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This revised report contains the correct Table 6 and Figure 10 on pages 36 and 37

Report of the NOAA Southwest Fisheries Science Center & Pacific Fishery Management Council Workshop on CPS Assessments

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1. OVERVIEW

A workshop to provide recommendations for conducting stock assessments that may apply to management advice for short-lived coastal pelagic species (CPS) on the U.S. West Coast, with an emphasis on the central subpopulation of northern anchovy (CSNA), was held at the Southwest Fisheries Science Center (SWFSC) in La Jolla, California, during 2-5 May 2016 (see Appendix A for the draft Agenda). The panel (see Appendix B for all participants) included six members of the Scientific and Statistical Committee (SSC) of the Pacific Fishery Management Council (PFMC; Council), invited experts, and representatives of the PFMC Coastal Pelagic Species Advisory Subpanel and of the PFMC CPS Management Team. Other scientists with knowledge of west coast CPS attended the workshop.

Dr. André Punt, the workshop co-chair, called the meeting to order, and Mr. Dale Sweetnam welcomed the participants. Dr. Jim Ianelli (co-chair) outlined the purpose of the workshop. The objectives of the workshop were:

1. Evaluate model-based assessment approaches by using examples from other parts of the world where small coastal pelagic species are routinely assessed. Other eastern boundary current systems, such as the Benguela or Humboldt are of particular interest.
2. Compare available data, surveys, equipment, staffing resources, and other factors that affect stock assessments with reference to the situation for the CSNA stock.
3. The first priority stock to consider is the CSNA. Other CPS stocks that will be considered are the northern subpopulation of northern anchovy (NSNA), jack mackerel, and other CPS stocks as appropriate.
4. Consider non-assessment approaches that use only an empirical estimate of biomass in a harvest control rule.
5. Develop recommendations for methods and data collection/analyses given constraints for the key CPS stocks.

Section 2 of this report provides a summary of the fisheries for CPS off the U.S. west coast, the data available for assessment purposes, the current assessment methods for U.S. west coast CPS, and expectations related to future assessments. Section 3 summarizes the key data sources available for stock assessments, highlighting their advantages and disadvantages, and indicating potential future analyses that could be undertaken. Section 4 summarizes the bases for assessments and management advice for some of the CPS fisheries in the U.S. Atlantic, Europe, South Africa, South America, and Australia, with a focus on the lessons that those fisheries provide for assessment of U.S. west coast CPS fisheries. Section 5 introduces some new assessment tools that could be applicable to U.S. west coast CPS, and Section 6 provides suggestions for next steps for the two sub-stocks of northern anchovy, *Engraulis mordax* (CSNA and NSNA), jack mackerel (*Trachurus symmetricus*), and Pacific mackerel (*Scomber japonicus*). Section 7 provides statements by the CPS Advisory Subpanel and Management Team representatives.

In closing the Workshop, the Chairs thanked the SWFSC for hosting the workshop and the SWFSC staff, who provided logistical support to the workshop. They thanked all the rapporteurs for their work.

2. BACKGROUND

The SWFSC is responsible for assessing the status of CPS that inhabit the northeast Pacific Ocean (California Current) and providing management advice based on stock assessments formally reviewed in the PFMC process. The broader CPS assemblage includes Pacific sardine (*Sardinops sagax*), Pacific mackerel, jack mackerel, northern anchovy (central and northern sub-stocks), and California market squid (*Doryteuthis opalescens*). In general, these CPS are epipelagic/schooling populations with extensive ranges, relatively small in size, short-lived with high intrinsic rates of increase/decrease, and serve as important forage for higher-level predators in the marine ecosystem. The CPS are characterized by high inter-annual/-decadal variability in recruitment success and abundance levels, based primarily on prevailing oceanographic conditions, which also directly influence distribution, spatial patchiness, and timing/extents of seasonal migrations for respective species.

The main fisheries for CPS use purse seine gear, with small recreational catches of Pacific sardine, Pacific mackerel, and northern anchovy (the latter two mainly for bait in sport fisheries targeting larger pelagic species such as tuna, billfishes, and sharks). CPS assessments have been prioritized based on magnitudes of catch, with two stocks classified as *actively managed*[1]: Pacific sardine and Pacific mackerel. The other four stocks are classified as *monitored:* jack mackerel, market squid, and two sub-stocks of northern anchovy. The most recent assessment for the CSNA was 1995, while the NSNA and jack mackerel never have been formally assessed. Market squid are in the CPS FMP, but are primarily regulated under state-based fishery management plans that include a limited entry program, annual catch limit, and spatial/temporal fishing constraints. A species' management classification (actively managed or monitored) and associated assessment timeline can change over time, based on species occurrence (abundance) and value (economic, recreational, and/or public interest).

Many types of fishery-independent and fishery-dependent data have been considered and/or used in the past for conducting CPS stock assessments, including indices and compositional data from acoustic surveys, aerial surveys, egg and larval surveys, and fisheries including fishery catch-per-unit-effort (CPUE). For "monitored" stocks, priority of data collection and processing (e.g., age reading) has been low. In general, fishery-independent data are believed to be the least biased type of data for fish stock assessments. For CPS, current abundance time series are from the acoustic-trawl method (ATM[2]) survey (2006-present) and from egg and larval data collected during ichthyoplankton surveys (1951-present).

Integrated age-structured stock assessments incorporating multiple sources of data have been completed annually or biennially for Pacific sardine and Pacific mackerel since the early 2000s (currently using the Stock Synthesis software, SS). Assessments of these actively managed stocks are reviewed formally as part of SWFSC and PFMC processes. Reviews have identified various issues in these assessments including, apparent conflicts between length, age, and conditional age-at-length data. Selectivity parameterization and estimation have proved challenging.

The most recent stock assessment of the CSNA was conducted in 1995 using the *SMPAR* model, which is an age-structured statistical model similar in concept to but simpler than SS. Given that landings of CSNA have increased in recent years and that the species is important as a forage fish, there have been discussions regarding the need to assess the CSNA stock.

Questions identified by the SWFSC regarding the best available stock assessment data and practice for U.S. west coast CPS include:

1) Can the available data (e.g., abundance indices, biological compositions, and catch time series) reasonably be ranked and qualified for assessment purposes?;
2) What are the pros and cons of simple survey-based biomass assessments, given, e.g., their dependence on survey catchability *q*, which can have large uncertainties from acoustic-trawl surveys in particular?

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[1] "Actively managed" CPS stocks have biologically significant levels of catch, and are assessed annually. "Monitored stocks" do not require intensive harvest management, and monitoring of landings and available abundance indices are considered sufficient to manage the stock.

[2] An acoustic-trawl survey refers to an acoustic survey supplemented by trawling to ascertain species composition, size distribution, and other biological characteristics

3) How can integrated models best be applied for providing management advice, given, e.g., their highly detailed parameterizations of age structure, selectivity, growth, and recruitment?

The Panel noted that data and corresponding analyses could be used in several ways in management of U.S. west coast CPS: (a) evaluation of trends in relative or absolute abundance, (b) estimation of current biomass, (c) specification by the SSC of the Overfishing Level (OFL), (d) setting of harvest specifications such as ACLs HGs and OYs, and (e) evaluation of whether current biomass is above or below the Minimum Stock Size Threshold, MSST (for those stocks with MSST defined). A time-series of biomass estimates could be used to refine the value of MSST. Thus, there is value in estimating current biomass as well as a time series of biomass estimates. However, methods for estimating current biomass may differ from those used to estimate biomass time-series. It was also noted that there may be value in smoothing estimate of biomass from surveys over several years to reduce sensitivity to variability in terminal-year biomass estimates. A developed and approved biological model could be projected forward given future catches rather than being updated annually, but such projections would be subject to considerable uncertainty, particularly for anchovy.

3. DATA FOR U.S. WEST COAST CPS

Table 1a lists the various data sources for west coast CPS.

The Panel discussed the typical patterns in abundance of CPS species, which undergo large fluctuations on a decadal scale. This makes assessing these species challenging, especially during periods of low abundance, when fish are patchier and more difficult to survey. Fishery sampling, in particular, can drop to very low levels when abundance declines. Therefore, effective assessment of CPS would seem to require extra effort in collecting data during periods of low abundance. Maintaining data collection programs during periods of low abundance saves the expense and other difficulties of rebuilding sampling capacity when the stock again becomes the focus of management concern.

All the potential indices of abundance in Table 1b are subject to bias when used as measures of absolute abundance. All are also subject to various sources of uncertainty. The Panel recognized that the advantages and disadvantages of each data type are not independent of the intended use. It therefore considered each index within the context of four possible uses.

a. a survey-based assessment conducted in fall 2016;
b. a model-based assessment conducted in fall 2016;
c. a survey-based assessment conducted in the future; and
d. a model-based assessment conducted in the future.

3.1 Acoustic Trawl Method (ATM) survey

Dr. Juan Zwolinksi (SWFSC) gave an overview of the Center’s ATM survey. The National Oceanic and Atmospheric Administration National Marine Fisheries Service endeavors to manage fish stocks with an ecosystem perspective. This objective requires an understanding of the effects of the environment and fishing on all major ecosystem components. For example, in large upwelling systems such as the California Current Ecosystem (CCE), natural cycles in the oceanographic and atmospheric conditions appear to drive large fluctuations in the distributions and relative abundances of CPS. These changes may be accelerated or delayed by changes in mortality due to fishing or predation of larger fish, marine mammals, and seabirds. The data necessary to manage CPS with an ecosystem perspective may be obtained from frequent surveys focused on multiple CPS stocks and their biotic and abiotic environment. This may be practical, with surveys based on a combination of acoustic and trawl sampling coupled with complementary measures from numerous other sensors, at least for some CPS and within the survey area.

The Panel noted that a 2011 review of the SWFSC's acoustic-trawl methodology (PFMC, 2011) provided recommendations on suitability of the ATM survey to provide information for stock assessment. Those recommendations are still generally applicable and are listed here:

- *Pacific sardine. Given current information, the ATM surveys can be considered to provide estimates of absolute abundance for the survey area with the associated length-composition.*
- *Pacific mackerel. While the estimates for survey area are valid, if the ATM data are to be used to provide estimates of total stock biomass, auxiliary information will be needed to estimate the annually-varying proportion of the whole stock in the survey area.*
- *Jack mackerel. The estimates of absolute abundance for the survey area can be used as estimates of the biomass of jack mackerel in U.S. waters.*
- *Northern anchovy. There is also no reason why acoustic-trawl surveys cannot be used to estimate abundance for northern anchovy. However, the perceived current size of the population, along with its more inshore distribution, means that the present survey data cannot be used to provide estimates of relative or absolute abundance for northern anchovy.*

During this workshop, the acoustic group at SWFSC stated that it was not yet able to provide an abundance estimate for northern anchovy in 2015 due to the wider distribution of anchovy in the survey area that year, but the estimate is expected in the future. The Panel agreed that such an estimate will need careful review if used for stock assessment. Methodology Panels may be needed if new methods are developed to address the uncertainties identified during the 2011 and other reviews. The acoustic group also discussed their plans for a summer 2016 ATM survey with expanded coverage in areas where anchovy are found (although the expanded area does not include the nearshore inside 50 meters depth), but noted that results from this survey will not be available for either survey-based or model-based assessments in 2016.

The year 2015 is the first time, according to the ATM survey team, that the ATM survey can provide adequate information to develop an estimate of absolute biomass for the CSNA within the surveyed area. The Panel noted that converting from biomass within the survey area to total biomass requires devising methods to estimate: (a) the proportion of the biomass inshore of the survey area and (b) the biomass missed in surface waters. These two issues were raised during the 2011 review of the ATM survey and pertain to the use of ATM survey results as the basis for estimation of absolute (rather than relative) abundance for all CPS to a greater or lesser degree. The Panel noted that aerial surveys could be used to address the first issue. In relation to schools missed in surface waters, Juan Zwolinski noted that work done in 2006 using side-looking multibeam sonar did not detect either avoidance or schools occurring above the area covered by the standard downward facing transducer. Moreover, he noted that a 2015 summer comparison of spotter pilot vs ATM survey detection of sardine schools in Pacific Northwest revealed that pilots missed some sardine schools observed during the ATM survey, but no sardine schools detected by the pilots were missed by the ATM survey. The use of aerial surveys to complement the ATM survey is detailed in Section 3.3.2. However, as noted in Section 3.3.2, estimating the proportion of the biomass inshore of the survey area is a complex undertaking that would, among other things, require coordinating the aerial and ATM surveys.

Table 2 lists the values of correction factors developed for acoustic surveys of South African sardine. Based largely on expert opinion, negative bias due to surface schooling (being missed by their ATM survey) is estimated to be between 5 and 15%.

