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Information in Support of Recovery Potential Assessment for White Hake (*Urophycis tenuis*) from the Scotian Shelf (NAFO Divs. 4VWX5z)

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Foreword

This series documents the scientific basis for the evaluation of aquatic resources and ecosystems in Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

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ABSTRACT

The Northwest Atlantic Fisheries Organization (NAFO) Divs. 4VWX5Zc White Hake (*Urophycis tenuis*) population has significantly decreased in abundance since 1982 in spite of low fishing mortality. In NAFO Div. 4X5Zc, juveniles declined by 38% per decade since 1991 and adults by 46% per decade during 1982-2004 after which the abundance remained stable. Total instantaneous mortality is currently estimated at 1.03 for adults, while relative fishing mortality has declined since the 1970s and is currently estimated at 0.09 per year. The abundance is currently just above the proposed biomass recovery target while the proportion of older mature fish in the population is low (6% in 2013). At the current mortality rate, the Spawning Stock Biomass (SSB) has an 84% probability of remaining above the recovery target. Removing fishing mortality from the model does not result in any detectable changes in population trends.

In 4VW, juveniles declined at a rate of 33% per decade between 1982-2013 while adult abundance decreased more abruptly between 1982-1995 (73% per decade), after which the abundance remained stable. Total instantaneous mortality increased since the 1970s and is currently estimated at 1.6. Relative fishing mortality decreased during the same period. The population is currently below the proposed recovery target and with a low proportion of older mature fish (3%). At the current mortality rate and mean observed recruitment, SSB is predicted to increase above the recovery target; however, there is a 34% probability of being below the recovery target. If recruitment were to remain as low as the last three years and with the current mortality rate, there is a 63% probability that SSB would remain below the recovery target.

Both an increase in Grey Seal abundance and a decrease in Atlantic Herring may have contributed to higher mortality. For Divs. 4VW, adult abundance is below its recovery target; however, consequences of current fishing rates on population projections (relative to its recovery target) do not differ from conditions when F = 0.

Information à l'appui de l'évaluation du potentiel de rétablissement de la population de merluche blanche (*Urophycis tenuis*) du plateau néo-écossais (division 4VWX5z de l'OPANO)

RÉSUMÉ

La population de merluche blanche (*Urophycis tenuis*) qui vit dans la division 4VWX5Zc de l'Organisation des pêches de l'Atlantique Nord-Ouest (OPANO) a considérablement diminué depuis 1982, malgré une faible mortalité par pêche. Dans la division 4X5Zc, le nombre de juvéniles a diminué de 38 % par décennie depuis 1991, et celui d'adultes a diminué de 46 % par décennie entre 1982 et 2004, après quoi l'abondance est demeurée stable. La mortalité instantanée totale est actuellement estimée à 1,03 pour les adultes, tandis que la mortalité par pêche relative a diminué depuis les années 1970 et est actuellement estimée à 0,09 par année. L'abondance se situe actuellement juste au-dessus de l'objectif de rétablissement de la biomasse proposé, tandis que la proportion de poissons matures plus âgés dans la population est faible (6 % en 2013). Selon le taux actuel de mortalité, il y a 84 % de probabilité que la biomasse du stock reproducteur (BSR) reste inférieure à l'objectif de rétablissement. Le fait de retirer la mortalité par pêche du modèle ne donne pas lieu à des changements perceptibles dans les tendances de la population.

Dans la division 4VW, le nombre de juvéniles a diminué à un taux de 33 % par décennie entre 1982 et 2013, tandis que l'abondance des adultes a dangereusement diminué entre 1982 et 1995 (73 % par décennie), après quoi l'abondance est demeurée stable. La mortalité instantanée totale a augmenté depuis les années 1970 et elle est actuellement estimée à 1,6. La mortalité par pêche relative a diminué au cours de la même période. La population est actuellement inférieure à l'objectif de rétablissement proposé et comprend une faible proportion de poissons matures plus âgés (3 %). Selon le taux actuel de mortalité et le recrutement moyen observé, la BSR devrait augmenter au-delà de l'objectif de rétablissement; toutefois, il y a 34 % de probabilité qu'il se situe en dessous de l'objectif de rétablissement. Si le recrutement demeure aussi faible qu'au cours des trois dernières années et selon le taux de mortalité actuel, il y a 63 % de probabilité que la BSR demeure inférieure à l'objectif de rétablissement.

Une augmentation de l'abondance du phoque gris et une diminution de la population de hareng de l'Atlantique pourraient avoir contribué à l'augmentation du taux de mortalité. Dans la division 4VW, l'abondance des adultes est inférieure à l'objectif de rétablissement. Toutefois, les conséquences des taux actuels de pêche sur les prévisions concernant la population (par rapport à l'objectif de rétablissement) ne diffèrent pas de celles dans des conditions où F = 0.

INTRODUCTION

White Hake (*Urophycis tenuis*) are caught in all groundfish fisheries in the Northwest Atlantic Fisheries Organization (NAFO) Divisions (Divs.) 4VW and Divs. 4X5Zc, and landings in 2013 were 128 t and 520 t, respectively; less than 10% of peak landings reported in the 1980s (Figure 1). The majority of White Hake landings were taken by fixed gear (Figure 2; Appendix Table A1). A Total Allowable Catch (TAC) was first introduced in 1996 and since 1999 fisheries have been limited to White Hake bycatch only, with quota caps to restrict landings. The cap for the Divs. 4X5Zc management unit varied annually, but was reduced to 650 t in 2013.

Catch and abundance were at their highest in the 1980s but the rapid decline observed in the last 20 years has raised concern about the status of the species in Atlantic Canada. The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) (2013) identified two Designatable Units (DUs) for White Hake in eastern Canada as DU 1, the Southern Gulf of St. Lawrence, and DU 2, Atlantic and Northern Gulf of St. Lawrence. Based on historic and recent data (Simon and Cook 2013), COSEWIC assessed the Atlantic and Northern Gulf of St. Lawrence population as threatened due to a decline in abundance (COSEWIC 2013).

This document provides supporting data and analyses for the Recovery Potential Assessment (RPA) of the Atlantic and Northern Gulf of St. Lawrence population. Data and analyses are specific to the Eastern Scotian Shelf (NAFO Divs. 4VW) and the Western Scotian Shelf, Bay of Fundy and northern Georges Bank (NAFO Divs. 4X5Zc; Figure 3). White Hake from these two areas are treated as separate management units. Recovery Targets (RTs) are proposed and projections under four scenarios are presented to assess probabilities of recovery.

METHODS

TRENDS IN ABUNDANCE

Fisheries and Oceans Canada (DFO) Summer Research Vessel (RV) survey-based abundances were used to compare average abundances per decade, and derive linear trends for the entire period of sampling (1970-2013) and beginning in 1982 corresponding to the most recent period of high abundance. Trends in abundance were calculated for two size groups: juveniles (<42 cm) and adults (42+ cm) and examined using the natural logarithm of abundance (N):

$$\text{Log}_e(N) = a + b * \text{Year}$$

The percent change per decade is calculated as 100 * (exp(*b**10)-1) with b the slope of the relationship above.

The rate of change was not linear after 1981 for several of the indices. A “piecewise” regression was performed to test for and identify a break point using the R Package “Segmented” (Muggeo 2008). When a break point was identified, separate slopes and percent changes over the time period were calculated.

TRENDS IN WEIGHT AT AGE

To be consistent with earlier surveys and with the protocols followed for collecting otoliths to develop age-length keys, White Hake were grouped into 3 cm fork-length size classes, i.e. 43 cm means 42-44 cm fish. The weights at length for fish of nine length classes (43-67 cm) were examined for changes in body condition. The analyses included only years with age samples. For readability, figures present results for every second class (5 classes).

MORTALITY

Total mortality (Z) was calculated from:

- survey catch at age curves (ln of abundance at age where the slope of the regression equals Z, and
- analysis of covariance using cohort as a class (Sinclair 2001) with
  ln(N) = *a* *cohort + *b**age + c

where *b* is a common slope for all ages and a gives the intercepts for each cohort. Given the lack of data for ages 8 and older in 4VW in recent years, only ages 5-7 were used in both analyses (Appendix Table A4). The samples used were the years for which survey-based age-length keys (ALKs) were available (i.e. 1978-1979, 1983-1984, 2002-2013). Commercial catch age-length keys were applied to 4X5Zc length frequencies from the survey for 1998-2001 and 2004.

The relative F was calculated as the ratio of the commercial catch (t) to the estimated trawlable biomass from the survey (t) (a minimum estimate of the population size as it assumes a catchability of one for all sizes of White Hake).

POPULATION STRUCTURE

A formal age-structured assessment was not possible given the short time series of commercial catch (Appendix Table A2) and survey (Appendix Tables A3 and A4) data for which there was age information. Thus, there was no estimate of catchability at age (q) or partial recruitment to the fishery. Partial recruitment was taken from the Gulf of St. Lawrence assessment (D. Swain, DFO, Moncton, pers. comm.) but catchability was deemed not transferable from the southern Gulf due to the tradeoff of the catchability parameter estimate with the estimated natural mortality. The abundances at ages 2-4 were approximated using the following steps:

- Assuming that fish of age 5 and older were fully recruited to the survey trawl, and using a constant mortality, numbers at age were back-calculated from age 5 to age 2 (named "B2 wZ"). In 4X, juvenile mortality was set at 0.5, similar to that estimated in 4T in the 1970s (D. Swain, DFO, Moncton, pers. comm.). This gives numbers of fish of ages 2-4 that are higher than that of the survey-based abundances. In 4VW, Z was increased to 1.0 to generate higher abundances than in the survey, and these are likely to be a minimum estimate. This resulting population biomass did not closely follow the survey trends and relied too directly on the assumption of a constant mortality rate (Appendix Figure A1).
- The ratios of estimated abundances (B2 wZ) to the numbers caught in the survey was averaged by age for all observed years (i.e. 1998-2010; when age data available). The ratios calculated for ages 2, 3 and 4, respectively, were: 6.91, 5.35, and 2.37 for 4X, and 8.11, 2.7 and 1.03 for 4VW. The numbers at age were obtained by multiplying the numbers caught in the survey by the age-specific ratio. This estimated biomass (named "B2 w proportion") followed the trends from the survey, and did not change the relative numbers of age 2 (used as recruitment index) (Appendix Figure A1).

This method is reasonable to provide a minimum number of younger fish not fully recruited to the trawl but it assumes that older fish are deemed fully catchable by the gear. These raised biomass and age structure were used in the projections.

PROPOSED BIOMASS RECOVERY TARGETS

The proposed biomass recovery targets are consistent with guidelines for reference points as described in DFO (2009). The biomass recovery target (RT) was set at a value of 40% B_{msy}. B_{msy} was estimated as the geometric mean of the index of trawlable biomass for mature White Hake from the survey during a productive period defined as 1970-1998 for the 4X5Zc management unit and 1970-1991 for the 4VW management unit. The three-year geometric mean of mature survey biomass index is used to determine status relative to the recovery target. Average length at maturity for White Hake in 4VWX5Zc was determined using all maturity data collected during the survey time series (1970-2014), a total of 19,140 observations.

PROJECTIONS

Projections were performed using a Thompson and Bell yield-per-recruit model. Probabilistic projections were carried out by adding uncertainty to recruitment, weight at age, and total mortality (Tables 1 and 2). Recruitment uncertainty was generated by resampling all observed years for recruitment using the whole time series in 4X, and the time series minus year 1983 (an exceptionally high recruitment) in 4VW. Weight at age and total mortality deviates were obtained from a normal distribution using the standard deviation of annual estimates of mean weight at age in the last seven years, and the standard deviation of the covariance-based estimate of Z. Fishing mortality was assumed to be negligible and included in total mortality in 4VW. Projections were carried out with four scenarios of mortality (Table 3):

1. current mortality (Z) and fishing rate (in 4X5Zc);
2. in 4X, removal of fishing mortality and in 4VW, current mortality and recruitment of the last three years instead of the average of the whole time series (minus year 1983);
3. mortality rate that would result in increasing Spawning Stock Biomass (SSB) close (+/- 10%) to B_{msy}; and
4. mortality rate that would result in increasing the proportion of older adults (6+/3+) to the proportion observed during the productive period (+/- 10%). Given the restriction in age samples available during the productive periods, 6+/3+ averages are limited to four years of samples in 4VW and five years in 4X5Zc (Tables 1 and 2).

All scenarios were run a 1000 times. The levels of SSB were described relative to the proposed recovery targets, and the probability that SSB would be below the recovery target. The projected proportions of older adults were compared to the proportion observed during the productive period.

RESULTS

LENGTH AT MATURITY

Length-at-maturity, defined as the length at which the percentage mature exceeds 50%, was estimated as 42 cm for White Hake in 4VWX5Zc (Figure 4). Mature biomass was then calculated by summing over length the product of the numbers at length for hake ≥ 42cm and the predicted weight at length (from a von Bertalanffy growth curve).

Trends in Biomass

Biomass indices for all sizes of White Hake from this survey of Divs. 4VW and Divs. 4X5Zc are shown in Figure 5. For both management units, biomass was relatively low in the 1970s, peaked in the mid=1980s, and then declined to levels near those observed in the 1970s.

4X5ZC MANAGEMENT UNIT

Trends in Abundance

The survey estimated abundance varies widely within decades. The total abundance of White Hake peaked in the 1980s (Figure 6, Appendix Table A5). The abundance of adults (≥ 42 cm) decreased from 13 million in the 1980s to 5 million in recent years, a level slightly lower than in the 1970s (average = 8.4 million). Juveniles were the most abundant in the 1980s and 1990s (average = 8 to 9 million) and their numbers declined in the last decade to 4.7 million, and lower than that of the 1970s (average = 6 million).

The log-linear decline in both juvenile and adult abundances were not statistically significant ($p > 0.05$) over the series beginning in 1970 but the declines were statistically significant ($p \leq 0.05$) since 1982. The regression by segments identified a break point in 1991 for juveniles and a statistically significant decline of 38% per decade during 1991 to 2013 (Figure 7). The decline for adults was significant for years 1982 to 2004 (47% per decade) after which abundance remains about stable (Figure 7). No break point was identified for the total population abundance with a statistically significant decline over the period 1982-2013 of 31% per decade.

Trends in Weight

There was no statistically significant temporal change in body weight during the study period for the nine length groups considered (Figure 8). Given the low sample numbers for large fish, the standard error was large in some years and sizes. Note that the measurements of condition were taken in July, after the spawning season and thus, would likely not be informative of the condition at the crucial pre-spawning period.

Mortality

Total mortality increased over time, from an average value of 0.54 in 1977-1978 to 1.12 in 1983-1984 and 0.99 (0.43 to 1.36) since 1998, but the trend is not statistically significant ($p > 0.05$; Figure 9, Appendix Table A6) because of the high mortality in the 1980s. The average mortality estimated with the analysis of covariance using cohorts 1992-2007 was estimated at 1.03 (Standard Deviation (std) = 0.12, adjusted $R^2 = 0.65$, $p < 0.001$). The latter estimate was used in the projections.

