Agenda Item C.3.a
Attachment 1
April 2011

Pacific Fishery Management Council

Acoustic-Trawl Survey Method for Coastal Pelagic Species

Report of Methodology Review Panel Meeting

National Marine Fisheries Service (NMFS)
Southwest Fisheries Science Center (SWFSC)
La Jolla, California
3-5 February 2011

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OVERVIEW

A review of the acoustic-trawl method, developed by the Southwest Fisheries Science Center (SWFSC) for surveying coastal pelagic finfish species (CPS) off the west coast of the United States of America, including Pacific sardine, jack mackerel, Pacific mackerel, and northern anchovy, was conducted by a Methodology Review Panel (Panel), at the SWFSC Torrey Pines Court Laboratory, La Jolla, CA, from 3-5 February 2011. The Panel followed the Terms of Reference for Stock Assessment Methodology Reviews (November 2010).

The meeting began with a welcome by Dr Francisco Werner, Director of the SWFSC. The Chair then identified six key issues which provided a focus for discussions during the review: (a) design of the acoustic and trawl sampling, including the representativeness of the data for the four CPS species; (b) analysis of the survey data for estimating CPS abundances; (c) evaluation of potential biases in sampling design and analysis; (d) characterization of uncertainty in estimates of CPS biomass; (e) decision if acoustic-trawl estimates of CPS biomass can be used in stock assessments and management advice for Pacific sardine, jack mackerel, Pacific mackerel, and northern anchovy; and (f) guidance for future research. Dr Kevin Hill, SWFSC, then gave a brief presentation of the most recent Pacific sardine stock assessment to orient the Panel on important issues for CPS assessments and management. Dr David Demer, Leader of the Advanced Survey Technologies Program, SWFSC, gave a presentation on the acoustic-trawl method for assessing CPS, and this was followed by responses to several requests by the Panel for additional information.

This report first summarizes the Panel's requests to the acoustic-trawl survey team (henceforth "Team"); then summarizes discussions related to the six key issues and the key unresolved problems, then summarizes comments by CPSAS representative, and concludes with a list of research recommendations. Appendix 1 lists the participants and their affiliations. Appendix 2 includes short biographies for the Panel. Appendix 3 includes a list of the primary background documents which were provided to the Panel in advance of the meeting, via email and on an ftp site. These documents included descriptions of the acoustic-trawl method; example applications of the method for acoustically estimating the distributions and abundances of Pacific sardine and other CPS from data collected in spring 2006, 2008, and 2010, and summer 2008 ('present surveys'); and four supporting references. Wireless access to the FTP site functioned intermittently during the meeting.

Considerable information was provided by the Team. This information was made available in the papers and presentations provided to the Panel, and is not repeated here. The acoustic-trawl surveys also have the potential to provide estimates of fish distribution and behavior, as well as information for ecosystem-based fishery management. The review was, however, focused on the provision of abundance estimates and this report reflects that focus.

The Panel **commends** the Team for their thorough presentation, detailed background material, and willingness to respond to the Panel requests. Although the review focused on the areas of potential concern with the acoustic-trawl estimates of abundance, the Panel wishes to emphasize that the Team had already identified most of the issues identified by the Panel and had prepared information pertinent to these which helped to Panel in its deliberations. The work related to avoidance of CPS to vessels was particularly helpful, allowing the Panel to draw conclusions related to whether avoidance, or at least its effects on the acoustic-trawl survey results, is likely substantial.

Overall, the Panel is satisfied that the design of the acoustic-trawl surveys, as well as the methods of data collection and analysis are adequate for the provision of advice on the abundance of Pacific sardine, jack mackerel, and Pacific mackerel, subject to caveats, in particular related to the survey areas and distributions of the stocks at the times of the surveys. The Panel concluded that estimates from the acoustic-trawl surveys can be included in the 2011 Pacific sardine stock assessment as 'absolute estimates', contingent on the completion of two tasks. Estimates of absolute abundance for the survey area can be used as estimates of the biomass of jack mackerel in US waters (even though they may not cover all US waters). The estimates of abundance for Pacific mackerel are more uncertain as measures of absolute abundance than for jack mackerel or Pacific sardine. A major concern for this species is that a sizable (currently unknown) fraction of the stock is outside of the survey area. However, the present surveys cannot provide estimates of abundance for the northern anchovy stocks for use in management. The Panel notes that the acoustic-trawl method potentially could be applied to survey CPS currently in low abundances, e.g., northern anchovy and Pacific herring, but the sampling design would need to differ from that used in the present surveys.

The Chair thanked SWFSC for hosting the meeting and the participants for the excellent and constructive atmosphere during the review, the results of which should help inform the Council and its advisory bodies determine the best available science for the management of CPS. He specifically thanked the primary rapporteur (Dr Martin Dorn) for composing a substantial report in a very short period.

1. DISCUSSION AND REQUESTS MADE TO THE TECHNICAL TEAM DURING THE MEETING

A: Map the backscatter excluded by the final VMR filter in the spring 2008 survey.
Rationale: The first stage Multifrequency VRM filter worked well in the northern areas. However, the final stage VMR filtering algorithm was needed to deal with layers of backscatter which were prevalent in the south. The Panel wished to evaluate the impact of this final stage on the selection of CPS.
Response: Results were presented for the spring 2008 survey which included extensive layers of diffuse, low-level backscatter, passing, in the absence of final stage VMR filter, for CPS backscatter. More backscatter was filtered by the final stage VMR filter in the southern part of the survey. The Panel **agrees** that the excluded backscatter was unlikely to be from CPS as the morphology of the scattering did not appear to be representative of a characteristic CPS school. Furthermore since there was no direct sampling of the layer, it was appropriate to exclude it. The Panel deemed the filtering approach appropriate. However, it **cautions** that the filtering algorithms must be checked every survey to ensure their effectiveness under changing conditions. Furthermore, backscattering spectra with unknown origin should be identified using net sampling.

B: Graph the autocorrelations of transect-densities for the spring 2006, 2008, and 2010, and summer 2008 surveys.
Rationale: The bootstrap procedure to estimate variance is only valid if the transects are spatially uncorrelated.

Response: Graphs were presented which indicated that the spatial correlations of the transects within strata were uniformly low, indicating that the bootstrap method for variance estimation was appropriate. While spatial correlation did not appear to be significant, the power to detect statistically-significant correlation was low due to the small number of transects sampled per stratum. It was noted that CPS habitat is almost certainly spatially coherent, suggesting that correlation is very likely to be present in the CPS distribution, even if it cannot be quantified. It was also noted that the post-stratification of the transects likely served to reduce the effect of any inter-transect correlation on the estimation of variance.

C: Repeat the bootstrap variance estimation procedure for the summer 2008 survey except: (a) remove the jackknife procedure for resampling trawls; and (b) remove the bootstrap procedure for resampling the transect densities.
Rationale: One of these two elements may contribute most to the total sampling variance.
Response: Results were presented for estimates of sardine biomass for all surveys and strata. As expected, the sampling variance due to inter-transect variability dominated the overall sampling variance in nearly all cases. The Team clarified that the stratum area included the area bounded by the western ends of the transects, the coastline, and one-half transect spacing beyond the most northern and southern transects. It was noted that this area included the unsurveyed area between the eastern ends of the transects and the coastline.

D: Provide tables of catch in numbers and weight for CPS and other species in all surveys split into northern and southern areas.
Rationale: Are there other species in the surveyed volume, particularly that occupied by CPS, that are important to consider?
Response: The Panel was referred to cruise reports of the Daily Egg Production Method (DEPM) and California Current Ecosystem surveys for this information (these reports had not been made available to the Panel). CPS are usually the dominant species in the trawl catches. It was noted that this information should also be included in the reports of the acoustic-trawl surveys. It was noted that catches in general were very small, with the associated uncertainty in catching what is actually there (see also Section 2.1.7).

E: Compare the distributions of CPS backscatter versus distance below the surface for different survey vessels.
Rationale: This may allow some evaluation of vessel avoidance.
Response: A plot was presented which showed that the distribution peaked slightly shallower for measurements of mean nautical-area backscattering coefficient (m^2 nmi^{-2}) values made from *F/V Frosti* compared to the other survey vessels. However, statistical evaluation of this potential difference was not possible without information about measurement and sampling uncertainties. Regarding sampling uncertainty, it was noted that each survey vessel operated in a different geographic area and at different times of the year, so diel-vertical and seasonal migration behaviors could easily obfuscate detection of any avoidance behavior. Consequently, different methods are needed to investigate fish reactions to different survey vessels, and such studies were considered beyond the scope of the review meeting. See Section 2.2.4 for further discussion of avoidance.

