Recommendations for Red, Silver, and Offshore Hake (Whiting) Allowable Biological Catches for 2012-2014

Whiting Plan Development Team
Report to the Scientific and Statistical Committee
July 2011

1.0 Issue

The Magnuson Stevens Fishery Conservation and Management Act requires Councils and NOAA's National Marine Fisheries Service (NMFS) to establish annual catch limits (ACLs) for managed fish stocks, overfished stocks by 2010 and all stocks by 2011. As stocks with index based assessments, the small mesh multispecies stocks (silver, red, and offshore hake, collectively known as whiting in the fishery and the Multispecies Fishery Management Plan) have never had total allowable catches (TACs) established and are currently managed by minimum mesh and possession limits by the Northeast Multispecies Fishery Management Plan (FMP). For simplicity, this report will refer to these species as 'hakes', as they are known in the scientific literature. A related species, white hake, managed by the Northeast Multispecies FMP as a large mesh species is not addressed here.

Now the Scientific and Statistical Committee (SSC) must approve an Acceptable Biological Catch (ABC) limit for each stock and the New England Fishery Management Council (Council) must set ACLs for the managed small mesh multispecies stocks based on new benchmark assessment data, completed in December 2010 and published in January 2011 (NEFSC 2011a and NEFSC 2011b). During the ABC methods review in April 2011, the SSC asked for additional analyses to evaluate the scientific risk of setting alternative ABCs.

One type of risk arises from using a smoothed biomass index (e.g. a recent three year moving average) to index changes in stock biomass and allow for consistent changes in the ABC when specifications are set. For managing the whiting fishery where no stocks are overfished and overfishing is not occurring, the Council is contemplating a three year specification cycle, with the 2012-2014 specifications relying on the fall 2008-2010 silver hake and spring 2009-2011 red hake survey biomass indices. On one hand, this choice creates a lagged response and source of uncertainty that the ABCs are consistent with existing stock conditions. On the other hand, it creates a more reliable limit to allow businesses to plan accordingly and time for the Council to manage other priorities.

At the April 2011 meeting, the SSC asked the PDT to evaluate other types of approaches, ones that would be more robust and potentially do a better job separating true changes in biomass from noise (aka interannual variation or sampling error). In response, the PDT presents and compares the performance of three approaches, or alternative smoothers, which are described in Section 5.1 and applied to the northern and southern stocks of red and silver hake.

A second source of uncertainty arises from reliance on index-based reference points to set ABCs. The SAW 51 (NEFMC 2011a and 2011b) review did not accept the analytical stock assessment model results for red and silver hake to due to poor diagnostics. And as a result, the assessment relied on historic index biomass and exploitation values to determine stock status. For red hake, the SAW chose the 1980-2010 period for this purpose. For silver hake, the SAW made no changes to the 1973-1982 period previously in use.

In recent years, the silver hake biomass has increased, but the age structure has become more truncated (i.e. lower proportion of older fish and spawners) despite the relatively low exploitation rates (catch/biomass). The analytic model (ASAP Run 6) for silver hake was unable to resolve these contradictory signals, but the SSC wanted to explore the potential effects of alternative ABCs using the model in case the signal from the age structure truncation (and other factors) are a more important signal than the recent increase in survey biomass (a Type III error, rejecting the analytic model even though the results may be correct[1]). The Whiting PDT ran medium term projections using the results from ASAP Run 6 results to demonstrate the potential risk. Because the projections did not perform well and the SAW had rejected the ASAP Run6 results, the PDT did not run other ABC alternatives. The results and discussion of this exercise is presented in Section 5.2.

At the request of the SSC, a third analysis was completed to evaluate the social and economic effects of alternative ABCs. There is an offsetting cost of being overly conservative to account for scientific uncertainty which results in the inability of the fishing industry to catch and land MSY. Being conservative can also provide more stable yield and have less dire economic and social consequences if the fishery exceeds MSY due to scientific uncertainty. The economic and social consequences of alternative whiting ABC levels is presented and discussed in Section 5.3.

Finally, the Whiting PDT noted at the April 2011 SSC meeting that the MSY proxy would be different for silver hake if it had been calculated on time periods other than 1973-1982 and this involves another source of scientific uncertainty and risk.

The SSC asked the PDT to evaluate the risk associated with ABC alternatives based on different time periods, using the Model 2 formulation that the SSC approved in April 2011 for evaluating scientific uncertainty. This analysis and evaluation is presented in Section 5.4, and is used as the basis for the PDT's recommendation for silver hake ABCs. It does not change the SAW-approved status determination, but recognizes that the Council may consider alternative ABCs that carry appropriate levels of risk accounting for the added scientific uncertainty.

The ABC recommendations based on Method 2 (approved by the SSC in April 2011 to estimate scientific uncertainty) are presented in Section 6.0. For red hake, the recommendation is based on the 25th percentile of the ABC distribution (Table 12; 222.6 mt for the northern stock and 2,954 mt for the southern stock) and the analysis includes an estimate of the probability that the ABC may exceed the MSY proxy. Compared to the April 2011 report (Document 2), these results were updated to include the recently available spring 2011 bottom trawl survey results.

For silver hake, the Whiting PDT is recommending that the SSC consider setting the ABC at a value less than the 25th percentile (Table 15): 13,180 mt for the northern stock and 32,640 mt for the southern stock (34,000 mt when augmented to account for catches of offshore hake). These values would have a lower probability of exceeding the MSY proxy and would account for a greater amount of scientific uncertainty in our knowledge of silver hake stock dynamics. In April 2011, the Whiting PDT recommended and the SSC approved augmenting the southern silver hake ABC to account for mixed catches of offshore hake. Historically the proportion of the catch from offshore hake is 4%, using the SAW model based estimates of species composition in the catch of the southern stock area.

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[1] A statistical test between models was not formally tested, however.

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3.0 Acronyms Used in the Document

3yr MA – A three year moving average of a variable, often of survey biomass or an exploitation rate.
ABC – Allowable Biological Catch
ACL – Annual Catch Limit
AIM – An Index Method assessment model or analysis
ARIMA - Auto-regressive moving average: a type of statistical time series model.
B_{msy} – The target biomass that would produce MSY when fished at a rate equal to Fmsy, theoretically ½ the carrying capacity for most populations
FMP – Fishery Management Plan
F_{msy} – The fishing rate the would produce MSY when the biomass is at the MSY target.
MSY – Maximum Sustainable Yield
NEFSC – Northeast Fisheries Science Center, NOAA
NMFS – National Marine Fisheries Service, NOAA
OFL – Overfishing Level, catches that exceed F_{msy}
PDT – Whiting Plan Development Team of the New England Fishery Management Council
SSC – The Scientific and Statistical Committee of the New England Fishery Management Council

4.0 Background

Amendment 19 to develop ACLs for hakes was postponed until after the benchmark assessment results became available (NEFSC 2011) in January 2011. It was hoped that the benchmark would produce analytical assessments with estimates of maximum sustainable yield (MSY) based reference points and scientific uncertainty. Unfortunately, despite many attempts with different models, the analytical assessments ultimately could not resolve different signals coming from low catches (especially compared with those in the early part of the time series), increasing stock biomass, and an increasingly truncated age structure in survey catches (i.e. increasing absence of older fish, particularly silver hake).

Nonetheless, the benchmark assessment made progress on resolving stock structure, species identification in the survey and commercial catches, and in estimating consumption. Despite the inclusion of predatory consumption estimates which were almost an order of magnitude greater than catch, the analytical models still did not perform well. Instead, the SAW accepted an index based assessment for both red and silver hake status determination, similar to previous assessments, with updated reference points. For offshore hake, there was no reliable information about catch or trends in abundance and biomass to guide management of offshore hake.

During a methods meeting in April 2011, the Whiting PDT presented information about scientific uncertainty in the whiting benchmark assessments (NEFSC 2011a and 2011b), and analyzed three methods for estimating the risk of the ABC exceeding the OFL. The SSC approved using Method 2 to estimated scientific uncertainty and directed the Whiting PDT to conduct additional analyses to evaluate ABC alternatives at different levels of scientific uncertainty estimated by Method 2. All analyses in this document are based on Method 2 to estimate scientific uncertainty (i.e. risk of exceeding OFL).

5.0 Sensitivity Evaluations

5.1 *Noise reduction methods and trend analysis*

The following analyses were applied to the biomass indices for the northern and southern stock areas for red and silver hake. These analyses offer potential substitutes for a three year moving average smoother that could do a better job at separating signal (a true change in biomass) from noise. One method uses an auto-regressive moving average (ARIMA) model to smooth data. Another method uses a Kalman filter which uses a recursive data processing algorithm for updating a system's linear projections to generate optimal estimates of desired quantities given a set of measurements. Using a retrospective approach, for silver hake only, both smoothing models are compared to a three year moving average smoother, which is commonly used for indexed based species for setting ABCs in the New England region. The Whiting PDTs conclusion is that while the more complex models may eventually offer a higher level of robustness and reduce scientific uncertainty, more work is needed and the three year moving average is an adequate choice for setting ABCs and making future specification adjustments.

At the 2011 April meeting, the SSC requested that the PDT, SSC, and NEFSC collaborate to explore alternative noise–reduction techniques relative to survey indices. The intent of theses explorations was to provide a measure of sensitivity to the 3- year moving average approach used for determining stock status for both the red and silver hake. Given the measurement error inherent in surveys, noise-reduction techniques may improve the ability to monitor both stock size and determine stock status. The biomass 'overfished' status determination for both red and silver hake was evaluated comparing the most recent 3-year moving average of the stratified mean weight per tow (kg/tow) from the spring and autumn survey, respectively, with the biomass threshold reference point. The exploitation 'overfishing' status determination for red hake is evaluated by comparing the most recent exploitation rate (annual catch/annual spring survey biomass) with the threshold reference point, whereas the 'overfishing' status determination for silver hake is evaluated comparing the most recent 3- year average of catch/autumn survey biomass to the biomass threshold reference point.

The two noise-reduction techniques, ARIMA and Kalman filter, were compared to the 3-year- moving average (3yr MA) used for status determination for red and silver hake. The use of a smoothed time series would have a potential effect on the overfishing limit (OFL) for silver hake, since the estimate is based on the survey time series, however, this would not be so for red hake since the OFL is based on the relative F distribution from the AIM analysis.

A detailed description for the ARIMA is provided in Appendix 1 and for the Kalman filter in Appendix 2.

5.1.1 Red hake

Comparison of the observed survey index with the three time series estimated from the ARIMA, Kalman filter and 3yr MA are presented for northern (Figure 1) and southern (Figure 2) red hake. In general, the three methods follow the same overall trend, although each model smoothes through the extreme values to a different degree given the respective assumptions about variance. The 3yr MA , which does not account for any variance in the survey estimate, is off center from the ARIMA, as expected, since the end year is used rather than the midpoint of 3 years. The Kalman filter, which accounts only for the variance in the previous estimate, smoothes the time series to a greater degree than the ARIMA or 3-yr MA . The ARIMA, which accounts for the past perturbations to the system on a moving average basis, more closely follows the observed indices.

For comparison purposes, BRPs were estimated using the three smoothed time series to determine the effect on the 2010 biomass status determination for each stock. Each of the smoothed time series scale the population differently to a relatively small degree and in all sensitivities the status determination remains as 'not overfished' (Table 1). The ARIMA and 3yr MA biomass threshold reference points were similar to the observed biomass, however, the Kalman filter differed by more than 10% in both the northern and southern stock.

A determination of the effect of a smoothed time series from either the ARIMA or Kalman filter on the exploitation reference point or the distribution of the OFL would require re-doing the assessment and re-running the AIM model with the smoothed time series to produce the bootstrap frequency distribution of relative F. A revised reference point could then be used for current status determination of exploitation. In addition, the probability distribution of a 'smooth' OFL could then be derived from the joint probability of the frequency distribution of the smoothed relative F (F_{msy} proxy) and the most recent annual estimate from the smoothed spring survey time series and subsequently, an ABC could be estimated.

Figure 1. Observed NEFSC spring survey biomass (kg/tow) time series with 3-year-endpoint moving average, ARIMA and Kalman filter time series fit for northern red hake, 1968-2009.

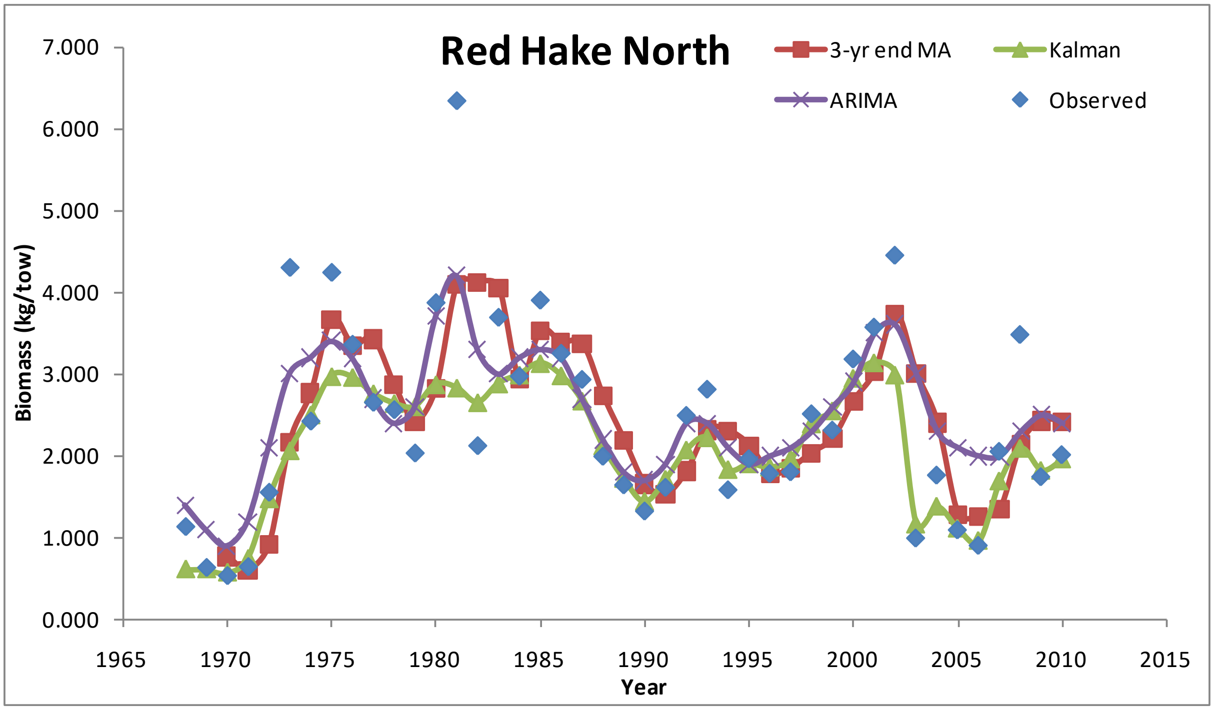


Figure 2. Observed NEFSC spring survey biomass(kg/tow) time series with 3 year-endpoint moving average, ARIMA and Kalman filter time series fit for southern red hake, 1968-2009.

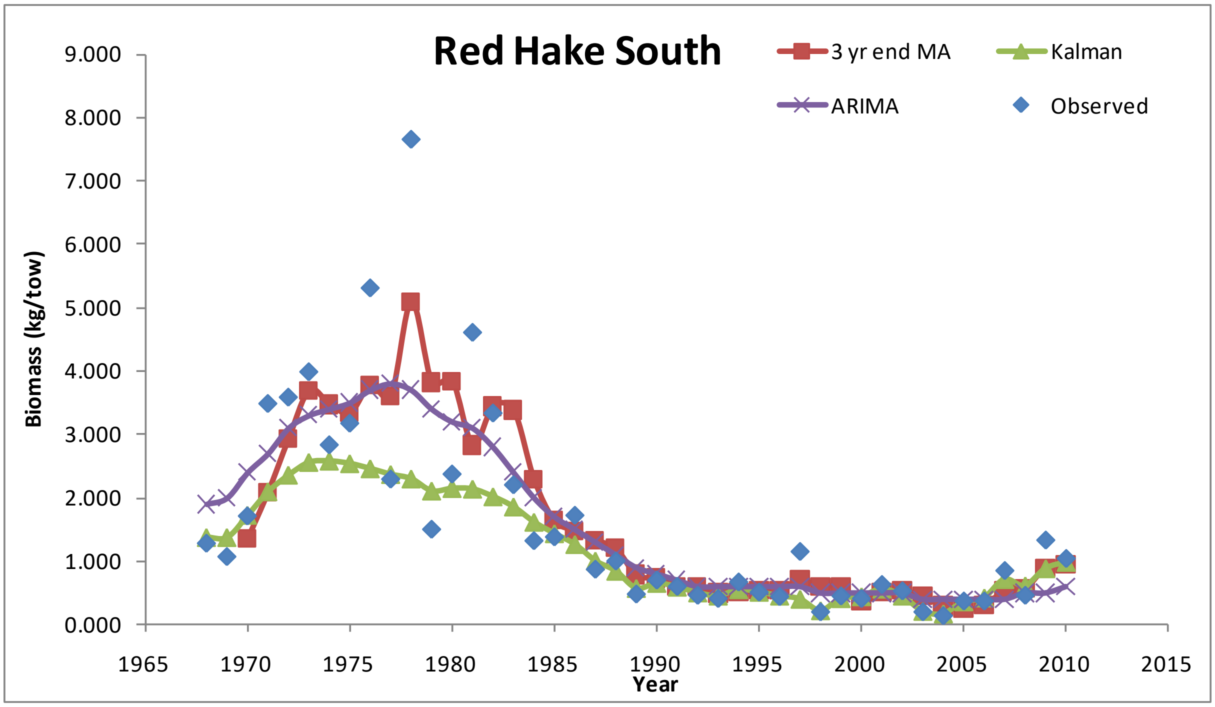


Table 1. Biomass threshold reference point for annual survey biomass and the ARIMA, Kalman, and 3yr MA smooth, percent difference to the observed, and status determination for each estimator.

