Canadian Fishery Distribution, Index Analysis, and Virtual population Analysis of Pacific Hake, 2008

A. F. Sinclair and C. J. Grandin
Fisheries and Oceans Canada
Pacific Biological Station
Nanaimo, BC, Canada

Prepared for the 2008 joint Canada / USA Pacific hake stock assessment meeting in Seattle WA, February 11-14, 2008. This document is for the purposes of the assessment peer review process and represents a work in progress. The original document was amended in response to comments from the review process.

Abstract

The Canadian fishery distribution shifted in 2006 and 2007 with most of the catch taken in Queen Charlotte Sound, well north of the traditional fishing grounds off southwest Vancouver Island. Catch timing suggests hake may have migrated past the traditional location in late spring and returned in early fall. There was very little difference in the size and age distribution of the catches between north and south. The 1999 year-class dominated commercial catches in both years. The 1999 year-class has dominated catch of Pacific hake for several years. These results suggest that the fish caught in the north in 2006 and 2007 were mainly the offshore stock. However, the 2007 hydroacoustic survey caught a large number of age 1 year hake in the Canadian zone. This has not been seen before.

Analysis of the hydroacoustic survey abundance index at age indicated that the 1980, 1984, and 1999 year-classes were the largest year-classes in the population since the acoustic survey began in 1977. Two of the year-classes produced since the 1999 are estimated to be very small (2002 and 2004), the 2000, 2001, and 2003 year-classes were estimated to be below average. The 2005 year-class was estimated to be slightly above average. A qualitative analysis of the acoustic survey results indicated that hake are experienced a consistent rate of total mortality over the age range of 7-14. This supports the idea that recruitment to the acoustic survey is asymptotic An analysis of total mortality rate indicates the adults of the population have a total mortality rate of 0.48. The survey data alone do not indicate temporal patterns in total mortality, however the statistical power to detect such changes is limited. An analysis of relative fishing mortality at age, based on a combined analysis of the survey results and the commercial catch at age, indicates that hake recruit to the acoustic survey before they recruit to the commercial fishery. Secondly, fishing mortality reached an asymptote at age 4 and was consistent at older ages, suggesting that recruitment to the commercial fishery is asymptotic. Relative fishing mortality appeared to increase from the late 1970s to the late 1990s, then there was a decline, followed by an increase from 2003 to 2007.

Several formulations of virtual population analysis were undertaken. The results were in close agreement regarding temporal trends in spawning biomass, recruitment and fishing mortality. The results also suggested that recruitment to both the survey and fishery was asymptotic. However, the scale of estimates and the magnitude of forecast catches was sensitive to the formulations. Two issues of concern were described. The first had to do with how estimates of fishing mortality at age were distributed and the associated estimates of fishery selectivity. The second had to do with high estimates of target fishing mortality (F40%). Catch forecasts are provided consistent with the 40/10 rule. Alternative forecasts at a *status quo* fishing mortality are also provided.

These analyses have revealed several important assessment uncertainties. Management procedure evaluation is an approach that could be used to gain a better understanding of how to assess this stock in the future.

Introduction

The Pacific hake, also referred to as Pacific whiting (*Merluccius productus*) is a transboundary stock which is jointly managed by Canada and the USA. A treaty dealing with joint management was signed in 2003. The treaty specifies a number of committees and procedures for stock assessment and management. However, these are yet to be fully implemented. In the mean time, scientists from the USA and Canada have endeavored to continue the assessment process “in the spirit of the treaty”.

Canadian fishery managers prepared a request for advice on this stock in advance of the 2008 assessment meeting (Appendix 1). The request indicates concern that recent catch advice for the stock was well above the historic maximum catch when the population was dominated by a single year-class which is declining in biomass. The managers asked that alternative assessment methods be considered in order to provide more certainty about projected catches. There has been a recent shift in the location of the fishery in Canadian waters from the traditional area off southwest Vancouver Island to a more northerly location in Queen Charlotte Sound. Managers have asked for additional information about the stock structure of hake that were caught in the northern area.

This working paper addresses the request for advice. There are three main sections. The first provides a description of the recent changes in distribution of the Canadian fishery along with a comparison of the size and age compositions of hake caught in the traditional and new area. The second section presents an analysis of the basic assessment input data “on their own”, before they are used in a more complex stock assessment model. This analysis is focused on structural information regarding relative year-class size, mortality rates, and selectivity patterns. The third section presents a virtual population analysis (VPA) of the stock. The “on their own” and VPA analyses used the same input data as were used in the other two stock assessment models presented at this 2008 meeting, SS2 and TINSS.

Recent Changes in the Canadian Pacific Hake Fishery

The commercial fishery catches for Pacific Hake are monitored by on-board observers or the landings by shoreside observers. Random samples are taken at sea and from the conveyors which carry fish to the processing plants. Lengths and weights are recorded, and otoliths taken for age determination from a subset of the sampled fish. The otolith samples are aged using either break and burn or surface ageing methods. Samples are either age-length or length only but are random and representative of the length and age composition of the population.

The following approach was used to calculate the length and age composition of all Canadian commercial catches based on the collected within strata fleet and year (Gavaris and Gavaris 1983). It begins by applying. The weights of individual samples are then calculated using the allometric equation (1), where $\alpha = 7e-6$ and $\beta = 2.9624$ and equations (2) and (3). An estimate of the number of fish in a sampled catch is produced (equation (4), (6)). This number is multiplied by the ratio of the weight of all catches to the sum of the weight of the sampled catch (equations (5), (7)) to give numbers at length and numbers at age and length respectively. An age-length key is then produced using equation (8). The age-length key is multiplied columnwise by the length frequency to give numbers at length and age (equations (9), (10)).

a	age
l	length
m	sample
fy	stratum (fleet and year)

n	number sampled for length
n'	number sampled for age and length
N	number caught in sampled catches
$\dot{N}$	number caught in all catches
w	sample weight
W	weight of sampled catches
B_{fy}	weight of all catches for fleet f in year y.
P_{lfy}	length frequency proportion by fleet f and year y
α	coefficient of the allometric relationship
β	exponent of the allometric relationship
ϖ	predicted weight of a fish from an allometric relationship
n_{lmfy}	number of fish in a length-only sample at length l in sample m taken in fleet f for year y.
n'_{almfy}	number of fish in a length-age sample at age a, length l in sample m in fleet f for year y.

Weight at length l

(1) $$\varpi_l = \alpha\, l^{\beta}$$

Weight of sample m in fleet f for year y

(2) $$w_{mfy} = \sum_l n_{lmfy}\varpi_l \qquad \text{for a length-only sample}$$

(3) $$w_{mfy} = \sum_l n'_{almfy}\varpi_l \qquad \text{for a length-age sample}$$

Number of fish at length l in sample m in fleet f for year y

(4) $$N_{lmfy} = n_{lmfy}\frac{W_{mfy}}{w_{mfy}}$$

Number of fish at length l caught in all catches in fleet f for year y

(5) $$\dot{N}_{lfy} = \sum_m N_{lmfy}\frac{B_{fy}}{\sum_m W_{mfy}}$$

Number of fish at age *a* and length *l* in sample *m* in fleet *f* for year *y*

(6) $$N_{almfy} = n'_{almfy} \frac{W_{mfy}}{w_{mfy}}$$

Number of fish at age *a* and length *l* caught in all catches in fleet *f* for year *y*

(7) $$\dot{N}_{alfy} = \sum_m N_{almfy} \frac{B_{fy}}{\sum_m W_{mfy}}$$

Proportions of fish at age *a* given a length of *l* in fleet *f* for year *y*

(8) $$P_{a|lfy} = \frac{\dot{N}_{alfy}}{\sum_l \dot{N}_{alfy}}$$

If only age-length samples were taken

(9) $$\dot{N}_{afy} = \sum_l \dot{N}_{alfy}$$

If both age-length and length only samples were taken. Note, $\dot{N}_{lfy}$ would include age-length samples.

(10) $$\dot{N}_{afy} = \sum_l \dot{N}_{lfy} P_{a|lfy}$$

Changes in the spatial and temporal distribution of catch in the Canadian fisheries

The spatial distribution of hake catches in Canadian waters was analysed by minor statistical areas (Figure 1).The commercial fisheries before 2006 took most of their catch from minor area 23, also known as Big Bank (Figure 2). Commercial fishing in 2006 and 2007 shifted northward into minor statistical areas 8 and 11, well north of Vancouver Island (Figure 3). The JV fishery shows a similar pattern.

Cumulative catch trajectories for combined commercial catch reveal that before 2006, almost all catch, ~300,000 t, was taken from area 23, Big Bank (Figure 4). Fishing typically occurred there at a fairly constant rate from days 140 to 300 of the year (April 20 – November 1). In 2006 and 2007, however, most of the catch was removed from areas 8 and 11, much further north (Figure 5). Figure 6 shows cumulative proportion of catch for commercial fisheries prior to 2006, commercial fisheries for 2006 and 2007, and survey catch for 2007. Southern areas show a major change in the timing of the fishery, it appears that in 2006 and 2007 vessels tried fishing in area 23 around days 110-150, and then moved to the north due to lack of catch. Areas 8 and 11 show an earlier fishery for 2006 and 2007 and there was another flurry of catch in area 23 in September, implying that the catch for these years was not taken from area 23 until the stock began their migration back southward.

The age-length compositions and distributions of all commercial catches for years prior to 2006 were calculated using the above methods. For these plots, north is considered to be minor areas 1-9, 11, 31, 34, and 35 (see Figure 1). Southern areas include minor areas 20, 21, and 23-27. The fishery was mainly southern-based (Figure 7 and Figure 8) during the years prior to 2006, with catch numbers being an order of magnitude larger in the south; also the northern hake were generally younger and smaller than the southern hake. The northern domestic catch in Figure 3 is mainly located in Goletas Channel (area 11, northeast Vancouver Island), which may suggest either that some of the gulf stock was being caught or that some of the offshore stock missed their southward migratory path (Workman pers. comm.). Gulf hake are generally smaller at age than those in the offshore stock (Mcfarlane and Beamish 1985). The 1999 year class is distinct in both age compositions for 2006 and 2007 with slightly larger fish in the north (Figure 9 and Figure 10).

The acoustic survey has seen a dramatic difference in composition in 2007 (figures 11-14). The northern catch from 1999 to 2006 has been unimodal, at lengths 46-48 cm, or ages 6 and 7 (Figure 11). The 1999-2006 southern catch also has one length mode, 46 cm, and two age modes, 4 and 6 (Figure 12). The 2007 age and length compositions can be seen in and. The acoustic survey age composition was bimodal in the north in 2007, with the majority being age 8, but with a very large age 1 group (Figure 13). The southern age composition in 2007 was dominated by age 1 hake with a small number of age 8 fish (Figure 14). The acoustic survey was fishing in the southern areas before the commercial fisheries took most of their catch (Figure 6), which may explain the difference in age-length compositions between the acoustic survey and commercial fisheries for the southern areas (Figure 10 and Figure 14).

Hallowed 1992 notes that there has been evidence of spawning in more northern waters in the past. The National Marine Fisheries Service has found hake eggs as far north as the coast of Washington state (Hallowed 1992) and Workman (pers. comm.) has found them off the west coast of Vancouver Island. McFarlane is undertaking a comparative DNA/parasite survey in February 2008 to determine if the hake being caught in the north are of the gulf or offshore variety (McFarlane pers. comm.). The gulf stock differs genetically from the offshore stock and lack the parasite *Kudoa paniformis*, which causes offshore hake flesh to rapidly degrade (McFarlane and Beamish, 1985).

Analyses of the Acoustic Survey and Fishery Catch at Age Data for Pacific Hake "On Their Own"

Catch advice for Pacific hake has been based on the results of an SS2 stock assessment model for a number of years. Model input includes total catch weight, proportional catch at length and conditional proportions at age given length for the USA and Canadian fisheries (separately), as well as a biomass index, proportional catch at length, and conditional proportions at age given length from an acoustic survey.

Model estimates presented in last year's assessment were highly sensitive to changes in model structure (Helser and Martell 2007). Two catch options were presented that varied only in assumptions regarding survey catchability, one assumed catchability of 1.0, the second used a prior distribution with a mean of 1 and a standard deviation of 0.10. Both model formulations gave spawning stock biomass estimates for the final year of the assessment to be near the lowest previously observed, however the advised catches were 1.6 and 2.4 times the highest catch previously observed. Other trial model runs indicated similar sensitivities. It is not clear why the outputs are so sensitive to relatively minor changes in assumptions.

The SS2 model estimates age-dependent selectivity patterns to the USA and Canadian fisheries as well as to the acoustic survey. The estimated selectivity patterns were strongly dome shaped, with full selection at intermediate ages and a sharply declining selectivity at older ages. If true, this indicates there is a substantial biomass of mature hake somewhere in the system that are not exploited by the fishery and not counted by the acoustic survey. It was suggested that older fish may be close to bottom and not available to the mid-water gear commonly used in the fishery and survey (Helser and Martell 2007). This was supported by a comparison on age composition data from the USA triennial bottom trawl survey and the acoustic survey by. However, the estimated selectivity patterns had a significant effect on catch forecasts and it was not clear if they were real or an artefact of model misspecification. The direction of the bias appears to be toward overoptimistic results, and the consequences on the resource could be devastating.

The intent of this section is to apply simple techniques to the input data to gain insight into population processes such as year-class strength, total mortality, selectivity to the survey and commercial fishery. These estimates may then be compared to assessment model estimates of the same of similar quantities.

Catch at Age by Fleet and Year

These analyses require estimates of catch at age in the commercial fisheries and in the acoustic survey. The required data may be found in the input data file for the SS2 model. There are 3 fleets (*f*), USA commercial fishery, Canada commercial fishery and the acoustic survey. Annual (*y*) catch weights for each commercial fleet and annual acoustic biomass index for each year a survey was conducted are available (B_{fy}). We have assumed that the length frequency vectors used as input to the assessment model are representative of the annual length frequency of the fleet specific catch, and that the conditional proportions at age given length used as input to the assessment model are also representative of the fleet specific catch. These data were obtained from the SS2 input file presented at this meeting.

We have length frequencies for each fleet and year, expressed as proportions P_{lfy}. There is an allometric equation used to estimate the weight of an individual fish of a given length

$$\overline{w}_l = \alpha l^{\beta}$$

where

where $\alpha = 7e-6$ and $\beta = 2.9624$ are the allometric growth coefficients. The mean weight of fish in a given length frequency can be found as

$$\overline{w}_{fy} = \sum_l \overline{w}_l P_{lfy} .$$

We have tables giving conditional proportions at age for a given length for each fleet and year $P_{a|lfy}$. The proportions at age for the fleet and year may be found as

$$P_{afy} = \sum_l P_{lfy} P_{a|lfy} .$$

The number of fish in the catch by fleet and year is

$$C_{afy} = \frac{P_{afy} B_{fy}}{\overline{w}_{fy}} .$$

I will use a slightly different notation for the acoustic survey index of abundance at age,

$$I_{ay} = C_{afy} \quad where\ f = acoustic\ survey .$$

The mean length at age is

$$\bar{l}_{af} = \frac{\sum_l P_{lfy} P_{a|lfy} l}{P_{afy}}$$

and the mean weight at age is

$$\overline{w}_{af} = \frac{\sum_l P_{lfy} P_{a|lfy} \overline{w}_l}{P_{afy}} .$$

Multiplicative Analysis of the Survey Index

Fish abundance surveys are designed to give a consistent index of population abundance at age through time. In order to be effective, the design must attempt to maintain constant catchability at age over time. Catchability (*q*) is the ratio between the survey index (*I*) and the population abundance (*N*) such that

$$I_{ay} = q_a N_{ay}$$

That survey catchability is lower at younger ages is clear from the fact that the index values for younger ages are often lower than the index for the same cohort at older ages. However, if we follow the index for a cohort at successive ages, the index usually reaches a maximum value then declines at older ages. This decline will be due at least in part to declining cohort numbers due to mortality. This rate of mortality is of primary interest in stock assessment. However, the decline may also reflect declining catchability at older ages, or migration out of the survey area. There are also interannual variations in the survey indices that can be attributed to sampling variability and changes in fish behaviour. To be effective, the design must attempt to minimize these extraneous effects on the index if it is to be useful for stock assessments.

Let's assume that the hydroacoustic survey for hake has been successful in minimizing interannual variations in catchability at age. The following analysis was introduced to AS by John Shepherd at an ICES assessment methods meeting in 1985. It has been used it in many Atlantic cod stock assessments, for example Sinclair et al. 1998. The survey index may be analysed with a separable model

$$\ln I_{ay} = \beta_0 + \beta_1 A + \beta_2 R + \varepsilon_{ay}$$

where *A* is a class variable for age and *R* is a class variable for year-class. β_0 is a scalar intercept term, β_1 is a vector for age effects with a length of the number of ages in the index less one, and β_2 is a vector for year-class effects with a length of the number of year-classes in the index less one. ε_{ay} is the residual, assumed to normally distributed. A general linear model may be used to estimate the parameters and least square means (LSM) may be estimated to represent the average index value for each age and each year-class, adjusted for all other model effects. The LSM of age can be used as an average catch curve for the index. The LSM value will increase with age as fish recruit to the survey. The declining pattern with respect to age will be affected by total mortality and the availability of older ages to the survey. The slope of the declining limb will increase as total mortality increases, i.e. as the fish recruit to commercial fisheries. If the declining limb becomes linear with respect to age, this indicates a constant total mortality rate, full recruitment to fishing and to the survey. If the slope of the declining limb continues to increase, this may indicate the fish are becoming less available to the survey, i.e. declining catchability with age. The LSM of year-class can be used as an index of relative year-class strength. It should be noted, however, that variations in total mortality during the survey period will be absorbed in the index and while the LSM values may represent averages, they will not reflect changes in conditions throughout the survey time period. Systematic interannual differences may be reflected in model residuals.

Estimates of Total Mortality From Acoustic Survey Results

A modified catch curve analysis can be used to estimates total mortality rates using the acoustic survey results (Sinclair 2001). The model is an analysis of covariance with year-class as a categorical variable and age as a continuous variable.

$$\ln I_{ay} = \beta_0 - Za + \beta_2 R + \varepsilon_{ay}$$

This is a traditional catch curve modified with separate intercepts for individual year-classes. The parameter Z is an estimate of the instantaneous rate of total mortality. To be accurate, the analysis must be performed over a range of ages where total mortality is constant and where the age classes are fully recruited to the survey. Residual patterns vs. age may be examined to select an appropriate age range.

Relative Fishing Mortality at Age and Selectivity

Sinclair 1998 described a method for examining trends in fishing mortality using a relative index obtained from the ratio of catch at age divided by survey estimates of abundance at age. Annual fishing mortality (*F*) at age may be expressed as a separable function of the annual fully recruited fishing mortality (F_y) and selectivity at age (s_a). Fishing mortality is also the ratio between catch at age and mean population numbers at age (Ricker 1975). The final part of the equation below is obtained by substituting the catchability adjusted survey index for mean population size.

$$F_{ay} = s_a F_y = \frac{C_{ay}}{\overline{N}_{ay}} = \frac{C_{ay} q_a}{I_{ay}}$$

Rearranging, we get

$$\frac{C_{ay}}{I_{ay}} = \frac{s_a}{q_a} F_y$$

This can be expressed as a multiplicative analysis for statistical estimation.

$$\ln\left(\frac{C_{ay}}{I_{ay}}\right) = \beta_0 + \beta_1 A + \beta_2 Y + \varepsilon_{ay}$$

The coefficient vector β_1 will express the combined effects of catchability and selectivity. Over a range of ages where survey catchability is constant, this vector is an estimate of fishery selectivity. The coefficient vector β_2 is an estimate of interannual variation in fishing mortality.

Results of Index Analyses

Multiplicative Analysis

The main effects age and year-class were statistically significant in the multiplicative analysis (Table 1) and the assumption of normal distribution of residuals was not violated (Figure 15). Interannual variation in model residuals (Figure 16) indicates that the 1989 and 2001 surveys had anomalously low estimates. The 1986 estimates did not stand out as being anomalously high as was thought in previous assessments. Apart from apparent year effects, there did not appear to be a systematic temporal trend in annual residuals.

The three largest year-class estimates in the time series were the 1980, 1984, and 1999 respectively (Figure 17). The year-class estimates tended to be higher for year-classes from the 1960s and 1970s than for those since 1985. The estimate for the 2005 year-class was relatively large, however this was considerably lower than the 1999 year-class and it was from a single observation in the 2007. The estimates of the 2002 and 2004 year-classes were among the smallest in the time series. There is also only one estimate of the 2004 year-class.

Adult Total Mortality Rate

A number of preliminary analyses were conducted to identify the age range over which the rate of total mortality appeared to be constant. The test was to examine the residual pattern with respect to age and find the age range where there was no pattern. Each analysis used up to age 14 fish, and began with ages 4 – 7 respectively. The results indicated the most favourable pattern was with the analysis for ages 7-14 (Figure 18). The other analyses produced dome-shaped residual patterns.

As with the multiplicative analysis, the main effects are and year-class were statistically significant in the analysis of total mortality for ages 7-14 (Table 2). In this case, however, the independent variable age was a continuous variable. The assumption of normal distribution of residuals was not violated (Figure 19). The interannual distribution of residuals was similar as that for the multiplicative analysis and is not shown here. A test for an interaction between age and year-class was not statistically significant, and we could not reject the hypothesis of constant total mortality rates among year-classes. However, the power of this test was very low due to the low number of estimates for each year-class (between 2 and 4 estimates each), with the lowest least significant difference of 0.40. A second analysis tested for differences in total mortality between the early (1977 – 1992) and later (1995 – 2007) periods of the survey. This also indicated no significant difference. A power test indicated the least significant value given the number of observations was 0.29.

The total mortality estimate for the entire period was $Z = 0.48 \pm 0.09$, about twice M.

Relative Fishing Mortality and Selectivity

The main effects age and year were statistically significant in the analysis of relative fishing mortality at age (Table 3). The assumption of residual normal distribution was not violated (Figure 20).

Estimates of relative fishing mortality at age, retransformed to the arithmetic scale, are shown in Figure 21. The lowest estimate was for age 2 followed by age 3. This is because the relative abundance of these two age groups was consistently higher in the acoustic survey than the commercial catch at age. The relative F estimates for ages 4 and above were relatively consistent. The estimate for age 12 was higher than the others, but this leveraged by a high estimate in 1995. Overall, the pattern of relative f at age indicates similar fishing mortality at ages 4-14, and thus asymptotic selectivity to the commercial fishery.