F. Provide an estimate of the area between the eastern ends of the transects and the coastline, by survey and strata.
Rationale: The CPS density in this area may not be represented accurately by the mean transect densities.
Response: A table was presented which showed that the mean distance to the shoreline was 12 km north of Cape Mendocino, and the inshore area was 4.4% of the total area. CPS density tends to increase towards the inshore end of the transects for the summer 2008 survey (**Fig. 1**). A sensitivity analysis indicated that if this higher density was used for the unsurveyed nearshore area, the estimate of total abundance for this survey would increase by about 15 % (see Sections 2.2.1 and 2.3 for further details related to spatial coverage).

2. SUMMARY COMMMENTS ON THE TECHNICAL MERITS AND/OR DEFICIENCIES OF THE METHODOLOGY AND RECOMMENDATIONS FOR REMEDIES

2.1 Design of the acoustic and trawl sampling

The Panel reviewed the available information to evaluate the acoustic-trawl method and the results of present surveys for estimating the distributions and abundances of Pacific sardine, jack mackerel, Pacific mackerel, and northern anchovy. Ideally, the surveys should cover the geographic extents of all four species, and the acoustic and trawl samples should be representative of the stocks within the survey area. The Panel recognized the added complexity in meeting the ideal design requirements for surveys of an ecosystem with large natural fluctuations, and that, pragmatically, setting priorities by species inherently influences survey design and ultimately, will likely result in less (and less precise) information for one or more of the target species within the overall assemblage.

2.1.1 Are the acoustic-trawl surveys representative of the distribution of CPS species?

Appendix 4 provides a summary of the distributions of CPS in the California Current, compiled by a group of meeting participants at the request of the Chair.

2.1.1.1 Pacific sardine

One sampling strategy of the acoustic-trawl method is to survey along transects until the density of CPS is essentially zero. The Panel **supports** this approach. However, it **agrees** that the evidence available suggests that some Pacific sardine may have been outside of the area surveyed (e.g., the high densities at the western ends of the transects in spring 2006). The proportion of the population outside of the survey area (north of the northernmost transect, south of the southernmost transect, further offshore than the western ends of the transects and inshore of the eastern ends of the transects) will likely differ between spring and summer, and among years. In order to address these spatial distribution issues and noting the concerns expressed by the CPSAS representative the Panel **recommends** that analyses be conducted using auxiliary information (e.g., trends in biomass density estimated along transects; information from ichthyoplankton surveys south of the survey area; and fishery-catch information) to provide best estimates for the biomass outside of the survey area at the time of the survey, as well as ranges of possible total biomass. The estimates of the biomass outside of the survey area should be included in the estimates of biomass on which the assessment of Pacific sardine is based and form the basis for sensitivity tests.

2.1.1.2 Jack mackerel

Less is known about the distribution in CCE of jack mackerel than of Pacific sardine. However, the Panel **agrees** that the available evidence suggests that jack mackerel are also found outside of survey area, though perhaps to a lesser extent during the summer than the spring surveys.

2.1.1.3 Pacific mackerel

The primary concern regarding the distribution of Pacific mackerel in relation to the acoustic-trawl surveys is that a large, but unknown, fraction of the population is likely south of the survey area in any year, particularly during spring.

2.1.1.4 Northern anchovy

The distribution of northern anchovy appears to be more nearshore than that of Pacific sardine, and the biomasses of the sub-populations within the survey area appear to be very low.

2.1.2 Transect design and stratification

The current approach utilizes the design for the egg surveys on which the DEPM indices are based for both spatial coverage and trawl data. Thus, the design has not been chosen explicitly to conduct an acoustic-trawl survey. Nevertheless, the transect design in the present surveys is close to regular, but with higher effort, closer transects, in areas of expected high abundance. The Panel **agrees** that while not necessarily optimized, the current approach is adequate. A design with parallel-transects normal to the coastline, and uniform transect spacing within any identified strata, will allow reliable abundance estimates and is preferred over any randomization of transect spacing. Formally, if the survey is to provide an 'absolute estimate', a random starting point is required to allow a possibility that samples can be obtained from all locations, i.e., meet probability sampling criteria for unbiased abundance estimation. If for logistical reasons a random start is not possible, the fish locations must be assumed to be unrelated to geographical features on the scale of one transect spacing. For an index, a fixed starting point is sufficient. The Panel was not concerned with a fixed starting point for the acoustic surveys, except for the small localised populations of northern anchovy.

The potential for using stratification of effort to obtain improved estimates of Pacific sardine abundance is clearly demonstrated (Zwolinski *et al*., in press). Such an approach would improve the precision of the estimates of abundance for Pacific sardine, although this may lead to poorer estimates for the other species. Stratification would need to be based on estimations of habitat that would be specific to season and year. Habitat information can be derived from satellite-sensed oceanographic conditions (Zwolinski *et al*., in press) prior to the survey, and can potentially be refined during the survey using direct oceanographic samples.

The Panel **recommends** that prior to modifying (e.g., optimizing) the present survey design, it will be necessary for the survey objectives to be clearly identified and agreed (e.g., primarily for Pacific sardine or adequate for all CPS species). The design would clearly need to be changed if useable estimates of abundance for northern anchovy or Pacific herring, or both, are needed, given the current population sizes and distributions of these species. The Panel **emphasizes** that the abundances of CPS species fluctuate over time and that the optimal survey design may change over time, for example if anchovy were to increase substantially in abundance. If the survey is for multiple species, or has an ecosystem emphasis, further work may be required to estimate the utility of stratified versus uniformly-distributed sampling effort.

2.1.3 Trawl sampling

The current survey design utilizes trawl samples obtained during the egg surveys to provide species proportions and length distributions. Trawls generally occur at night on dispersed fish at predetermined, well-spaced stations, with the addition of a few *ad hoc*, target trawls. The data are used to apportion the CPS backscatter to species and estimate target strength (TS; dB re 1 m^2) values for estimating abundances.

A potential concern with the trawl sampling is that there may be species selectivity; selectivity for size is less likely, except for 0-group animals. There appears to be considerable spatial separation among CPS species, especially during the summer survey, indicating that species proportions are relatively well established. Although nighttime catches are not coincident with daytime acoustic observations, the Panel considered this to be a minor issue for Pacific sardine and jack mackerel because the areas occupied by these species are generally homogeneous. Increased effort will be required in areas dominated by the less abundant species, if useable estimates of abundance are needed for the full range of all species.

If estimates of species selectivity were required, the Panel notes that the effects of 'gross' species selectivity may be detectable by comparing the ratios of mean catch rates and acoustically-estimated densities where single species dominate. If the ratios were similar this would indicate that catch rates were similar (assuming TS is correct). In contrast, if there were significant differences, this would indicate the potential for species selectivity, but not identify its cause. In the long-term, efforts should be made to evaluate if different fishing practices or gears, or both, would facilitate daytime fishing on target fish schools for improved species identification and TS estimation.

2.1.4 Allocation of effort between trawl and transect data collection

The balance of time spent sampling acoustically along transects and with trawls at stations is currently based on the needs of the DEPM surveys. This balance appears to be adequate at present, although a different balance may be optimal. The current variance estimation procedure could be utilized to investigate an optimal sampling strategy in terms of variance in the estimated biomass. However, some studies (e.g., Simmonds and MacLennan, 2005; Simmonds *et al.*, 2009) suggest that a broad range of time allocations lead to similar overall variance estimates, which indicates that optimization of the time allocation may not be a critical issue.

2.1.5 Multi ship issues

The use of multiple vessels in standard assessment surveys may add complexity to the interaction between the observer and the observed. The present surveys were conducted using four vessels ranging from 41 to 65 m in length, with displacements ranging at least two fold. Such differences require consideration of the following issues:

- Vessel noise may potentially affect fish behavior during surveys. Fish may avoid the sound source, either by diving or moving to the side, or both. Such behavior may lead to reduced fish density under the transducer during the moment of recording. Furthermore, TS might change as a result of changing fish tilt angle during the avoidance response, thus impacting, in most cases reducing, estimates of density. Some studies (e.g. Dagorn *et al.*, 2001; Røstad *et al.*, 2006) suggest that vessels may attract fish, thus increasing densities measured by acoustics. The International Council for the Exploration of the

Seas (ICES) has therefore recommended using noise-reduced vessels to reduce these potential impacts.