Red Hake											
Biomass Threshold (1980-2010)			% difference to Annual SV Ref. Pt.				2010 Survey biomass estimate				Status
Reference Point	North	South		North	South		North		South		Determination
							mean	var	mean	var	
Annual SV biomass	1.265	0.508	Annual SV biomass	0.0	0.0	Annual SV biomass	2.419	0.033	0.954	0.022	not overfished
ARIMA	1.302	0.504	ARIMA	2.9	-0.8	ARIMA	2.403	0.246	0.600	0.009	not overfished
Kalman	1.102	0.409	Kalman	-12.9	-19.5	Kalman	1.970	0.042	0.984	0.028	not overfished
3 yr MA-endpt	1.269	0.547	3 yr MA-endpt	0.3	7.7	3 yr MA-endpt	2.419	0.033	0.954	0.022	not overfished

5.1.2 Silver hake

A comparative analysis was carried out between the 3yr MA smoother and the ARIMA and Kalman filter to examine the implied difference in survey estimates and the relative exploitation ratios for both northern and southern silver hake. Exploitation ratios for each of the smoothers were calculated as the ratio of the total catch to the smoothed survey estimates. The associated reference points were also examined, including the implied stock status under the alternative noise reduction algorithms. Of special note, the 3 year centered moving average was used for basis of comparison in the figures as opposed to the end point moving average that was approved at SARC 51. The centered moving average was chosen because it does not incorporate the lag effect that is often inherent in the end point moving averages. However, the implication of using the centered average for this exploration is that one less year informs the start and terminal year of the time series. In the absence of an ARIMA variance estimates for the survey biomass, CV's from the survey in Albatross IV units were applied to the smooth estimates to calculate the variance for this sensitivity. Currently, the variance estimate for the ARIMA is under development and will be provided at a later time if deemed necessary. For the Kalman filter, variances for the survey were calculated based on the 95% confidence interval from the filtered estimates and assuming a normal distribution in the following equation:

$$Var = \left[\frac{95\%CI - Kalman\_Smooth}{1.96} \right]^2$$

Results of the observed survey index including the three smoothing methods estimated from the ARIMA, Kalman filter and the 3yr MA are illustrated for the northern stock in Figure 3 and for the southern stock in Figure 4. Generally, the ARIMA and the Kalman filter follow the same trend and the degree of smoothing was fairly similar for the majority of the time series compared to the 3yr MA. However, the degree of smooth through some of the extreme values (i.e. peaks and troughs) varied, particularly during the early and recent periods of the time series influenced by the variance assumptions in each model. The 3yr MA does not account for any variance in the survey estimate. The ARIMA model, which resulted in greater smoothing in the latter part of the time series accounts for past perturbations to the system on a moving average basis. However, the Kalman filter which exhibited greater smoothing at the beginning of the time series but only accounts for the variance based on prior estimates in the time series.

Results of the biological reference points from the three smoothed time series approaches are presented in Table 2 and Table 3 to evaluate the effect of the estimator on the 2010 survey biomass and exploitation ratio for both stocks. Each of the smoothed time series scaled the population differently by a relatively small degree and in all sensitivities the status determination did not change as being 'not overfished' and "overfishing" not occurring. The biomass threshold reference points for the ARIMA and Kalman filter were relatively similar in both the north and the south and the smoothed estimates were within 10% of the 3yr MA results used for status determination in the benchmark assessments. The ARIMA and Kalman filter 2010 survey variances were almost three times the variance estimates from the three year moving average in the north (Table 2). However in the south, the variances for the ARIMA was similar to the 3yr MA with the Kalman filter estimates being slightly higher (Table 3).

The 3yr MA for biomass was used in the benchmark assessment to determine status, compared with the 1973-1982 average exploitation rate. For the northern silver hake stock, when the ARIMA smoother is applied to the current exploitation rate, it does not change status (Table 2), but the current exploitation is higher relative to those calculated with a 3yr MA. In comparison, the exploitation rate using the Kalman filter also did not change the status determination, but the current exploitation rate was lower than those estimated using either the ARIMA or the 3yr MA. The opposite results were found for the southern stock when the same smoothing procedures were applied, but also did not change the status determination (Table 3).

Overall, the exploratory analyses among the various smoothers were informative but require further investigation on the assumptions regarding the variance estimators, particularly for the ARIMA models. The improvement in the variance estimates in the smoothers should be interpreted with caution, particularly for the exploitation ratios because the steep change in productivity during 1973-1982 still persists (see Figures A3 and A5 in NEFSC 2011a) and remains as source of uncertainly for deriving OFL. Although the 3yr MA smother is considered a low pass filter and most parsimonious relative to the ARIMA and Kalman filter, the similarity in the trends for stock status and reference points provides additional support for the use of the 3yr MA. Finally, caution should be taken when applying these noise reduction techniques to survey data because of the potential of misinterpreting what could be a signal as noise. For example, strong year classes could potentially be treated as an anomaly which could in fact reflect real signal in the population.

Figure 3. Observed NEFSC fall survey biomass(kg/tow) time series with 3 year-centered point moving average, ARIMA and Kalman filter time series fit for northern silver hake, 1963-2010.

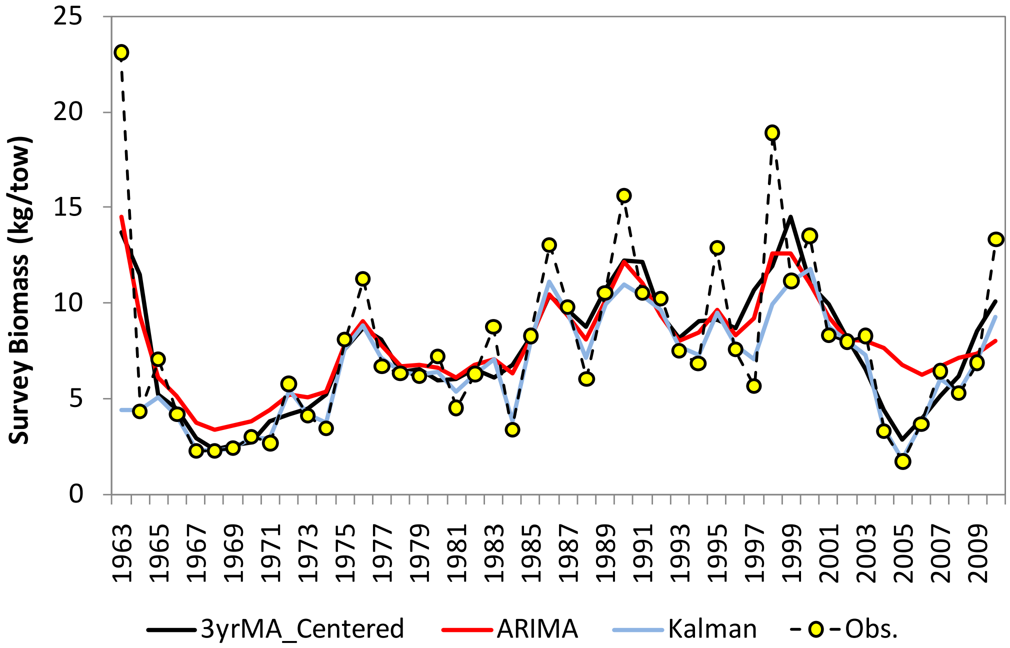


Figure 4. Observed NEFSC fall survey biomass(kg/tow) time series with 3 year-centered point moving average, ARIMA and Kalman filter time series fit for southern silver hake, 1963-2010.

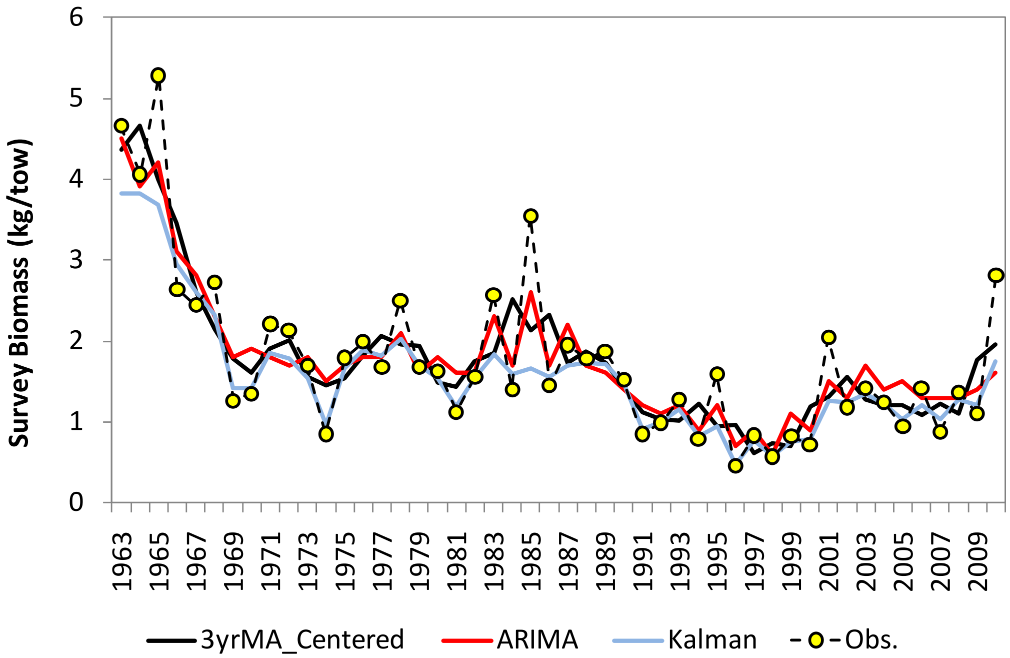


Table 2. **Northern silver hake** biomass (TOP) and exploitation (BOTTOM) threshold reference points for annual estimates, the ARIMA, Kalman, and 3 yr MA smooth, percent difference to the observed and status determination for each sensitivity smooth estimator.

Northern Silver Hake
Biomass Threshold (1973-1982)

Reference Points	Estimate
Annual SV Biomass	3.21
ARIMA	3.41
Kalman	3.11
3 yr MA- Centered	3.28
3 yr MA- End Point	3.16

% Difference to Annual SV Ref Point

	Estimate
Annual SV Biomass	0.0%
ARIMA	-6.2%
Kalman	3.1%
3 yr MA- Centered	-2.2%
3 yr MA- End Point	1.5%

2010 Smoother Estimate

	Estimate	Variance	Status Determination
Annual SV Biomass (2010)	13.35	0.00	Not Overfished
ARIMA (2010)	7.99	3.10	Not Overfished
Kalman (2010)	9.30	3.54	Not Overfished
3 yr MA- Centered (09-10	10.12	1.02	Not Overfished
3 yr MA- End Point (08-10	8.50	1.06	Not Overfished

Northern Silver Hake
Exploitation Threshold (1973-1982)

Reference Points	Estimate	Variance
Annual Exploitation	2.77	6.38
ARIMA	2.37	4.03
Kalman	2.75	6.06
3 yr MA- Centered	2.51	2.51
3 yr MA- End Point	2.84	2.84

% Difference to Annual SV Ref Point

	Estimate
Annual Exploitation	0.0%
ARIMA	14.4%
Kalman	0.9%
3 yr MA- Centered	9.4%
3 yr MA- End Point	-2.4%

2010 Smoother Estimate

	Estimate	Status Determination
Annual Exploitation (2010)	0.19	No Overfishing
ARIMA (2010)	0.31	No Overfishing
Kalman (2010)	0.27	No Overfishing
3 yr MA- Centered (09-10)	0.25	No Overfishing
3 yr MA- End Point (08-10	0.29	No Overfishing

Table 3. **<u>Southern silver hake</u>** biomass (TOP) and exploitation (BOTTOM) threshold reference points for annual estimates, the ARIMA, Kalman, and 3 yr MA smooth, percent difference to the observed and status determination for each sensitivity smooth estimator.

Southern Silver Hake **Biomass Threshold (1973-1982)**	
Reference Points	Estimate
Annual SV Biomass	0.83
ARIMA	0.87
Kalman	0.79
3 yr MA- Centered	0.85
3 yr MA- End Point	0.86

% Difference to Annual SV Ref Point	
	Estimate
Annual SV Biomass	0.0%
ARIMA	-4.9%
Kalman	3.9%
3 yr MA- Centered	-2.9%
3 yr MA- End Point	-4.5%

2010 Smoother Estimate			
	Estimate	Variance	Status Determination
Annual SV Biomass (2010)	2.82	0.00	Not Overfished
ARIMA (2010)	1.60	0.06	Not Overfished
Kalman (2010)	1.74	0.13	Not Overfished
3 yr MA- Centered (09-10)	1.96	0.04	Not Overfished
3 yr MA- End Point (08-10	1.76	0.05	Not Overfished

Southern Silver Hake **Exploitation Threshold (1973-1982)**		
Reference Points	Estimate	Variance
Annual Exploitation	34.18	1211.38
ARIMA	28.62	479.00
Kalman	33.75	984.26
3 yr MA- Centered	29.84	574.42
3 yr MA- End Point	29.10	467.05

% Difference to Annual SV Ref Point	
	Estimate
Annual Exploitation	0.0%
ARIMA	16.3%
Kalman	1.2%
3 yr MA- Centered	12.7%
3 yr MA- End Point	14.8%

2010 Smoother Estimate		
	Estimate	Status Determination
Annual Exploitation (2010)	2.52	No Overfishing
ARIMA (2010)	4.40	No Overfishing
Kalman (2010)	4.09	No Overfishing
3 yr MA- Centered (09-10)	3.63	No Overfishing
3 yr MA- End Point (08-10)	4.04	No Overfishing

5.2 Projections – ASAP Run 6 for silver hake

In response to the SSC's request at the April meeting, short term projections using the proposed ASAP model at SAW 51 were conducted to gauge population response to ABC alternatives. The SSC recognized that the ASAP model was not accepted by the SAW for management, but because the model was deemed informative, the SSC felt that it may provide some insight on the population response in the short term given the uncertainty associated from the recommended ABC (Method 2, PDT small mesh 2011).

The proposed ASAP model results from Run 6 (combined north and south), and the NOAA toolbox AGEPRO program were used to evaluate stock trends during 2010 – 2016 for the northern and southern stock of silver hake. $F_{0.1}$ (0.16) was assumed as a proxy for F_{msy} based on the overfishing definition in the 2003 SAFE report and was used in the projections for years 2012 – 2015. The start year of the projections was based on the 2010 observed catches and in 2011 assumed calculated ABC's were applied (Table 4). To demonstrate the effect of a probable ABC framework having a constant allowable catch for 2012-2013, the PDT also developed a northern stock projection using a constant ABC as a sensitivity analysis.

In the stochastic projections, recruitment was resampled from the empirical distribution as estimated by the ASAP model for 1989-2007 and SSB weights at age were calculated using the most recent three years (2007-2009). Catch weight at age, maturity at age (which was time variant), and selectivity at age for the fishery and consumption based natural mortality were also used in the projections (Table 5). Additional details on the ASAP model run 6 are given in NEFSC 2011b.

Results of the stochastic projections are summarized in Figure 5 to Figure 7 and in Table 6 to Table 8. Detailed tables of the projections are provided in Appendix 3 of this document. Overall, the projections in the north and south show that both SSB and catch will increase over time with 0% chance of attaining SSB_{msy} (112.6 kmt). However, the example projections in the north that assumes a constant ABC for 2011-2015 do show a 28% chance of attaining SSB_{msy} in 2015 at the 5th percentile of OFL (5.36 kmt) and 4% at the 10th percentile of OFL (7.43 kmt) explained by the lower catches in subsequent years. The increases in catch and SSB can be explained by the high recruitment estimated from ASAP model (80% CI = 616 – 867 million fish). The inability to reach SSB_{msy} can be attributed to some scaling issues and underlying model assumptions informing these projections. These projections were viewed by the PDT as non-informative for a couple of reasons:

- The ASAP model assumes a single stock structure, combining both north and south in the model formulation. Hence, the underlying population dynamics is inconsistent with the methods for deriving ABC which assumes a two stock structure.

- The ASAP model incorporates predatory consumption which is not accounted for in the ABC calculations.

Considering the scaling problem in these projections and that the ASAP model was not accepted for management purposes, the results of this exercise should be interpreted cautiously. The results from these runs can be examined in Figure 5 and Table 6.

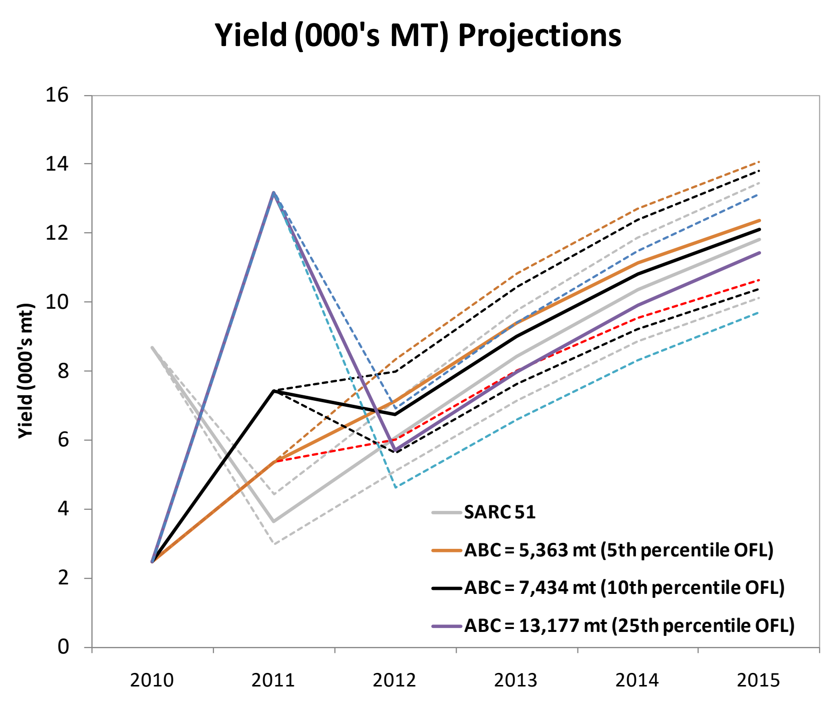
Table 4. 2011 ABC options (metric tons) assumed in the short term projections for the northern and southern stock of silver hake.

Pecentile OFL	North	South
5th %ile	5.363	13.072
10th %ile	7.434	18.29
25th %ile	13.177	32.635

Table 5. Input data for the short term projections based on ASAP model Run 6.

Age	Selectivity F	Selectivity M	Stock Weight (kg)	Catch Weight (kg)	SSB Weight (kg)	Maturity
1	0.028	1.000	0.071	0.085	0.071	0.050
2	0.250	0.376	0.108	0.131	0.108	0.860
3	1.000	0.089	0.150	0.192	0.150	0.998
4	0.996	0.018	0.248	0.368	0.248	1.000
5	0.979	0.003	0.392	0.530	0.392	1.000
6+	0.969	0.001	0.638	0.638	0.638	1.000

Figure 5. **Northern silver hake** median catch (TOP) and SSB (BOTTOM) plotted with 5th and 95th percentiles (dash lines) for ABC projections at the 5th, 10th and 25th percentiles of OFL.