In contrast, relative F decreased significantly during the study period and was estimated at 0.12 (an overestimate, see the next section) in the last five years, corresponding to an average catch of 1,273 t (Figure 10).

Population Structure and Recovery Targets

The raised abundances at age 2+ provides an estimate of relative F = 0.09 for the last five years.

Estimated recruitment at age 2 ranged between 2 million and 29 million during the study period and years available, with an average of 14.5 million fish (Figure 11). There is no trend in recruitment over time or across SSB estimates suggesting apparent independence of recruitment from SSB (Figure 11). Fish older than 7 years old were virtually absent in the 2000s compared to the 1970s and 1980s (Figure 12). The proportion of older fish was 16% between 1977 and 1998 (n = 5) compared to 11% in the last 5 years and 6% in 2013.

Based on survey data, B_{msy} is estimated at 17,167 t and the biomass recovery target (40% of B_{msy}) is 6,867 t. Mature biomass fell below the recovery target from 2004 – 2008 but has remained above the recovery target since (Figure 13).

Projections

At current total mortality rates (Z = 1.03), SSB is predicted to remain above the recovery target with a probability of 84% (Figure 14). The removal of fishing (Z = 0.94) does not modify the projections and the probability of remaining above the recovery target. The proportion of older adults would remain at 6% (4-10%), lower than the target (16%). A reduction in total mortality to 0.7 (which includes current fishing mortality rate), would lead to an increase in SSB to 18,800 t (2,500-39,800 t), slightly above B_{msy} and an increase in the probability of remaining above the recovery target (90%; Figure 14). The proportion of older adults would increase to 13%. Decreasing Z to 0.6 would result in a proportion of older adults that slightly exceeds the target (18%) while biomass is predicted to increase to 23,180 t (95% Confidence Interval (C.I.) 3,133 - 50,809 t) and the probability of remaining above the recovery target was estimated at 90%. Biomass predictions are accompanied with increasingly large uncertainties as Z decreases. As SSB increases, current fishing mortality would result in larger catches of 1,800-2,800 t.

The stability of the results over time is due to the relatively large recruitment that was observed in the last decades in spite of lower SSB. The increase in biomass at the 1980s level could result in a lower recruitment rate, a factor that has not been taken into account here.

4VW MANAGEMENT UNIT

Trends in Abundance

The abundance of 4VW White Hake peaked in the 1980s (Figure 6, Appendix Table A5). The abundance of juveniles has decreased since the 1980s from 15.5 million to 6.6 million, but remained above the 1970s levels (5.5 million). Adults have decreased to a very low level since the 1990s remaining below 1.9 million compared to that of the 1970s. The apparent good recruitment of the mid-1990s did not result in a subsequent increase in adult abundance (Figure 6).

There is a statistically significant linear decreasing trend for juveniles (≤ 42 cm) since 1982 ($p < 0.001$, $R^2 = 0.46$, Figure 7) at a rate of 33% per decade. The percentage of variation explained is low due to high inter-annual variation, notably in 2012-2013 which is what the piece-wise regression identified. Adult declining trends are significant in both time periods (1970-2013 and 1982-2013); however, the piecewise regression reveals that the decline was accentuated between 1982 and 1995 (73% per decade), after which the abundance remained stable (Figure 7). Similarly, the decline in total abundance is more important between 1982 and 1991 (63% per decade) than in the following years (28% per decade).

Trends in Weight

There were no statistically significant trends in body weight during the study period for 8 of the 9 length groups considered, the exception being a declining trend for the 43 cm length class (Figure 15). Given the low sample numbers for large fish, the standard error was large or not estimable (n = 1) in larger size classes. The measurements of condition were taken in July, after spawning season and thus, would not be informative of the condition at the crucial pre-spawning period.

Mortality

Based on annual catch curves, total mortality increased significantly over time from an average value of 1.25 in 1977-1978 to 0.97 in 1983-1984 and 1.77 (1.04-2.41) since 2002 ($p < 0.05$; Figure 16; Appendix Table A6). The average instantaneous mortality based on the analysis of covariance using cohorts 1992-2007 was estimated at 1.6 (std = 0.19; adjusted $R^2 = 0.76$; $p < 0.001$). The latter estimate was used in the projections.

In contrast, relative F decreased significantly during the same period and is estimated at 0.03 in the last 5 years, based on annual catches that averaged 118 t (Figure 17).

Population Structure and Recovery Targets

The raised 4VW population estimate was used in subsequent analyses, giving a relative F value of 0.01 instead of the value of 0.03 previously mentioned using survey biomass. The average recruitment at age 2 was estimated at 29.2 million fish but only at 20.2 million in the 2000s, the difference mainly attributed to the very large 1983 recruitment (Figure 17). Note that abundances at age 2 were low in 2012 and 2013, at 33% and 40% of the average while 1977 was the lowest estimated recruitment year.

There is no trend in estimated recruitment at age 2 over time or relative to SSB (2 years prior to recruitment year) suggesting that recruitment has been independent of SSB (Figure 18). The inverse relationship of the recruitment rate ($\log_e$(recruitment at age 2 / SSB)) with SSB is not statistically significant due to the paucity of observations at high SSB values (Figure 18; $p > 0.05$). Fish older than 7 years old have been virtually absent in the 2000s compared to the 1970s and 1980s (Figure 19). The proportion of older fish (6+/3+) was 13% between 1977 and 1998 (n = 4) compared to 2% in the last five years and 3% in 2013.

Based on survey data, B_{msy} is estimated at 9,711 t and the biomass recovery target (40% of B_{msy}) is 3,885 t. Mature biomass fell below the recovery target in 2003 and has remained below since then (Figure 20).

Projections 4VW

At the current estimated total mortality rate (Z = 1.6), SSB is predicted to increase to 4,973 t, slightly higher than the recovery target (3,885 t) but with a 34% probability of being below the recovery target (Figure 21). The proportion of older adult fish would decrease to 1% compared to the recent 2%. A reduction in total mortality to 0.7 would result in SSB increasing to 9,756 t (95% C.I. 2,900 - 22,400 t), close to B_{msy}, and with a lower probability (8%) of being below the recovery target (Figure 21). The proportion of older adults would increase to 11%, while a reduction in Z to 0.6 would increase the proportion of older adults to 15%. The increase in biomass predicted in the preceding scenarios results from the large mean recruitment assumed in the projections. However, if the recruitment remained at the current low value (approximately 13.3 million for the last 3 years) and at the current mortality rate (Z = 1.6), SSB is predicted to remain below the recovery target, 63% probability of being below target (scenario lowR, Figure 21). Eliminating fishing at estimated current rate of F = 0.01 would not alter the trends of the projections.

ECOSYSTEM CONSIDERATIONS

The increase in adult mortality could be attributed to several factors including increased predation, decreased prey abundance, the presence of contaminants, or disease.

PREDATION

White Hake was found in small proportions in the diets of 13 fish species covered by scientific surveys (less than 0.3% to 2.7%) (Simon and Cook 2013). In addition, most of these fish species (except Atlantic Halibut) have decreased in abundance since the 1970s (DFO 2013a). Predation by Grey Seals, however, has been proposed as the cause of higher mortality for Atlantic Cod, Winter Skate, and White Hake in the Gulf of St. Lawrence (Benoît et al. 2011a, Benoît et al. 2011b, Swain et al. 2011) and Atlantic Cod on the Eastern Scotian shelf (Mohn and Bowen 1996). Available data, however, are not conclusive on the role that seal predation plays in increased natural mortality for White Hake in 4VW or 4X5Zc.

PREY DECLINE

Atlantic Herring constitute an important prey for adult White Hake, along with unidentified fish, gadidae and Silver Hake (Simon and Cook 2013). In 4X, Atlantic Herring biomass has declined by more than half since the 1970s (Clark et al. 2012) and some spawning aggregations have virtually disappeared over the last 30 years (Clark et al. 1998).

In 4VW, the level of Atlantic Herring biomass is considered to be low. Herring schools and whales, known for being associated in these waters, could not be located during aerial surveys in the 1992-1993 winter months (Stephenson et al. 1993). Difficulties in tracking herring schools on the Eastern Shore and more specifically in Chedabucto Bay during winter from both surveys and the commercial fishery led to the hypothesis that herring distribution and migration routes had changed since 1991 (Stephenson et al. 1993). Acoustic surveys showed a 50% decrease in herring biomass in 2007 for 4W (Halifax/Eastern Shore) followed by an increase between 2008 and 2010.

Biomass estimates from acoustic surveys of the coastal Nova Scotia spawning components in 2011 and 2012 indicated that there were continued decreases in spawning stock biomass for Little Hope and Halifax/Eastern Shore areas, while Glace Bay again showed virtually no fish in the one survey completed in 2011 (DFO 2013b).

Assuming that commercial catches can be used as a proxy for an index of abundance, Atlantic Herring biomass in the region has declined in the last 20 years (Figure 22). Catches declined from around 26,000 t in the 1970s to around 10,000 t in the late 1980s to none since 2001. The last catch from Chedabucto Bay was taken in 1999.

It is possible that a decline in Atlantic Herring as suggested by surveys and decreasing catches, contributed to the decline in adult White Hake in both 4X5Zc and 4VW. The decline in Herring would be expected to result in a decline in body condition but this was not observed for White Hake. However, sampling for White Hake condition occurs during the summer survey in July and it is unlikely to reveal a decline in body condition that would be most important in the winter months or just before spawning time in June.

CONTAMINANTS AND DISEASES

Available data, although very limited, does not support pollutants and diseases as a major cause of mortality in adult White Hake.

Dedicated surveys searching for bacterial and viral parasites (linked to aquaculture sites) in 4VWX between 2000 and 2008 examined 164 specimens of White Hake, 1 of 19 species collected, and few cases of infections were noted (Swain et al. 2011). Surveys of fish for other signs of contamination and disease, between 1998 and 2000, have shown few cases of contamination (Swain et al. 2011). Based on this limited data, and the comparison with European contamination levels leads to the conclusion that contamination is likely not the cause of the large increase in mortality in marine fish in the Gulf of St. Lawrence (Swain et al. 2011). Nevertheless, it should be noted that very few of the 65,000-75,000 substances in commercial use today are routinely monitored in commercial species (Robinson and Pederson 2005) and that the current state of knowledge does not always allow for discerning the respective effect of pollutants from other environmental stresses (Thurberg and Gould 2005).

SUMMARY

White Hake in NAFO Divs. 4VWX5Zc has significantly decreased in abundance since 1982 in spite of low fishing mortality.

In Divs. 4X5Zc, juveniles declined by 38% per decade since 1991 and adults by 46% per decade during years 1982-2004 after which abundance has remained stable. Total instantaneous mortality is currently estimated at 1.03 for adults while relative fishing mortality has decreased since the 1970s and is currently estimated at 0.09 per year. The abundance is currently just above the proposed recovery target (6,867 t). At the current mortality rate, the model projections are that the SSB would have an 84% probability of being over the biomass recovery target. At a lower mortality rate of 0.7, SSB would reach B_{msy} (17,167 t). Setting fishing mortality to zero in the projections does not result in any changes in abundance or age structure trajectories.

In Divs. 4VW, White Hake juveniles declined at a rate of 33% per decade between 1982-2013 while adult abundance decreased more abruptly between 1982-1995 (73% per decade), after which the abundance remained stable. Instantaneous mortality has increased significantly since the 1970s and is currently estimated at 1.6. Relative fishing mortality decreased during the same period. The population currently has a truncated age structure and the ratio of 6+ abundance to 3+ abundance = 3%. At the current mortality rate and the mean estimated recruitment at age 2, SSB is predicted to increase above the proposed biomass recovery target of 3,884 t but with a 34% probability of being below the recovery target. A lower mortality of 0.7 would result in an increase in projected biomass close to B_{msy} (9,711 t). If recruitment were to remain as low as that estimated for the most recent three years, under the current mortality rate, SSB is projected to have a 63% probability of being below the biomass recovery target.

Herring, an important prey for White Hake, has declined in both areas. Both the increase in grey seal abundance and the decrease in herring may have contributed to the high estimated mortality. However, the paucity of data precludes determining the exact causes at this time. As fishing mortality is very small, a further decrease in fishing pressure alone is unlikely to increase the probability of recovery of White Hake.

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TABLES

Table 1. Parameters used for projections for the NAFO Div. 4X5Zc management unit. M is natural mortality, waa is weight at age, std is standard deviation, pr is partial recruitment to the fishery.

Parameter	Recovery Targets	Ages 2	3	4	5	6	7	8	9	10	11	12+
B_{msy} (t)	17,167											
Recovery Target (t)	6867											
maturity		0	0.5	1	1	1	1	1	1	1	1	1
M		0.5	0.5	0.5	1.03	1.03	1.03	1.03	1.03	1.03	1.03	1.03
std M		0.06	0.06	0.06	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
waa (kg)		0.30	0.50	0.81	1.41	2.34	3.44	4.55	4.75	8.45	8.30	8.30
std waa		0.135	0.240	0.095	0.085	0.269	0.557	1.528	2.106	4.873	3.320	3.320
pr		0.00014	0.003	0.036	0.319	1	1	1	1	1	1	1

Table 2. Parameters used for projections for the NAFO Divs. 4VW management unit. M is natural mortality, waa is weight at age, std is standard deviation, pr is partial recruitment to the fishery.

Parameter	Recovery Targets	Ages 2	3	4	5	6	7	8	9	10	11	12+
B_{msy} (t)	9,711											
Recovery Target (t)	3,885											
maturity		0	0.5	1	1	1	1	1	1	1	1	1
M		1.0	1.0	1.0	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
std M		0.1	0.1	0.1	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
waa (kg)		0.28	0.47	0.69	1.24	2.01	2.88	3.19	3.86	4.37	6.81	6.81
std waa		0.052	0.063	0.080	0.149	0.371	0.609	0.877	0.293	2.026	1.565	1.565
pr		0.00014	0.003	0.036	0.319	1	1	1	1	1	1	1

Table 3.Description of scenarios used in NAFO Divs. 4X5Zc and NAFO Divs. 4VW projections of White Hake abundance and age structure. (NA = not applicable.)

	4X5Zc			4VW		
Scenario	**Scenario Name**	**Z**	**F**	**Scenario Name**	**Z**	**Mean R**
Current Z and F	Z = 1.03	1.03	0.09	Z = 1.6	1.6	21 million
No fishing	Z = 0.94	1.03	0	NA	NA	NA
R of the last 3 years	NA	NA	NA	low R	1.6	19 million
Z to reach B_{msy}	Z = 0.7	0.7	0.09	Z = 0.7	0.7	21 million
Z to increase older adults	Z = 0.6	0.6	0.09	Z = 0.6	0.6	21 million

Table 4. Results of the stochastic simulations for White Hake from NAFO Divs. 4X5Zc for mature biomass (median and 95% percentile range), age structure expressed as proportion 6+/3+ (median and 95% percentile range), probability that biomass would be below the recovery target (RT), and years required for the median of the biomass to be above the recovery target starting in 2013.

