

none of these data sources provided sufficient information to develop indices of abundance for cabezon.

Data Input Files

The SS2 input files for each substock are provided in Appendices B-1 (NCS) and C-1 (SCS).

Assessment

Assessment Model

This is the second assessment of the cabezon resource off the California coast. It differs in several key ways from the past assessment (Cope *et al.* 2004). The past assessment was based on an age- and sex-structured population dynamics model developed specifically for cabezon in AD Model Builder (Otter Research Ltd.). In contrast, the present assessment is based on Stock Synthesis 2 (SS2; Methot 2005), a flexible length- and age-based population dynamics modeling environment. The two models differ in terms of how the recruitment bias-correction is modeled, whether the impact of selectivity on weight-at-age is accounted for, and whether additional survey index variability is estimated. A formal comparison of the two models is provided in Appendix D.

Another major difference from the past assessment is that California is divided into two regions for the purposes of this assessment. The ecology of nearshore reef fishes leads to the expectation of low rates of movement among reefs. This, combined with the different fishing histories of central/northern California and southern California, imply different time-trajectories of population size in these two broad regions. Although even finer scale assessments would be desirable (e.g. by conducting assessments separately for northern and central California), the two-substock approach is the only one that can be supported by the currently available data. Results from a one-stock model with twelve fleets representing the area-specific fleet designations of the two-substock model are also presented for comparison. This model includes all of the indices used in the assessments of the NCS and the SCS.

The population dynamics model

The base case assessment for each substock is based on the following assumptions:

1. There are two fishery sectors (commercial and recreational). The commercial sector consists of two fleets and the recreational sector consists of four fleets.
 - Fleet 1: Commercial non-live-fish fishery
 - Fleet 2: Commercial live-fish fishery
 - Fleet 3: Recreational mode: Man-made
 - Fleet 4: Recreational mode: Shore
 - Fleet 5: Recreational mode: Private boat and rentals (PBR)
 - Fleet 6: Recreational mode: Commercial Passenger Fishing Vessel (CPFV).Fleet distinctions imply different length-specific selectivity patterns.
2. Selectivity is assumed to be dome-shaped for the commercial live-fish fishery and the man-made and shore fleets in the recreational fishery because each of these fleets tends not to land the larger sized fishes. Selectivity is assumed to be asymptotic and related to length by a logistic function for the remaining

fleets. All selectivities are assumed to be constant over time. The sensitivity of the results of the assessment to alternative specifications related to selectivity is examined in the tests of sensitivity. The selectivity patterns for the commercial fleets in the assessment of the SCS are set to those for the commercial fleets in the NCS owing to a lack of size composition data for the commercial fleets in the SCS.

3. There is one fishing season each year and the removals are taken instantaneously in the middle of the year after half of the natural mortality.
4. The estimates of removals-in-mass are known with negligible error.
5. Recruitment is related to reproductive output by means of a Beverton-Holt stock-recruitment relationship with log-normally distributed process error.
6. Length-at-age is normally distributed about its expected value.
7. There is no connection between the two substocks of cabezon, either through recruitment or migration.

Parameter estimation

The population dynamics model includes many parameters. The values for some of these parameters are based on auxiliary information, while others are estimated by fitting the model to the data (Table 15). The base-case value for steepness (h) is assumed to be 0.7 based on a recommendation from the past assessment. The implications of this choice of steepness is evaluated using a likelihood profile. Recruitment variation, σ_R , is set equal to 1.0 as was case for the past assessment. The base-case values for the instantaneous rate of natural mortality are set to 0.25yr^{-1} for females and 0.3yr^{-1} for males (Table 2). Given the considerable uncertainty associated with the (assumed) base-case values for σ_R and M , sensitivity tests examine the consequences of changing the values for these parameters.