Overall, the Panel concluded that ATM surveys have the potential to provide data on absolute abundance of anchovy. However, use of these data for management purposes should be restricted to providing an estimate of abundance only for the area and the portion of the water column surveyed, until a Methodology Review (and possibly additional research) can be undertaken to address concerns about the proportion of the population inshore of the survey area and that in the surface waters.

3.2 Egg/larval and abundance surveys

Dr. Edward Weber (SWFSC) gave a presentation on available egg and larval data, historical and potential applications of egg and larval data to assessments of northern anchovy and jack mackerel, and he identified research and potential survey modifications that would facilitate use of egg and larval data in these assessments. The Panel also considered written public comments on these topics from Dr. Richard Parrish.

The largest source of egg and larval abundance and composition data is the California Cooperative Oceanic Fisheries Investigations (CalCOFI) survey, which consistently sampled a core area (roughly from San Diego to Point Conception) in fall and summer since 1951 and also sampled from roughly San Diego to Point Reyes in the spring and winter since 1994. Other data sources were discussed, but they cover much shorter time periods.

Dr. Weber discussed the historical use of the Daily Egg Production Method (DEPM), as used in anchovy assessments during the 1980s and in the current (2016) sardine assessment. In this method, egg and larval densities estimated from surveys are used to calculate the number of newly released eggs that yielded the observed number of older eggs and larvae, with egg/larva age typically estimated from a temperature-dependent growth curve, and lab-derived mortality estimates used to account for losses over the intervening period. The stock size required to release this number of eggs is then estimated from biological data about adults (obtained by trawling), ideally including sex ratio, spawning fraction, and size/fecundity of adults. When detailed adult data are lacking, a "DEPM light" method can be employed, assuming constant egg mortality and adult parameters. The assumption of constant egg/larval mortality and adult parameters results in the "DEPM light" method's having a considerably higher, and typically underestimated variance. The Panel therefore recommends using year-specific biological data (i.e., the full DEPM). The Panel also noted that area-specific adult parameters would also be expected to improve stock size estimates, given considerable differences across ages in fecundity and some indications that age structure consistently differs with distance from shore. However, overall spatial patterns in the age structure of the spawning stock adds complexity and is therefore challenging to properly characterize.

There was considerable discussion of the fixed station design of the CalCOFI survey and the implications of this design for both variance and potential biases. Dr. Weber expressed concern that the fixed design was inferior to a probabilistic design and was reluctant to support its use in assessments as a result. The spatially-weighted jackknife procedure employed by MacCall *et al*. (2016) was viewed as a partial solution to this problem, and it was noted that the resultant variance estimates were quite high and sensitive to particularly high densities estimated for a few locations. The Panel judged that this result likely reflected true spatial variance, rather than sampling variance. It was generally acknowledged that although numerous confounding factors (e.g., variation in spawning time and fish movement) could contribute to high variance in stock size estimates, and thus could obscure short-term changes in stock size, there was no clear reason that DEPM from a fixed survey design could not provide unbiased (although possibly noisy) estimates of relative abundance/trends in abundance (assuming confounding factors were without consistent trends themselves). It was noted that model-based estimators do not require random sampling, and applying model-based estimators (e.g., geostatistical models or Generalized Linear Models) would be appropriate in this case.

The Panel also discussed the degree of spatial overlap between the CalCOFI egg and larvae sampling and the spawning ranges of the stocks under consideration for assessment. Habitat models indicate that much of the good habitat for jack mackerel is outside the CalCOFI sampling area, so that the current CalCOFI survey is not likely to be informative in assessing jack mackerel. Overlap of the CalCOFI survey area with CSNA spawning habitat is higher, although historically anchovy eggs have been found well down the coast into Mexico, and there can be considerable spawning activity inshore that is not well captured by the current design. This lack of full coverage could cause biases when DEPM data are used in assessments, particularly when the range of anchovy contracts shoreward.

The DEPM was implemented for the CSNA over the six-year period from 1980 to 1985, and provided estimates of spawning biomass in absolute terms. Since that time, egg and larval surveys have continued and provide information on associated densities per station for anchovy, but corresponding data were not collected on biological factors such as spawning fraction and egg mortality rate, factors needed for full DEPM estimates of spawning biomass.

The possibility was raised of extending the DEPM series by scaling the six DEPM estimates to estimates of egg and larval abundance for other years for the area to which the DEPM estimates pertained. Thus, for example, the mean and standard deviation of such DEPM/egg-larval-abundance ratios for those six years could be used as a multiplicative factor for converting egg and larval abundance estimates for other years to estimates of spawning biomass, under the assumption that the distribution of this multiplicative factor had remained stationary. This implies that net effects of the biological factors (spawning fraction, etc.) has remained stationary.

For a first approach, the Panel agreed to use egg and larval abundance estimates provided by weighting the egg and larval density estimate at each station by an associated area provided by a tessellation approach, with associated variance estimates provided by the jacknife method. Furthermore, to correspond most closely to the time periods for which the DEPM estimates had applied, egg and larval data for the months of January and March-April would be used. The possibility of disaggregating by spatial stratum in the scaling process was considered, but was agreed not to be of high priority, because the original DEPM estimates had been calculated without such stratification. Specific recommendations for further work, in order of priority, were as follows.

1) Check and extend the computations above to cover two different approaches to specifying egg and larval density estimates:
    a) Use total numbers of eggs and larvae without adjustments.
    b) As in DEPM estimates, correct these numbers for extrusion of eggs through the net during tows, diel variation in net avoidance by larvae, shrinkage of preserved samples due to formalin, and temperature-dependent incubation time of eggs. Then fit a mortality curve and back-calculate production at age zero.

   The subsequent selection between these two approaches should be based on the results. Although b) would reduce bias, concerns were expressed that it could increase variance appreciably (although higher variance might be a realistic representation of the true uncertainty of the estimates), and those tradeoffs should be considered.
2) There were concerns that the tessellation approach might be sub-optimal, particularly with respect to the associated variance calculations. Hence, other approaches, such as model-based integration of the density values (e.g., geostatistical approaches, such as the integrated nested Laplace approximations approach; http://www.r-inla.org/), to obtain abundance estimates should be explored.

3.3 General discussion

3.3.1 Fishery data

The Panel noted that fishery data (length- and age-composition information) were not available for all years for all species (Table 1a). In several cases (e.g., the CSNA between 1983 and 2013), this was because fishery catches were very low. The utility of age data for assessment purposes depends on how well each specimen can be accurately aged (both in theory and in practice). SWFSC staff stated that complete ageing of historical samples would take about a year. They also noted that a workshop to refine and standardize ageing methods for U.S. west coast CPS will occur in the next year.

3.3.2 Other data sources

Aerial surveys

There was considerable discussion during the workshop on the utility of, desire to continue, issues with, and methods for inclusion of aerial survey (AS) results in population modeling and management of anchovy and sardine, with a focus on immediately addressing management needs for the CSNA. A small group (see Appendix D for additional details) met during the workshop to develop the discussion further.

The goal and purpose of the aerial surveys largely dictate the data issues to be resolved, methodology adopted, and data analysis and/or modeling required. Four potential goals were specified that could be aided by use of aerial surveys:

- producing an index of anchovy abundance for inclusion in an integrated stock assessment;
- producing an inshore to offshore correction factor primarily for anchovy (but potentially also for sardine, given the overlap of the stocks);
- development of an absolute abundance estimate and index of recruitment for anchovy; and
- development of an integrated aerial-acoustic assessment survey for the northern subpopulation of sardine.

Factors limiting the incorporation and adoption of aerial survey data for CPS assessments and management include:

- lack of methods for analyzing data from aerial surveys;
- several potential methods for analyzing aerial survey data have yet to be reviewed by a Methodology Panel; and
- natural impediments such as weather restrictions, especially sea fog, that limit the ability to conduct aerial surveys on schedule.

The following issues are common to all AS data, regardless of survey purpose or goal:

- **Species validation**. This requires catch or image confirmation by school measured or a shape/feature discrimination model, similar to Brown *et al.* (2000).
- **Vertical distribution**. This is required to determine the proportion of the population represented by the surface schools observed – this can be accomplished using a fixed acoustic measurement (vessel not moving or moored acoustic buoy) in the areas of school measurements (see Kaltenberg and Benoit-Bird, 2009).
- **Conversion factor to determine biomass from school surface area**. This is typically achieved by using a “point set” tonnage measurement, which can be difficult and costly to obtain, particularly off California.

Error sources common to all AS data include surveyor bias, sightability (altitude dependent – similar in concept to a survey catchability term), weather bias, sun angle impacts, and the impacts of a detection curve. Survey design and establishing terms of error specific to expansion models are issues to be resolved. Key sources of error (e.g., Brown *et al*., 2000) tend to be goal-specific. For the goal of inshore/offshore ratios, an area of overlap of aerial and acoustic surveys is required (for example in the offshore AS California Bight transects), as well as a way to analyze the data for this area of overlap. The problem of how to scale acoustic and aerial data is common to the other goals, but a suggested solution, similar to the biomass conversion issue, is to compare the data at varying levels of resolution and using the minimum scale for comparing the two indices selected.

Diet

There are time-series of proportions of CPS from diet of predators, such as seabirds and California sea lions. These data are potentially useful for evaluation, but it was unclear to the Panel whether such indices would be proportional to abundance and how they best might be used.

<u>Juvenile rockfish survey</u>

The SWFSC juvenile rockfish survey (which has been conducted annually since 1983) encounters anchovy and sardine. This survey has not been used regularly in assessments of CPS, although data from this survey informed decisions about treatment of recent recruitment in the 2016 Pacific sardine assessment. The Panel agreed that this data source held promise for the assessment of the CSNA, but there is uncertainty regarding the proportion of the adult stock covered by the survey area (Hastie and Ralston, 2007). It was suggested that indices of anchovy for the CalCOFI area could be compared to the anchovy indices from the juvenile rockfish survey based on the CalCOFI area to assess whether the latter is indexing spawning biomass.

3.4 General matters

The Panel also discussed the use of habitat suitability models to inform design of surveys, especially when earlier survey data are used to construct the habitat suitability model. While this strategy may help to focus survey effort in areas of highest expected density, there is a danger that areas where fish are present may vary and thus in some years be poorly sampled by or even excluded from the survey. This may be a particularly acute problem during periods of climate change. Generally, it is good practice to have a stable survey footprint that encompasses the distribution of the stock under the expected range of environmental conditions, as has been a priority in the design of the acoustic survey of Pacific hake (see Section 4.7).

4. REVIEW OF ASSESSMENTS AND MANAGEMENT OF CPS STOCKS

4.1 Australia stocks

4.1.1 Author summary (Punt)

The Australian Small Pelagic Fishery extends from the Queensland/New South Wales border, typically outside 3 nm, around southern Australia to a line at latitude 31°S. The fishery, which is managed by the Australian Fisheries Management Authority Management, targets four species, Australian sardine (*Sardinpos sagax*), blue mackerel (*Scomber australasicus*), jack mackerel (*Trachurus declivis, T. murphyi*), and redbait (*Emmelichthys nitidus*). Sardine and blue mackerel are typical "small pelagic species" (natural mortality, M, assumed to be 0.62yr^{-1}), while jack mackerel is relatively long-lived (M = 0.26yr^{-1}). The primary gears used to catch small pelagic fishes off southern Australia are midwater trawl and purse seine. Blue mackerel, jack mackerel and redbait are divided into "west" and "east" stocks at 146°30"E (southern Tasmania).

There is no model-based assessment for any of the stocks. Management advice is based on multiplying an estimate of abundance based on the DEPM (e.g., Ward *et al.*, 2015) by an exploitation rate. The exploitation rate on which the Total Allowable Catch is based is a function of the time since the last survey (e.g., Tier 1: 5 years; Tier 2: 6-15 years; Tier 3: 16+ years). At present, the Tier 2 rate is half that of the Tier 1 rate, and the Tier 3 rate is half that of the Tier 2 rate (A.E. Punt, pers. commn). The value for the Tier 1 exploitation rate, and hence the Tier 2 and 3 rates (by stock) is selected to achieve pre-specified management objectives (no more than a 50% probability [as determined using a management strategy evaluation, MSE] of dropping below the target reference point for a base-case set of specifications; a 10% [or less] probability of dropping below the limit reference point for a wide range of scenarios). The 1st probability is computed over the last 20 years of a projection period, while the 2nd probability is the maximum over a set of sensitivity tests of the probability of dropping below the limit reference point either in any future year or over the last 20 years of the projection period). The sensitivity tests (e.g., Smith *et al*., 2015) explore sensitivity to the precision of the DEPM estimates, the bias of the DEPM estimates, the steepness of the stock-recruitment relationship, and the selectivity pattern of the fishery. The fishery takes some immature fish even though the Recommended Biological Catch is based on an estimate of spawning biomass.

The advantages of the management system for the Australian Small Pelagic Fishery are that it is tailored to the fishery concerned and the exploitation rate is selected to achieve pre-specified management objectives.