- Other parts of the sound spectrum, particularly infrasound, also appear to be responsible for changes in fish behavior in response to survey vessels (Ona *et al*., 2007; Sand *et al*., 2008). This implies that noise as measured by the ICES standard (Mitson, 1995) does not necessarily reflect the strength of the vessel's avoidance stimulus. Rather, the stimulus may be more associated with the size of the vessel and its displacement than the noise emission.
- Visual stimuli may attract fish similarly to a Fish Aggregating Device and will affect observations in shallow water and at short distances from the vessel.

Further complexity in potential fish behavior is caused by interactions among the above sources. This is reflected in the literature as large variability in the observed responses of fish to survey vessels. In the present case, the vessels vary substantially in size and horse power and have different propulsion and noise-reducing arrangements. The potential exists for vessel-specific impacts on the survey results if the target species are sensitive to any of the stimuli described above (Hjellvik *et al*., 2008). As an example, the FV *Frosti*, which is considered a noisy vessel by the Team, recorded fish closer to the surface than the other vessels. If vessel noise represents the stimulus, it could signify a vessel avoidance effect. On the other hand, *FV Frosti* is the smallest ship (least displacement) and the vessel difference could be due to infrasound impacts from the larger vessels (Ona *et al*., 2007; Sand *et al*., 2008).

The issue of avoidance is discussed further in Section 2.2.4.

2.1.6 Timing of acoustic and trawl sampling

Pelagic species have diel and seasonal behavioral characteristics which can have large impacts on survey results. These characteristics may influence the results due to variations in the availability of the fish to acoustic sampling as a result of their vertical and horizontal movements. The acoustic sampling occurs during the day when the CPS are typically aggregated deeper, and trawling occurs at night when the CPS are typically dispersed near the surface. The current trawl and vessel configurations have been generally unsuccessful catching schooling fish during the day. The Panel **agrees** that conducting acoustic sampling during the day and trawling at night is a reasonable approach because the available effort is used efficiently. Nevertheless, validation of CPS backscatter to species and size should be improved through target-trawl sampling.

The Panel also notes that the trawl catches are small compared to those in other acoustic-trawl surveys, which emphasizes the question whether trawl catches are representative of the populations. It **recommends** further investigation of how trawls are allocated to acoustic signals, for example by conducting sensitivity tests in which stations are pooled and allocated to acoustic values over a larger area.

In the longer-term, a goal is to have a trawl and vessel configuration that can support target-trawl sampling. This would increase the number of samples, and enhance the representativeness of the trawl samples to species and their sizes in the populations sampled acoustically. Also, repeated trawl sampling experiments could lead to a better understanding of small-scale variability and could help improve the sampling design.

2.1.7 Trawl design and operation

Appendix 5 outlines the design of the Nordic trawl used during the trawls. Trawl efficiency depends on the interaction between trawl design and use and fish behavior. This may cause size- and species-selectivity due to: (a) fish avoiding the trawl before entering the net; (b) fish escaping through the meshes near the mouth of the net; and (c) fish escaping through the meshes in front of the codend. The latter problem is particularly probable if there is a large change in mesh size from the trawl to the codend and the net is towed at a high speed. If pelagic species exhibit schooling rather than individual behavior, these problems may be minor. However, the low trawl catches may indicate individual behaviors of the fish during the trawls, which could influence species and size selection. Concerning species-selection, there are normally species-related behavioral characteristics that influence trawl selectivity and may affect estimates of species proportions in areas where the species are mixed. This may be the case here, but selectivity is not limited to this particular trawl design. For the survey and sampling design used here, the trawl appears to be adequate, but the small catches call for further studies, likely leading to improvements to the trawl sampling.

The Panel **recommends** that experts in trawl design should be consulted to evaluate the gear and fishing protocols in relation to the survey objectives. The available drawings (Appendix 5) indicate that the small-mesh codend is very short and the change in mesh size from the codend to the trawl is large. This could cause the so-called "bucket effect". This is partly documented and partly anecdotal information about a large loss of fish in front of the codend due to a combination of trawl design and trawling speed. In such cases, fish might swim in the transition zone between the codend and the trawl, and escape through the trawl meshes, and cause size- and species-selection (see e.g. http://www.worldfishing.net/features101/product-library/fish-catching/trawling/increasing-efficiency-in-pelagicsemi-pelagic-trawling; Fernoe and Olsen, 1994; Wardle *et al*., 1986). Simple adjustments, e.g., increasing total length and mesh size of the codend and the extension piece, could mitigate this potential problem

Over long-term, the efficiency and selectivity of the trawl could be tested by comparing samples from same area taken with the survey trawl and a purse seine. Further, state-of-the-art acoustic and optic technology allows direct observation of trawl efficiency by observing fish behavior and escapement at various critical positions of the trawl. The panel **recommends** that such approaches be pursued and that, in the long-term, trawl and vessel configurations be used that enable direct sampling of pelagic schools.

2.1.8 Acoustic equipment specifications

The acoustic data collected depends on the type of equipment installed and the settings decided at the start of the survey. For vertical echosounders, several issues should be considered in relation to these settings:

- Choice of frequencies. Each group of species is better observed by a given set of frequencies (e.g., plankton, small and big fish, fish with and without swimbladders, and squids). Multiple frequencies allow for group differentiation.
- 'VRM extraction process and overall threshold'. This may lead to exclusion of some of the total biomass (mostly plankton, but also small non-schooling fish), and must consequently be set given the survey objectives. This is especially important for visual analysis of the echograms.

- Ping rate. The ping rate will affect the description of small spatial structures (e.g., schools). A too low ping rate results in a loss of information about these structures, while a too high rate will lead to redundant data. The use of multiple acoustic devices may impose a certain ping rate, but this may affect the precision of the results or their use for some particular research topics, principally studies on school structure and behavior
- Transducer location. The choice between a fixed and a towed transducer depends on the location of the target species (e.g., shallow versus deep).
- Complementary sensors. Use of additional acoustic devices (e.g., multibeam and short-range and long-range scanning sonar may be used for behavior and avoidance observations; an ADCP may be used for measuring vertical stratification of the seawater and for describing habitat features) can add information, but this may affect fish behavior (e.g., the sonar signal may affect schools) or the transmission rates of other devices.

In relation to these considerations, the acoustic-trawl surveys have been conducted with four to five frequencies (typically 18, 38, 70, 120, and 200 kHz). The use of a vertical echo sounder is appropriate for assessing fish distribution and estimating abundance. Multiple-frequency data are likely to permit automatic group recognition (e.g., plankton versus fish versus invertebrates) and potentially species identification. Multiple-frequency methods were applied for apportioning the acoustic backscatter to CPS (e.g., Demer *et al*., 2009) as detailed in Demer *et al.* (background document).

The transducer is mounted on a blister or keel extending from the vessel hull, precluding observation of animals present nominally 10 m below the surface. The vertical echosounder is unable to provide information about organisms residing near the surface, particularly at night. However, this is not a concern for abundance estimation because the acoustic observations contributing to the biomass estimates are made during the day. The pulse-repetition interval is, in general, 0.5 seconds, or one ping each 2.5 m at 10 knots. This may be low for observing small, near-surface schools close to the vessel, but is adequate for estimating biomass.

The Panel **agrees** that the acoustic specification is appropriate for abundance estimation, noting that a layer near the surface is not sampled (see also Section 2.2.3 on avoidance). However, the acoustic sampling may not be adequate for research on school characteristics and a description of the global pelagic ecosystem.

The Panel **recommends** that the team continues to: (a) consider other existing methods (e.g. Lawson *et al*., 2001; Haralabous and Georgakarakos, 1996; Kloser *et al.* 2002; Lebourges-Dhaussy and Fernandes, 2010) for species identification; (b) evaluate the potential use of non-vertical echosounders; (c) develop methods that categorize the acoustic record and thus support automatic species identification, and (d) work on definition and precision of the VMR process.

2.2 Analysis of the survey data for estimating CPS abundances

2.2.1 Filtering Algorithm

The method most commonly used elsewhere to identify acoustic backscatter from a target species is to conduct trawls on various types of backscatter. Once the sources of the various types of backscatter have been identified, the backscatter is classified using a rather laborious process, relying heavily on expert judgement. A different approach is used for the acoustic-trawl surveys of CPS. A series of filters, including those based on the variance to mean ratios (VMR;

Demer *et al.*, 2009) and differences in volume backscattering strength measured at multiple frequencies, are used to apportion the backscatter to CPS and other organisms. Although the initial development of the filtering algorithm was based on nighttime tows and expert judgement (without the benefit of daytime target tows), application of algorithm is a completely numerical process. The Panel **accepts** the filtering approach as being appropriate, but **recommends** that it is checked every year to ensure that it remains effective under changing conditions. Furthermore, tows on various kinds of backscatter should be added to routine survey operations to assure that the filtering algorithm accurately identifies backscatter from CPS, as intended.