Growth is not estimated within the model. Rather, the values for the parameters related to growth and fecundity are taken from Table 1. The values that determine the variability in length-at-age are computed by assuming that the coefficient of variation of the length at age 1 is 0.14 and that at age 17 is 0.09. There is an indication that the CV of length-at-age decreases linearly with age for many marine fishes (Erzini 1994). The only data on length-at-age for cabezon (Grebel 2003; Fig. 3A) indicates that the coefficient of variation for age-0 females is 0.11 and that for age-0 males is 0.14, while the coefficient of variation of length-at-age for age-10 is 0.01 for females and 0.09 for males. These values were based on small sample sizes (2 to 13 animals), therefore the upper limit for the CVs (0.14 and 0.09) are assumed for the base-case analyses and the value for age 10 is increased slightly and assumed to apply to age 17.

No attempt is made to estimate recruitment deviations for the first year of the assessment period (1916), nor those for some of the subsequent years, because the data are completely uninformative regarding the values for some of the early (and most recent) recruitment deviations. Running the NCS model while estimating all recruitments produces a recruitment event in 1960 almost three times larger than any another recruitment event, while doing the same in SCS, produces a relatively poor recruitment history (Fig. 31). The past assessment considered the availability of length-composition and impingement data to determine the years for which recruitment deviations should be estimated. For this assessment, the base-case models for each substock were run estimating recruitment deviations for all years to determine the first year for which recruitment deviations could be estimated with

reasonable precision. The asymptotic standard deviations for the recruitment deviations are shown in Fig. 32. A decrease in these standard deviations may indicate when estimation of recruitment deviations should begin because the data provide some information about the recruitment deviations. There is a dramatic drop in the asymptotic standard deviation of the recruitment deviations for the SCS in 1970, but only a slow and steady decline in these asymptotic standard deviations for the NCS after 1960. Considering all of these factors, 1970 was chosen as the first year for which a recruitment deviation is estimated for the SCS and 1980 for the NCS (the latter based mostly on available length data). The base case models end recruitment estimation in 2003 because there is no information available to estimate a 2004 value, though the choice of the last year for which a recruitment deviation is estimated may impact the results of the assessment (Fig. 33). Therefore, sensitivity of the assessment results to the years for which recruitment deviations are estimated is considered in the tests of sensitivity.

Selectivity as a function of length was estimated for all fleets for which mean weight or length-composition data were available. Dome-shaped selectivity was modeled using an eight-parameter double-logistic curve for the commercial live-fish and recreational man-made and shore fleets. All parameters were estimated except for the minimum size selectivity (parameter 2) and the width of the dome (parameter 8) for the live-fish and shore fleets. For the man-made fleet, the initial slope (parameter 4) and the selectivity at the maximum size (parameter 5) were also pre-specified (Table 15). Length selectivities for the non-live commercial and recreational PBR and CPFV fleets were described using a logistic equation with both parameters estimated. There are no length-frequency data for the commercial fleets for the SCS, so the selectivity patterns for these fleets were set to those estimated for the NCS. The selectivity pattern for the CPFV fleet used when calculating the model-estimates for the indices of abundance derived using the catch and effort data for the CPFV fleet were set to those for the CPFV fleet. Age selectivities with full selectivity at age 0 and age 0 to 1 only were assumed when fitting to the CalCOFI larval tows and power plant impingement data, respectively. Sensitivity to alternative formulations of the CalCOFI larval survey selectivity was explored by parameterizing to fully select age 5 and older individuals and matching the selectivity to the maturity function.

Likelihood components

The following five components comprised the objective function that was minimized to estimate the free parameters of the model:

1. Abundance Index (assumed to be log-normally distributed).
2. Mean Weight (assumed to be normally distributed).
3. Length Composition (assumed to be multinomially distributed).
4. Recruitment Deviations.
5. Parameter Priors (penalties on deviations from the prior distribution; generally very small for these model parameterizations)

Coefficients of variation about the abundance indices derived from bootstrapping or jackknifing techniques may greatly underestimate the true uncertainty regarding the relationship between these indices and biomass. A catchability scaling parameter was estimated during the 2003 assessment to inflate the coefficients of variation for the indices. That option is not currently available in SS2, so the pre-specified coefficients of variation for the abundance indices were adjusted iteratively until the model-

calculated R.M.S.E. matched the pre-specified coefficient of variation for each index. The sensitivity of the results to setting the coefficients of variation to those obtained from the bootstrap procedure (Tables 13 and 14) is explored in the tests of sensitivity.