The trend in relative fishing mortality by year indicates large values in 2001 and 1989 (Figure 22). As noted earlier, the residual distributions for other analyses of the survey data alone suggested the survey estimates for these two years were lower than expected. This would inflate the estimates of relative F. If these two estimates (2001 and 1989) are discounted, the tend indicates an increase in fishing mortality from 1977 to 1998, a subsequent decline, then another increase from 2003 to 2007.

Virtual Population Analysis

Virtual Population Analysis (VPA) is a well recognized age structured stock assessment method widely used throughout the world. Input data include catch at age estimates for a suitably long time period to allow reasonable calibration and an index of population abundance, preferably at age. Catch at age is assumed to be known without error. The leading parameters include a single estimate of population abundance for each year-class in the analysis and a catchability relationship relating the population estimates to the index. The leading population estimates may be at any age within the year-class and the algorithm proceeds to estimate abundance at all younger and older ages within the year-class. It is common practice to begin with population estimates at age in the final year of the analysis and at the oldest age in the analysis, however the choice of which ages to begin with has no effect on the model estimates. Early versions of VPA employed *ad hoc* methods for fitting. Gavaris 1988 introduced ADAPT, a statistically based fitting method. Subsequent enhancements to the software included approximation of the parameter covariance matrix and estimates of parameter bias (Gavaris 1993). Documented software is available at (http://www.mar.dfo-mpo.gc.ca/science/adapt/adapt-e.html). ADAPT uses the Baranov catch equation and not the so called cohort approximation of Pope 1972. There are various options regarding the functional form of the relationship between the population abundance and the index (i.e. catchability). We have assumed that the index is proportional to population abundance and estimate separate catchability for each age. Residual variance is stabilized using a natural log transform. The software also produces risk analysis of a range of catches on forecast fishing mortality, changes in biomass, and terminal biomass relative to specific targets or limits.

Common Formulation

Input Data
- Catch at age 2 – 15+, 1977-2007
  - (note, catch at age 14 = 0 in 2001 and 1985, age 15+ is a plus group)
- Acoustic survey relative abundance at age 2 – 14

Objective Function
- Minimize sum of squared residuals

Parameters
- Acoustic Survey catchability
  - q_i, i = 2 to 12, combined 13 and 14
- Terminal N estimates
  - $N_{i,2008}$, i = 3 to 12

Structure Imposed
- Error in catch at age assumed negligible
- M known and 0.23
- Survey assumed to occur on June 30

Summary
- Number of observations to fit 150

Run Formulations

A number of alternative run formulations were used to examine the sensitivity of catch forecasts to structural assumptions. These alternative formulations focused on the number of year-classes that were directly estimated and the rule used to assign fishing mortality to the oldest age group. VPA is notorious for having difficulty directly estimating all year-classes. The “average F” rule is widely used as a way around these difficulties. however, the rule implies an assumption about fishery selectivity in the years it is applied. In Run 1, it was assumed that selectivity was asymptotic with full recruitment at age 7. The oldest age F was estimated as the population numbers weighted mean of ages 7+ in the same year. Run 2 assumed full recruitment occurred at age 4, and in run 3 it was assumed that the F on the oldest age was equal to the weighted mean of the last 2 ages. Note that the catch at age 14 was 0 in 2001 and 1985. Thus, the initial year-class estimates had to be made at age 13, and in run 3 the average F at ages 11 and 12 in the same year was used. In all other cases, the average at ages 12 and 13 were used. Note also that in the case of run 3, selectivity was not constrained to be asymptotic.

W were able to explore an alternative formulation where more year-classes were estimated directly. It was found that the relatively large 1977, 1980, and 1984 year-classes could be estimated directly. In addition, the year-classes beginning at age 14 in 2003 – 2007 could also be estimated. The advantage of this formulation was that it minimized the influence of any assumptions regarding selectivity on the terminal population estimates. Unfortunately, this last formulation was not possible for run 3.

Run	Additional Parameters	Structural Options	Number of Parameters
1		F_T =wt average 7+	22
1A	$N_{i,2008}$, i = 13-14 $N_{y,14}$, y = 1991, 1994, 1998, 2003-2007	F_T =wt average 7+	32
2		F_T =wt average 4+	22
2A	$N_{i,2008}$, i = 13-14 $N_{y,14}$, y = 1991, 1994, 1998, 2003-2007	F_T =wt average 4+	32
3		F_T =wt average 12+	22

Reference Points for Advice

Canada has been a strong proponent of the management principles outlined in the United Nations Fish Stock Agreement (UNFSA - also commonly referred to as UNFA) that it ratified in the fall of 1999. The Agreement came into effect in December 2001, and amongst other things, it requires countries to use the Precautionary Approach (PA) in the management of fisheries. At about the same time, the Privy Council Office (PCO) of the Government of Canada developed the Federal Framework for the precautionary approach to ensure that precaution would be applied consistently across disciplines in the government. The framework became government policy in 2003. Over the last few years, benchmarks have been identified that would be consistent with the approach and that may be applied in fisheries management. A harvest strategy compliant with the PA was described in DFO 2006.

The harvest strategy prescribes three stock status zones divided by two stock status reference points. The Limit Reference Point (LRP) is the stock level below which productivity is sufficiently impaired to cause serious harm to the resource but above the level where the risk of extinction becomes a concern. The zone below the Limit reference point is called the Critical zone. The Upper stock reference point is the stock level threshold below which the removal rate is reduced. The stock status zone above the Limit reference point but below the Upper stock reference is called the Cautious zone. The stock status zone above the Upper stock reference is called the Healthy zone. The harvest strategy also includes a Removal reference designed to scale resource exploitation to stock status. In the healthy zone, the exploitation rate should be moderate and designed to meet social, economic, and biological objectives of management. In the cautious zone, the removal reference declines as status declines and management actions should promote stock rebuilding toward the Healthy Zone.. In the Critical Zone, management actions must promote stock growth. Removals by human activities must be kept at the lowest possible level.

The F-40 percent with a 40/10 adjustment harvest control rule (40/10 rule) that has been used for Pacific hake in past assessment has qualities similar to the Canadian PA compliant harvest strategy. The 40/10 rule specifies a maximum constant harvest rate when the population is above 40% of the unfished equilibrium, a reduction in harvest rate when the population is below this biomass, and essentially a 0 harvest rate when the population is below 10% of the unfished equilibrium. Canadian fisheries managers have requested catch advice using the 40/10 rule. However, they have added the provision "but not restricting the provision of scientific advice on alternate rates necessary to sustain the offshore hake resource", similar to wording the new Hake Treaty.

The following biological reference points relevant to the Canadian PA compliant harvest strategy, were used. Input data for reference point calculations include

- weight at age at the beginning (spawning) and middle of the year (catch) calculated as the means for the period 2003-2007.
- maturity at age was taken from Dorn et al. 1999.
- fishery selectivity at age calculated as a logistic fit to the population number weighted mean fishing mortality at age over the period 2003-2007.

The maximum removal reference was the fishing mortality that gave 40% of the maximum spawning stock biomass per recruit (F40%). A proxy estimate of the unfished equilibrium spawning stock biomass (B_0) was the average recruitment multiplied by the maximum spawning stock biomass per recruit, and a proxy for the upper stock reference was 40% of the unfished biomass. The 40-10 adjustment was applied if the 2008 spawning stock biomass was estimated to be below $0.4 B_0$. The procedure was

1. Calculate the yield corresponding to F40%
2. Calculate the 2008 depletion as $dep = \frac{B_{2008}}{B_0}$

3. Calculate an adjustment as $\frac{4}{3}\left(\frac{dep-.1}{dep}\right)$
4. Multiply the adjustment by the yield estimated with F40% to get the 40/10 adjusted yield
5. Find the fishing mortality that would give this yield

While the SPR based reference points are widely used, and this framework complies with the PA, we found that our estimates of the target fishing mortality rate (F40%) were very high. An alternative approach was to do the catch forecast at a *status quo* fishing mortality, estimated as the average over the past 5 years. This is suggested as an interim measure to be used until the entire management procedure can be evaluated.

Results of Virtual Population Analysis

Parameter estimates from the 5 model runs are given in Table 7 and Table 8. The goodness of fit, summarized my the mean square residual, indicated that runs 1 and 2 had similar fits and that run 3 was slightly poorer fit. With additional parameters, runs 1A and 2A also had similar mean square residual. We were unable to fit the additional parameter equivalent of Run 3. The population parameter standard errors were quite high, in several cases being of similar magnitude as the estimates. The parameter bias estimates were also relatively high. All of these observations indicate a relatively parameter uncertainty.

Diagnostic plots of observed, predicted, and residual values provided had similar patterns among the various runs. Plots from Runs 1A are shown for illustration. The large 1980, 1984, and 1999 year-classes dominated the observed and predicted survey time series (Figure 24). The spread of residuals by age was consistent, with slightly more spread at older ages (Figure 25). However, this was not sufficient in our opinion to attempt iterative weighting of the age specific observations. There were strong year effects in the model residuals (Figure 26) with the 1989 and 2001 surveys being dominated by negative residuals, and the 1977, 1980, and 1986 surveys dominated by positive residuals.

A retrospective analysis was performed on Run 1 as a check for model stationarity when single year's data are eliminated from the VPA. The last data year in this assessment is 2007. Additional runs were performed with 2006 – 2001 as the last data years. We attempted to maintain the same model formulation for these additional analyses. The number of ages that could be estimated in the terminal year depended upon the proximity of the last survey year to the terminal year. There was information on the 2005 year-class in the 2007 acoustic survey and the 2007 catch at age, and thus the leading parameter for this year-class was age 3 in 2008. However, the youngest year-class for which there was a survey estimate in the 2005 survey was the 2003. Consequently, this was also the youngest year-class that could be estimated as a leading parameter in both the 2006 and 2005 assessments. In addition, this model formulation did not produce a reasonable solution for the analyses ending in 2001 and 2002. The formulation was changed slightly to accommodate this. It should be noted that in these 2 analyses, the 2001 survey provided the most influential points in the VPA calibration. As noted earlier, diagnostics indicated that the 2001 survey estimates appear to be anomalously low. The model formulations are summarized in Table 9.

The retrospective estimates of spawning stock biomass, fishing mortality, and recruitment converged to stable values in the early part of the time series (Figure 27). The estimates for 2003 – 2007 model runs were very similar and did not deviate in any consistent direction. However, the 2002 and 2001 runs gave lower biomass and recruitment estimates, and higher fishing mortality estimates. The 2001 acoustic survey results were the most influential calibration data in these two runs, and previous diagnostic information suggested that these estimates were anomalously low. Overall, the retrospective estimates were remarkably consistent given the overall variability of the acoustic survey results.

The 5 ADAPT runs gave very similar time trend estimates of spawning stock biomass, fishing mortality, and recruitment (Table 10, Figure 28). The temporal correlations in estimates among runs was highest for the recruitment estimates with the 1980, 1984, 1999, and 1977 year-classes being consistently estimated as the four highest in the time series. The trend in spawning stock biomass had an initial increasing trend with the recruitment of the 1980 and 1984 year-classes, reaching a peak in 1987. This was followed by a decline until 2000 as these two large year-classes declined in biomass. There was another period of increase as the 1999 year-class recruited to the spawning population. This peaked in 2003 and there was a decline to 2008. The highest estimates of SSB come from run 2. The difference in annual SSB estimates between runs 1 and 2 were considerably higher than between runs 1A and 2A (Figure 29). It is interesting to note that there was greater variation among the SSB trends during the initial period of the VPA than in the last years. This is unusual since VPA estimates tend to converge in the historical period as the integrated catch becomes the dominant portion of the population estimate. In this case, convergence is limited due to low estimates of fishing mortality in the early period.

The fishery selectivity pattern was estimated from estimates of fishing mortality at age. However, there are two disconcerting patterns apparent in these estimates (Figure 30). The first is that, in all runs, the fishing mortality estimates on the plus group (age 15+) were considerably lower than those at age 14. The second is a diagonal pattern indicating year-class tracking. However, the fishing mortality estimates on the large 1980 and 1977 year-classes were considerably lower than those on adjacent ages in the same years. If real, this means the fishery selectively avoided these large year-classes. Then, the fishing mortality estimates on the 1984 year-class at ages 10 and above were greater than on adjacent ages in the same year. These patterns may also be reflective of ageing errors that have not been accounted for, or possibly changes in natural mortality. At this point, we cannot fully explain these patterns. And, it adds considerable uncertainty to estimates of selectivity.

With the exception of the low fishing mortality estimates on the plus group, the selectivity pattern appears to be asymptotic. The selectivity at age was estimated by fitting a logistic curve to the mean fishing mortality at age for the period 2003-2007. Selectivity curves from the 5 ADAPT runs are shown in Table 11 and Figure 31. The pattern for Run 3 showed a continuous increase across age. This is the run where the selectivity pattern was the least constrained. However, it is highly unlikely that this represents the true selectivity pattern given the growth of Pacific hake making age groups indistinguishable from each other by length after about age 4. As was the case with SSB, the selectivity patterns for runs 1A and 2A were very similar.

These selectivity patterns were used as input for yield per recruit and spawning stock biomass per recruit calculations. The estimated F40% SPR were very high (

Table 12) ranging from 0.55 for Run 2 to 1.02 for Run 1A, or 2.4 to 4.4 times natural mortality. All of these F reference points were above the maximum value in the respective time series. Each run 2008 SSB estimate was below the respective B40 proxy and thus the 40/10 adjustment was applied. Each adjusted forecast fishing mortality was also above the respective time series maxima (Table 13). These high reference fishing mortalities are largely due to the difference between the maturity at age and the selectivity at age. According to these estimates, hake mature well before they recruit to the fishery, thus it takes high fishing mortalities to reduce the spawning stock biomass per recruit to 40% the unfished value.

Yield forecasts with the 40/10 adjustment from the 5 runs ranged from 282,000 t (Run 3) to 472,000 t (Run 2) (Table 13, Figure 32).

Two things about the 40/10 rule catch forecast are counterintuitive. The first is that the reference fishing mortalities are between 1.3 (Run 3) and 1.9 (Run 2A) times higher than the fishing mortality estimate in 2007. The 2007 fishing mortality was the highest in each time series with the exception of Run 2 where it was 90% of the highest. It seems dangerous to advise such a large increase in fishing mortality on a population at the lowest spawning biomass on record. Secondly, the estimated F40% was between 2.4 (Run 2) and 4.4 (Run 1A) times the assumed natural mortality rate. This is well outside the rules of thumb of optimal fishing mortality being close to the rate of natural mortality.

An alternative catch forecast rule is to use the recent average fishing mortality instead of the 40/10 rule. This is an interim measure that could be used until a more satisfactory approach can be found (see discussion below). The advantage of such an approach is that it avoids the large increase in fishing mortality suggested by the 40/10 rule. Catch forecasts using the *status quo* rule ranged from 200,000 t (Run 1A) to 257,000 t (Run 2) (Table 14).

Model Selection

Of the 5 ADAPT model formulations, Run 3 may be the easiest to eliminate as a candidate for providing catch advice. For the same number of parameters, it has the highest mean square residuals. The selectivity pattern indicated by F at age in the most recent period was the least plausible of any examined. Model Run 1 and 1A had slightly lower mean square residuals than their counterparts, Run 2 and 2A. The selectivity pattern from these runs were the closest to the assumption used to estimate F on the oldest age. More year-classes were directly estimated in Run 1A than in Run 1 and thus Run 1A was the least constrained by the oldest age F assumption. Thus, if one had to choose among these 5 model runs, Run 1A seems the best. Population and fishing mortality estimates are given in Table 15 and Table 16.

Estimated trends in recruitment, biomass, and fishing mortality from Run 1A are compared to the catch history in Figure 33. Catches were initially in the 100,000 – 150,000 t range and fishing mortality was relatively low. It is clear that the 1980 and 1984 year-classes were major contributors to the increase in biomass in the early to mid 1980s. Catches increased to around 300,000 t in the late 1980s, and the stock biomass declined as the 1984 year-class passed through the population. Catches remained relatively high and fishing mortality increased. The arrival of the 1999 year-class and a reduction of catches to around 200,000 t in the early 2000s resulted in a decline in fishing mortality and an increase in biomass. This increase was short lived as catches and fishing mortality increased again and biomass has now declined to the lowest in the time series.

The deterministic catch forecast from Run 1A, using the 40/10 adjustment, gives a 2008 catch of 332,000 t. A risk analysis of the 2008 catch forecast considered three performance measures, the probability of the 2008 fishing mortality being above the F40/10, the probability of the spawning stock biomass declining between 2008 and 2009, and the probability of the 2009 spawning stock biomass being below 25% of the unfished equilibrium (Figure 34). Arbitrary levels of probability for risk averse (25%) and risk neutral (50%) decision making are suggested. For the fishing mortality performance measure, the risk averse catch for 2008 is 90,000 t and the risk neutral catch was 265,000 t. For the decline in spawning stock biomass performance measure, the risk averse catch is 350,000 t and the risk neutral catch is 490,000 t. There was a 28% probability that the 2009 spawning stock biomass would be below the overfished level with a catch of 40,000 t. The risk neutral catch for this performance measure was 700,000 t.

We Need a Management Procedure Evaluation

Management Procedure Evaluation[1] (MPE) is a process designed to identify the combination of assessment data, analysis method, and decision rule that is robust to uncertainties about how nature works and provides adequate performance in terms of fishery outcomes (Butterworth and Punt 1999, de la Mare 1998). This is a developing field in fisheries research and there is considerable expertise in the Pacific northwest that could be tapped. MPE is likely to be the most efficient way to design and apply effective management of the hake fishery given the uncertainties about nature, the sensitivity of advice to small changes to the assessment method, and the inability to resolve key uncertainties with the available data. The assessment team has also accumulated a good deal knowledge and experience with the issues. There will be three assessment methods used at this meeting, SS2, the Martell model, and VPA, each of which would be reasonable candidates. There are also several alternative decision rules that could be evaluated, in addition to the 40/10 rule, for example the *status quo* rule. Insights into the variability and potential errors in the input data have been discussed. The three methods noted above have used different levels of input data aggregation, and this has also helped understand how this affects results. If there are trade-offs regarding aggregation / model complexity and reality, these should become evident with the MPE simulations. It is difficult at the outset to anticipate what these will be. What is crucial for the MPE is to establish an acceptable reference set of states of nature, a reasonable number of candidate management procedures, and what performance measures will be used in the evaluation developed". The way I see it, MPE is an approach to investigate how priors should be set, as well as many other aspects of the assessment model structure.

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[1] The popular term in the literature is "Management Strategy Evaluation". However, I prefer "Procedure" rather than "Strategy" because it implies something broader and better describes the combination of data, assessment model, and decision rule that is being evaluated.

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Table 1: Analysis of variance summary from a multiplicative analysis of the Pacific hake acoustic survey relative abundance index. The main effects age and year-class (yc) were class variables.

Summary of Fit

RSquare	0.846853
RSquare Adj	0.760708
Root Mean Square Error	0.817903
Mean of Response	4.254655
Observations (or Sum Wgts)	151

Analysis of Variance

Source	DF	Sum of Squares	Mean Square
Model	54	355.12006	6.57630
Error	96	64.22075	0.66897
C. Total	150	419.34081	

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
age	12	12	151.63701	18.8895	<.0001
yc	42	42	177.73619	6.3259	<.0001

Table 2: Analysis of variance summary from an analysis of covariance of the Pacific hake acoustic survey relative abundance index designed to estimate the total mortality rate of adults. The main effect age was a continuous variable and year-class (yc) was a class variable. The analysis included ages 7-14.

Summary of Fit

RSquare	0.808786
RSquare Adj	0.687439
Root Mean Square Error	0.878915
Mean of Response	3.676797
Observations (or Sum Wgts)	86

Analysis of Variance

Source	DF	Sum of Squares	Mean Square
Model	33	169.90743	5.14871
Error	52	40.16959	0.77249
C. Total	85	210.07702	

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
age	1	1	82.670315	107.0177	<.0001
yc	32	32	86.291774	3.4908	<.0001

Table 3: Analysis of variance summary from a multiplicative analysis of relative fishing mortality at age estimates obtained from the Pacific hake acoustic survey abundance index and the commercial catch at age.

Summary of Fit

RSquare	0.650864
RSquare Adj	0.587635
Root Mean Square Error	0.693662
Mean of Response	-1.93162
Observations (or Sum Wgts)	151

Analysis of Variance

Source	DF	Sum of Squares	Mean Square
Model	23	113.91867	4.95299
Error	127	61.10812	0.48117
C. Total	150	175.02679	

Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
age	12	12	37.354787	6.4695	<.0001
yr	11	11	76.456267	14.4453	<.0001

Table 4: Catch at age (million) of Pacific hake from 1977 to 2007.