	Biomass (t)			Proportion 6+/3+				
Scenarios	**0.025**	**Median**	**0.975**	**0.025**	**Median**	**0.975**	**Probabilty Biom<RT**	**Years to RT**
Z = 1.03	1714	12419	25500	0.04	0.06	0.09	0.16	0
Z = 0.94	1928	12930	27210	0.05	0.07	0.10	0.16	0
Z = 0.7	2562	18796	39815	0.09	0.13	0.19	0.10	0
Z = 0.6	3133	23191	50809	0.12	0.18	0.23	0.09	0

Table 5. Results of the stochastic simulations for White Hake from NAFO Divs. 4VW for mature biomass (median and 95% percentile range), age structure expressed as proportion 6+/3+ (median and 95% percentile range), probability that biomass would be below the recovery target (RT), and years required for the median of the biomass to be above the recovery target starting in 2013.

	Biomass (t)			proportion 6+/3+				
Scenarios	**0.025**	**Median**	**0.975**	**0.025**	**Median**	**0.975**	**Probabilty Biom<RT**	**Years toRT**
RWZ z16	1510	4973	10164	0.01	0.01	0.03	0.34	2
RWZ z16 lowR	2193	3275	6120	0.01	0.01	0.03	0.63	Not Reached
RWZ z07	2930	9756	22437	0.06	0.11	0.19	0.08	1
RWZ z06	3588	11644	27172	0.09	0.15	0.23	0.04	1

FIGURES

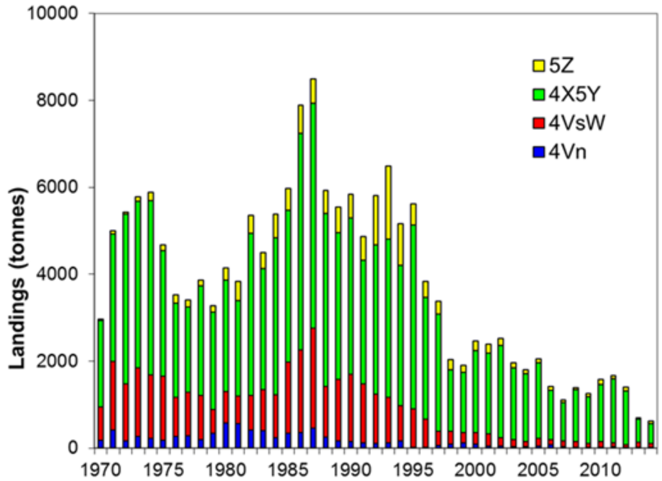


Figure 1. Reported landings (tonnes) of White Hake by Canadian fleets in NAFO Subdivs. 4Vn, 4VsW, 4X5Yc and 5Zc, 1970-2014.

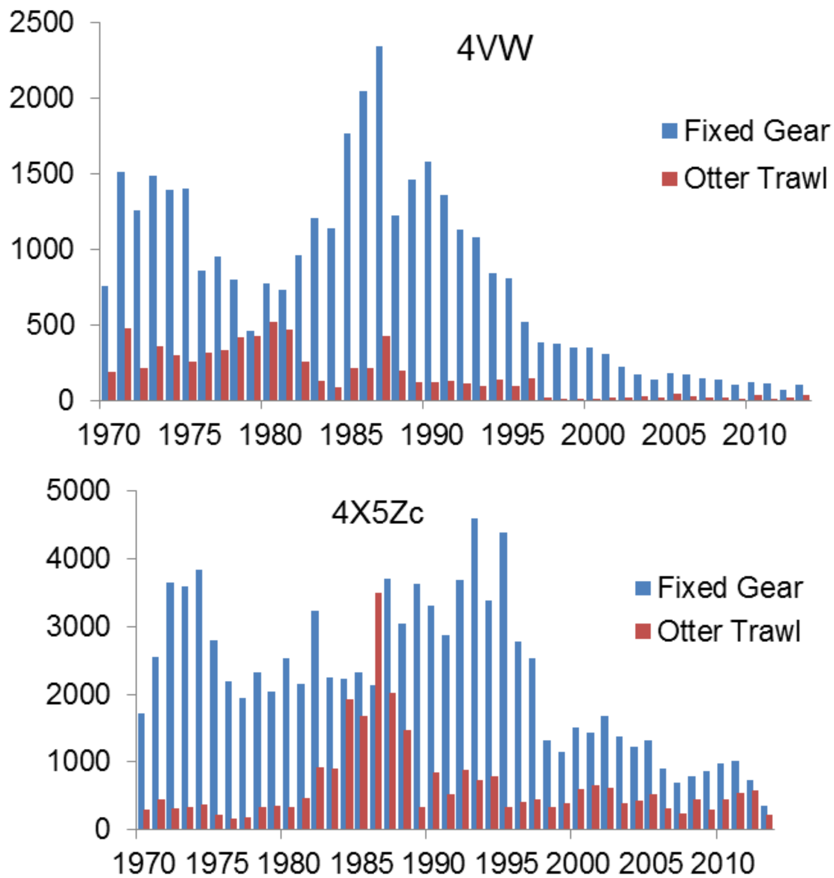


Figure 2. Reported landings (tonnes) of White Hake by Canadian fleets fishing with mobile and fixed gears in Divs. 4VW and 4X5Zc, 1970 to 2013.

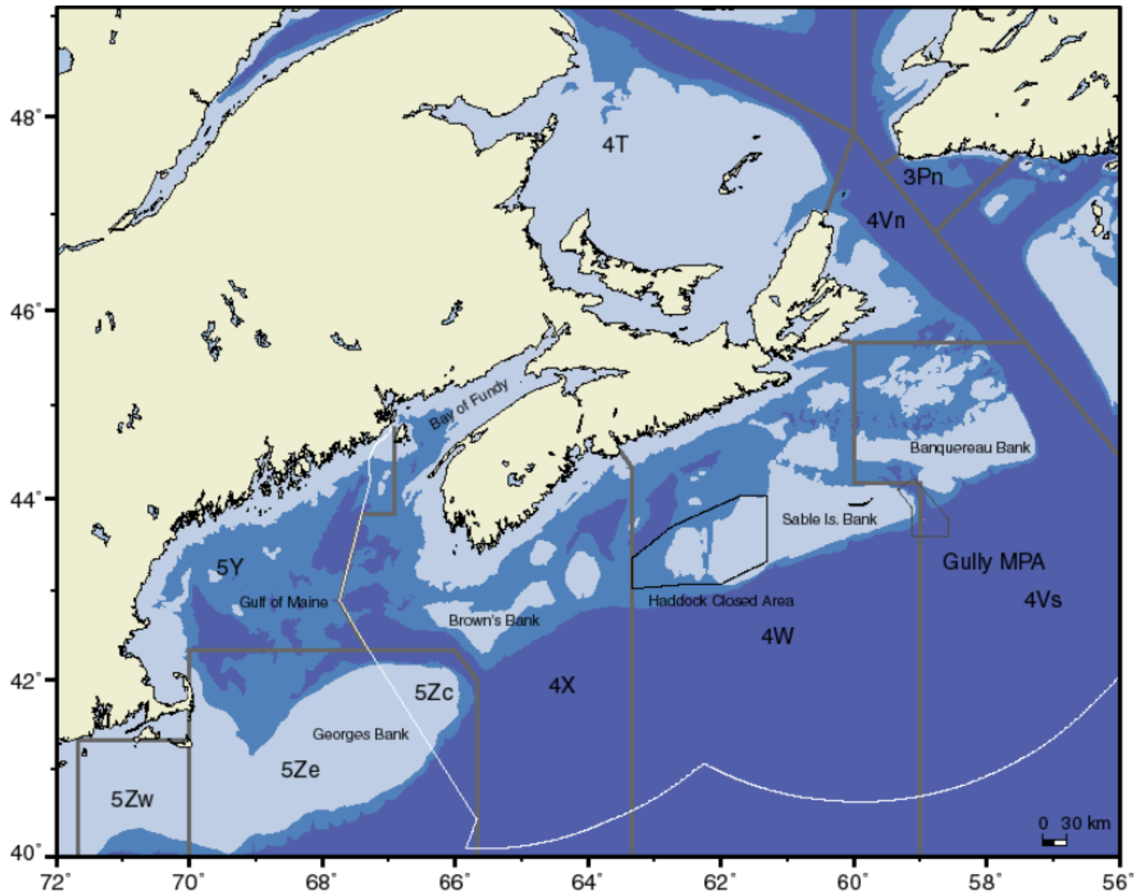


Figure 3. Map showing the NAFO Regions relevant to 4VW and 4X5Zc White Hake. Divs. 4VW includes 4Vs, 4Vn and 4W. Divs. 4X5Zc includes 4X, 5Zc and the small portion of 5Y which lies in Canadian waters.

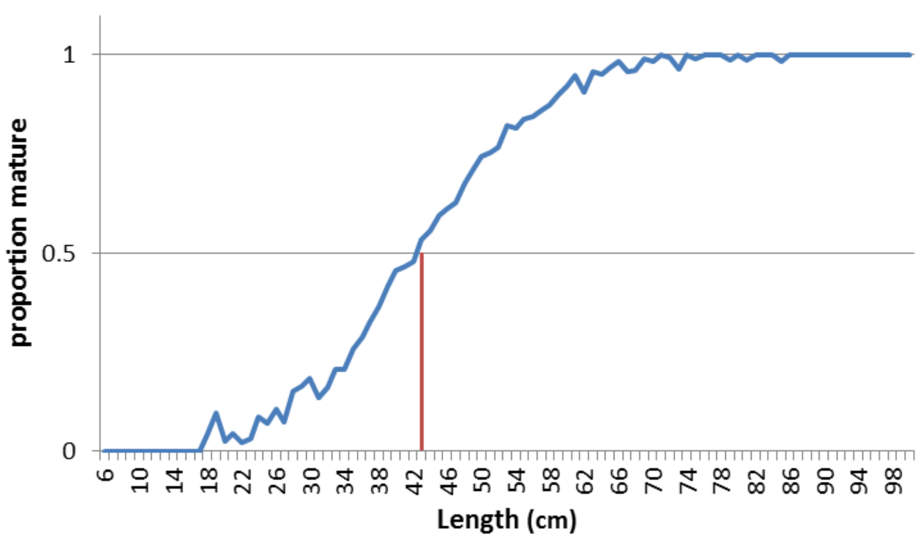


Figure 4. Proportion mature at length for White Hake in NAFO Divs. 4VWX5Zc.

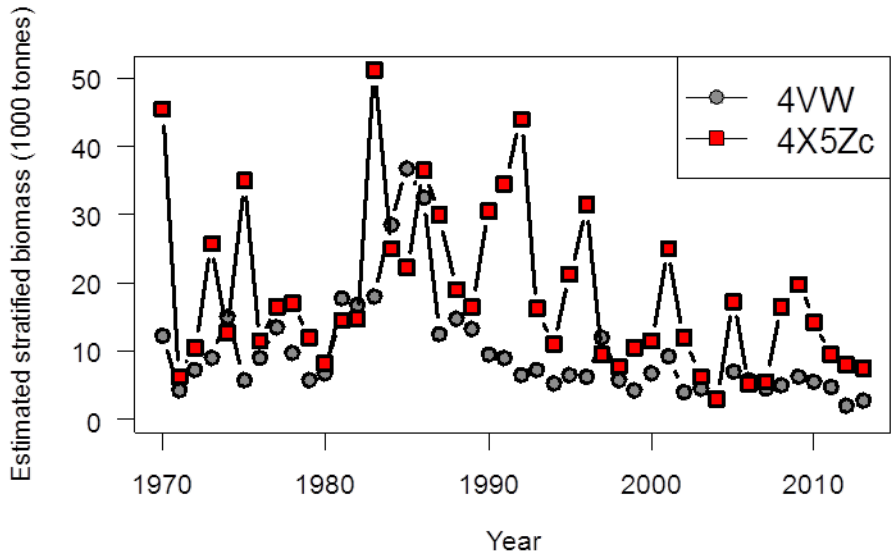


Figure 5. Estimated stratified survey biomass (1000 tonnes) of White Hake in Divs. 4VW and Divs. 4X5Zc, 1970-2013.

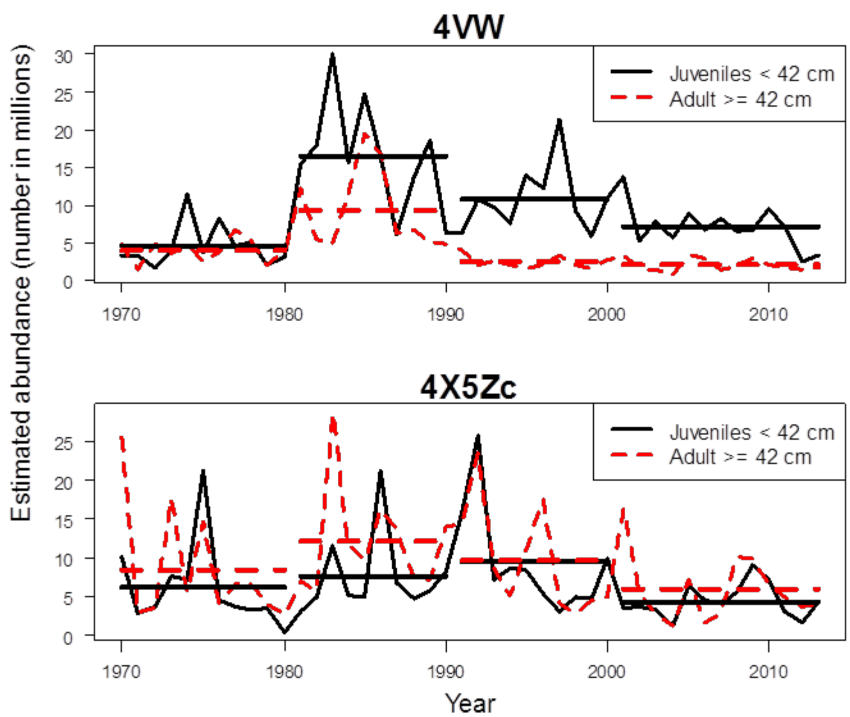


Figure 6. White Hake abundance (number in millions) by size class (solid thin black lines: juveniles < 42 cm; dashed thin red lines: adults ≥ 42 cm) in Divs. 4VW (top panel) and Divs. 4X5Zc (bottom panel), 1970-2013. Thick horizontal lines are approximate decadal (1970–1980, 1981–1990, 1991–2000, 2001–2013) averages for each size group.