The mean weight data (Table 9) were assumed to be normally distributed with coefficients of variation based on the raw data when these data were included in the objective function. The coefficients of variation for the estimates of mean weight for the CPFV fleet for 1947–51 for the NCS were set to 0.5 (larger than observed for RecFIN – average CV = 0.41) to avoid over-weighting these early data.

The catch length-composition data were pooled into 44 length-classes, each of width 2cm (first length-class 0–7.9cm). Although the length compositions can be based on hundreds or thousands of measurements, fits to length-frequency data usually exhibit substantial overdispersion relative to a multinomial distribution where the sample sizes are set to the number of animals measured. Therefore, for the purposes of the present analyses, the sample sizes are compared to the “effective” number of animals measured each year using the approach developed by McAllister and Ianelli (1997). Sample sizes are then iteratively changed to the effective sample sizes until the mean inputted sample sizes are similar to the mean effective sample sizes. Alternatively, one could set an upper limit to the effective sample size (say 200) to avoid large differences in sample sizes across fleets. For instance, the fleet with the largest average sample size would receive a maximum value 200 for all sampled years. The average sample sizes for all other fleets could then be re-scaled in relation to 200 based on their relationship to the fleet with the highest average sample size. Finally, the iterative procedure would be followed to obtain the final effective sample sizes internally consistent with the model, with the maximum value possible being 200. Model sensitivity to the method used to assign effective sample sizes and to assuming the original sample sizes (Table 8) was explored in the tests of sensitivity.

Recruitment deviation and parameter priors were calculated assuming lognormal and normal error structures, respectively. The variances for all of the estimated parameters were set very high to minimize the influence of the prior on the results.

Parameter (Control) Input Files

The SS2 files for the assessments of each substock are provided in Appendices B-2 (NCS) and C-2 (SCS).

Model diagnostics (base models)

Abundance Surveys

Figures 34 and 35 show the fits to the base-case indices of abundance for the NCS and SCS respectively. As expected from the 2003 assessment, the model tracks the changes in the CPFV indices qualitatively, but there are considerable differences between the model-estimates and the data for some years. These differences are consistent with the very wide confidence intervals assumed for the data. The fit of the CPFV index for the SCS (Fig. 35) is particularly poor in the most recent years. This is because the length and weight data drive population dynamics rather than the abundance index information, with the result that the model predictions are substantially in excess of the observations. The NCS model also tends to overestimate the index values in more recent (post-1990) years (Fig. 34). The CalCOFI and Impingement indices are imprecise, and the fits to these data series are also not very good, particularly that to the CalCOFI index in recent years (Fig. 35).

Mean Weights

Figures 36 and 37 show the fits to the mean weight data by substock. The confidence intervals for the mean weights are wide (as expected given the CVs in Table 8), which implies that the model is not constrained to a substantial extent by these data, particularly for the NCS. The fit of the model to the data for the PBR mode (fleet 5) for the NCS is very poor with the model consistently over-estimating the mean weight of the catch. Given that the model is able to mimic the length-frequency data for this fleet, this suggests a conflict between the length and weight data, undersampling of the weight data, or error in the length-weight relationship (or both). There are no very poor fits to the mean weight data for the SCS (Figure 36), although there remain runs of residuals for some fleets. The 95% confidence intervals for some of the mean weights are quite narrow for the SCS and the model consequently attempts to mimic these mean weights quite closely. One reason for the increasing trend in abundance evident for the SCS is the low mean weight for the man-made fleet (fleet 3) in 2000. This weight is interpreted as a recruitment event, which translates into large increases in biomass during the final years of the assessment period. Sensitivity to the inclusion in the assessment of this data point is explored below.