The concerns with the basic approach include: (a) the survey frequency is unknown so the exploitation rate for Tier 1 needs to be selected so that conservation goals are met irrespective of the true survey frequency, (b) the limit reference point (and its associated probability) are policy calls (DAFF, 2007) and are unrelated to, for example, the extent of variation in recruitment, (c) there is currently uncertainty about the target and limit reference points for the Australian small pelagic fishery, and (d) the results are highly dependent on whether the stocks are currently close to the unfished level or to the target biomass.

4.1.2 Panel discussion

The Panel noted that the operating model is single-species without spatial structure and that the time periods on which the tiers are based relate to fish longevity and biology and are fixed, e.g. 5:5:5. The operating model is not conditioned on the data for any species so while management performance relates to unfished biomass, this quantity is not estimated by species. Similar to the U.S., there is limited or no information available to inform the constant of proportionality between the DEPM estimates and actual spawning biomass, so various constant values are tested in the analyses.

In response to a question, André Punt noted that there was no evidence of local depletion, but that the power to detect local depletion is likely low. An issue noted was the lack of DEPM estimates for all stocks.

4.2 South African stocks

4.2.1 Author summary (Butterworth, Carryn de Moor, and Janet Coetzee)

Sardine, anchovy and round herring are the species that contribute most to the South African fishery for small pelagic species. They are short-lived, with natural mortalities of about 1 yr^{-1}. Broadly speaking they spawn on the Agulhas Bank to the south of the country, eggs and larvae are carried northwards up the west coast by the Benguela current, with the recruits later returning southwards in a nearshore counter current back to the Agulhas Bank. Most of the anchovy fishing takes place on these recruits during this southward migration over the April-August period.

The purse-seine fishery on these species commenced shortly after World War II, focusing initially on sardine. However after a collapse of sardine catches in the mid-1960's, smaller mesh nets capable of catching anchovy were introduced. Anchovy has dominated the catches by volume since. Sardine catches peaked briefly across the turn of the 21st century. However, they fell again soon thereafter, though the concurrent increase in anchovy catches has been broadly maintained over the following decade. By comparison, round-herring catches are relatively small. Recent average annual catches of all species have been about 400,000 t. A key feature of the fishery is the unavoidable bycatch of juvenile sardine in the anchovy fishery, which means that the higher the anchovy catch, the lower the directed catch for the more valuable adult sardine has to be.

The key data for assessments, apart from annual catches and their length compositions, are two near coast-wide hydroacoustic surveys of abundance for which the associated target-identification trawls also provide length distribution data. These surveys started for both sardine and anchovy in November 1984, focusing on an estimate of total biomass at a time of the year when recruitment is complete. Commencing the following year, an annual survey focused mainly on the South African west coast was added to index recruitment for the year. From 1987, these surveys also collected information on round herring. The November survey sampling coefficients of variation (CVs) range typically from about 10 – 25% for anchovy and round herring, and 20 – 40% for sardine. Data to estimate anchovy abundance using the DEPM were collected over 1984 to 1993, and have assisted with providing unbiased results in absolute terms, given particularly the target strength uncertainty associated with the hydroacoustic abundance estimates. Unfortunately, no age data are available; although ageing research for sardine has been conducted, the results are not considered reliable.

Bayesian applications of statistical-catch-at-length (SCAL) models (age-structured models coupled to a growth curve to be able to fit to catch-at-length information) are used to assess both the sardine and anchovy populations. Results follow the November survey results closely for both species, though less so for the recruitment survey results. There are strong indications of reduced recruitment at lower biomasses for sardine, but less so for anchovy. Both species experienced periods of strong recruitment over the turn of the century. Since then, anchovy has maintained abundances averaging some three times the levels of the 1980's and early 1990's; in contrast, sardine has experienced a decade of relatively poor recruitments.

Management of both the sardine and anchovy resources follows an Operational Management Procedure (OMP) approach. In December each year, pre-agreed formulae are used to set a directed sardine Total Allowable Catch (TAC) and an initial (and somewhat conservative) TAC for anchovy together with an initial bycatch allowance (TAB) for juvenile sardine. The OMP is empirical, i.e. the TAC formulae use survey data directly without any intermediate assessment process. Hence, for example, the sardine TAC is, at base, a fixed percentage (near to 10%) of the result from the November biomass survey. In the middle of the year, depending on the results from the May recruitment survey (the anchovy catch consists mainly of the recruits of the year), both the initial anchovy TAC and juvenile sardine TAB may be increased.

In line with the general OMP approach, the empirical TAC formulae above are selected to achieve a desired trade-off amongst maximizing average catch, minimizing the extent to which the population may be unintentionally depleted, and minimising TAC variations from one year to the next to enhance industrial stability. The description of the current OMP that follows is necessarily simplified, and is intended to capture the main features of the OMP without giving too much detail. The sardine TAC formula is essentially one of constant fishing mortality, setting the TAC for the year to 8.7% of the biomass estimate from the November survey of the previous year, subject to a 500,000 t maximum. Importantly though this TAC is subject to a maximum change of 20% from the TAC for the previous year. However, if these rules would result in a TAC of less than 90,000 t, the TAC is maintained at 90,000 t to minimise industrial dislocation. Nevertheless, should the November survey result drop below an "Exceptional Circumstances" threshold of 300,000 t, the TAC falls rapidly to zero in a quadratic relationship with the November biomass estimate, with any limitations on inter-annual TAC changes overridden. The anchovy TAC formula has many similar features, including Exceptional Circumstances provisions and a constraint of 25% on the maximum TAC inter-annual change. It is, however, more complex because it must allow for the possibility of a mid-season increase. The initial allocation at the start of the season is given by a constant together with a term that is linear in the November biomass estimate. However, only 85% of the result is awarded immediately; this is to allow for the possibility that recruitment is poor, since quotas to rights holders, once awarded, cannot be reduced. Dependent on the recruitment strength indicated by the May survey, the initial TAC may be increased (but not decreased). The juvenile sardine TAB is set primarily as a fraction of the anchovy TAC, and revised at mid-year together with the anchovy TAC.

The parameters of these TAC formulae are chosen based on simulation tests that evaluate the probabilities of the populations falling below pre-defined abundance thresholds over 20-year periods. These calculations are based primarily on operating models that correspond to the best assessments as described above, but checks of robustness to variations in inputs and assumptions for those assessments are also considered. This results in a risk trade-off plot between the expected average directed sardine and anchovy catches. At low levels of average anchovy catch, the risk to sardine is the determining factor, but as the anchovy catch is increased, the average directed sardine catch drops because of the impact of the additional juvenile sardine bycatch with anchovy. Ultimately the anchovy risk threshold is reached. OMP control parameters are chosen to correspond to this point where the anchovy threshold has been reached, given that the loss of sardine catch is fairly small, as anchovy catch is increased. A difficulty that has arisen, however, is that these risk probabilities depend heavily on the extent of recruitment variability and natural mortality values; estimates of these can change when the OMP is reviewed and revised every four years or so given the changes to the assessments that result from the further monitoring data then available. For more meaningful continuity across these reviews then, a different approach has been used to maintain the intended unchanged threshold for perceived risk. This is to compare projected biomass probability distributions under zero removals and under the OMP proposed. Under fishing, these distributions move towards the left (lower biomasses), and the intent is to update choices for the parameter values in the TAC formulae so that these “leftward shifts” remain as similar as possible, particularly at low-medium biomass levels, across each review and OMP revision.

Round herring is not included in the joint sardine-anchovy OMP. This species is difficult to catch because it is often found much deeper in the water column, and furthermore is generally available to the fishery for only the first few months of the year. Given that acoustic biomass estimates over the last decade have generally been over 1,000,000 t, a Precautionary Upper Catch Limit (PUCL) of 100,000 t has been set, which would reduce proportional to the November survey estimate if that were to drop below 750,000 t. The PUCL applies to all rights holders together, without any quota allocations, in part because annual catches have generally been well below this limit. Given this underutilization, finalization of a SCAL assessment has not been a high priority; work is proceeding with an approach that allows for multiple cohorts within a year, with achieving adequate fits to catch-at-length data not proving straightforward.

There is uncertainty in stock structure for sardine (as there is some degree of the regional catch being disproportionate to regional biomass estimates). Constraints on personnel resources to conduct age-determination studies have limited improvements to data for assessment purposes. In the area of ecosystem aspects of fishing, focus on the potential impact that reduced forage fish may have on predators (especially the depleted penguin population) has been an active area of research and debate. This has included economic considerations by way of the evaluation of the cost to industry of an experimental program to close regions around penguin colonies to pelagic fishing to assist determine the possible benefits of such an approach for penguins.

4.2.2 Panel discussion

It takes only two weeks in South Africa, between finishing the acoustic survey and providing advice related to a TAC (although the time for the Ministry to set the TAC can add to the process). This leads to a savings in government and scientific personnel cost, and less conflicts with industry. However, time-lags are inherent in the U.S. management system. In response to a question, Janet Coetzee (DAFF, South Africa) stated that kriging is not used for biomass estimation, but a similar approach is used for visualizing the results from the survey. An important aspect of this approach that was noted was the correction of the survey results for known sources of bias and variance (Table 2).

4.3 South Pacific jack mackerel

4.3.1 Author summary (Ianelli)

Jack mackerel in the South Pacific has been exploited by fisheries since the 1970s. Owing to large recruitment influxes in the mid-eighties, the stock grew to an estimated 14,000,000 t of spawning biomass, and had catches of nearly 5,000,000 t per year for a short period. This stock is distributed throughout the sub-tropical waters of the South Pacific Ocean, from South America to New Zealand and Australia. Management of jack mackerel in the high seas has been officially organised through the South Pacific Regional Fisheries Management Organisation (SPRFMO) since 2013. The SPRFMO area includes the international waters from South America on the east to west of New Zealand to the west (see inset). The majority of jack mackerel are observed throughout the year within the jurisdictional area of Chile, though the stock does migrate in substantial proportions onto the high-seas area. Current data and indicators on the status of jack mackerel indicate that the population is estimated to be increasing again after a substantial decline in abundance. On balance, the evidence for stock improvement (higher abundance observed in the acoustic survey in the northern part of Chile, relatively abundant age-3 jack mackerel in the fisheries, better catch rates apparent in some fisheries) is somewhat offset by declines observed in the Chilean fishery CPUE (which is used as one of the nine indices in the integrated assessment). The assessment approach applies a version of a simulation-tested statistical age-structured model with origins based on the model used for Alaska groundfish stocks (SWG, 2010; Anon., 2015a). Summary results for the “one stock” hypothesis using an “areas-as-fleets” approach (Anon 2015a) are shown in Figure 1.

Area covered by the SPRFMO.

Environmental conditions (e.g., the strong El Nino that developed in 2015) likely affects jack mackerel distribution and thus age-specific vulnerability to surveys and fisheries. This may have led to the changes in CPUE in many of the fisheries. Stock structure dynamics also add to uncertainty in a management context, and recently the assessment software has been modified to allow for regional stock splits with some sharing of information.

Short-term issues related to the jack mackerel assessment include near-term recruitment patterns (which are low) and long-term averages (which are considerably higher). For precautionary purposes, the Commission selected the long-term average for estimating a provisional biomass target (5,500,000 t of spawning biomass), but used near-term average recruitment for catch and projection evaluations. This gives catch limits for the entire jack mackerel range in the southeast Pacific at or below 460,000t, based on a status quo fishing mortality during 2014. Fishing mortality in the next ten years at or below this level appears to have a reasonably good probability of leading to increased spawning biomass from the current level of 2,710,000t, to a projected level of 3,200,000 t in 2016.

The advice presented above is based on evaluation of indicators including the single- and two-stock hypotheses. Within the area of the southeast Pacific, the two-stock model shows generally similar trends in the biomass as that from the single-stock model.

4.3.2 Panel discussion

The Panel noted that the frequency of the Chilean acoustic survey had decreased in recent years, which will inflate the variance associated with abundance estimates and could lead to bias if less sampling results in a decoupling of the survey area with jack mackerel migration/distribution patterns. It was noted that ocean circulation models are currently being used to identify where oceanographic eddies emerge as an indicator of jack mackerel habitat and this has been used to evaluate the relationship to the fishery distribution. Auxiliary habitat information has been used post-hoc for the Peruvian acoustic survey, which resulted in better consistency with other data in the model. The Chilean acoustic survey time-series fits reasonably well without accounting explicitly for habitat variability—likely because the area covered is where the majority of jack mackerel are observed throughout the year. Lastly, the Panel agreed that data workshops, such as that mentioned for the international jack mackerel fishery, would be advantageous for West Coast CPS given the data complexities often associated with assessing CPS.