Catch	2	3	4	5	6	7	8	9	10	11	12	13	14	15+
1977	4.73	5.08	49.23	9.10	18.25	64.74	15.16	9.69	6.15	3.85	2.09	0.77	0.10	0.05
1978	0.34	7.20	8.62	44.42	8.37	18.94	38.04	8.60	5.34	3.05	1.06	0.60	0.26	0.04
1979	6.32	13.54	23.08	11.64	49.96	14.63	31.77	24.77	6.74	4.05	1.62	0.92	0.53	0.35
1980	0.68	28.16	5.69	9.18	9.30	22.64	9.28	12.47	16.19	3.95	2.24	1.73	0.62	0.49
1981	19.33	5.16	85.08	4.58	11.84	11.65	32.89	11.10	11.82	17.74	3.37	1.31	1.24	0.19
1982	21.94	3.35	2.61	59.25	6.13	7.76	7.48	20.40	4.30	4.67	15.76	1.36	0.84	0.50
1983	0.06	73.08	7.84	4.85	65.48	6.44	6.04	6.88	14.13	3.28	2.31	6.03	0.78	0.31
1984	0.00	2.26	132.87	9.01	18.00	47.73	6.38	4.86	3.92	8.90	1.80	2.07	4.20	0.71
1985	8.64	1.00	12.78	100.68	13.58	11.37	26.33	2.71	1.58	2.46	2.34	0.44	0.00	1.61
1986	57.21	15.69	3.27	12.88	193.96	23.29	15.65	34.53	4.89	4.03	2.51	4.10	0.69	1.99
1987	0.00	111.36	6.61	1.55	6.78	209.19	13.53	6.28	36.65	1.63	0.78	1.72	4.87	1.93
1988	3.01	2.59	167.74	6.04	3.49	4.84	197.55	8.67	3.16	31.37	0.55	0.68	0.27	5.65
1989	19.01	18.92	8.12	244.80	5.66	2.38	3.23	200.63	7.97	3.16	19.29	0.49	0.39	2.24
1990	7.00	92.75	11.73	2.00	176.65	2.95	1.12	0.91	140.67	1.62	0.00	13.83	0.03	1.08
1991	3.16	54.61	92.66	16.52	4.88	189.60	7.09	0.64	0.77	109.47	2.59	0.00	19.76	6.21
1992	21.87	21.31	70.32	114.22	13.06	6.16	180.56	3.84	0.69	1.09	80.07	1.05	0.20	5.46
1993	1.59	83.79	12.15	54.03	65.40	5.59	2.95	105.24	2.70	0.19	0.18	37.10	0.23	2.50
1994	0.26	20.19	123.11	7.51	80.03	122.64	7.42	2.63	183.38	1.24	2.61	0.20	55.33	4.44
1995	17.40	0.82	28.00	104.98	5.10	32.17	78.79	7.31	1.29	96.55	1.50	1.06	0.10	33.10
1996	101.77	85.33	6.33	50.99	105.99	5.95	32.68	64.45	3.84	1.95	96.13	0.08	0.62	22.00
1997	2.68	197.07	140.54	6.88	40.84	80.14	11.32	22.71	42.21	6.94	0.83	39.50	4.04	12.92
1998	35.57	124.53	108.82	164.35	17.66	35.10	71.17	7.62	11.66	33.57	3.75	0.87	31.41	5.66
1999	57.15	134.95	115.91	125.65	76.98	16.49	29.05	31.36	6.13	10.81	19.38	4.32	5.52	18.91
2000	15.40	42.51	60.47	55.80	75.25	42.46	28.49	20.82	7.31	7.23	8.34	5.05	4.13	12.88
2001	55.19	77.91	55.82	69.40	35.51	47.74	23.17	6.29	6.75	6.67	4.06	3.56	0.00	3.98
2002	0.15	147.34	53.45	32.10	21.29	15.37	19.73	11.94	2.78	2.08	3.09	0.36	1.24	2.98
2003	0.54	6.13	270.92	46.19	12.38	20.19	11.85	12.31	7.03	3.30	0.97	1.91	0.31	1.10
2004	0.01	37.57	39.49	393.11	48.89	13.77	24.70	15.42	8.25	6.04	1.88	1.42	0.87	0.91
2005	7.61	2.76	43.40	32.86	406.40	52.96	14.89	18.07	13.48	5.70	4.75	1.33	0.21	1.10
2006	18.35	72.35	10.25	55.30	30.28	376.16	30.45	10.55	11.37	7.62	5.32	2.91	0.96	1.42
2007	53.62	14.57	69.49	7.65	36.44	22.20	226.29	29.24	9.60	9.27	6.43	2.04	2.08	0.71

Table 5: Catch weight at age for Pacific hake. Age 15+ is a plus group. Values for 2008 are the average for 2003-2007. These weights were assumed to represent mid-year weights at age for the population. Values shown in read were missing and estimated using the means of the closest 2 adjacent values at age. The values for 2008 were the average of 2003-2007.

Year	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1977	0.354	0.454	0.533	0.605	0.700	0.748	0.853	0.944	0.974	1.070	1.168	1.218	1.274	1.653
1978	0.135	0.460	0.523	0.600	0.649	0.754	0.812	0.915	0.973	1.055	1.106	1.169	1.231	1.573
1979	0.217	0.287	0.515	0.619	0.687	0.822	0.841	0.951	1.060	1.154	1.211	1.282	1.327	1.435
1980	0.279	0.407	0.487	0.624	0.684	0.796	0.850	0.877	1.010	1.066	1.184	1.163	1.233	1.196
1981	0.123	0.328	0.491	0.619	0.725	0.776	0.816	0.864	0.884	1.043	1.189	1.245	1.213	1.384
1982	0.235	0.389	0.503	0.604	0.688	0.838	0.873	0.907	0.934	1.029	1.049	1.132	1.209	1.095
1983	0.264	0.355	0.428	0.563	0.631	0.742	0.827	0.855	0.883	0.969	0.994	0.941	1.155	1.094
1984	0.238	0.393	0.429	0.531	0.669	0.699	0.796	0.873	0.894	0.953	1.104	0.965	1.008	1.100
1985	0.181	0.316	0.455	0.526	0.639	0.739	0.813	0.979	0.914	1.020	1.035	1.156	1.040	1.067
1986	0.273	0.314	0.426	0.537	0.562	0.633	0.724	0.821	0.921	0.992	0.989	1.102	1.047	1.086
1987	0.236	0.374	0.422	0.499	0.629	0.626	0.683	0.746	0.799	0.903	0.895	1.023	0.950	1.049
1988	0.264	0.357	0.443	0.461	0.598	0.591	0.628	0.687	0.775	0.809	0.895	0.997	0.993	1.026
1989	0.226	0.317	0.367	0.502	0.531	0.617	0.656	0.670	0.717	0.789	0.896	0.860	1.052	1.030
1990	0.272	0.379	0.443	0.531	0.568	0.617	0.604	0.604	0.701	0.749	2.047	0.880	1.002	1.052
1991	0.229	0.341	0.449	0.543	0.554	0.641	0.716	0.599	0.885	0.728	0.724	0.854	0.952	1.060
1992	0.248	0.338	0.458	0.525	0.581	0.598	0.638	0.638	0.612	0.679	0.698	0.851	0.716	0.931
1993	0.263	0.343	0.426	0.502	0.560	0.593	0.547	0.638	0.645	0.704	0.931	0.679	0.798	0.756
1994	0.335	0.344	0.424	0.510	0.552	0.608	0.694	0.620	0.689	0.636	0.739	0.812	0.725	0.794
1995	0.114	0.515	0.484	0.511	0.625	0.623	0.679	0.706	0.713	0.724	0.661	0.892	0.711	0.772
1996	0.271	0.379	0.462	0.547	0.565	0.628	0.621	0.663	0.712	0.736	0.705	0.553	1.092	0.724
1997	0.328	0.409	0.472	0.519	0.615	0.620	0.601	0.692	0.665	0.741	0.732	0.743	0.696	0.813
1998	0.235	0.350	0.458	0.497	0.518	0.587	0.598	0.619	0.637	0.651	0.775	0.638	0.735	0.734
1999	0.243	0.318	0.417	0.538	0.554	0.578	0.625	0.661	0.672	0.748	0.727	0.746	0.661	0.786
2000	0.282	0.424	0.496	0.564	0.647	0.677	0.658	0.740	0.719	0.818	0.746	0.835	0.786	0.820
2001	0.289	0.454	0.599	0.608	0.681	0.778	0.780	0.806	0.854	0.832	0.831	0.901	0.863	0.962
2002	0.310	0.413	0.558	0.752	0.702	0.812	0.916	0.885	0.885	0.927	0.893	1.064	1.002	1.100
2003	0.304	0.380	0.469	0.573	0.664	0.659	0.679	0.732	0.709	0.766	0.752	0.709	0.827	0.941
2004	0.241	0.419	0.489	0.550	0.625	0.709	0.691	0.713	0.758	0.765	0.742	0.880	0.928	0.836
2005	0.333	0.426	0.497	0.550	0.573	0.612	0.647	0.693	0.680	0.729	0.722	0.804	0.629	0.760
2006	0.251	0.418	0.497	0.552	0.584	0.607	0.645	0.785	0.744	0.798	0.838	0.866	0.801	0.805
2007	0.241	0.408	0.512	0.580	0.619	0.639	0.641	0.698	0.781	0.743	0.777	0.796	0.805	0.863
2008	0.274	0.410	0.493	0.561	0.613	0.645	0.661	0.724	0.734	0.760	0.766	0.811	0.798	0.841

Table 6: Pacific hake acoustic survey relative abundance index (million) by age and year.

Year	2	3	4	5	6	7	8	9	10	11	12	13	14
1977.5	141.10	117.27	611.90	72.09	124.28	1038.47	191.44	135.47	101.97	65.21	35.95	14.74	4.47
1980.5	4.91	848.64	86.62	170.99	147.84	706.22	190.08	507.74	208.72	117.31	28.08	23.84	5.64
1983.5	12.06	2198.09	50.78	42.36	679.16	59.18	73.44	65.05	109.96	39.03	29.54	23.72	4.79
1986.5	2532.95	81.46	32.98	141.15	2652.29	287.84	182.12	318.03	33.16	31.11	8.37	27.51	3.70
1989.5	167.87	54.34	18.27	1297.75	26.52	15.45	21.74	633.84	27.37	3.69	43.43	0.00	0.00
1992.5	404.18	68.65	360.87	779.32	94.00	34.10	1522.62	50.97	26.36	13.31	549.73	26.71	0.00
1995.5	966.27	119.03	36.68	606.12	31.48	109.03	434.43	8.98	0.00	461.82	1.14	20.92	0.00
1998.5	327.28	480.39	366.53	457.90	37.38	106.00	247.50	39.69	22.86	152.85	3.31	13.28	123.22
2001.5	1524.17	227.43	126.46	118.39	56.21	54.33	33.14	10.85	11.31	7.52	4.54	4.31	0.00
2003.5	103.77	89.19	2224.39	384.97	101.45	223.64	147.07	83.54	83.21	26.84	15.85	16.75	11.30
2005.5	549.87	57.92	184.43	135.14	1275.22	140.00	47.54	66.49	37.66	29.72	12.48	6.79	0.97
2007.5	646.15	43.55	185.65	21.60	83.22	54.79	617.62	65.91	31.69	31.20	16.82	14.60	6.83

Table 7: ADAPT parameter estimates from Run 1, 2, and 3. The columns give the parameter estimate (Est), the standard error (SE), the bias (Bias), and the bias-corrected estimate (Corr).

	Run 1	msr=0.808			Run 2	msr=0.819			Run 3	msr=0.913		
Parameter	Est	SE	Bias	Corr	Est	SE	Bias	Corr	Est	SE	Bias	Corr
N[2008 3]	3047.4	2893.6	1393.8	1653.7	3157.9	3015.8	1445.0	1712.9	3105.7	3133.8	1613.2	1492.5
N[2008 4]	121.9	120.5	58.9	63.0	138.0	136.7	67.7	70.3	115.4	121.6	63.1	52.3
N[2008 5]	810.0	586.7	204.6	605.4	643.4	425.5	102.4	541.0	776.7	599.9	224.2	552.4
N[2008 6]	42.1	33.4	12.1	30.0	46.0	36.3	13.1	32.9	40.6	34.3	13.2	27.4
N[2008 7]	155.1	115.8	35.3	119.8	172.4	125.0	34.4	138.0	141.4	114.5	37.7	103.7
N[2008 8]	46.2	41.4	14.1	32.1	52.1	45.7	15.5	36.7	38.4	38.5	14.7	23.7
N[2008 9]	472.1	263.5	38.5	433.6	720.6	436.9	46.0	674.6	474.9	442.2	149.7	325.2
N[2008 10]	55.9	47.8	14.0	41.9	57.0	50.1	15.8	41.2	39.4	40.9	15.3	24.1
N[2008 11]	16.4	14.9	4.7	11.8	22.0	18.6	5.6	16.4	11.9	10.8	2.8	9.1
N[2008 12]	17.2	15.4	4.8	12.5	17.1	15.7	5.2	11.8	10.6	10.1	2.9	7.6
q2	0.188	0.053	0.006	0.182	0.181	0.051	0.006	0.175	0.184	0.055	0.006	0.178
q3	0.303	0.085	0.007	0.296	0.269	0.076	0.006	0.263	0.319	0.095	0.008	0.311
q4	0.333	0.091	0.010	0.324	0.314	0.086	0.011	0.304	0.364	0.105	0.011	0.353
q5	0.706	0.192	0.018	0.688	0.658	0.181	0.016	0.643	0.713	0.205	0.020	0.693
q6	0.433	0.117	0.013	0.420	0.359	0.099	0.012	0.348	0.483	0.139	0.017	0.467
q7	0.890	0.242	0.028	0.862	0.795	0.218	0.022	0.773	1.076	0.310	0.038	1.038
q8	1.501	0.405	0.049	1.452	1.235	0.339	0.043	1.192	1.530	0.439	0.061	1.468
q9	0.847	0.229	0.029	0.818	0.663	0.183	0.019	0.643	1.056	0.303	0.042	1.014
q10	1.237	0.350	0.049	1.188	0.953	0.273	0.032	0.921	1.684	0.506	0.080	1.604
q11	1.828	0.495	0.064	1.763	1.409	0.387	0.045	1.364	2.155	0.617	0.094	2.061
q12	0.642	0.171	0.017	0.625	0.415	0.113	0.009	0.406	0.972	0.274	0.033	0.939
q13-14	1.314	0.288	0.016	1.298	0.810	0.183	0.008	0.802	2.468	0.567	0.048	2.420

Table 8: ADAPT parameter estimates from Run 1A and Run 2A. The columns give the parameter estimate (Est), the standard error (SE), the bias (Bias), and the bias-corrected estimate (Corr).

	Run 1A	msr=0.664			Run 2A	msr=0.669		
Parameter	Est	SE	Bias	Corr	Est	SE	Bias	Corr
N[2008 3]	3026.5	2939.6	1518.0	1508.5	3195.9	3115.7	1624.8	1571.2
N[2008 4]	117.5	119.4	64.1	53.4	127.4	129.6	70.3	57.1
N[2008 5]	809.6	600.4	235.8	573.8	861.9	639.1	254.0	608.0
N[2008 6]	40.5	33.1	13.7	26.8	44.6	36.2	15.2	29.4
N[2008 7]	150.9	116.6	43.3	107.6	170.3	128.9	48.3	122.1
N[2008 8]	43.8	41.0	16.9	26.9	50.6	45.9	18.8	31.8
N[2008 9]	496.9	442.4	173.2	323.6	620.1	521.3	200.4	419.6
N[2008 10]	47.6	45.6	19.4	28.2	50.7	48.2	20.4	30.3
N[2008 11]	15.8	15.1	6.3	9.5	19.3	17.5	7.2	12.1
N[2008 12]	13.2	13.5	6.3	6.9	15.2	15.2	6.9	8.3
N[2008 13]	10.5	10.5	4.7	5.8	13.6	12.9	5.5	8.1
N[2008 14]	5.8	5.6	2.5	3.3	8.8	7.7	3.3	5.6
N[1991 14]	92.3	69.5	24.2	68.1	105.6	80.8	28.6	77.0
N[1994 14]	466.9	306.9	105.1	361.7	352.3	252.2	83.6	268.7
N[1998 14]	94.8	67.7	34.6	60.2	179.3	133.5	58.7	120.5
N[2003 14]	4.9	3.7	1.6	3.3	8.0	5.7	2.3	5.7
N[2004 14]	3.5	3.7	1.9	1.6	6.4	6.1	2.8	3.7
N[2005 14]	1.4	1.2	0.6	0.9	2.8	2.2	0.9	1.8
N[2006 14]	2.5	2.5	1.2	1.3	4.4	3.9	1.7	2.8
N[2007 14]	6.0	4.1	1.9	4.1	9.1	6.3	2.7	6.4
q2	0.189	0.055	0.002	0.187	0.179	0.053	0.001	0.178
q3	0.313	0.093	-0.002	0.316	0.290	0.087	-0.003	0.293
q4	0.331	0.093	0.002	0.330	0.312	0.089	0.001	0.311
q5	0.726	0.204	0.002	0.724	0.671	0.191	-0.001	0.672
q6	0.455	0.133	-0.003	0.458	0.396	0.118	-0.003	0.399
q7	0.913	0.260	0.001	0.913	0.817	0.236	-0.001	0.817
q8	1.545	0.440	-0.003	1.548	1.338	0.390	-0.007	1.345
q9	0.909	0.282	-0.008	0.917	0.742	0.238	-0.006	0.748
q10	1.286	0.397	-0.004	1.290	1.054	0.333	-0.002	1.056
q11	1.967	0.615	-0.033	2.001	1.509	0.489	-0.013	1.522
q12	0.686	0.241	0.003	0.682	0.487	0.175	0.006	0.481
q13-14	1.408	0.461	0.007	1.401	0.861	0.277	0.004	0.857

Table 9: Summary of retrospective analysis model formulations for run 1.

Last Data Year (Y)	Ages Estimated in Y+1	Mean F Ages in year Y
2007	3-12	7-11
2006	4-12	7-11
2005	3-12	7-11
2004	4-12	7-11
2003	3-12	7-11
2002	4-8, 10	7, 9
2001	3-11	7-10

Table 10: Correlations among time series estimates of spawning stock biomass (SSB), population weighted age 7+ mean fishing mortality (F), and age 2 recruitment (REC) from 5 ADAPT runs.

SSB	Run 1	Run 1 A	Run 2	Run 2 A	Run 3
Run 1	1	0.989	0.992	0.977	0.927
Run 1 A	0.989	1	0.967	0.994	0.960
Run 2	0.992	0.967	1	0.946	0.877
Run 2 A	0.977	0.994	0.946	1	0.980
Run 3	0.927	0.960	0.877	0.980	1
F	Run 1	Run 1 A	Run 2	Run 2 A	Run 3
Run 1	1	0.990	0.991	0.992	0.891
Run 1 A	0.990	1	0.970	0.996	0.914
Run 2	0.991	0.970	1	0.975	0.844
Run 2 A	0.992	0.996	0.975	1	0.924
Run 3	0.891	0.914	0.844	0.924	1
REC	Run 1	Run 1 A	Run 2	Run 2 A	Run 3
Run 1	1	0.985	0.999	0.990	0.974
Run 1 A	0.985	1	0.979	0.993	0.974
Run 2	0.999	0.979	1	0.984	0.965
Run 2 A	0.990	0.993	0.984	1	0.990
Run 3	0.974	0.974	0.965	0.990	1

Table 11: Input vectors for reference point estimates. Weight beginning of the year (wboy), weight at age middle of the year (wmoy), and sexual maturity (mat) vectors were the same for each run. The fishery selectivity vectors from each run are shown.

Age	wboy	wmoy	mat	sel 1	sel 1 A	sel 2	sel 2 A	sel 3
2	0.224	0.274	0.176	0.137	0.046	0.146	0.049	0.137
3	0.335	0.410	0.661	0.243	0.109	0.283	0.119	0.183
4	0.450	0.493	0.890	0.394	0.238	0.475	0.260	0.240
5	0.526	0.561	0.969	0.569	0.443	0.675	0.478	0.308
6	0.586	0.613	0.986	0.728	0.670	0.826	0.704	0.386
7	0.629	0.645	0.996	0.844	0.838	0.916	0.861	0.470
8	0.653	0.661	1.000	0.917	0.930	0.962	0.942	0.556
9	0.692	0.724	1.000	0.957	0.971	0.983	0.977	0.638
10	0.729	0.734	1.000	0.978	0.988	1.000	1.000	0.714
11	0.747	0.760	1.000	0.989	0.995	1.000	1.000	0.778
12	0.763	0.766	1.000	1.000	0.998	1.000	1.000	0.832
13	0.788	0.811	1.000	1.000	0.999	1.000	1.000	0.875
14	0.804	0.798	1.000	1.000	1.000	1.000	1.000	1.000
15	0.819	0.841	1.000	1.000	1.000	1.000	1.000	1.000

Table 12: Fishing mortality reference points from runs 1, 1A, 2, 2A, and 3. Spawner per recruit at F = 0 was the same for each run, 2.24 kg. Fishing mortality at 40% of SPR0 (F40%), fishing mortality where the slope of the yield per recruit curve is 10% of the slope of the yield per recruit curve at F = 0 (F0.1), average age 2 recruitment (million), and the unfished SSB (B0 proxy).

Run	F40%	F0.1	avg Rec	B0 proxy
1	0.63	0.47	1848	4140
1A	1.02	0.51	1726	3867
2	0.55	0.44	2026	4538
2A	0.94	0.50	1765	3953
3	0.71	0.94	1810	4053

Table 13: Fishing mortality in 2007, forecast fishing mortality in 2008, and catch biomass forecast for 2008 from ADAPT runs following the 40/10 rule.

Run	F 2007	F 2008	Catch (‘000 t)
1	0.40	0.55	383
1A	0.51	0.83	346
2	0.29	0.50	456
2A	0.42	0.82	417
3	0.52	0.76	312

Table 14: Fishing mortality in 2007, forecast fishing mortality in 2008, and catch biomass forecast for 2008 from ADAPT runs following the *status quo* rule.

Run	F 2007	F 2008	Catch (‘000 t)
1	0.40	0.30	232
1A	0.51	0.38	200
2	0.29	0.27	257
2A	0.42	0.34	213
3	0.52	0.38	224

Table 15: Beginning of the year estimates of population numbers at age (million), total biomass ('000 t) and spawning stock biomass ('000 t) of Pacific hake from Run 1A.

	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Total Biomass	SSB
1977	98	115	668	108	227	456	80	57	44	27	12	5	1	7	1906	1705
1978	17	99	103	573	87	183	348	57	39	32	19	7	4	6	1574	1495
1979	478	29	92	91	491	75	146	283	43	29	25	15	5	7	1810	1386
1980	76	709	40	74	76	416	57	101	229	30	21	19	12	9	1870	1558
1981	31	71	836	44	64	62	345	40	72	176	21	15	14	16	1806	1662
1982	2474	74	74	769	39	51	47	267	24	52	126	14	11	20	4040	1944
1983	30	2967	108	76	660	30	37	33	204	17	40	81	10	23	4315	3261
1984	27	35	3162	97	67	525	21	26	21	155	12	29	58	24	4258	3870
1985	62	28	36	3001	89	49	442	14	18	15	126	8	21	62	3972	3813
1986	1940	83	30	28	2679	70	33	361	10	14	11	105	6	67	5437	3768
1987	82	2095	96	28	20	2220	44	17	260	4	7	6	76	55	5008	4210
1988	149	98	2080	90	26	13	1748	28	9	179	2	5	3	93	4523	4135
1989	507	141	97	1845	77	21	8	1323	17	5	127	1	4	73	4247	3712
1990	336	670	139	90	1544	68	16	4	989	9	4	90	0	61	4020	3476
1991	77	333	716	139	87	1291	61	12	3	730	6	3	62	47	3567	3302
1992	391	90	324	629	119	71	980	45	9	2	509	4	1	63	3237	2828
1993	180	424	90	283	503	92	53	674	32	7	1	342	2	37	2719	2402
1994	109	187	412	83	221	397	76	41	495	24	6	1	254	31	2337	2131
1995	96	133	194	349	76	154	277	62	36	304	18	4	0	199	1903	1744
1996	362	252	124	182	270	64	112	183	45	30	184	13	3	131	1954	1547
1997	350	405	375	96	136	181	47	75	106	34	23	87	10	120	2045	1572
1998	213	296	343	281	78	91	105	31	47	59	24	17	44	71	1698	1374
1999	118	222	223	264	166	57	54	47	21	32	29	16	12	71	1331	1124
2000	249	148	208	175	184	112	42	31	22	16	20	13	10	50	1278	992
2001	1620	314	165	199	147	128	78	21	14	14	8	12	7	43	2772	1303
2002	117	1821	316	142	148	117	86	54	15	7	7	4	8	41	2883	2128
2003	180	115	1786	255	98	110	83	52	33	9	4	3	3	35	2765	2372
2004	19	197	112	1515	190	68	75	54	29	20	5	2	1	25	2313	2168
2005	409	27	185	89	1135	129	45	46	34	18	12	2	1	20	2151	1765
2006	25	406	30	148	61	735	75	29	26	20	11	7	1	13	1585	1415
2007	338	27	370	23	103	36	411	46	18	14	11	5	3	11	1415	1084
2008	386	506	24	302	16	68	18	224	21	7	5	5	3	9	1592	1090

Table 16: Estimates of fishing mortality at age and year of Pacific hake from ADAPT Run 1A.

Year	2	3	4	5	6	7	8	9	10	11	12	13	14	15 +	7+ Mean
1977	0.017	0.021	0.042	0.057	0.062	0.121	0.191	0.193	0.159	0.180	0.261	0.212	0.139	0.011	0.139
1978	0.002	0.033	0.047	0.050	0.070	0.088	0.100	0.162	0.160	0.114	0.071	0.115	0.104	0.010	0.104
1979	0.002	0.107	0.146	0.085	0.076	0.173	0.215	0.090	0.191	0.181	0.084	0.084	0.143	0.073	0.143
1980	0.003	0.013	0.061	0.082	0.093	0.046	0.163	0.126	0.081	0.169	0.148	0.125	0.077	0.079	0.077
1981	0.050	0.025	0.052	0.066	0.150	0.167	0.090	0.310	0.175	0.123	0.220	0.125	0.128	0.018	0.128
1982	0.002	0.011	0.016	0.048	0.123	0.143	0.159	0.076	0.195	0.100	0.158	0.133	0.114	0.032	0.114
1983	0.000	0.008	0.034	0.039	0.071	0.189	0.163	0.221	0.072	0.232	0.068	0.086	0.110	0.018	0.110
1984	0.000	0.023	0.019	0.051	0.205	0.070	0.300	0.198	0.196	0.061	0.199	0.082	0.082	0.038	0.082
1985	0.022	0.011	0.183	0.018	0.104	0.199	0.052	0.207	0.094	0.187	0.021	0.070	0.000	0.031	0.064
1986	0.008	0.052	0.046	0.292	0.045	0.270	0.478	0.091	0.731	0.378	0.306	0.048	0.154	0.036	0.154
1987	0.000	0.019	0.029	0.029	0.255	0.065	0.257	0.371	0.137	0.603	0.120	0.369	0.076	0.042	0.076
1988	0.005	0.009	0.037	0.034	0.085	0.302	0.082	0.269	0.334	0.171	0.439	0.149	0.094	0.069	0.094
1989	0.007	0.044	0.035	0.073	0.041	0.079	0.351	0.116	0.441	0.687	0.156	0.922	0.125	0.035	0.125
1990	0.006	0.046	0.036	0.011	0.071	0.028	0.050	0.162	0.115	0.153	0.001	0.166	0.112	0.021	0.112
1991	0.009	0.057	0.062	0.067	0.035	0.104	0.090	0.038	0.207	0.127	0.404	0.000	0.389	0.165	0.117
1992	0.013	0.077	0.101	0.104	0.072	0.057	0.141	0.067	0.054	0.525	0.134	0.293	0.133	0.095	0.133
1993	0.002	0.067	0.059	0.108	0.082	0.041	0.036	0.118	0.063	0.019	0.158	0.087	0.097	0.058	0.097
1994	0.001	0.037	0.136	0.048	0.238	0.225	0.072	0.042	0.319	0.038	0.407	0.274	0.187	0.134	0.235
1995	0.013	0.003	0.068	0.170	0.043	0.147	0.228	0.098	0.027	0.287	0.061	0.297	0.210	0.150	0.210
1996	0.072	0.082	0.028	0.176	0.268	0.067	0.225	0.305	0.070	0.054	0.535	0.004	0.293	0.145	0.293
1997	0.003	0.200	0.194	0.040	0.215	0.345	0.182	0.250	0.348	0.180	0.030	0.457	0.313	0.121	0.313
1998	0.038	0.173	0.167	0.378	0.141	0.300	0.613	0.185	0.203	0.536	0.145	0.041	0.856	0.066	0.430
1999	0.105	0.205	0.250	0.305	0.316	0.196	0.452	0.633	0.231	0.304	0.720	0.255	0.402	0.254	0.402
2000	0.015	0.109	0.138	0.189	0.313	0.298	0.628	0.718	0.302	0.483	0.421	0.428	0.428	0.238	0.428
2001	0.009	0.105	0.210	0.239	0.182	0.347	0.273	0.280	0.562	0.517	0.577	0.331	0.000	0.095	0.337
2002	0.000	0.032	0.100	0.186	0.111	0.115	0.244	0.228	0.199	0.348	0.501	0.092	0.190	0.082	0.190
2003	0.001	0.021	0.078	0.121	0.104	0.150	0.126	0.244	0.210	0.397	0.279	0.701	0.111	0.035	0.178
2004	0.000	0.079	0.186	0.159	0.188	0.167	0.286	0.248	0.266	0.291	0.430	0.888	0.865	0.034	0.253
2005	0.006	0.037	0.128	0.240	0.254	0.331	0.284	0.363	0.370	0.308	0.407	0.649	0.315	0.053	0.337
2006	0.178	0.077	0.195	0.245	0.377	0.408	0.334	0.346	0.426	0.384	0.547	0.489	1.661	0.090	0.404
2007	0.031	0.217	0.102	0.226	0.262	0.546	0.480	0.648	0.636	0.778	0.681	0.433	0.825	0.061	0.513

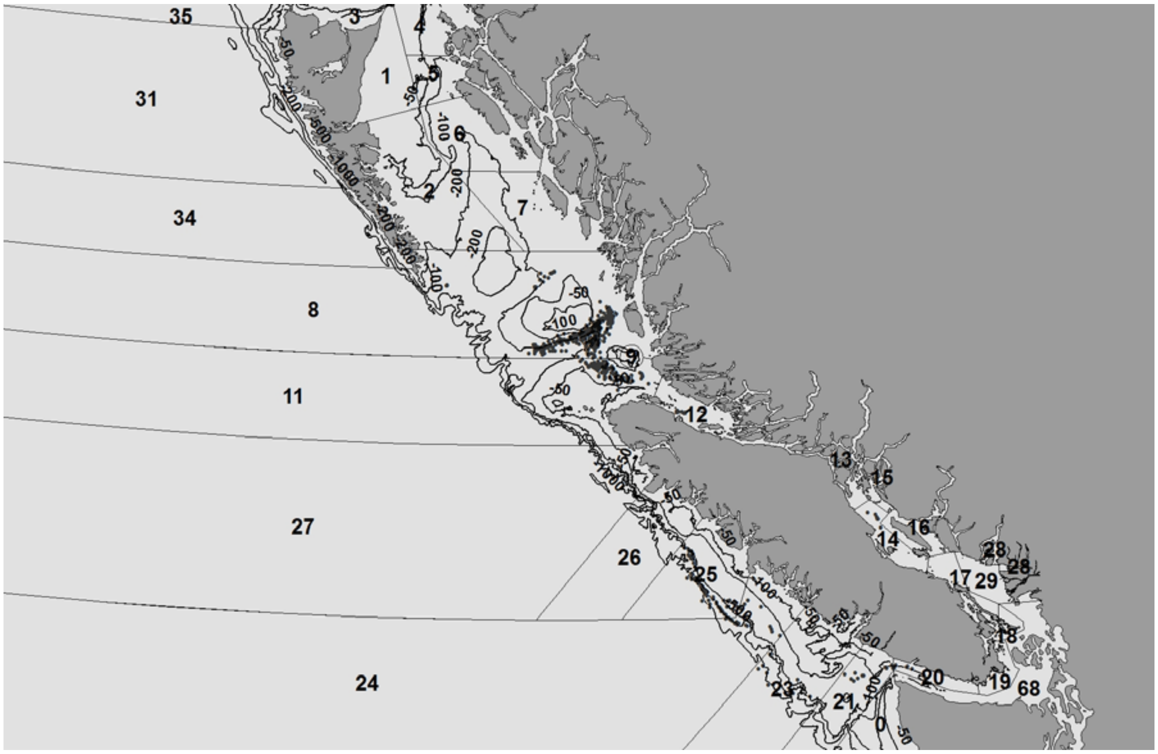


Figure 1: 2007 commercial catch locations by minor statistical area. Contours show depth in meters.

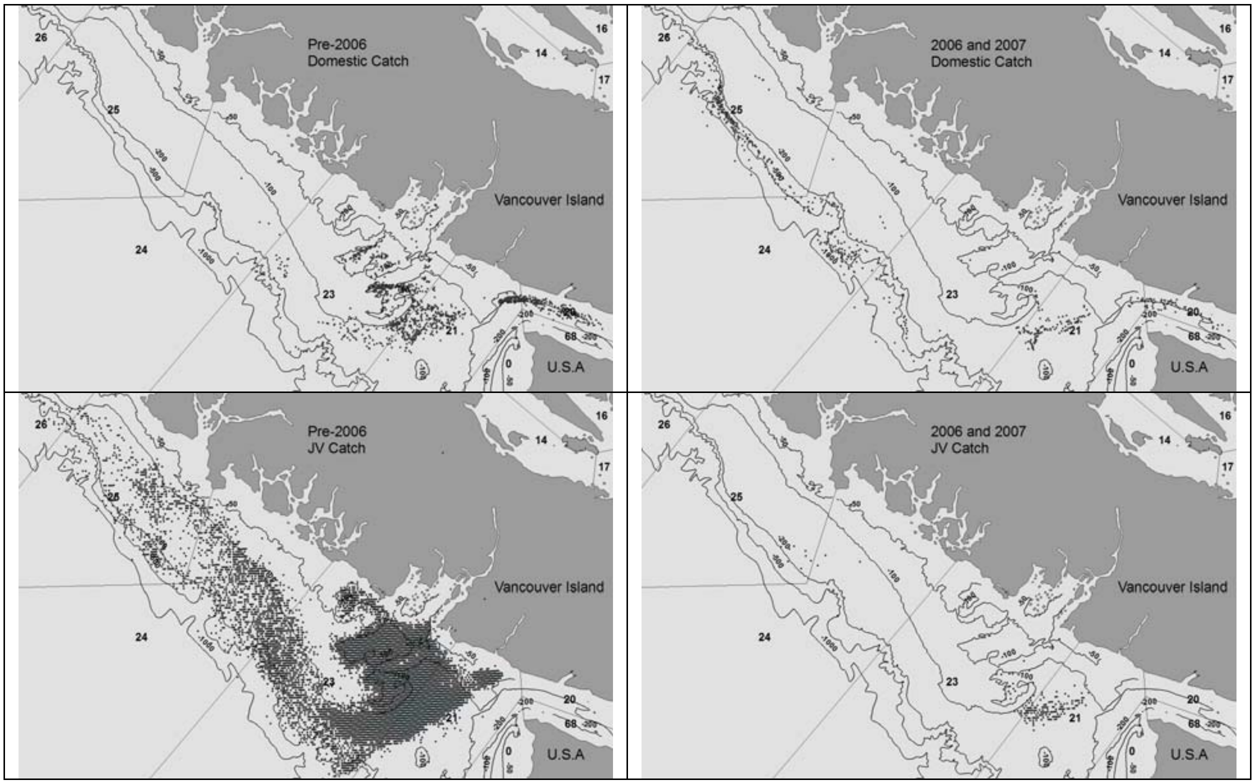


Figure 2: Southern catch locations by fishery before and after 2006. Contours show depth in meters.

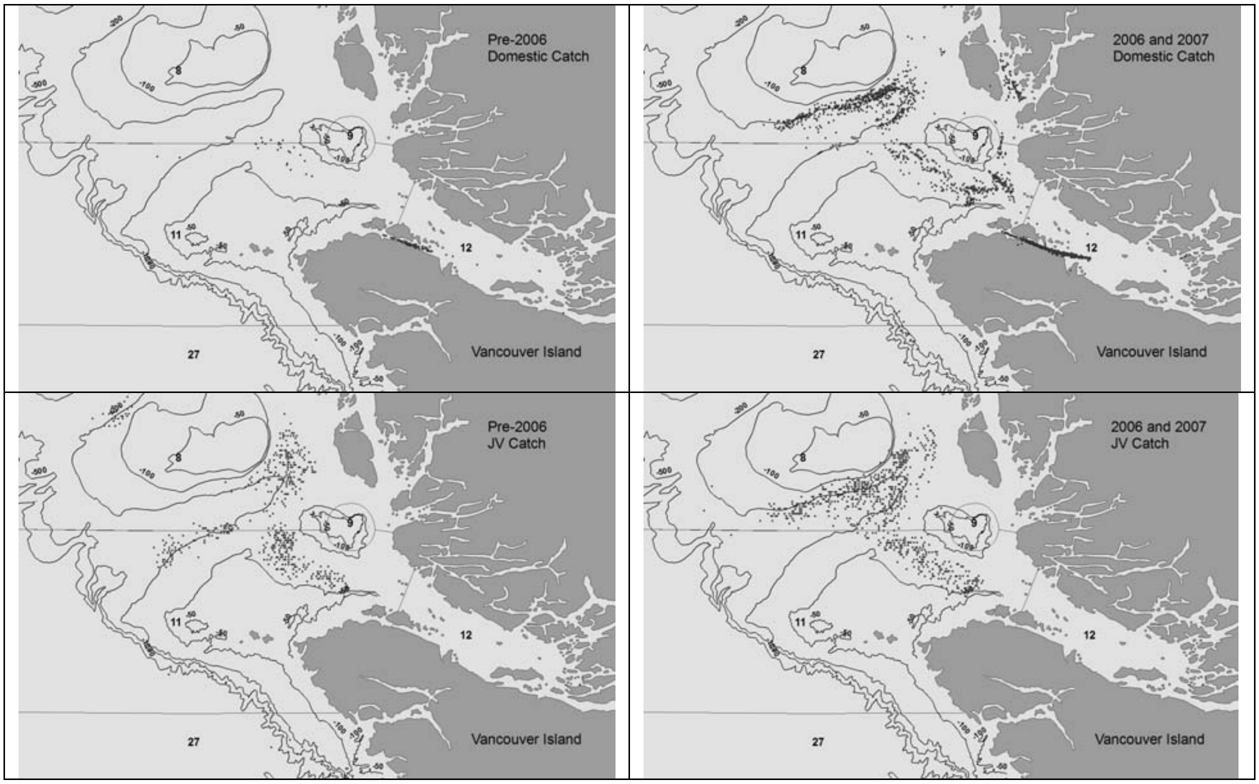


Figure 3: Northern catch locations by fishery before and after 2006. The catch located north of Vancouver Island in the JV fishery before 2006 was all taken in 2000. Contours show depth in meters.

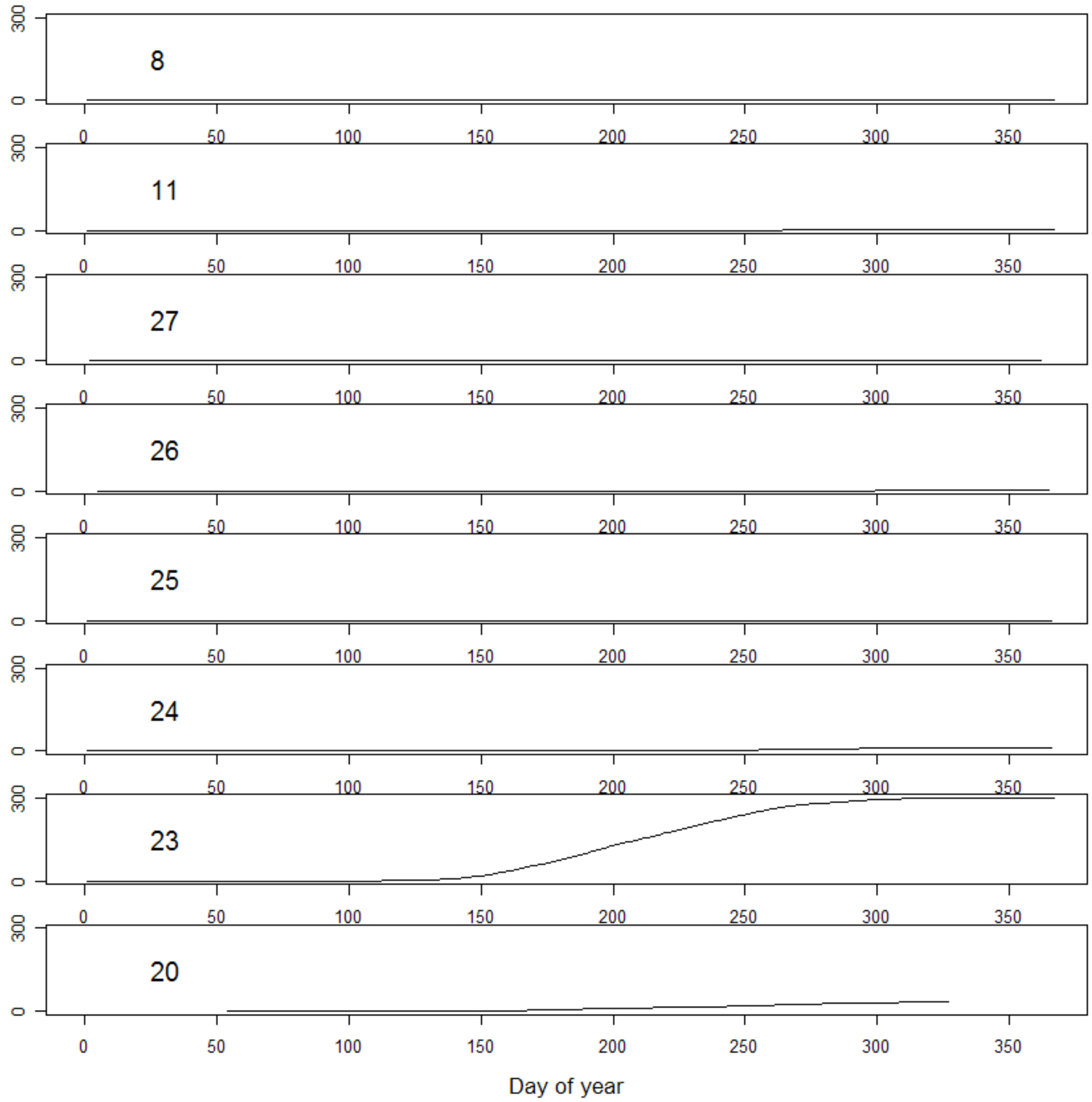


Figure 4: Cumulative commercial catch by area number, prior to 2006. Area plots are in the same north-south spatial orientation in which they occur. Weight is in thousands of metric tonnes.

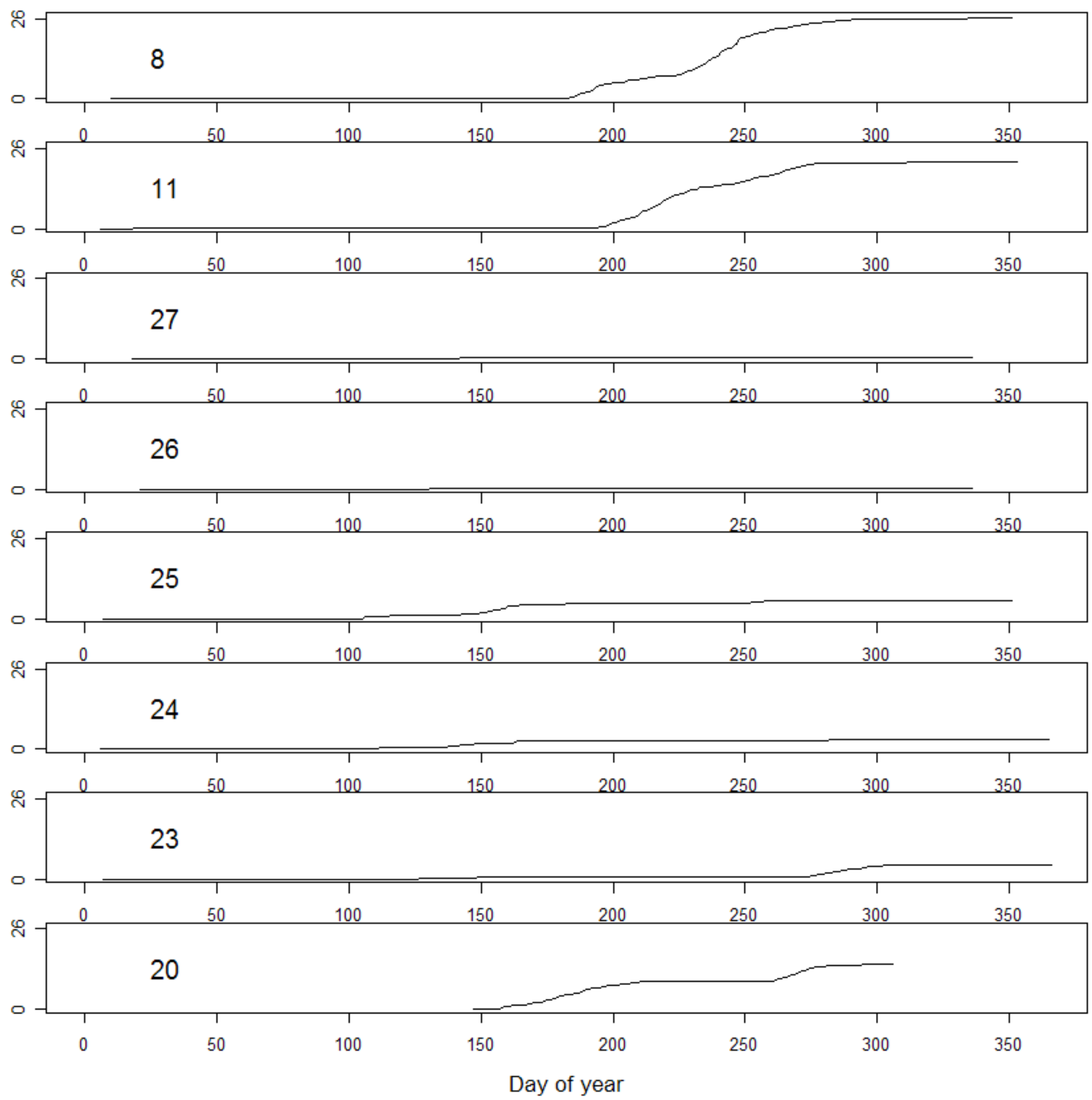


Figure 5: Cumulative commercial catch by area number, 2006 and 2007. Area plots are in the same north-south spatial orientation in which they occur. Weight is in thousands of metric tonnes.

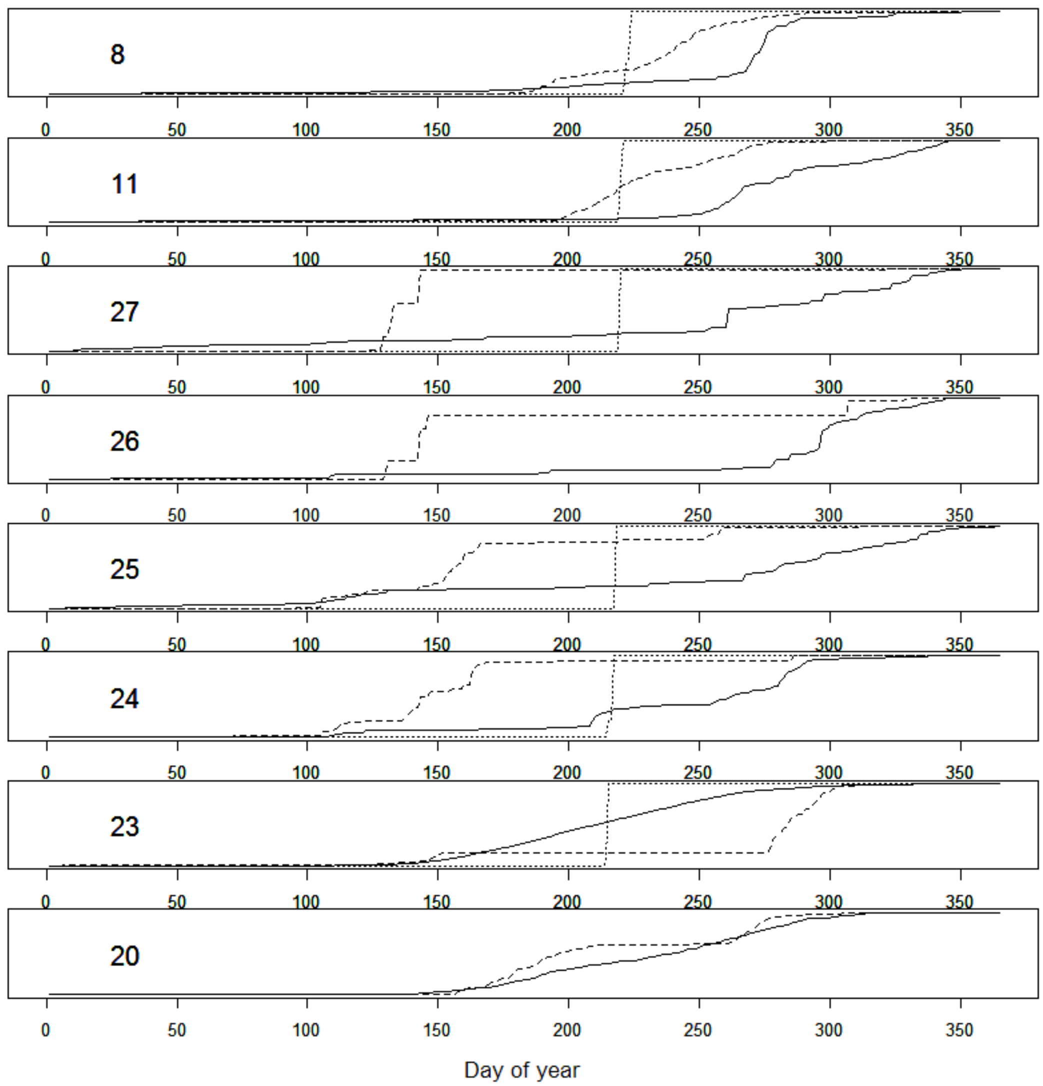


Figure 6: Cumulative commercial and survey catch proportions by area number. Area plots are in the same north-south spatial orientation in which they occur. Solid lines show commercial fishery catch prior to 2007, dashed lines show 2007 commercial, dotted lines show 2007 acoustic survey.

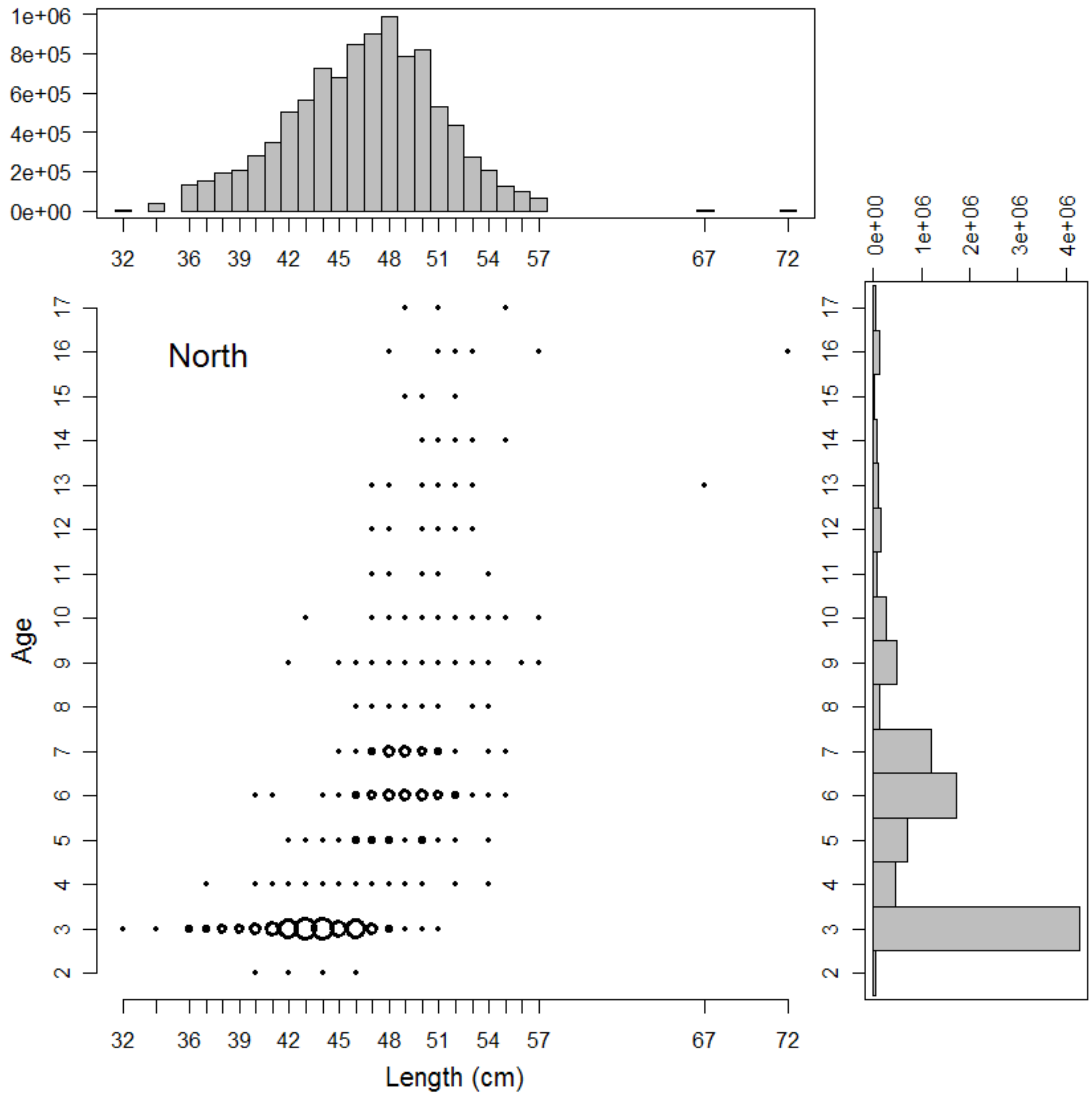


Figure 7 Aggregated age-length composition for all years prior to 2007, northern area.

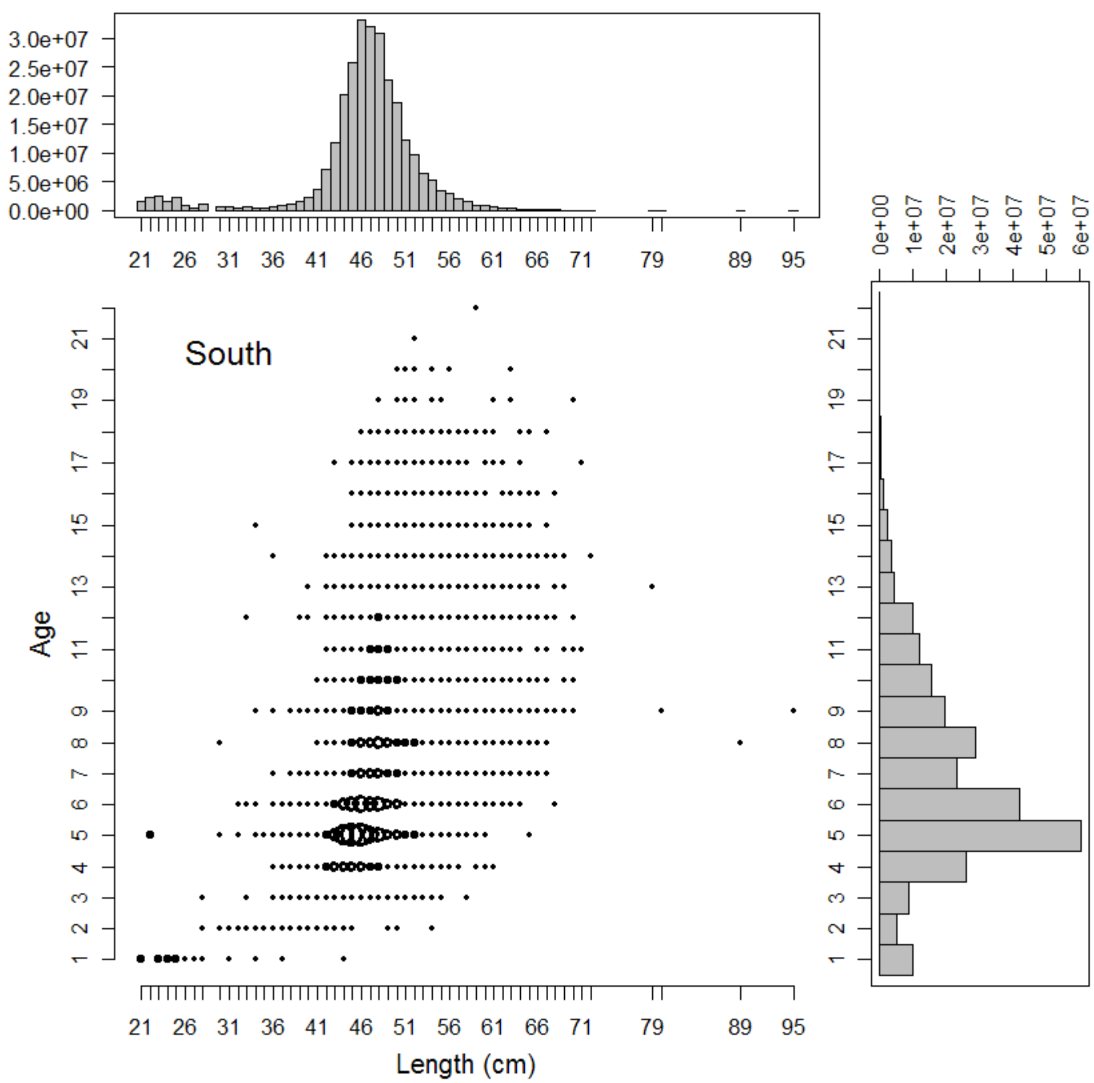


Figure 8: Aggregated age-length composition for all years prior to 2007, southern area.

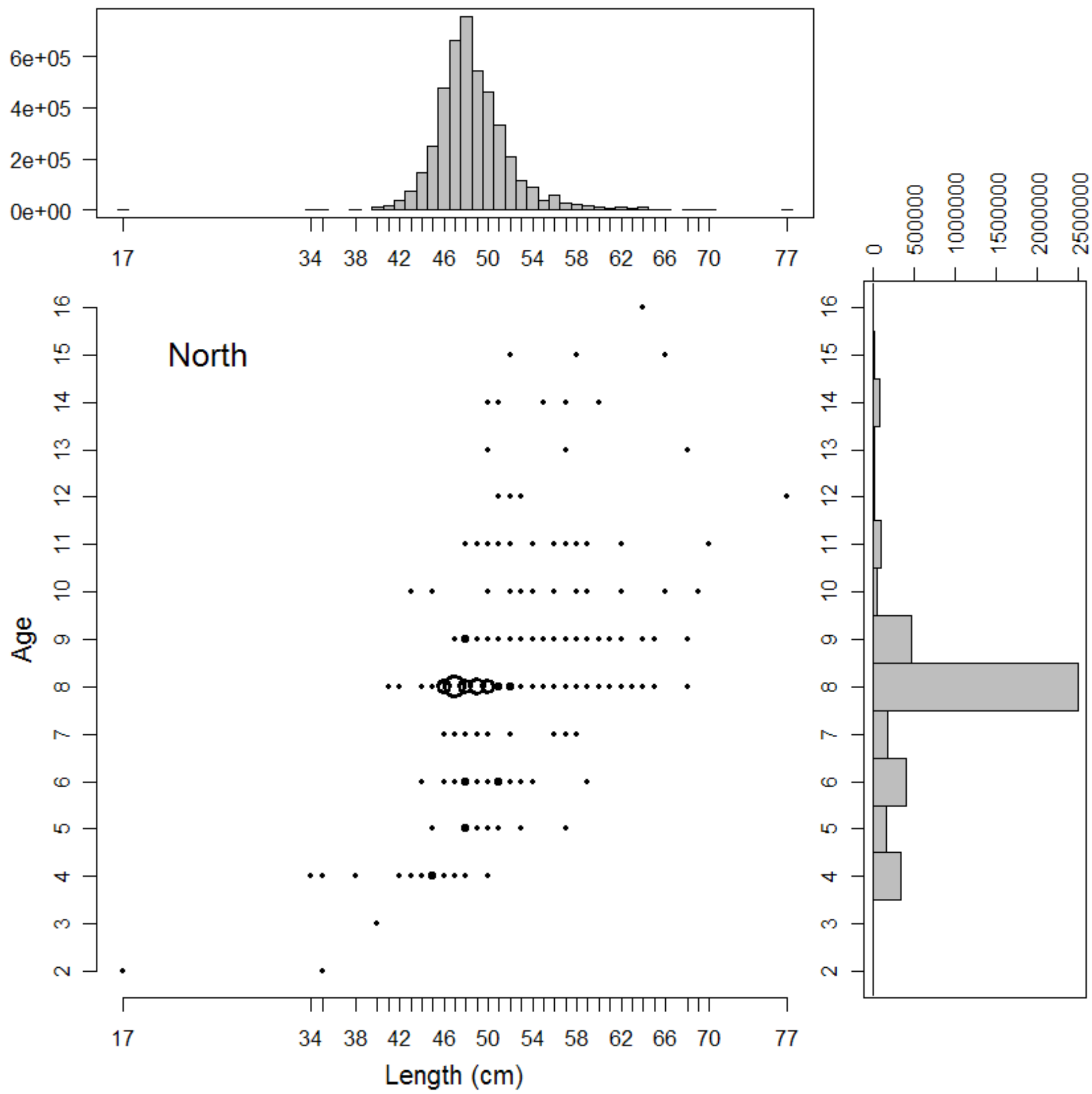


Figure 9: Age-length composition for 2007 commercial fisheries, northern area.

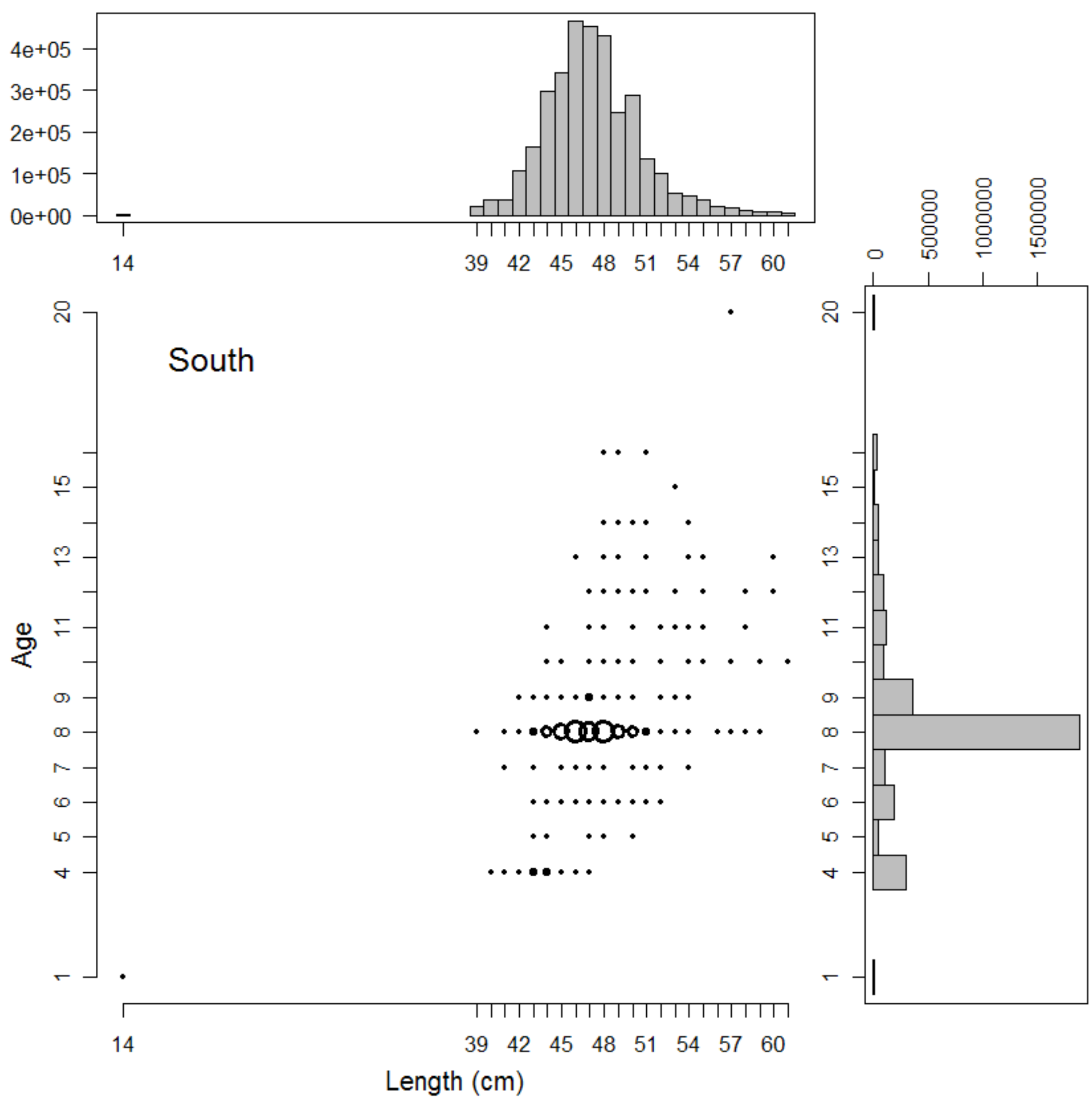


Figure 10: Age-length composition for 2007 commercial fisheries, southern areas.

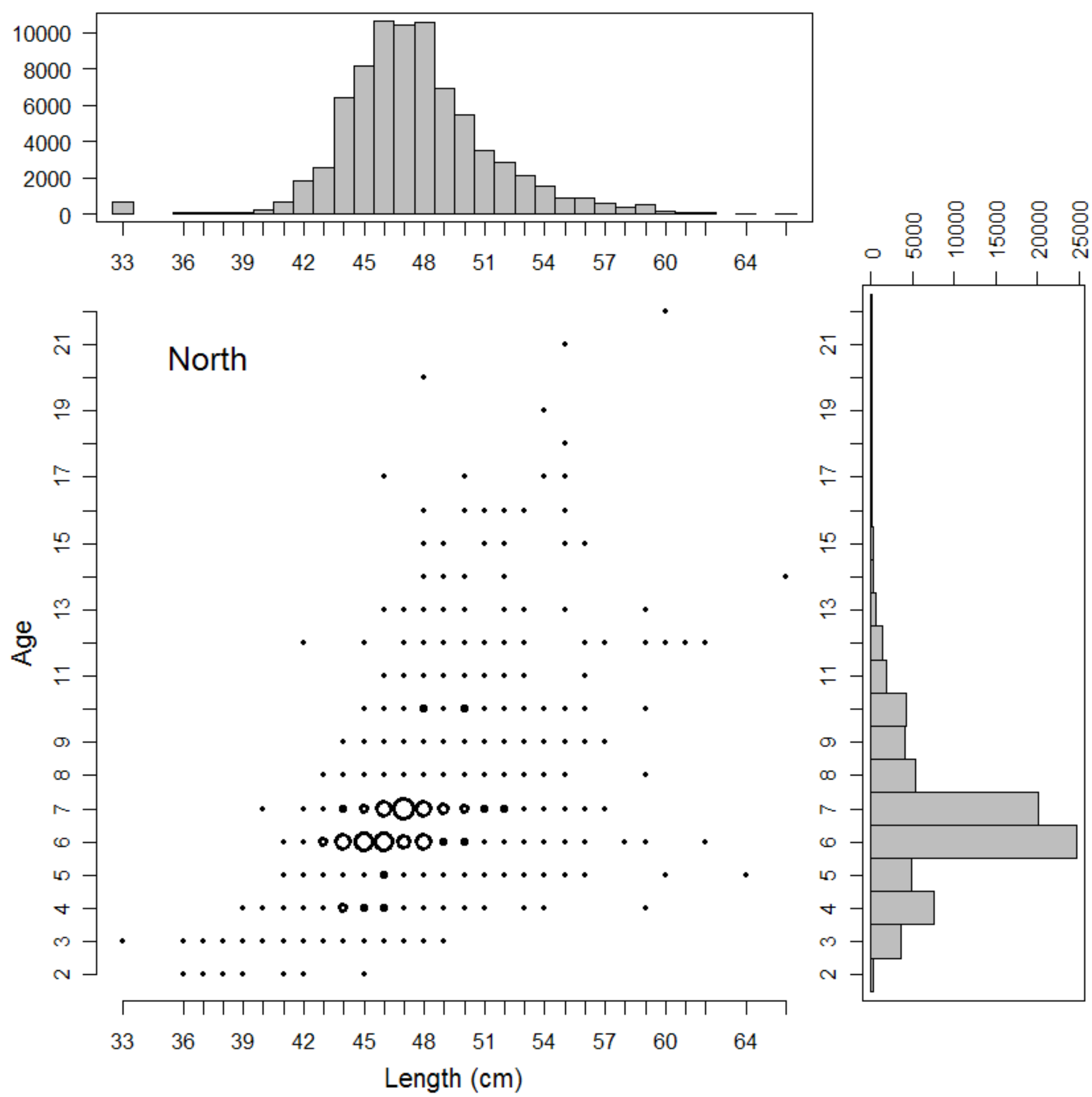


Figure 11: Age-length composition for acoustic surveys 1999 to 2006, northern areas.

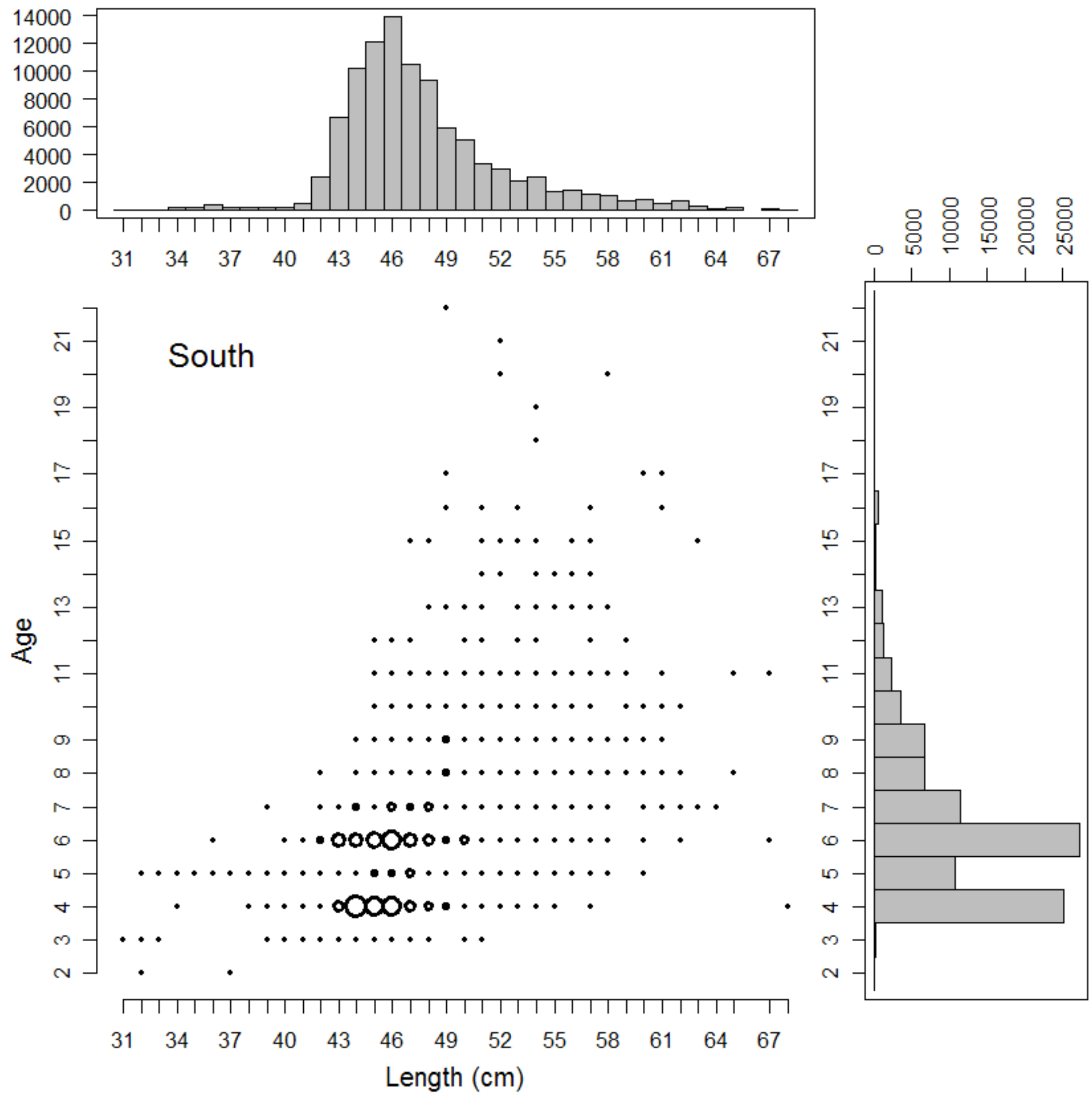


Figure 12: Age-length composition for acoustic surveys 1999 to 2006, southern areas.

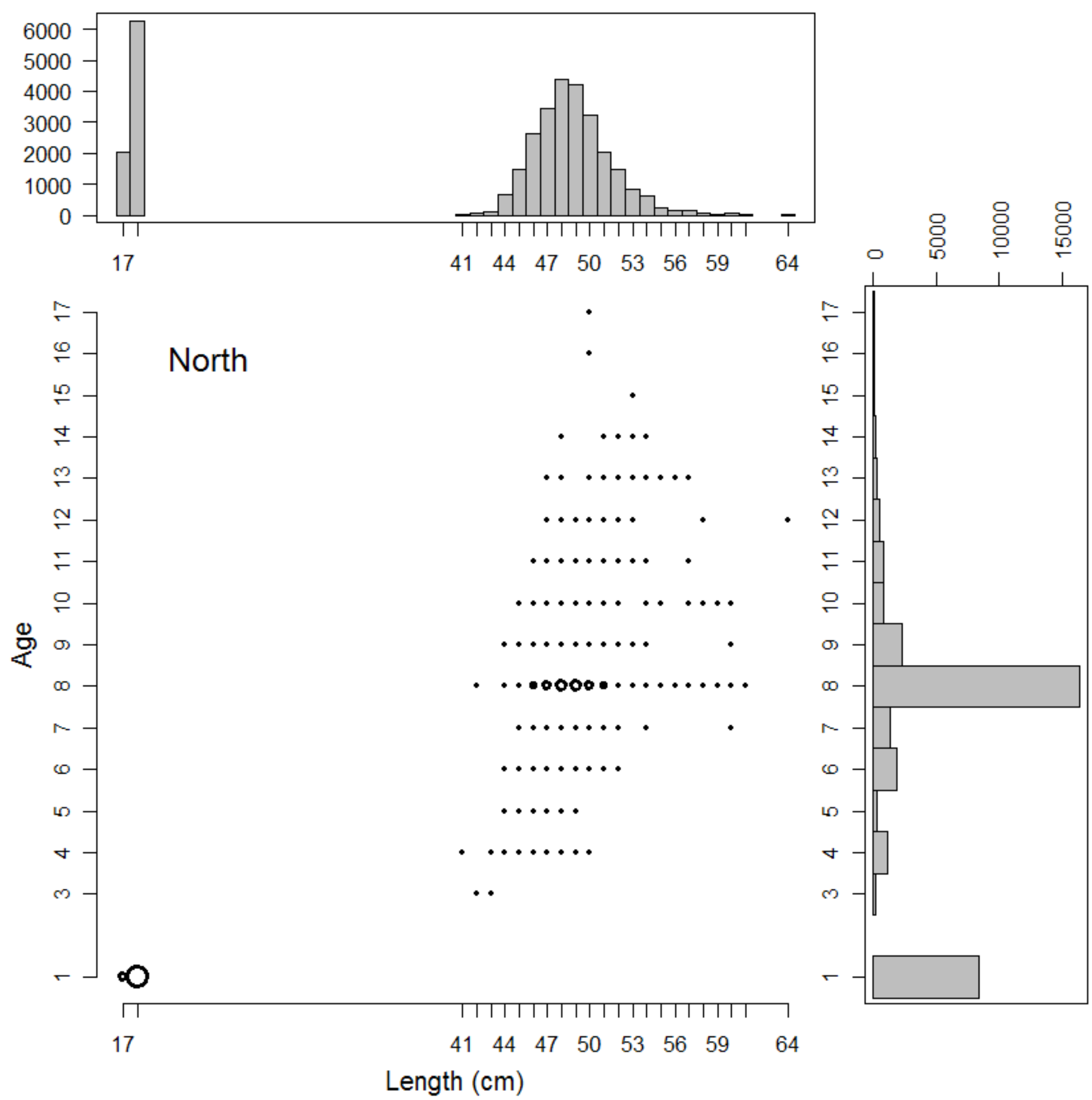


Figure 13: Age-length composition for the acoustic survey of 2007, northern areas.

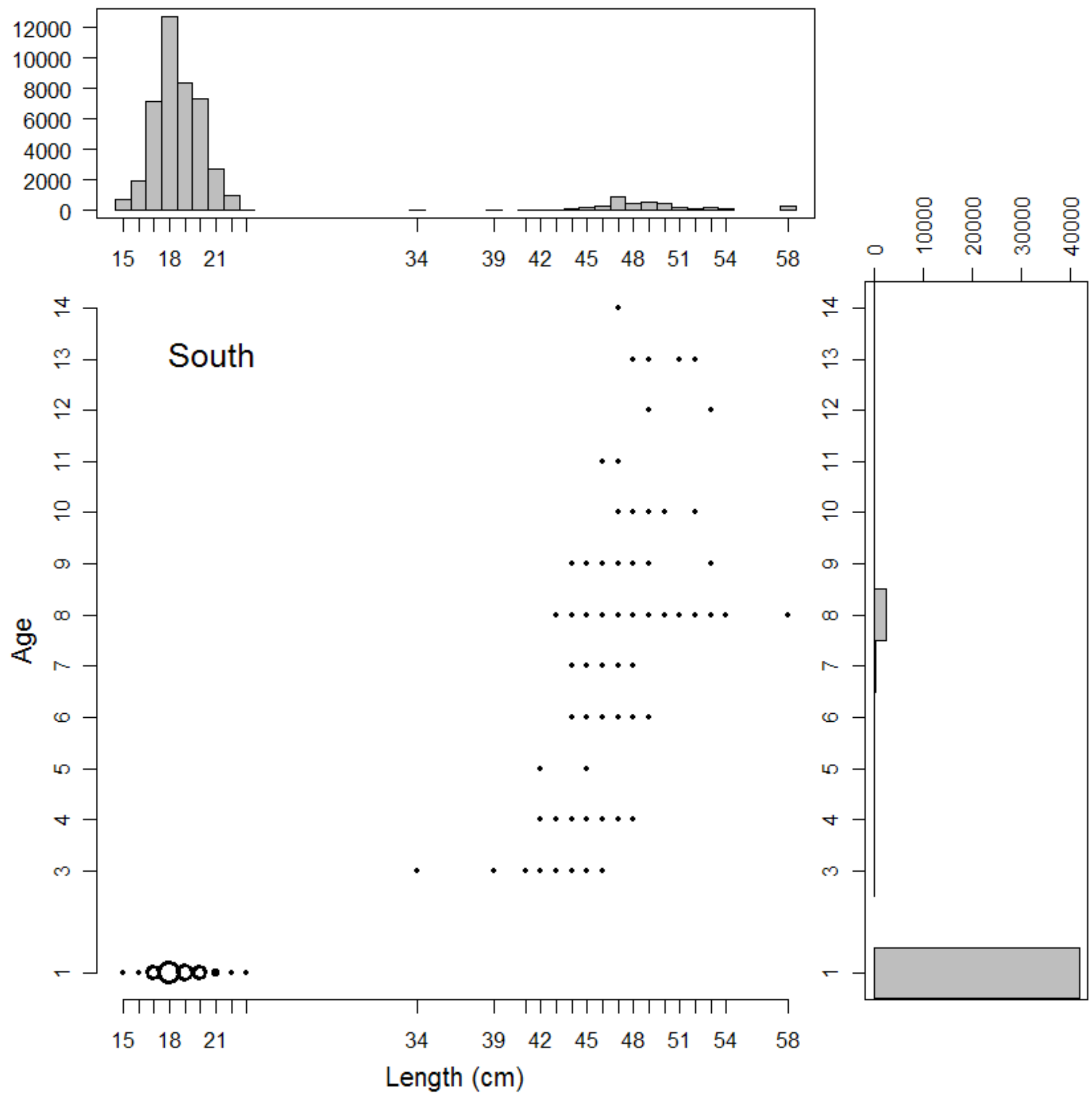


Figure 14: Age-length composition for the acoustic survey of 2007, southern areas. The 1999 year class is not present.

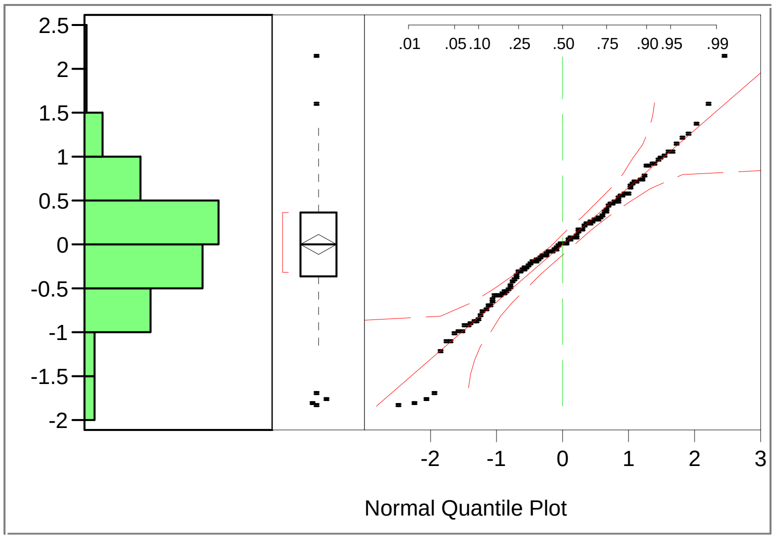


Figure 15: Residual distribution from a multiplicative analysis of the Pacific hake acoustic survey relative abundance index.

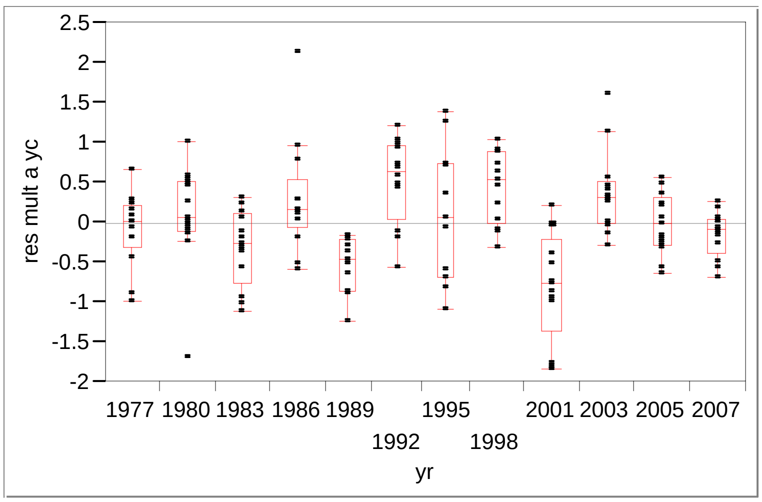
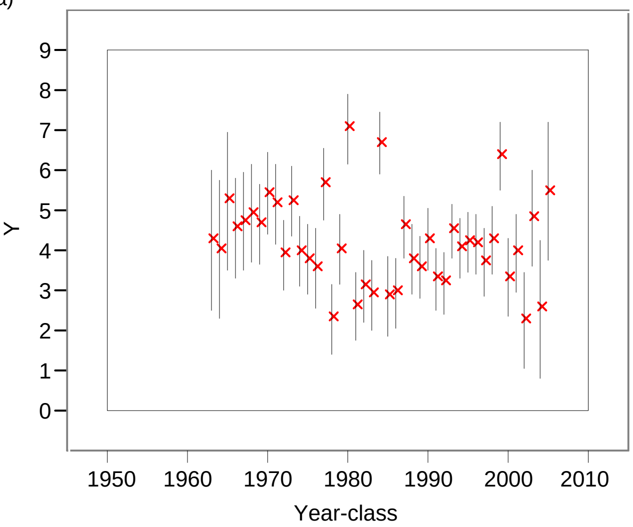


Figure 16: Annual residuals from a multiplicative analysis of the Pacific hake acoustic survey relative abundance index.

a)



b)

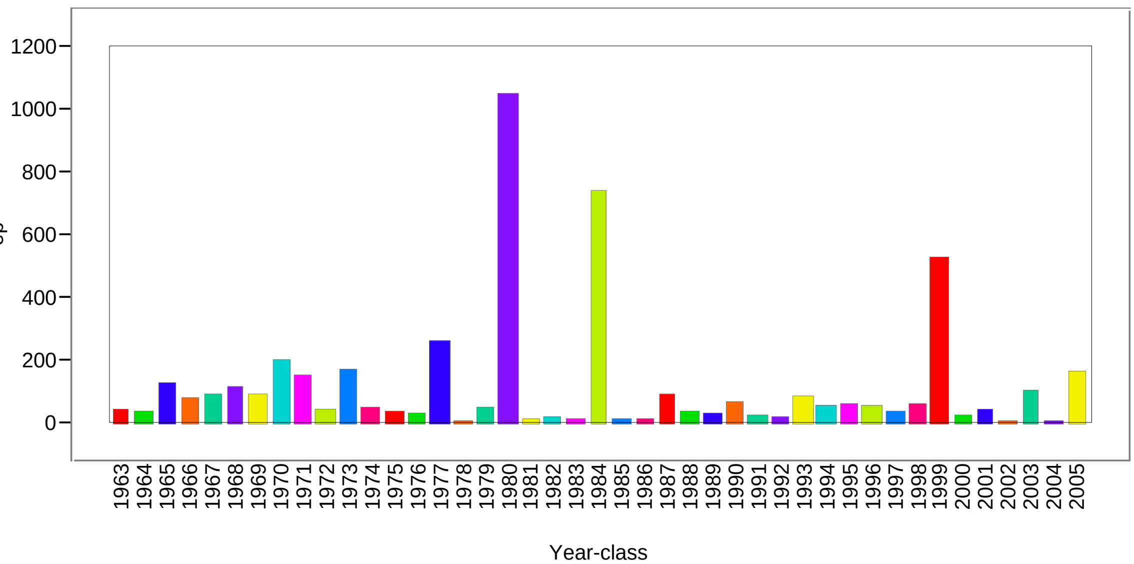


Figure 17: Relative abundance of year-classes estimated with a multiplicative analysis of the Pacific hake acoustic survey relative abundance index; a) least square mean estimates of ln year-class abundance with 95% confidence intervals, b) estimates converted to the arithmetic scale.

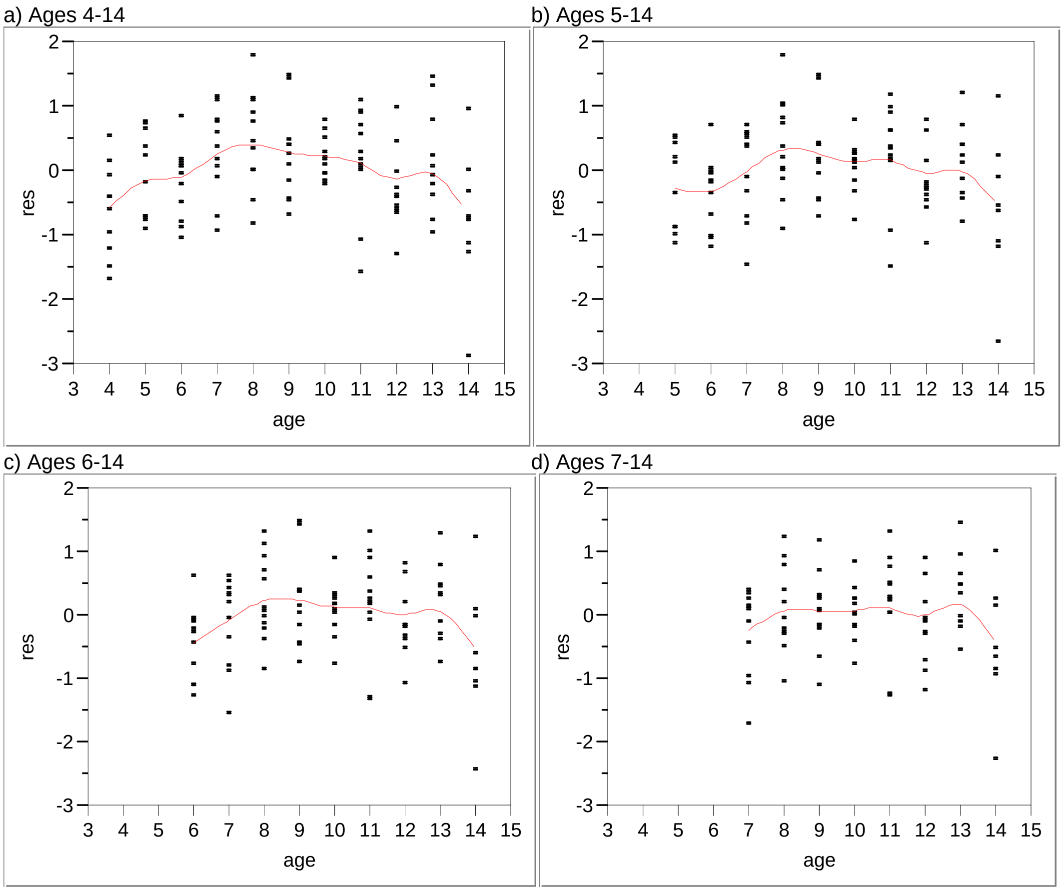


Figure 18: Residual patterns with respect to age from preliminary analyses of total mortality of Pacific hake based on the results of the acoustic survey. Four analyses were conducted, a) ages 4-14, b) ages 5-14, c) ages 6-14, d) ages 7-14.

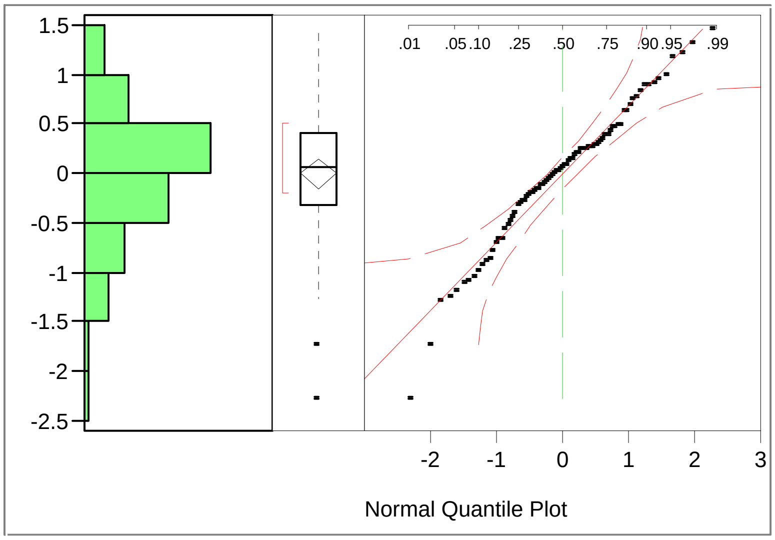


Figure 19: Residual distribution from an analysis of covariance of the Pacific hake acoustic survey relative abundance index designed to estimate the adult total mortality rate. The analysis included ages 7-14.

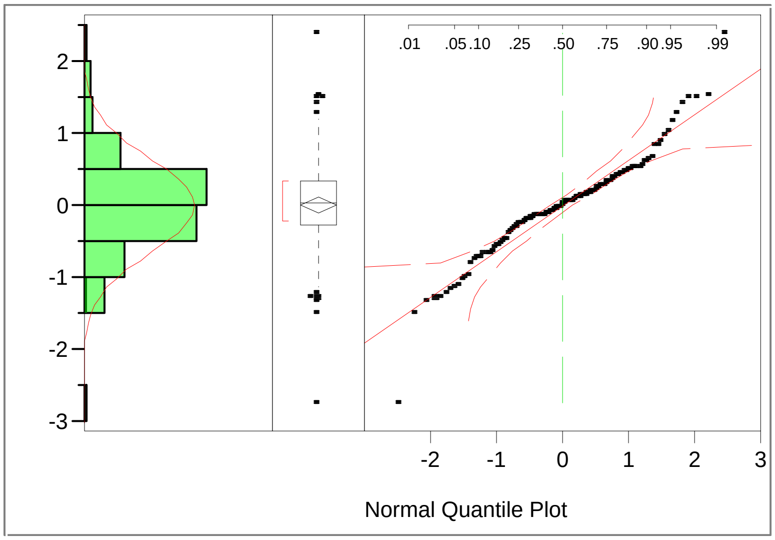


Figure 20: Residual distribution from a multiplicative analysis of Pacific hake relative fishing mortality at age.

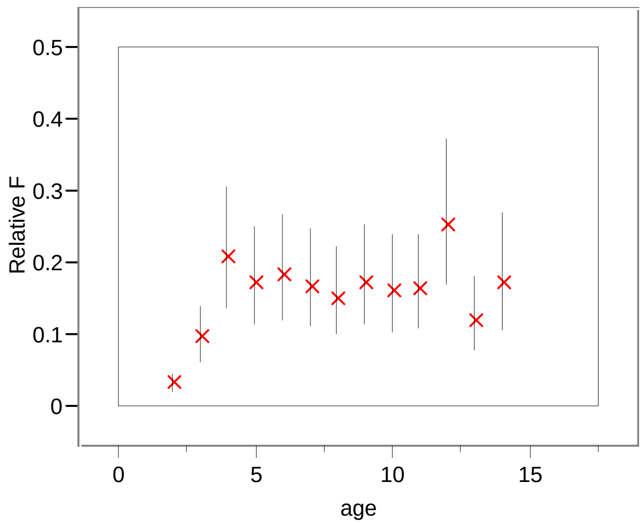


Figure 21: Parameter estimates for relative fishing mortality at age for Pacific hake.

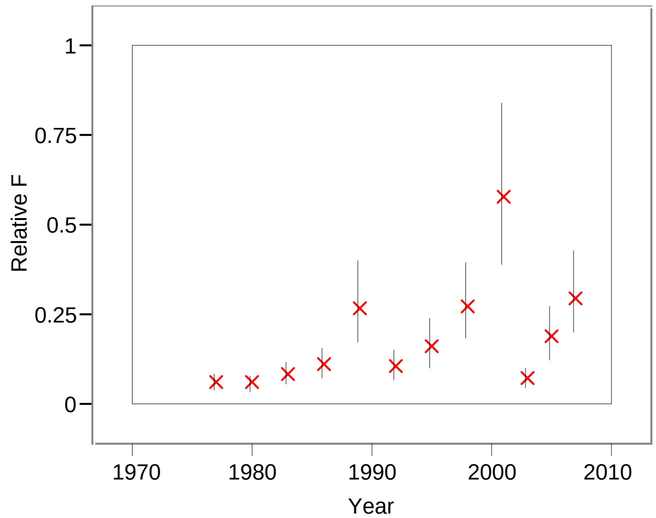


Figure 22: Parameter estimates for relative fishing mortality by year for Pacific hake.

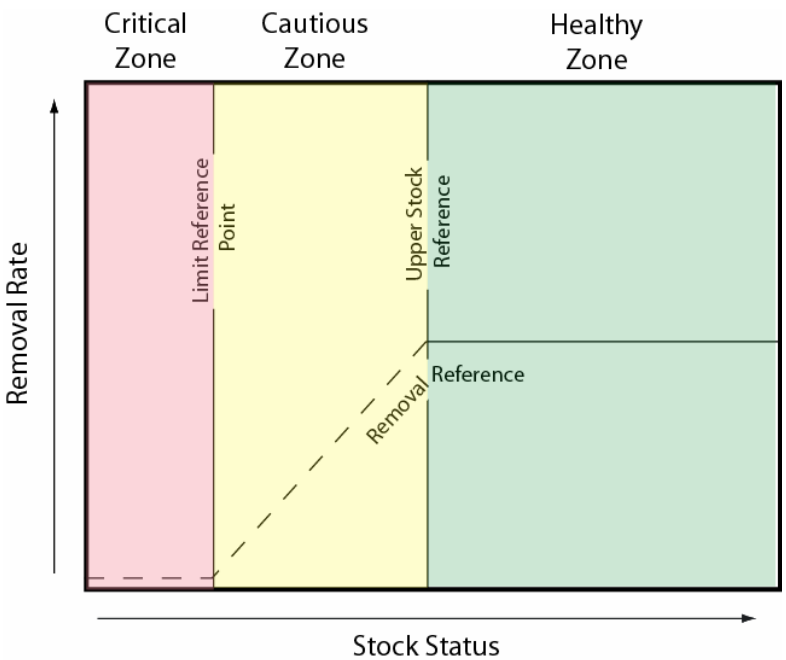


Figure 23: A harvest strategy consistent with the Precautionary Approach (from DFO 2006)

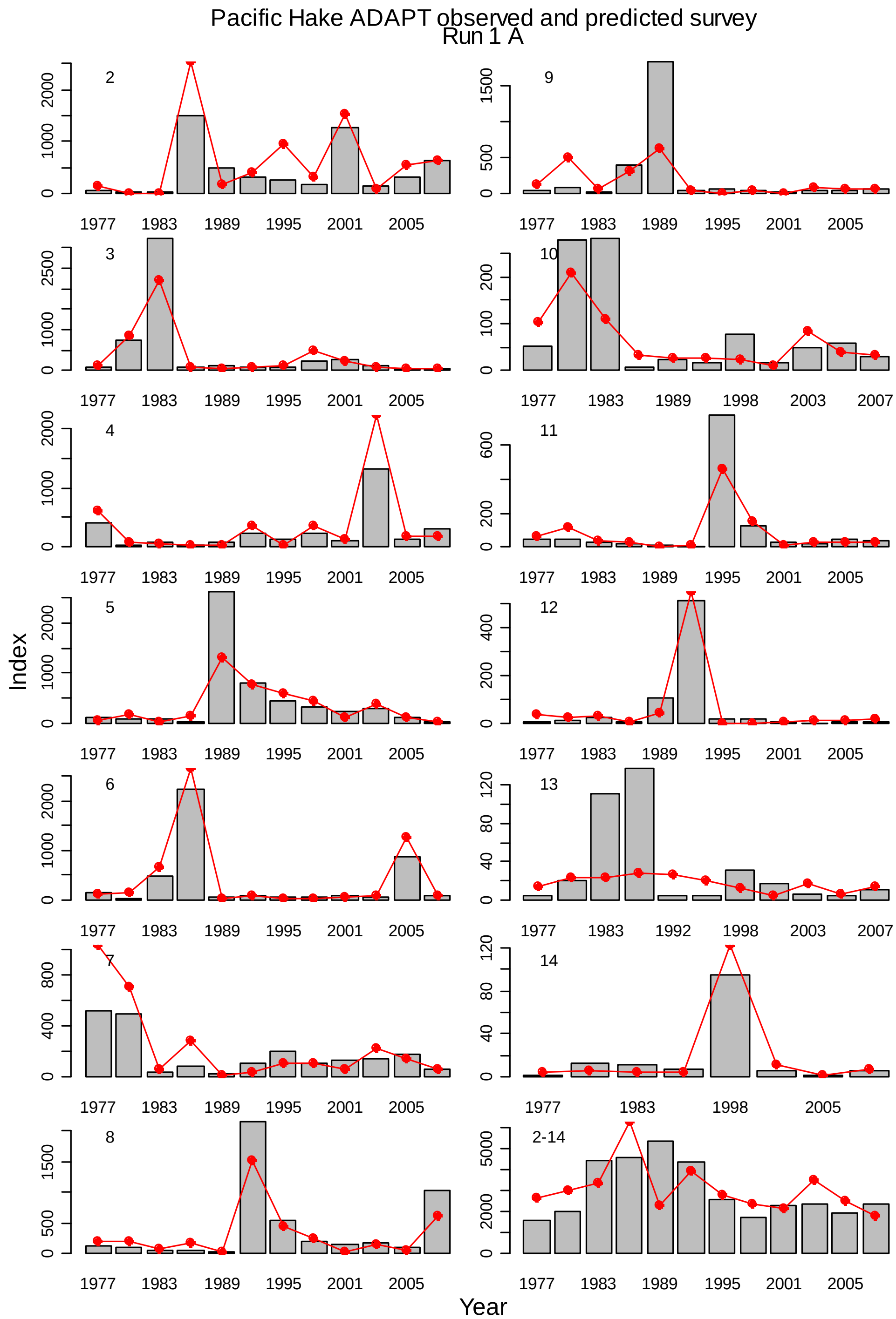


Figure 24: Observed (points) and predicted (lines) acoustic survey abundance indices at age from Run 1A. Age is indicated in the upper left corner of each plot. The survey catchability adjusted aggregate index is shown in the last plot labeled 2-14.

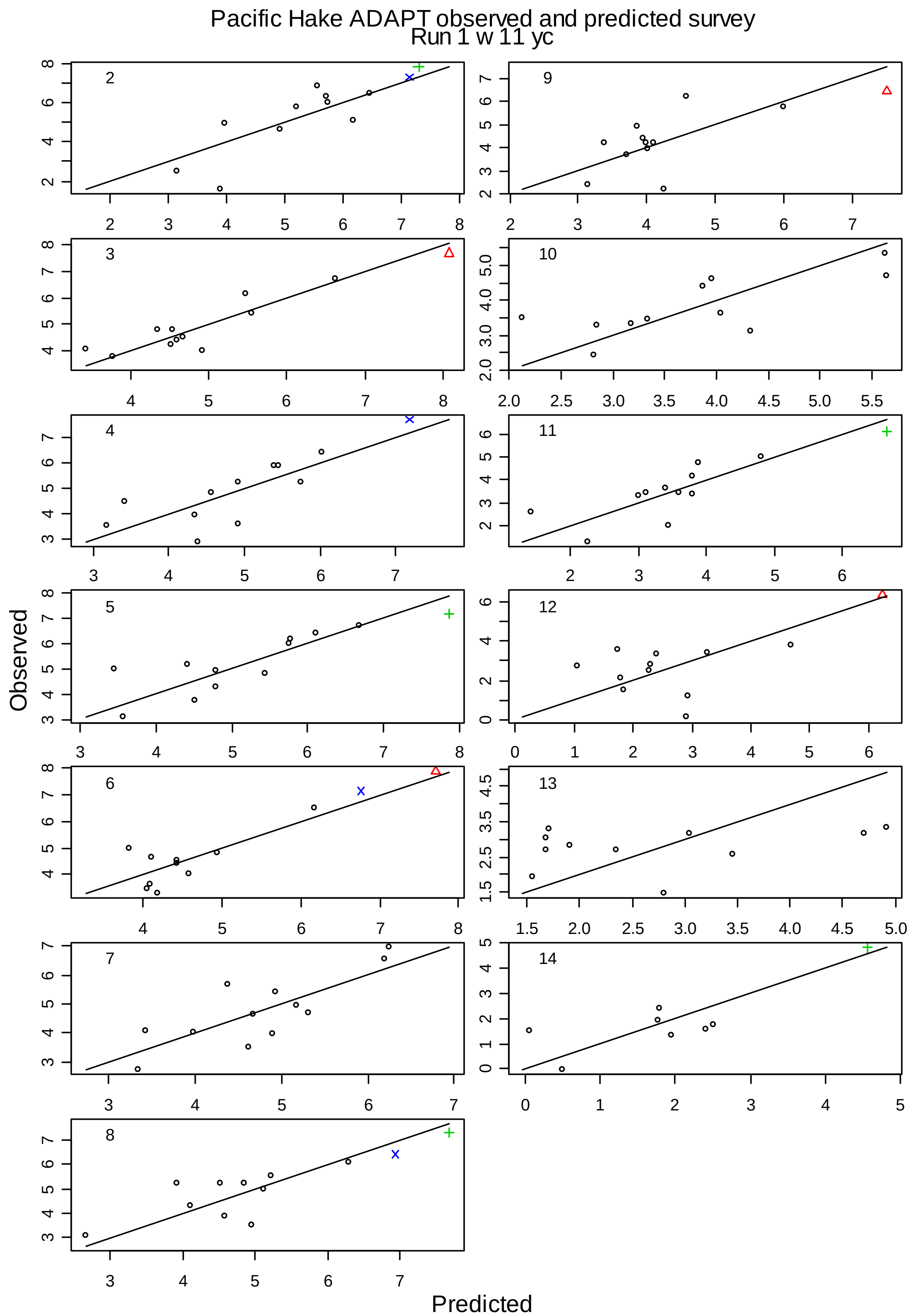


Figure 25: Calibration plots of observed vs predicted acoustic survey relative abundance indices from Run 1 A. The 1980 (diamond), 1984 (cross) and 1999 (x) year-class values are highlighted. Age is indicated in the upper left corner of each plot.

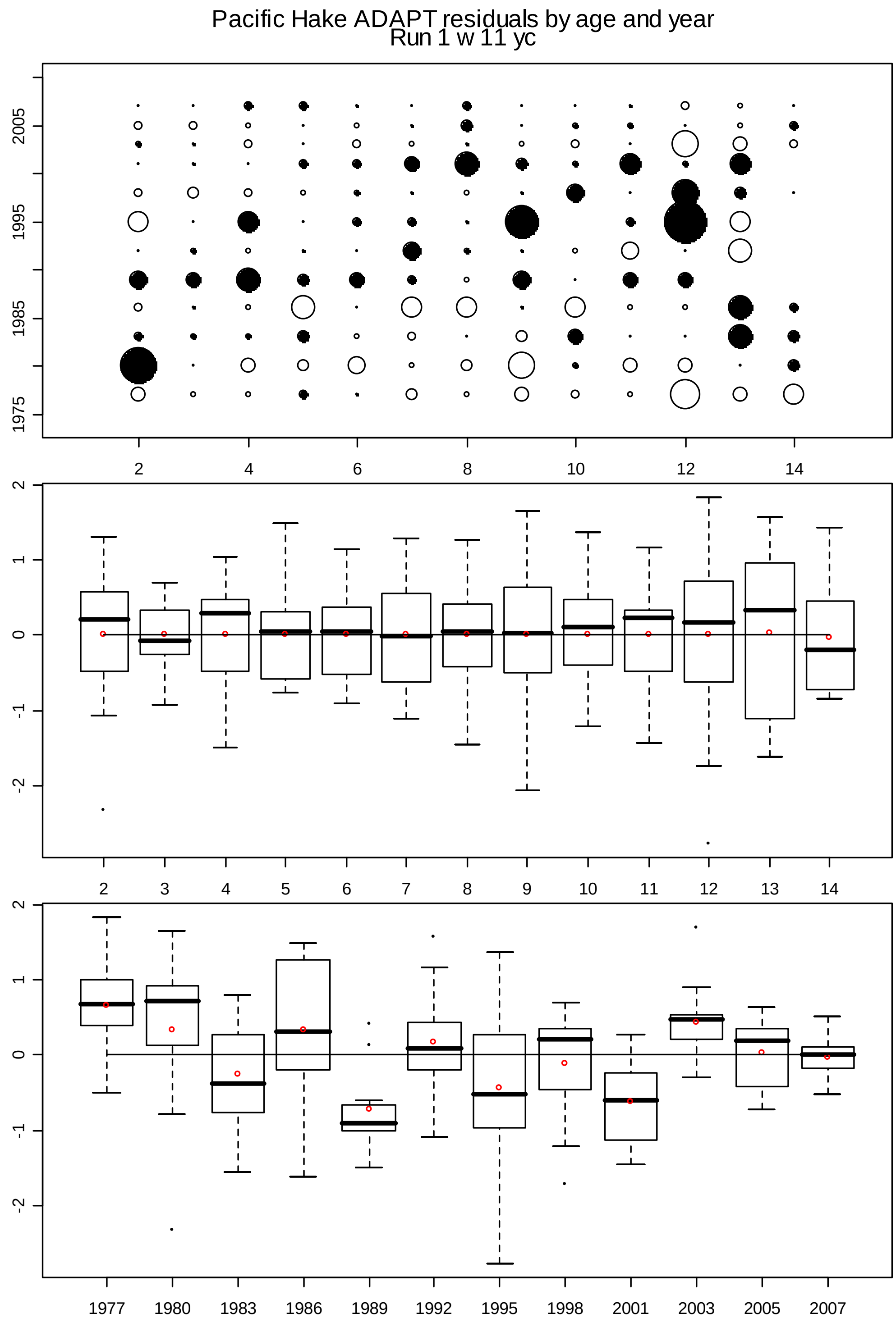


Figure 26: Residuals from Run 1 A. The upper plot shows residuals by age and year. Solid circles are negative. The area of the circles is proportional to the absolute value of the residual. Box and whisker plots are shown by age and year.

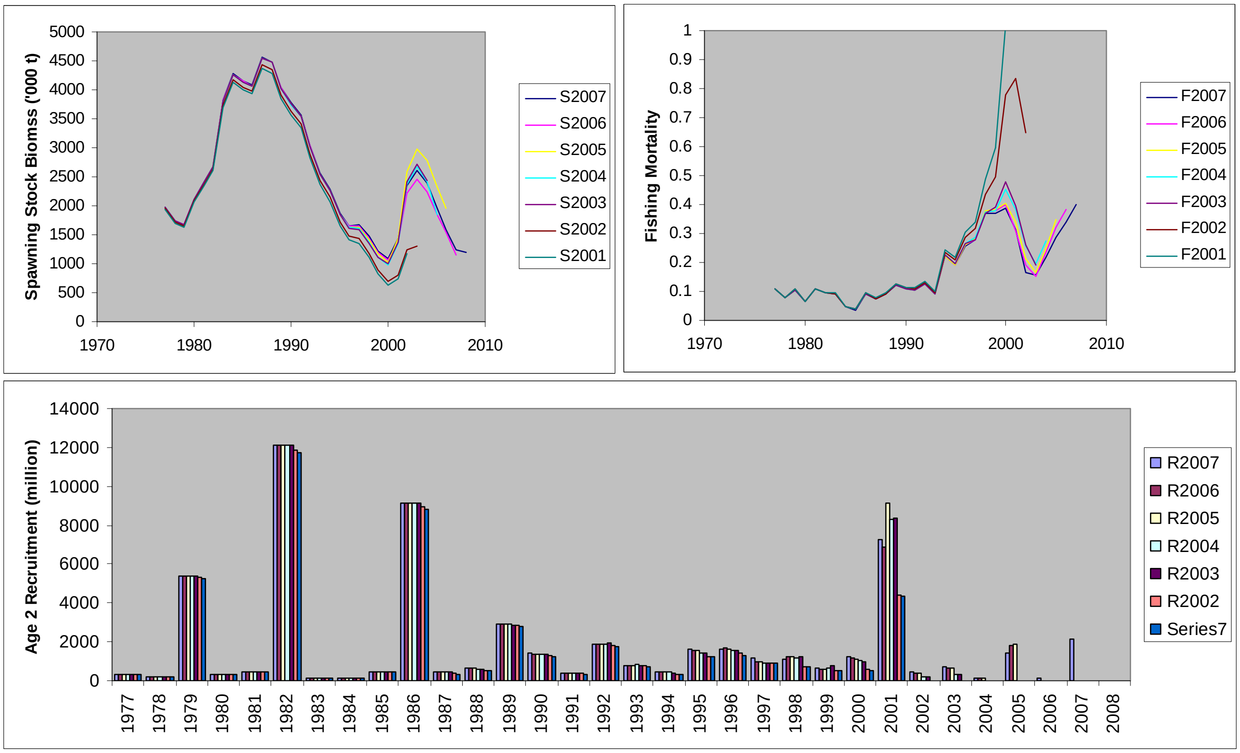


Figure 27: Retrospective estimates of spawning stock biomass, fishing mortality, and recruitment from VPA run 1.