Length-composition Data

The base-case fits to the length-composition data for the NCS are given in Figures 38–43 and the corresponding Pearson residuals are summarized in Figures 44 and 45. Note that fits for the shore and man-made fleets are not shown because the lengths for these fleets are derived from weights (Table 7). When interpreting these figures, it should be noted that the observed and model-predicted lengths are “plussed” at low and high sizes. This has little impact on the results at high size, but can give a misleading impression at low size (e.g. the fit to the data for 1999 and 2000 for the non-live-fish fleet (Figure 38)). The fits to the length frequency data for the commercial fleets (Figures 38 and 39) are better than those to the data for the recreational fleets (Figures 40–43) and consequently have the higher effective sample sizes. Of the recreational fleets, the fits to the observer data for the CPFV fleet (Figure 42) are better than those to the data for the remaining fleets. This result is hardly surprising given the actual sample sizes for the various recreational fleets (Table 8). The fits to the length-composition data for the SCS (Figures 46 and 47) and the corresponding Pearson residuals (Figure 48) are only shown for two of the six fleets as there are either no length data or the length data are all computed from measured weights for the remaining fleets. As before, the fits to the CPFV observer data are better than the fits to the recreational PBR data.

Results

Base-case results: NCS

Figure 49 shows the MPD estimates of the time-trajectories of reproductive output (in absolute terms) and recruitment, along with their asymptotic 95% confidence intervals. There is considerable inter-annual variation in recruitment. The estimates of recruitment are most precise before 1980 and recently, because no recruitment deviations are estimated for these years and the estimates of recruitment consequently reflect expectations based on the stock-recruitment relationship (Figure 49B). In contrast, the estimates of reproductive output are most precise during the late 1980s and early 1990s (Figure 49A). The NCS is estimated to have been at 40.1% of its virgin level at the start of 2005 (445 mt). Major recruitment events are seen in the

1990s. Figure 50A shows the estimated spawner-recruit relationship. Appendix E lists the MPD estimates of the numbers-at-age matrix for each gender.

Figures 51 and 52 show the length- and age-specific selectivity ogives for each fleet. The live-fish fishery (fleet 2) is dome-shaped with respect to length. Selectivity for the man-made and shore fleets (fleets 3 and 4) also decline with size. Males are less selected than females for a given age because females are larger at age. Selectivity based on age and length suggests that immature fish are not completely excluded from the current and historical catch, especially in the man-made and shore fisheries.

Harvest rates for each fleet are given in Figure 53. The onset of the live-fish fishery in the late 1990s is dramatic and the peak harvest rate by this fleet is greater than that for any other fleet. The PBR harvest rates during the 1980s also represent a major period of removals from NCS.

Base-case results: SCS

Figure 54 shows the MPD estimates of the time-trajectories of reproductive output (in absolute terms) and recruitment, along with their asymptotic standard errors. The time-trajectory of reproductive output drops dramatically after 1980, stays low until the early 2000s, and then increases substantially. The increase in reproductive output occurs because of the 2000 year-class, the largest in the time-series. The size of this year-class is inferred primarily from the mean weight data for 2000 for the man-made recreational fleet (fleet 3). The major recruitment events are consistently lagged 1 year compared to the NCS. The reproductive output is estimated very precisely during the 1990s. The SCS is estimated to have been at 28.3% of its virgin level at the start of 2005 (71 mt). The biomass of cabezon off southern California is smaller than that off central / northern California and the resource is estimated to be more depleted off southern California than off central/northern California. Figure 50B shows the estimated spawner-recruit relationship. Appendix F lists the MPD estimates of the numbers-at-age matrix.

Figures 55 and 56 show the length- and age-specific selectivity ogives for each fleet. The selectivity patterns for the non-live-fish and live-fish fleets are set to those for the NCS. The selectivity patterns for the man-made and shore fleets decline more rapidly with length for the SCS than is the case for the NCS. Males are less selected than females for a given age because females are larger at age and fish are generally caught smaller in the SCS relative to the NCS. Selectivity based on age and length suggests that immature fish are not completely excluded from the current and historical catch, especially in the man-made recreational fishery.

