (Figure 14; $p=0.004$; $r^2=0.22$).

In 4X, there was a decrease in the area occupied by large fish from the early 1980s until the mid to late 1990s, and again since 1999. Since 1990, more large fish have been below the long term mean than in the earlier years. Small fish have varied around the mean with no clear trend.

Growth and Mortality

Until recently there were no aged white hake data from the RV survey with which to estimate growth. In the past, Fowler et al.(1996) and Fowler (1998) used growth data from George's Bank to estimate growth and thus mortality. Bundy et al. (2001) used aging data from the commercial sampling program from the Scotian Shelf (1998-2000) to estimate growth and mortality on the eastern and western Scotian Shelf. However, this was not informative about growth or mortality in earlier years, or changes over time. In order to explore growth and mortality spatially and temporally, white hake otoliths collected during the summer RV Survey were aged. It was not possible to age all white hake otoliths for all years over the whole area (lack of funds and expertise), so three time periods (1977/78, 1983/84 and 2002/03) and three areas (eastern Scotian Shelf (strata 445-452, 457), central Scotian Shelf (strata 460-472), and Bay of Fundy (strata 480-495) were selected to estimate growth and mortality (Figure 15). Sample sizes are given in Table 4.

Estimation of Growth

Mean length-at-age was estimated for the 3 time periods and 3 areas. (Figures 16 and 17).

Temporal comparisons: in the Bay of Fundy there was no change in mean-length-at- age over the three time periods (Figure 16). However, for the eastern Scotian Shelf, the mean length-at-age in the time period 2002/03 is less than in the other two time periods for ages 1 to 4, suggesting decreased growth rate. Overall, the 1970s and 1980s are similar in the eastern Scotian Shelf. In the central area there is more variation (note that sample sizes are smaller here).

Spatial comparisons: there is no significant difference in mean length-at-age in the 1970s, but in the 1980s and 2000s, the mean length-at-age of fish from the Bay of Fundy is generally greater than in the other two areas (Figure 17). This is particularly evident in the 1980s for age 4+ fish. However, there is little difference in mean length-at-age for fish from the eastern Scotian Shelf and central Scotian Shelf.

The differences between growth in the different time periods and areas are not large. However, the data do suggest that mean length-at-age in the Bay of Fundy is greater than on the Scotian Shelf and that mean length-at-age was higher in the 2000s than in the 1970s and 1980s. In order to explore the effects of differences in growth on mortality estimates, the central and eastern Scotian Shelf age-length data were combined and the 1970s and 1980s age-length data (1978/79/83/84) were combined (Figure 18).

Estimate von Bertalanffy growth parameters for the 4 time/area combinations

Method:

$$L_t = L_\infty*(1-\exp(-k*(t-t_0)))$$

The von Bertalanffy growth model was fitted using using EXCEL and SOLVER, minimizing the sum of squares between estimated and observed L_t. There is a high correlation between $L\infty$ and K making estimation uncertain and producing many "optimal" combinations of $L\infty$ and K. The specific combination produced here was dependent on the starting values of the parameters. For $L\infty$, values encompassing the likely "real" value of $L\infty$ were used, ranging from 150 to 250 cm. Each optimisation began with different estimates of L_∞ to explore feasible solution space, and in some cases, restrained other parameters (Table 5, Figures 19 and 20).

Growth on the Scotian Shelf is slower than in the Bay of Fundy during both time periods (Figure 18). When these data are modeled using von Bertalanffy parameters and compared to a growth curve for Georges Bank (K. Sosebee, NMFS, pers. Comm.), it can be seen that growth on Georges Bank is faster than in the other two areas (Figure 21).

Mortality Estimation

Total mortality, Z

Total mortality of white hake in the Bay of Fundy and the Scotian Shelf was estimated using the Jones length-converted catch curve, where numbers at length (1970-2004) were converted to numbers at age using the growth curves described above for each area/time combination. A constant length window between 37 and 73 cm was used to capture the descending limb of the catch curve. Results are presented for both growth curves using a 4-year moving window (Figures 22a and 23a). As might be expected from the similarity of the curves in Figure 17 (a) and (b), the difference in mortality estimates for the two time periods are small. Figures 22b and 23b compare the 4-year moving window Z estimates to the annual estimates of Z.

Scotian Shelf

Total mortality of white hake on the Scotian Shelf has increased through time (Figure 22a). In the 1970s, average mortality was around 0.4 yr^{-1}. It then increased during the 1980s to around 0.5 yr^{-1}, then in the 2000s increased to a high of over in 1995 1.0 yr^{-1}. Since 1995, total mortality has decreased, but is still high. These results are comparable to those of Bundy et al., (2001), and changes in growth do not account for the high mortality estimates for recent years.

Figure 22a used a 4 yr moving window, and indicates that total mortality has decreased since a peak in the mid 1990s, perhaps due to the cod moratorium on the eastern Scotian Shelf. Looking at annual variability in the Z estimates (Figure 22b), Z plateaued during the mid-1990s, decreased in 2002, then increased again in 2003 and is still high in 2005.

Bay of Fundy

Total mortality of white hake in the Bay of Fundy is variable without trend (Figure 23a). It was around 0.5 yr-1 during the mid-1970s and the early 1990s. Although a 4 year moving window was used (in order to attain a more stable age structure), there are still fluctuations in the age distribution through time. The two large dips in the late 1970s and the mid 1990s are caused by a shift in the age distribution to older fish (due to lack of recruitment of younger fish) such that the slope of the regression line, and hence the estimate of mortality is positive. This can be seen more clearly in the annual estimates of mortality (Figure 23b). Arguably, total morality of Bay of Fundy white hake has been around 0.3 yr^{-1} since the mid 1980s, and may have decreased since 2000. This variability in total mortality of white hake in the Bay of Fundy is possible indicative of migration in and out of the area by white hake from the Gulf of Maine, George's Bank and/or the Scotian Shelf. The data suggest that mortality has increased over the last three years.

In any decade since 1970, total mortality of white hake is higher on the Scotian Shelf than in the Bay of Fundy (Table 6). Average total mortality in the Bay of Fundy (1970-2004) is 0.27 yr^{-1}, whereas on the Scotain Shelf it is 0.61 yr^{-1} (using the growth curves for the 1970s/80s).

Relative Fishing Mortality

Relative fishing mortality is an approximate measure of exploitation and is estimated as the commercial catch divided by the fishable biomass estimated from the summer RV survey, here defined as large fish (45+ cm). Relative fishing mortality was estimated for 4Vn, 4VsW and 4X (Figure 24). In 4Vn and 4VsW, there was a decrease in relative F from 1970 to the mid-1980s, then an increase in the early to mid-1990s. In 4VsW this increase was very large, peaking in 1996 and dropping, very sharply in 4VsW, to below the long term average in 1997. The increase in relative F in both areas from the late 1980s to early 1990s could be due to redirected fishing effort, improved reporting practices, or both. The 1996 peak in 4VsW is due to a year effect in the survey (estimated biomass of 45+ cm white hake decreased by 45 % from 1995). The subsequent low estimates of F in 1997 - 2003 are due to low catches (in keeping with the quota caps). Relative fishing mortality has been less than 0.1 yr^{-1} in 4Vn in recent years, and between 0.1yr^{-1} and 0.2yr^{-1} in 4VsW and is below the long term mean. The higher value of relative F in 2004 should be treated with caution since the RV survey in 2004 was conducted using the RV Teleost, not the RV Alfred Needler.

In 4X there was a decrease in relative F from 1970 to the mid-1980s. Since then, relative F has generally varied around the mean of 0.22 yr^{-1}.

Comparison between total and fishing mortality

Total mortality is comprised of fishing mortality and natural mortality. It is possible to compare these trends for the Scotian Shelf (the estimates of total mortality in the Bay of Fundy are too variable to make this exercise useful). Fishing mortality was converted to an instantaneous rate for comparative purposed (Figure 25). In the 1970s, there was good correspondence between fishing mortality and total mortality. However, in the 1980s, total mortality fluctuated around 0.6, whereas fishing mortality increased to levels comparable to total mortality in 1992, indicating that most of the mortality of white hake was caused by fishing. Since 1992, fishing mortality decreased, while total mortality remained high, indicating that natural mortality is high.

Total Removals of white Hake from 4VWX/5

Total removals of white hake from 4VWX/5 are non-distinguishable from removals of white hake by the commercial fishery (Table 7). Since 1994, Industry Surveys (ITQ survey, 4VsW Sentinel Survey, 4Vn Sentinel Survey, Halibut Survey, Monkfish Survey, Skate Survey and the 5Z Fixed Gear Survey) have removed between 0.1 and 2% of total removals. Until 2001, most of this was taken by the 4Vn and 4VsW Sentinel Surveys, but since then, the proportion removed by the Halibut Survey has increased (Figure 26).

Sources of Uncertainty

There are several sources of uncertainty for this assessment, including uncertainty over stock or sub-stock definition. The RV surveys do not cover the full depth range of white hake distribution, possibly inflating estimates of total mortality, and catchability to the RV survey within the sampled range is not well understood. While total mortality is high, the source of the increase in mortality is unknown. Landings prior to 1993 may be inaccurately reported, due to misreporting as other species.

White and Red Hake

One particular source of uncertainty, is the uncertainty over the identification of *Urophycis* species, which in 4VWX/5 consist of red hake (*Urophycis chuss*) and white hake. In the RV survey, almost all *Urophycis* species were identified as white hake prior to 1981, which could bias our interpretation of survey trends and relative abundance. This is a problem particularly associated with smaller fish since the maximum length of red hake is around 51 cm (Markle et al. 1982). Thus larger fish were correctly identified as white hake. This issue was investigated here (Appendix 1), and a conversion ratio estimated by strata (or strata group) and length group to retroactively adjust for species misidentification prior to 1981 in the RV Survey. Results indicate that adjusting for species misidentification does not change the overall picture for either white hake or red hake (Figure A.3).

Discussion

In general, the status of white hake is better in 4X/5 than on the Scotian Shelf. On the Scotian Shelf (4VW), white hake abundance has been very low since the early 1990s, large fish have been lost from the population, the area occupied by large fish has decreased, total mortality is high and fishing mortality has decreased in recent years. In 4X/5, there has been a noisy but consistent decrease in the abundance of white hake since the early 1990s, the area occupied by large fish has decreased a little, total mortality has decreased since around 2000 and fishing mortality has had little trend over time. Growth is faster than on the Scotian Shelf, fish are larger and biomass is higher.

On the Scotian Shelf, the RV index of abundance of large and small fish suggests that in 4VW small fish are not surviving to become large fish. The proportion of large fish in the population has decreased since the 1970s. If small fish are lost to the population of large fish, this could have a serious effect on the production of white hake since a large white hake (90 cm) is 4 times more fecund than a small white hake (50 cm) (Markle et al.1982).

Since the mid-1980s the status of several species such as cod and haddock has been poor in 4VW and there are comparisons that can be drawn between these species and white hake. In particular, total mortality of white hake increased to a high in the mid 1990s in 4VW, while fishing mortality decreased (Figure 25). This leaves a large, unknown source of mortality affecting white hake between 37 and 73 cm in length. 4VsW cod, 4Vn cod and 4TVW haddock are also experiencing apparent high natural mortality with minimal fishing mortality.

Summary

There are very few large white hake on the Scotian Shelf (4VW) now compared to the 1980s, despite reduced catches in all areas and indications of good recruitment. Area occupied by large fish has decreased, total mortality is high and fishing mortality has decreased in recent years. The status of white hake in 4Vn and 4VsW is poor and requires rebuilding.

In 4X, there has been a general decrease in the abundance of white hake since the early 1990s, the area occupied by large fish is below the long-term mean, total mortality and fishing mortality have had little trend over time. Growth is faster than on the Scotian Shelf, fish are larger and biomass is higher. Unless there is good recruitment in 4X over the next few years, catches at the current level may lead to further decreases in abundance.

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Table 1. Nominal landings from 4VWX/5, by country as reported to NAFO and DFO statistics.

Year	Canada[1]	USA[2]	Cuba	Spain	France	Ireland	Japan	USSR	Total	TAC/QUOTA[3]
1964	3163	612	-		-	-	-	-	3775	
1965	7	352	-	146	-	-	-	-	505	
1966	1617	97	-	13	-	-	-	-	1727	
1967	916	202	-	229	-	-	-	-	1347	
1968	1546	166	-	9	-	-	-	8	1729	
1969	2412	120	-	41	-	-	-	-	2573	
1970	2971	144	-	126	-	-	96	-	3337	
1971	5004	177	-	18	-	-	135	-	5334	
1972	5422	244	-	374	-	-	164	-	6204	
1973	5779	99	-	16	-	-	5	-	5899	
1974	5891	147	-	-	-	-	5	-	6043	
1975	4677	112	-	-	-	-	-	-	4789	
1976	3534	96	-	-	-	1	2	-	3633	
1977	3411	182	-	-	-	-	-	48	3641	
1978	3871	149	14	-	-	-	7	-	4041	
1979	3284	443	1	-	-	-	3	-	3731	
1980	4154	231	-	-	-	-	13	-	4398	
1981	3832	650	-	-	-	-	1	-	4483	
1982	5355	752	-	-	-	-	15	-	6122	
1983	4500	1005	-	-	-	-	5	-	5510	
1984	5379	960	-	-	-	-	7	-	6346	
1985	5977	61	2	-	-	-	19	-	6059	
1986	7929	164	-	-	20	-	30	-	8143	
1987	8597	70	15	-	-	-	15	-	8697	
1988	6001	27	-	-	-	-	1	-	6029	
1989	5669	41	5	-	-	-	3	-	5718	
1990	5874	140	-	-	-	-	2	-	6016	
1991	4931	24	-	-	-	-	-	-	4955	
1992	5868	6	1	-	-	-	-	-	5875	
1993	6500	0	-	-	-	-	-	-	6500	
1994	5224	-	-	-	-	-	-	-	5224	
1995	5636	-	-	-	-	-	-	-	5636	
1996	3892	-	-	-	-	-	-	-	3892	3420
1997	3453	-	-	-	-	-	-	-	3453	3100
1998	2085	-	-	-	-	-	-	-	2085	3500
***1999	2258	-	-	-	-	-	-	-	2258	1700
2000	2439	-	-	-	-	-	-	-	2439	1400
2001	2361	-	-	-	-	-	-	-	2361	2800
2002	2418	-	-	-	-	-	-	-	2539	2800
2003	1987	-	-	-	-	-	-	-	1968	2800
2004	1844	-	-	-	-	-	-	-	1805	2323
2005	2055								2055	2323

(1) Canadian landings are taken from the NAFO database from 1964 to 1985, from the DFO ZIF database from 1986 onwards, and from MARFIS for 2002 - present.
(2) USA landings in Subareas 5Yb and 5Zc from Sosebee et al 1998.
(3) TAC on fixed gear 1996-1998, quota caps since 1999 (see text for more details
*** Note: Beginning in 1999 the fishing year was extended to Mar 31,2000. Subsequent fishing years began on Apr 1 and ended Mar 31 the following year.

Table 2. Nominal landings of white hake by NAFO Division and country.