2.2.1 Target strength

No TS measurements are available for *in situ* CPS from the CCE. Used instead are published TS versus length relationships for the same or similar species in other ecosystems. While this substitution is not ideal, the Panel **agrees** that such TS estimates likely do not have a large impact on abundance estimates (probably less than 5 %). The largest error may result from the use of Chilean jack mackerel TS for Pacific mackerel. TS measurements of *in situ* CPS are difficult to obtain, but the effort should be made to do so in future CPS acoustic-trawl surveys. Alternative approaches such as school capture with purse seine, inference from models, and multi-frequency observations of *ex-situ* fish could be explored if it is considered that TS measurements of *in situ* CPS are not feasible.

2.2.2 Abundance estimation

The surveys are post-stratified into strata which exclude, in most cases, a region of contiguous survey transects where no CPS were detected. The approach for estimating abundance is then to sum over strata the area of each stratum multiplied by the mean transect density. This is a standard approach, and the Panel **agrees** that it is appropriate. The Panel notes that some of the strata do not have uniform transect coverage, which could be a problem, but **agrees** that this is relatively inconsequential for abundance estimation. (If this becomes an issue, transect estimates can be weighted by their inter-transect spacing.) CPS backscatter is assigned to species based on the species composition of the nearest trawl, which is a reasonable approach, but this relies on the untested assumption that species composition in the trawl is representative of the fish sampled acoustically. While this assumption can be questioned, it is fairly standard when analysing data from acoustic-trawl surveys. The Panel would have liked to have seen a more rigorous comparison of the CPS catch in the trawls with the backscatter attributed to CPS along the transects, but did not have a good idea about how to do this. In addition, the Panel discussed alternative approaches for ascribing the acoustic backscatter into the different species using the trawl data. These issues need to be explored further (see also Section 2.1.7).

2.2.3 Avoidance

Fish response to vessel passage has been documented for small pelagic species in other areas (e.g. Freon and Misund, 1999). There is a potential for bias in abundance estimates from acoustic surveys if vessel passage causes fish to change their orientation in the water column, or exhibit some kind of consistent movement, either avoidance or attraction. Echosounders used in the CPS acoustic-trawl survey are mounted approximately 3.75 to 7.5 m deep. Sardine, in particular, are often found near the surface at least at some times of the year, and fishermen have noted strong avoidance responses to vessel passage. This is a critical issue to address when deciding how or whether to use the abundance estimates based on acoustic-trawl data for stock assessment. The Panel consequently spent considerable time discussing the issue of avoidance.

The influence of fish avoidance has been investigated using two approaches: (a) the distribution under and to the side of the vessel was examined using multibeam sonar, and (b) volume backscattering (S_v; dB re 1 m^{-1}) of fish schools observed in successive pings was examined to test the hypothesis that a vessel impact would lead to a reduction in S_v and an increasing average depth during passage. Studies with similar equipment on European pilchard in the Mediterranean Sea show increased schools off track (Soria *et al*., 1996), while Chilean sardine in contrast showed no increase in schools off track (Gerlotto *et al*., 2004). Results from the first study indicated that CPS school counts peaked sharply under the vessel, and declined steadily with distance away from the vessel track and depth, suggesting no increase in schools off track, as might be expected if there is lateral movement in response to the vessel. Results from the second study indicated that in most cases for CPS in the CCE there was little evidence for differences in depth or backscatter from the front to the end of schools, suggesting that any diving behavior takes place before the school passes through the acoustic beam, although a minor diving apparently was noted when schools were shallow. The Panel did not consider this very strong evidence for lack of avoidance, since other interpretations are possible, but definitely useful information which should be considered when drawing conclusions during the review

The Panel **concludes** that, based on the information presented during the meeting, vessel-induced behavior, including vessel-specific behavior, although clearly demonstrated vertically, appears unlikely to have a substantial effect on the estimates of CPS biomass during the present surveys. However, the Panel notes that the results related to the potential for lateral avoidance are somewhat difficult to interpret without reference to expected patterns under alternative hypotheses of fish response. Nevertheless, they do not appear to be suggestive of large avoidance effects.

Although the Panel concluded that vessel avoidance has been studied using appropriate methods and there was no evidence for substantial avoidance effects, the issue warrants further study. For example, variation in vessel size (41m – 65m) and survey speed (11-14 knots) calls for further follow up studies. Future studies should resolve the information by species and address the possibility of spatial and temporal variability in potential vessel effects.

- The frequency response of schools should be studied for trends versus depth, e.g. utilising frequency-dependent directivity (Godø *et al*., 2006). A change in fish tilt angle due to vessel-induced avoidance will affect higher frequencies more than lower frequencies. The frequency response may change versus depth if avoidance behavior diminishes with depth beneath the vessel.
- Differences in the transducer beamwidths (12º for the 18 kHz transducer versus 7º for the other frequencies) could be used to observe fish diving beneath the vessel. The wider beamwidth will be less sensitive to changes in fish orientation than narrower beamwidth. Thus, an avoidance reaction may be indicated if depths measured at the top of schools are shallower in the 18 kHz recordings compared to the other frequencies.
- Long-term research should use more advanced instrumentation and methods for studying potential vessel effects and avoidance. In particular, the Panel suggests that a vessel by vessel study following the model of the Bering Sea comparative studies be conducted.

The Panel was informed that sophisticated multibeam systems (Simrad MS70 and ME70) will be available on the new SWFSC vessel in near future. This represents state-of-the-art instrumentation to clarify issues related to school behavior in the vicinity of the vessel and should be fully utilised to clarify vessel impact factors. Presently, not all vessels have been noise measured according to the ICES standard. Standard vessel noise measurements should routinely be conducted to allow comparison of stimuli and fish reactions to allow vessel comparisons in the future.

2.2.4 Characterization of uncertainty

Uncertainty is characterized using a Monte Carlo approach. Specifically, a bootstrap resampling approach is used to characterize between-transect variance and a jacknife-like approach (removing one trawl for each Monte Carlo replicate) is used to quantify uncertainty due to trawl location. The Panel **agrees** that the bootstrap approach for estimating transect density variation is appropriate given the lack of autocorrelation. However, the jackknife, which attempts to characterize a potentially important source of uncertainty in a pragmatic manner, would lead to negatively-based estimates of uncertainty, although the magnitude cannot be evaluated. The Panel discussed alternative approaches to characterizing trawl uncertainty, but all were considerably more complex than the approach used. The Panel thought that a simple solution would be preferable, and **recommends** further work on this issue before estimates of abundance based on the acoustic-trawl surveys are used in assessments.

The Panel considered other potential sources of uncertainty in the abundance estimates, such as TS and the parameters of the filtering algorithm. The Panel **concludes** that uncertainty in TS is unlikely to be large compared to those due to trawl location and particularly between-transect variation in density to be worth quantifying at present. Uncertainty in the filtering algorithm is difficult to evaluate, but is certainly present. However this kind of uncertainty is seldom quantified in acoustic surveys, so the CPS surveys follow conventional procedures in this regard.

2.3 Use of acoustic-trawl survey data in stock assessments

The Panel evaluated how the acoustic-trawl data could be used in PFMC assessment and management for each of the four finfish CPS species, noting that the information available differs markedly among these species and that the basis for the management advice differs between monitored and actively managed species. The focus for Panel discussions was Pacific sardine which is currently the CPS species with the largest biomass. Not unexpectedly, there was less information for the other species and the Panel is unable to make as definitive conclusions for jack mackerel, Pacific mackerel, and northern anchovy as for Pacific sardine.

2.3.1 *Pacific Sardine*

Pacific sardine are an actively-managed CPS species with an SS3-based stock assessment. Estimates of abundance based on acoustic-trawl data can be included in this stock assessment as absolute estimates of abundance or as relative indices of abundance. Given the relatively short time-series of abundance estimates, including the acoustic-trawl data as relative indices of 1+ biomass would likely not impact the assessment results substantially (but this should be examined in the assessment). The major potential sources of uncertainty related to using the acoustic-trawl data as estimates of absolute abundance identified during the review were:

- The relationship between TS and length are not based on measurements of *it situ* CPS from the CCE.
- Sardine may avoid the vessel to some extent.
- A proportion of the sardine stock may reside outside of the area covered by the acoustic transects, with the proportion depending on season as well as environmental conditions.