4.4 Iberian CPS

4.4.1 Author summary (Silva)

There are five main species of pelagic fish in Iberian-Biscay coastal waters: sardine (*Sardina pilchardus*), anchovy (*Engraulis encrasicolus*), Atlantic mackerel (*Scomber scombrus*), horse mackerel (*Trachurus trachurus*) and Atlantic chub mackerel (*Scomber colias*). The relative abundance of each species varies across the region. While temporal variation is also large, there is a general pattern of predominance of sardine and anchovy in the Bay of Biscay, Atlantic mackerel and sardine in the Cantabrian Sea, sardine and horse mackerel off western Iberia and anchovy and sardine in the Gulf of Cadiz.

The presentation provided an overview of fisheries, assessment and management of four coastal pelagic stocks assessed by the International Council for the Exploration of the Sea (ICES) Working Group WGHANSA: Bay of Biscay Anchovy, Iberian sardine, Bay of Biscay sardine and Gulf of Cadiz anchovy. All stocks are fished mostly by purse seiners with catches used for human consumption. Bay of Biscay anchovy and Iberian sardine are considered “data-rich”, i.e. are assessed and forecasted using analytical models. Bay of Biscay anchovy is assessed using a Bayesian two-stage biomass-based model using data from the fishery and three surveys: DEPM, spring acoustic (whole population) and autumn acoustic (recruitment). Sardine is assessed using Stock Synthesis in a direct age-based formulation using data from the fishery, a DEPM survey and an acoustic survey. In both cases, management advice is based on catch-based harvest control rules. Bay of Biscay sardine and Gulf of Cadiz anchovy are data-limited, classified as Category 3 according to the ICES guidelines, i.e. their assessment is based on survey trends and indicators of harvest rate levels. The stock size indicator for Bay of Biscay sardine is the average of standardized indices from two surveys: biomass from an acoustic survey and total egg abundance from a DEPM survey. Catch advice is based on a harvest control rule that uses the stock trend in the most recent five years. The stock size indicator for Gulf of Cadiz anchovy is the average biomass from a DEPM survey and from two acoustic surveys. ICES does not advice on catches for this stock due to lack of data on year classes that constitute the bulk of the biomass and catches (the stock and catches consist mostly of age-1 fish).

All of the assessments integrate multiple types of data, namely catch data and data from several types of surveys. The assessments also illustrate different uses of survey data. In most cases the use of multiple surveys increases the robustness of the assessment and avoids drastic/possibly wrong advice based on outliers.

4.4.2 Panel discussion

In her summary, Dr. Silva reflected that the availability of multiple surveys using different methods has proven to be beneficial to the assessment and management of CPS in the Iberian-Biscay region. In this region, acoustic surveys, DEPM surveys, and recruitment surveys are used to monitor CPS, and in some cases multiple surveys of each type are conducted annually. Multiple surveys add robustness to assessments, and can help to avoid giving bad advice based on outliers. Some of the stocks presented are assessed following the ICES approach for data-limited stocks (specifically Category 3), where survey trends, assuming q=1, may be used in a simple harvest control rule to derive catch advice. The Panel discussed this view, and concluded that on the whole taking multiple surveys into account was a good approach. Some screening criteria for inclusion of surveys in assessments is a necessity.

The Panel also discussed whether a CPS stock would be considered to be harvested sustainably when $F = M$ on average, as was concluded for ICES for Bay of Biscay sardine. There are some papers that have concluded that $F = 0.5M$ or lower is more appropriate for CPS stocks (e.g., Patterson, 1992), particularly if the role of CPS as forage species is considered. However, this is a matter that has not been fully resolved, and additional research is needed.

4.5 Atlantic Menhaden

4.5.1 Author summary (Prager)

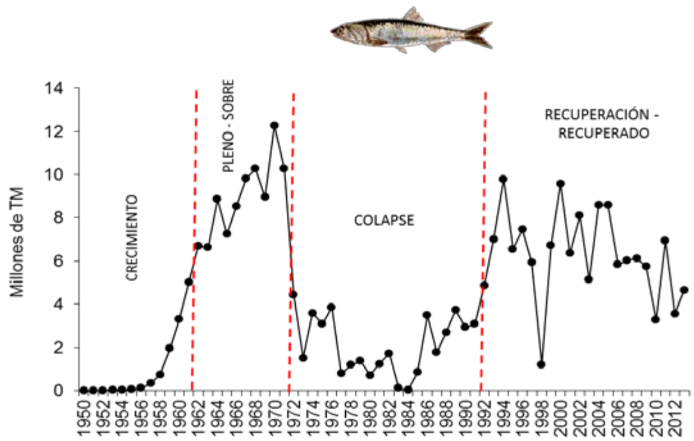
Atlantic menhaden (*Brevoortia tyrannus*) is a clupeid fish common in nearshore waters of the U.S. Atlantic coast from northern Florida to the Gulf of Maine. It is a filter feeder, a coastal oceanic spawner, and develops in estuaries, most notably in Chesapeake Bay. Menhaden tends to migrate northward in spring, and southward in fall. The species was used as fertilizer by American Indians and has been fished commercially since U.S. Colonial times. Current fishing is almost entirely by purse seine, in recent decades aided by spotter airplanes. Peak landings (1956) were about 735,000 t; 2013 landings were about 170,000 t, under fishing mortality that is estimated as the lowest since 1955. The stock is assessed using the Beaufort Assessment Model (Williams and Shertzer, 2015), a statistical catch–age model, in a “fleets-as-areas” configuration, reflecting seasonal migrations with size stratification (larger fish northwards) during the fishing season. The basic data are three fishery-independent indices (two of adult relative abundance, one of relative recruitment) constructed from multiple states’ general sampling programs, length-compositions corresponding to the adult indices, landings, and age-compositions of the landings. None of the fishery-independent sampling programs were designed specifically to sample menhaden. Natural mortality is assumed to decline with age in a time-invariant fashion, as indicated by tagging data. Growth varies over time; fecundity is size-dependent. The stock is managed by the Atlantic States Marine Fisheries Commission with spawning biomass-per-recruit (SPR) reference points of 15% (limit) and 30% (target). The 2014 assessment estimated that the stock was not overfished, nor was overfishing occurring. Despite considerable discussion around ecological reference points (ERPs), the Menhaden Technical Committee holds that recommendations on an ERP cannot be made “until (a) a more explicit statement of ecological/ecosystem goals and objectives for menhaden management is provided by the [Management] Board, and (b) the performance of the proposed ERPs and the models used to generate them can be formally evaluated through multi-model comparisons, simulation testing, and the completion of single (and possibly multispecies) management strategy evaluations.” In the interim, the Technical Committee has proposed lower SPR reference points of $F_{20\%}$ (limit) and $F_{39\%}$ (target)

4.5.2 Panel discussion

The Panel highlighted the importance of good age data (as in this assessment) for interpreting patterns in catch-at-length. Size-at-age can vary substantially across years (as it does in this stock), so if inferences were based on a static routine for converting length into age, they could be misleading. It was also noted that in contrast with a more pessimistic earlier assessment, the recent assessment's inclusion of dome-shaped fishery selectivity and modeling fleets as areas provided an explanation for the relative lack of old fish in catches from the southern area, a pattern that otherwise could be interpreted as reflecting high fishing mortality.

4.6 Peruvian anchoveta

4.6.1 Author summary (Ianelli)



Fishery catch history for Peruvian anchoveta showing the period of overfishing, followed by collapse and subsequent recovery. *Source IMARPE.*

Management of the world's largest fishery, Peruvian anchoveta, is driven by extensive and comprehensive survey and fishery data collection programs. The information available for this assessment can reasonably be considered as the opposite of a "data poor" situation. Nonetheless, there remain some key uncertainties and variability in estimates of the stock size. Presently there are two fishing seasons within each year that are both preceded by extensive acoustic surveys from which TAC recommendations arise. Comparisons of different assessment approaches capture the high biomass prior to 1970 (>10,000,000 t) and the subsequent large declines from the early 1970s through to the mid-1980s (see insert). The subsequent apparent recovery of the stock after that period is well established but estimates vary considerably. This assessment approach has strong support in that TACs are directly linked to empirical observations prior to the fishery. However, it seems that some continuity of data from the previous survey (or surveys) and the fishery might reasonably be used to inform or provide some carry over from one season to the next.

4.6.2 Panel discussion

The Panel noted that there is an extensive and sophisticated data collection program for the Peruvian anchoveta fishery which includes a Vessel Monitoring Scheme, observers, and real-time reporting for the industrial components. The acoustic surveys are comprehensive, conducted twice per year (to inform the two separate fishing seasons) and serve as the basis for setting annual catch limits. Many stock assessment analyses have been conducted that are in general agreement regarding the historical trends (crash and recovery), but differ in annual estimates and recent trends. These assessments serve to inform the management system in a broad sense, and represent part of an ecosystem research program. However, integrated stock assessment models are not used for setting annual catch limits. Control rules (including environmental effects) appear to be relatively *ad hoc*, and not directly based on simulation or MSE testing. These control rules depend on the state of the environment (e.g., El Nino, La Nina), while assessment models are used to evaluate the biology, understanding of environmental processes and other factors. There was some discussion of the collaborative aspect of some of the survey activity, apparently using a test fleet to validate/verify the observations of the survey and perhaps direct the fleet to areas of higher abundance. The nearshore (artisanal) fleet has a large number of participating vessels and may have some monitoring issues. There is currently a national effort to make more of the catch available as food fish.

4.7 West coast hake

4.7.1 Author summary (Stewart)

The acoustic survey conducted off the west coast of the United States and Canada has served as the primary source of fishery-independent trend and demographic information for the Pacific hake stock assessment over the last 40 years. This survey estimates the biomass of age-2+ Pacific hake and collects age- and length-frequency observations as well as maturity and other biological data on a roughly biennial basis. Surveys conducted prior to 1995 did not represent comprehensive coverage of northern latitudes or deeper depths, and after many years of re-analysis were dropped from the time series in 2011. Recently, design-based estimators of abundance have been replaced with kriging-based estimators.

The commercial fishery for Pacific hake exploits the species as early as age-1, and increasingly at ages 2-4, such that there is very little ‘lag’ between incoming cohorts and full exploitation. This situation, in conjunction with very high recruitment variability, results in very broad uncertainty regarding current stock sizes and harvest rates, often proving to be challenging for management decision-making. Time-varying dynamics in the commercial fishery (including some targeting of strong cohorts, and confounding spatial patterns) leaves the acoustic survey as the only clear source of trend information available to the annual stock assessment. In addition to the mostly biennial point estimates, due to the extremely high volatility of hake dynamics, the variance estimates applied to the annual survey index have proven to be very important in model fits. Currently, the sampling variance is inflated with an additive constant to the log(SE) that is greater than three times the variance derived from the kriging-based estimator. This is largely a result of two survey observations (2001 and 2009) that retrospectively cannot be reconciled with now well understood trends in the underlying population. The effect of these outlying observations was particularly pronounced during the 2011 assessment, when model results could be consistent with the 2009 observation (very high) or the 2011 observation (very low) but not both. An ‘emergency’ survey, conducted in collaboration with industry during 2012 proved to be a very successful tool for avoiding a very difficult management decision given the lack of compelling guidance from the previous surveys. In hindsight, the unsuccessful delineation of Humboldt squid mixed with hake was very likely the cause of this anomaly. However, in general, outlying survey observations cannot be identified until dominant cohorts have already passed through the fishery, creating significant uncertainty in the annual management decisions despite biennial surveys. Recently, the investigation of the relative benefits to the stock assessment of a reduction in variance for the adult survey vs. construction of an age-1 index has been investigated through a simple MSE framework.

Remaining issues likely to be important to future analyses include: calculation (likely by bootstrapping) of more comprehensive variances estimates for the annual index, offshore extrapolations during years when hake distribution likely includes these areas but surveys do not, the target strength relationship, species identification and delineation, trawl representativeness, bottom associated dead-zone effects, and automation of scoring and consistent analysis for efficient and reproducible production of annual results.

4.7.2 Panel discussion

Discussion ensued around several aspects of the hake acoustic-trawl survey. Participants questioned whether the outlying estimates (2001, 2009) might be more reasonably be modeled using a mixture distribution for fitting purposes. The authors advised that such an approach does seem preferable and one that has been suggested in an MSE or simulation testing of the Pacific hake assessment as an important robustness test.

In 2016, the survey team developed a preliminary index of age-1 hake, which the hake assessment review panel judged sufficiently informative for sensitivity tests of the assessment. The hake assessment review panel recommended that development be continued, with the aim of generating an age-1 index from each future year’s survey. Such an index could be a valuable addition to the assessment, allowing earlier detection of large incoming year classes.

Participants noted that the hake assessment is a good example of the value of model-based assessments. Through providing smoothing and a theoretical framework, models can help identify and resolve data anomalies and conflicts. This is less likely to happen when status is determined directly from survey or index values.