	4Vn				4Vs				4W			
Year	Canada[1]	USA[2]	Other	**Total**	Canada[1]	USA[2]	Other	**Total**	Canada[1]	USA[2]	Other	**Total**
1964	192	0	0	**192**	23	2	0	**25**	320	6	0	**326**
1965	6	0	0	**6**	1	0	86	**87**	0	2	60	**62**
1966	348	0	0	**348**	9	0	13	**22**	433	0	0	**433**
1967	125	0	2	**127**	27	0	227	**254**	241	0	0	**241**
1968	138	0	0	**138**	33	0	17	**50**	325	0	0	**325**
1969	137	0	0	**137**	38	0	27	**65**	543	0	1	**544**
1970	182	1	6	**189**	47	0	36	**83**	718	2	21	**741**
1971	422	0	11	**433**	117	0	7	**124**	1453	4	1	**1458**
1972	173	0	26	**199**	95	0	176	**271**	1203	9	86	**1298**
1973	273	0	0	**273**	126	0	20	**146**	1445	5	0	**1450**
1974	223	0	0	**223**	137	0	5	**142**	1329	2	0	**1331**
1975	181	0	0	**181**	138	0	0	**138**	1336	2	0	**1338**
1976	262	0	0	**262**	157	0	0	**157**	756	1	2	**759**
1977	288	0	0	**288**	152	0	0	**152**	848	0	0	**848**
1978	202	0	0	**202**	242	0	15	**257**	769	0	4	**773**
1979	338	0	0	**338**	181	0	1	**182**	366	0	1	**367**
1980	585	0	0	**585**	369	0	0	**369**	341	0	1	**342**
1981	564	0	0	**564**	222	0	0	**222**	412	0	1	**413**
1982	414	0	0	**414**	204	0	0	**204**	595	0	14	**609**
1983	401	0	0	**401**	315	0	0	**315**	626	0	4	**630**
1984	237	0	2	**239**	298	0	3	**301**	688	0	2	**690**
1985	345	0	1	**346**	526	0	16	**542**	1105	0	4	**1109**
1986	373	0	25	**398**	518	0	20	**538**	1406	0	5	**1411**
1987	554	0	1	**555**	725	0	8	**733**	1588	0	21	**1609**
1988	323	0	0	**323**	376	0	1	**377**	788	0	0	**788**
1989	291	0	0	**291**	475	0	0	**475**	937	0	8	**945**
1990	190	0	0	**190**	310	0	0	**310**	1236	0	2	**1238**
1991	170	0	0	**170**	293	0	0	**293**	1076	0	0	**1076**
1992	158	0	0	**158**	301	0	0	**301**	829	0	1	**830**
1993	136	0	0	**136**	281	0	0	**281**	768	0	0	**768**
1994	224	0	0	**224**	213	0	0	**213**	598	0	0	**598**
1995	32	0	0	**32**	286	0	0	**286**	594	0	0	**594**
1996	68	0	0	**68**	126	0	0	**126**	522	0	0	**522**
1997	141	0	0	**141**	77	0	0	**77**	252	0	0	**252**
1998	138	0	0	**138**	105	0	0	**105**	193	0	0	**193**
***1999	138	0	0	**138**	96	0	0	**96**	236	0	0	**236**
2000	95	0	0	**95**	62	0	0	**62**	225	0	0	**225**
2001	63	0	0	**63**	75	0	0	**75**	208	0	0	**208**
2002	58	0	0	**58**	43	0	0	**43**	146	0	0	**146**
2003	34	0	0	**34**	67	0	0	**67**	100	0	0	**100**
2004	38	0	0	**38**	41	0	0	**41**	73	0	0	**73**
2005	49	0	0	**49**	49	0	0	**49**	126	0	0	**126**

(1) Canadian landings are taken from the NAFO database from 1964 to 1985, from the DFO ZIF database from 1986 onwards, and from MARFIS for 2002 - present.
(2) USA landings in Subareas 5Yb and 5Zc from Sosebee et al 1998.
5Y: US landings until 1986 are for all 5Yb. Since 1986 there has been minimal US catch in Canadian 5Yb.
5Zc: Canadian landings until 1986 are for 5Zjm and US landings are for US Statistical areas 523 and 524. Since 1986, Canadian landings are mainly from 5Zc.
*** Note: Beginning in 1999 the fishing year was extended to Mar 31,2000. Subsequent fishing years began on Apr 1 and ended Mar 31 the following year

Table 2 (cont). Nominal landings of white hake by NAFO Division and country.

	4X				5Y (2)				5Zc (2)			
Year	Canada	USA	Other	**Total**	Canada	USA	Other	**Total**	Canada	USA	Other	**Total**
1964	2599	181	0	**2780**	3	339	0	**342**	26	85	0	**111**
1965		114	0	**114**		160	0	**160**		76	0	**76**
1966	827	0	0	**827**		33	0	**33**		64	0	**64**
1967	507	0	0	**507**		141	0	**141**	16	62	0	**78**
1968	965	0	0	**965**	5	96	0	**101**	80	70	0	**150**
1969	1660	43	7	**1710**	4	24	0	**28**	30	53	6	**89**
1970	1978	69	16	**2063**	12	20	0	**32**	34	52	143	**229**
1971	2912	62	29	**3003**	18	54	0	**72**	82	57	105	**244**
1972	3911	82	91	**4084**	8	60	0	**68**	32	93	159	**284**
1973	3818	25	0	**3843**	17	38	0	**55**	100	31	1	**132**
1974	3970	43	0	**4013**	36	63	0	**99**	196	39	0	**235**
1975	2876	34	0	**2910**	17	37	0	**54**	129	40	0	**169**
1976	2164	51	1	**2216**		20	0	**20**	195	24	0	**219**
1977	1953	99	0	**2052**		28	0	**28**	170	55	48	**273**
1978	2503	30	1	**2534**	20	35	0	**55**	135	84	1	**220**
1979	2148	12	0	**2160**	102	342	0	**444**	149	90	2	**241**
1980	2554	38	11	**2603**	14	86	0	**100**	291	107	1	**399**
1981	2180	184	0	**2364**	21	59	0	**80**	433	407	0	**840**
1982	3378	196	1	**3575**	352	299	0	**651**	412	257	0	**669**
1983	2348	246	1	**2595**	441	427	0	**868**	369	333	0	**702**
1984	3143	276	0	**3419**	479	354	0	**833**	534	331	0	**865**
1985	3048	61	0	**3109**	452	0	0	**452**	501	0	0	**501**
1986	4676	164	0	**4840**	307	0	0	**307**	648	0	0	**648**
1987	5072	70	0	**5142**	104	0	0	**104**	555	0	0	**555**
1988	3893	27	0	**3920**	86	0	0	**86**	534	0	0	**534**
1989	3161	41	0	**3202**	222	0	0	**222**	582	0	0	**582**
1990	3542	140	0	**3682**	50	0	0	**50**	546	0	0	**546**
1991	2807	24	0	**2831**	34	0	0	**34**	550	0	0	**550**
1992	3316	6	0	**3322**	127	0	0	**127**	1137	0	0	**1137**
1993	3561	0	0	**3561**	73	0	0	**73**	1681	0	0	**1681**
1994	3137	0	0	**3137**	98	0	0	**98**	955	0	0	**955**
1995	4194	0	0	**4194**	47	0	0	**47**	481	0	0	**481**
1996	2743	0	0	**2743**	60	0	0	**60**	372	0	0	**372**
1997	2546	0	0	**2546**	147	0	0	**147**	290	0	0	**290**
1998	1364	0	0	**1364**	57	0	0	**57**	228	0	0	**228**
***1999	1528	0	0	**1528**	36	0	0	**36**	224	0	0	**224**
2000	1795	0	0	**1795**	59	0	0	**59**	203	0	0	**203**
2001	1797	0	0	**1797**	61	0	0	**61**	158	0	0	**158**
2002	1948	0	0	**1948**	187	0	0	**187**	158	0	0	**158**
2003	1441	0	0	**1441**	198	0	0	**198**	128	0	0	**128**
2004	1480	0	0	**1480**	82	0	0	**82**	90	0	0	**90**
2005	1561	0	0	**1561**	185	0	0	**185**	85	0	0	**85**

(1) Canadian landings are taken from the NAFO database from 1964 to 1985, from the DFO ZIF database from 1986 onwards, and from MARFIS for 2002 - present.

(2) USA landings in Subareas 5Yb and 5Zc from Sosebee et al 1998.

5Y: US landings until 1986 are for all 5Yb. Since 1986 there has been minimal US catch in Canadian 5Yb.

5Zc: Canadian landings until 1986 are for 5Zjm and US landings are for US Statistical areas 523 and 524. Since 1986, Canadian landings are mainly from 5Zc.

*** Note: Beginning in 1999 the fishing year was extended to Mar 31,2000. Subsequent fishing years began on Apr 1 and ended Mar 31 the following year

Table 3. Nominal Canadian landings of white hake by NAFO division and gear.

	4Vn				4Vs				4W				4X				5Y				5Z			
Year	OT	LHP	GN	Misc	OT	LHP	GN	Misc	OT	LHP	GN	Misc	OT	LHP	GN	Misc	OT	LHP	GN	Misc	OT	LHP	GN	Misc
1964	75	37		80	21	2			152	11		157	435	140		2024	3				26			
1965	6				1																			
1966	234	76	1	37	3	6				433				827										
1967	52	47		26	18	9			1	240			1	506							1	14		1
1968	49	71		18	14	19			53	234		38	178	756	7	24	5				18	62		
1969	34	78	8	17	10	28			117	280	13	133	356	974	154	176	4				15	15		
1970	60	93	5	24	25	22			104	370	1	243	287	1361	54	276	12				4	30		
1971	281	111	5	25	81	36			117	1044	3	289	414	2262	40	196	18				24	58		
1972	62	77	19	15	61	34			89	809		305	297	3484	5	125	8				4	28		
1973	162	55	51	5	86	40			107	1138		200	288	3421	7	102	17				38	62		
1974	142	28	40	13	97	40			57	1046	10	216	316	3589	44	21	36				19	177		
1975	116	33	24	8	79	59			58	1214		64	186	2459	66	165	3	14			34	95		
1976	230	13	17	2	46	111			42	587	1	126	144	1901	106	13					17	178		
1977	166	102	5	15	67	85			99	608	9	132	161	1519	246	27					22	148		
1978	144	51		7	151	91			119	549	62	39	245	1647	538	73	20				65	70		
1979	252	82		4	112	69			63	265	23	15	245	1739	131	33	102				12	137		
1980	337	229	2	17	132	237			50	260	4	27	263	2060	154	77	14				57	234		
1981	321	236		7	98	124			51	334	27		446	1636	63	35	6	15			20	413		
1982	161	229	24		56	148			34	516	44	1	539	2644	194	1	350	2			23	389		
1983	86	289	26		34	281			11	545	70		472	1633	240	3	384	2	55		51	318		
1984	27	210			35	263			20	566	88	14	1386	1526	223	8	407		72		129	405		
1985	135	209	1		53	473			23	852	230		1109	1415	510	14	439		13		133	362	6	
1986	118	258	469	1207	52	466			56	1200	149	1	2906	1373	396	1	251		57		348	294	5	1
1987	360	194	0	0	81	644			82	1412	85	8	1866	2755	444	7	33	0	70		121	417	11	5
1988	195	128	0	0	38	331	7		17	719	41	10	1322	2114	456	2	38	11	36		106	392	32	4
1989	196	94	1	0	17	413	45		27	801	110	0	315	2150	695	0	8	2	212		12	524	41	5
1990	109	79	2	0	19	291	0		29	1060	148	0	768	2208	553	12	16	2	32		45	487	13	1
1991	110	58	2		18	275			52	946	78	0	475	1752	575	5	10	0	24		29	508	12	2
1992	113	45	0		18	283			29	727	73	0	804	1925	586	1	54	4	68		26	1052	58	1
1993	95	41		0	7	274			5	704	55	4	650	1887	1022	2	49		24		26	1603	51	1
1994	155	69		0	29	183	2		3	551	28	16	737	1356	1041	3	33		64		27	876	50	2
1995	17	15		0	39	225	22	0	41	500	51	2	300	2713	1179	2	7	0	41		19	426	36	0
1996	14	53	1		16	102	8		115	349	57		371	1218	1155	0	9	0	51		24	333	15	
1997	5	135	1		9	67	2		2	213	37		421	915	1210	0	8	0	139		16	261	13	
1998	7	131	0		2	102	1		4	151	38		314	664	386		9	1	47		10	207	11	
*1999	3	135			7	87	2		3	209	24		486	644	399	0	12	2	22		11	153	11	
2000	4	90			17	45			10	185	29		583	665	547	0	9	2	48		14	191	19	
2001	7	56			5	69	1		11	161	36		570	625	602		6	0	54		33	159	12	
2002	1	56			5	38			11	119	17		582	631	735		22	1	164	0	9	141	7	
2003	4	30			12	55			12	86	3		366	522	553		18	1	179		8	111	9	
2004	4	34			2	39			10	53	10		419	518	543		9	1	73		9	78	3	
2005	6	43	0		11	37	0		26	82	18		459	566	537		26	3	156		34	50	1	

* Note: Beginning in 1999 the fishing year was extended to Mar 31,2000. Subsequent fishing years began on Apr 1 and ended Mar 31 the following year

Table 4. Number of otoliths used to construct age-length keys for growth analysis

Time Period	BoF	Central	Eastern
1977/78	346	187	233
1983/84	601	206	362
2002/03	363	104	187

Table 5. Von Bertalanffy Growth Parameters for the Bay of Fundy and the Scotian Shelf

	Bay of Fundy		Scotian Shelf	
	1970s and 1980s	2000s	1970s and 1980s	2000s
L_∞	206.9	190.1	205.7	131.2
K	0.05	0.06	0.04	.09
t0	-1.34	-1.26	-2.06	-0.96

Table 6. Comparison of decadal changes in mortality of white hake in the Scotian Shelf and the Bay of Fundy (using the growth curves for the 1970s/80s).

	Scotian Shelf	Bay of Fundy
1970s	0.40	0.29
1980s	0.54	0.24
1990s	0.81	0.29
2000s	0.79	0.29
Average	0.61	0.27

Table 7. Total removals (t) of white hake from 4VWX/5 by the commercial fishery and research surveys by the Industry and by DFO (RV Survey).

					% removed by		
	Fishery	**Industry Survey**	**RV Survey**	**Total**	**Fishery**	**Industry Survey**	**RV Survey**
1970	3337		0.57	3338	1.000	0.000	0.000
1971	5334		0.14	5334	1.000	0.000	0.000
1972	6204		0.31	6204	1.000	0.000	0.000
1973	5899		0.67	5900	1.000	0.000	0.000
1974	6043		0.45	6043	1.000	0.000	0.000
1975	4789		0.71	4790	1.000	0.000	0.000
1976	3633		0.34	3633	1.000	0.000	0.000
1977	3641		0.39	3641	1.000	0.000	0.000
1978	4041		1.79	4043	1.000	0.000	0.000
1979	3731		1.94	3733	0.999	0.000	0.001
1980	4398		1.33	4399	1.000	0.000	0.000
1981	4483		1.85	4485	1.000	0.000	0.000
1982	6122		2.24	6124	1.000	0.000	0.000
1983	5510		3.10	5513	0.999	0.000	0.001
1984	6346		2.58	6349	1.000	0.000	0.000
1985	6059		0.95	6060	1.000	0.000	0.000
1986	8143		2.94	8146	1.000	0.000	0.000
1987	8697		1.95	8699	1.000	0.000	0.000
1988	6029		0.74	6030	1.000	0.000	0.000
1989	5718		0.81	5719	1.000	0.000	0.000
1990	6016		0.77	6017	1.000	0.000	0.000
1991	4955		1.03	4956	1.000	0.000	0.000
1992	5875		0.78	5876	1.000	0.000	0.000
1993	6500		0.53	6501	1.000	0.000	0.000
1994	5224	0.5	0.40	5225	1.000	0.000	0.000
1995	5636	5.3	0.73	5642	0.999	0.001	0.000
1996	3892	12.0	0.79	3905	0.997	0.003	0.000
1997	3453	11.0	0.48	3464	0.997	0.003	0.000
1998	2085	43.4	0.22	2129	0.979	0.020	0.000
1999	2258	38.6	0.46	2297	0.983	0.017	0.000
2000	2439	42.0	0.73	2482	0.983	0.017	0.000
2001	2361	19.2	0.78	2381	0.992	0.008	0.000
2002	2418	27.5	0.61	2446	0.988	0.011	0.000
2003	1987	33.4	0.33	2021	0.983	0.017	0.000
2004	1844	15.9	0.08	1860	0.991	0.009	0.000
2005	2055	7.7	0.82	768	0.989	0.010	0.001

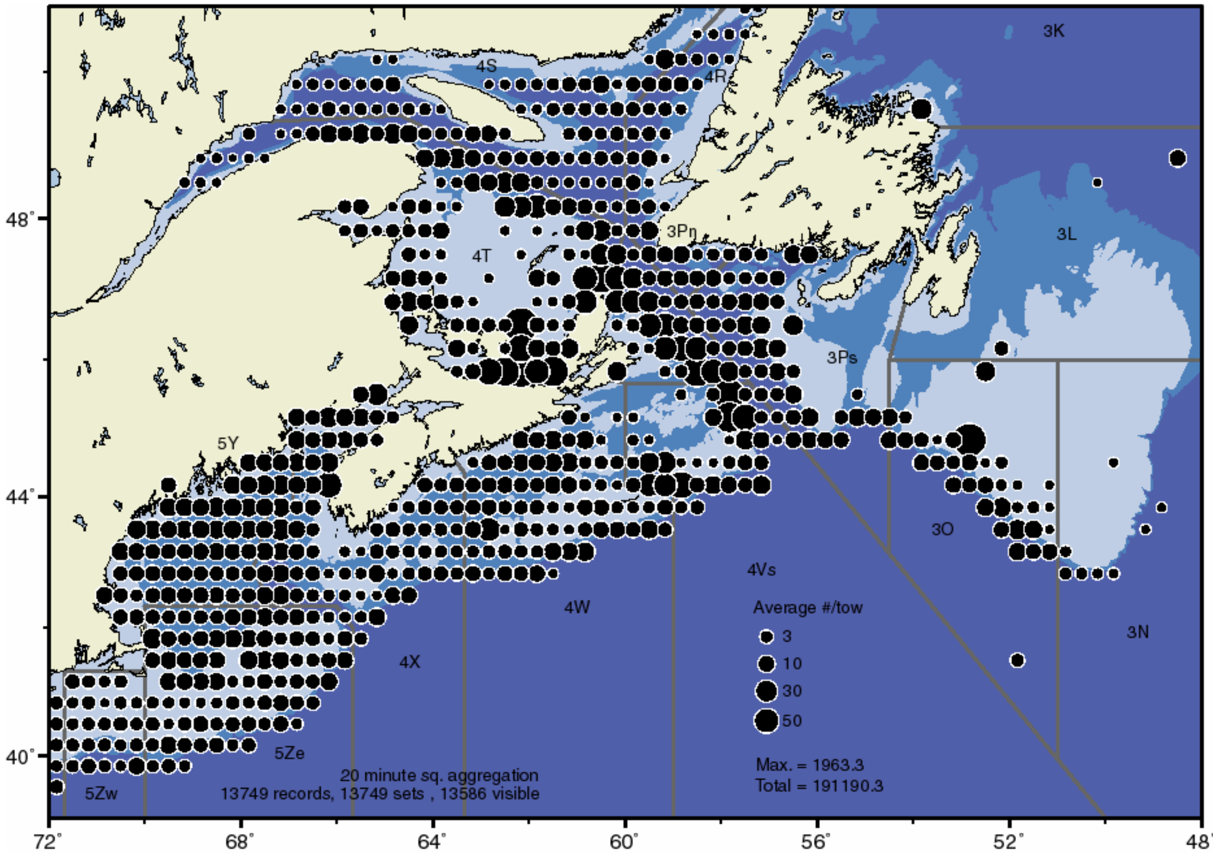

Figure 1. Distribution of white hake in the northwest Atlantic as described by ECNASAP data, 1970-1995.