Harvest rates for each fleet are given in Figure 57. There are two significant periods of removals: 1) the 1980s when harvest rates increased dramatically because of the increase in recreational fishing, particularly by the PBR mode; and 2) the late 1980s when the live-fish fishery took large catches. The first of these periods of harvest, along with the lack of strong recruitment events, led to the large reduction in reproductive output during the early 80s (Fig. 54).

Base-case results: One California stock

Figures 58 and 59 show MPD estimates of the time-trajectories of reproductive output (in absolute terms) and recruitment, along with their asymptotic standard errors when the data for the NCS and SCS are combined, and cabezon off California are

consequently treated as a single homogenous population. Results are shown when all of the data are used and when the 2000 mean weight datum for the man-made fleet off southern California is ignored. The time-trajectory of reproductive output for the combined assessment is qualitatively similar to that for the SCS, although, as expected, biomass levels are higher. There is a large increase in reproductive output at the end of the time-series, which can be attributed to the 2000 mean weight datum for man-made fleet off southern California. The depletion of the combined resource is 50% at the start of 2005 (634 mt compared to an unfished spawning biomass of 1,268 mt).

Table 16 compares the estimates of the total California cabezon reproductive output from the two substock model, the one stock model, and the 2003 assessment model. Total reproductive output in 2003 is greater for both of the current models compared to the 2003 assessment. However, both 2003 depletion estimates from this assessment are within the uncertainty ranges presented in the 2003 assessment (Cope *et al.* 2004). The estimate of 2003 depletion from the one stock model is larger than that from the two substock model (Table 16). When the one stock model uses all of the length data reported in RecFIN (meaning all weights converted to lengths and true measured lengths), as was the case for the 2003 assessment, the estimate of the 2003 depletion is very similar to that obtained during the 2003 assessment (Table 16, “one stock/all lengths”).

Sensitivity analyses

The sensitivity tests related to data set choices differed among substocks. The selectivity pattern for a fleet is fixed to that for the base-case analysis if removal of a data source causes selectivity for that fleet to be inestimable.

NCS

- Trial 1: Ignore the length composition data for the commercial non-live-fish fleet (fleet 1).
- Trial 2: Ignore the length composition data for the commercial live-fish fleet (fleet 2).
- Trial 3: Ignore the mean weight data for the recreational man-made fleet (fleet 3).
- Trial 4: Ignore the length composition and mean weight data for the recreational shore fleet (fleet 4).
- Trial 5: Ignore the length composition and mean weight data for the recreational PBR fleet (fleet 5).
- Trial 6: Ignore the length composition and mean weight data for the recreational CPFV fleet (fleet 6).
- Trial 7: Base the analysis on the CPFV index for 1957–2003 (Table 13).
- Trial 8: Base the analysis on the CPFV indices for 1957–61 and 1962–2003 (Table 13).
- Trial 9: Do not include the CPFV index
- Trial 10: Add the Monterey adult survey and the TENERA adult survey.
- Trial 11: Add the TENERA adult survey.
- Trial 12: Add the Monterey adult survey.
- Trial 13: Nonlinear relationship between CPUE and abundance ($\beta = 0.5$).

SCS

- Trial 1: Ignore the mean weight data for the recreational man-made fleet (fleet 3).
- Trial 2: Ignore the mean weight data for the recreational shore fleet (fleet 4).
- Trial 3: Ignore the all mean weight data for the recreational shore fleet except the data point for 2000.
- Trial 4: Ignore the length composition and mean weight data for the recreational PBR fleet (fleet 5).
- Trial 5: Ignore the length composition and mean weight data for the recreational CPFV fleet (fleet 6).
- Trial 6: Base the analysis on the CPFV index for 1947–2003 (Table 13).
- Trial 7: Base the analysis on the CPFV indices for 1947–61 and 1962–2003 (Table 13).
- Trial 8: Ignore all CPFV indices.
- Trial 9: Ignore the CalCOFI index.
- Trial 10: Ignore the Impingement index.
- Trial 11: Use the CPFV index only.
- Trial 12: Nonlinear relationship between CPUE and abundance ($\beta = 0.5$)