4.8 Conclusions arising from the case studies

- **Survey indices are commonly well-designed in other places.** Across most of the examples presented to the workshop the surveys seemed to cover the area of the stock (inshore/offshore, and over the entire range) much better than do the surveys of U.S. west coast CPS. The sampling intensity is often greater for both the acoustics and tows. Differences in biology and geography do affect this in some cases. It can be beneficial to have multiple surveys to cross check (e.g., DEPM and acoustic surveys). There are two acoustic surveys off South Africa, where one provides a recruitment index and the other a biomass index. This leads to a question: How can the SWFSC optimize our current survey efforts? Could for example, more days be added to the summer survey by eliminating the spring survey, so that the summer survey could better cover the range, including the depth range, of the pertinent CPS? Does the SWFSC need another vessel to cover nearshore areas? When considering stocks with southern distributions that extent into Mexico, the Panel sees value in collaborating with Mexico on surveys.

- **It is important to account for biases and uncertainty in acoustic survey data.** The unknown effect of avoidance as well as fish that remain in the surface acoustic dead zone, represent potential biases that must be addressed. The same is true for the inshore portion of the stock outside the normal survey area. More research is needed to determine the extent these factors may contribute to biases. In the shorter term, best estimates and ranges of possible values for these biases should be developed and included in the processing of the survey data and in the assessment. In South Africa they have developed bias corrections (if by expert opinion in some cases) for target strength, catchability (in terms of missed inshore/offshore as well as surface/bottom), and calibration error (Table 2). Generally simple, if incomplete, corrections are used for known biases.
- **Age, growth and maturity data were generally really quite variable when they were collected**. There are adequate data in these cases to suggest that the variability in these factors is real and not an artifact. The extent that these patterns may be due to seasonal, geographic, and sampling error needs study (and also to ensure estimates, if related to the fishery, appropriately account for these factors).
- **Data workshops are important**. The importance of such workshops was emphasized for South Pacific jack mackerel. This has streamlined preparation for the complex assessment as conducted in international fora. Data workshops also have proven invaluable in assessments in the southeastern U.S., where data workshops form a regular part of the SEDAR (Southeast Data, Assessment, and Review) process.
- **Habitat information may be useful.** An ocean circulation model was used as an indicator of potential jack mackerel habitat for spatial structure and survey. A habitat suitability approach could be used for stratifying a survey (while still covering the entire area because predictions are imperfect). The hake experience shows the challenge of predicting where fish will occur.
- **Harvest control rules do not need to be complex**. Most of the case studies presented to the workshop used much simpler harvest control rules than the MSY-based rules used for U.S. west coast CPS. Approaches tend to provide stability within the context of the time series of indices observed. The Magnuson-Stevens Act as implemented through NOAA Fisheries National Standard Guidelines and the NEPA process tend to lengthen the time between when data are collected and when they can be used for assessment-based ACL/OFL recommendations. This time-lag problem is likely a larger problem for short-lived CPS than for longer-lived species such as groundfish.

5. OTHER METHODS

5.1 Biomass-dynamic approach

André Punt presented a method developed by Alec MacCall (NMFS, retired) for assessing data-poor stocks. The method is a version of the biomass-dynamic delay-difference model proposed by Jacobson *et al.* (1994) but expressed as a state-space model, and so allows for process error in the population dynamics and observation error in the relationship between the model predictions and the observations. The stock-recruitment model is based on the Ricker model. The density-independent component of this relationship is based on the product of biomass and the mean age of the population (to reflect age-specific fecundity), while the density-dependent component is proportional to the product of the mean population age and density. The parameters of the model are the initial biomass / mean age, the parameters of the stock-recruitment relationship, the extent of process error (and the annual process errors), and any catchability parameters. The model can be fitted to DEPM estimates of absolute abundance, indices of relative abundance, and time-series of information on the mean age of the catch / biomass. This method has yet to be implemented / tested but it could be implemented using the random effects model of the Automatic Differentiation Model Builder (ADMB), Template Model Builder (TMB), or WinBUGS.

In discussion, it was noted that this approach assumes that catch and the estimates of absolute and relative abundance are in the same units. In addition, there was concern about the assumption that the temporal variation in recruitment was the same as in biomass growth and natural mortality was unlikely to be valid.

The Panel noted that this method has yet to be implemented so could not be reviewed during the current workshop. Moreover, if the method is developed for use in stock assessment, it would need to be reviewed by a PFMC Methodology Panel before it could be used for management purposes.

5.2 DLMTool

Martin Dorn introduced DLMTool, an analysis package in R that performs simulation testing of management procedures (MPs) appropriate for data-poor stocks (Carruthers *et al*., 2014). DLMtool has been used by the Mid-Atlantic Fisheries Management Council SSC to develop an Acceptable Biological Catch (ABC) for blueline tilefish, and is being used in other venues.

The first step in application of DLMTool is to evaluate the performance of a set of management procedures in an operating model of a population impacted by a fishery. The model is parameterized using life history parameters from the species under consideration, and does not require trend information for the stock. DLMtool includes over 55 management procedures, including methods such as Depletion-corrected Average Catch (DCAC) and Depleted-based Stock Reduction Analysis (DB-SRA), which have been used for U.S. west coast groundfish stocks. It is designed to be extendable to encourage the development and testing of new MPs. The MPs are evaluated against a set of user-defined performance measures in a closed-loop simulation (MSE) that projects a population forward under a defined MP by sampling from distributions of biological, fishery and observation processes. An important point is that the approach can be used to evaluate whether a MP for setting an ABC achieves the objectives of the Magnuson-Stevens Act (achieving Optimum Yield, avoiding overfishing) and any other objectives established by the Council, without going through the formal process of assessment and status determination.

The package is structured such that the same MP functions that are tested by MSE can be applied to provide management recommendations from actual data, which is an advantage of the software. A set of related functions automatically detect what MP can be applied given the available data, and what additional data are required to get other MPs working. The Panel noted that the MSE-testing software is not set up to emulate the long-term fluctuations in abundance characteristic of CPS, but given the open-source nature of the software, it is likely that this feature could easily be added. Many of the MPs specify what may be more similar to an ABC, not an OFL as it is defined by the NMFS national standard guidelines. The Panel regarded the DLMTool as a way that could be of use for providing management advice for monitored stocks, but additional research and review is needed before it could be applied.

6. SYNTHESIS AND RECOMMENDATIONS

6.1 Recommendations for CPS assessments

The Panel notes that developing assessments for the data-limited CPS will require several steps.

6.1.1 Central sub-stock of northern anchovy (CSNA)

The Panel agreed that the best approach for providing management advice for the CSNA was to develop an integrated stock assessment model that would use, *inter alia*, fishery-dependent monitoring data on age and length, and abundance indices based on ichthyoplankton and ATM surveys. This assessment should also consider the use of data from the SWFSC juvenile rockfish survey. A model-based assessment would have to be reviewed by a STAR Panel. The Panel noted that there may be a need for data workshops to refine the inputs to such an assessment. In addition, if the assessment were to be conducted in 2017, data from the ATM surveys in 2015 and 2016 could be available, as might age-composition estimates for some recent years. Use of data from the ATM survey in an assessment for the CSNA would be more straightforward if a Methodology Review of the ATM survey was undertaken prior to the STAR Panel that reviews any model-based assessment. The DEPM estimates of biomass will likely form a core component of any model-based assessment of the CSNA, so the STAR Panel that reviews the assessment would need to review the technical basis for the current DEPM estimates.

Jim Ianelli examined the feasibility of conducting a model-based assessment of the CSNA using the AMAK (Assessment Model for Alaska) (Anon, 2015b) approach. While the AMAK assessment did not use all of the data that would be included in an assessment of the CSNA, the results suggested a model-based assessment was feasible when estimates of absolute abundance (i.e., from the DEPM survey) were available for informing the model. The presence of patterns in the residuals about the fit to the preliminary ichthyoplankton index highlighted the need for review, as with any model-based assessment. The Panel noted that given the degree of uncertainty from existing data, an assessment structure (perhaps using SS3, which is commonly applied for PFMC assessments) might provide an appropriate way to combine disparate data, be amenable to review, and have the advantage of updating historical evaluations with recent data.

The Panel recognized that assembling all the necessary data and conducting and reviewing a model-based assessment, while certainly possible, may not be feasible during 2016 with the present SWFSC assessment capacity and schedule. The Panel identified the following options for a short-term approach to provide some preliminary information on the status of the CSNA at the November 2016 Council meeting:

- The approach of Section 3.2 (DEPM/DEPM light) could be used to construct an index of abundance for CSNA and provide estimates of absolute spawning biomass. These estimates will be negatively biased to an unknown extent due to the egg and larval surveys not covering the full range of the stock, and could be further biased due to the “DEPM light” approach.
- The analysts should quantify the uncertainty of any resulting estimates of biomass, accounting for the uncertainty in the ichthyoplankton index as well as that associated with calibrating the historical DEPM estimates with the associated ichthyoplankton data. Specifically, the contribution of variation in adult parameters to the variance in DEPM estimates should be analyzed, and thus accounted for when estimating biomass using the approach in Section 3.2.
- The ATM survey results for 2015 could be analyzed to provide a (negatively biased) estimate of absolute abundance of the CSNA for the surveyed area if catchability is assumed to be 1. The estimates of absolute spawning biomass from the ichthyoplankton-based model should be compared to the estimate of biomass from the ATM survey, while realizing that both are expected to be underestimates.
- The analyses required to provide this information should be reviewed by the SSC. Whether, the analyses should be reviewed by the SSC, its CPS subcommittee or a STAR Panel is beyond the scope of this workshop. However, the SSC could make a recommendation in this regard at its June 2016 meeting.
- The SSC will need to provide a recommendation to the Council about how the “DEPM light” approach could be used. Potentially, it might be used either to 1) make a decision whether a point of concern exists (as described in the CPS FMP), 2) establish a new ABC and OFL for anchovy as

a monitored species, or 3) establish a new ABC and OFL for anchovy as an actively managed species.

6.1.2 Northern sub-stock of northern anchovy (NSNA)

There are fewer data for the NSNA (Table 1) than for the CSNA. The Panel notes that a (likely negatively biased) estimate of biomass could be computed from the 2015 ATM survey results. In addition, the data from the NWFSC survey of the Columbia plume should be analyzed to assess whether these data could be used to provide a relative index of abundance.

6.1.3 Jack mackerel

Jack mackerel is amongst the most data-poor of the CPS stocks. In principle, and as noted by the 2011 review of the ATM survey, the estimates of absolute abundance for the survey area can be used as estimates of the biomass of jack mackerel in US waters and perhaps as an index of relative abundance. The species is caught in the hake fishery, and the data on jack mackerel bycatch in the hake fishery should be analyzed to assess whether these data could provide an index of relative abundance. Historically such an index has been constructed for widow rockfish, among other species.

6.1.4 Pacific mackerel

A model-based assessment of Pacific mackerel already exists, although it depends on an index of abundance based on recreational charter boat CPUE data, whose reliability depends on the accuracy of questionable assumptions. The Panel recommends that the next assessment also consider evaluating an index of abundance for Pacific mackerel based on data from the hake fishery as noted above for jack mackerel.

6.2 General research recommendations

6.2.1 Fishery data

1. The workshop noted the importance of ageing the anchovy otoliths collected for recent years and assessing maturity for these years.

6.2.2 Indices of abundance

2. CalCOFI-related
    a. Estimate an index of spawning output using ichthyoplankton data using the algorithm described in Section 3.2.
    b. The CalCOFI survey data should be re-analyzed using a model-based estimator, e.g., a geostatistical model such as kriging.
    c. The benefits of adding sampling locations to the CalCOFI survey, with the locations of these points chosen in a stratified random fashion, targeted to where fish are expected in the hope of reducing estimation variance should be evaluated
    d. Additional inshore sampling locations and sampling in Mexican waters as well as the collection of additional data on temperature-dependent egg development and larval growth would be beneficial.
    e. Collect data on adult parameters whenever possible to allow full DEPM estimates to be produced.
    f. The DEPM method relies heavily on detailed annual information on sex-ratio, fecundity, percent spawned, fish size, and other factors which seems to be missing for many species and recent years.
3. ATM survey
    a. There is a need for the ATM survey team to specify the criteria by which an estimate of a species biomass for the survey area would be considered useable for management purposes.
    b. Develop a defensible means to estimate the proportion of each U.S. west coast CPS outside the survey area and in surface waters. For example, some discussion indicated that use of

sidescan sonar could detect fish presence and behavior (e.g., avoidance and diving) to some degree, however these species do inhabit the surface layer under some conditions.
   c. Continue collaboration with Mexico to obtain a synoptic survey result.
   d. Routine aging of samples collected on this survey could be very valuable to future modelling efforts.
4. Aerial survey
   a. Develop methods for using aerial surveys to estimate abundance and/or calculate inshore correction factors which can be applied for the CSNA and NSNA.
   b. Establish collaboration between those conducting aerial surveys and those conducting the ATM surveys to estimate inshore correction factors.
5. Other
   a. Data on the spatial distribution of anchovy should be used to estimate the proportion of the population outside the core area used to compute ichthyoplankton indices (and the uncertainty of this proportion) (see Section 3.2.2).
   b. Compare indices of anchovy for the CalCOFI area to the anchovy indices from the juvenile rockfish survey based on this CalCOFI area to assess whether the latter is indexing spawning biomass.