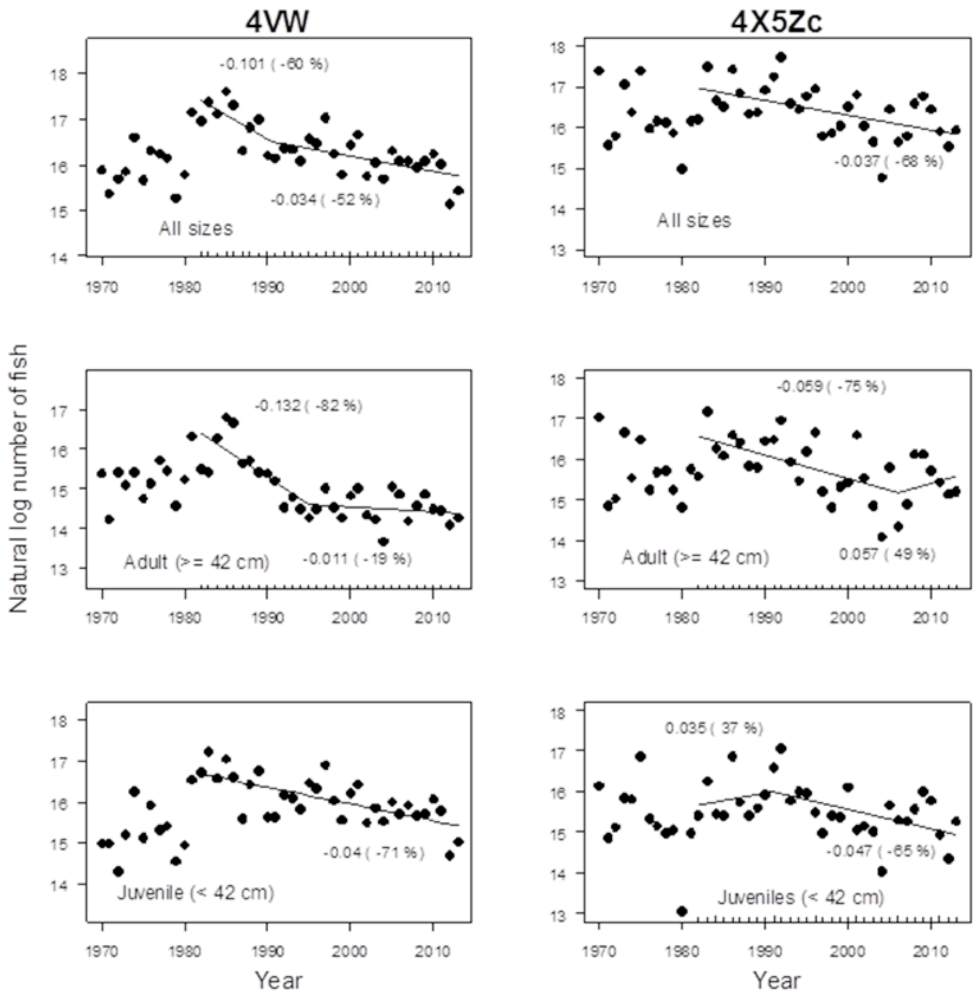


Figure 7. Trends in natural log-transformed estimates of White Hake survey abundance for all sizes (top panels), adults (≥ 42 cm; middle panels), and juveniles (< 42 cm bottom panels) for Divs. 4VW (left column) and Divs. 4X5Zc (right column). Linear changes were estimated for 1982-2013, or by segments (starting in 1982) when applicable. The instantaneous rate of change over year (slope) is displayed beside each line, and percent change (in parentheses) over each regression time period.

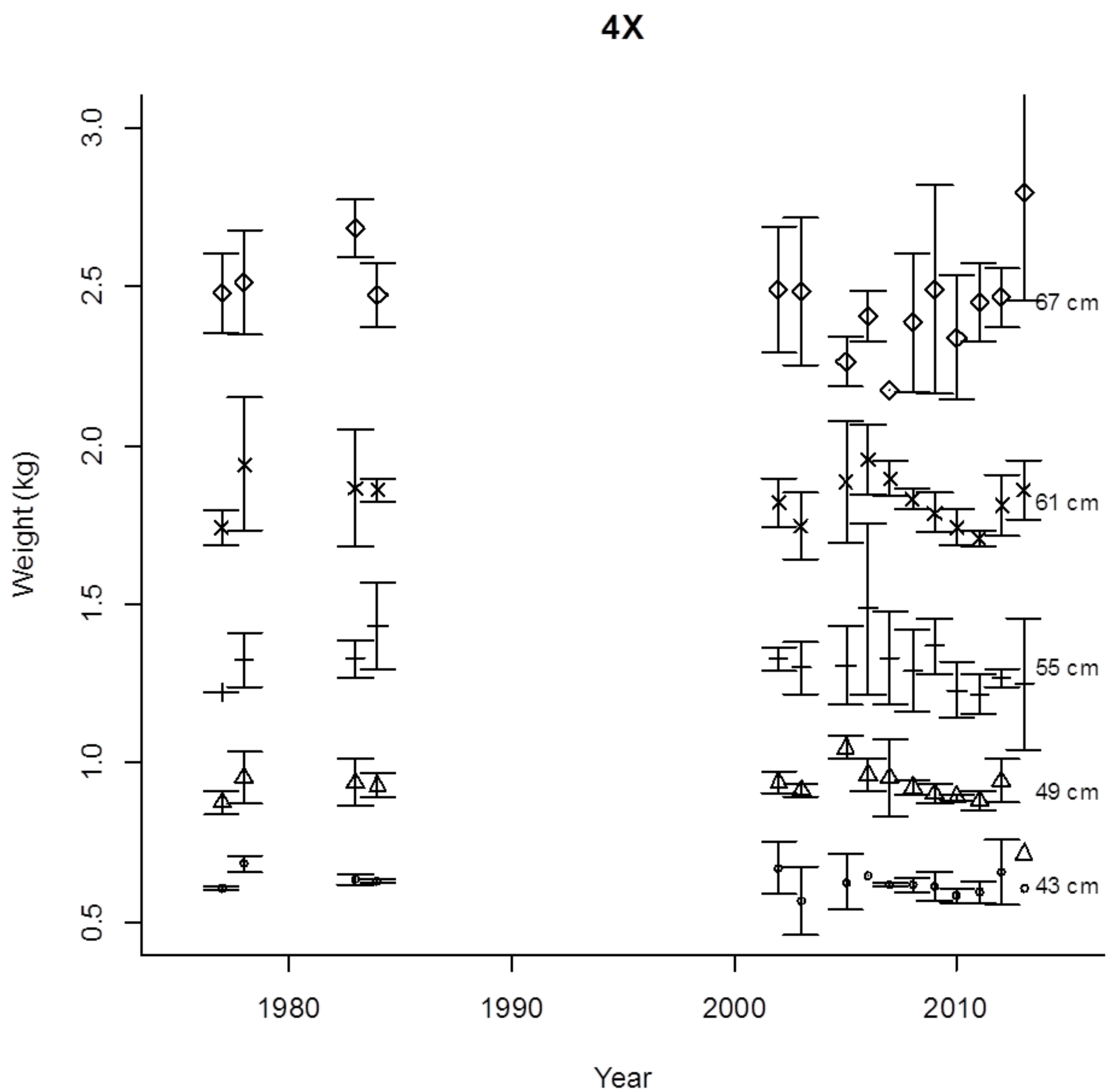


Figure 8. Mean weight (and 95% confidence interval widths) by fork length group of White Hake sampled from NAFO Divs. 4X5Zc for years with age samples. Summaries are shown for five fork length bins (43 cm, 49 cm, 55 cm, 61 cm, 67 cm).

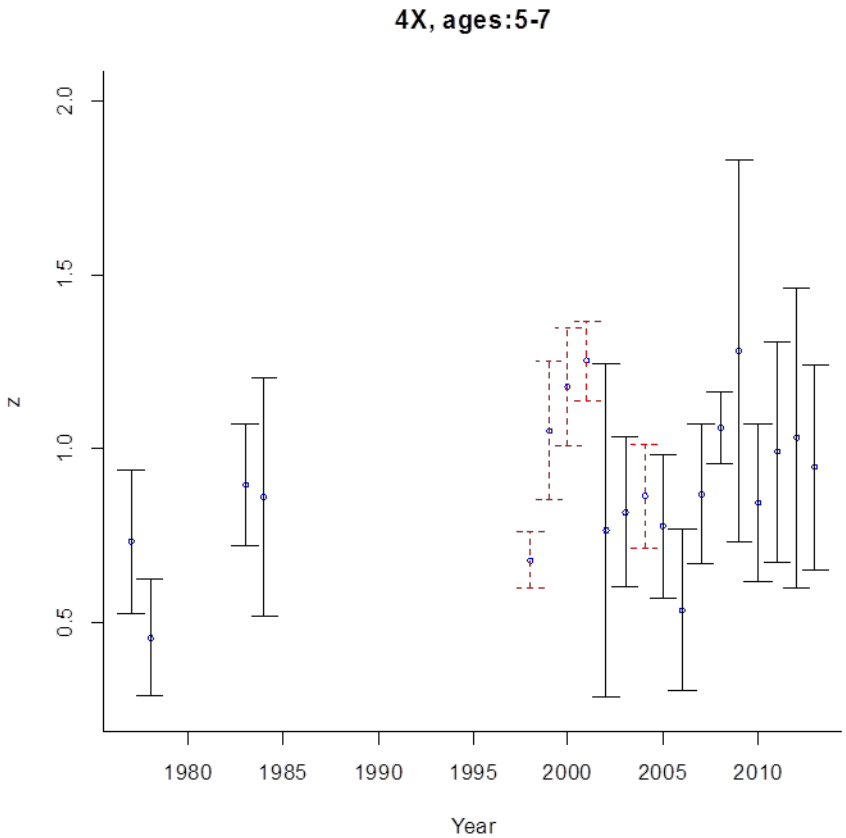


Figure 9. Total mortality (Z; mean and 95% confidence intervals) for White Hake, ages 5-7 based on survey catch at age from NAFO Divs. 4X5Zc. The red stipled confidence intervals indicate the years when the ages were assigned using commercial age-length keys.

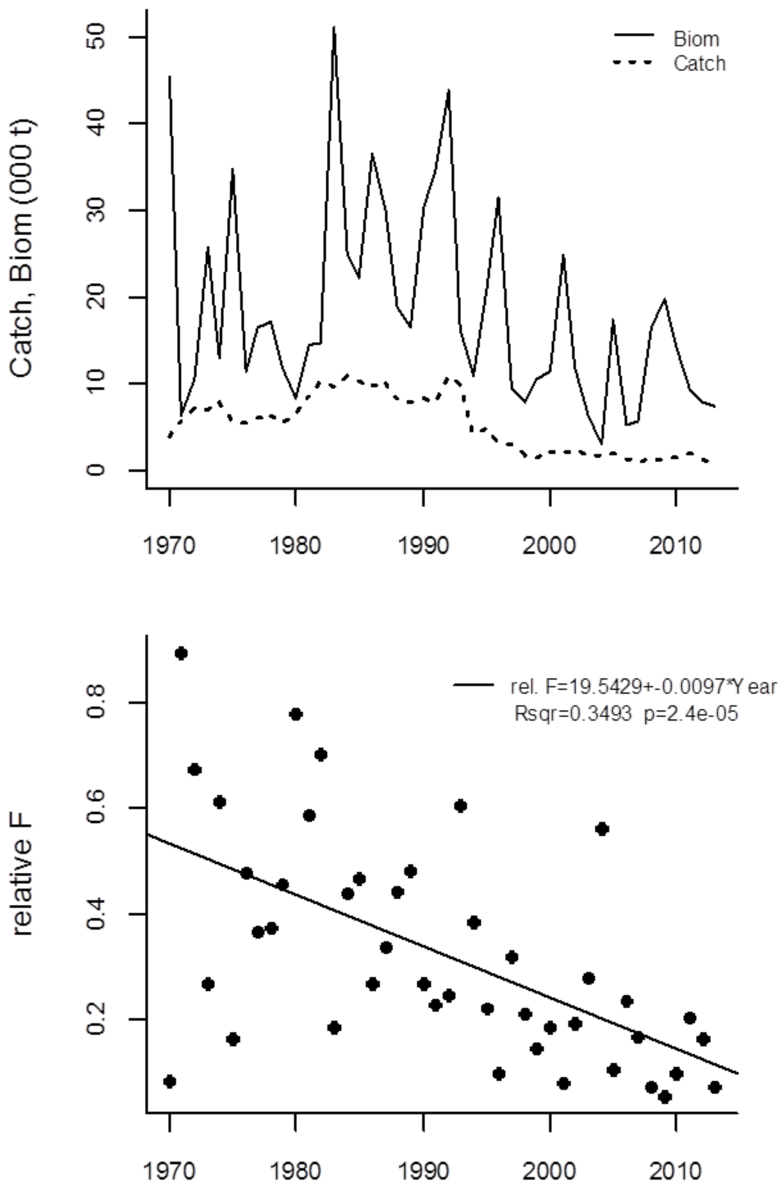


Figure 10. Commercial catch and estimated trawlable biomass from the survey (top panel), and relative F (catch / biomass) for White Hake in NAFO Divs. 4X5Zc.

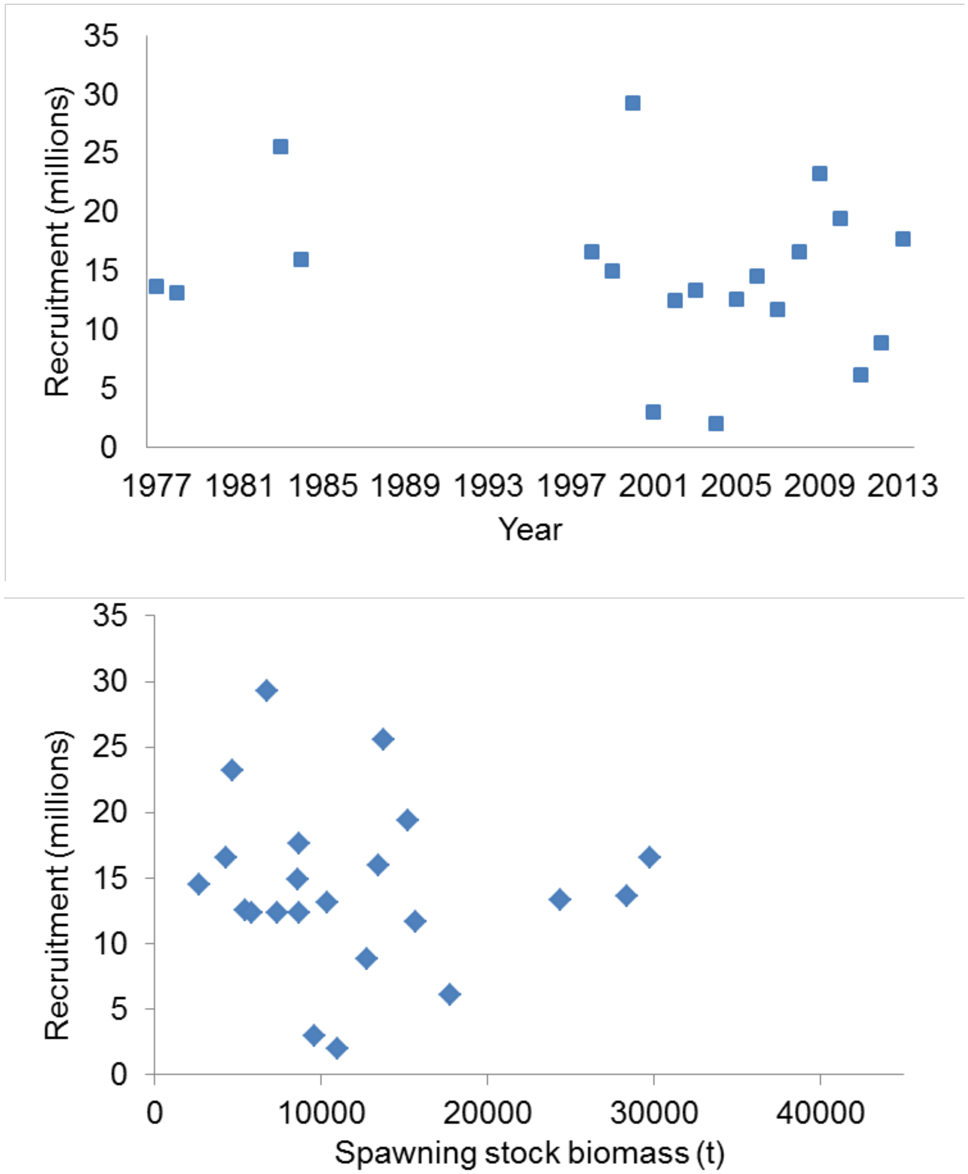


Figure 11. Estimated recruitment (year-class abundance in million) of age 2 White Hake in NAFO Divs. 4X5Zc by year (top) and as a function of SSB (bottom).