The results of these sensitivity analyses are provided in Table 17. Table 18 examines the sensitivity of the results to changing the values for M and σ_R , and Table 19 explores the sensitivity of the results to: a) the years for which recruitment residuals are estimated, b) the specifications for length-/age-specific selectivity, c) the specifications of the CalCOFI selectivity, d) the length data included in the analyses, e) the coefficients of variation assumed for the abundance indices, f) the effective sample sizes assumed for the length-composition data, g) the historical catches, and h) the coefficients of variation assumed for length-at-age.

Overall, the results in Tables 17 indicate that the NCS model is not greatly sensitive to adding or removing data sources. Ignoring the length-composition data for the live-fish commercial fleet (trial 2), ignoring the size information for the recreational man-made and shore fleets (trials 3 and 4), including the longest CPFV time-series (trial 7), and excluding all CPFV indices (trial 9) all lead to less optimistic estimates of depletion. Ignoring the size information for the CPFV fleet (trial 6) leads to more optimistic estimates of depletion. The results are most sensitive to including the TENERA adult survey (trials 10 and 11). The inclusion of this index leads to markedly lower estimates of current depletion, though the fits to the TENERA index are not good (Fig. 60). The potential to miss cryptic species using SCUBA surveys, and the inconsistency between the CPFV index for Morro Bay and the TENERA index (Fig. 26) suggests that the limited spatial coverage of the TENERA survey is such that this index does not provide an index of abundance for the entire NCS. This finding should not, however, rule out future use of other spatially-limited fishery-independent surveys.

The SCS model is also generally insensitive to the data sources included in the assessment (Table 17), except for one important case; the exclusion of the man-made mean weight data (trial 1). Exclusion of these data leads to the conclusion that stock is much more depleted than is suggested by the base-case analysis. Figure 61 compares

the estimated time-trajectory of reproductive output (upper panel) and recruitment (lower panel) with and without the mean weight data for the man-made fleet for 2000. The estimates of recruitment are similar up to 2000, when the analysis that ignored the 2002 mean weight datum suggests complete recruitment failure. Figure 62 compares the fits to the length-composition data for PBR fleet when the mean weight datum in year 2000 for this fleet is (base case) or is not included in the analysis. The fit to the length-composition data for 2002 is slightly better when this data point is ignored, but the fit to the length-composition data for 2003 data is better when this data point is not ignored. There is also a noticeable cohort in the data for years 2002-2004 of correct length to support a recruitment event in year 2000. These results, along with evidence for strong year-classes in 1999 or 2000 for several other species off the California coast, suggests that there may have been a strong year-class in 2000 and consequently that the 2000 mean weight datum for the man-made fleet should not be ignored.

The results in Table 18 indicate that the assessments for both substocks are more sensitive to the values assumed for M than to that assumed for σ_R , and more sensitive to the value for female M than to that for male M . Decreasing female M from its base-case value leads to a more depleted resource and *vice versa*. Both substocks are estimated to be more depleted as σ_R is increased. The fit of the model to the data, as quantified by the value for the negative-log-likelihood, improves as M is increased.

The factors considered in Table 19 generally had less impact on the outcomes from the assessment than those examined in Tables 17 and 18. The factors that changed the depletion for the NCS the most were starting recruitment estimation before 1970 or in 1990, the use of RecFIN weights as lengths (“all lengths”), and the values assumed for variation in length-at-age. Specifically, the results for NCS are sensitive to the assumption that length-at-age CVs change linearly and decrease with age, although this assumption seems biologically realistic. The results for the SCS were most sensitive to the years for which recruitment residuals are estimated (mainly pre-1970 and 2004), making the selectivity patterns for all fleets logistic, halving catches, and the assumed level of variation in length-at-age. These sensitivities lead to less optimistic appraisals of stock status, including that the stock may be depleted to below 25% of its unfished level at present. The estimates of absolute spawning biomass are more sensitive than those of depletion.