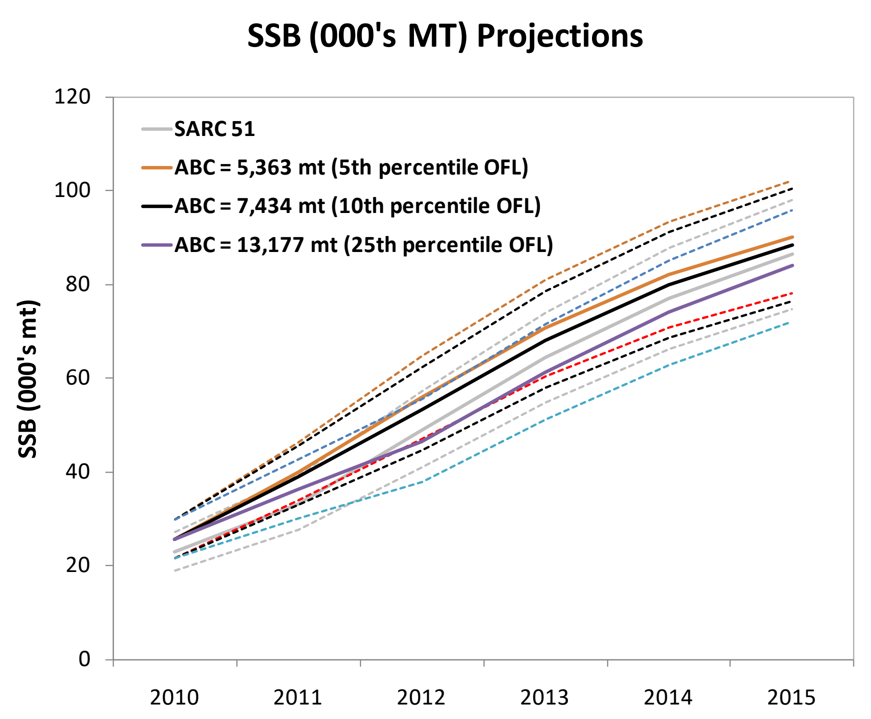


Figure 6. **<u>Southern silver hake</u>** median catch (TOP) and SSB (BOTTOM) plotted with 5th and 95th percentiles (dash lines) for ABC projections at the 5th, 10th and 25th percentiles of OFL.

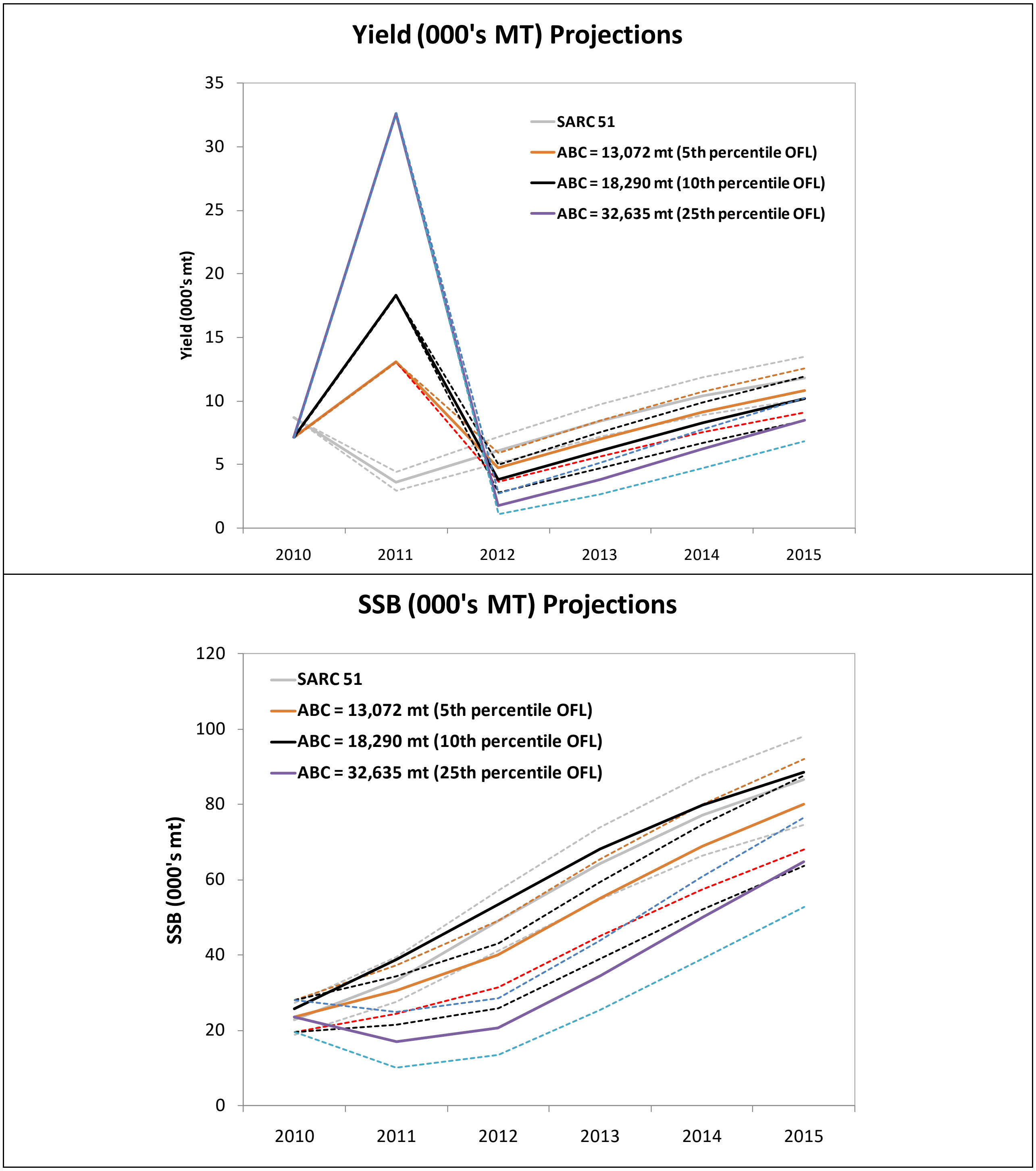


Figure 7. <u>Northern silver hake</u> median fishing mortality (TOP) and SSB (BOTTOM) plotted with 5th and 95th percentiles (dash lines) for ABC projections at the 5th, 10th and 25th percentiles of OFL. Demo projection assumes constant ABC 2011-2015.

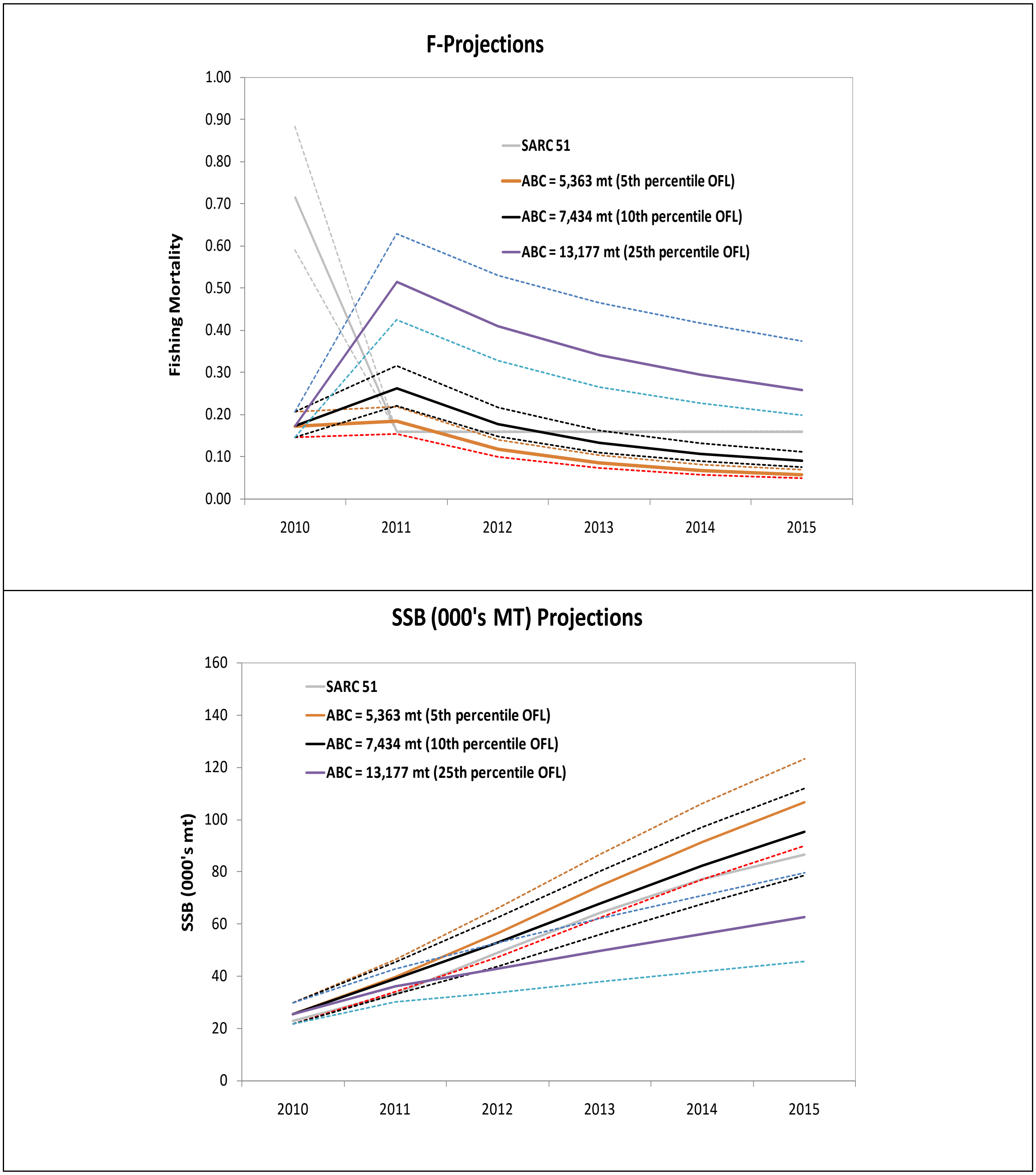


Table 6. Northern silver hake risks of exceeding SSB_{msy} (112.6 kmt) in 2015 and F_{msy} in 2011 for ABC alternatives. P > Rel F is the risk of exceeding F_{msy} proxy under Method 2 ABC in 2011 from the median distribution.

	2011 ABC Options	AgePro	AgePro	Method 2
Pecentile OFL	(000's MT)	P > SSBMSY	P > FMSY	P > Rel F
5th %ile	5.363	< 1 %	91%	0%
10th %ile	7.434	0%	100%	0%
25th %ile	13.177	0%	100%	2%

Table 7. Southern silver hake risks of exceeding SSB_{msy} (112.6 kmt) in 2015 and F_{msy} in 2011 for ABC alternatives. P > Rel F is the risk of exceeding F_{msy} proxy under Method 2 ABC in 2011 from the median distribution.

	2011 ABC Options	AgePro	AgePro	Method 2
Pecentile OFL	(000's MT)	P > SSBMSY	P > FMSY	P > Rel F
5th %ile	13.072	0%	100%	0%
10th %ile	18.29	0%	100%	0%
25th %ile	32.635	0%	100%	0%

Table 8. Northern silver hake risks of exceeding SSB_{msy} (112.6 kmt) in 2015 and F_{msy} in 2011 for ABC alternatives. Projections assume a constant ABC from 2011-2015. P > Rel F is the risk of exceeding F_{msy} proxy under Method 2 ABC in 2011 from the median distribution.

	2011 ABC Options	AgePro	AgePro	Method 2
Pecentile OFL	(000's MT)	P > SSBMSY	P > FMSY	P > Rel F
5th %ile	5.363	28%	91%	0%
10th %ile	7.434	4%	100%	0%
25th %ile	13.177	0%	100%	2%

5.3 Social and Economic Risk

It is difficult to predict the revenue impacts to fishermen targeting whiting without fully understanding the cost structure of the fleet targeting whiting. However, it is possible to evaluate the changes to gross revenue under various ABC levels.

Figure 8 shows the trend in total landings and gross revenue for northern and southern silver hake. These trends are also shown for red hake in Figure 9. Trends in the average price of silver hake and red hake are also displayed by stock area in Figure 10.

Figure 8. Total landings (top) and gross revenue (bottom) for northern and southern silver hake, 1996-2010.

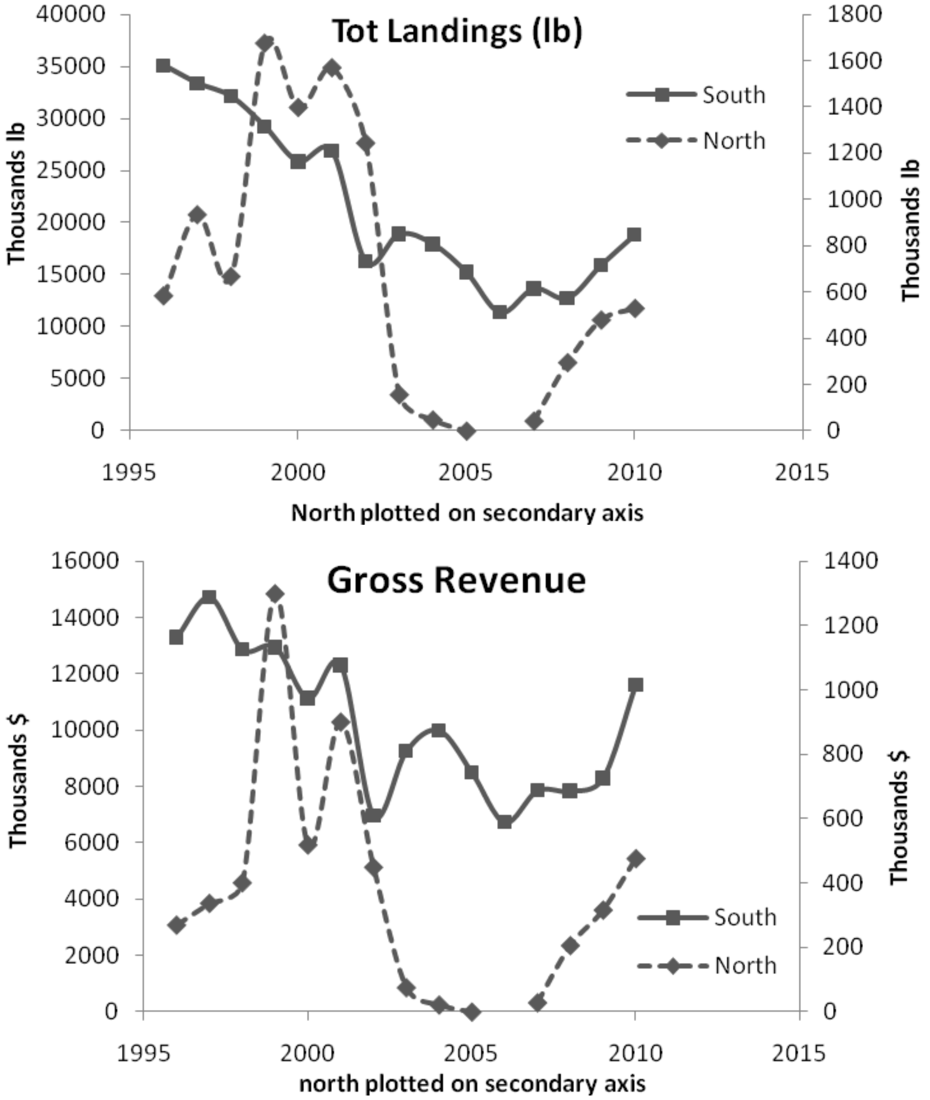


Figure 9. Total landings (top) and gross revenue (bottom) for northern and southern red hake, 1996-2010.

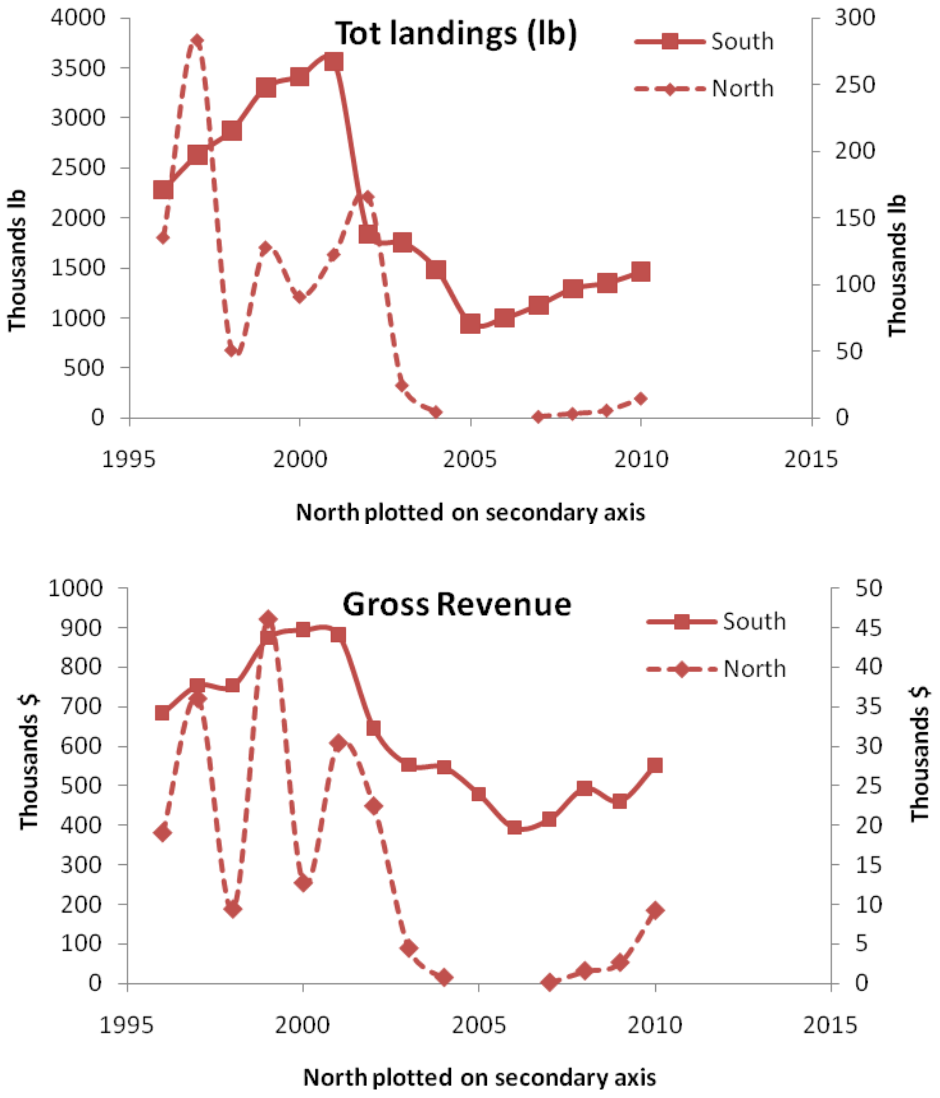
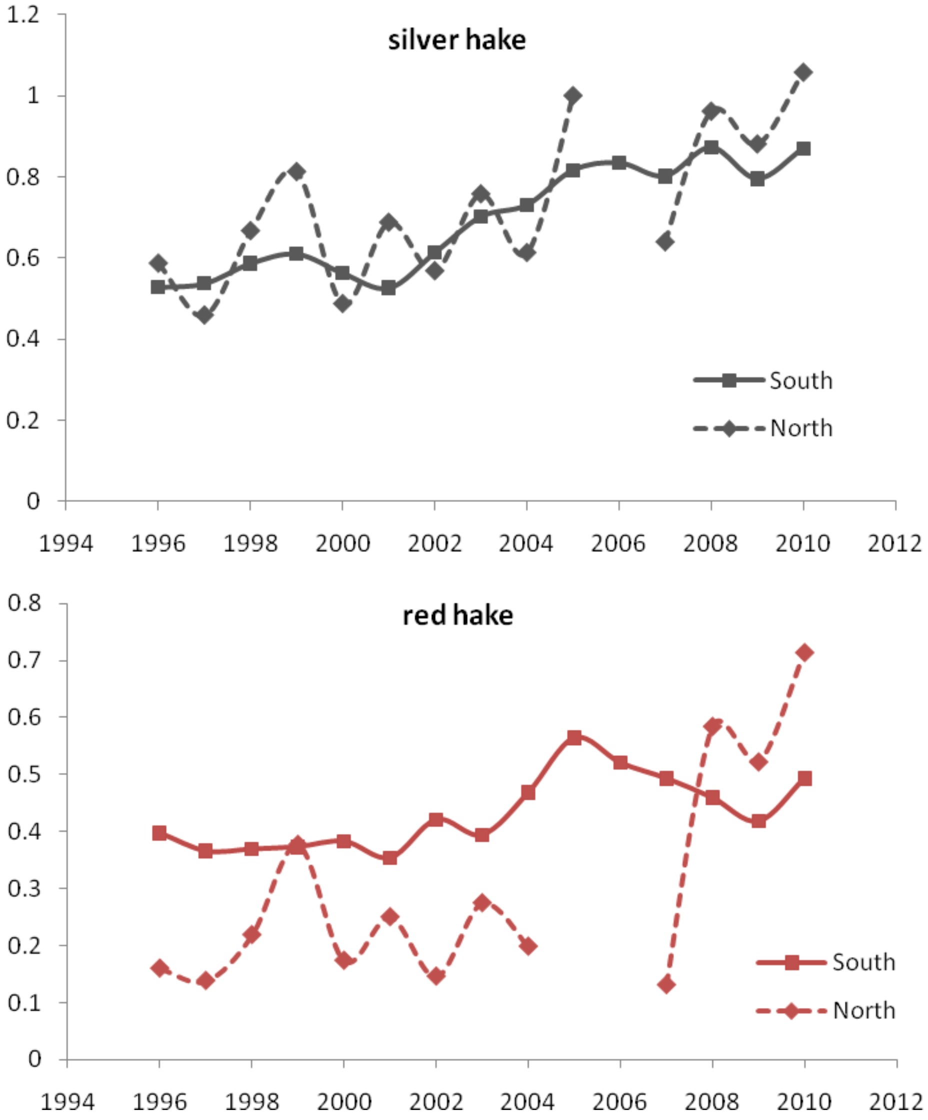


Figure 10. Average price per whole pound for silver hake (top) and red hake (bottom) by stock area.