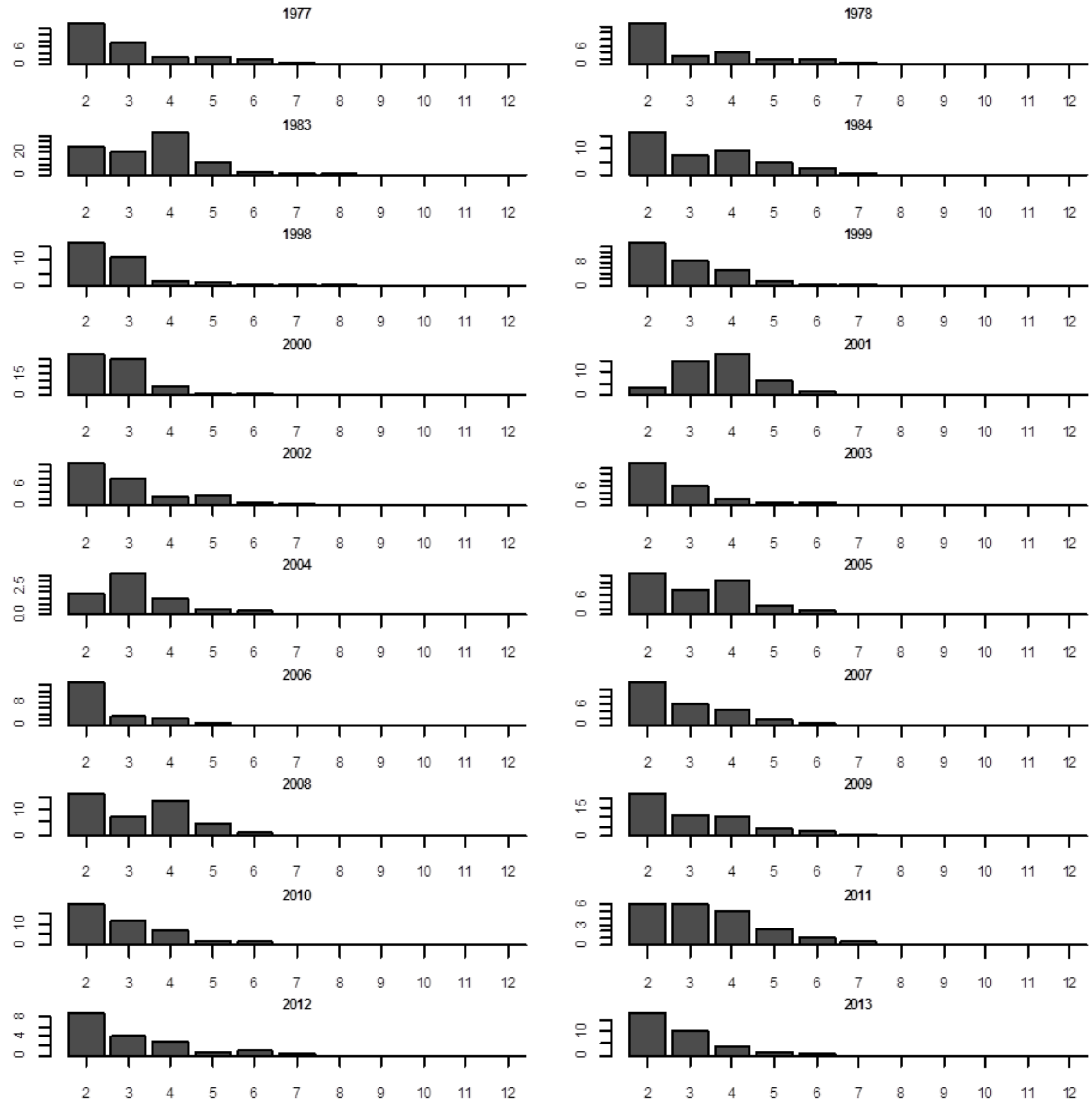


Figure 12. Relative (within year) abundances at age of White Hake sampled from NAFO Divs. 4X5Zc. Age 12 is a plus group and represents the sum of abundances of ages 12 to 16.

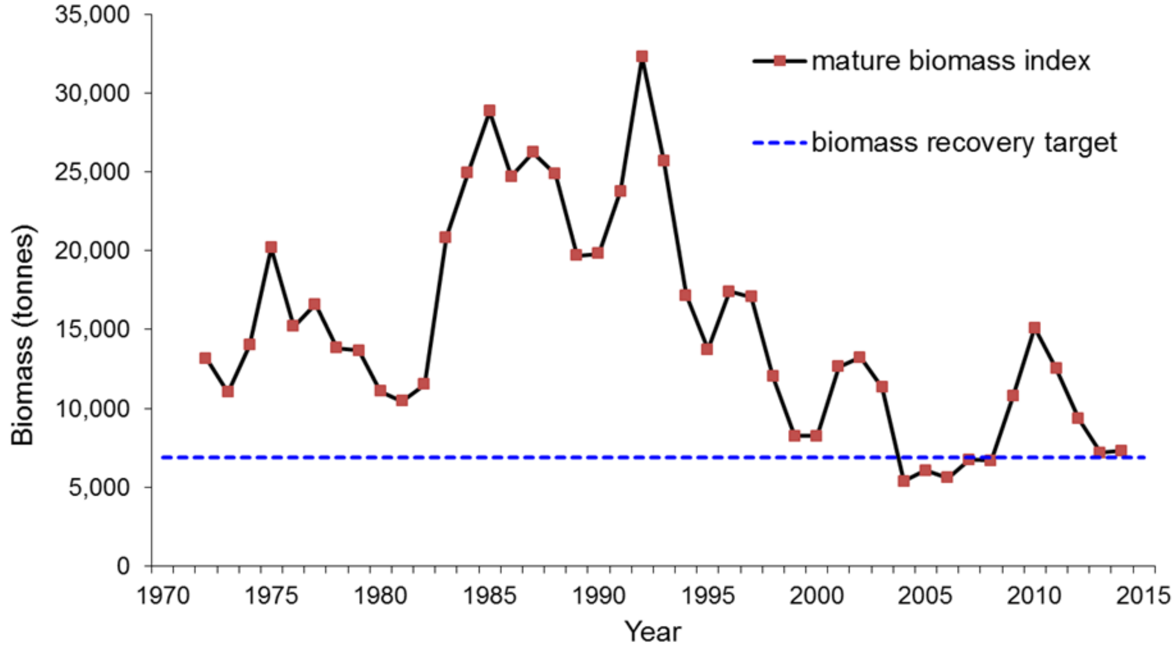


Figure 13. Estimated survey mature biomass index (t) of White Hake in NAFO Divs. 4X5Zc relative to the proposed biomass recovery target of 6867 t.

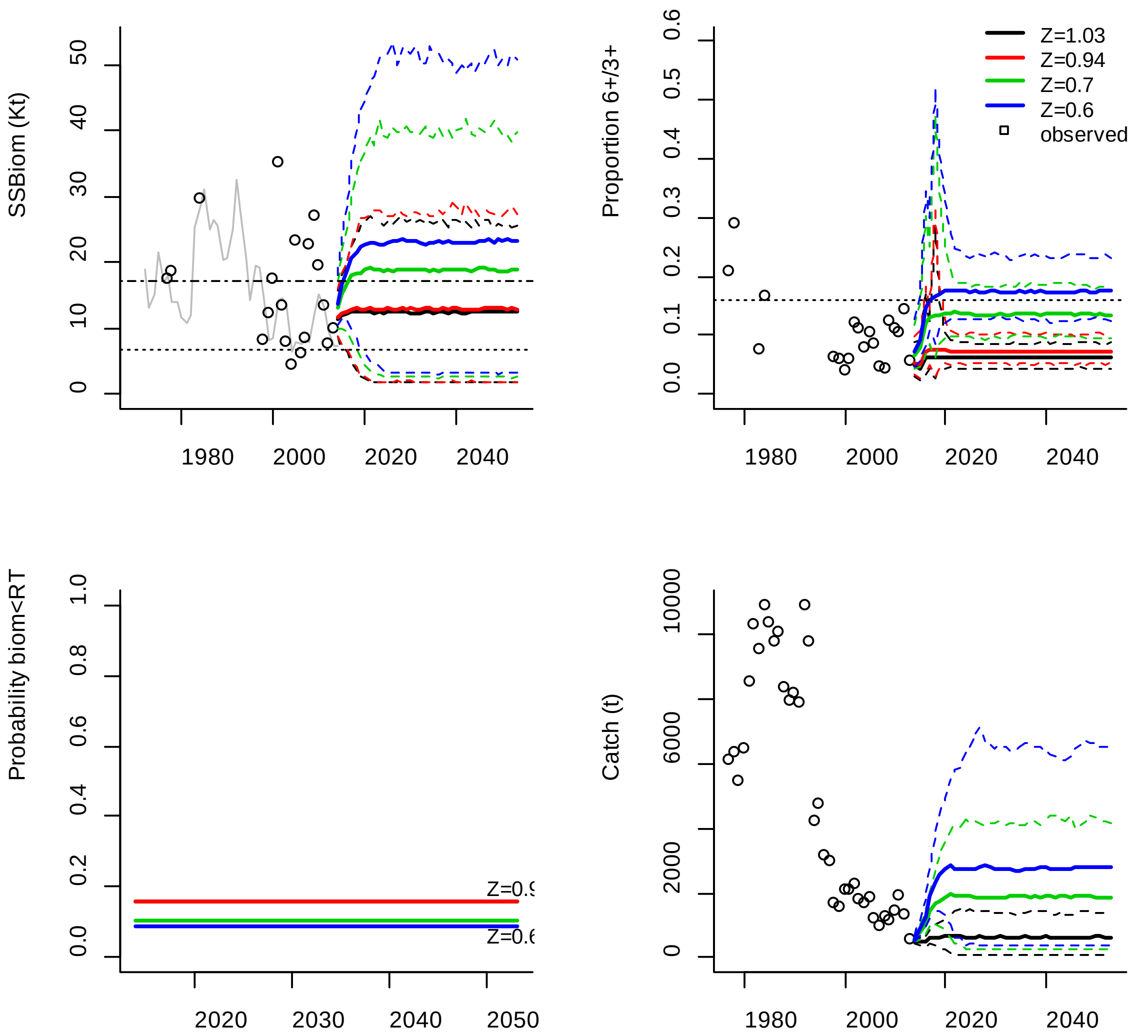


Figure 14. Results of stochastic projections of White Hake abundance (t) and age structure in NAFO Divs. 4X5Zc relative to four scenarios of assumptions of Z (see Table 3 for more details). The medians are shown in solid lines while 0.025 and 0.975 percentiles are shown as stippled lines. The upper left panel shows projections of biomass with the horizontal dotted line at 6.867 equal to the biomass recovery target and the upper horizontal dashed line the estimate of B_{msy} (17,167 t). The grey line is the 3-year moving average for SSB. The upper right panel is the age structure expressed as the ratio of fish age 6+ to fish age 3+. The horizontal dotted line is the ratio observed during the productive period of 1970–1998 (0.16). The bottom left panel is the probability of the biomass being less than the biomass recovery target while the bottom right panel shows the anticipated realized catch (t) at the corresponding F values of each scenario. Only the scenario Z = 0.94 (red line) has no fishing thus the realized catch is zero.

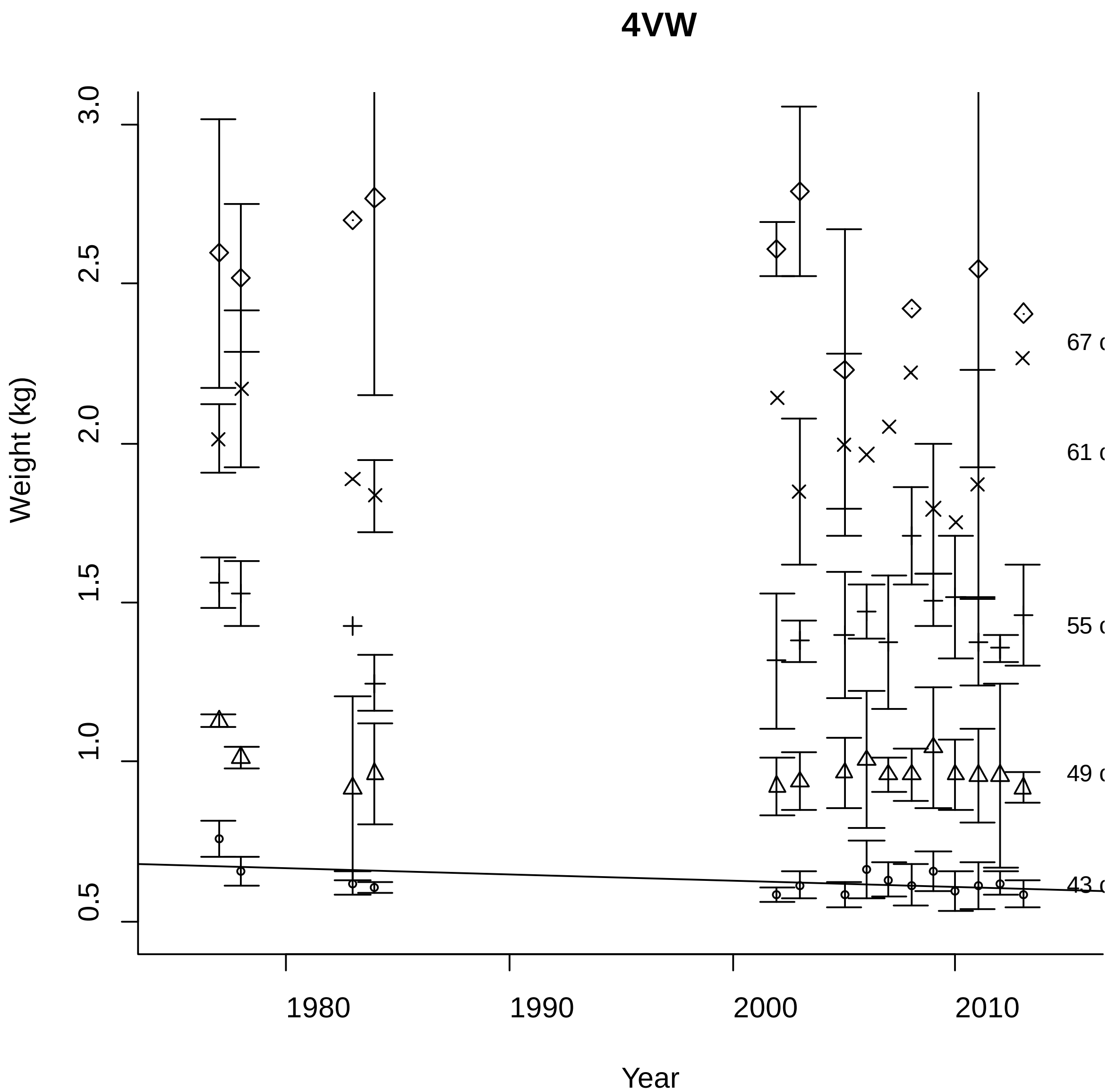


Figure 15. Mean weight (and 95% confidence interval widths) by fork length group of White Hake sampled from NAFO Divs. 4VW for years with age samples. Summaries are shown for five fork length bins (43 cm, 49 cm, 55 cm, 61 cm, 67 cm). There is a statistically significant decline (b = -0.002, p = 0.04) in weight for length class 43 cm only.