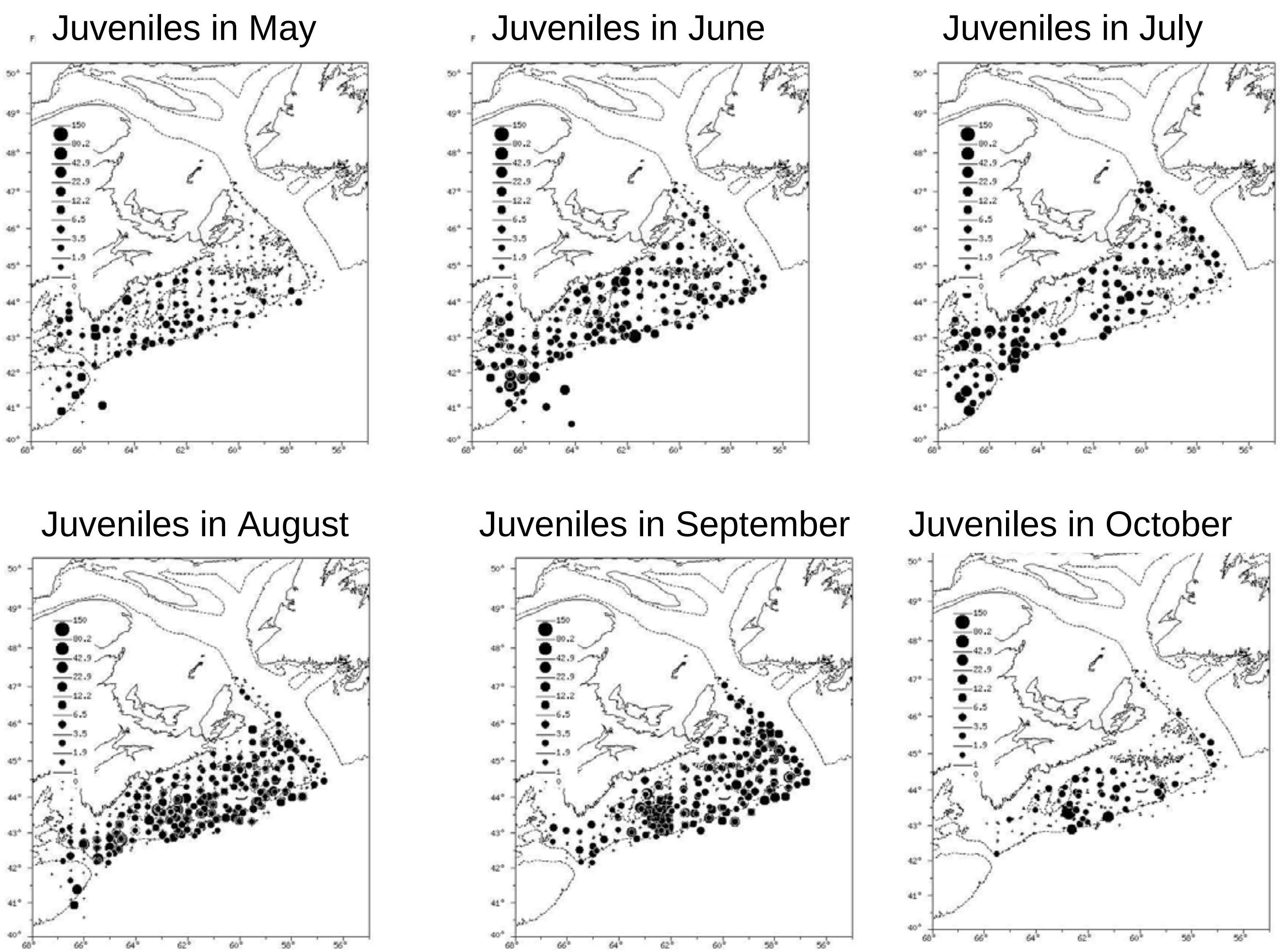

Figure 2. Distribution of juvenile white hake from Scotian Shelf Ichthyoplankton Survey (SSIP 1977-1982)

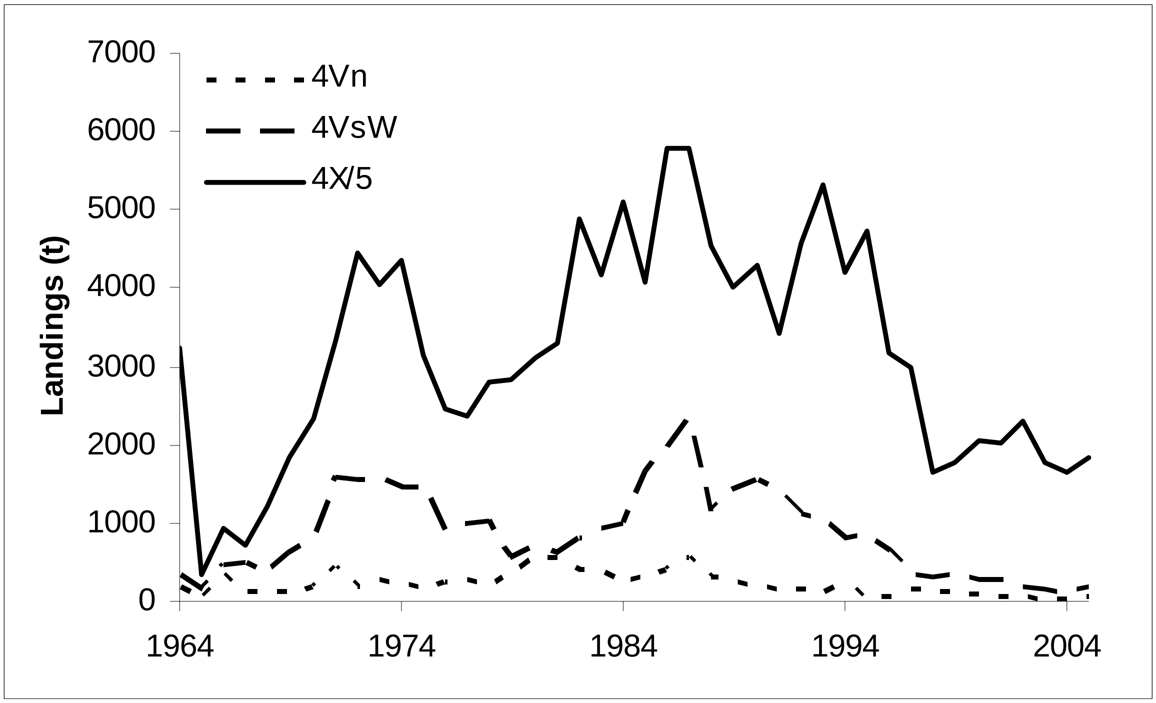

Figure 3. Total nominal landings of white hake by NAFO area.

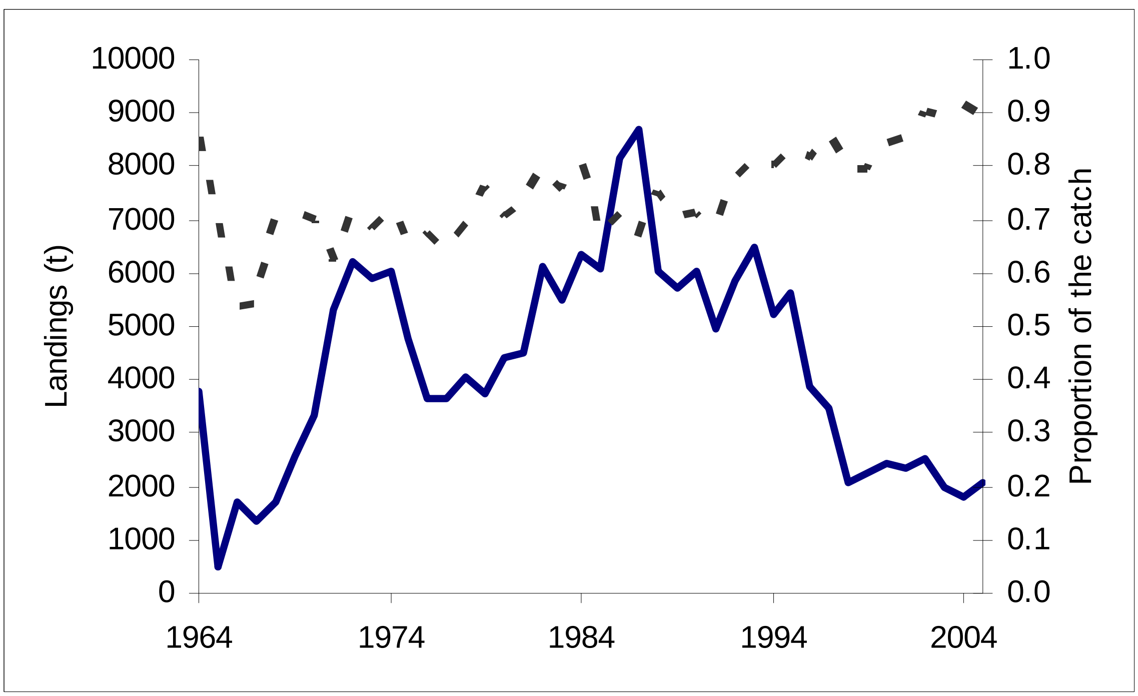

Figure 4. Total catch (solid line) and proportion of the total catch (dashed line) originating in 4X/5

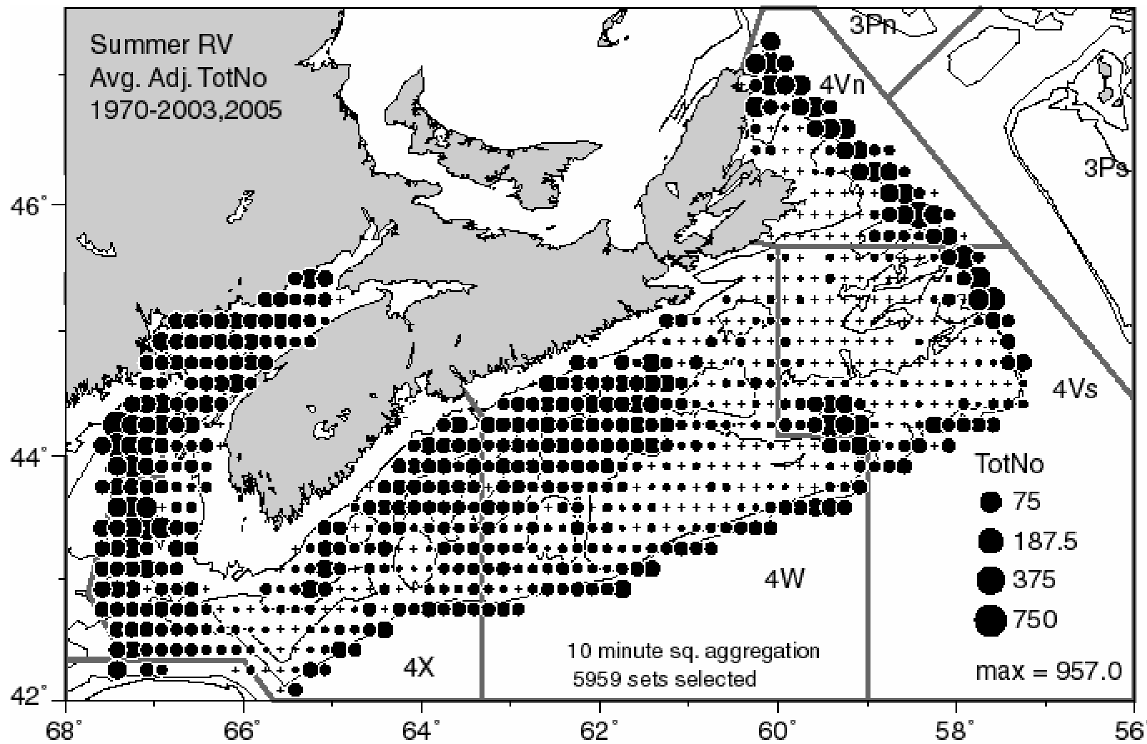

Figure 5. Map showing distribution of white hake in 4VWX/5 based on RV Survey data (1970-2005, excluding 2004).

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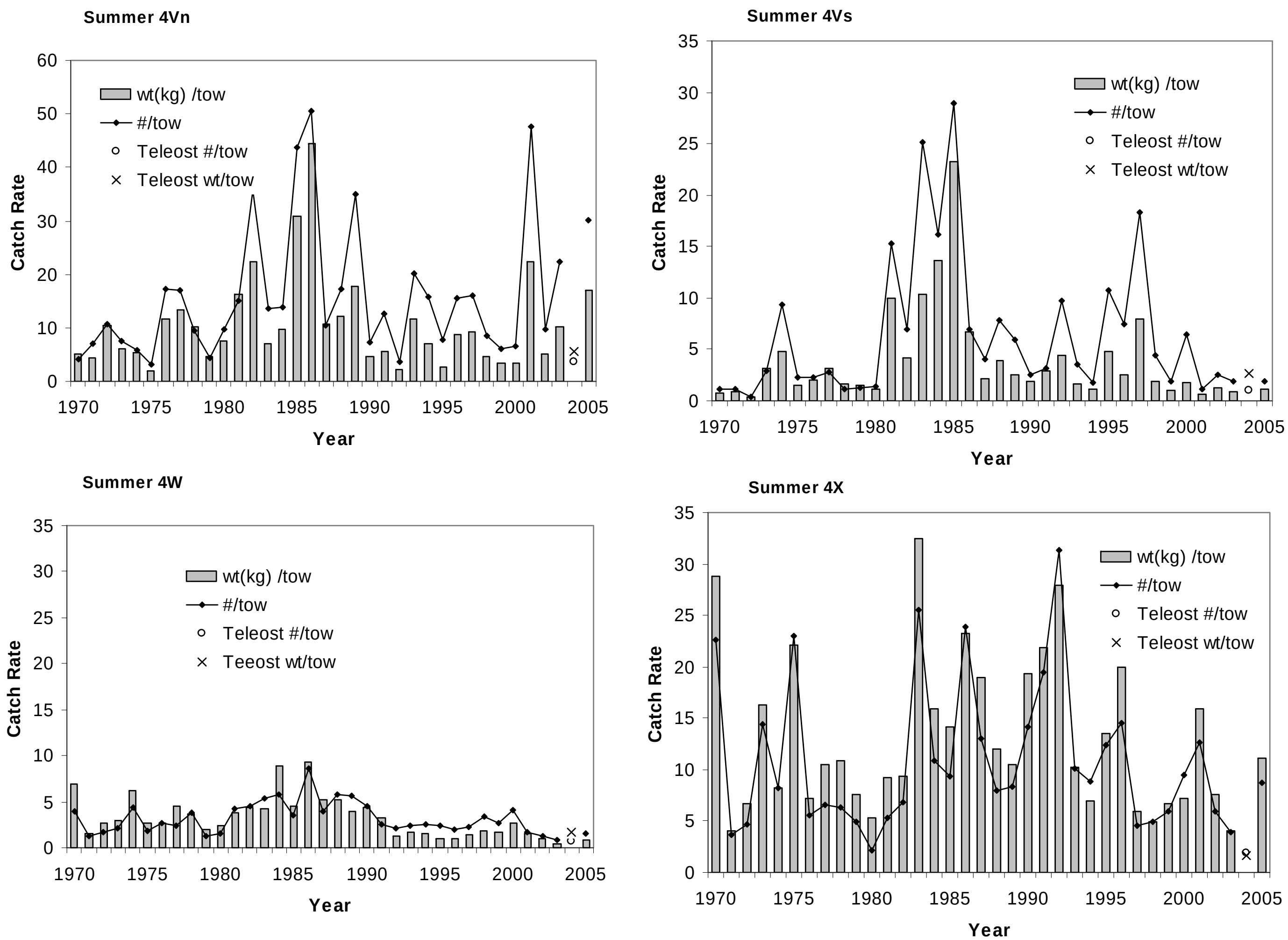


Figure 6. Stratified mean catch rates of white hake from the summer RV survey. Note that In 2004, the CCGS Teleost was used to conduct the RV survey, since the CCGS Alfred Needler was unavailable and may not be representative.