Estimated gross revenue for different ABC alternatives (Figure 11 for silver hake, Figure 12 for red hake) were estimated as the product of average price paid and ABC level, using the average price per pound from the last three years (see table below). Estimated gross revenue results suggest what one would expect: under increasing ABCs gross revenues are predicted to increase. These results should be interpreted with caution; they simply represent the gross revenue. Without any information about costs, it is difficult to predict the true impacts to the fleets

Table 9. Silver and red hake average price per whole pound, 2008-2010.

	Silver hake	Red hake
North	$0.97	$0.61
South	$0.85	$0.46

Figure 11. Estimated gross revenue from silver hake landings for various ABC alternatives, assuming landings equal the ABC.

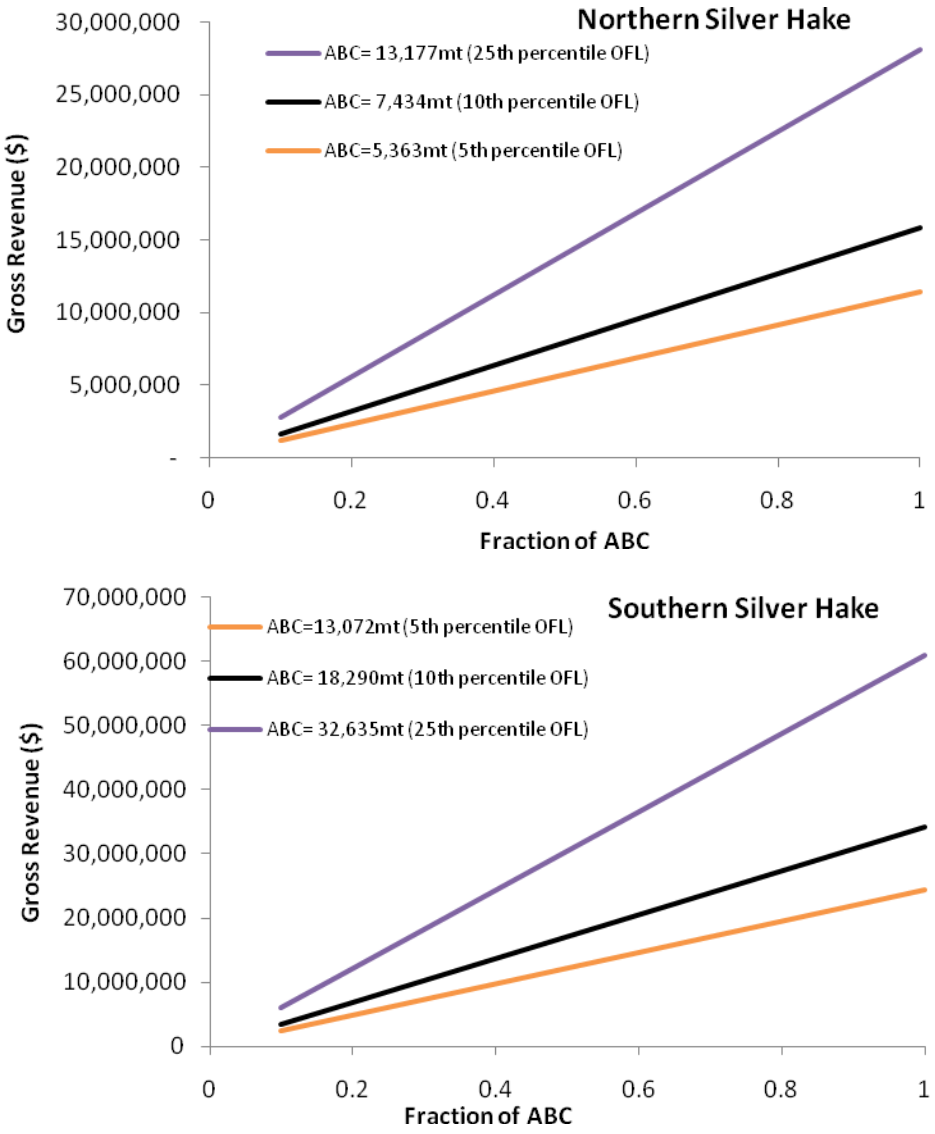
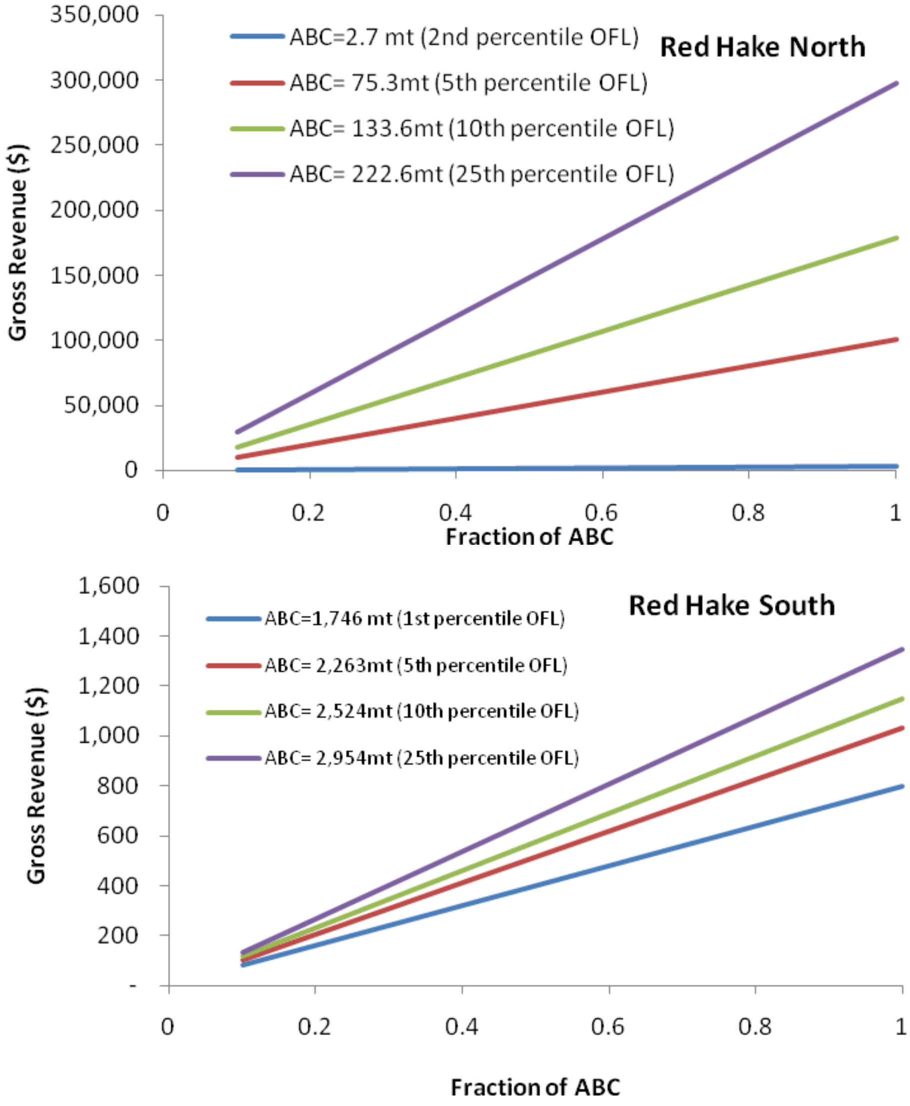


Figure 12. Estimated gross revenue from red hake landings for various ABC alternatives, assuming landings equal the ABC.



5.4 Candidate ABC calculations and possible productivity changes in silver hake, effect on risk tolerance

Some of these factors were discussed during the benchmark assessment (NEFSC 2011a), particularly with regard to trends in consumption, geographical distribution, spawning capacity, and age structure. And although the SAW 51 adopted the status quo status determination for silver hake, the Whiting PDT examined the effect of choosing periods with different exploitation rates as a threshold to define ABC. Although not formally adopting a different period as a basis for setting ABC, the PDT is recognizing the potential for non-stationary productivity as a justification for choosing more conservative (i.e. less risk of exceeding OFL) values for ABC in Section 6.2.

The recommended ABC's for silver hake derived from Method 2 are considered to be highly uncertain and do not reflect current fishery conditions. The range of years (1973-1982) used for deriving the overfishing reference points are sources of uncertainty for both the northern and southern stock of silver hake because it represents a period of steep contrast in the fishery productivity. Catches between the early and late 1970's dropped substantially by over 90% in the north and about 83% in the south. The decline in the fishery was likely due heavy exploitation in the mid-1960's (NEFSC 2011b) and possibly market competition that resulted from imports of fish meal after the early 1960's (Anderson et al. 1980).

Although the transition from the 1970's to the 1980's highlight high and low productivity in the stock dynamics, this resulted in high estimates of OFL's with wide variances for both northern and southern stock of silver hake (Figure 13 and Figure 14). Sensitivity analyses that consider a contemporary basis for defining F_{msy} proxy highlights the uncertainty in the current computation for the overfishing reference points and evidence of non-stationarity in stock productivity. Hence, a more conservative estimate of ABC should be considered to account changes in stock productivity as well as for other sources of uncertainties in the population dynamics which includes age truncation in the population, predatory consumption and catch.

Figure 13. Northern silver hake OFL estimates and 95% CI based on 10 moving averages in the F_{msy} and fall survey index from 2008-2010. The triangle represents OFL derived from SARC 51

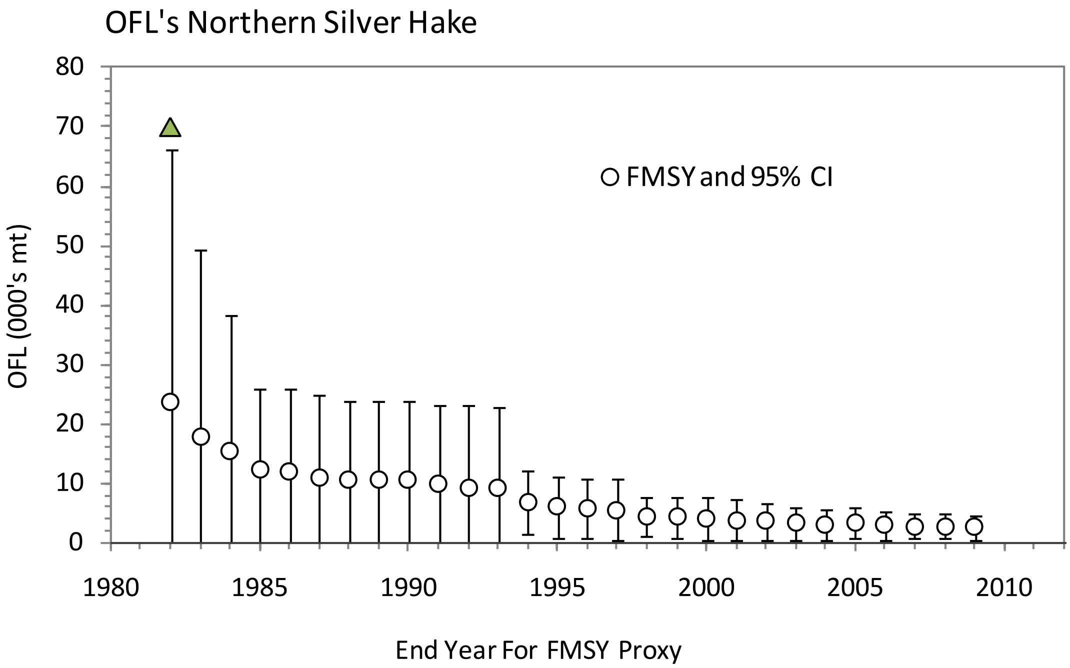
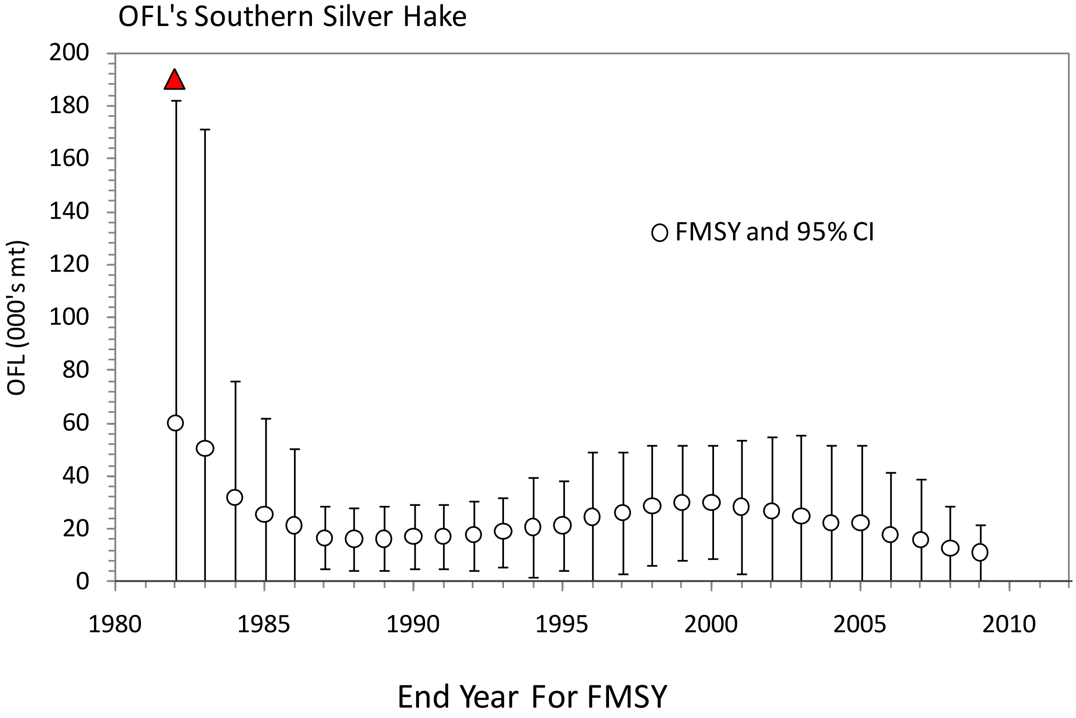


Figure 14. Southern silver hake OFL estimates and 95% CI based on 10 moving averages in the F_{msy} and fall survey index from 2008-2010. The triangle represents OFL derived from SARC 51.



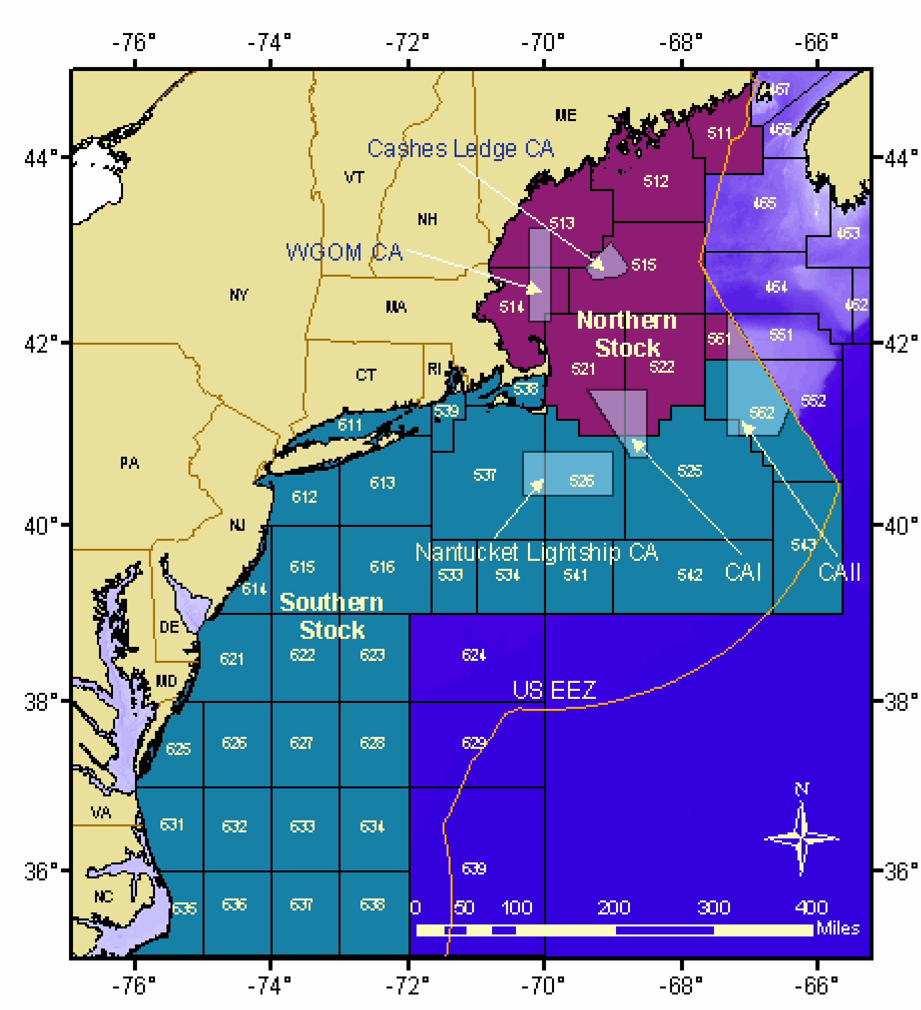
6.0 ABC recommendations

6.1 Red hake

For both stocks of red hake, the PDT recommends using the 25th percentile of the Method 2 ABC distribution for setting 2012-2014 ABCs. This method relies on the 1980-2010 MSY proxy for establishing the OFL (a greater duration than the SAW approved for silver hake status determination) and for estimating the risk of exceeding that OFL at different ABC levels (defined as percentiles of our estimated ABC, using a 2009-2011 spring survey biomass index and the F_{msy} proxy (1980-2010 average exploitation estimated by AIM).