In relation to the first and second of these sources of uncertainty, information presented to the Panel suggests that they are unlikely to be substantial (see Sections 2.2.1 and 2.2.4 above). In contrast, Fig. 1 suggests that an inshore correction (in summer survey) of up to 15 % of the total abundance estimate may be needed.

Given current information, the Panel **agrees** that the acoustic-trawl surveys can be considered to provide estimates of absolute abundance for the survey area with the associated length-composition, and the assessment author should consider the use of these data in the September 2011 sardine assessment. It **recommends** that prior to the September 2011 assessment, analyses be conducted using auxiliary information (e.g., trends in density along transects, information from ichythoplankton surveys south of the survey area, and catch information) to provide best estimates for the biomass outside of the survey area as well as range of possible biomass levels. In addition, the CVs for the estimates need to be modified to fully account for the uncertainty of the trawl data (see Section 2.2.4).

The Panel **recommends** that the assessment should: (a) examine the sensitivity of the results to alternative acoustic-trawl abundance estimates; (b) determine if use of the acoustic-trawl results as absolute estimates of abundance leads to patterns in the residuals; (c) examine the implications of ignoring some or all of the acoustic trawl estimates [e.g., the estimates from the summer 2008 and spring 2006 surveys], and (d) treating these estimates as relative indices of biomass. Treating any survey estimate as an absolute estimate of abundance is a strong constraint in stock assessment models, and the appropriateness of that assumption can only be evaluated in the context of the other information available for the assessment.

The Panel **recommends** that future STAR Panels review any research conducted in relation to acoustic-trawl surveys, and how these data are used to estimate absolute abundances of CPS.

2.3.2 *Jack mackerel*

Jack mackerel are a monitored CPS species. There are few recent data on which to base estimates of abundance and distribution for this species. The acoustic-trawl survey data are the only scientific information on abundance for the area surveyed. The Panel **agrees** that even though less information is available for this species than for Pacific sardine on the key uncertainties, the estimates of absolute abundance for the survey area can be used as estimates of the biomass of jack mackerel in US waters (even though they may not cover all US waters). The catchability for jack mackerel may not be the same as that for Pacific sardine. The estimate for summer may therefore be more reliable as the various CPS are more separated at that time.

2.3.3 *Pacific mackerel*

While there is no reason why the acoustic-trawl surveys cannot be used to provide estimates of abundance for Pacific mackerel, the estimates of abundance for Pacific mackerel are more uncertain as measures of absolute abundance than for jack mackerel or Pacific sardine. This is reflected by very high CVs for the spring surveys. A major concern for this species is that a sizable (currently unknown) fraction of the stock is outside of the survey area. While the estimates for survey area are valid, if the acoustic-trawl 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.

2.3.4 *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. A few northern anchovy were sampled nearshore, mostly off Oregon and Washington (2006, 2008, and 2010), north of Monterey Bay (2006) and in the Southern California Bight (2006 and 2008). Apart from the occasional large catches (~ 300kg) off the mouth of the Columbia River and other locations such as off Santa Barbara and Monterey Bay, anchovy were scarce in these surveys, even off southern California where they once were the most abundant species. The sampling scheme would need to be modified (more transects and trawls in the areas where northern anchovy are found) if estimates of abundance of northern anchovy are needed given its current abundance.

3. AREAS OF DISAGREEMENT REGARDING PANEL RECOMMENDATIONS

There were no major disagreements between the Panel and the Team or among Panel members.

4. UNRESOLVED PROBLEMS AND MAJOR UNCERTAINTIES

The CCE has seen major changes in CPS abundance historically, and there should be little doubt that similar changes will occur in the future. Any long-term survey program for CPS should be designed to respond adaptively to changing conditions. Monitoring increases and declines of CPS is likely to present difficulties if range expansion and contraction occurs at the same time that abundance changes. In addition, changes in abundance and range may affect species mixing and overlap and thus increase uncertainty due to trawl sampling given the existing sampling strategy. Although precise estimates of abundance of monitored species (northern anchovy and jack mackerel) are not presently required by the management system, some ability to track the abundance of these species is desirable. For northern anchovy, abundance estimates using the current layout of transects is not feasible, and consideration should be given to a periodic focus on this species for baseline monitoring.

5. MANAGEMENT, DATA OR FISHERY ISSUES RAISED BY THE PUBLIC AND CPSMT AND CPSAS REPRENTATIVES

The following issues were presented by the CPSAS representative as issues of concern:

- Spatial range of survey
- Survey timing
- Vessel avoidance

Appendix 6 includes a statement provided to the Panel by the CPSAS Advisor, further elucidating his concerns.

6. RECOMMENDATIONS FOR FUTURE FOR FUTURE RESEARCH AND DATA COLLECTIONS

1. Immediate (prior to the next stock assessments)

a. Analyses be conducted using auxiliary information (e.g. trends in density along transects, information from ichythoplankton surveys south of the survey area, catch information) to provide best estimates for the biomass outside of the survey area as well as the range of possible biomass levels.

b. The CVs for the estimates need to be modified to fully account for the uncertainty of the trawl data.

2. Short-term

a. Investigate potential species selectivity effects by comparing the ratios of catch rates and acoustically-estimated densities in areas where single species dominate.
b. Compare total CPS backscatter along transects to trawl catch rates using statistical techniques.
c. Conduct sensitivity tests in which stations are pooled and allocated to acoustic values over a larger area.
d. Consult experts in trawl design to evaluate the current trawl design in relation to the survey objectives
e. Develop methods that categorize the acoustic record and thus support automatic species identification and continue to work on definition and precision of the VMR process
f. Evaluate the potential use of the echosounder in a non-vertical position.
g. Check the filtering algorithm every year to ensure that it is still suitable under changing conditions.
h. Study trends in frequency response over depth strata in schools.
i. Compare results from the 18 kHz and other transducers to examine possible avoidance reactions.
j. Continue to consider the advantages and disadvantages of conducting acoustic-trawls surveys at different times of the year.
k. Evaluate the potential to give age-based abundance or biomass estimates for sardine and consider their utility in the SS3 assessment given the lack of contrast in length-at-age at older ages and the ability to directly estimate total mortality from the survey result.
l. Conduct standard (ICES) vessel noise measurements for all vessels.

3. Long-term

a. Evaluate if different trawling practices or gears, or both would be beneficial
b. Use the current variance estimation procedure to investigate the trade-offs in terms of variance of different time allocations between acoustic transect and trawl data collection.
c. Use a trawl/vessel configuration that can support directed trawl sampling.
d. Conduct repeated trawl sampling experiments to obtain a better understanding of small-scale variability.
e. Test the efficiency and selectivity of the trawl by comparing samples from same area taken with the survey trawl and purse seine.
f. Apply state-of-the-art acoustic and optic technology to investigate fish behavior and escapement at various critical positions of the trawl.
g. Conduct validation tows on various kinds of backscatter to assure that the filtering algorithm is performing as intended to apportion backscatter to CPS.
h. Make efforts to obtain TS measurements for *in situ* CPS in the California Current Ecosystem.
i. Focus on utilizing more advanced instrumentation and resource-demanding research for studying vessel impacts.

Although the review focused on abundance estimation, the Panel recognised that acoustic-trawl data could be used in ecosystem studies and for ecosystem based fishery management. Recommendations about this broader use of acoustic-trawl data are:

- estimate plankton biomass;
- describe the vertical habitat (e.g. thermocline, oxycline, currents, and plankton); and
- estimate school characteristics which may provide information on species and on possible changes in the fish behavior due to environmental variations.

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Table 1: Relative merits of spring and summer surveys for Pacific sardine.

Factor	Spring	Summer
North/South geographic coverage	Stock may extend into Mexico.	Stock may extend into Canada.
Onshore/offshore coverage	Stock mostly offshore, but distribution is more extensive.	Stock mostly inshore; fishing regularly inshore of current survey lines.
Migrating at time of survey	Potentially.	Potentially.
Species separation	More mixed-species samples.	Species more geographically segregated.
Sampling precision (per transect mile)	Lower, with current survey design, due to distributed spawning-stock distribution.	Higher, with current survey design, due to greater east-west concentration of the stock.
Hours of daylight	Lower, allowing more time for species-identification samples.	Higher, allowing more time to for acoustic sampling along transects.