6.2.3 Other recommendations

6. The workshop was hampered by the lack of guidelines for what information is needed for the assessment of “monitored” CPS (in contrast with “actively managed” stocks). The Council and its Advisory Bodies should identify this information and include it in the Terms of Reference for Stock Assessments.

7. COMMENTS BY THE ADVISORY SUBPANEL AND MANAGEMENT TEAM REPRESENTATIVES

7.1 Advisory Subpanel representative

As the CPSAS advisor to the CPS Assessment Workshop, I extend our thanks and appreciation to the Pacific Fishery Management Council (PFMC), Southwest Fisheries Science Center (SWFSC) and the international panel of fishery assessment experts for their interest and contributions to help improve the best scientific methods to assess the variability of CPS. International presentations summarizing assessment and management of CPS spotlighted the differences between international management and the precautionary management of CPS on the U.S. west coast: international CPS fisheries presented generally were significantly larger in terms of both number of vessels and total harvest. International assessments also seemed more adaptive; some surveys were conducted directly by fishing interests; and fishery management policies factored in consideration for industry preservation.

In comparison, the anchovy fishery in California is very small. Catches have averaged half of the precautionary 25,000-mt limit for more than two decades, despite an estimated two million mt population outbreak during that time. The loss of canning / reduction capability and limited markets explains the low landings, the rationale for the fishery’s current “monitored” status. This also reveals why there are virtually no length/age data since 1982. However, this fishery is very important to California’s historic wetfish fleet as a fishery of “last resort” -- a target when no other CPS are available. Considering the current prohibition on sardine coupled with the unavailability of squid and mackerel, anchovy is the lifeline keeping CPS “wetfish” vessels fishing and market doors open. A sharp reduction in existing harvest limits, precluding fishing opportunity, could be the proverbial last straw that curtails California’s wetfish industry, the backbone of California’s fishing economy. This impact is real if the outcome of this workshop supports a “two phase” process, suggesting that the SWFSC produce an interim stock assessment based on data from one of the two survey indices available now — the 2015 acoustic trawl survey or egg-larval surveys –

neither of which include evidence of recent significant recruitment and for several reasons were deemed unsuitable as currently designed to produce a realistic biomass estimate for anchovy.

From an industry perspective, the CPSAS advisor shares the frustration expressed by several participants, that the available data – particularly for anchovy – are insufficient to produce a realistic biomass estimate accurately reflecting the current status of the stock.

The CPSAS conservation representative supports the “two phase” approach, which would be to develop a survey-based abundance estimate, updating the MacCall et al method with available data, prior to September for Council deliberation in November, followed by a model-based assessment over the longer term. However, the majority of the CPSAS, representing industry, point out that “available” data now exclude recent evidence of strong recruitment. We reiterate the concerns expressed by both the SWFSC and some SSC members present at the workshop. Producing a hurried ‘back of the envelope’ interim assessment that might not be endorsed by the SSC as “best available science” diverts time and resources from other high priority research needs. Based on the record abundance of anchovy young of the year (YOY) observed in surveys since summer 2015, as well as anchovy abundance observed by fishermen in nearshore waters and estuaries from southern to northern CA, industry believes there is no anchovy “crisis” that requires immediate action, and supports recommendations by various panel and SSC members to conduct a thorough review of recent data, including consideration of the juvenile rockfish survey and other recent indices, test various modeling options, and take the time needed to “do it right.”

Please review Appendix E for further details.

7.2 Management Team representative

On behalf of the CPSMT, the MT representative thanks organizers and the SWFSC for conducting and hosting this workshop, and greatly appreciates the support of the Pacific Fishery Management Council and federal and state agencies. Nearly the entire CPSMT was able to attend and benefit first-hand from the panelists’ experience and expertise.

The workshop spent considerable time reviewing the merits and limitations of various surveys (e.g. acoustic, aerial, trawl). It was noted that conducting complementary surveys might have the potential to address gaps or uncertainties associated with any single method. For example, a previous review of the SWFSC Acoustic Trawl survey found it unsuitable for anchovy based on its inability to access the fishes’ nearshore distribution. The CDFW-CWPA southern California aerial survey has not yet been reviewed but is conducted in nearshore areas and was suggested for consideration of aligning it to other surveys. Efforts to explore expanded and/or coordinated surveys might begin now but will produce useful information only in the long term. Similarly, immediately available biological data are limited.

Estimating biomass from surveys or models is feasible but panelists noted additional work may be required to fully vet methods and results depending on how that number is used. However, the CPSMT supports using a method for determining an estimate of biomass with existing data, as this estimate and its associated uncertainty better reflects present stock status compared to status quo, recognizing that time will be required to address limitations for more robust modeling approaches.

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Table 1a. Fishery data available for west coast CPS.

Source	Data type	N. anchovy (central sub-stock)	N. anchovy (northern sub-stock)	Jack mackerel	Pacific sardine	Pacific mackerel
Washington (WA)	Landings	Na	1948-15	1948-15	1948-15	1948-15
	Length	Na	2014-15	unknown	2000-15	unknown
	Age	Na	2014-15	unknown	2000-15	unknown
	Maturity	Na	2014-15	unknown	2000-15	unknown
Oregon (OR)	Landings	Na	1981-15	1981-15	1981-15	1981-15
	Length	Na	2013, 2015	1995-15 (P. hake)	1999-15	1995-15 (P. hake)
	Age	Na	2013, 2015 (not aged)	1995-15 (not aged)	1999-15	1995-15 (not aged)
	Maturity	Na	2013, 2015	some data	1999-15	some data
California (CA)	Landings	1916-15	na	1916-15	1916-15	1916-15
	Length	1966-82; 2014-15	na	1967-88	1978-15	1962-15
	Age	1966-82 (2014-15 not aged)	na	1967-88	1978-15*	1962-15*
	Maturity	1966-82; 2014-15	na	1967-88	1978-15	1962-15
Mexico (Ensenada-ENS)	Landings	1971-15	na	1988-15	1962-15	1962-15
	Length	1978-89	na	no data	1989-09	Unavailable
	Age	1978-89	na	no data	1989-09 (not used)	Unavailable
	Maturity	1978-89	na	no data	data unavailable	Unavailable

* earlier age data are available but have not been used in recent assessment.

Table 1b. Indices of abundance data available for west coast CPS.

Source	Data type	N. anchovy (central sub-stock)	N. anchovy (northern sub-stock)	Jack mackerel	Pacific sardine	Pacific mackerel
ATM/DEPM CPS survey - spring (SD-SF, CA)	Ichthyoplankton	1994-15	na	1994-12	1994-15	1994-12
	Acoustic biomass	2015	na	2006-15	2006-15	2006-15
	Adult comp/biology	1994-15 (not aged)	na	1994-15 (not aged)	1994-15	1994-15 (not aged)
ATM Sardine/Hake survey - summer (CA-BC)	Ichthyoplankton	2008; 2011-12 (2013-15 in prep.)	2008; 2011-12 (2013-15 in prep.)	2008; 2011-12 (2013-15 in prep.)	2008; 2011-12 (2013-15 in prep.)	2008; 2011-12 (2013-15 in prep.)
	Acoustic biomass	2015	2015	2008; 2011-15	2008; 2011-15	2008; 2011-15
	Adult comp/biology	2008; 2012-15 (not aged)	2008; 2012-15 (not aged)	2008; 2012-15 (not aged)	2008; 2011-15	2008; 2011-15 (not aged)
SWFSC CalCOFI survey - winter (SD-SF, CA)	Ichthyoplankton	1951-12	na	na	na	na
SWFSC CalCOFI survey - spring (SD-SF, CA)	Ichthyoplankton	1951-15	na	1951-15	1951-15	1951-15
SWFSC CalCOFI survey - summer (SCA)	Ichthyoplankton	na	na	1951-12	na	1951-12
SWFSC Juvenile rockfish midwater-trawl survey (CA)	Abundance, length	1990-15	na	1990-15	1990-15	1990-15
MRFSS (WA-OR-CA) / CRFS (CA) [RecFIN data base]	Catch-effort, length	na	na	1980-03 / 2004-15	na	1980-03 / 2004-15
CPFV logbook (CA)	Catch-effort	na	na	1936-15 / 1981-15	na	1936-15 / 1980-15
NWFSC BPA pelagic surface-trawl survey (WA-OR)	Adult comp/biology	na	1998-15	na	1998-15	na
NWFSC Predator-forage fish trawl survey (Columbia R.)	Adult comp/biology	na	1998-12	na	1998-12	na
NWFSC Estuary seine survey (Columbia R.)	Adult comp/biology	na	2001-13	na	2001-13	na
CDFW Aerial (Spotter pilot) survey (SCA)	Biomass	2013-15	na	na	2013-15	na

Table 2. Individual error factors for hydro-acoustic surveys of sardine biomass, where the values define trapezium form pdfs. Note that these error factors apply to the observed biomass (source: de Moor and Butterworth, 2015). The "Nature" column refers to whether the error is the same or varies from year to year.

Error	**Minimum**	**Likely (lower)**	**Likely (midpoint)**	**Likely (upper)**	**Maximum**	**Nature**
(On-axis sensitivity)	0.9	0.95	1	1.05	1.1	Variable
(Beam factor)	0.755	0.9	1	1.1	1.25	Constant
Surface Schooling	1	1.05	1.075	1.1	1.15	Variable
Target Identification	0.5	0.9	1	1.1	1.5	Variable
Weather Effects	1.01	1.05	1.15	1.25	2	Variable

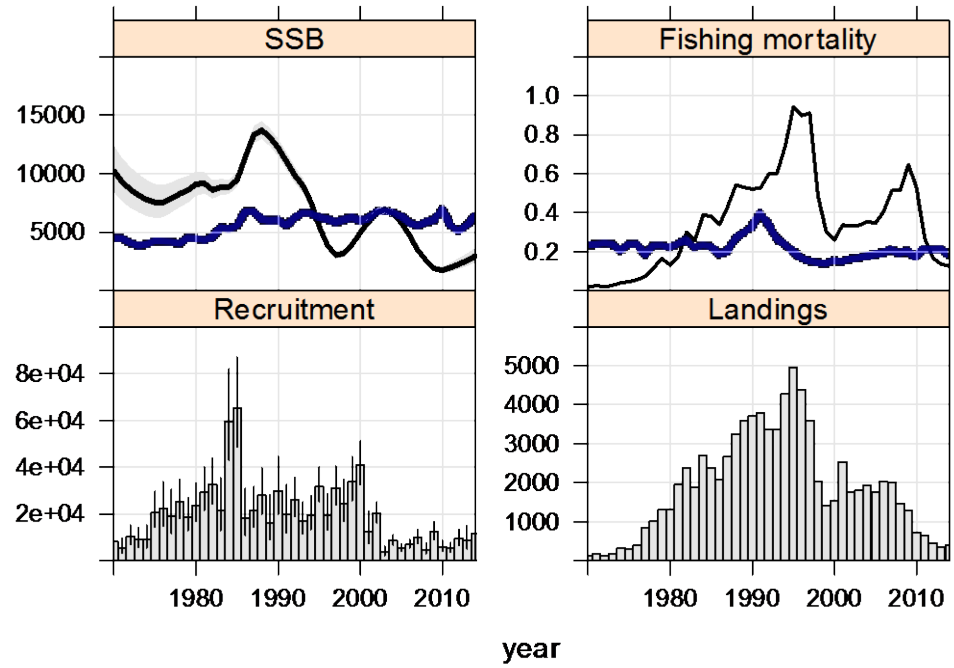

Figure 1. South Pacific jack mackerel. Summary estimates over time showing spawning biomass (kt; top left), recruitment at age 1 (millions; lower left) total fishing mortality (top right) and total catch (kt; bottom right). Blue lines in top figures represent dynamic estimates of F_{MSY} and B_{MSY} for each year (for model 0.4). Confidence bands reflect $\pm$1 standard deviation of the estimate. See Anon (2015a) for details.