Using the 25th percentile of the ABC to account for scientific uncertainty (Table 12) equates to 222.6 mt for the northern stock and 2,954 mt for the southern stock (see Map 1). These limits, not accounting for management uncertainty that the Council may consider, compare to 2009 catches of 180 and 1,543 mt, respectively.

Map 1. Statistical areas used to define the northern and southern red and silver hake stocks.



6.1.1 Current Status

The 2011 overfishing limit (OFL= F_{msy} *2011 spring survey biomass (2009-2011 moving average)) for northern and southern red hake is estimated at 0.323 kt and 3.529 kt, respectively (Table 10 and Figure 15). The OFL for red hake is based on the 1980-2010 period, a greater range than considered for the silver hake status determination. The uncertainty in the OFL estimate was estimated as the joint probability distribution of F_{msy} and the 3-year spring survey moving average of biomass. The probability distribution of the proxy F_{msy} was obtained from the AIM bootstrap distribution of relative F. The probability distribution of the spring survey three-year (2009-2011) moving average of biomass was estimated from a normal distribution of the mean and variance. Further details of the OFL estimation are described in Document 2, presented at the 2011 April SSC meeting.

Red hake is not overfished and overfishing is not occurring in both the northern and southern stocks in 2011. For the northern stock, the 3-year moving average (2009-2011) of the NEFSC spring bottom trawl survey (1.982 kg/tow) was above the biomass threshold reference point (1.27 kg/tow) and the annual 2010 exploitation index (catch/survey biomass) of 0.154 kt/kg was below the threshold (0.163 kt/kg) (Table 10). For the southern stock the 3-year moving average (2009-2011) of the NEFSC spring bottom trawl survey (1.162 kg/tow) was above the biomass threshold reference point (0.508 kg/tow) and the annual 2010 exploitation index (catch/survey biomass) of 1.294 kt/kg was below the threshold (3.038 kt/kg) (Table 10).

Table 10. Biological reference points, 2011 overfishing limit (OFL), and current biomass and exploitation estimates for northern and southern red hake.

Red Hake	North	South
Reference Points		
Fmsy (kt/kg)	0.163	3.038
Bmsy (kg/tow)	2.53	1.016
MSY (mt)	412	3087
Biomass threshold (kg/tow)	1.265	0.508
Exploitation threshold (kt/kg	0.163	3.038
OFL (kt) 2011	0.3231	3.5293
Biomass (3-yr MA kg/tow)		
2011	1.982	1.162
Exploitation Index (annual)		
2010	0.154	1.294

6.1.2 ABC Estimation

The probability of the 2012 ABC exceeding F_{msy} was estimated for three scenarios of F_{msy} (25th, 50th, and 75th percentiles) for the northern and southern stocks (derived from the cumulative percentiles on OFL as shown in Figure 15). The risk of exceeding the 25th percentile of the F_{msy} proxy is 39% in the north and 37% in the south (Table 11). The risk at the 50th and 75th percentile of the F_{msy} proxy is 0% in the north about 10% and 4%, respectively, in the south.

Table 12 presents alternative ABCs estimated for different percentiles of OFL.

Table 11. Probability of the 2012 ABC (25th percentile of OFL) overfishing the 25th, 50th, and 75th percentile of F_{msy} for northern (top panel) and southern (bottom panel) red hake.

2011 OFL = 323 mt			North	
Method 2	mt	25th %tile FMSY	50th %tile FMSY	75th %tile FMSY
		115	163	203
ABC 2012	222.6	39%	0%	0%
2011 OFL = 3529 mt			South	
Method 2	mt	25th %tile FMSY	50th %tile FMSY	75th %tile FMSY
		2660	3038	3311
ABC 2012	2954	37%	10%	4%

Table 12. Northern and Southern red hake ABCs estimated at different percentiles of OFL and the percentage of the ABC relative to current and historic catches for various time periods.

Red Hake North		**ABC- percentage of currrent catch**			
Percentile OFL	**ABC (mt)**	2010	3yr Avg	5 yr Avg	10y Avg
2	2.7	1%	1%	1%	1%
5	75.3	24%	37%	35%	31%
10	133.6	43%	66%	62%	55%
25	222.6	72%	111%	103%	92%
OFL	323.1	104%	161%	150%	133%

Red Hake South		**ABC- percentage of currrent catch**			
Percentile OFL	**ABC (mt)**	2010	3yr Avg	5 yr Avg	10y Avg
1	1746	129%	120%	116%	127%
5	2263	167%	156%	151%	165%
10	2524	187%	174%	168%	184%
25	2954	218%	203%	197%	215%
OFL	3529	261%	243%	235%	257%

Figure 15. Frequency distribution and cumulative probability of 2011 OFL and the proposed 2012 ABC (25th percentile of OFL – Method2 (M2)) for northern red hake (top panel) and southern red hake (bottom panel).

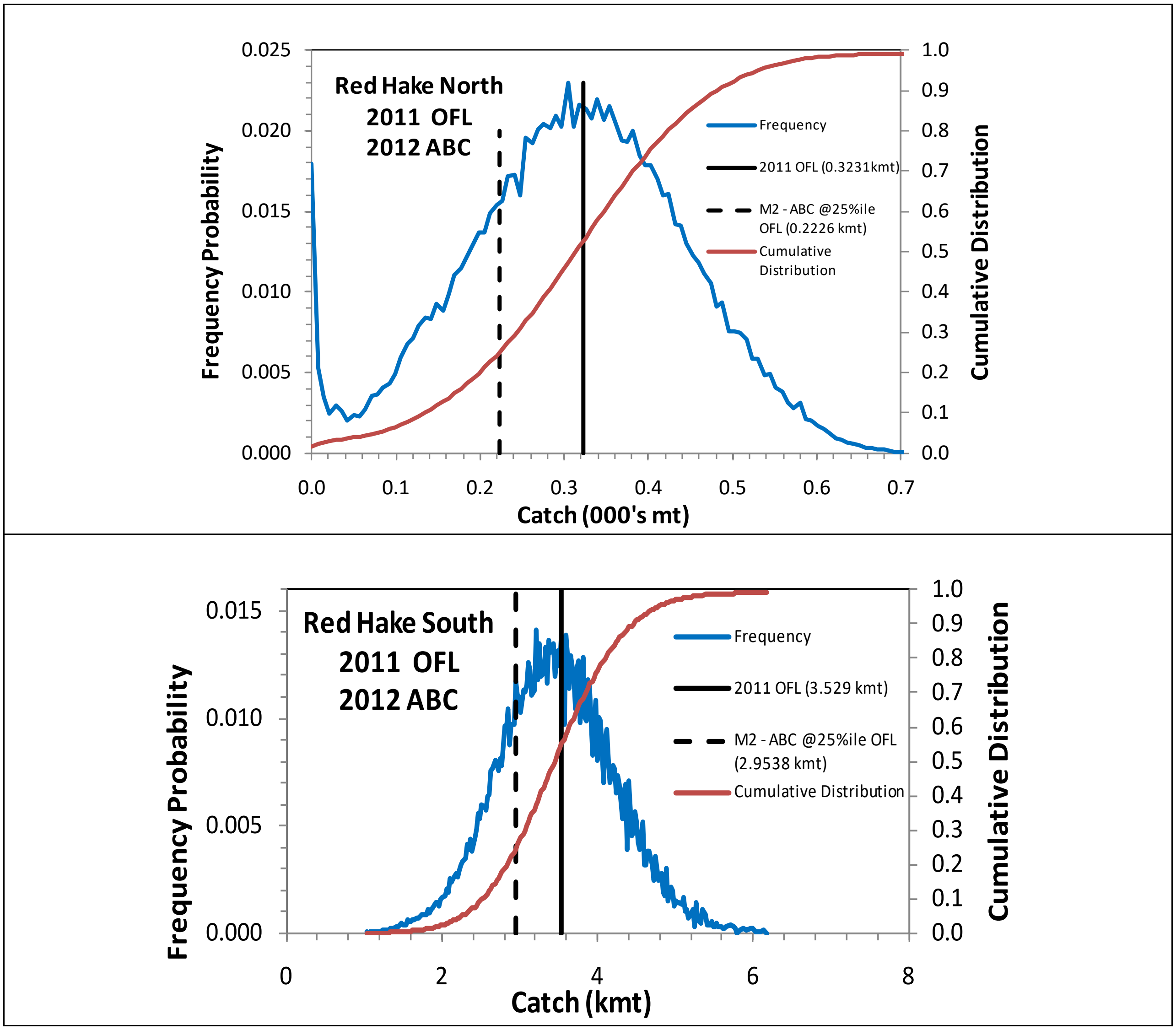
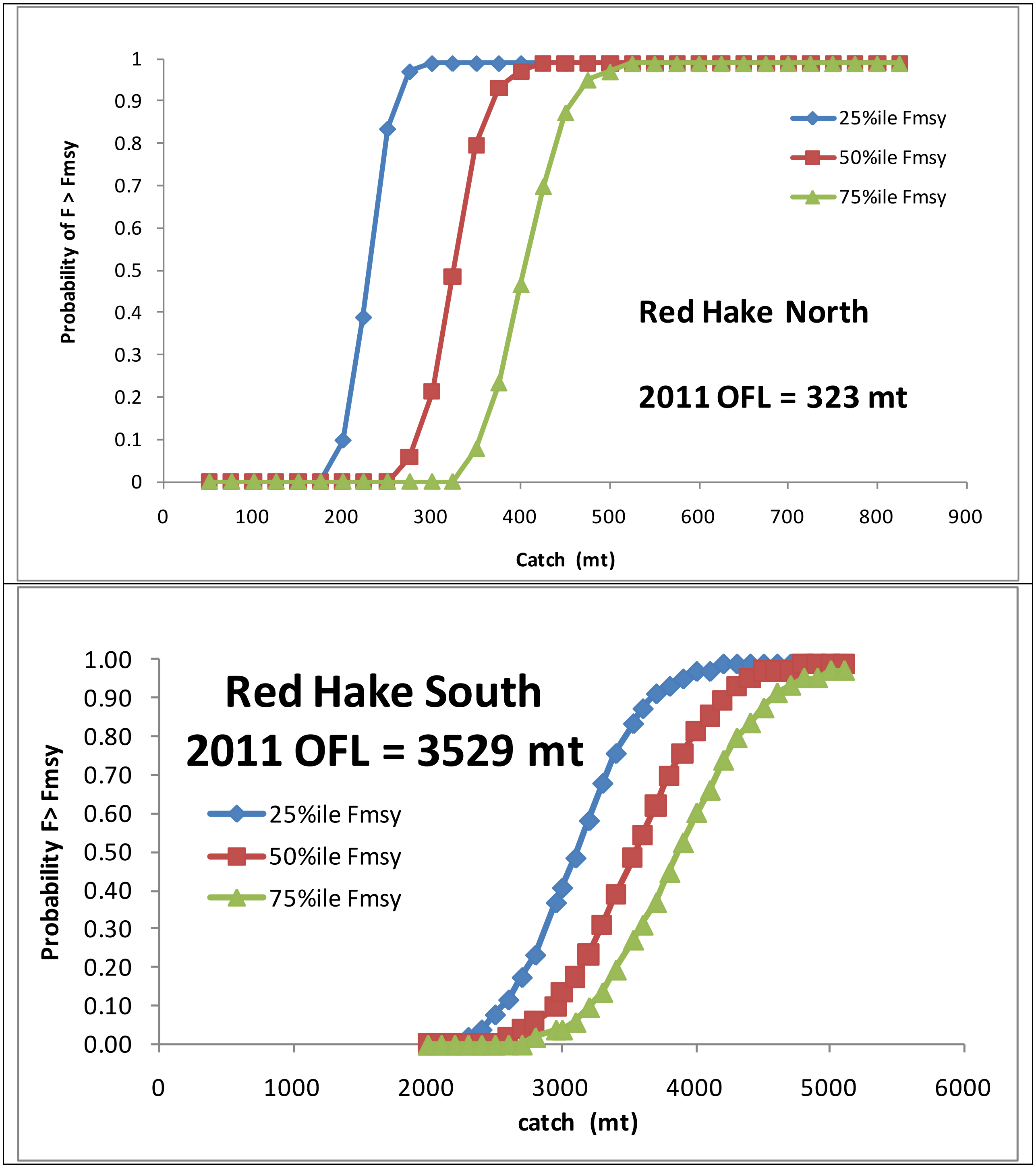


Figure 16. Probability of overfishing for northern (top) and southern (bottom) red hake based on 2011 OFL at the 25th, 50th and 75 percentile of F_{msy}. The probability of overfishing is a product of the probabilities of $F > F_{msy}$ at each realization of the survey biomass distribution and the probabilities corresponding to the survey biomass distribution.



6.2 Silver hake

For the northern and southern silver hake stocks, the Whiting PDT recommends using Method 2 to estimate scientific uncertainty for ABC calculations (as approved by the SSC in April 2011), but the SSC should consider more conservative values of ABC than the 25th percentile (13.2 mt northern stock; 32.6 mt southern stock). More conservative values are appropriate to account for extra sources of scientific uncertainty that are not taken into account in the silver hake assessments or in the Method 2 estimates of uncertainty and apparent non-stationary productivity (see Figure 15 and Figure 16).

Silver hake biomass status determination is based on the fall survey and therefore, unlike red hake, the current biomass index is based on the 2008-2010 survey. Since the 2011 fall survey value will become available before the Council submits Amendment 19, the SSC may want to consider updating the biomass data and ABC before the final amendment is submitted for approval.

6.2.1 Current Status

The 2011 overfishing limit (OFL= F_{msy} *2010 fall survey biomass (2008-2010 moving average) for northern and southern silver hake was estimated at 24,880 mt and 62,300 mt, respectively (Table 13 and Figure 9). The OFL for silver hake is based on the 1973-1982 period, for status determination. The uncertainty in the OFL estimate was estimated as the joint probability distribution of F_{msy} and the 3-year fall survey moving average of biomass.

The probability distribution of the proxy F_{msy} was obtained from the lognormal distribution of the mean and variance of the exploitation ratios from 1973-1982. Similarly, the probability distribution of the fall survey three-year (2008-2010) moving average of biomass was estimated from a normal distribution of the mean and variance. Further details of the OFL estimation are described in Document 2 presented at the 2011 April SSC meeting.

Silver hake is not overfished and overfishing is not occurring in both the northern and southern stocks in 2010. For the northern stock, the 3-year moving average (2008-2010) of the NEFSC fall bottom trawl survey (8.50 kg/tow) was above the biomass threshold reference point (3.208 kg/tow) and the 3-year moving average (2008-2010) exploitation index (catch/survey biomass) of 0.17 kt/kg was below the threshold (2.77 kt/kg) (Table 13). For the southern stock, the 3-year moving average (2008-2010) of the NEFSC spring bottom trawl survey (1.76 kg/tow) was above the biomass threshold reference point (0.825 kg/tow) and the 3-year moving average (2008-2010) exploitation index (catch/survey biomass) of 4.72 kt/kg was below the threshold (34.18 kt/kg) (Table 13).

Table 13. Biological reference points, 2010 overfishing limit (OFL), and current biomass and exploitation estimates for northern and southern silver hake. Exploitation reference points derived from both the arithmetic (SAW 51 threshold; NEFSC 2011a) and re-transformed log-normal distribution estimates are presented.

Silver hake	North	South
Reference Points		
Biomss Threshold (kg/tow)	3.21	0.83
Exploitation Threshold (kt/kg) - SARC 51 Arithmetic	2.77	34.18
Exploitation Threshold (kt/kg) - LognormalDistribution	2.89	35.12
3 yr Moving average 2008-2010		
Biomass Index (kg/tow)	8.50	1.76
Exploiation Index (kg/kt)	0.17	4.73
2010 OFL (kt)_SARC 51 Arithmetic	23.60	60.14
2010 OFL (kt)_Lognormal_Distribution	24.84	62.30

6.2.2 ABC Estimation

The SSC approved using Method 2 to estimate uncertainty in the OFL and choose a suitable percentile to set ABC, accounting for scientific uncertainty. Using the 25th percentile as a threshold, similar to red hake, an ABC would be 13,180 mt and for the southern stock ABC would be 32,640 mt (34,000 mt when augmented to account for catches of offshore hake).

The probability of the 2012 ABC exceeding F_{msy} was estimated for three scenarios of F_{msy} (25th, 50th, and 75th percentiles) for the northern and southern stock (Table 14). The risk of exceeding the 25th percentile of the F_{msy} proxy was approximately 40% in both the north and south and 0% risk at the median and 75th percentile of F_{msy} for both stocks.

For both stocks of silver hake, the risk of exceeding the median F_{msy} proxy at each estimated ABC was calculated as the product of the survey probability distribution and the probability of the "implied" exploitation ratios derived from each survey realizations. The implied exploitation ratios was computed for a range of ABC's and expressed as the ratio of the ABC's to the survey realizations from the probability distribution. Probabilities for each of the implied exploitation ratios were then generated based on a binary response of either being above or below the F_{msy} proxy (i.e. 1 = greater than F_{msy} and 0 = less than F_{msy}). Further details of the OFL estimation and risks analyses are described in Document 2, presented at the 2011 April SSC meeting.

Alternative ABC values, their estimated risk of exceeding the OFL (MSY proxy), and their relationship to recent catch is shown in Table 14. And even though the risk of exceeding OFL is estimated to be low for ABC values less than or equal to the 25th percentile, the Whiting PDT believes that more conservative alternatives are appropriate for the reasons given below. In addition, an ABC at the 25th percentile implies that silver hake catches could increase by about 5 fold over 2010 catches, a result that may not be sustainable given the truncation in age structure in silver hake caught by the survey and uncertainty about the assessment.

Figure 17. OFL frequency distribution for the northern (top) and southern (bottom) stock of silver hake derived as a product of the fall survey probability distribution from the most recent 3yr mean and variance and the probability distribution for $F_{threshold}$ (1973-1982) with an underlying lognormal error structure. M2 is the recommended ABC corresponding to the 25th percentile of OFL.

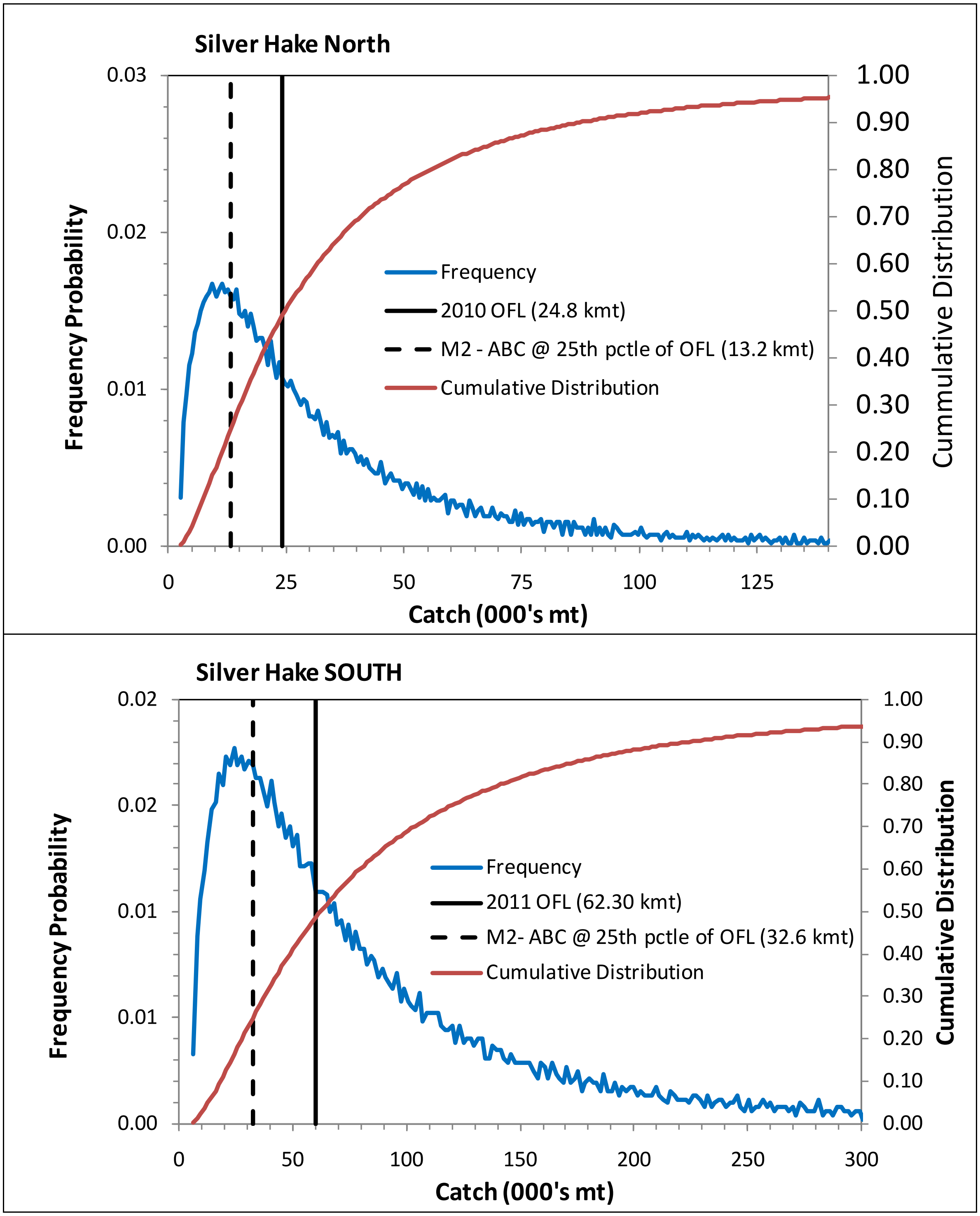


Table 14. Probability of the 2012 ABC (25th percentile of OFL) overfishing the 25th, 50th, and 75th percentile of F_{msy} for northern (top panel) and southern (bottom panel) silver hake.

2010 OFL = 24.88 kt			NORTH	
Method 2	000's mt	25th %tile FMSY	50th %tile FMSY	75th %tile FMSY
ABC 2011	13.18	40%	0%	0%

2010 OFL = 62.30kt			SOUTH	
Method 2	000's mt	25th %tile FMSY	50th %tile FMSY	75th %tile FMSY
ABC 2011	32.64	41%	0%	0%

Additional factors that contribute to scientific uncertainty in silver hake ABC estimates, which cannot be quantitatively estimated include:

- The OFL that is used to estimate risk is based on the 1973-1982 period, when productivity conditions may have differed from the present. Therefore, the catch as a proportion of biomass removed from the fishery at that time is probably risky under current conditions.

- Silver hake survey catches have a substantial truncation in age structure (absence of older fish)..

- Changes in fishery size selectivity that are not reflected in a catch/biomass exploitation ratio over all sizes of silver hake captured by the survey. While young ages generally contribute small amounts to total biomass, this issue becomes more important when fewer older ages exist in the population, as is the case for silver hake.

- Consumption is an important component of silver hake removals (NEFSC 2011b and Document 2), primarily for age 1 and 2 silver hake. Estimates of these removals from consumption are large and have been very variable, due in part to changes in prey abundance.

- Setting the ABC at the 25th percentile means a substantial and large increase in allowable catch over current levels. Such a large change in catch could carry additional risk.

The recommended ABC for silver hake based on the 25th percentile of OFL (Method 2) raises some concerns about the potential risk impact on the population. The current OFL estimate was derived from a time period with very different fishery productivity compared to current fishery conditions (see Section 5.4). Although the risk analyses indicate a low probability of exceeding F_{msy} proxy, the baseline period for defining F_{msy} proxy remains highly uncertain and exceeds current exploitation levels observed in recent years. Therefore setting ABC's at the 25th percentile may not be practical and sustainable in the long term. The PDT acknowledges that recent catches of silver hake may have been driven by market and regulations; however, there is no evidence of strong productivity in the population in recent years.

Hence, the PDT is proposing alternative ABC's that are more conservative than the 25th percentile of OFL as a precautionary approach for management considerations. ABC's ranging from 1-10% of OFL were estimated and provided in Table 15. Relative to the 25th percentile on OFL, more conservative ABC alternatives would reduce allowable catches by 44-77% but are still well above recent catches and have a

0% chance of exceeding F_{msy} (Table 15). The PDT recommends a more conservative silver hake ABC to account for additional scientific uncertainty in the assessment results listed above and minimize the potential risk for overexploitation without constraining the fishery.

Table 15. Northern (top) and southern (bottom) silver hake ABC alternatives calculated at different percentile of OFL and risks of exceeding F_{msy} proxy from the median distribution. M2 represents the ABC recommendation from Method 2, compared to historic catches over four time periods.

Silver Hake NORTH			ABC - Percentage of Current Catch			
Percentile OFL	**ABC (000 mt)**	**Risk F > FMSY**	2010	3yr Avg Catch	5 yr Avg Catch	10 yr Avg. Catch
1	3.18	0%	128%	212%	221%	175%
5	5.36	0%	216%	358%	372%	295%
10	7.43	0%	300%	496%	516%	408%
25 (M2)	13.18	0%	532%	878%	915%	724%
OFL	24.88	50%	1004%	1659%	1728%	1367%

Silver Hake SOUTH			ABC - Percentage of Current Catch			
Percentile OFL	**ABC (000 mt)**	**Risk F > FMSY**	2010	3yr Avg Catch	5 yr Avg Catch	10 yr Avg. Catch
1	7.57	0%	106%	107%	122%	111%
5	13.07	0%	184%	185%	210%	191%
10	18.29	0%	257%	259%	294%	267%
25 (M2)	32.64	0%	459%	463%	525%	476%
OFL	62.30	50%	876%	884%	1002%	910%

6.3 *Offshore hake*

Southern silver hake and offshore hake are sometimes landed as a mixed catch and often mis-reported, rarely separated when landed, and many times both species are caught on the same trip. The Whiting PDT recommends augmenting the 32,640 mt southern silver hake stock ABC by 4% to 34,000 mt to account for these mixed catches which would be monitored as one ABC. Offshore hake catches in the northern stock area are either negligible or mis-identified, so no adjustment in the northern silver hake stock ABC is needed.

In the absence of an assessment model for offshore hake, independent estimates of ABC for offshore hake were not feasible. Offshore hake is considered a sympatric species of silver hake and often landed as silver hake mostly due to the lack of market incentive to disaggregate the species. In 1991, landings of offshore hake began to be reported separately in landings by some dealers, although the extent to which offshore hake landings are reported accurately is still unknown.

The geographical distribution of offshore hake is limited to the southern stock of silver hake. Therefore, reported offshore hake landings from the northern stock area are considered to be silver hake while southern landings are mixed silver and offshore hake. Species composition for combined catches of offshore and silver hake in the southern region is estimated via a length-based model using the NMFS spring and fall bottom trawl surveys. More details on the models developed to allocate mixed hake landings to silver and offshore hake are presented in NEFSC 2011b.

Updated catches in 2010 indicate that offshore hake constitute a small fraction of the total hake catches in the southern region. Offshore hake landings for 2010 were estimated to be 67 mt, a 53% decrease from 2009 and only constituting 1% of the total hake landings (Table 16). Based on the entire time series from 1955-2010, offshore hake was estimated to be 4% of the total hake landings in the southern stock area. Including hindcast landings from 1955-1967 also suggested a 4% composition of offshore hake in the total hake landings (Table 17).

Table 16. Summary of offshore hake and silver hake landings for the southern management region

	Length-based Model based estimate		
Year	Offshore hake	Silver hake	Percent offshore
2004	494	6,965	7%
2005	288	6,395	4%
2006	82	4,583	2%
2007	290	5,067	5%
2008	84	5,582	1%
2009	142	6,595	2%
2010	67	6,330	1%

Table 17. Proposed supplement for southern silver hake ABC to account for offshore hake in the mixed hake landings.

	%Offshore	%Silver
TS avg. (1955-2010)	4%	96%
Excl. Hindcast (19698-2010)	4%	96%

7.0 References and Background Material

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8.0 Appendix 1: ARIMA

Noise Reduction using Empirical Time Series Models

Research vessel surveys are routinely used to generate indices of abundance of fish and shellfish populations. Given a sufficiently large sample size and an appropriately randomized design, the survey provides an asymptotically unbiased estimate of the relative population size available to the sampling gear. In practice however, interannual changes in the availability or catchability of target populations to the sampling gear, can introduce an additional source of variability in the relative population estimates (Pennington 1985, 1986). The underlying model can be written:

$$Y_t = k' P_t e^{\delta_t + \varepsilon_w} \qquad (1)$$

where Y_t is the survey index, P_t is the population size, k' is a constant of proportionality between the survey index and the population size, $\square_t$ is the error attributable to interannual variation in catchability or availability, and $\square_w$ is the error due to within-survey sampling variability (Pennington and Godo 1995). Letting $y_t = \log_e Y_t$, $p_t = \log_e P_t$, and $k = \log_e k'$, we can write:

$$y_t = k + p_t + (\delta_t + \varepsilon_w) \qquad (2)$$

where $\square_t$ and $\square_w$ are normally distributed random variables with zero mean and constant variance. In the following, we will let

$$e_t = \delta_t + \varepsilon_w \qquad (3)$$

and the associated variances are taken to be independent and additive:

$$\sigma^2{}_e = \sigma^2{}_\delta + \sigma^2{}_\varepsilon \qquad (4)$$

The classical survey sampling theory estimators consider only the within-survey variance component. The actual total variance associated with the survey can be substantially higher (Pennington 1985).

Next, we are interested in constructing a model for the population process. To provide a simple example, suppose we have a simple stochastic population model:

$$P_t = \mu P_{t-1}^{\phi_1} e^{a_t} \qquad (5)$$

where □□is a constant, $\square_\square$ is the order 1 autoregressive parameter (0<□□□□□□ and the population size is measured without error. The population size at time t is a function of the population at the previous time step. This power function model embodies a simple form of population compensation. We can write this model as:

$$p_t = \log_e \mu + \phi_1 p_{t-1} + a_t \qquad (6)$$

which is a first-order autoregressive process (the state variable is regressed on itself, hence the term autoregressive).

We can write a more general model form allowing the potential for higher order autoregressive terms and also incorporating the delayed effects of previous random perturbations affecting the error term a_t. We can write the general Autoregressive Moving Average (ARMA) process model as:

$$\phi(B)\,p_t = \theta(B)\,a_t \qquad (7)$$

where □□□□□□□and □□□□ □are autoregressive and moving average operators respectively, and the a_t are normally distributed random variables with zero mean and constant variance (Box and Jenkins 1976). The autoregressive component again represents past values of the state variable (p_t) and the moving average component refers to past values of random 'shocks' (the a_t) or perturbations to the system. Note that the reference to moving averages here is distinct from the more conventional definition sometimes applied to this term

We can extend this compact representation can readily accommodate stationary and nonstationary stochastic processes (see below). An integrated process is one in which we model the differences in the state variable at specified points in time. For example, if we take the first differenced series, we have (using the backshift operator),

$$(1-B)\,p_t = p_t - p_{t-1} \qquad (8)$$

and higher order differences are represented as polynomials in *B*. Differencing is used to induce stationarity in nonstationary series. An ARMA model including integrated processes is an Autoregressive Integrated Moving Average (ARIMA) model. Often, taking first differences is sufficient to make a trending series stationary although higher order differences are sometimes required.. The method however, differs from other detrending methods that may, for example, involving fitting a polynomial to the time trajectory of observations and then focusing on the residuals of the secular model for further analysis.

Our interest is in connecting the basic population model with a model of the survey series. Recall that $y_t = k + p_t +$ □$_t$. For simplicity in the following we will take *k'* = 1 and therefore *k*=0; we can then write $p_t = y_t -$ □$_t$.

We will write the general population model as:

$$\phi(B)\,p_t = \alpha(B)\,c_t \qquad (9)$$

And substituting y_t-□$_t$ for p_t, we have:

$$\phi(B)\,y_t = \alpha(B)\,c_t + \phi(B)e_t \qquad (10)$$

which can be further simplified to:

$$\phi(B)\,y_t = \eta(B)\,d_t \qquad (11)$$

where □□□□□□ is now the moving average operator..

The expected value of the population size given a survey estimate can be expressed:

$$E(p \mid y_t) = \omega(B)\, y_t \tag{12}$$

where □□□□□ is a smoothing polynomial given by:

$$\omega(B) = \left[1 - \frac{\sigma_e^2}{\sigma_d^2} \frac{\alpha(B)\alpha(F)}{\eta(B)\eta(F)} \right] \tag{13}$$

where now (*F*) is the forward shift operator (the inverse of the backshift operator; Stockhausen and Fogarty 2004). We can therefore use Eq. 10 in conjunction with Eq.11 to develop smoothed estimates of the population series.

Results

To illustrate the application of the method, we provide examples for two species of silver hake and two species of red hake which are currently assessed using survey index-based methods. Plots of the original survey series and the smoothed population estimates are provided in Figure 1 and estimates of the parameters for the four models are provided in Table 1. Several of the survey data estimates for the hake stocks (notably northern silver and red hake) exhibit high volatility at the end of series and this can be expected to have important implications for the status determination for these species because it depends on the estimated abundance in the last three years of the series relative to the mean of a specified time period in each survey time series.

To determine the stability of the parameter estimates for the ARIMA models, we examined the implications of successively deleting up to five points at the end of the time series and re-estimating the model parameters. We performed this test on the northern stock of silver hake as a case study. The model estimates were quite robust despite the fact that there was substantial variation in the abundance estimates in the raw series at the end of the series (Table 2; Figure 2).

The reference level for status determination depends on the mean of a relative exploitation index (defined as the ratio of the total catch to the survey index) for the period 1973-1982 for silver hake and for the period 1980-2009 for red hake. Table 3 provides estimates of the mean and variance for the reference periods using the current approach based on the raw survey series and the method using the smoothed data series in the calculation of the relative exploitation index. The use of the smoothed series resulted in a reduction in the variance of the estimate from 18-65%. This would substantially affect the width of the probability distributions used in assessing the significance of the difference between the reference level and the current status and therefore increase the power of tests for departures from the reference level.

References

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Table 1. Parameter estimates for ARIMA models applied to silver and red hake stocks.

Stock	***Parameter***	***Type***	***Lag***	***Estimate***	***Standard Deviation***	***t-value***	***Differenced***
Silver Hake North							No
	□o*Constant*	0	0.007869	0.00096601	8.146107		
	□.*Autoregressive*	1	0.386149	0.1379252	2.799701		
Silver Hake South							No
	□o*Constant*	0	0.002172	0.00060227	3.605535		
	□.*Autoregressive*	1	0.376421	0.13122403	2.868535		
	□.*Autoregressive*	2	0.469732	0.13563919	3.463097		
Red Hake North							No
	□o*Constant*	0	0.002404	0.00027706	8.675454		
	□.*Autoregressive*	1	0.388899	0.14323295	2.715148		
Red Hake South							
Red Hake South	□e*Constant*	0	-2.6E-05	7.0497E-05	-0.37067	Yes	
	□e*Moving Average*	1	0.639098	0.1273112	5.019965		

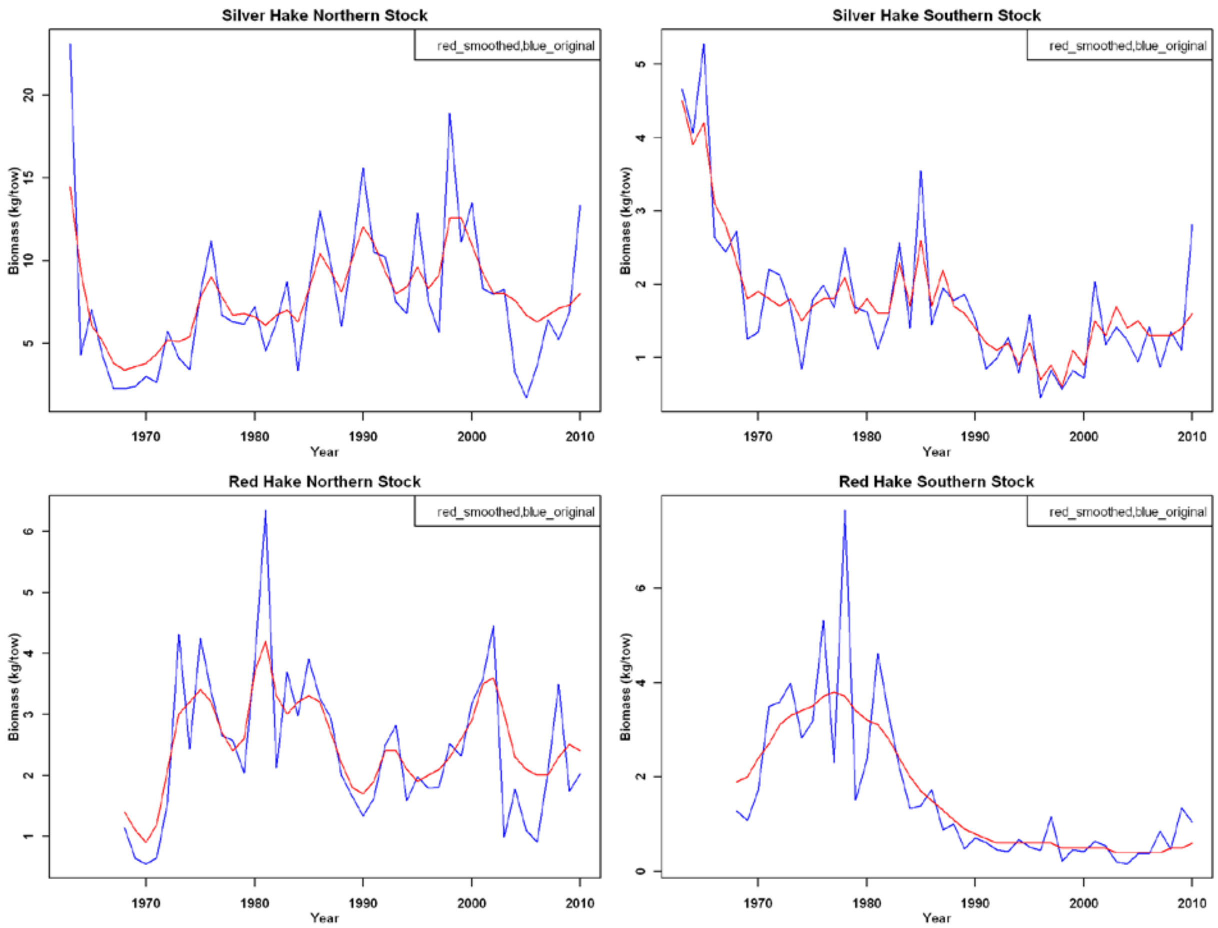
Table 2. Stability of parameter estimates for first order autoregressive model for the northern stock of silver hake as data points are progressively eliminated from the series.