Figure 63 shows substock-specific likelihood profiles for steepness and Figure 64 provides the subsequent estimates of unfished spawning and current biomass and current depletion. The data argue for a steepness of 1 for the SCS, but this may be more indicative of the data being uninformative. Local minima are also apparent within these profiles, though they seem not to affect the results greatly.

Projection and decision analysis

Twelve-year yield forward projections are conducted for each substock under two alternative ABC control rules (based on F_{MSY} proxies of $F_{45\%}$ and $F_{50\%}$) and two OY threshold control rules (40-10 or 60-20). The standard PFMC OY control rule for groundfish such as cabezon is based on $F_{45\%}$ with a 40-10 adjustment for stocks below the target level of 40% of the unfished reproductive output. The California Nearshore Fishery Management Plan proposes the use of a F_{MSY} proxy of $F_{50\%}$ and a 60-20 adjustment for stocks below 60% of the unfished reproductive output. The relative

proportion of the six fleets in future harvests is assumed to be the same as the last year (2004) in the model.

The results in Table 20 suggest that a reduction in population size will occur for the NCS under the two control rules based only on the F_{MSY} proxies. In contrast, the projections for the remaining control rules suggest that some increase in reproductive output will occur. The extent of this increase is greatest for the most conservative OY control rule ($F_{50\%}$ with a 60-20 adjustment) and least for the least conservative control rule ($F_{45\%}$ with a 40-10 adjustment). The projections for the SCS model beyond 2006–07 should be interpreted with considerable caution because they are influenced by the (strong, but uncertain) 2000 year-class.

Projections based on alternative states of nature for each substock were explored to capture uncertainty in population conditions. For the NCS, the low and high M scenarios refer to different assumptions about sex-specific natural mortality and were selected to represent the 95% confidence intervals for terminal spawning biomass based on the Hessian approximation. The low scenario assumes $M = 0.2\text{yr}^{-1}$ and 0.25yr^{-1} for females and males respectively, while the high scenario assumes 0.3yr^{-1} and 0.35yr^{-1} respectively. For the SCS, the low and high depletion rates refer to depletion rates in 2005 of roughly 20% and 35%, respectively. This range of depletion for the SCS was determined by the STAR panel to adequately cover uncertainty in its value and was determined by modifying the year 2000 man-made fleet mean weight CV value (*e.g.* an increase in the CV lead to a less depleted resource in 2000). These states of nature attempt to capture the uncertainty in current depletion based on the uncertainty in the magnitude of the 2000 recruitment. Probabilities for each state of nature were calculated, as directed by the STAR panel, assuming a normal probability density function (pdf) parameterized by the expected base case depletion rate and its asymptotic standard deviation. These respective substock pdfs were used to estimate the cumulative densities at the low and high depletion rates of 0.3 and 0.49 for the NCS and 0.2 and 0.35 for the SCS. Each cumulative density, representing the mid-point of the total density of each state of nature, was then doubled to determine the associated probability for each state of nature. Results from each of the states of nature are given in Figure 65.

Decision analysis population projections are provided in Table 21 for each state of nature and several state-dependent future catch series. The NCS will drop below the overfished level if catch levels are based on the 40-10 rule and the high M scenario, but the true state of nature is either the base case or low M scenario. This also occurs if catches are based on the base case model but the low M state of nature is correct. All other scenarios lead to depletion levels above 25% in 2016. Under the 60-20 rule, only the high M catch with a low M true state of nature leads to a depletion level in 2016 below 25%. In the SCS, all combinations of catch and true state of nature under either control rule lead to a depletion level in 2016 larger than 25%.

Response To STAR Panel Review

The STAR panel, during its review of the assessment, made several recommendations for further model exploration. The following is a list of these recommendations and the subsequent STAT team responses: