# CANADIAN ASSESSMENT OF PACIFIC HAKE IN U.S. AND CANADIAN WATERS IN 2009 

## Context

The Pacific hake, also referred to as Pacific whiting (Merluccius productus) is a transboundary stock which is jointly managed by Canada and the U.S. Annual stock assessment has been coordinated by the U.S. National Marine Fisheries Service (NMFS), reviewed in the groundfish stock assessment review (STAR) process, providing catch advice to the Pacific Fisheries Management Council (PFMC). Scientists from NMFS have led the stock assessment modeling for many years with the assistance of Canadian scientists. For the last number of years, the stock assessments were done using the Stock Synthesis (SS2) software package (Helser et al. 2008). Two alternative assessment models were developed by Canadian scientists and presented to the STAR panel for review in February, 2008 (Martell 2008, Sinclair and Grandin 2008). The 2008 fishery ran later than usual resulting in delays in assembling Canadian fishery data. These data were not available for the February, 2009 STAR panel review. However, results of these assessments will be presented to the PFMC Science and Statistics Committee (SSC) at its meeting on March 8, 2009. This report summarizes the results of Canadian assessment of Pacific hake in 2009. The assessments are essentially updates of methods reviewed by the 2008 STAR Panel.

## Background

Pacific hake are a highly migratory and transboundary stock with a distribution from southern California to the Queen Charlotte Islands. Spawning occurs in winter at the southern extent of the range. Adult hake begin a northern migration in the spring along the continental shelf and slope, and form dense feeding aggregations in BC waters in the summer. The Canadian fishery was traditionally concentrated off southern Vancouver Island, however the fishery shifted northward to Queen Charlotte Sound in 2006 - 2008. A detailed description of the fishery may be found in Hamel and Stewart (2009).

Following recommendations of previous STAR panel reviews (PFMC 2007) and requests for scientific advice from Canadian fisheries managers, two alternative assessment models were developed for this stock for the 2008 STAR panel, an age-structured production model (TINSS, Martell et al. 2008) and a virtual population analysis (VPA, Sinclair and Grandin 2008). The intent was to compare results with the traditional stock synthesis model which has proven to be extremely sensitive to changes in model structure.

A Science Response was required for the 2009 hake stock assessment because 1) the late availability of the 2008 Canadian fishery data precluded presentation at the 2009 STAR panel and the PMFC SSC indicated the results could be presented th their meeting. This resulted in a short time frame for a full review. 2) the methods were reviewed by the STAR panel in 2008, 3) DFO Science is not the final advisory authority for management of the Pacific hake fishery. The TINSS and VPA models were updated when the 2008 Canadian fishery data were available and the results of these analyses were peer reviewed at a meeting coordinated by the CSA, Pacific

Region held in Nanaimo, BC on March 4, 2009. The results of the meeting are described in this report. Meeting participants are listed in the Contributors section.

## Analysis and Response

## VPA Results

A VPA of Pacific hake was reviewed by the STAR panel in 2008 using catch and survey data up to 2007 (Sinclair and Grandin, 2008). The analysis was repeated with the addition on catch data for 2008. There were no new stock abundance indices for 2008. The VPA results for 2009 were highly variable and included a very large bias component. Bootstrapping was used to estimate the variance, distribution, and bias of the VPA parameters (Rivard and Gavaris 2003). Further examination of the bootstrap estimates revealed that in a large number of bootstrap replicates cohorts appeared to be completely fished out in the terminal year. One potential cause was because there was not a survey estimate for the terminal year. The analysis fit the survey data up to 2007 and then applied the "known" catch in 2008. In several instances, there were not enough fish to support these catches. The cumulative distributions were also extremely skewed, thus leading to the very high estimated bias. This did not occur in a bootstrap analysis of the data up to 2007, suggesting the main cause was the lack of survey data for the terminal year.

Given the evidence for large bias in the estimates and thus the need for a reliable method of estimating bias, and the apparent pathology of the bootstrap results, it is suggested that these results be deemed unreliable for providing catch advice for 2009.

## TINSS Results

This model directly estimates the management variables $C$ (the maximum sustainable yield) and F (the fishing mortality rate that produces C ). The model was implemented in the AD Model Builder software and is based on the methods in Martell et al. (2008). The structural assumptions are similar to that of Stock Synthesis: a Beverton-Holt stock recruitment relationship is assumed, it is assumed that the population was at an unfished state in 1966, and the model is conditioned on historical catch information. The data for TINSS were extracted from the input files use for Stock Synthesis and the catch and catch-age information from U.S. and Canadian fisheries are aggregated into a single fishery and the selectivity curve for this aggregate fishery is assumed to be asymptotic. The selectivity curve for the fisheries independent acoustic trawl survey was assumed to be asymptotic. In contrast to previous assessments, this assessment attempts to reduce the amount of prior information on key population parameters and subjective weighting of data that ultimately defines the catch advice. Model parameters were estimated at the posterior mode and using full Bayesian integration (Markov Chain Monte Carlo simulation). Catch advice is provided in the form of a decision table and is based on the Bayesian view of the model parameters.

There was a substantial change in the likelihood kernel used for the age-composition data in comparison to the assumed model structure in last years assessment prepared by Martell (2008). In last years assessment, a robust normal approximation to the multinomial distribution was used as the likelihood for the age composition data. This is the same likelihood function that is used in Multifan CL (see Fournier et al., 1990; Martell et al., 2008) and requires a subjective estimate of the effective sample size. In this assessment a more objective approach was adopted that used the multivariate logistic kernel (see Richards and Schnute, 1998) where the conditional maximum likelihood estimate of the variance (for the residual differences in the
age-composition data) was used to weight the age-composition data in both the commercial fishery samples and the acoustic survey samples.


Figure 1: Maximum likelihood estimates of vulnerable and spawning biomass (panel a), fishing mortality (b), age-1 recruits (c) and the observed historical landings (d) for U.S. and Canadian fisheries combined.

Estimates of the vulnerable biomass, spawning stock biomass, fishing mortality rates, age-1 recruits at the posterior mode and historical landings are summarized in Fig. 1. During the late 1960s and 1970s, annual landings averaged $169,000 \mathrm{t}$ and the corresponding fishing mortalities were less than 0.18 per year. During the 1980s catches increased from $90,000 \mathrm{t}$ to just over 300,000 tons and the fishing mortality rates during this period averaged less than 0.11 per year. Two exceptionally strong cohorts $(1980,1984)$ were responsible for a large increase in the vulnerable biomass during this time period. The vulnerable biomass peaked in the mid 1980s and declined steadily to a low of 1.35 million tons in 2000. During this time period, there were no significant recruitment events, annual landings increased from 110,000 tons in 1985 to nearly 312,000 tons in 1999, and the fishing mortality rate increased to 0.34 . The 1999 year class was also exceptional in numbers, as a result the vulnerable biomass more than doubled from 1.35 million tons in 2000 to 2.75 million tons in 2004. Catches declined as this year class recruited to the fishery, resulting in a reduction in fishing mortality to 0.15 in 2003. Catches increased
again, reaching 360,000 t in 2005 and 2006, causing another sharp increase in fishing mortality. As the 1999 year class passed through the fishery and was not replaced with another exceptional year class, catches remained high. Vulnerable and spawning biomass reached their historical minima following the 2008 fishery, and fishing mortality continued to spike in 2008, reaching an extremely high value well in excess of the estimate of $\mathrm{F}^{*}$ (nearly 3 times $\mathrm{F}^{*}$ ).

Five criteria were examined in developing risk profiles for catch options in 2009 (Table 1, Fig. 2). A risk neutral catch option would correspond to the 0.5 risk level in Table 1. Risk averse options would be at a lower risk level, and risk prone options would be at a higher risk level. The first criterion is the probability of the fishing mortality rate exceeding the estimated value of $\mathrm{F}^{*}$. The risk neutral catch option for the 2009 fishing season based on achieving the target fishing rate of $\mathrm{F}^{*}$ is $174,000 \mathrm{t}$. The second criterion is the probability of the spawning stock declining between 2009 and 2010. Under this criterion the risk neutral option is $113,000 \mathrm{t}$. The third criterion examines the probability that the spawning stock biomass in 2010 will remain below the estimate of SBMSY. Under this criterion the risk neutral option is $35,000 \mathrm{t}$. The last two criteria examine the probability that the spawning stock in 2010 will be below the management target SB40 and SB25. Under these criterion, the risk neutral catch options are 0 and 443,000 t respectively.