Appendix A. Agenda

May 2, 2016 (Monday)

10am	Opening remarks	Cisco Werner
	Introductions, and workshop goals	A. Punt, J. Ianelli
	Logistics, format	D. Sweetnam/K. Griffin
	Assignment of rapporteurs	Co-chairs
1030	Background: species, fisheries, assessment, management	P. Crone
1130	Acoustic-trawl survey and abundance time series	J. Zwolinski
1215	*Lunch*	
1315	Egg/larval and abundance (CalCOFI) surveys	E. Weber
1400	Discussion of data (e.g., age, length, CPUE)	All
1500	*Break*	
1530	Australian stocks	A. Punt
1600	Anchovy Assessment Methodology	A. Punt
1630	Public comment	

May 3, 2016 (Tuesday)

0830	South African stocks (anchovy, sardine, round herring)	D. Butterworth
0915	South Pacific (SPRFMO) jack mackerel	J. Ianelli
1000	*Break*	
1030	Iberian CPS	A. Silva
1130	Atlantic Menhaden	M. Prager
1200	*Lunch*	
1300	Overview of Peruvian anchoveta assessment methods	J. Ianelli
1330	Utility of acoustics in hake surveys	I. Stewart
1400	Group discussion: advantages and disadvantages of current and alternative methods given data availability and management needs (including benefits of methods that use multiple data types)	
1500	*Break*	
1530	Group discussion continued, generate summary table	Co-Chairs
1630	Requests	

May 4, 2016 (Wednesday)

0830	Report update (summary sections should be completed)	Rapporteurs
0900	New approaches based on overnight thoughts	Rapporteurs
1000	*Break*	
1030	Merits & drawbacks of integrated assessment vs survey only approaches	
1130	Report development #1 / small groups to further develop ideas	
1300	*Lunch*	
1400	Small group report back	Rapporteurs
1500	*Break*	
1530	Discussion TBA	

May 5, 2016 (Thursday)

0830	Discussions TBA	Co-Chairs
1000	*Break*	
1100	Report preparation #2	Rapporteurs
1200	*Lunch*	
1330	Co-chairs to prepare summary of key points	Co-Chairs
1400	Presentation of summary points	
1430	Initial report review #1	
1530	*Break*	
1600	Initial report review #2	
1630	Concluding remarks	(G. Dinardo, Co-Chairs)
1700	ADJOURN	

Appendix B. Attendance List

Name	Affiliation	Name	Affiliation
	Panelists		***Other Attendees***
Jim Ianelli	AFSC Co-chair	Dale Sweetnam	SWFSC
André Punt	U. Washington Co-chair (SSC)	Kerry Griffin	PFMC
Evelyn Brown	Lummi Nation (SSC)	Alan Sarich	CPSMT/Quinault Indian Nation
Will Satterthwaite	SWFSC (SSC)	Al Carter	CPSAS/Ocean Gold
Owen Hamel	NWFSC (SSC)	Emmanis Dorval	SWFSC
Doug Butterworth	U. Cape Town, S. Africa	Juan Zwolinski	SWFSC
Mike Prager	SWFSC, SEFSC (retired)	Chelsea Protasio	CPSMT/CDFW
Alexandra Silva	IPMA, Portugal	Kirk Lynn	CPSMT/CDFW
Martin Dorn	AFSC (SSC)	Kevin Piner	SSC/SWFSC
Aaron Berger	SSC/NWFSC (SSC)	Kevin Hill	CPSMT/SWFSC
Diane Pleschner-Steele	CPSAS rep	Cyreis Schmitt	CPSMT/ODFW
Lorna Wargo	CPSMT rep	John Budrick	SSC/CDFW
David Crabbe	PFMC	Mike Okoniewski	CPSAS/Pacific Seafood
Corey Niles	PFMC	Katie Nichols	NMFS WCR
Steve Haeseker	PFMC/USFWS	Steve Marx	Pew Trusts
Josh Lindsay	NMFS WCR	Anna Weinstein	Audubon
Ian Stewart	IPHC	Russ Vetter	SWFSC
		Ed Weber	SWFSC
		Bev Macewicz	SWFSC
		Steve Teo	SWFSC
		Donna Dealy	SWFSC
		Theresa Tsou	SSC/WDFW
		Hui Hua Lee	SWFSC
		Bill Watson	SWFSC
		Youhong Gu	SWFSC
		Mike Kinney	SWFSC
		Sam McClatchie	SWFSC
		Gilly Lyons	CPSAS/Pew Trusts
		Bill Sydeman	Farallon Institute
		James Hilger	SWFSC
		Theresa Labriola	Wild Oceans
		Christina Show	SWFSC
		Noelle Bowlin	SWFSC
		Andrew Thompson	SWFSC
		Joel Van Noord	CWPA
		Gerard DiNardo	SWFSC

Appendix C. Workshop Description

I. Purpose

The purpose of the workshop is to provide recommendations for conducting stock assessments that may apply to management advice for short-lived coastal pelagic species (CPS) on the U.S. West Coast, with an emphasis on the central subpopulation of northern anchovy (CSNA).

II. Approach

The workshop will compare and contrast stock assessments applied to similar stocks around the world, and evaluate strengths and weaknesses of various methods. Specifically, tradeoffs in the extent that assessments provide point estimates of biomass or projections of stock status given limited data will be discussed. The intent is to provide recommendations to the Southwest Fisheries Science Center (SWFSC), which will be conducting a stock assessment of CSNA in fall 2016, and other CPS stocks in the future.

III. Objectives

- Evaluate model-based assessment approaches by using examples from other parts of the world where small coastal pelagic species are routinely assessed. Other eastern boundary current systems, such as the Benguela or Humboldt are of particular interest.
- Compare available data, surveys, equipment, staffing resources, and other factors that affect stock assessments with reference to the situation for the CSNA stock.
- The first priority stock to consider is the CSNA. Other CPS stocks that will be considered are the northern subpopulation of northern anchovy, jack mackerel, and other CPS stocks as appropriate.
- Consider non-assessment approaches that use only an empirical estimate of biomass in a harvest control rule.
- Develop recommendations for methods and data collection/analyses given constraints for the key CPS stocks.

IV. Deliverables

A workshop report for consideration by the Council and Advisory Bodies at a future meeting will be drafted, and will include:

- A detailed description of methods discussed relative to how they can best be applied to U.S. West Coast CPS stocks.
- An evaluation of data requirements and tradeoffs given stock biology and resources
- Recommendations for CSNA and other CPS stock assessments.
- Other appropriate records of the workshop.

V. Responsibilities

- The Workshop co-Chairs will be responsible for overall facilitation and order of the workshop. The co-Chairs will make rapporteur assignments, delegate tasks to Panel members; and will be responsible for assigning section authors and preparing the final report.
- Workshop Panel members are responsible for (as appropriate) presenting information on approaches from other fisheries that may be applicable to the U.S. West Coast, for reviewing methods, for making requests to presenters as necessary, and to constructively contribute to the technical discussions.
- Panel members and the workshop co-Chairs are responsible for writing a workshop report in a timely manner, for presentation at a future Council meeting

Appendix D. Summary of the Aerial Survey Small Group

Participants: Evelyn Brown, David Crabbe, Kirk Lynn, Diane Pleschner-Steele, and Al Carter. Discussions with ODFW and WDFW representatives occurred prior to the meeting and their comments and views were incorporated in this report as interpreted by Dr. Brown.

Brown and Moreland (2000) and Brown *et al*. (2000) provide thorough reviews of the methods developed as well as references to other areas that developed and used aerial surveys for fisheries assessment and research (e.g., Carscadden *et al*. 1994; Hara *et al*. 1985a,b; Lebida and Whitmore, 1984; Brady, 1987). Within these works, there have been estimates and applications of error along with explicit instructions for scientifically valid surveys. Particularly of interest to this group is the existence of protocols for the combination of aerial-acoustic surveys which could be a powerful tool for improving future stock assessment methods (Cram and Hampton, 1976; Hampton *et al*., 1979). Future efforts to improve and incorporate AS data into anchovy and sardine management should include a thorough review of these studies with an incorporation of some of the methods described. This is a critical step in order to pass the scientific scrutiny required by NMFS, the SSC, and ultimately the PFMC.

1. AS Program Support and 2016 Survey Plans

There was consensus among the three state agency representatives, the Council representative, and the two advisory panel representatives that the AS program provides valuable information and that it should be continued. There were commitments from the industry representatives and from CDFW that there would continue to be funding to support these efforts, although explicit details concerning the level of funding were not provided.

The 2016 survey for the California Bight region, managed by CDFW, is already underway with the completion of a spring survey. As in 2013-2015, only the alongshore and island transects will be completed (excludes offshore parallel transects). The focus of these surveys is providing an index of abundance for CPS including the CSNA. There is a desire to extend these surveys to the Monterey Bay region. However, funds and plans to do so in 2016 are lacking.

Washington and Oregon industry representatives expressed the intention to continue the Northwest Sardine surveys in 2016 over the entire extent of the joint Southwest Fisheries Science Center-Northwest Fisheries Science Center-industry sardine/hake survey where possible. Although the purpose of these surveys is to provide an additional index of abundance for the Pacific sardine in the Pacific Northwest, there are data on anchovy that have not been extracted and reviewed. Industry has, however, initially agreed to modify survey flights to collect anchovy information at the start and end of surveys. The goal will be to provide indices of abundance in the Columbia River Plume and other areas where anchovy are known to aggregate in large numbers.

2. Data Inventory, Management and Analysis of Existing Data

Although industry-funded data are currently unavailable, industry representatives have contacted the contractors and have agreed to provide the detailed survey data in digital form. At this point, the effort required to standardize and perform QA/QC on the data is unknown. No date for the receipt of these data was provided. Industry survey data span from 2008 to 2013, with variation in coverage, dates and potential data quality or usefulness. In addition, there are aerial survey data that are coupled with acoustic data in a research program funded in 2004 and 2005 (Brown, 2006) that will be provided upon request. The group expressed a desire to see the full aerial data set (California, Washington, Oregon) compiled, reviewed and standardized if possible. Reports for all of the AS efforts to date, with the exception of the 2014-2015 Northwest Sardine Survey data summary, have already been provided to the SSC and have been archived on the Council website (www.pcouncil.org).

For the existing Southern California Bight data, it would be of value to compare the spring and summer AS biomass estimates with the CalCOFI trawl and egg surveys if they have estimates of the number of anchovy eggs. There should be four years of comparisons available. Correlations between the two would provide some information that could shed light on potential AS uncertainty. The California fishery operates at night when fish are generally at the surface, while the AS, following protocol the developed in the Northwest, operates during daylight and may miss fish lower in the water column, a caveat noted in both small group and workshop discussion The California industry representative pointed out the need to develop nighttime survey techniques to optimize the probability of measuring biomass accurately, in essence recreating the former spotter pilot index of abundance. This survey could also be used as a relative index of recruitment.

The utility of extracting information from the bluefin tuna surveys as a proxy index of abundance or distribution, given that anchovy and sardine are important prey items was discussed. However, diet information was provided for bluefin indicating their ability to switch prey according to prey availability; therefore, their distribution may be an unreliable reflection of the anchovy and sardine distribution.

3. Data Inventory, Management and Analysis of Existing Data
A major issue for existing data and for the utility of AS data in general is the identification of sources and estimates of error. Of specific interest is the table of estimated error sizes (from measurements) in Table 3 in Brown *et al*. (2000).

Point sets were used as part of the AS survey in the Pacific Northwest. These prove difficult and expensive to perform. A simple alternative might be to obtain the school depth ranges from static fishing vessels and to obtain samples for fork length and species for at least one school in a given shoal; then the length-based school spacing or surface-area to biomass from the literature (Squire, 1978; Hara. 1985; Misund, 1993; Carscadden *et al.*, 1994) using this information in combination with a measured length-wright relationship to convert surface area to biomass A second alternative to point sets is comparisons of aerial and acoustic data over defined spatial and temporal strata to develop comparative indices. This was done off the coast of Oregon and Washington for a study focused on sardines and in cooperation with the industry; this study was a precursor to the subsequent work by Jagielo *et al*. (2012). In the industry, the spotter pilot flies over a large area, identifies locations of sardine shoals, and reports the coordinates of a box around that concentration of fish. The fishers save the cost of searching large areas by going directly to the reported boxes. In the targeted study, a box was defined by scientific surveyors and the biomass estimate obtained from surface area estimates and biomass conversion terms were compared with the spotter pilot estimates (to measure surveyor bias). Then a scientific acoustic survey was conducted within the same box within 24 hours and catch sampling was used to obtain target strength. These two indices (aerial and acoustic) could then be modeled to produce a method correction factor. For use in stock assessment, the two could be modeled to produce a hybrid estimate or kept separate to produce two estimates. Ultimately, this box method would be folded into an adaptive survey design in order to produce an area wide population estimate.

4. Ship Avoidance and Other Immediately Relevant Information
Measuring avoidance from a platform that might induce that avoidance (such as a vessel) is perhaps not the best technique to use. Others have approached this in a variety of ways. For example, ship avoidance has been detected and measured in schooling mullet in the Gulf of Mexico (Churnside *et al.*, 2003) and in schooling capelin in Alaskan waters using airborne light detecting and ranging (lidar), which pulses green light and receives the backscatter reflected from objects in the water column.