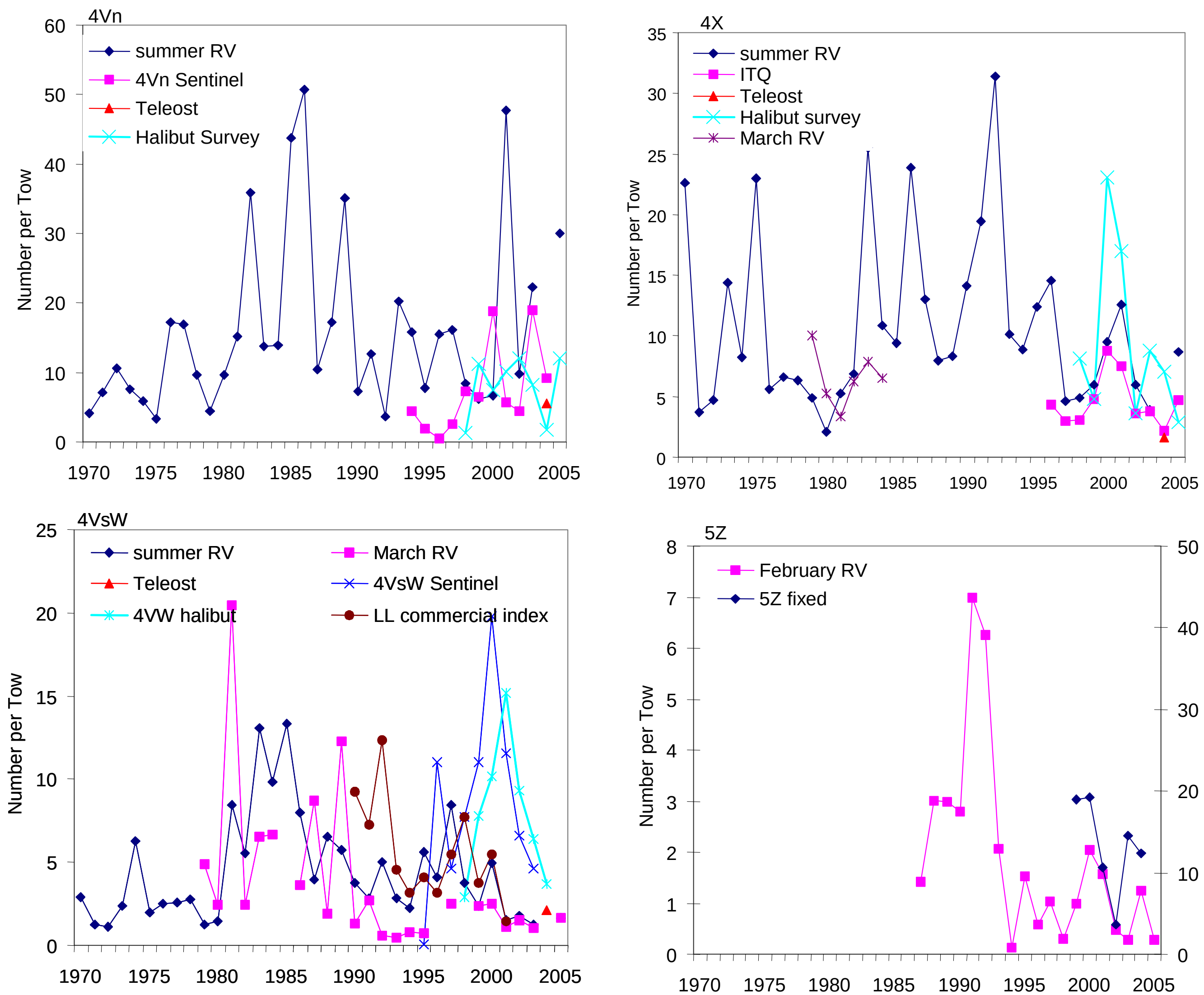


Figure 7. Comparison of catch rates among Industry and Research Vessel Surveys.

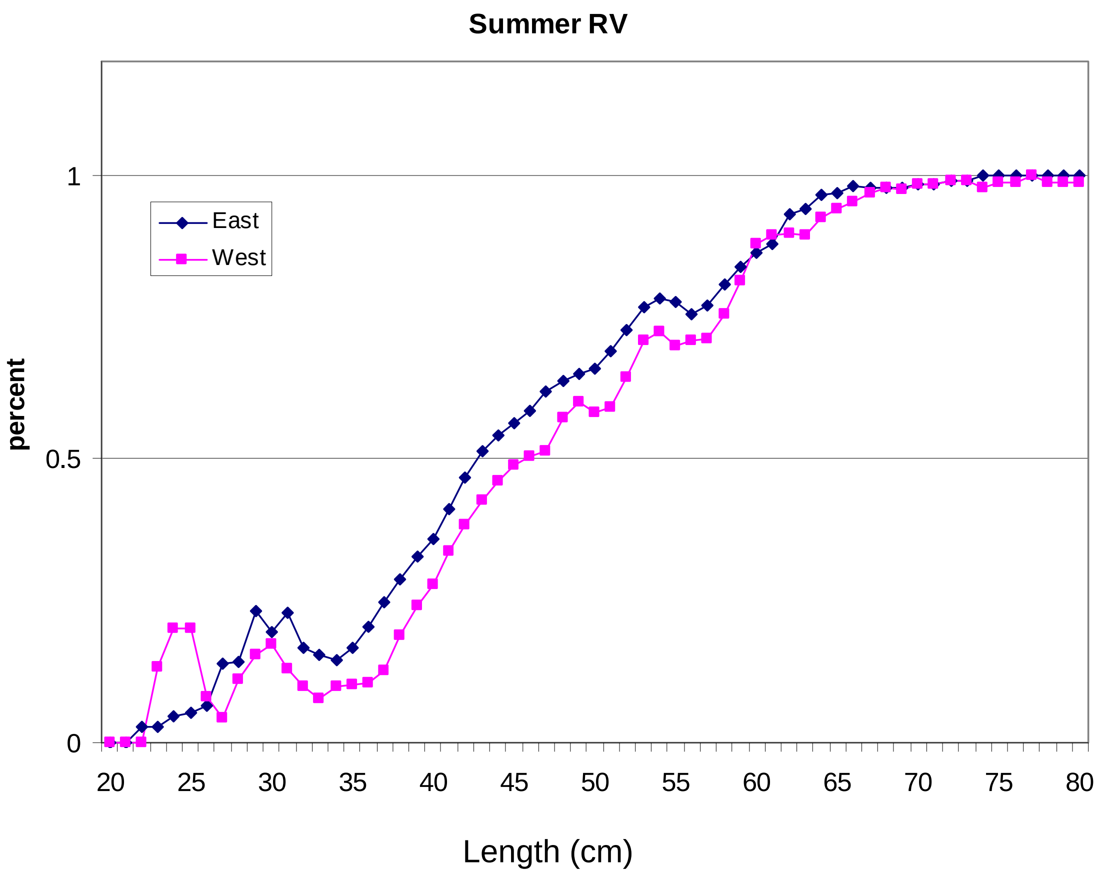


Figure 8. Maturity Ogives estimated from RV data for the Scotian Shelf and the Bay of Fundy, 1970-1985.

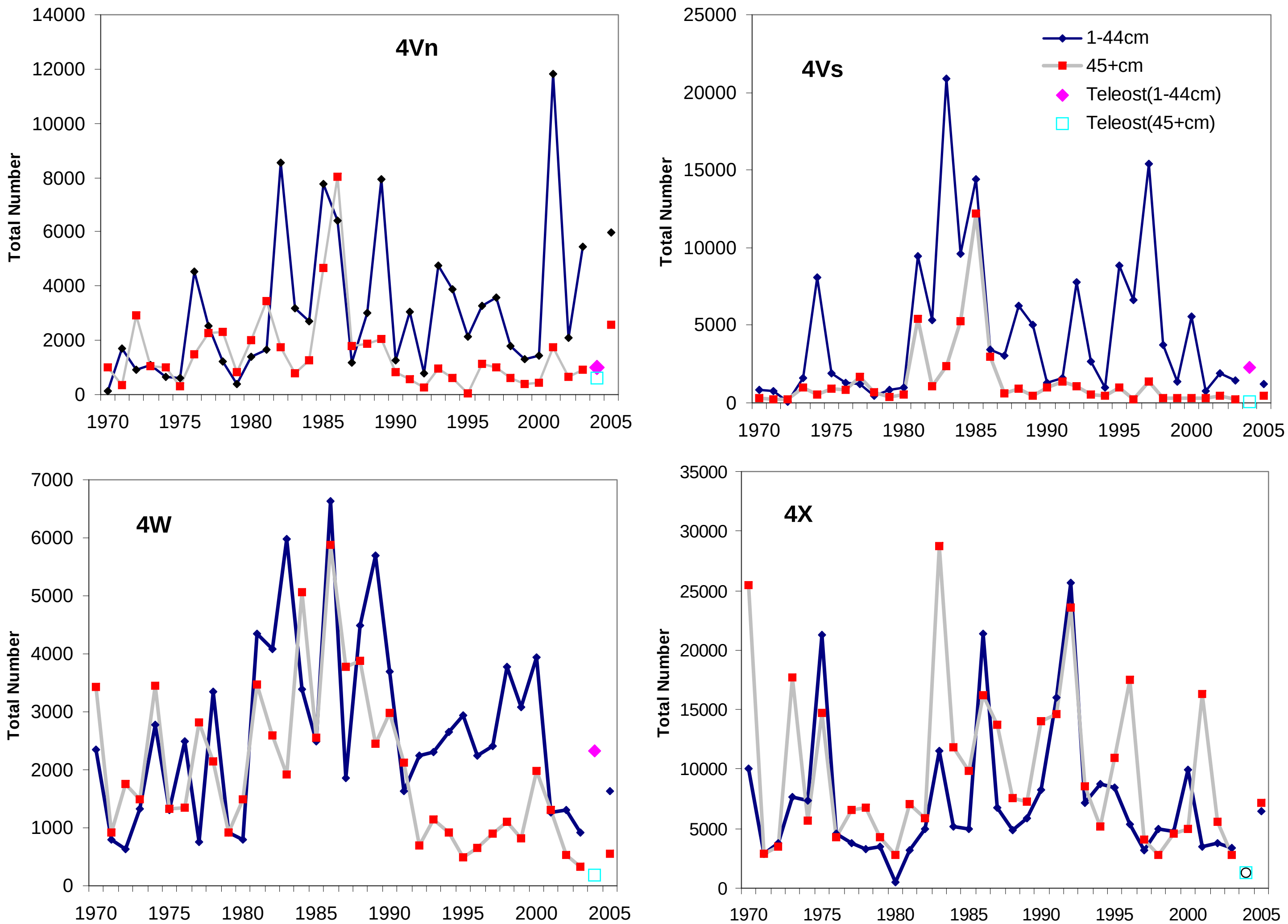


Figure 9: RV Survey Total Numbers (000s) of large (> 45 cm) and small <45 cm) fish

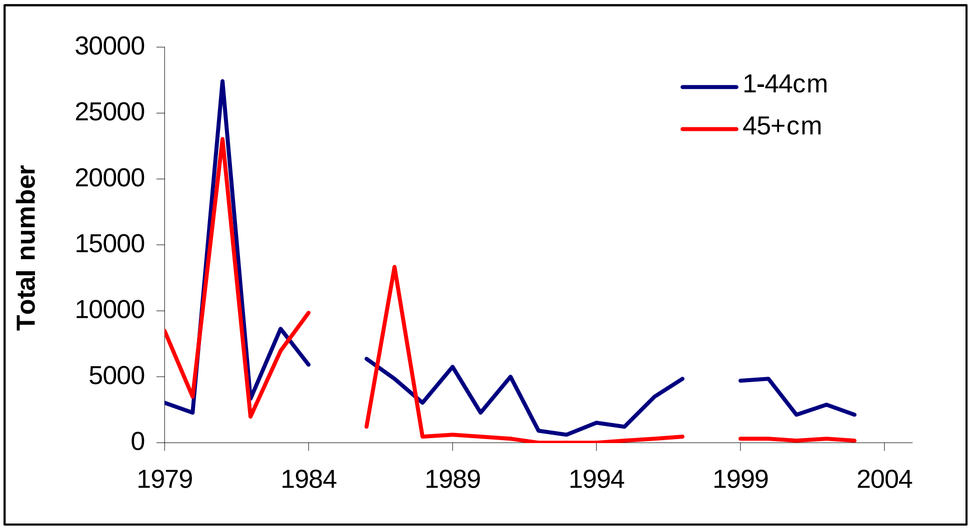


Figure 10. Spring RV Survey Total Numbers (000s) of large (> 45 cm) and small <45 cm) fish in 4VsW. 1979-1984, Spring Survey; 1986-present, 4VsW Cod Survey. Note there were no surveys in 1998 and 2004 and the 1996 survey was incomplete.

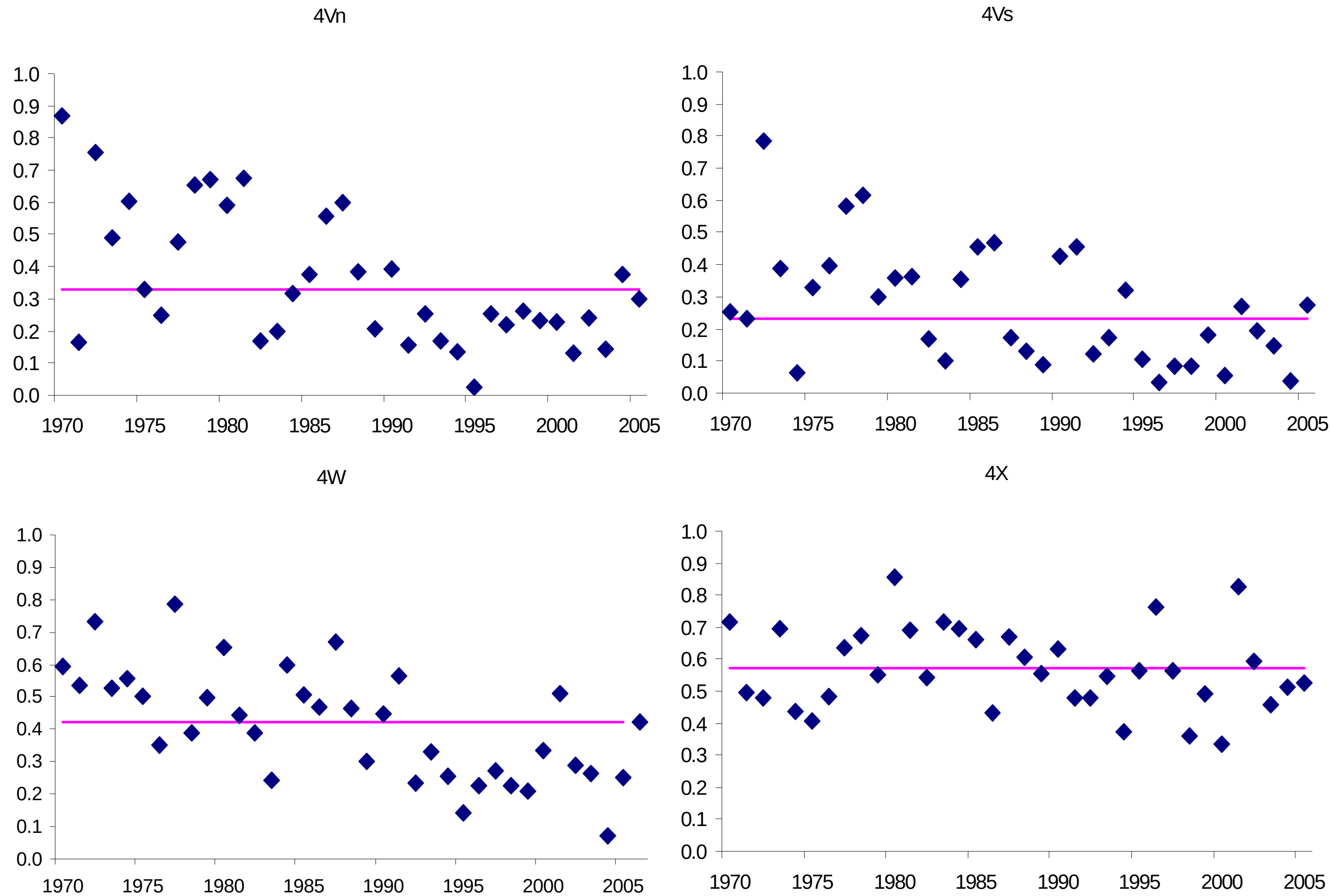


Figure 11. Proportion of large (45+cm) white hake in the population (Summer RV Survey)

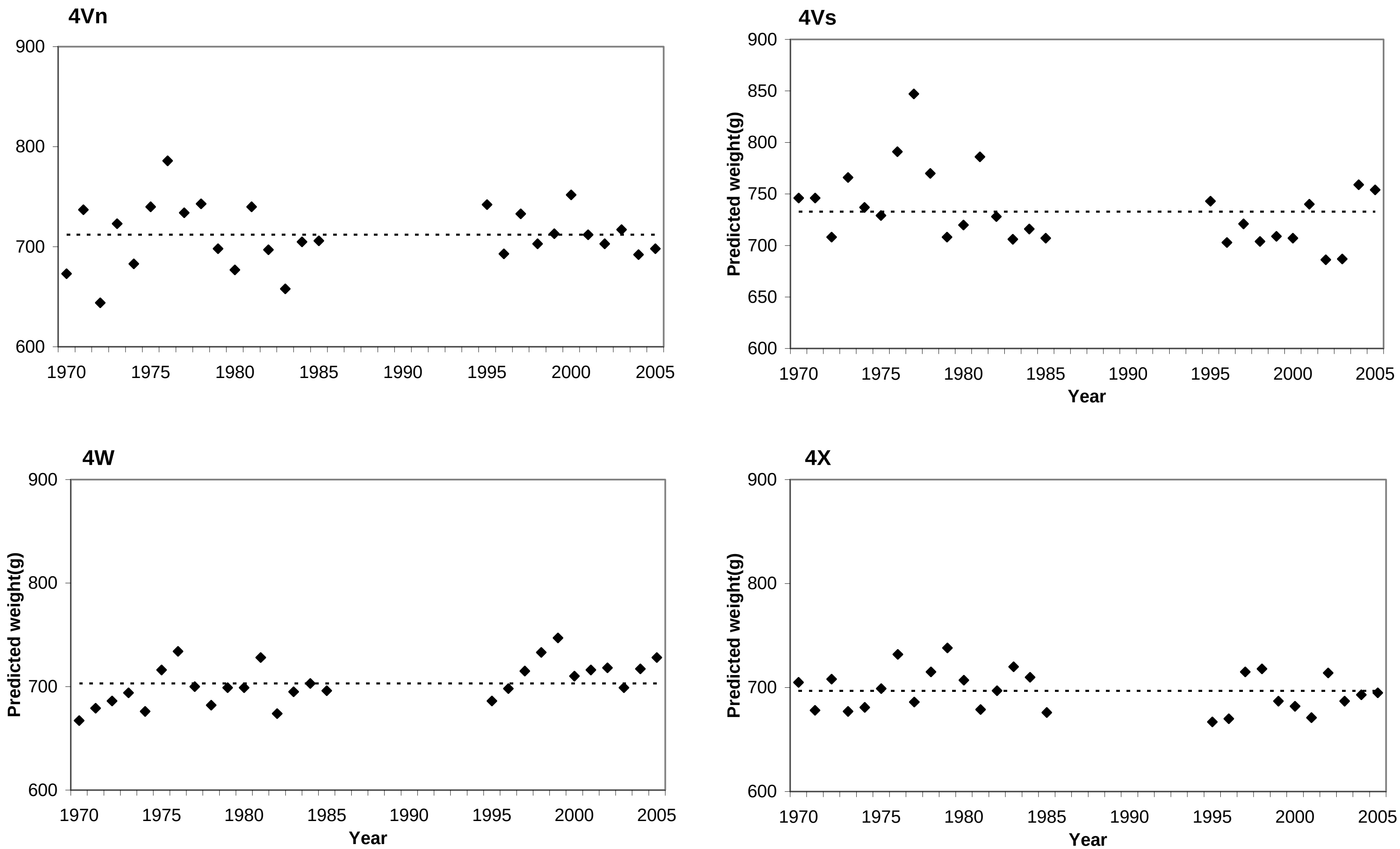


Figure 12. . Condition Factor - Predicted weight at 45 cm from Summer RV Survey data for 4Vn, 4Vs, 4W and 4X

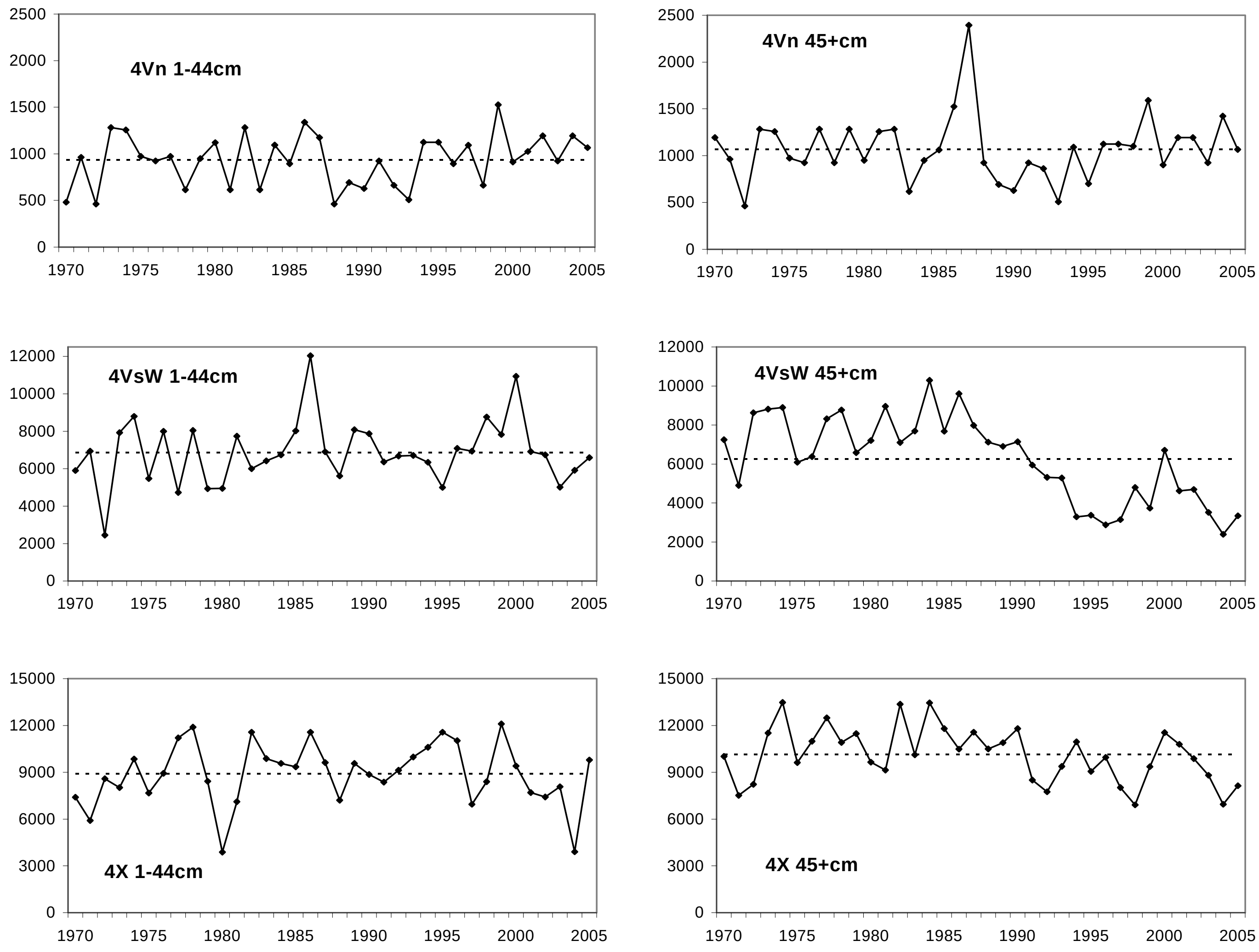


Figure 13. Area Occupied (km^2) of small and large white hake in 4Vn, 4VsW and 4X based on Summer RV Survey data.

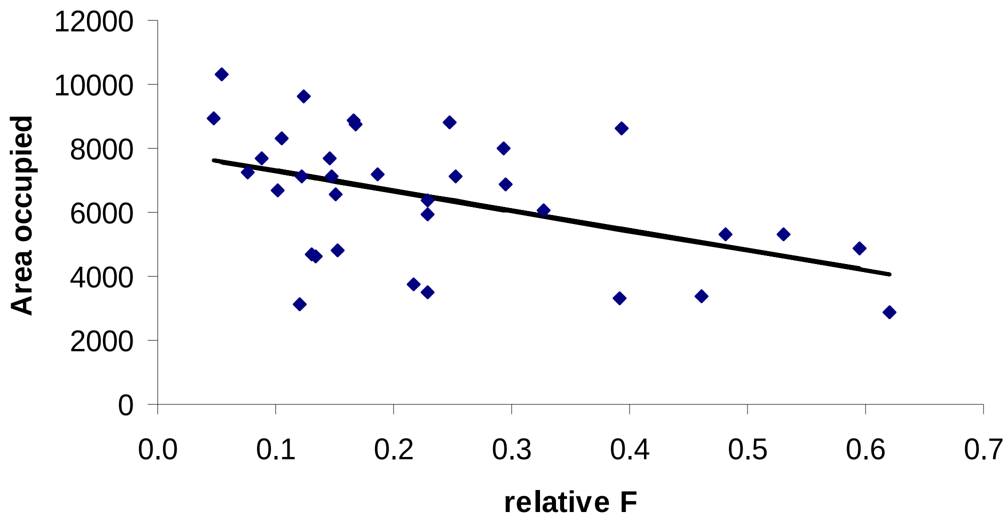


Figure 14. Regression of Area occupied on relative F of white hake in NAFO Division 4VsW ($p=0.004$; $r^2=0.22$).

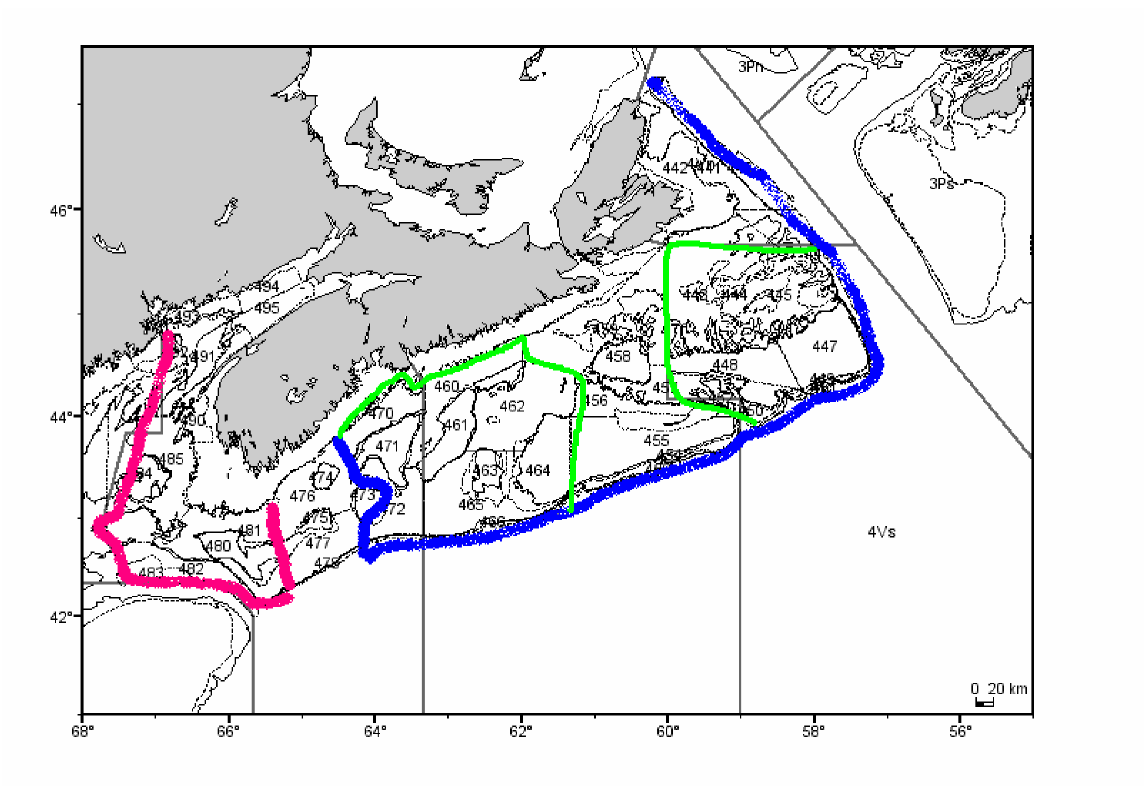


Figure 15. Map of 4VWX/5 showing summer survey strata and areas strata sampled for the age-length analysis. Red area area outlines the strata used to represent the Bay of Fundy, the middle green area outlines the strata used to represent the central Scotian Shelf and the right hand green area outlines the strata used to represent the eastern Scotian Shelf. In the final analysis, the two green areas were merged to form the blue area representing the Scotian Shelf

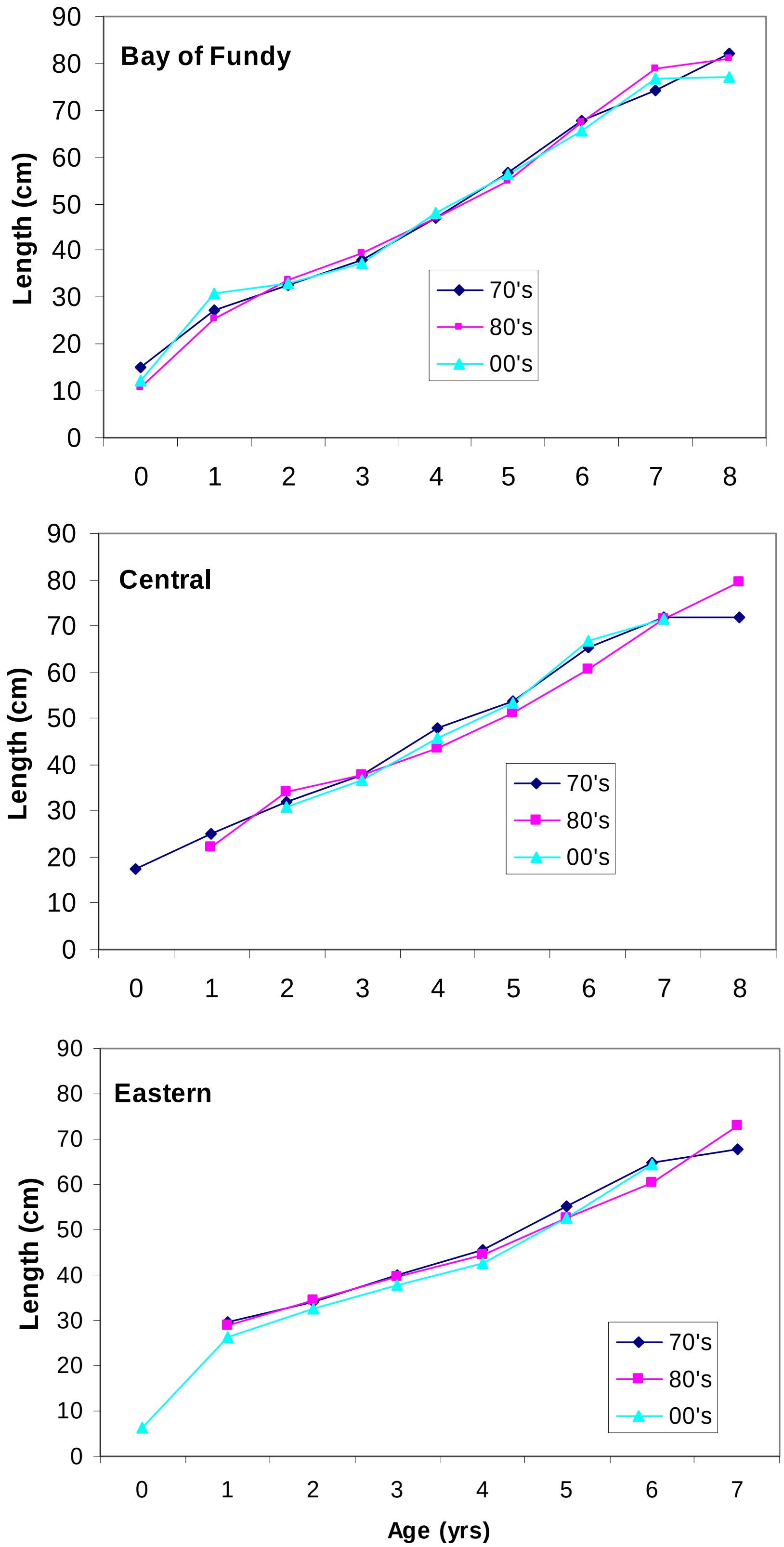


Figure 16. White hake mean length (cm) at age (years) by area

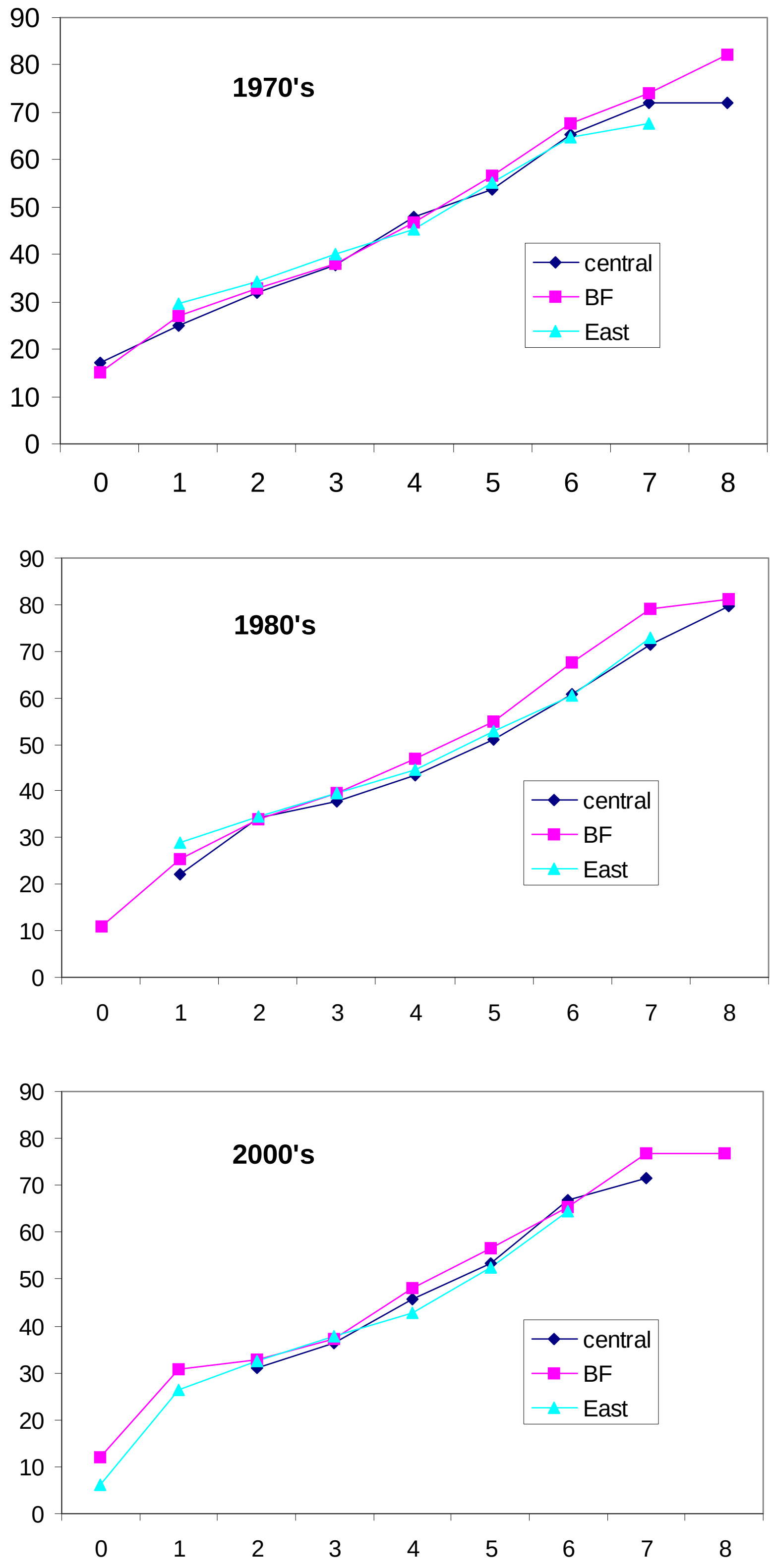


Figure 17. White hake mean length (cm) at age (years) by time period

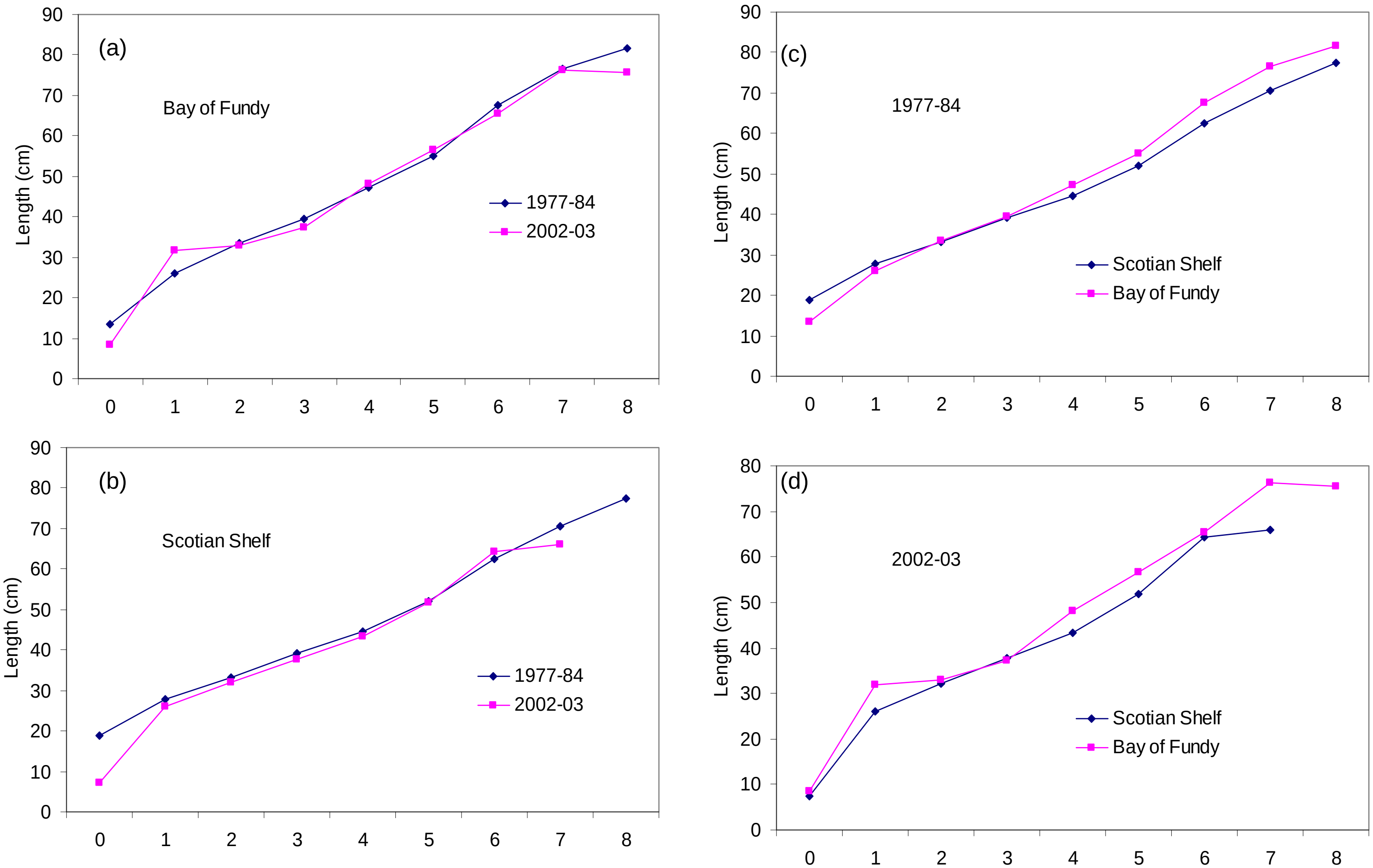
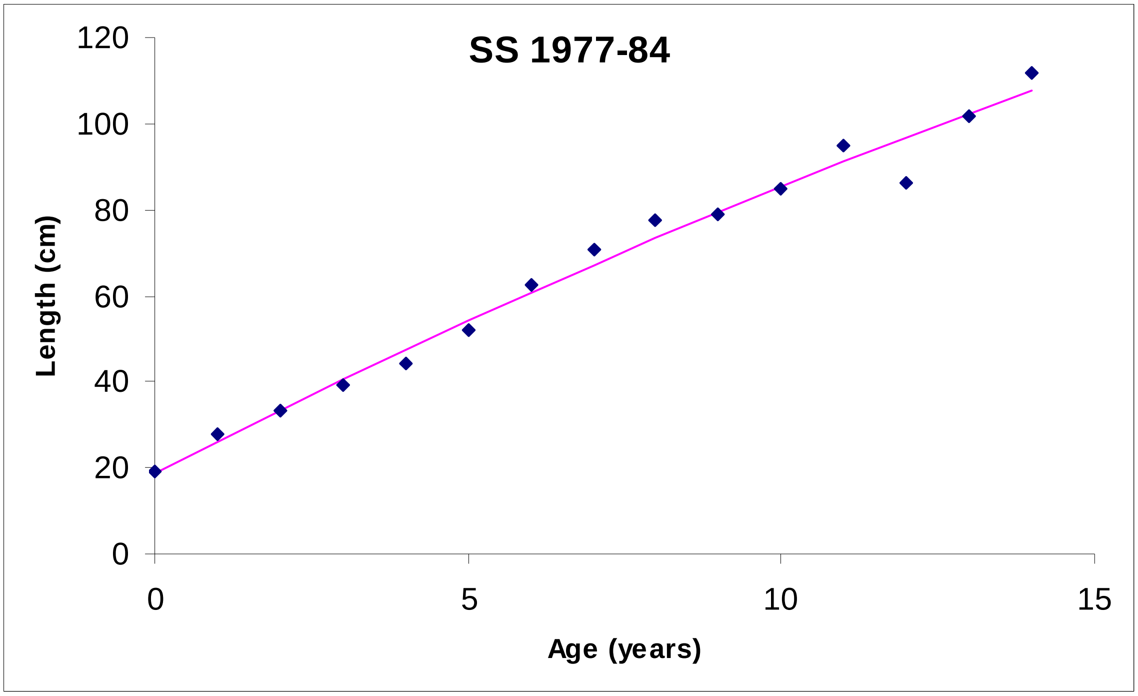


Figure 18. Estimates of mean length at age (years):: (a) Bay of Fundy, (b) Scotian Shelf, (c) Scotian Shelf and Bay of Fundy in the 1970s/1980s and (d) Scotian Shelf and Bay of Fundy in 2002/03.



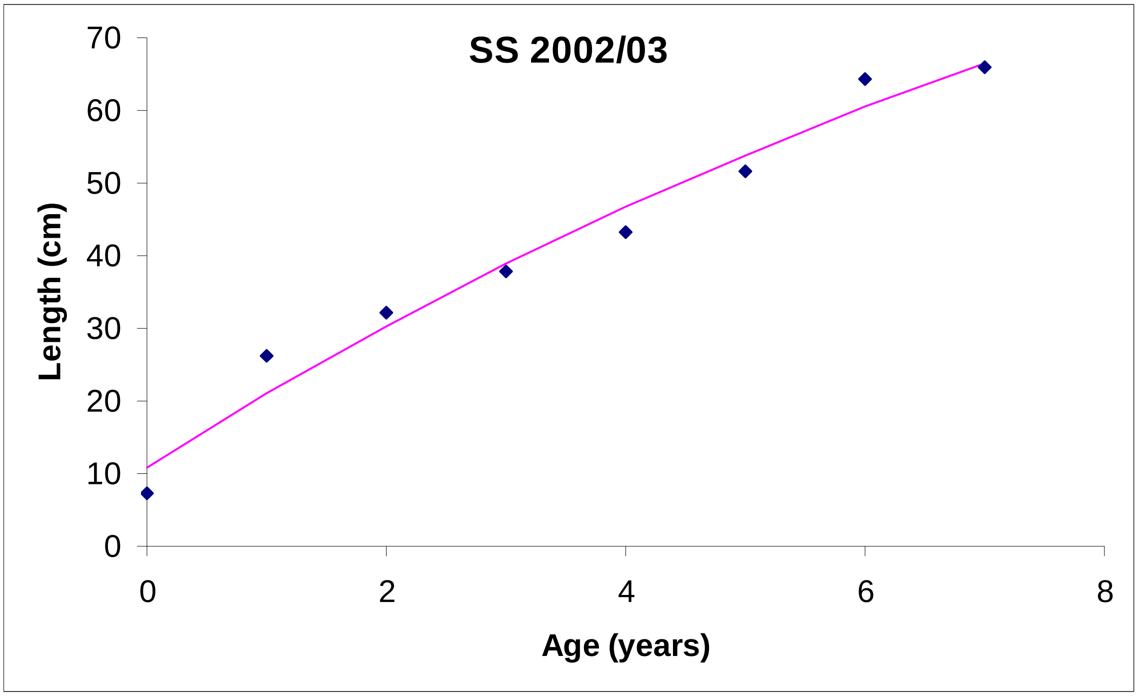


Figure 19. Estimated growth curves for the Scotian Shelf: (a) using a growth curve estimated for the 1970s/80s and (b) using a growth curve estimated for the 2000s. Lines represent the growth curves, points the data.

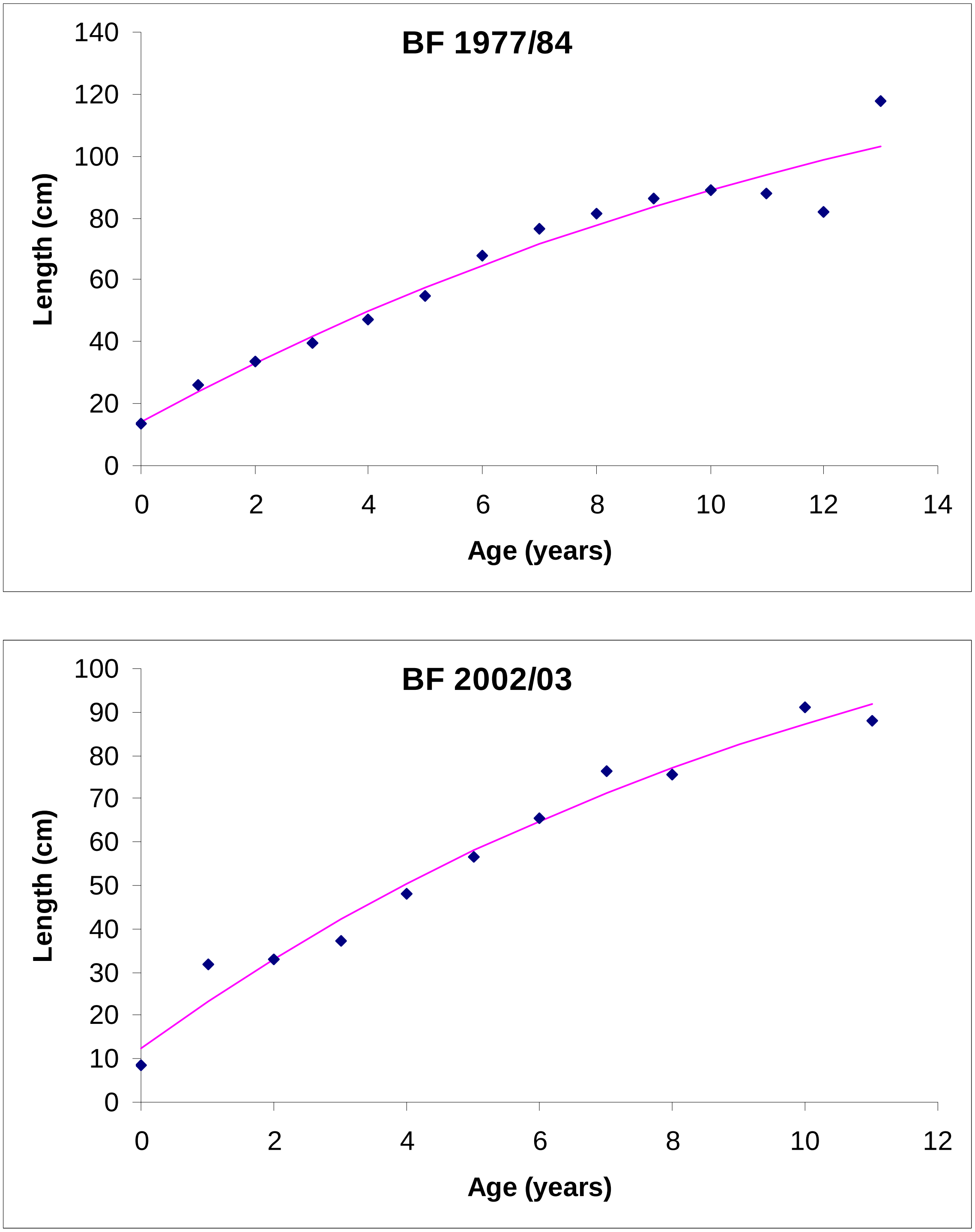


Figure 20. Estimated growth curves for the Bay of Fundy: (a) using a growth curve estimated for the 1970s/80s and (b) using a growth curve estimated for the 2000s. Lines represent the growth curves, points the data.