Table 1: Decision table for catch advice (million $t$ ). The risk level represents the probability of exceeding a specified management target for a given catch option. The interpretation of this table is as follows; if the management goal is not to exceed the target fishing mortality rate of $F^{*}$ (Fmsy) in 2009 with a 0.25 probability, then the catch option should be set at 0.091 million mt or less. If the management target is to prevent further decline in spawning stock biomass with a 0.5 probability then the catch should be 0.113 million $t$ or less.

| Risk level | $F_{09} \geq F^{*}$ | $S B_{10} \leq S B_{09}$ | $S B_{10} \leq S B_{M S Y}$ | $S B_{10} \leq S B_{40}$ | $S B_{10} \leq S B_{25}$ |
| ---: | ---: | ---: | ---: | ---: | ---: |
| 0.05 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 0.10 | 0.009 | 0.000 | 0.000 | 0.000 | 0.000 |
| 0.15 | 0.043 | 0.000 | 0.000 | 0.000 | 0.000 |
| 0.20 | 0.069 | 0.000 | 0.000 | 0.000 | 0.023 |
| 0.25 | 0.091 | 0.000 | 0.000 | 0.000 | 0.110 |
| 0.30 | 0.110 | 0.000 | 0.000 | 0.000 | 0.186 |
| 0.35 | 0.127 | 0.030 | 0.000 | 0.000 | 0.255 |
| 0.40 | 0.143 | 0.058 | 0.000 | 0.000 | 0.320 |
| 0.45 | 0.159 | 0.086 | 0.000 | 0.000 | 0.382 |
| 0.50 | 0.174 | 0.113 | 0.035 | 0.000 | 0.443 |
| 0.55 | 0.189 | 0.139 | 0.112 | 0.052 | 0.504 |
| 0.60 | 0.204 | 0.167 | 0.191 | 0.133 | 0.566 |
| 0.65 | 0.220 | 0.195 | 0.273 | 0.218 | 0.631 |
| 0.70 | 0.237 | 0.226 | 0.361 | 0.309 | 0.700 |
| 0.75 | 0.256 | 0.259 | 0.457 | 0.409 | 0.776 |
| 0.80 | 0.278 | 0.298 | 0.568 | 0.523 | 0.864 |
| 0.85 | 0.304 | 0.344 | 0.702 | 0.661 | 0.969 |
| 0.90 | 0.339 | 0.406 | 0.880 | 0.845 | 1.110 |
| 0.95 | 0.395 | 0.506 | 1.167 | 1.141 | 1.336 |

In summary, a catch of $174,000 \mathrm{t}$ in 2009 will be risk neutral with respect to overfishing ( $\mathrm{F}>$ Fmsy). At this catch, the probability of continued decline in spawning biomass and of the
spawning biomass being below Bmsy and the B40 proxy is about 60\%, and there is a probability of about 0.25 that the 2010 biomass will be below $25 \%$ of Bmsy.

## Conclusions

The Pacific hake population has been dominated by the exceptionally large 1999 year class for the last several years. This year class is currently declining in biomass and available data do not indicate that is going to be replaced by another year class of similar size. Fishery catches have remained high during the decline in the 1999 year class resulting in a very rapid increase in fishing mortality and a decline in vulnerable and spawning stock biomass. Fishing mortality in 2008 was the highest on record and well in excess of the management target. Stock biomass reached the lowest level on record at the beginning of 2009.


Figure 2: Risk plots of 5 criteria relative to catch in 2009 (million $t$ ) of Pacific hake: (a) Probability of F2009 >F*, (b) probability of a decline in spawning biomass, (c) probability of the SB2010 falling below SBmsy, and (d) probability of SB2010 falling below SB25 (bottom line) or SB40 (uper line).

## Research Recommendations

The hake stock is monitored jointly by Canada and the U.S. using a coastwide combined hydroacoustic/midwater trawl survey. The collection and processing of biological data on hake during these surveys was discussed. It was recommended that the protocols used to determine when trawl samples are collected be reviewed. It was also recommended that the procedures used to derive estimates of the age composition of the population using the trawl catches be reviewed. These recommendations are similar to recommendations from the 2009 STAR panel.

There was discussion of the possibility of incorporating information on ageing error into the hake assessment. This has been done in the last two U.S. assessments. Further work in this area is recommended.

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