There has already been work with fixed acoustics to determine school movement, shape and diurnal behavior for the species in the area of interest (e.g., Kaltenberg and Benoit-Bird, 2006). This kind of information can help improve interpretation, correction, and expansion of both aerial and acoustic data. Bottom-up and top-down fixed acoustics could be key tools in resolving current survey issues.

Additionally, measurements from a fishing vessel's sonar can evaluate the depth and extent of schools. Scientific sonar gear can also provide useful data at relatively low cost to improve understanding of potential biases.

The group expressed the opinion that, given the limited resources available for the current surveys and variation in spawn timing and spatial distribution, the survey start times should be adaptive and include input from industry representatives who closely monitor forage fish activity relative to their environment. It was noted that procedures should be developed for using and incorporating this type of local expert opinion to supplement survey activities. Such cooperative research should be expanded and extended to using acoustics on smaller commercial vessels where practical, especially in cases where fish avoidance is less likely to occur.

Appendix D References

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Appendix E. Additional CPSAS comments

Issues identified at the workshop included (but were not limited to):

- Egg-larval data updated to spring 2015 do not include evidence of "record" anchovy recruitment measured in the Rockfish Recruitment Cruise Report (Apr 30-Jun 14, 2015)
- Any update should also include data from the rockfish recruitment survey: "…catches of larvae and pelagic juveniles [for 2015] were the highest ever in the core and north and still relatively high in the south (Appendix III)." (D.Pleschner-Steele)
- Current anchovy egg development state data and adult reproductive parameters are not known, so the historical egg production method is used, with assumed constant egg mortality and constant adult parameters. (E. Weber presentation)
- If updated to 2015, the MacCall analysis should be modified to account for published information on age-dependent distribution and age-dependent egg production (not averaged). Including recent nearshore abundance data also is important. (R. Parrish comments)
- MacCall et al (2015) averaging methods and resultant biomass estimate were questioned (R.Parrish statements submitted to workshop and PFMC; Prager, Butterwowrth pers. comm.).
- CalCOFI data alone are not suitable for stock assessment. The core CalCOFI area is smaller than the range of anchovy. Inshore sampling is needed. (E.Weber presentation).
- The acoustic trawl (AT) team declined to produce a point estimate of anchovy abundance using AT data prior to 2015, and noted that the 2015 survey excluded the Southern CA Bight. (J.Zwolinski)
- The current AT survey, which was designed for sardine, also does not measure the nearshore anchovy biomass adequately, a "non trivial" omission (D. Butterworth, M. Prager)
- AT survey catchability assumption of q = 1 was challenged for anchovy [and sardine]. (several commenters)
- Two correction factors are needed for the AT survey – inshore vs. offshore and the upper water column (i.e. surface to @10-20 meters depth) vs. lower water column (below 10 meters depth). (Ian Stewart).

The need to expand surveys to completely assess biomass (both anchovy and sardine) in the nearshore, as well as the upper water column, were themes repeated throughout the workshop. Neither the CalCOFI nor AT surveys, both designed primarily for sardine, effectively quantify the nearshore abundance of anchovy that has been observed by fishermen since summer 2015.

Regarding the MacCall et al (2015) analysis, which was discussed in subcommittee during the workshop, it will be important to consider the comments by Dr. Richard Parrish, who was invited to participate in the workshop but could not attend. He submitted comments on the methods and conclusions of the MacCall et al (2015) analysis, both for workshop consideration (posted on the ftp site under Assessment Workshop Public Comment) and earlier, in a letter to the PFMC, (Agenda Item H.3.b, Supplemental Comment 4, Nov 2015).

Dr. Parrish began his letter to the Council: "*In my opinion the MacCall et al paper is conceptually one of the most significant papers on the population dynamics of pelagic fishes in the California Current in recent years. The analysis shows that the biomass of the central stock of northern anchovy is extremely variable and that this variability occurs with and without a significant fishery on the stock.*" He then addressed issues with analysis methods and conclusions based on his 50 years of experience with anchovy research / management. Following are excerpts of Dr. Parrish's comments from his workshop submittal: "Comments on 20th and 21st Century Analyses of Northern Anchovy, April 30, 2016" [annotated for emphasis]

(Note: Italicized comments interspersed are excerpted from PFMC Supplemental Comment 4, Nov. 2015)

Nearshore-Offshore Age Composition:

Parrish et al (1985) showed that young northern anchovies (ages 0 and 1) are concentrated in areas where the water is less than 50 fathoms in depth and that older anchovies (ages 2-6) are concentrated in areas that are deeper than 500 fathoms (Figure 6).

Table 6. Age composition (%) of northern anchovies taken in shallow and deep-water areas (depth in fathoms). (From Parrish et al 1985).

		Lat. 32°-34°N						
Age	Depth:	5-25	26-50	51-150	151-300	301-500	501-700	701 +
0		56.5	26.3	16.9	7.8	5.5	3.0	6.5
I		20.6	29.5	26.5	27.4	25.8	17.9	15.5
II		12.5	24.1	26.0	27.9	30.6	32.0	26.8
III		7.0	12.3	20.1	22.8	22.7	28.2	27.1
IV		2.5	5.8	6.8	9.1	10.5	13.3	15.3
V		0.8	1.5	3.2	3.6	3.8	4.9	7.2
VI +		0.2	0.5	0.6	1.4	1.1	0.6	1.7
n		1,579	1,492	1,102	2,199	3,704	2,091	1,086

The MacCall et al (2015) analysis stratified the egg and larval data to account for the apparent concentration of anchovy in the nearshore area during periods when biomass is low. They used the Jacobson et al (1994) estimate of daily egg production to convert the egg and larval abundances to biomass. Jacobson et al (1994) estimated average daily egg production for the entire area surveyed. **When the egg and larval abundances are used with the stratified areas used by MacCall et al (2015), the assumption that average daily egg production is the same in all areas is a questionable assumption as it has been shown that the age composition of anchovies sampled in shallower areas (i.e. nearshore) is dominated by young anchovies where as deeper areas (i.e. offshore) is dominated by older mature anchovies.**

The conversion of egg and larval abundance to spawning biomass is dependent on the daily egg production that is highly age-dependent and therefore area-dependent in northern anchovy.

From Supplemental Comment 4, Nov. 2015)

It should also be noted that the offshore areas in the egg and larvae sampling grid have fewer eggs than the nearshore areas ***even when the biomass is high****. This is particularly true in central California.*

Seasonality of Spawning:

From Supplemental Comment 4, Nov. 2015)

The seasonality of spawning and fecundity was examined by Parrish et al. (1985) using the maturity stages of central stock northern anchovy taken in mid-water trawls by the Sea Survey Program and the California purse seine fishery during the high abundance period (1966-80) and histological information for the gonads of females taken during the months of February-April from 1977-1984. This information was primarily from the high abundance period when the anchovy fishery in California and Northern Baja California were at their highest level. ***The maturity stages, spawning incidence and fecundity information derived from these data shows that egg production peaks in March and is highest from February to April; very few anchovies are spawning in January (Figure 10 and Table 3). This makes the January data in the MacCall et al paper somewhat suspect. Note that one-year-old anchovies have peak spawning in February, that age 2 and older anchovy have peak spawning in March and that there is a high percentage of 3 year and older anchovy with a high egg production in April. Neither February nor March were used in the MacCall et al paper****.*

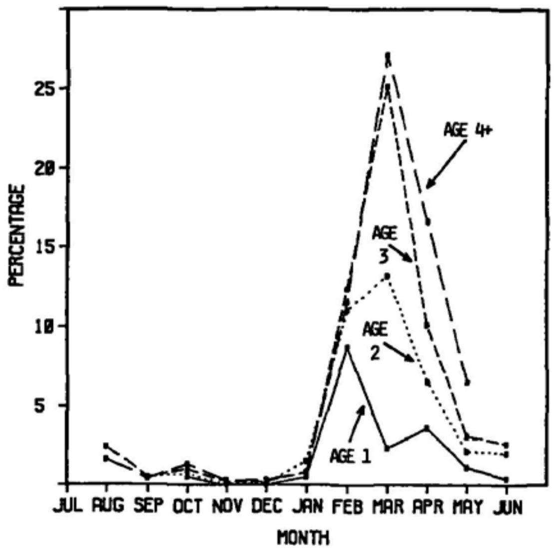

Figure 10. The monthly percentages of female northern anchovies with maturity stages 5+6 by age group (from Parrish et al 1986).

Egg production:

The Parrish et al study (1986 – Table 3 – omitted here due to lack of space) shows that the production of eggs/gm body weight is highly age-dependent in northern anchovy. Anchovies in their first spawning year produce only 43% of the eggs produced by those in their second spawning season and only 20% of those in their fourth, and later, spawning seasons.

This factor is not included in the MacCall et al (2015) analysis and it may greatly bias the estimates of biomass as eggs produced in the offshore stations (i.e. the majority of the stations) require a significantly smaller eggs to biomass conversion rate than those in the nearshore area. The eggs to biomass conversion rate for age 1 anchovies should be five times that of age 4+ anchovies.

Comparison of Jacobson et al vs MacCall et al Studies:

The Jacobson et al (1994, 1995) and MacCall et al (2015) analyses of spawning biomass have several features in common and some significant differences. …

The large, abrupt biomass fluctuations seen in the MacCall et al (2015) study strongly suggest that the northern anchovy stock has extreme population outbreaks that last from 1-3 years. Following outbreaks, even in the absence of a significant fishery, the spawning biomass can decline an order of magnitude within two years.

Excerpts from Supplemental Comment 4, Nov. 2015

Age-dependent fecundity:

A related source of bias in the MacCall et al paper is caused by the fact that fecundity (i.e. eggs per gram body weight) is highly age-dependent. Calculations from the data in Table 10 (Parrish et al 1985) show that the annual egg production per gram body weight is 4.9 times greater for 4+ year-old anchovies than for age 1 anchovies. In the peak spawning month (March) 4+ year-old anchovies produce 11.7 times as many eggs per gram body weight than age 1 anchovies. In January the difference between age 1 and age 4+ is not great (1.3 times) but there are very few anchovies spawning; only 3% of the annual egg production of 1 year olds and 1% of the 4+ year-olds occurred in January in the Parrish et al (1985) data (Table 10). The April difference is about the same as the annual difference (4.7 times).

It appears that the use of January data is questionable due to the very small proportion of spawning that occurs in this month, as small variations in the percent spawning will have relatively large proportional *affects. In addition, the choice of January, with very low spawning rates during the peak of the fishery prior to 1985, increases the potential of decadal and inter-annual bias in biomass estimates caused by alterations in the seasonal distribution of egg production.*

The second potential source of bias associated with age-dependent egg production is that the egg and larval surveys have no way to distinguish between a spawning population composed primarily of age 1 anchovies vs. one composed primarily of age 3 and age 4+ anchovies. Biomass estimates are likely to be more than twice as high if the biomass is dominated by older anchovies than the situation that occurs when a super abundant year-class occurs during a period of low biomass. In addition if the biomass is smaller due to increased numbers of predators (i.e. California Sea Lions and/or albacore) the increased natural mortality will produce a younger age composition and the resultant biomass estimate would have a low bias due to the reduced egg production associated with a younger population.

Conclusions:

The biomass estimates in the MacCall et al paper cannot be used to estimate the 2016 biomass of the northern stock of anchovy. The paper clearly shows that the population can increase, or decrease, an order of magnitude in two years. …. Clearly with northern anchovy a 5 year old biomass estimate is not significantly better at estimating current biomass than a 25 year old biomass estimate…

The central stock extends into Mexico and due to data limitations the authors did not include anchovies spawning in Mexican waters in their estimates. This results in an underestimation of the total spawning biomass …

Excerpts from Email comments from Richard Parrish during the workshop

May 2

The important thing will be to use the newer [most recent] data so that the assessments can be brought up to 2015. **Alec avoided inclusion of the additional stations in the near shore area. I think he could use this data by simply averaging the eggs and larvae where there are two or more stations within his stratified boxes. I think this is preferable to dropping the data out of the analysis.**

May 3

… I think that Alec's analysis is likely to be the best thing going. Although I agree with Weber about [not] using only CalCOFI data, especially the scaling problem, I think that the extreme changes seen in [Alec's] analysis are still very real and have great importance for any ecosystem-based analyses. …

Essentially the problem boils down to how many tons does each egg in the survey area count for. For example, the offshore stations should have a lower multiplier (conversion rate) than the nearshore stations because the older anchovy in the offshore area produce more eggs per ton of fish than the nearshore stations with young fish.

It might be interesting to ask this question. Does one egg equal 10 mt, 100 mt or 1000 mt?