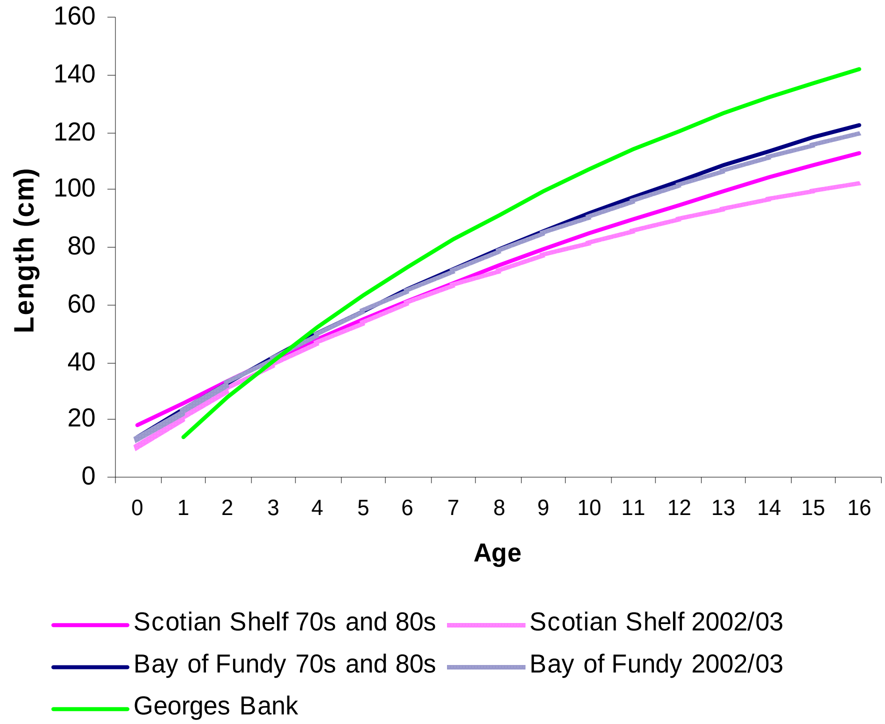


Figure 21. Von Bertalanffy growth curves for the Scotian Shelf, Bay of Fundy and Georges Bank ((K. Sosebee, NMFS, pers. Comm.).

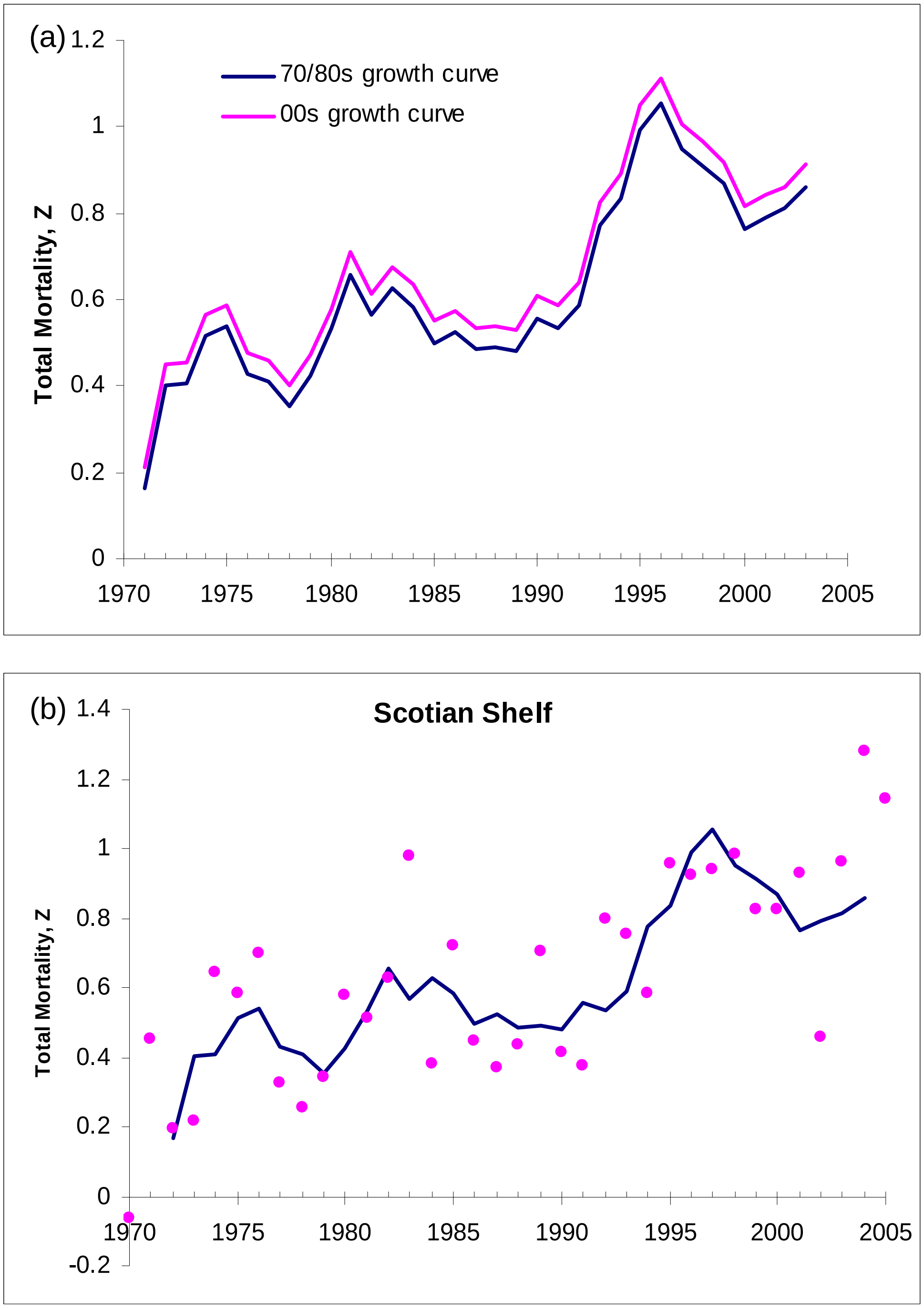
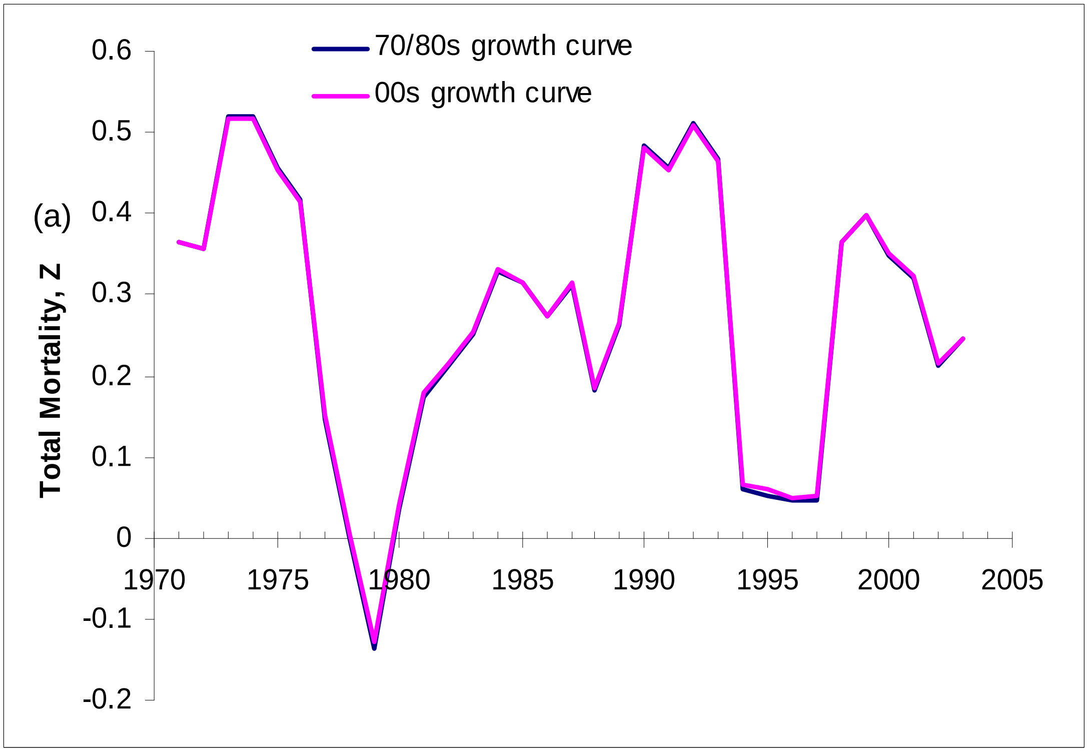


Figure 22. Estimate of annual total mortality of white hake on the Scotian Shelf (strata 440-478) using (a) a 4 year moving window and (b) growth parameters for 1970s/80s, with a 4 year moving window (line) and annual estimates (points).



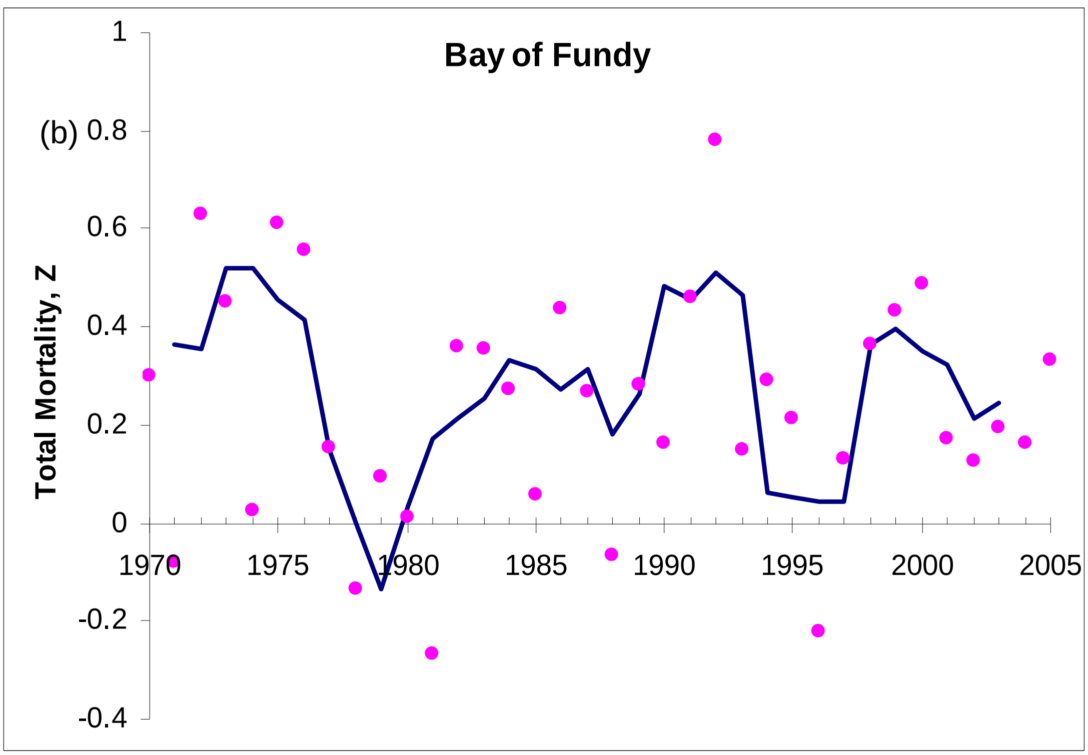


Figure 23. Estimate of annual total mortality of Bay of Fundy white hake (strata 480-495), using (a) a 4 year moving window and (b) growth parameters for 1970s/80s, with a 4 year moving window (line) and annual estimates (points).

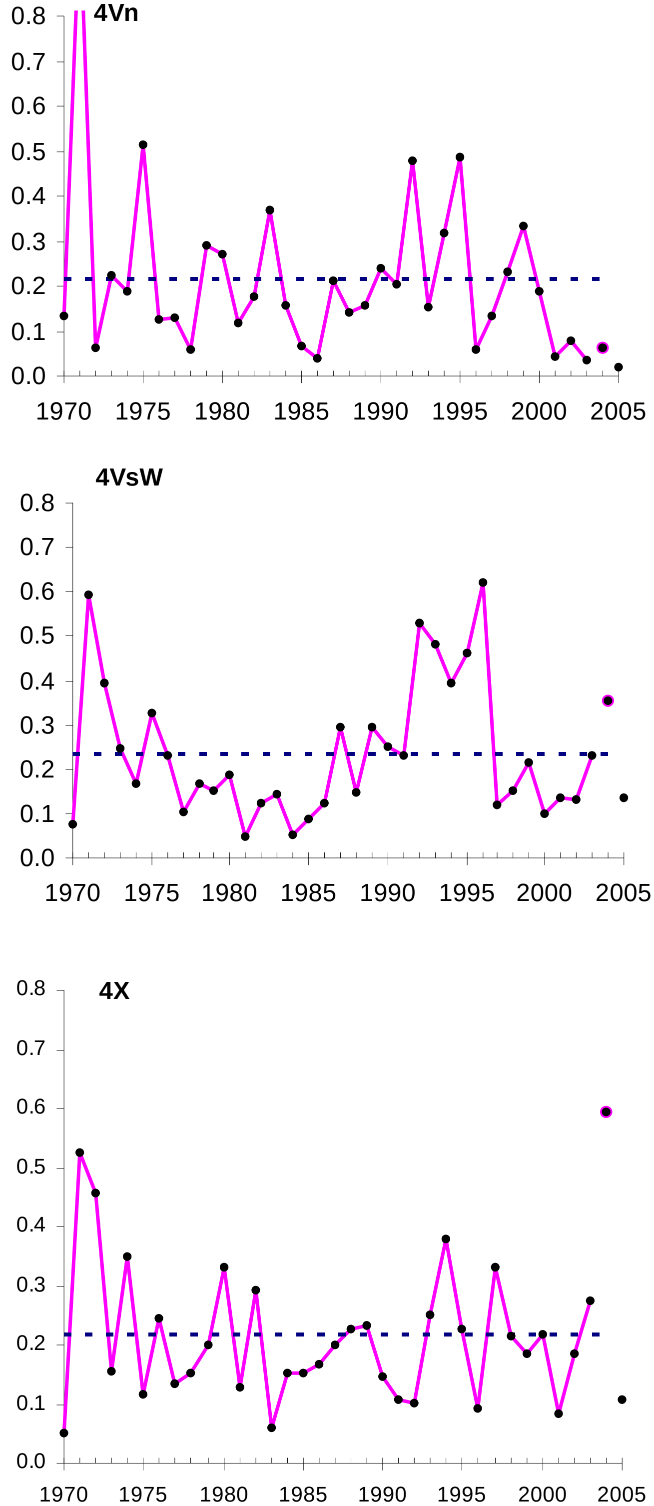


Figure 24. Relative fishing mortality (Catch/Biomass 45+ cm) of white hake in 4Vn, 4VsW and 4X. Dashed line represents the long term mean.