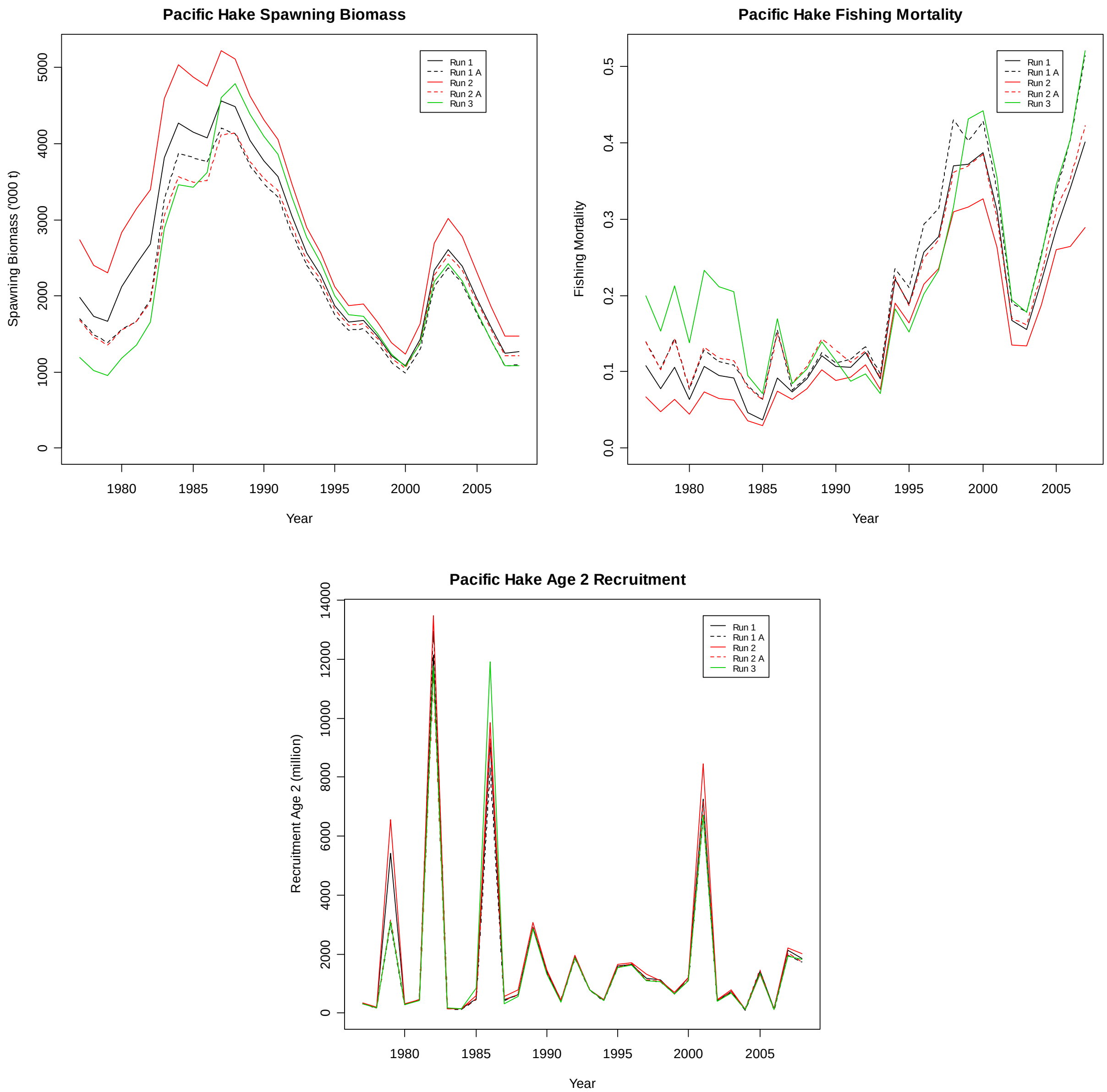


Figure 28: Trends in spawning stock biomass, population weighted age 7+ mean fishing mortality, and age 2 recruitment estimates from 5 VPA runs.

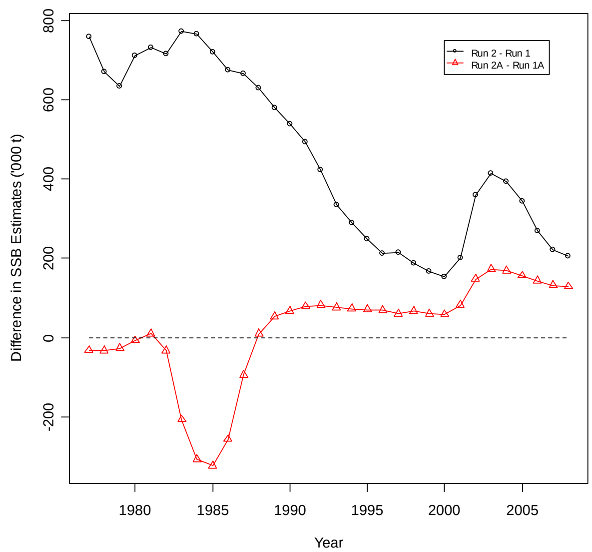


Figure 29: Annual differences in SSB estimates between ADAPT runs 1 and 2 (circles), and 1A and 2A (triangles).

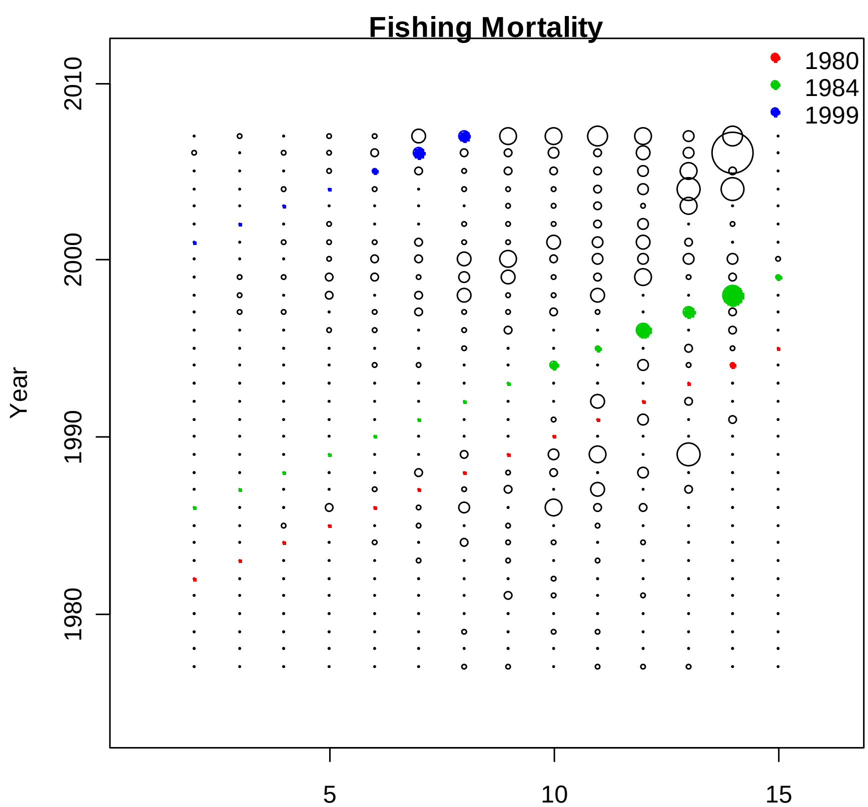


Figure 30: Fishing mortality at age and year from run 1 A. The large 1980, 1984, and 1999 year-classes are highlighted

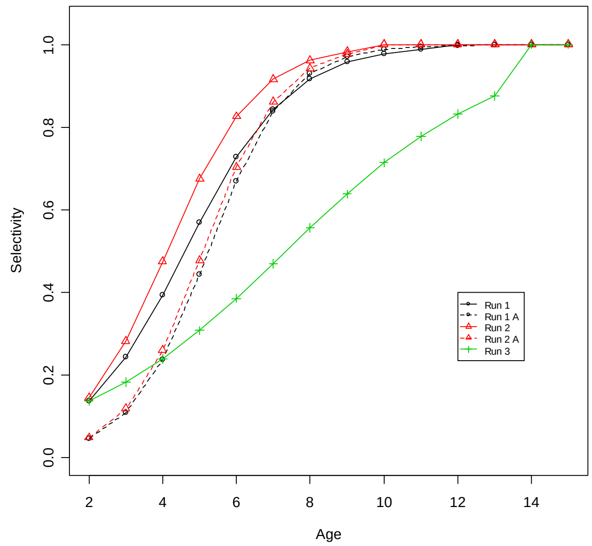


Figure 31: Selectivity estimates from the 5 ADAPT runs.

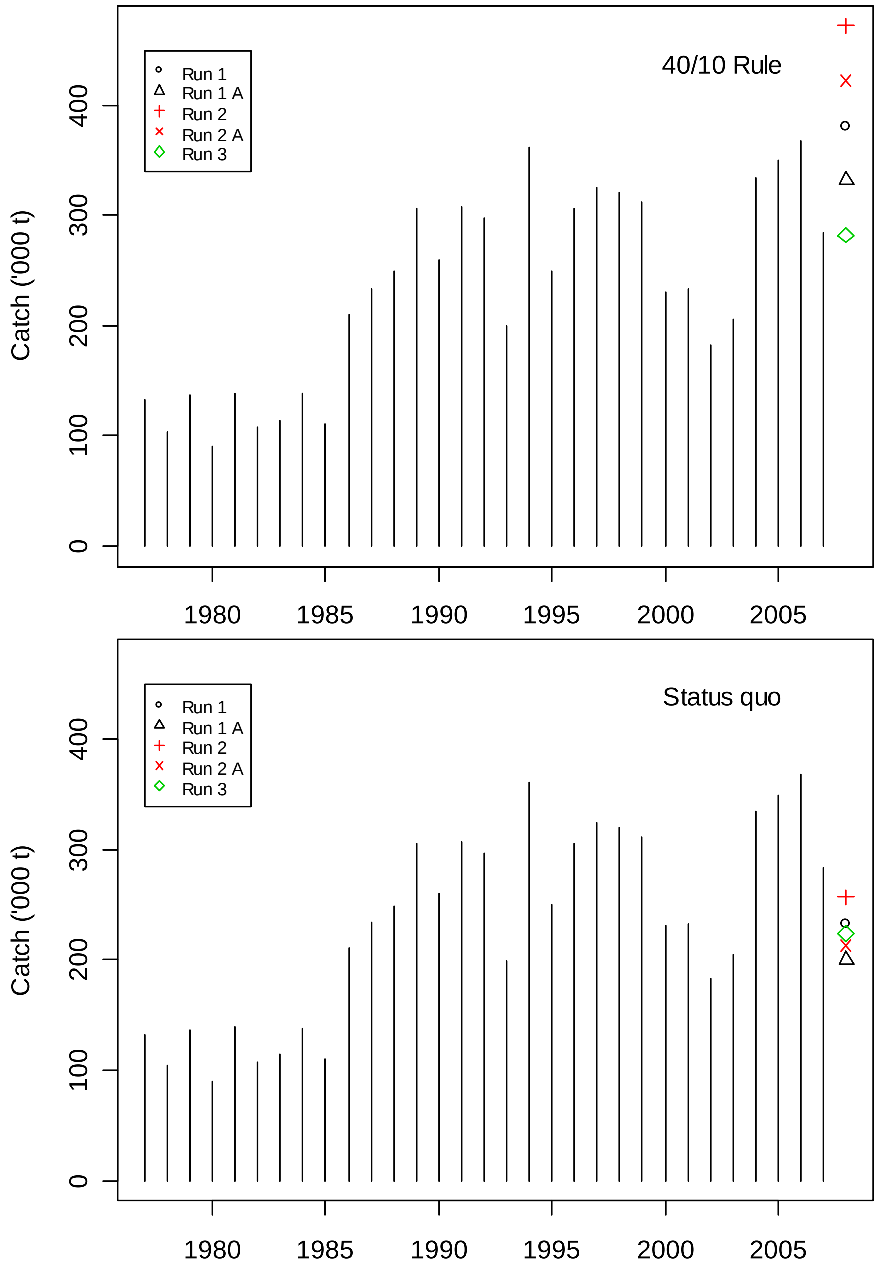


Figure 32: Annual catches of Pacific hake 1977 – 2007 compared to yield forecasts from the 5 ADAPT runs. The upper panel gives forecasts using the 40/10 rule. The lower panel given forecasts using the *status quo* rule.

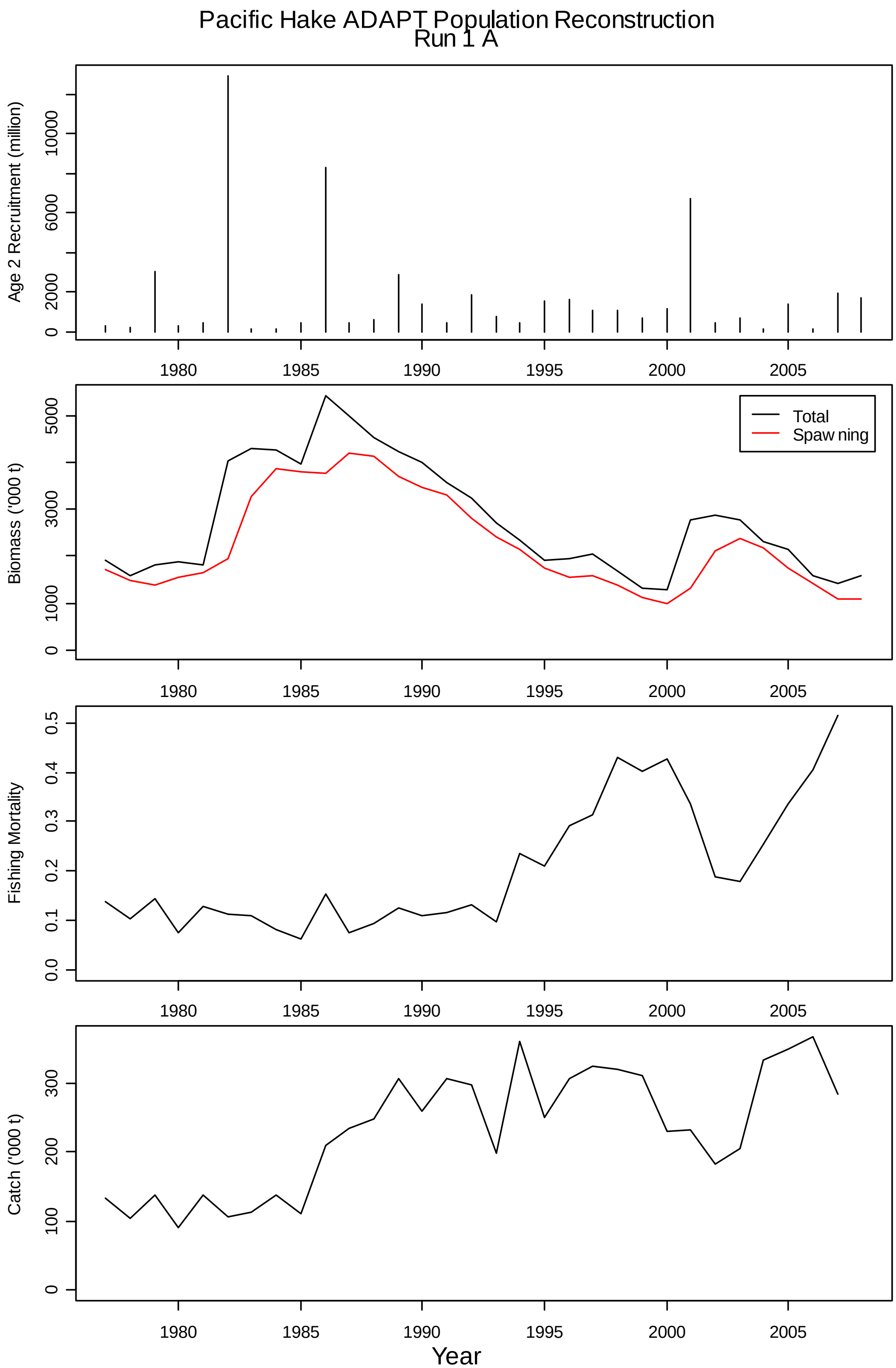


Figure 33: Recruitment, biomass, fishing mortality, and catch trends for Pacific hake from Run 1 A.

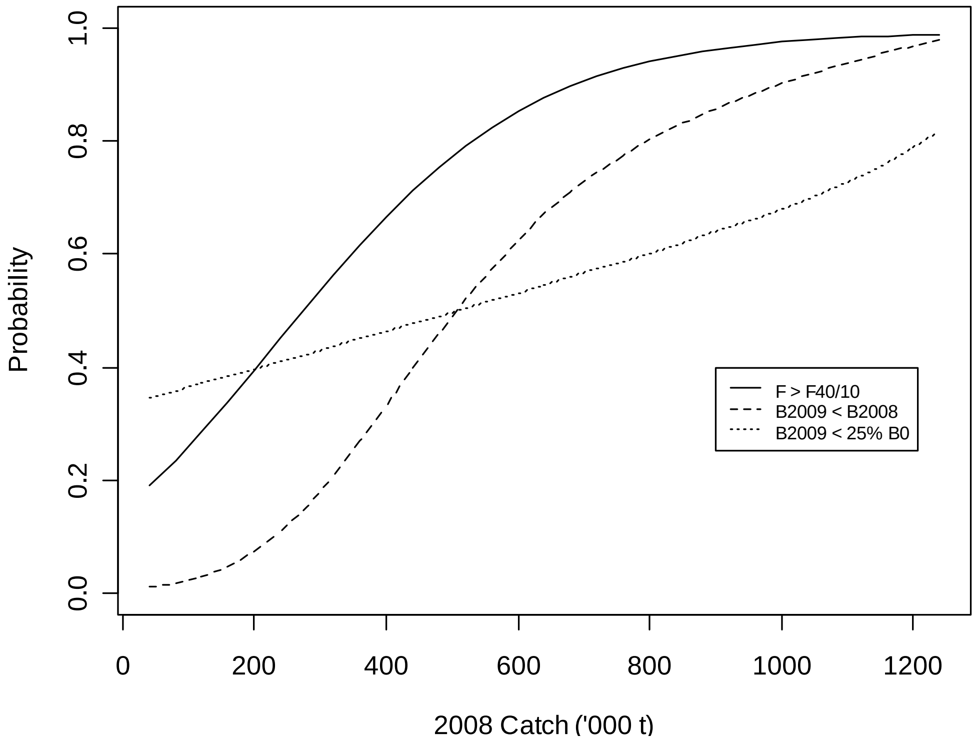


Figure 34: Risk analysis of the 2008 catch forecast for Pacific hake using the results of Run 1A. Three performance measures are presented, the probability of the 2008 fishing mortality being above F40/10, the probability of the spawning stock biomass declining between 2008 and 2009, and the probability of the 2009 spawning stock biomass being below 25% of the unfished equilibrium.

Appendix 1: Request for catch advice from Canadian fishery managers.

Request for Catch Advice

Date Submitted:

Individual or group requesting advice: DFO Fisheries Management, GTAC

Proposed Presentation Date: February, 2008

Subject of Paper (title if developed): Assessment of Pacific hake in the offshore area of Western Canada and the USA

Science Lead Author: Alan Sinclair

Resource Management Lead Author: Barry Ackerman/Gary Logan

Rationale for request:
The offshore fishery for Pacific hake is the largest single species fishery in BC. The stock is transboundary between Canada and the USA. A treaty dealing with the joint management of this fishery was signed by Canada and the USA in 2003. While all the committee structures outlined by the treaty have not been established, it has been proposed to proceed with the 2007 assessment as a collaboration between Canadian and USA scientists in the spirit of the treaty.

The Canadian and US combined fisheries on this stock in recent years have been some of the largest ever. Harvest levels in 2006 and 2007 were established considering the spirit of the 2003 treaty, the consideration and subsequent rejection of harvest advice generated thru the joint Canada/US assessment process (SS2 assessment model), and the overall ability of the industries in each country to effectively manage the harvest within established harvest levels.

Concerns with the current model ability to accurately assess the biomass and reconstruct of historic biomass levels exist. It is accepted that the hake biomass fluctuates widely due to the emergence and domination of strong year classes (ie.1980, 1984, 1999) in the stock. The most recent assessment relies heavily on the predominance of 1999 year-class, which is now declining in biomass. Despite uncertainty in the recruitment strength of particularly the 2004 year class, the current model continues to generate harvest ranges 2 to 3 times the current harvest levels. The current models outputs run counter to expectations for the ageing hake biomass with little indication of the emergence and recruitment of a new strong year class. Additionally accurate reconstructions of pre-fishery biomass estimates are intrinsic in the establishment of coast-wide total allowable catch levels. The perceived failure of the model to produce acceptable harvest advice resulted in mangers setting harvest levels at lower than recommended science advice in both 2006 and 2007.

These elements continue to be of concern to Canadian fisheries managers and members of the Canadian fishing industry. Fisheries managers have requested that science further investigate alternative stock assessment methodologies in order to provide more certainty associated with levels of projected catch in 2008 and beyond. This concern is further compounded by a shift in the Canadian fishery in 2006 and 2007 from the traditional area off southwest Vancouver Island (southern area 3C) northward and into southern Queen Charlotte Sound (areas 5AB).

Canada is committed to implementing the Precautionary Approach to fisheries management and meeting obligations set out in the Hake treaty. Harvest strategies are required for all fisheries that include target and limit stock status reference points, and a variable harvest rate which is adjusted according to the productivity of the resource. Catch advice for Pacific hake should reflect this approach respecting the default harvest rate of F-40 percent with a 40/10 adjustment set out within the treaty, but not restricting the provision of scientific advice on alternate rates necessary to sustain the offshore hake resource

Objective:
To review surveys, biological sampling, catch records, logbooks, observer reports and fishing practices for Pacific hake and recommend biological reference points for management and provide a basis for management for the 2008/09 fisheries in the offshore areas.

Question(s) to be addressed:
(To be developed by initiator)

What is the current biomass and size structure of the offshore Pacific hake stock and how does this relate to historical stock conditions?

What is the expected trajectory of offshore Pacific hake biomass to the end of the 2008/09 fishing season and how will this be affected by a range of annual TACs?

What are appropriate biological reference points for the stock? Include biological considerations and rationale used to form these recommendations.

What is known about the stock structure and origin of Pacific hake recently caught in southern Queen Charlotte Sound?

Stakeholders Affected:
GTAC/IHAC

How Advice May Impact the Development of a Fishing Plan:
The catch advice will directly affect TAC's set in the IFMP for 2008/09 and beyond.

Timing Issues Related to When Advice is Necessary:
Catch advice is required before March 2008

Approved:

Science Manager: ________________________________; Date:_______________________

Fisheries/Habitat/Oceans
Manager: ________________________________; Date:_______________________