Time Series	ARIMA	Parameter	Estimate	SE	t-value	p-value	lag
1963-2010	(1,0,0)	MU	0.0078692	0.000966	8.15	<.0001	0
		AR1,1	0.38615	0.13793	2.8	0.0051	1
1963-2009	(1,0,0)	MU	0.0076765	0.0009694	7.92	<.0001	0
		AR1,1	0.38934	0.13662	2.85	0.0044	1
1963-2008	(1,0,0)	MU	0.0076721	0.000991	7.74	<.0001	0
		AR1,1	0.38949	0.13862	2.81	0.005	1
1963-2007	(1,0,0)	MU	0.0077382	0.0010063	7.69	<.0001	0
		AR1,1	0.38682	0.14	2.76	0.0057	1
1963-2006	(1,0,0)	MU	0.0077299	0.0010317	7.49	<.0001	0
		AR1,1	0.38797	0.14301	2.71	0.0067	1
1963-2005	(1,0,0)	MU	0.0077845	0.001028	7.57	<.0001	0
		AR1,1	0.37139	0.14802	2.51	0.0121	1

Table 3. Comparison of the mean and variance of the relative exploitation ratio for the reference period for silver and red hake for the smoothed and original series. The percent reduction in variance using the smoothed abundance index is provided.

	Silver Hake	***North***	***Silver Hake***	***South***	***Red Hake***	***North***	***Red Hake***	***South***
Data Type	Mean	Variance	Mean	Variance	Mean	Variance	Mean	Variance
Smoothed	2.37485255	4.025428	23.678799	415.3055	0.437909	0.1157802	4.1844494	6.5364056
Original	2.77460693	6.380304	28.819355	1190.316	0.474762	0.1416104	5.0564668	15.411539
Percent Reduction In Variance		0.369085		0.651096		0.1824033		0.5758759

Figures


Silver Hake Northern Stock

Silver Hake Southern Stock

Red Hake Northern Stock

Red Hake Southern Stock

Figure 1. Original survey series (blue) and smoothed population estimates based on ARIMA models for silver and red hake stocks.

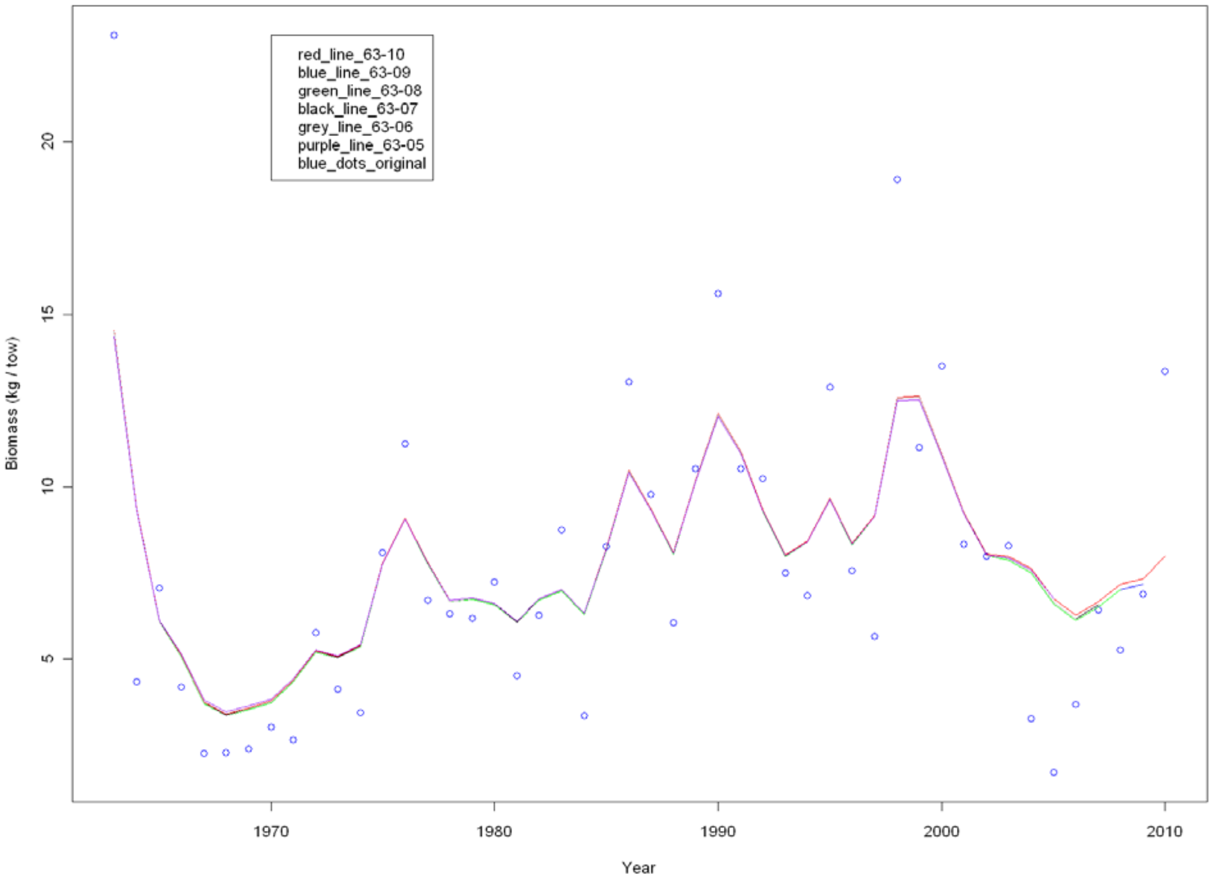


Figure 2. Comparison of the smoothed series derived by progressively eliminating data points from the end of the series.

9.0 Appendix 2: Kalman Filter

The Kalman filter (Meinhold and Singpurwalla 1983) is a recursive data processing algorithm for updating a system's linear projections to generate optimal estimates of desired quantities given a set of measurements. The desired quantities are derived by predicting a value, estimating the uncertainty of the predicted value and computing the weighted average of the predicted value and the measured value. The most weight is assigned to the value with least uncertainty. In the simplest form, the general concept of the Kalman filter can be expressed as:

$$\hat{X}_k = K_k \cdot Z_k + (1 - K_k) \cdot \hat{X}_{k-1}$$

where

$\hat{X}_k = \text{Current Estimate}$

$K_k = \text{Kalman Gain}$

$Z_k = \text{Measured Value}$

$\hat{X}_{k-1} = \text{Previous estimation}$

Note that the k's on the subscript represent states treated as discrete time intervals. From the general form of the Kalman filter, the objective is to find $\hat{X}_k$, the estimate of the signal value X for each consequent k's.

The general state-space representation for the Kalman filter can be expressed in the following discrete-time controlled process governed by the linear difference equation as follows:

Observation Equation

$$X_k = Ax_{k-1} + Bu_k + w_{k-1}$$

Where Xk, signal value is a linear combination of its previous value (x_{k-1}), a control signal (u_k) and a random noise (w_k)

State Equation

$$Z_k = Hx_k + v_k$$

Where Zk, the measurement value is a linear function of the signal value (x_k)and the random noise (v_k). Quantities *A*, *B*, *H* are generally matrices of parameters and are assumed to be non-stochastic which may vary over time. The matrix *A* relates the state at the previous time step (x_{k-1}) to the state at the current step (k). The *B* matrix relates the control signal to the state while the *H* matrix in the measurement equation relates the state to the measurement (Z_k). The random variables (w_k) and (v_k) represent process and random noise respectively and are assumed to be independent, normal random errors (i.e Gaussian) with zero means and variance-covariance matrices *Q* and *R* .

$$P(w) \sim N(0, Q)$$

$$P(v) \sim N(0, R)$$

The Kalman Filter Algorithm

The estimation process in the Kalman filter is an iterative process that utilizes a feedback control in which the filter estimates a process state at a given time and obtains feedback in form of (noisy) measurements. This iterative process is conditioned by two phases: The "*Time Update" and "Measurement Update"* phases, both which are applied at the k^{th} state. The time update phases (prediction) is responsible for projecting forward the current state and error covariance to obtain the *a priori* estimates for the next time step while the measurement update (correction)phase incorporates the current *a priori* prediction with the current observation to obtain *a posteriori* estimate. These two phases can also be referred to as the *predictor-corrector* algorithm for solving numerical problems as illustrated in **Figure S1**

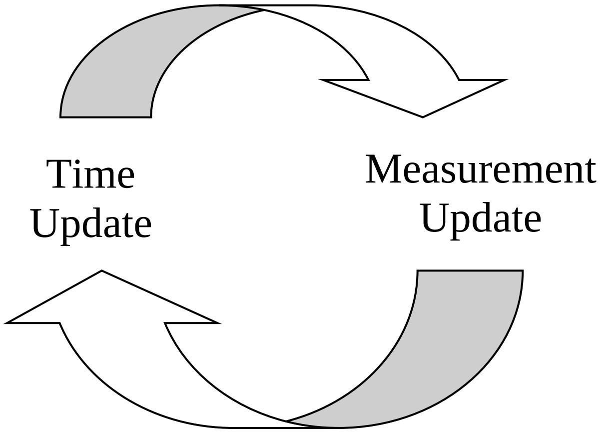


Figure S1: The phases of the Kalman filter algorithm. The Time update phase projects the current state estimates ahead of time. The measurement update phase adjusts the projected estimate by an actual measurement at that time

Mathematically, the time update and measurement phases can be represented by the following sets of equations:

Time Update Phase

$$\hat{X}_k^- = A\hat{X}_{k-1} + Bu_k$$

$$P_k^- = AP_{k-1}A^T + Q$$

Measurement Update

$$K_k = P_k^- H^T (HP_k^- H^T + R)^{-1}$$

$$\hat{X}_k = \hat{X}_k^- + K_k (Z_k - H\hat{X}_k^-)$$

$$P_k = (1 - K_k H) P_k^-$$

The $\hat{X}_k^-$ is the prior estimate which is considered the rough estimate before the measurement update correction phase. P_k^- is the prior error covariance used in the measurement update phase for deriving the Kalman gain K_k and the posterior estimates of the error covariance P_k. Besides the Kalman gain and the Posteriori covariance estimates in the measurement update phase, a posteriori state estimate is also generated as a function of the measured process, Z_k. After each time and measurement update pair, the process is repeated with the previous *a posteriori* estimate used to predict the new *a priori* estimates.

Fixed Interval Smoothing Algorithm

Application of the Kalman filter provides time series (filtered) estimates of X_k and P_k for $k = 1,2,\ldots K$, where each state estimate $x<K$ is conditional only on observations up to x. To produce estimates of X_k that are conditional on the full set of observations, a fixed-interval smoothing algorithm can be used. This is a recursive algorithm that begins with the final estimates X_k and P_k and then works backward from $K-1$ to $k=1$.

Data Input

Silver hake NMFS bottom trawl survey biomass estimates and estimated coefficient of variation (CV) from 1963-2010 was modeled in the Kalman filter from the NEFSC toolbox program to derive smooth survey estimates for both the northern and southern management regions. Survey estimates from 2009 and 2010 were calibrated using a length based calibration factor in numbers to derive the Albatross equivalent estimates. A length-weight relationship was then applied to the numbers at length to derive survey biomass. CV's in 2009 and 2010 were also adjusted to closely reflect the implied variance estimates in Albatross units. In the absence of a length based weight calibration factor, variance estimates in Albatross units were calculated by applying a constant weight-based calibration factor using a Taylor series expansion. The Albatross variance estimates were then applied to the length based calibrated survey biomass to derive the estimated CV.

Sensitivity Analyses

Using northern silver hake as an example, sensitivity analyses on the Kalman filter were conducted on starting conditions as well as on input data, by deteriorating the input CV's for some range of years. Additionally, a five year “quasi retrospective” analyses was conducted on the Kalman filter to examine the stability of the model by truncating the time series one year at a time in the terminal year. A total of ten sensitivity runs were conducted ranging from increasing or decreasing the initial guesses to the starting state value (**B0**) and starting variance as well as on the bounds around these parameters. Sensitivity on input data involved inflating the CV's for 2000-2010 five times the original estimated CV. Results of the sensitivity analyses in **Table S1 and Figure S2** generally indicate that the Kalman filter is not sensitive to initial guesses to the starting state value and variance. However, when the bounds around starting variance were restricted, the estimated standard deviation for the variance estimate improved dramatically. In the case when CV's in the input data was increased (run 10), the smoothed estimates showed some deviance from the other runs with a five point deterioration in the negative log likelihood and a slight increase in the estimated standard deviation for starting variance. Based on the quasi retrospective analyses, the Kalman filter was relatively stable. Relative difference on the six year peel indicated a 0-15% difference influenced by a high CV in 2006. When 2006 is ignored from the analyses, the relative difference was 0-5% (**Figures S3 and S4**)

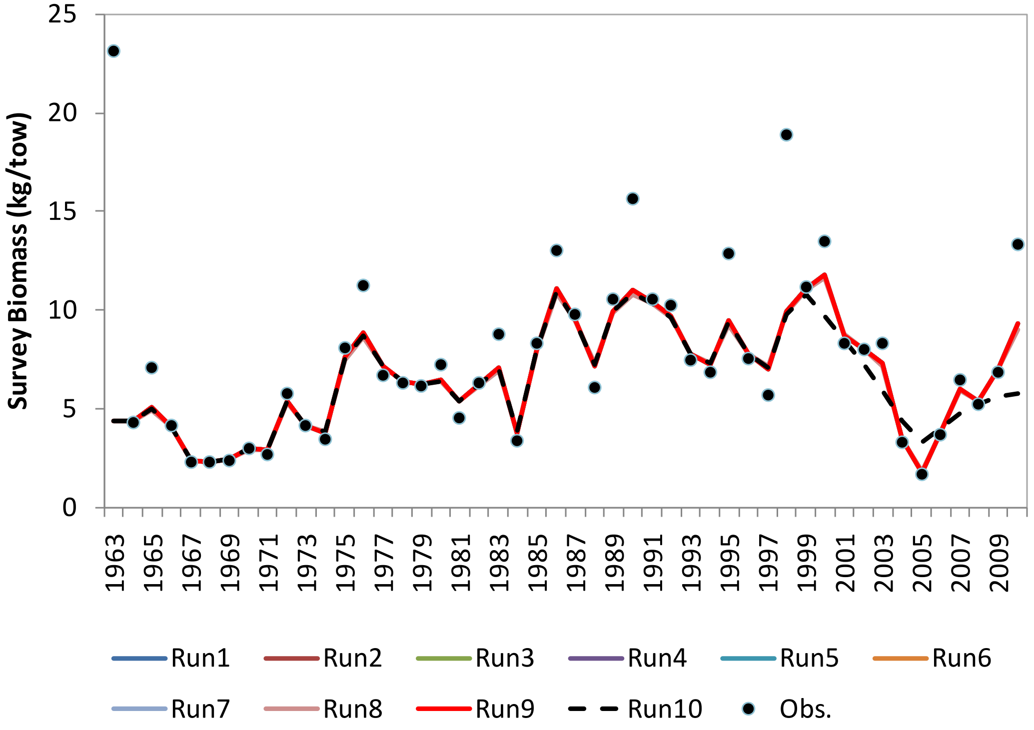


Figure S2: Sensitivity analyses on the Kalman filter using the Northern Silver hake as an example. See Table S1 below for details on the Runs.

Table S1: Sensitivity analyses on the Kalman filter for Northern Silver hake. B0 is the initial guess for the state value, B0 UB and B0 LB are the initial guess for the bounds on B0; Sigma is the initial guess on starting variance while sigma UB and Sigma LB are the starting guess for the bounds on sigma.

Input/Output	**Run1**	**Run2**	**Run3**	**Run4**	**Run5**	**Run6**	**Run7**	**Run8**	**Run9**	**Run10**
Description	Base	Incr. B0	Decr. B0	Decr. B0 Range	Incr. B0 Range	Incr. Sigma	Decr. Sigma	Decr. Sigma Range	Incr. Sigma Range	Inflate Input CV (00-10)
B0	25	50	10	25	25	25	25	25	25	25
B0 LB	1	1	1	1	1	1	1	1	1	1
B0 UB	50	50	50	20	75	50	50	50	50	50
Sigma	1.5	1.5	1.5	1.5	1.5	3.5	0.25	1.5	1.5	1.5
Sigma LB	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Sigma UB	5	5	5	5	5	5	5	2	10	5
Neg. LL	76.4	76.4	76.4	76.4	76.4	76.4	76.4	76.6	76.4	81.6
Est B0	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4
Est B0 SD	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.1	2.3	2.19
Est Sigma	2.21	2.21	2.21	2.21	2.21	2.21	2.21	2	2.21	2.1
Est Sigma SD	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.000364	0.35	0.38

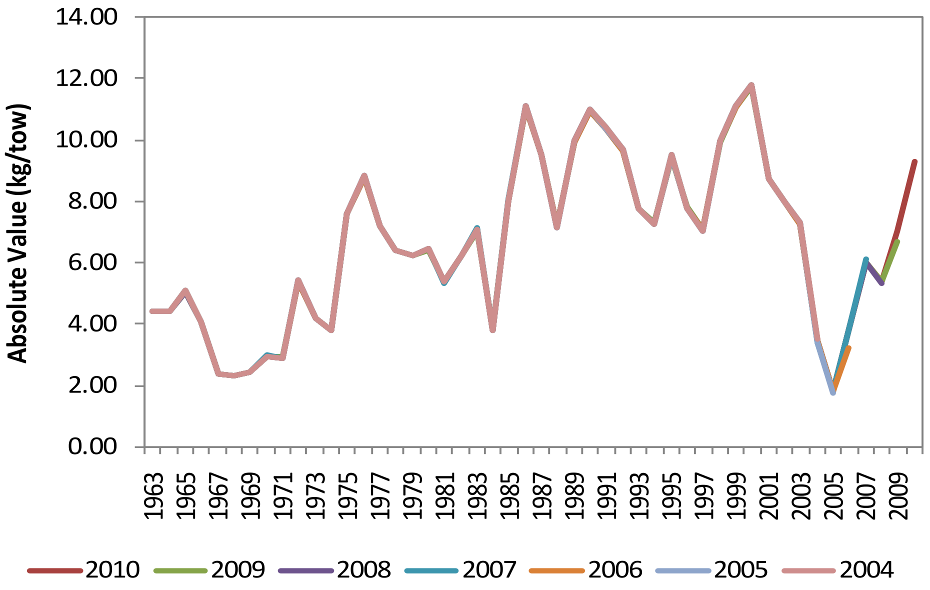


Figure S3: Quasi Retrospective analyses based on a six year peel on Kalman filter using Northern silver hake as an example.