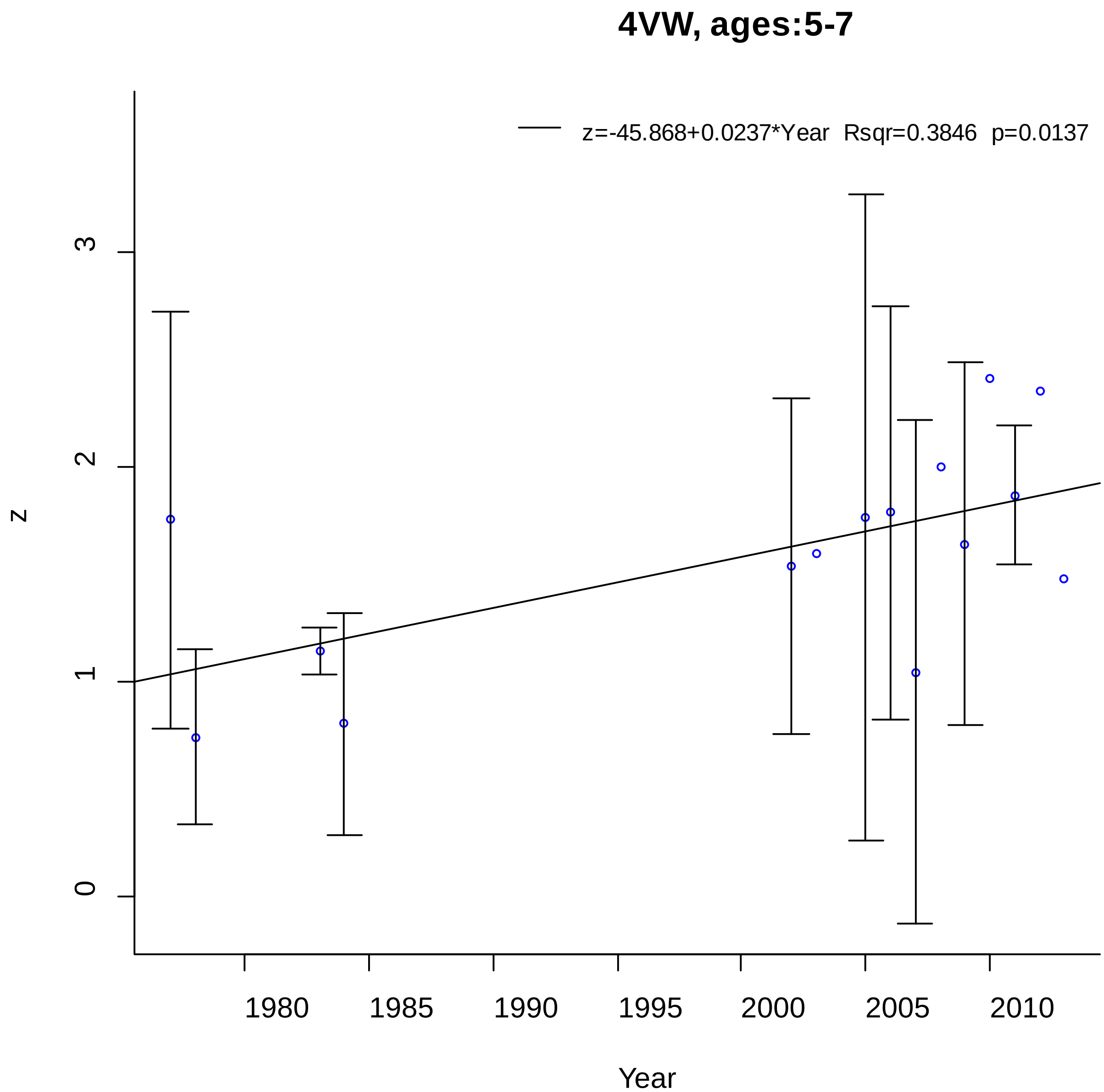
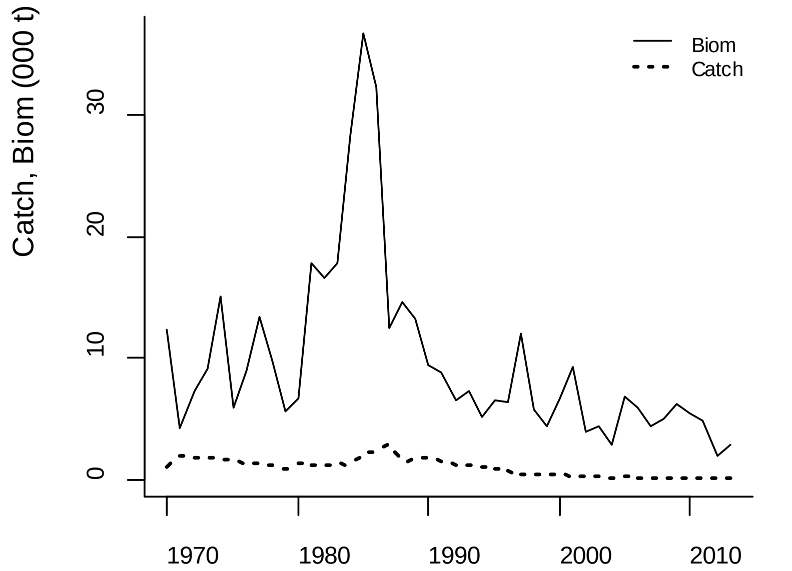


Figure16. Total mortality (Z; mean and 95% confidence intervals) for White Hake, ages 5-7 based on survey catch at age from NAFO Divs. 4VW.



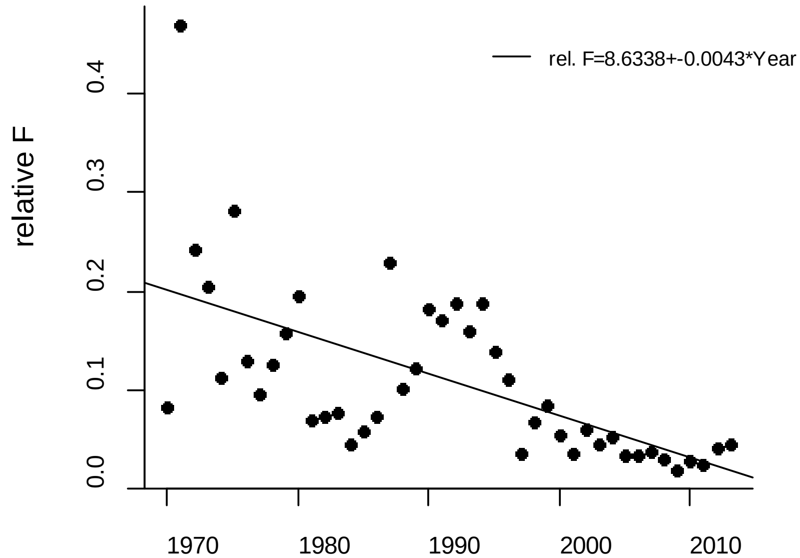


Figure17. Commercial catch and estimated trawlable biomass (1000 t) from the survey (top panel), and relative F (catch / biomass; lower panel) for White Hake in NAFO Divs. 4VW.

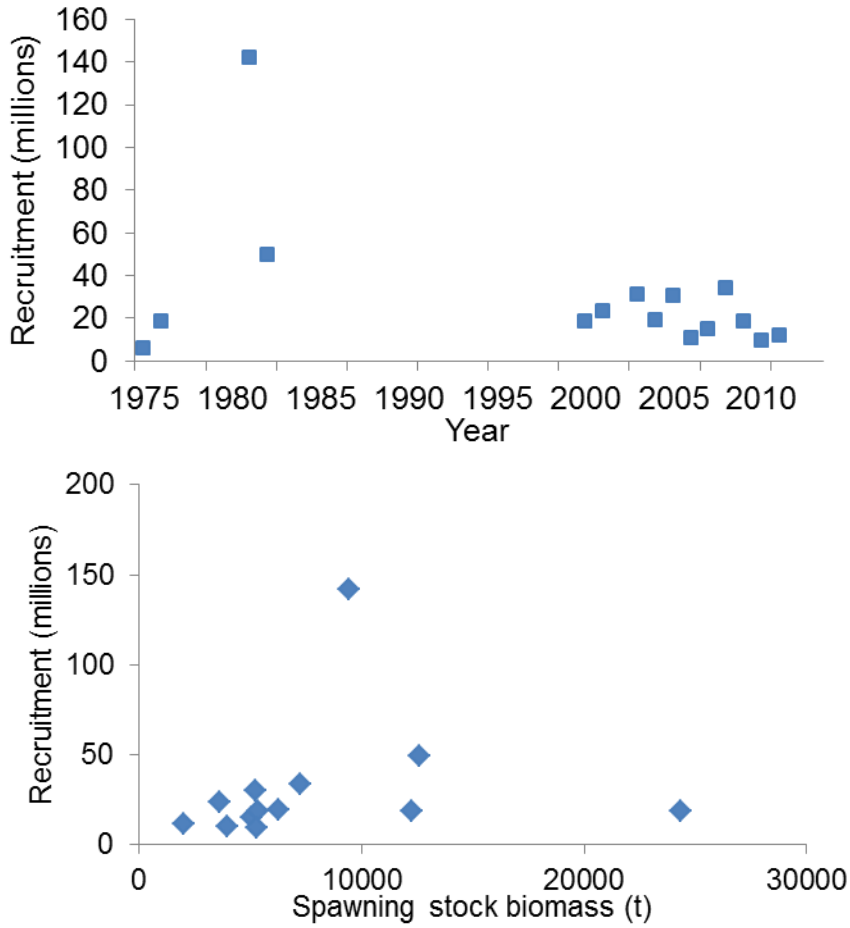


Figure18. Estimated recruitment (year-class abundance in million) of age 2 White Hake in NAFO Divs. 4VW by year (top) and as a function of SSB (bottom).

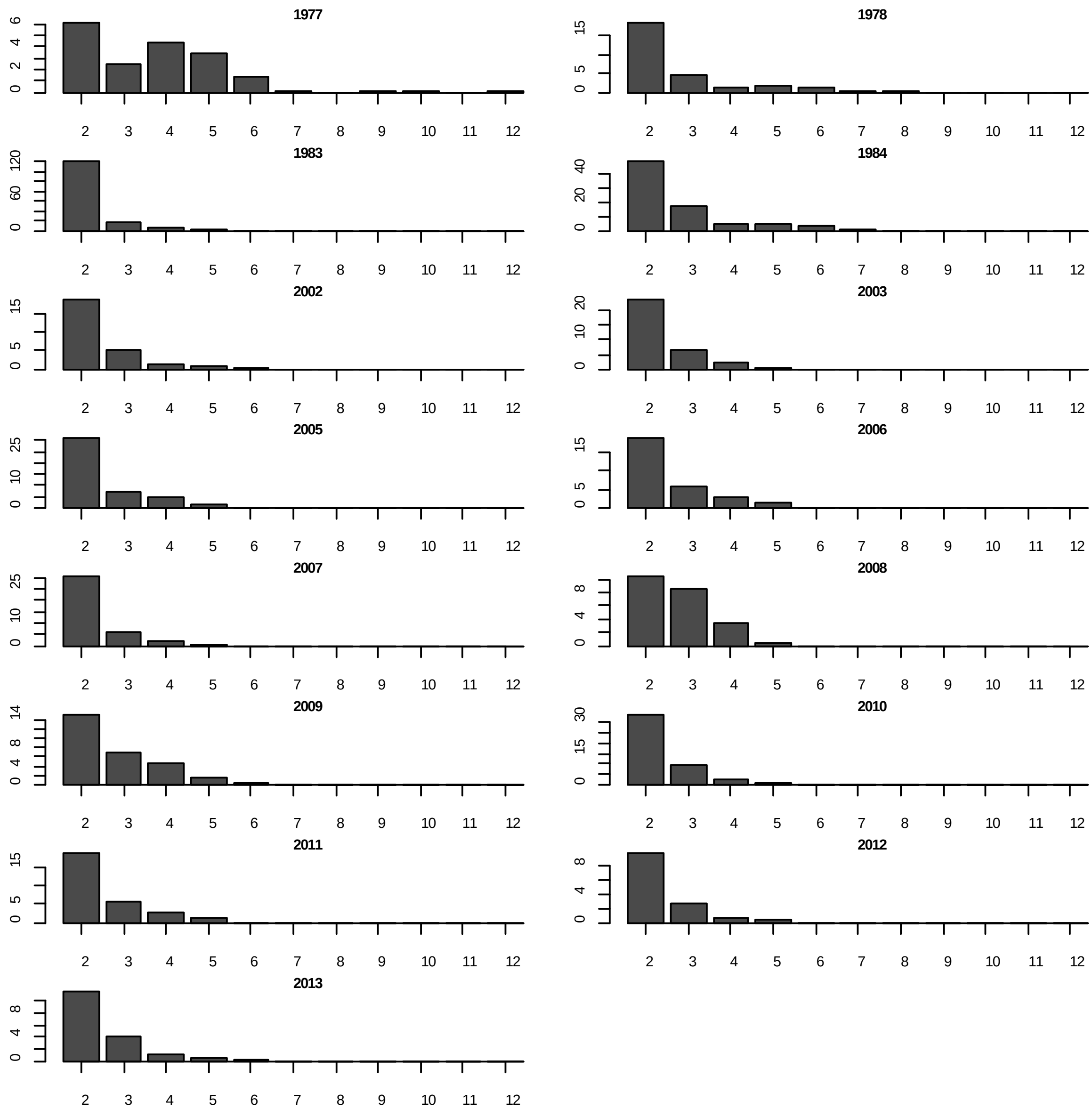


Figure 19. Relative (within year) abundances at age of White Hake sampled from NAFO Divs. 4VW. Age 12 is a plus group and represents the the sum of abundances of ages 12 to 16.