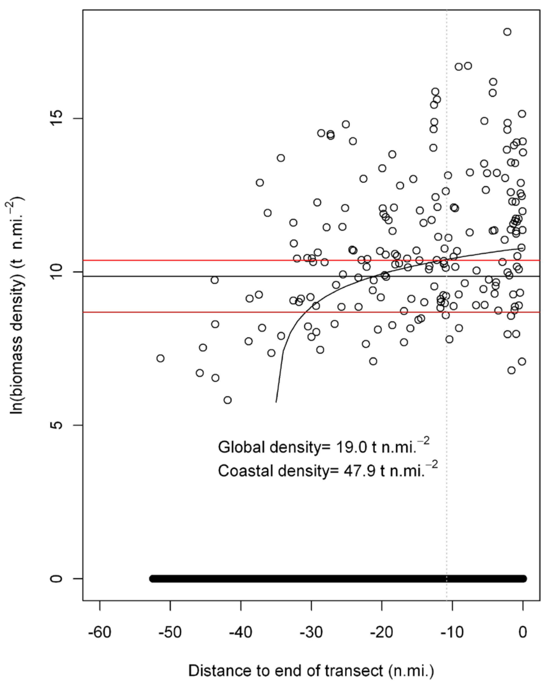

Figure 1. Relationship between biomass density and distance to the eastern end of a transect, based on the summer 2010 survey.

Appendix 1: List of Participants

Methodology Review Panel Members:

André Punt (Chair), University of Washington, Scientific and Statistical Committee (SSC)
Martin Dorn, National Marine Fisheries Service (NMFS), Alaska Fisheries Science Center, SSC
François Gerlotto, IRD, Center for Independent Experts (CIE)
John Simmonds, European Commission Joint Research Centre, CIE
Olav Rune Godø, Institute of Marine Research, CIE

Pacific Fishery Management Council (Council) Representatives:

Greg Krutzikowsky, Oregon Department of Fish and Wildlife, Coastal Pelagic Species Management Team (CPSMT)
Mike Okoniewski, Pacific Seafood, Coastal Pelagic Species Advisory Subpanel (CPSAS)
Kerry Griffin, Council Staff

Acoustic-Trawl Survey Technical Team:

David Demer, NMFS, Southwest Fisheries Science Center (SWFSC)
Kyle Byers, NMFS, SWFSC
George Cutter, NMFS, SWFSC
Josiah Renfree, NMFS, SWFSC
Juan Zwolinski, NMFS, SWFSC

Others in Attendance

Briana Brady, California Department of Fish and Game (CDFG), CPSMT
Ray Conser, NMFS, SWFSC, SSC
Ken Cooke, Department of Fisheries and Oceans, Canada
Paul Crone, NMFS, SWFSC, CPSMT
Emmanis Dorval, NMFS, SWFSC
Sam Herrick, NMFS, SWFSC, CPSMT
Roger Hewitt, NMFS, SWFSC
Kevin Hill, NMFS, SWFSC
Josh Lindsay, NMFS, Southwest Regional Office
Nancy Lo, NMFS, SWFSC
Sam McClatchie, NMFS, SWFSC
Beverly Macewicz, NMFS, SWFSC
Bill Michaels, NMFS, Science and Technology
Dianne Pleschner-Steele, California Wetfish Producers Association, CPSAS
Sarah Shoffler, NMFS, SWFSC
Dale Sweetnam, CDFG, CPSMT
Russ Vetter, NMFS, SWFSC
Cisco Werner, NMFS, SWFSC

Appendix 2: Panel Biographical Summaries

André E. Punt is a Professor of Aquatic and Fishery Sciences at the University Washington, Seattle. He received his B.Sc, M.Sc and Ph.D. degrees in Applied Mathematics at the University of Cape Town, South Africa. Before joining the University of Washington, André was a Principal Research Scientist with the CSIRO Division of Marine and Atmospheric Research. His research interests include the development and application of fisheries stock assessment techniques, bioeconomic modelling, and the evaluation of the performance of stock assessment methods and harvest control rules using the Management Strategy Evaluation approach. He has published over 170 papers in the peer-reviewed literature, along with over 400 technical reports. André is currently a member of the Scientific and Statistical Committee (SSC) of the Pacific Fishery Management Council and chair of its Coastal Pelagic Species subcommittee, the Crab PLAN Team of the North Pacific Fishery Management Council, and the Scientific Committee of the International Whaling Commission.

Martin Dorn is a Fisheries Research Biologist at the Alaska Fisheries Science Center, NOAA Fisheries, in Seattle, USA. He holds a M.Sc. in Biomathematics and a Ph.D. in Fisheries from the University of Washington. Martin has been involved in research on management strategy evaluations to evaluate impacts of climate and ecosystem change, modelling fishing behavior, and applying Bayesian methods to resource management problems. His current research focuses on the Bayesian meta-analysis of fish populations, and the development of cooperative research programs to address fisheries management issues. Martin leads the stock assessment team for walleye pollock in the Gulf of Alaska. He has been a member of the ICES working group on the ecosystem effects of fishing activities (WGECO) and the ICES study group on the use of acoustics on fishing vessels. He is Chair of Scientific and Statistical Committee (SSC) of the Pacific Fisheries Management Council and is an Affiliate Associate Professor at the School of Aquatic and Fishery Sciences at the University of Washington, Seattle.

Dr François Gerlotto (PhD, HDR, *Directeur de Recherches de 1ère Classe*) is a fisheries ecologist who specializes in pelagic fish behavior, particularly schooling. He has expertise and extensive experience using underwater acoustics for direct observations of animals in pelagic ecosystems and has coordinated several EU projects in this field. He was Chair of the ICES Working Group on Fisheries Acoustics Science and Technology (1997-2000), and the ICES Fisheries Technology Committee (2005-2007), and is currently the Chair of the ICES Study Group on fish avoidance to research vessels (see www.ices.dk). He was Convenor of the steering committee of the ICES Symposium on Fisheries Acoustics, in Montpellier, 2002. As an IRD scientist, he has worked for 20 years in/with South American and Caribbean countries as director of a partner's fisheries department (FLASA, Venezuela), Director of ORSTOM/IRD research units (1994-2004), coordinator of international networks (Caribbean Acoustic Network, 1991-2001, ECHOSPACE, 1991-1993), and as a scientist in several IRD projects. He is presently a member of the inter-institute research unit (UMR) EME n° 212 (Exploited Marine Ecosystems) in Sète, France, and Chairman of the IRD Scientific Commission CGRA1 (2008-2011: see www.ird.fr).

Olav Rune Godø is a senior scientist at Institute of Marine Research. He received his Cand. real. in fisheries biology and his Ph.D. in marine survey methods, both from the University of Bergen. He has worked in the Demersal Fish Department, served as Section Head in the Pelagic Fish Department before building a new Survey Methods Department, all duties at the Institute of Marine Research. Presently he is Chair of a new IMR initiative in marine ecosystem acoustics. His research interests include trawl-acoustic survey methods, fish behavior, biophysical interaction, and fisheries-induced evolutionary changes. He has published about 70 papers in peer-reviewed journals, several book chapters, and numerous technical papers and reports. Dr Godø has served on the board of four research programs of the Research Council of Norway, has been a member of the scientific steering committee of the Census of Marine Life, and has been a member of a SCORE WG on observation methods. He has also been a member of several ICES working groups.

John Simmonds is a Senior Fisheries Scientist at the European Commission Joint Research Centre, Ispra, Italy. He obtained BSc and MSc. degrees in Electronics and Underwater Acoustics in the UK. Before joining JRC he worked in fisheries research for 37 years at the FRS Marine Laboratory, Aberdeen, Scotland. He has worked with acoustic surveys of pelagic species for more than 30 years, and assessments involving acoustic, trawl, and egg surveys for more than 15 years. He is the author of a books on Fisheries Acoustics (1991 and 2nd Edition 2005), and has been responsible for developing approaches for combining acoustic, trawl, and ichthyoplankton surveys in assessments for North Sea herring. He has worked on absolute assessments using TAEP methods for North Eastern Atlantic mackerel and has developed extensive experience of fish stock assessment and fisheries management, chairing, among other groups, the herring survey planning group 1991-95, the ICES Fisheries Acoustics WG 1993-96, the ICES herring assessment working group 1998-2000, and the ICES study group on Management Strategies 2004-2009. He currently chairs the STECF group that prepares evaluations of the historic performance of management plans and the Impact Assessments for new multi-annual fisheries management plans.