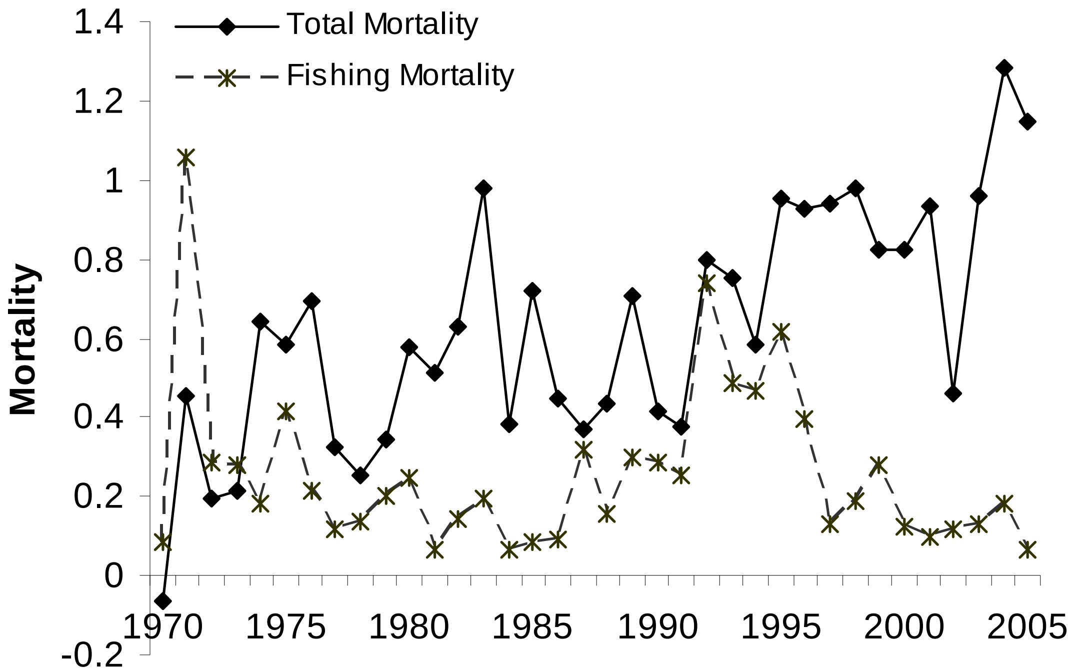


Figure 25. Comparison of total mortality (Scotian Shelf (strata 440-478) and fishing mortality (NAFO Divs. 4VW).

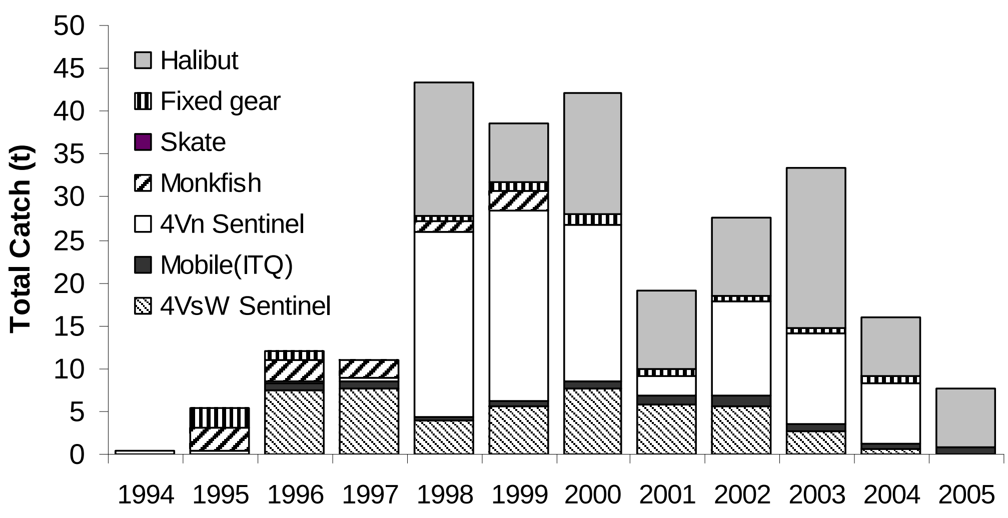


Figure 26. Total Removals of White Hake in 4VWX/5 by Industry Surveys, 1994-2005.

Appendix A

Identification of white hake and red hake on the summer RV survey.

An examination of the catch rates of *Urophycis* (red and white hake) from the summer RV survey revealed potential identification problems (Figure A1). Almost all *Urophycis* identified prior to 1981 were identified as white hake. In 1982 and for the next 2 years, there was a spike in the abundance of red hake. Except for another spike in 1996, red hake abundance has been relatively stable since then. White hake abundance exhibits some year to year variability, but has consistently decreased since a peak in the mid 1980s .

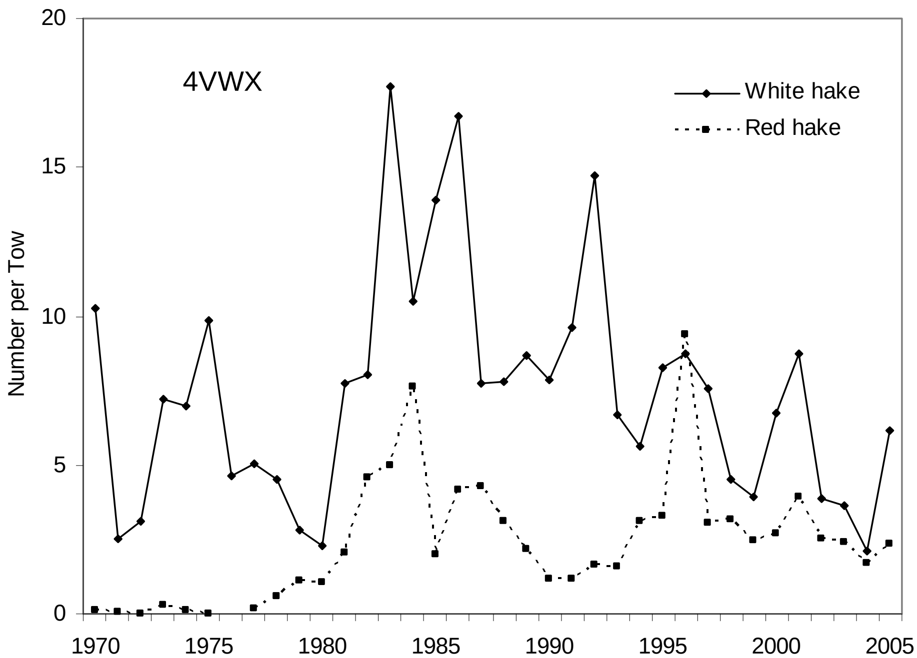


Figure A1. Catch rate (number per tow) of red and white hake from the summer RV survey in NAFO Divisions 4VWX.

To understand the possible reasons for the inconsistencies in the data the identification tools used to separate the two species were examined. The standard fish identification tool when the Summer RV Survey began in 1970 was Leim and Scott's, Fishes of the Atlantic Coast of Canada (1966). Prior to then the most comprehensive identification tool was Bigelow and Schroeder's Fishes of the Gulf of Maine (1953). The two key characteristics that Bigelow and Shroeder used to distinguish between red and white hake were number of scales along the lateral line and the position of the mouth in relation to the eye. The length of the ventral fin was described as an alternate character that was often used to separate the two species, but was felt to be unreliable. In Leim and Scott (1966), *Urophycis* were not separated by species in their gadid key and the text only referred to red hake. Their description indicated that there was uncertainty in whether there was 1 or 2 species and a footnote described possible differences between the two species by some authorities. These differences included scale count, lengths of dorsal and pelvic fins and position of the posterior angle of the mouth.

An internal publication by the Marine Fish Division (Laboratory Reference No. 81/3 by P. Koeller titled Manual for Groundfish Survey Personnel – Cruise Preparation, Conduct and Standing Orders) included a section on misidentified species. For the hakes he used the mouth position, the height of the 1st dorsal fin and the number of gill rakers to separate the two species. Also in 1981, Markle published, as part of the DFO Underwater World series, a pamphlet on red hake. It included a detailed description for separating red and white hake. He used gill rakers and scale counts as the most reliable methods to separate the two species. Markle et al. (1982) reported that maximum length of red hake seldom exceeded 51cm. The summer RV survey has records of red hake greater than 50 cm (maximum length 71cm) many of which are likely misidentified white hake. Since the percentage of red hake greater than 50cm makes up only 0.3% of the total number of hake recorded in the survey they were not considered to significantly affect analyses.

Given the identification tools available there shouldn't have been a problem separating the two species. The only publication that could have caused some confusion was Leim and Scott (1966) and it should have resulted in most of the fish being identified as red hake prior to 1981. The personnel on the early surveys were experienced and there were few changes from year to year. These people began to retire in the mid 1980's and by the mid 1990's they had been replaced by staff hired primarily in the late 1970's and early 1980's. Their at-sea training was primarily from the earlier cohort of employees. Anecdotal information from these staff would suggest that although the gill raker counts were thought to be the most reliable diagnostic, the length of the ventral fin in relation to the vent was used primarily. Secondarily the position of the jaw to the eye was used by some personnel. An unpublished field study conducted by Mark Showell, DFO (pers. comm.) indicated that ventral fin length was 95% accurate when compared to gill raker count and most sea going personnel have used this characteristic in recent years. Although this character is easy to use in the field there appears that many fish have a ventral fin that ends almost exactly at the vent and identification is ambiguous in these cases.

Although the problem of hake identification had been raised previously, it has not been addressed in a systematic way. Since the identification issue might be related to area as well as length, the catch per tow at length was extracted from the Summer RV Survey for both species by strata and length bin. White hake data is usually presented in 3cm bins (ie 32 cm = 31, 32 and 33 cm) and therefore red hake, which are extracted in 1 cm length data, were grouped into similar bins. These data were summarized by species and strata for each year of the survey from 1982 to 2005 for the entire Scotian Shelf and the Bay of Fundy and then a total estimate was calculated for the entire time period. The ratio of red to white hake was then calculated for each stratum where sufficient numbers of each species were present. This ratio was used as a key grouping characteristic. Where there were not enough fish to calculate a reasonable conversion ratio, adjacent strata with similar characteristics were compared and then grouped. For example, in the eastern Scotian Shelf strata (440-452) there were either no red hake (ratio 0) or the total number of red hake to white hake ratio was less than 0.2. Adjacent strata 457 and 458 had ratios of 0.2 and 0.4 respectively. Given their catch ratios each strata would have been dealt with as separate strata except there wasn't enough fish in either one and they were combined with 440-452. Other adjacent strata, 453,454,455,456 and 459 had ratios of 0.9, 3.5, 7.9, 3.1 and 0.8. Strata 454-456 were combined as were strata 463-465. Both groupings were adjacent and had similar ratios, but numbers were sufficient in the two groups to treat them separately. Other strata groupings were 473-477, 480-481,482-484 and 490-495.

Based on the new strata groupings and individual strata, conversion ratios were calculated again for each binned length frequencies. The variability in the individual length bin data made it necessary to take a 3 length bin running mean to smooth the data. The smallest smoothed length bin was applied to lengths that were shorter while lengths greater than 62cm were assumed to be all white hake.

The resulting ratios by individual stratum and strata groupings were plotted by length bins (Figure A2). This should provide some insight into whether there are any additional identification problems related to length and area, or whether one of the species might not be available to the survey at certain length ranges.

It is generally considered that there are very few red hake east of Sable Island. This is evident from the 440-458 strata grouping which peaks at approximately 25% red hake in the 13 and 16 cm length bins. Most other strata groupings show a tendency for red hake to make up greater than 75% of the hake numbers for fish less than 25cm and all fish greater than 53 cm to be white hake. Four strata groups 454-456 (Sable), 463-465 (Western, Emerald), 472 and 480-481 (Browns), had more and larger red hake. These are generally the offshore bank strata and their surrounding strata.

The general absence of small white hake may be due to their availability to the survey or a problem with identification of smaller fish due to morphological changes as the fish grow. The inconsistent application of the identification criteria makes this uncertain. There are a number of publications that indicate that small white hake are found in nearshore areas and as they mature they move offshore.

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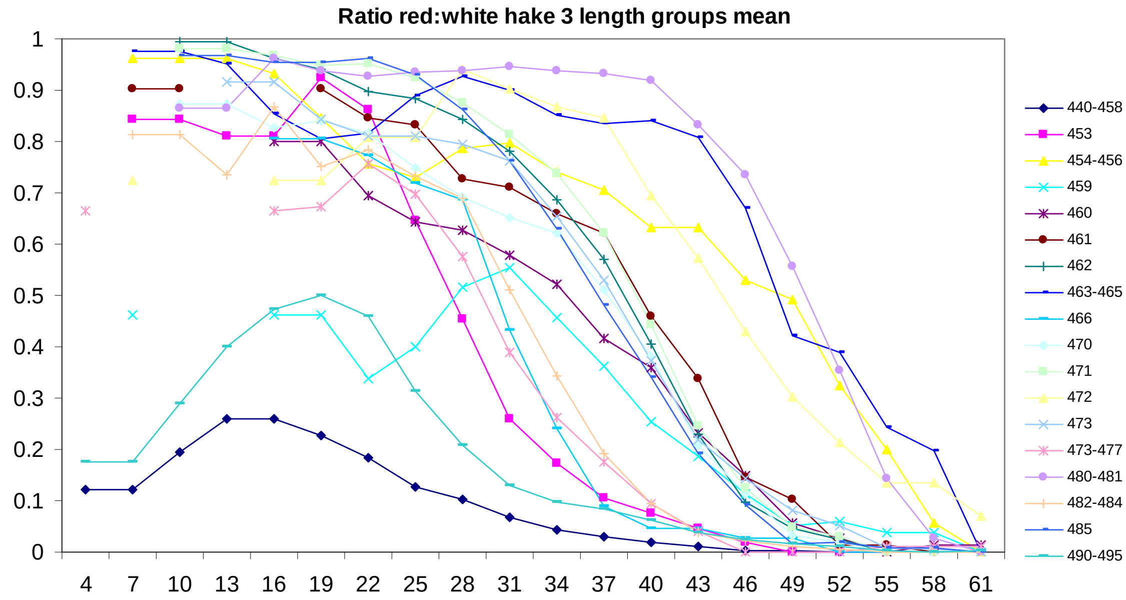

Figure A2. Ratio of red hake to white hake by 3cm length bins for individual strata or strata groupings from the summer RV survey in 4VWX (1982 - 2005).

The conversion ratios generated were applied to the white hake catches of the summer RV survey from 1970-1981 for each length bin and strata, the resulting product being the new red hake catch. The remainder was the new white hake catch. The new red hake catch has then added to the old red hake catch (assuming they were identified properly). For each species the length bins were summed and then weighted by the stratum areas to give new catch rate series for both species prior to 1982.The new red hake catch series generally increased from 1970 to 1981(Figure A3). The white hake catch series for the same time period was reduced only slightly in relation to the rest of the series and does not change the perception that white hake abundance was lower in the 1970's, increased to a peak in the mid 1980's followed by a general decline since then (Figure A3).

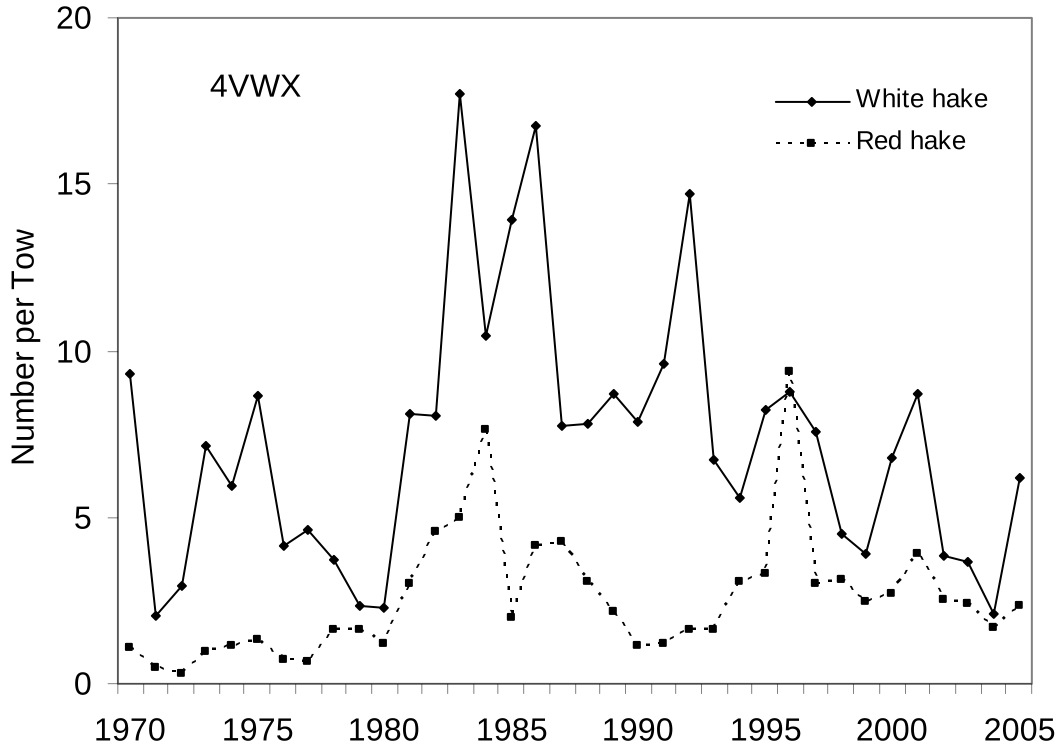

Figure A3. Revised catch rate (number per tow) of red and white hake from the summer RV survey in NAFO Divisions 4VWX.