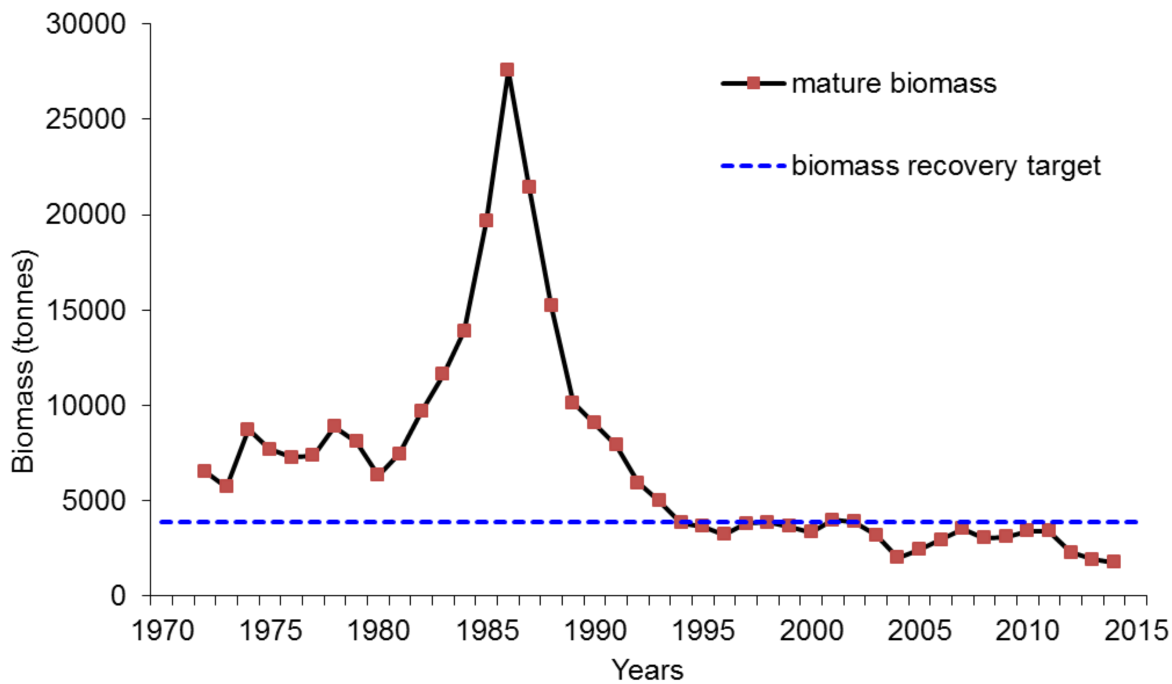


Figure 20. Estimated survey mature biomass index (t) of White Hake in NAFO Divs. 4VW relative to the proposed biomass recovery target of 3885 t, 1972 to 2014.

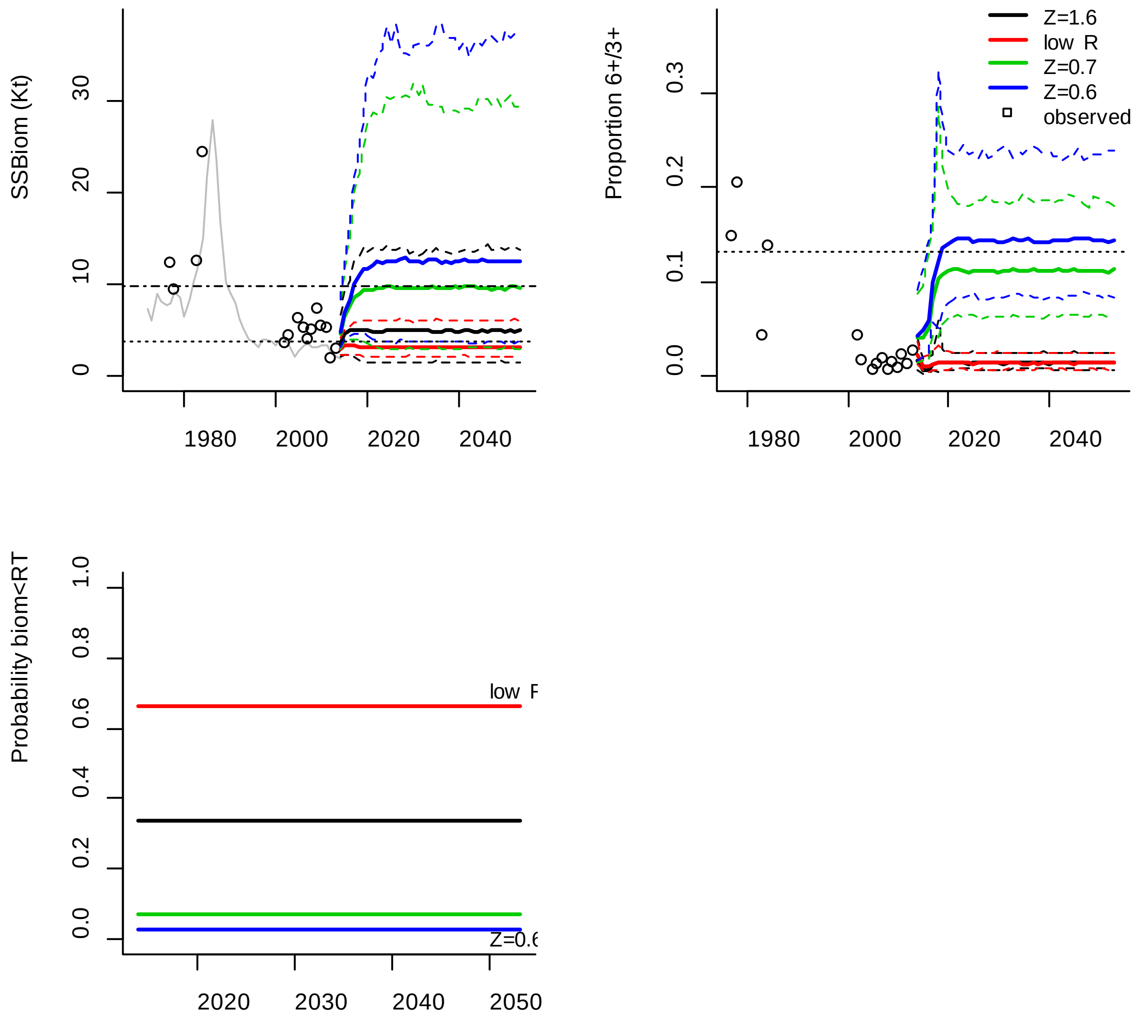


Figure 21. Results of stochastic projections of White Hake abundance (t) and age structure in NAFO Divs. 4VW relative to four scenarios of assumptions of Z and recruitment (see Table 3 for more details). The medians are shown in solid lines while 0.025 and 0.975 percentiles are shown as stippled lines. The upper left panel shows projections of biomass with the horizontal dotted line at 3.885 kt equal to the biomass recovery target and the upper horizontal dashed line the estimate of B_{msy} (9.710 kt). The grey line is the 3 year moving average for SSB. The upper right panel is the age structure expressed as the ratio of fish age 6+ to fish age 3+. The horizontal dotted line is the ratio observed during the productive period of 1970–1991 (0.13). The bottom left panel is the probability of the biomass being less than the recovery target. F values for all scenarios were set at zero.

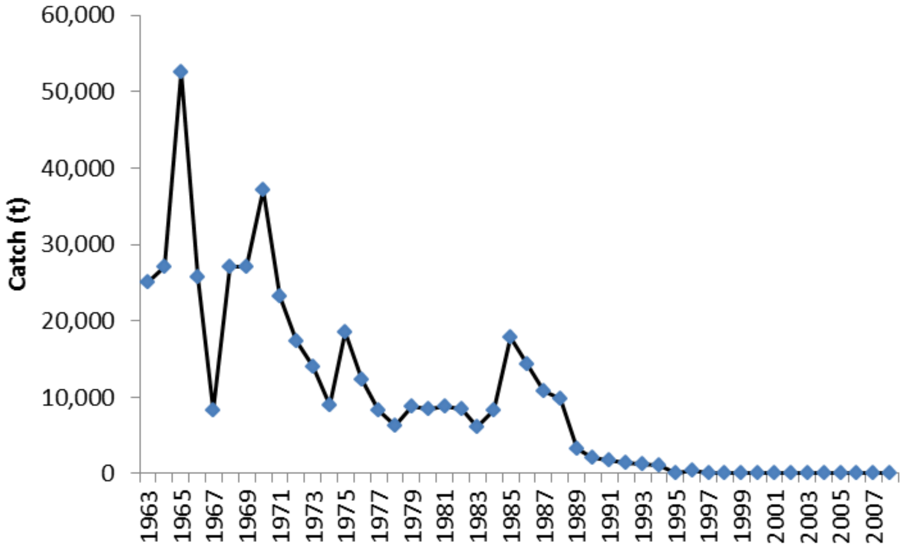


Figure 22. Trend in commercial catches of Atlantic Herring in NAFO Divs. 4VW, 1963 to 2008.

APPENDIX

Appendix Table A1a. 4X5Zc White Hake commercial landings data by gear category.

	4X		5Yb(Canadian)		5Zc		4X5Zc totals		
Year	Fixed	Mobile	Fixed	Mobile	Fixed	Mobile	Fixed	Mobile	All Gear
1970	1691	287	0	12	30	4	1721	303	2024
1971	2498	414	0	18	58	24	2556	456	3012
1972	3614	297	0	8	28	4	3642	309	3951
1973	3530	288	0	17	62	38	3592	343	3935
1974	3654	316	0	36	177	19	3831	371	4202
1975	2690	186	14	3	95	34	2799	223	3022
1976	2020	144	0	0	178	17	2198	161	2359
1977	1792	161	0	0	148	21	1940	182	2122
1978	2258	245	0	20	70	65	2328	330	2658
1979	1903	245	0	102	137	12	2040	359	2399
1980	2291	263	0	14	234	57	2525	334	2859
1981	1734	446	15	6	413	20	2162	472	2634
1982	2839	539	2	350	389	23	3230	912	4142
1983	1876	472	57	384	318	51	2251	907	3158
1984	1757	1386	72	407	405	129	2234	1922	4156
1985	1934	1114	13	439	368	133	2315	1686	4001
1986	1770	2906	57	251	299	349	2126	3506	5631
1987	3206	1866	71	33	428	127	3704	2026	5731
1988	2571	1322	47	38	424	110	3042	1470	4513
1989	2846	315	213	8	565	17	3624	340	3965
1990	2766	775	35	16	500	46	3301	837	4138
1991	2332	475	24	10	519	31	2876	516	3391
1992	2512	804	72	54	1110	27	3694	885	4579
1993	2910	650	24	49	1655	27	4589	726	5315
1994	2400	737	64	33	928	27	3392	797	4189
1995	3893	301	41	7	462	19	4396	327	4723
1996	2372	371	52	9	348	24	2772	403	3175
1997	2125	421	139	8	274	16	2538	445	2983
1998	1050	314	48	9	218	10	1316	333	1649
1999	966	376	24	11	164	10	1153	398	1551
2000	1248	573	50	8	210	14	1508	596	2104
2001	1199	610	54	6	170	33	1424	649	2072
2002	1402	583	123	21	149	9	1675	613	2287
2003	1075	366	180	18	120	8	1375	392	1767
2004	1061	419	74	9	81	9	1216	437	1653
2005	1102	459	159	26	51	34	1312	519	1831
2006	799	268	54	11	57	34	910	313	1223
2007	627	220	23	14	41	14	691	248	939
2008	735	436	13	14	39	0	786	450	1237
2009	771	249	10	45	76	3	857	296	1153
2010	892	327	10	89	69	36	971	451	1422
2011	917	488	32	35	58	28	1007	551	1558
2012	675	552	2	8	56	26	734	587	1320
2013	311	209	1	6	32	11	344	226	570

Appendix Table A1b. 4VW White Hake commercial landings data by gear category.

	4Vn		4Vs		4W		4VW totals		
Year	**Fixed**	**Mobile**	**Fixed**	**Mobile**	**Fixed**	**Mobile**	**Fixed**	**Mobile**	**All Gear**
1970	122	60	22	25	614	104	758	189	947
1971	141	281	36	81	1336	117	1513	479	1992
1972	111	62	34	61	1114	89	1259	212	1471
1973	111	162	40	86	1338	107	1489	355	1844
1974	81	142	40	97	1272	57	1393	296	1689
1975	65	116	59	79	1278	58	1402	253	1655
1976	32	230	111	46	714	42	857	318	1175
1977	122	166	85	67	749	99	956	332	1288
1978	58	144	91	151	650	119	799	414	1213
1979	86	252	69	112	303	63	458	427	885
1980	248	337	237	132	291	50	776	519	1295
1981	243	321	124	98	361	51	728	470	1198
1982	253	161	148	56	561	34	962	251	1213
1983	315	86	281	34	615	11	1211	131	1342
1984	210	27	263	35	667	21	1140	83	1223
1985	210	135	473	53	1082	23	1765	211	1976
1986	255	110	446	48	1350	56	2051	213	2264
1987	194	268	644	72	1505	83	2343	422	2765
1988	128	129	339	35	761	27	1228	192	1420
1989	94	76	458	17	911	27	1463	119	1582
1990	81	75	291	16	1207	29	1580	120	1700
1991	61	56	275	17	1024	52	1360	124	1484
1992	45	68	283	15	800	29	1128	113	1241
1993	41	83	274	7	763	5	1079	94	1173
1994	60	109	185	27	595	3	839	139	978
1995	5	16	247	36	553	41	805	94	899
1996	5	13	110	16	406	115	521	144	665
1997	61	4	68	9	250	2	379	15	394
1998	84	6	102	2	189	4	375	12	388
1999	113	2	66	5	172	3	351	10	361
2000	87	2	51	1	215	7	353	10	363
2001	48	2	45	4	215	8	308	14	322
2002	48	1	40	5	136	11	223	17	240
2003	30	4	55	12	88	12	174	28	201
2004	35	4	39	2	63	10	137	16	153
2005	43	6	38	11	100	26	181	43	224
2006	58	13	17	11	92	2	166	26	192
2007	31	5	24	11	91	1	147	17	165
2008	23	2	17	7	92	5	132	15	147
2009	22	1	21	3	60	3	103	7	110
2010	22	0	17	3	80	30	119	33	152
2011	33	0	9	0	72	2	114	3	117
2012	11	0	7	2	47	12	65	15	80
2013	21	0	8	2	70	33	98	35	133

Appendix Table A2. Commercial catch at age (number of fish) of White Hake in NAFO Div. 4X5Zc for years with available data, 1998 to 2013.