Appendix 3: Primary documents reviewed

Documents prepared for the meeting

1. Demer, D.A, Zwolinski, J.P., Byers, K.A., Cutter, G.R., Renfee, J.S., Sessions, T.S. and B.J. Macewicz. Acoustic-trawl surveys of Pacific sardine (*Sardinops sagax*) and other pelagic fishes in the California Current ecosystem: Part 1, Methods and an example application
2. Zwolinski, J.P., Byers, K.A., Cutter, G.R., Renfee, J.S., Sessions, T.S., Macewicz, B.J. and D.A. Demer. Acoustic-trawl surveys of Pacific sardine (*Sardinops sagax*) and other pelagic fishes in the California Current ecosystem: Part 2, Estimates of distributions and abundances in spring 2006, 2008, and 2010

Other primary documents

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Appendix 4: Summary of information on the distribution of CPS species

Gregory Krutzikowsky (Chair), Ken Cooke, Nancy Lo, Mike Okoniewski

Background

The CPS Fishery Management Plan (FMP) is an outgrowth of the Northern Anchovy Fishery Management Plan and work began on incorporating other CPS into the Plan with Amendment 8 in June 1997. This summary draws from that work and references cited in that Amendment are not generally repeated here. Essential Fish Habitat for CPS has been defined as waters with SST 10 - 26ºC to the depth of thermocline, and a recent review of Essential Fish Habitat (EFH) confirmed this designation. It was noted that EFH for CPS changes seasonally and EFH may not encompass the entire range of these species. Life history and distribution of CPS are provided in Section 1 of Appendix A to Amendment 8 and details of the analysis, available data, and discussion of the management issues for harvest levels for US fisheries with these transboundary finfish stocks can be found in Section 4.1.3 of Appendix B to Amendment 8 with literature cited given in Appendix E (PFMC 1998). The best estimates of the portion of CPS stocks available in US waters were derived from CalCOFI egg and larvae collections (1951-1984) (Moser *et al*., 1993) and aerial fish spotter data (1964-1992). It was recognized that these stocks did not reside entirely in US waters so a distribution term was utilized to account for the portion available to US fisheries. The estimates represent an average of CalCOFI data for spring and summer and fish spotter data from summer through winter. The best estimate for the average annual distribution for Pacific sardine in US waters was 87% and that for the average annual distribution for Pacific mackerel in US waters was 70%. Best estimates for the average distribution in US waters for monitored stocks of jack mackerel and the central subpopulation of northern anchovy were 65% and 82%, respectively. Information available at that time suggested that a higher proportion of each stock was in US waters during Summer-Fall than in Winter-Spring. It was noted that it was unlikely that these estimates could be updated frequently, but that these estimates should be updated and refined if additional data became available, fishery conditions changed, and/or significant changes in stock biomass occurred. The spatial coverage of data collected did not allow for any distribution or seasonal estimates for the northern supbpopulation of northern anchovy in US waters.

It should be noted that the relative biomass of CPS species has changed substantially since those data were collected. The biomass of Pacific sardine has substantially increased and the range of habitat occupied has increased as well. Pacific sardine supported an important fishery in the Pacific Northwest (PNW) during the 1930s and 1940s. Sardines were rarely observed in waters off the PNW after the population crashed in the mid-1950s. Pacific sardine resumed migrating into PNW waters during the 1990s (Emmett et al. 2005). With the increase in Pacific sardine, northern anchovy as well as other species now make up a smaller percentage of the biomass of CPS in the California Current Ecosystem (CCE) than they did when those distribution and seasonal data were collected. More recent information on seasonal distribution comes from both fishery-independent surveys and fishery data. Surveys have concentrated their efforts in spring and summer and have rarely gone more than 200 nm from shore. Fishery effort appears to be concentrated relatively close to ports with processing capabilities, and also depends on the presence of CPS, fishery regulations and markets for fish.

Pacific sardine

The northern subpopulation of Pacific sardine ranges from the waters off northern Baja California, Mexico northward to southeastern Alaska, and as far as 300 nm offshore. The main spawning biomass is thought to be south of San Francisco within 150 nm offshore from late March to May. Pacific sardine moving northward start arriving in waters off Oregon and Washington in late May where they are thought to concentrate within 50 nm of the coast in recent years (Emmett *et al.*, 2005). However, in the mid-1990's sardine eggs were observed as far as 200 nm off shore (Bentley *et al.*, 1996).. It is also worth noting that young of the year Pacific sardine have been captured in fishery-independent surveys off Oregon and Washington in some years, suggesting successful reproduction in northern waters (Emmett et al. 2005). Fishery data indicate that there has been successful fishery effort from February to December and inside of 3 nm off Oregon, but Washington prohibits commercial fishing for sardine until April 1 and within 3 nm of its shoreline. Data from British Columbia, Canada indicate that Pacific sardine can be found in those waters from July through December. Anecdotal information from Canadian fishermen suggests that sardines are found in commercially harvestable quantities in the inlets of Vancouver Island, areas where fishery-independent surveys have not occurred. Fishery landings and effort in early spring, late fall, and winter months in the PNW, including British Columbia, are limited and factors such as inclement weather, the acceptability of the fish for market purposes, and regulatory closures in US waters in recent years may all contribute to this fact. Sardine were apparently absent from Oregon to British Columbia during the period of low sardine abundance, suggesting that the extent of migratory behaviour may become significant only during periods of relatively high abundance. These observations argue against having a too tidy conceptual model of Pacific sardine seasonal migration and the need to reconcile these observations of uncertain density varying among years with the information on potential habitat and survey observations of CPS density.

Jack mackerel

Jack mackerel range from the southern tip of Baja California, Mexico and the Gulf of California to 160º W in the Gulf of Alaska, offshore up to 500 nm (Blunt 1969, Mac Call 1983). Egg distribution from the DEPM and CalCOFI surveys suggests that jack mackerel have a more offshore distribution than Pacific sardine. Commercial landings of jack mackerel occur all year in California, with the highest catches in Monterey from March through May and the highest catches in Southern California from September through May. Commercial landings of jack mackerel in the PNW occur in the summer months. There is presently no targeted fishery for jack mackerel and landings occur as incidental catch primarily in the sardine fishery. Fishery-independent data in the PNW suggest that jack mackerel are caught in higher densities in summer than in spring, with the earliest catches in late May (Emmett et al. 2006).

Pacific Mackerel

Pacific mackerel range from Banderas Bay (Puerto Vallarta), Mexico, including the Gulf of California to southeast Alaska. They usually occur within 16 nm offshore, but have been captured more than 100 nm offshore. Data from US surveys indicate two spawning peaks in the survey area: Southern California in May and central Baja in August. There are fishery landings in California all year with the peak being from June to August. Pacific mackerel occur seasonally in the northern part of their range. Fishery-independent data from surveys conducted in Oregon and Washington waters off the Columbia River from late April to August out to 35 nm indicate that Pacific mackerel are caught in higher densities in summer than in spring, with the earliest catches in late May (Emmett et al. 2006). Landings in Oregon and Washington occur into October.

Northern anchovy

Unlike the other CPS finfish, northern anchovy are not thought to engage in strong seasonal migrations. They are, however, known to exhibit diel migrations. There are three subpopulations off the west coast of North America, two of which, the central and northern, are found in US waters. The distribution of northern anchovy appears to be more inshore than that for Pacific sardine. The central subpopulation is the most abundant of the three and is found from central Baja, Mexico to San Francisco, with the bulk of the population in the Southern California Bight. The northern subpopulation ranges from roughly Cape Mendocino in California to British Columbia. The spawning area for the northern subpopulation appears to be centered in the Columbia River plume in the summer months (Richardson, 1981, Emmett et al. 1997). Recent fishery-independent surveys utilizing surface trawls in waters off Oregon and Washington indicate that the northern subpopulation occupies waters to at least 35 nm offshore with higher catch densities closer to shore (Emmett et al. 2006, Litz et al. 2008) and fishery data indicate that this stock occupies very nearshore waters, including estuaries, in commercially harvestable quantities (pers com. L. Wargo, Washington Department of Fish and Wildlife). Data from fishery-independent surveys collecting egg and larvae conducted off California indicate that the spawning area for central subpopulation of northern anchovy has a generally more inshore distribution than Pacific sardine in recent years. Older data from CalCOFI cruises indicate distribution of eggs and larvae extended offshore to well beyond the 200 nm EEZ of the U.S. (Hewitt, 1980).