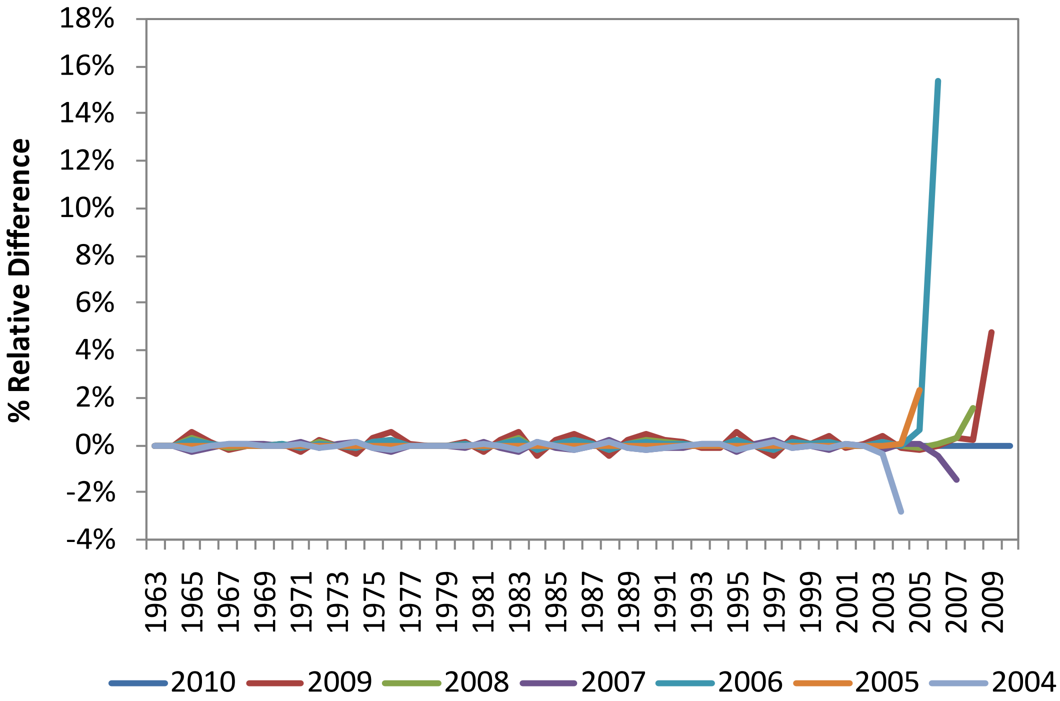


Figure S4: Six year peel quasi retrospective analyses calculated based on relative differences for Northern silver hake.

10.0 Appendix 3: ASAP Projections

Table S2: Silver hake short term projections (2010-2015) based on median F, Yield and SSB with alternative 2011 ABC for the northern and southern stocks

Northern Silver Hake						
SARC 51						
Catch = 8,666 mt (Combined)				AgePro	AgePro	Method 2
Year	F	Yield (000's mt)	SSB(000's mt)	P > SSBMSY	P > FMSY	P > Rel F
2010	0.72	8.666	22.842	0%	100%	NA
2011	0.16	3.644	33.147	0%	0%	NA
2012	0.16	6.076	48.959	0%	0%	NA
2013	0.16	8.432	64.288	0%	0%	NA
2014	0.16	10.373	77.051	0%	0%	NA
2015	0.16	11.810	86.461	0%	0%	NA
ABC = 5,363 mt (5th percentile OFL)				AgePro	AgePro	Method 2
Year	F	Yield (mt)	SSB(mt)	P > SSBMSY	P > FMSY	P > Rel F
2010	0.173	2.478	25.589	0%	78%	NA
2011	0.184	5.363	39.834	0%	91%	0%
2012	0.16	7.128	55.785	0%	0%	NA
2013	0.16	9.394	70.599	0%	0%	NA
2014	0.16	11.129	82.031	0%	0%	NA
2015	0.16	12.370	90.143	< 1 %	0%	NA
ABC = 7,434 mt (10th percentile OFL)				AgePro	AgePro	Method 2
Year	F	Yield (mt)	SSB(mt)	P > SSBMSY	P > FMSY	P > Rel F
2010	0.173	2.478	25.589	0%	78%	NA
2011	0.263	7.434	38.906	0%	100%	0%
2012	0.16	6.746	53.304	0%	0%	NA
2013	0.16	9.012	68.106	0%	0%	NA
2014	0.16	10.803	79.890	0%	0%	NA
2015	0.16	12.122	88.509	0%	0%	NA
ABC = 13,177 mt (25th percentile OFL)				AgePro	AgePro	Method 2
Year	F	Yield (mt)	SSB(mt)	P > SSBMSY	P > FMSY	P > Rel F
2010	0.173	2.478	25.589	0%	78%	NA
2011	0.514	13.177	36.140	0%	100%	2%
2012	0.16	5.704	46.524	0%	0%	NA
2013	0.16	7.966	61.284	0%	0%	NA
2014	0.16	9.906	73.998	0%	0%	NA
2015	0.16	11.435	83.991	0%	0%	NA

Southern Silver Hake						
SARC 51						
Catch = 8,666 mt (Combined)				AgePro	AgePro	Method 2
Year	F	Yield (mt)	SSB(mt)	P > SSBMSY	P > FMSY	P > Rel F
2010	0.72	8.666	22.842	0%	100%	NA
2011	0.16	3.644	33.147	0%	0%	NA
2012	0.16	6.076	48.959	0%	0%	NA
2013	0.16	8.432	64.288	0%	0%	NA
2014	0.16	10.373	77.051	0%	0%	NA
2015	0.16	11.81	86.461	0%	0%	NA
ABC = 13,072 mt (5th percentile OFL)				AgePro	AgePro	Method 2
Year	F	Yield (mt)	SSB(mt)	P > SSBMSY	P > FMSY	P > Rel F
2010	0.561	7.11	23.572	0%	100%	NA
2011	0.642	13.072	30.495	0%	100%	0%
2012	0.16	4.706	40.03	0%	0%	NA
2013	0.16	7.004	55.003	0%	0%	NA
2014	0.16	9.112	68.775	0%	0%	NA
2015	0.16	10.834	80.027	0%	0%	NA
ABC = 18,290 mt (10th percentile OFL)				AgePro	AgePro	Method 2
Year	F	Yield (mt)	SSB(mt)	P > SSBMSY	P > FMSY	P > Rel F
2010	0.561	7.110	23.572	0%	100%	NA
2011	1.022	18.290	27.577	0%	100%	0%
2012	0.16	3.816	34.213	0%	0%	NA
2013	0.16	6.080	48.984	0%	0%	NA
2014	0.16	8.295	63.410	0%	0%	NA
2015	0.16	10.196	75.829	0%	0%	NA
ABC = 32,635 mt (25th percentile OFL)				AgePro	AgePro	Method 2
Year	F	Yield (mt)	SSB(mt)	P > SSBMSY	P > FMSY	P > Rel F
2010	0.561	7.110	23.572	0%	100%	NA
2011	3.109	32.635	17.028	0%	100%	0%
2012	0.16	1.788	20.650	0%	0%	NA
2013	0.16	3.836	34.455	0%	0%	NA
2014	0.16	6.224	49.859	0%	0%	NA
2015	0.16	8.514	64.786	0%	0%	NA

Table S3: Northern Silver hake Short-term projections (2010-2015) for F, Yield and SSB with 5th and 95th percentiles

Northern Silver Hake											
Fishing Mortality				Yield (000 mt)				SSB (000 mt)			
ABC = 5,363 mt (5th percentile OFL)				5th percentile				5th percentile			
YEAR	ABC1_5%	50%	ABC1_95%	YEAR	5%	50%	95%	YEAR	5%	50%	95%
2010	0.146	0.173	0.207	2010	2.478	2.478	2.478	2010	21.691	25.589	29.95
2011	0.155	0.184	0.219	2011	5.363	5.363	5.363	2011	33.906	39.834	46.422
2012	0.16	0.16	0.16	2012	6.017	7.128	8.356	2012	47.083	55.785	64.843
2013	0.16	0.16	0.16	2013	8.016	9.394	10.841	2013	60.476	70.599	80.95
2014	0.16	0.16	0.16	2014	9.543	11.129	12.719	2014	70.74	82.031	93.241
2015	0.16	0.16	0.16	2015	10.641	12.37	14.056	2015	78.078	90.143	102.021
ABC = 7,434 mt (10th percentile OFL)				10th percentile				10th percentile			
YEAR	ABC2_5%	50%	ABC2_95%	YEAR	5%	50%	95%	YEAR	5%	50%	95%
2010	0.146	0.173	0.207	2010	2.478	2.478	2.478	2010	21.691	25.589	29.95
2011	0.221	0.263	0.316	2011	7.434	7.434	7.434	2011	32.968	38.906	45.505
2012	0.16	0.16	0.16	2012	5.638	6.746	7.972	2012	44.606	53.304	62.357
2013	0.16	0.16	0.16	2013	7.634	9.012	10.458	2013	57.99	68.106	78.454
2014	0.16	0.16	0.16	2014	9.218	10.803	12.393	2014	68.601	79.89	91.105
2015	0.16	0.16	0.16	2015	10.391	12.122	13.807	2015	76.442	88.509	100.378
ABC = 13,177 mt (25th percentile OFL)				25th percentile				25th percentile			
YEAR	ABC3_5%	50%	ABC3_95%	YEAR	5%	50%	95%	YEAR	5%	50%	95%
2010	0.146	0.173	0.207	2010	2.478	2.478	2.478	2010	21.691	25.589	29.95
2011	0.425	0.514	0.63	2011	13.177	13.177	13.177	2011	30.123	36.14	42.798
2012	0.16	0.16	0.16	2012	4.61	5.704	6.919	2012	37.855	46.524	55.547
2013	0.16	0.16	0.16	2013	6.591	7.966	9.41	2013	51.194	61.284	71.611
2014	0.16	0.16	0.16	2014	8.321	9.906	11.494	2014	62.697	73.998	85.195
2015	0.16	0.16	0.16	2015	9.703	11.435	13.121	2015	71.923	83.991	95.855

Table S4: Southern Silver hake Short-term projections (2010-2015) for F, Yield and SSB with 5th and 95th percentiles

Southern Silver Hake											
Fishing Mortality				Yield (000 mt)				SSB (000 mt)			
ABC = 13,072 mt (5th percentile OFL)				5th percentile				5th percentile			
YEAR	5%	50%	95%	YEAR	5%	50%	95%	YEAR	5%	50%	95%
2010	0.465	0.561	0.686	2010	7.11	7.11	7.11	2010	19.622	23.572	27.953
2011	0.51	0.642	0.828	2011	13.072	13.072	13.072	2011	24.488	30.495	37.127
2012	0.16	0.16	0.16	2012	3.631	4.706	5.906	2012	31.46	40.03	48.987
2013	0.16	0.16	0.16	2013	5.63	7.004	8.447	2013	44.911	55.003	65.327
2014	0.16	0.16	0.16	2014	7.52	9.112	10.705	2014	57.455	68.775	80.006
2015	0.16	0.16	0.16	2015	9.098	10.834	12.524	2015	67.939	80.027	91.932
ABC = 18,290 mt (10th percentile OFL)				10th percentile				10th percentile			
YEAR	5%	50%	95%	YEAR	5%	50%	95%	YEAR	5%	50%	95%
2010	0.47	0.56	0.69	2010	7.11	7.11	7.11	2010	19.622	23.572	27.953
2011	0.79	1.02	1.37	2011	18.29	18.29	18.29	2011	21.346	27.577	34.357
2012	0.16	0.16	0.16	2012	2.781	3.816	4.989	2012	25.785	34.213	43.046
2013	0.16	0.16	0.16	2013	4.72	6.08	7.509	2013	38.993	48.984	59.223
2014	0.16	0.16	0.16	2014	6.706	8.295	9.884	2014	52.111	63.41	74.613
2015	0.16	0.16	0.16	2015	8.46	10.196	11.886	2015	63.729	75.829	87.738
ABC = 32,635 mt (25th percentile OFL)				25th percentile				25th percentile			
YEAR	5%	50%	95%	YEAR	5%	50%	95%	YEAR	5%	50%	95%
2010	0.465	0.561	0.686	2010	7.11	7.11	7.11	2010	19.622	23.572	27.953
2011	2.079	3.109	5.11	2011	32.635	32.635	32.635	2011	10.106	17.028	24.761
2012	0.16	0.16	0.16	2012	1.068	1.788	2.734	2012	13.466	20.65	28.412
2013	0.16	0.16	0.16	2013	2.637	3.836	5.135	2013	25.398	34.455	43.892
2014	0.16	0.16	0.16	2014	4.706	6.224	7.753	2014	38.996	49.859	60.682
2015	0.16	0.16	0.16	2015	6.795	8.514	10.186	2015	52.773	64.786	76.572

Table S5: Sensitivity projections for northern silver hake assuming constant ABC from 2011-2015

Northern Silver Hake_Assuming Constant ABC						
SARC 51						
Catch = 8,666 mt (Combined)				AgePro	AgePro	Method 2
Year	F	Yield (mt)	SSB(mt)	P > SSBMSY	P > FMSY	P > Rel F
2010	0.72	8.666	22.842	0	1	NA
2011	0.16	3.644	33.147	0	0	NA
2012	0.16	6.076	48.959	0	0	NA
2013	0.16	8.432	64.288	0	0	NA
2014	0.16	10.373	77.051	0	0	NA
2015	0.16	11.81	86.461	0	0	NA
ABC = 13,072 mt (5th percentile OFL)				AgePro	AgePro	Method 2
Year	F	Yield (mt)	SSB(mt)	P > SSBMSY	P > FMSY	P > Rel F
2010	0.17	2.478	25.589	0%	78%	NA
2011	0.18	5.363	39.834	0%	91%	0%
2012	0.12	5.363	56.565	0%	0%	NA
2013	0.09	5.363	74.524	0%	0%	NA
2014	0.07	5.363	91.509	1%	0%	NA
2015	0.06	5.363	106.683	28%	0%	NA
ABC = 18,290 mt (10th percentile OFL)				AgePro	AgePro	Method 2
Year	F	Yield (mt)	SSB(mt)	P > SSBMSY	P > FMSY	P > Rel F
2010	0.17	2.478	25.589	0%	78%	NA
2011	0.26	7.434	38.906	0%	100%	0%
2012	0.18	7.434	52.999	0%	82%	NA
2013	0.13	7.434	67.988	0%	6%	NA
2014	0.11	7.434	82.271	0%	0%	NA
2015	0.09	7.434	95.333	4%	0%	NA
ABC = 32,635 mt (25th percentile OFL)				AgePro	AgePro	Method 2
Year	F	Yield (mt)	SSB(mt)	P > SSBMSY	P > FMSY	P > Rel F
2010	0.17	2.478	25.589	0%	78%	NA
2011	0.51	13.177	36.140	0%	100%	0%
2012	0.41	13.177	43.044	0%	100%	NA
2013	0.34	13.177	49.840	0%	100%	NA
2014	0.29	13.177	56.299	0%	100%	NA
2015	0.26	13.177	62.615	0%	100%	NA

Table S6: Northern Silver hake Short-term projections (2010-2015) sensitivity assuming constant ABC's for F, Yield and SSB with 5th and 95th percentiles

Northern Silver Hake_ASSUMING CONST ABC from 2011-2015													
Fishing Mortality					Yield (000 mt)					SSB (000 mt)			
ABC = 5,363 mt (5th percentile OFL)					5th percentile					5th percentile			
YEAR	ABC1_5%	50%	ABC1_95%		YEAR	5%	50%	95%		YEAR	5%	50%	95%
2010	0.15	0.173	0.207		2010	2.478	2.478	2.478		2010	21.691	25.589	29.95
2011	0.16	0.184	0.219		2011	5.363	5.363	5.363		2011	33.906	39.834	46.422
2012	0.10	0.118	0.141		2012	5.363	5.363	5.363		2012	47.413	56.565	66.144
2013	0.07	0.086	0.103		2013	5.363	5.363	5.363		2013	62.648	74.524	86.819
2014	0.06	0.068	0.082		2014	5.363	5.363	5.363		2014	77.01	91.509	106.217
2015	0.05	0.057	0.069		2015	5.363	5.363	5.363		2015	89.889	106.683	123.306
ABC = 7,434 mt (10th percentile OFL)					10th percentile					10th percentile			
YEAR	ABC2_5%	50%	ABC2_95%		YEAR	5%	50%	95%		YEAR	5%	50%	95%
2010	0.15	0.173	0.207		2010	2.478	2.478	2.478		2010	21.691	25.589	29.950
2011	0.22	0.263	0.316		2011	7.434	7.434	7.434		2011	32.968	38.906	45.505
2012	0.15	0.178	0.216		2012	7.434	7.434	7.434		2012	43.842	52.999	62.578
2013	0.11	0.132	0.162		2013	7.434	7.434	7.434		2013	56.092	67.988	80.269
2014	0.09	0.106	0.131		2014	7.434	7.434	7.434		2014	67.753	82.271	96.969
2015	0.08	0.090	0.111		2015	7.434	7.434	7.434		2015	78.563	95.333	111.960
ABC = 13,177 mt (25th percentile OFL)					25th percentile					25th percentile			
YEAR	ABC3_5%	50%	ABC3_95%		YEAR	5%	50%	95%		YEAR	5%	50%	95%
2010	0.15	0.173	0.207		2010	2.478	2.478	2.478		2010	21.691	25.589	29.95
2011	0.43	0.514	0.63		2011	13.177	13.177	13.177		2011	30.123	36.14	42.798
2012	0.33	0.409	0.53		2012	13.177	13.177	13.177		2012	33.841	43.044	52.64
2013	0.27	0.341	0.465		2013	13.177	13.177	13.177		2013	37.879	49.84	62.118
2014	0.23	0.294	0.417		2014	13.177	13.177	13.177		2014	41.68	56.299	71.057
2015	0.20	0.259	0.374		2015	13.177	13.177	13.177		2015	45.643	62.615	79.485