	Ages											
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12+**
1998	0	1,958	16,940	75,043	243,964	191,299	52,654	36,230	17,013	2,190	2,212	2,641
1999	0	811	45,431	135,493	274,303	155,045	56,164	21,708	19,009	7,682	4,251	3,674
2000	0	0	5,596	84,445	326,482	309,032	96,538	33,285	13,754	6,346	5,900	5,448
2001	0	0	19,111	143,315	339,220	256,504	83,932	26,565	12,735	6,395	5,902	6,886
2002	0	0	715	22,383	240,827	422,497	105,578	54,674	15,696	12,020	1,399	6,731
2003	0	293	1,404	14,249	105,946	220,722	112,547	39,899	11,784	1,541	3,866	3,493
2004	0	0	34,495	109,168	149,453	148,300	93,823	47,434	22,883	6,703	4,421	1,372
2005	0	0	2,399	11,684	159,829	171,670	93,026	44,837	18,363	12,033	6,730	4,392
2006	0	0	11,191	41,934	125,304	159,754	97,198	22,396	13,049	10,743	4,332	9,392
2007	0	2,889	29,668	157,779	189,471	84,545	23,095	13,689	8,492	5,941	4,595	3,721
2008	0	422	7,220	118,750	313,545	168,073	24,439	9,962	3,061	4,515	1,944	2,417
2009	0	1,825	6,620	81,005	196,244	200,745	45,507	7,686	5,087	1,854	1,438	837
2010	0	1,638	19,113	148,084	272,126	196,823	78,261	19,740	5,805	1,826	1,177	172
2011	0	850	15,968	90,402	145,155	76,421	16,411	1,950	1,208	306	330	230
2012	0	1,464	17,739	124,581	208,279	187,796	65,696	28,136	9,824	5,402	2,262	1,354
2013	0	2,324	20,718	87,741	105,157	68,786	24,493	12,076	3,009	1,176	713	861

Appendix Table A3. Survey catch at age abundance of White Hake in NAFO Divs. 4X5Zc for years with available data. Commercial age-length keys were used to derive the age structure of the survey catches for the years 1998 to 2001 and 2004.

	Ages												
Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12+**
1977	96,154	207,861	1,976,164	1,301,969	1,205,121	2,370,704	2,020,482	811,005	193,491	0	86,555	43,986	54,984
1978	90,551	263,490	1,903,545	562,164	1,727,201	1,847,711	2,107,233	854,740	400,288	0	2,54,290	0	0
1983	50,786	517,117	3,697,716	3,708,403	1,5792,217	1,0961,743	3,198,982	1,154,465	857,473	238,936	0	36,906	0
1984	0	33,552	2,309,129	1,406,357	4,084,524	4,735,471	2,901,457	1,020,323	240,788	57,265	161,307	0	31,579
1998	93,697	709,318	2,404,187	1,993,861	738,453	919,041	492,487	190,374	112,553	64,495	0	9,988	9,988
1999	131,676	458,027	2,160,781	1,604,919	2,204,133	1,828,379	603,162	197,370	35,455	18,585	13,186	21,776	65,067
2000	0	407,011	4,234,637	4,603,714	2,749,337	1,662,698	929,366	246,201	66,848	31,459	4,290	5,701	20,574
2001	0	0	424,532	2,807,808	7,752,897	6,304,629	1,801,205	430,608	92,820	49,953	11,337	4,866	122,833
2002	184,396	253,431	1,795,425	1,418,559	972,312	2,959,605	1,200,517	384,248	52,651	0	95,930	46,374	0
2003	9,202	75,800	1,925,810	1,088,563	953,715	970,097	843,241	147,466	130,474	0	18,619	0	0
2004	0	0	286,012	676,411	624,858	508,640	304,068	82,674	57,168	25,905	5,691	3,585	0
2005	0	372,007	1,825,164	1,412,834	4,489,255	3,129,360	1,447,465	293,247	403,479	160,321	47,422	94,843	0
2006	17,998	1,096,731	2,103,670	627,816	1,106,110	602,915	280,568	93,251	114,966	64,319	0	59,955	0
2007	39,260	650,302	1,691,509	1,079,275	1,827,040	1,313,157	332,493	122,948	63,952	38,508	0	0	0
2008	30,111	352,075	2,399,199	1,453,563	5,905,901	4,408,935	1,127,129	0	0	46,701	22,038	0	0
2009	277,011	1,077,237	3,356,616	2,174,954	4,584,663	3,780,386	3009,816	616,518	88,921	0	0	49,374	0
2010	848,849	569,855	2,810,301	2,248,678	2,993,191	1,816,189	1,836,802	404,498	125,895	52,265	52,265	0	132,546
2011	0	32,806	884,064	1,141,186	2,157,668	2,287,977	970,117	459,733	58,979	65,180	0	0	0
2012	0	375,891	1,276,338	725,638	1,276,982	627,662	939,324	261,799	38,371	17,900	0	0	0
2013	0	0	2,554,551	1,965,436	1,415,840	1,443,386	761,570	128,287	0	38,371	0	0	0

Appendix Table A4. Survey catch at age abundance (number of fish) of White Hake in NAFO Divs. 4VW for years with available data. (Dash equals no available data.)

	Ages												
Year	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12+**
1977	94,438	139,359	753,720	928,959	4,240,061	3,399,535	1,390,453	101,976	37,001	89,193	86,128	0	76,623
1978	309,919	612,901	2,295,972	1,723,525	1,351,693	1,840,790	1,251,246	416,019	216,296	51,713	19,155	61,148	0
1983	0	3,603,720	17,515,005	6,006,078	5,050,546	1,901,999	552,144	193,821	170,961	0	55,364	0	55,364
1984	0	301,253	6,110,317	6,733,495	5,048,219	4,516,783	3,186,124	905,574	0	121,669	37,318	46,147	132,971
2002	354,084	79,667	2,304,894	1,912,140	1,283,957	668,950	286,675	30,855	0	0	0	0	0
2003	0	552,143	2,889,331	2,376,087	2,398,975	761,937	154,016	0	0	0	0	0	0
2004	-	-	-	-	-	-	-	-	-	-	-	-	-
2005	0	456,160	3,839,065	2,509,710	4,125,995	1,201,844	54,389	35,280	0	0	0	0	0
2006	243,189	752,252	2,364,335	2,100,950	2,665,419	1,344,581	96,241	37,748	0	0	0	0	0
2007	123,164	894,126	3,763,623	2,183,372	1,849,278	666,575	83,010	82,449	0	0	0	0	0
2008	0	346,215	1,292,016	3,147,889	3,207,832	512,413	69,270	0	0	0	0	0	0
2009	0	249,164	1,870,622	2,519,442	4,549,734	1,571,871	144,360	59,030	0	0	0	0	0
2010	11,495	341,970	4,181,754	3,407,286	2,327,203	1,077,248	96,916	0	0	0	0	0	0
2011	10,278	536,138	2,305,781	2,013,096	2,764,597	1,132,501	131,367	26,917	13,974	20,194	32,052	0	0
2012	90,550	151,439	1,193,025	978,546	755,962	572,910	54,383	0	0	0	0	0	0
2013	9,567	58,369	1,431,909	1,481,259	1,211,078	649,160	148,307	0	0	10,552	0	0	0

Appendix Table A5. Estimated abundance (number of fish) of White Hake by size group (< 42 cm; ≥ 42 cm) in NAFO Divs. 4X5Zc and NAFO Divs. 4VW, 1970 to 2013.

	4X			4VW		
Year	**< 42cm**	**≥ 42 cm**	**Total**	**< 42cm**	**≥ 42 cm**	**Total**
1970	10,085,080	25,487,341	35,572,421	3,306,770	4,711,560	8,018,330
1971	2,871,032	2,837,640	5,708,672	3,265,468	1,479,743	4,745,211
1972	3,754,794	3,442,840	7,197,634	1,636,294	4,906,147	6,542,441
1973	7,696,383	17,675,923	25,372,305	4,044,973	3,569,197	7,614,169
1974	7,329,912	5,673,443	13,003,354	11,487,084	4,988,245	16,475,329
1975	21,301,426	14,690,759	35,992,185	3,831,493	2,569,325	6,400,818
1976	4,530,475	4,240,527	8,771,002	8,280,057	3,686,267	11,966,324
1977	3,780,773	6,535,216	10,315,989	4,500,008	6,803,427	11,303,436
1978	3,254,383	6,719,237	9,973,620	5,037,741	5,173,089	10,210,829
1979	3,473,257	4,227,303	7,700,560	2,148,354	2,105,168	4,253,522
1980	458,777	2,750,323	3,209,100	3,206,810	4,056,487	7,263,297
1981	3,148,130	7,073,995	10,222,126	15,416,680	12,311,362	27,728,042
1982	4,936,802	5,888,457	10,825,259	17,976,167	5,411,170	23,387,338
1983	11,494,141	28,720,602	40,214,744	30,030,039	5,040,193	35,070,232
1984	5,181,825	11,799,930	16,981,755	15,681,726	11,607,772	27,289,498
1985	4,981,974	9,805,687	14,787,661	24,699,895	19,381,250	44,081,145
1986	21,339,392	16,239,449	37,578,841	16,438,411	16,878,097	33,316,508
1987	6,764,447	13,761,786	20,526,233	6,090,931	6,199,083	12,290,014
1988	4,863,940	7,537,775	12,401,716	13,770,974	6,665,134	20,436,108
1989	5,831,741	7,277,007	13,108,747	18,616,133	4,990,175	23,606,308
1990	8,207,542	14,009,205	22,216,747	6,284,771	4,779,221	11,063,992
1991	15,960,685	14,591,655	30,552,340	6,260,648	4,018,794	10,279,442
1992	25,682,603	23,567,284	49,249,887	10,823,238	2,025,093	12,848,331
1993	7,184,912	8,598,416	15,783,328	9,730,963	2,671,887	12,402,849
1994	8,774,780	5,173,613	13,948,393	7,535,082	1,986,309	9,521,391
1995	8,476,705	10,977,861	19,454,566	13,942,465	1,574,501	15,516,965
1996	5,395,475	17,517,652	22,913,126	12,177,146	1,988,758	14,165,904
1997	3,144,914	4,079,090	7,224,005	21,363,308	3,288,634	24,651,942
1998	4,964,285	2,774,158	7,738,443	9,263,351	2,062,931	11,326,282
1999	4,763,283	4,579,231	9,342,514	5,796,510	1,533,268	7,329,778
2000	9,971,683	4,990,154	14,961,837	10,969,040	2,730,780	13,699,819
2001	3,477,473	16,326,015	19,803,488	13,720,471	3,320,247	17,040,718
2002	3,813,799	5,600,200	9,413,999	5,327,221	1,659,932	6,987,153
2003	3,331,099	2,831,888	6,162,986	7,800,720	1,486,040	9,286,760
2004	1,250,537	1,324,474	2,575,011	5,605,308	854,244	6,459,553
2005	6,503,208	7,172,190	13,675,398	8,829,151	3,404,112	12,233,262
2006	4,493,367	1,683,714	6,177,081	6,801,386	2,803,329	9,604,715
2007	4,234,442	2,940,593	7,175,035	8,169,592	1,476,005	9,645,597
2008	5,628,117	10,180,057	15,808,174	6,488,262	2,087,372	8,575,634
2009	9,005,782	10,009,714	19,015,496	6,643,836	2,874,926	9,518,761
2010	7,208,044	6,683,289	13,891,333	9,454,918	1,988,954	11,443,873
2011	3,043,441	5,036,095	8,079,535	7,138,518	1,848,376	8,986,894
2012	1,748,421	3,791,484	5,539,905	2,482,675	1,314,139	3,796,815
2013	4,280,459	4,026,982	8,307,441	3,431,773	1,568,428	5,000,201

Appendix Table A6. Estimates of slope of the catch curve for ages 5-7, associated statistics, and estimates of Z and confidence intervals for White Hake in NAFO Divs. 4X5Zc and NAFO Divs. 4VW. NaN values are not estimable because of too few (2) data points.

Year	Slope	Std Error	Prob (t)	Z	CI low	CI high
			4X5Zc			
1977	-0.54	0.22	0.25	0.54	0.11	0.96
1978	-0.39	0.30	0.42	0.39	-0.20	0.97
1983	-1.13	0.06	0.03	1.13	1.01	1.25
1984	-0.77	0.16	0.13	0.77	0.45	1.08
1998	-0.79	0.09	0.08	0.79	0.60	0.97
1999	-1.11	0.00	0.00	1.11	1.11	1.12
2000	-0.96	0.22	0.14	0.96	0.53	1.38
2001	-1.34	0.05	0.02	1.34	1.24	1.44
2002	-1.02	0.07	0.04	1.02	0.89	1.15
2003	-0.94	0.46	0.29	0.94	0.03	1.85
2004	-0.91	0.23	0.16	0.91	0.46	1.35
2005	-1.18	0.24	0.13	1.18	0.72	1.65
2006	-0.93	0.10	0.07	0.93	0.74	1.12
2007	-1.18	0.11	0.06	1.18	0.97	1.40
2008	-1.36	NaN	NaN	1.36	NaN	NaN
2009	-0.91	0.39	0.26	0.91	0.14	1.67
2010	-0.75	0.44	0.34	0.75	-0.11	1.61
2011	-0.80	0.03	0.03	0.80	0.74	0.87
2012	-0.44	0.49	0.53	0.44	-0.51	1.39
2013	-1.21	0.33	0.17	1.21	0.56	1.86
			4VW			
1977	-1.75	0.50	0.18	1.75	0.78	2.73
1978	-0.74	0.21	0.17	0.74	0.34	1.15
1983	-1.14	0.05	0.03	1.14	1.03	1.25
1984	-0.80	0.26	0.20	0.80	0.29	1.32
2002	-1.54	0.40	0.16	1.54	0.76	2.32
2003	-1.60	NaN	NaN	1.60	NaN	NaN
2005	-1.76	0.77	0.26	1.76	0.26	3.27
2006	-1.79	0.49	0.17	1.79	0.82	2.75
2007	-1.04	0.60	0.33	1.04	-0.13	2.22
2008	-2.00	NaN	NaN	2.00	NaN	NaN
2009	-1.64	0.43	0.16	1.64	0.80	2.49
2010	-2.41	NaN	NaN	2.41	NaN	NaN
2011	-1.87	0.16	0.06	1.87	1.55	2.19
2012	-2.35	NaN	NaN	2.35	NaN	NaN
2013	-1.48	NaN	NaN	1.48	NaN	NaN

Appendix Figure A1. Comparison of survey biomass (Survey) and biomass estimates using back calculation with Z (B2 w Z; = 0.5 for 4X, 1= 1.0 for 4VW) and using average proportions (B2 w prop) in NAFO Divs. 4X5Zc and Divs. 4VW.