Appendix 5: Details of the Nordic 264 trawl

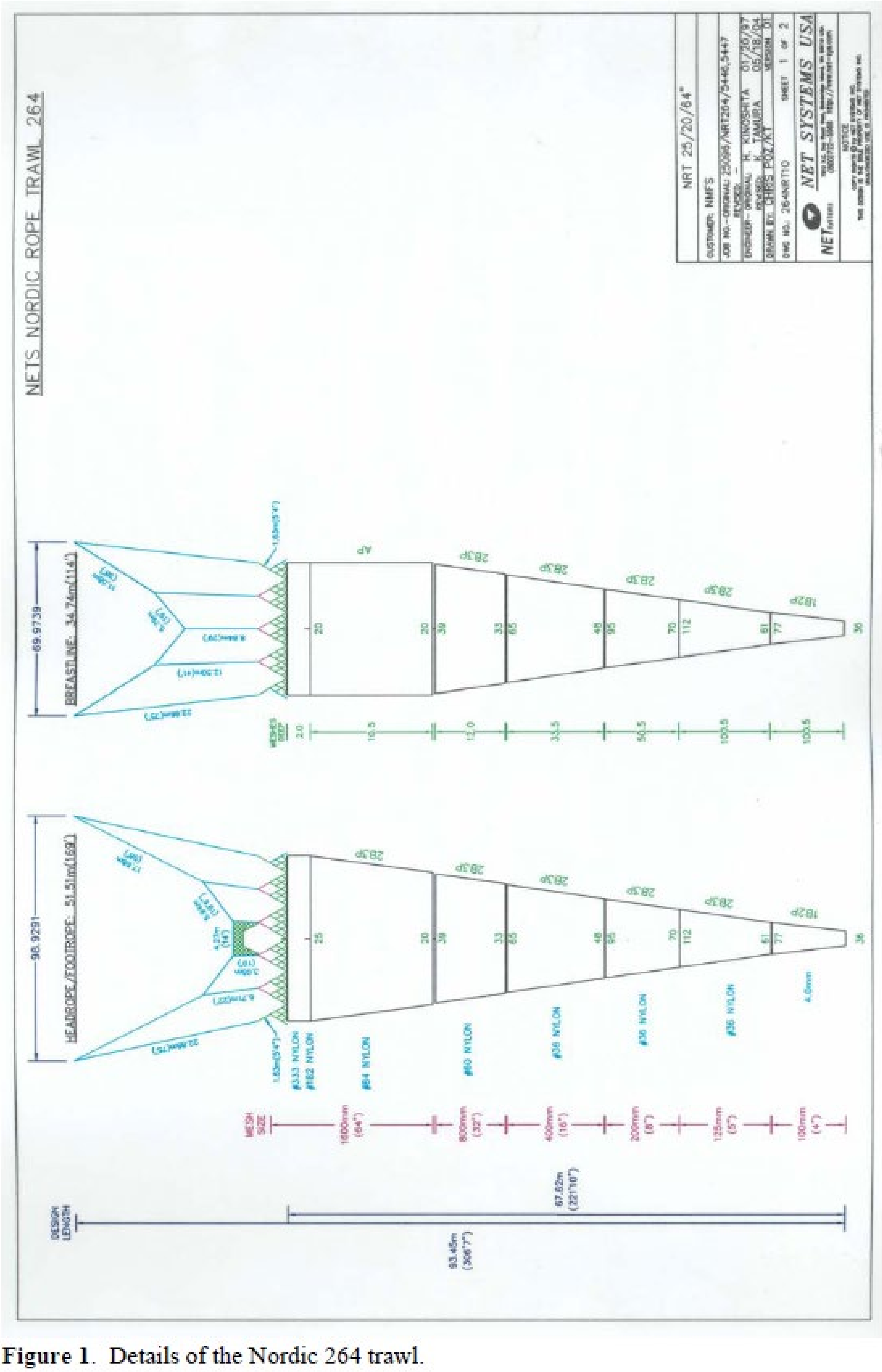

Figure 1. Details of the Nordic 264 trawl.

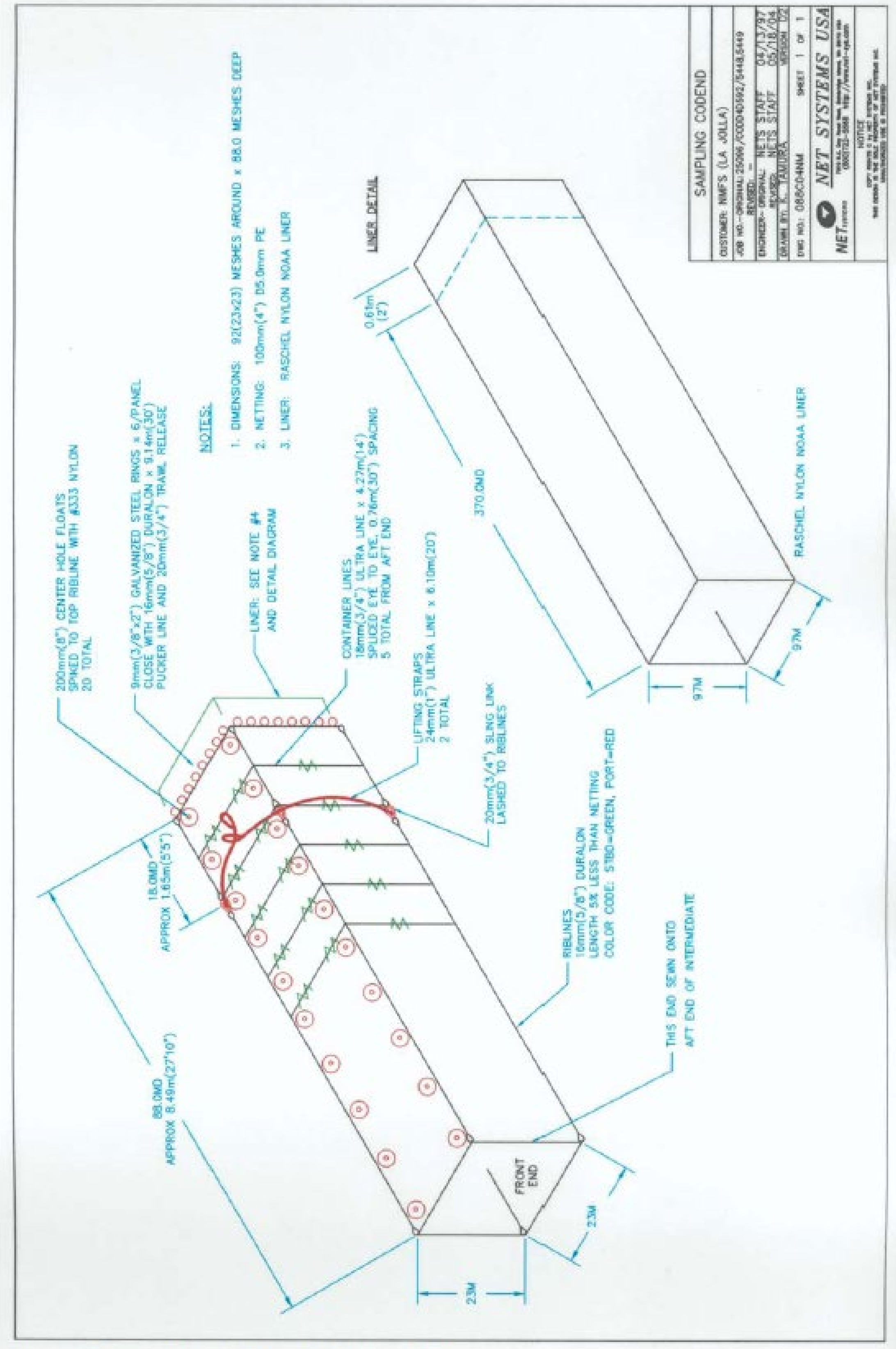

Figure 2. Details of the Nordic 264 codend.

Appendix 6: Statement of the CPSAS Advisor

First, I wish to applaud the SWFSC efforts to develop another survey that will inform the stock assessment model. While I have some specific issues with the acoustic-trawl surveys' measurement accuracy of the sardine populations in the Pacific Northwest (PNW), and lack of any survey work in Canada I believe this is an important step forward and commend Dave and his team for their work. There are 4 areas of concern I wish to address again: (a) northern and eastern range of the acoustic-trawl survey; (b) Timing of the survey in the PNW as it relates to habitat and migration theory utilized in the assessment; and (c) Vessel avoidance.

1. Range of survey: Ref: 2.2.1-2.1.2 & Appendix 5: 5-b (Dr. Cooke) The survey does not go into Canadian waters. The mean distance inshore for transects is approx. 10KM: Concerns: Canada harvest levels have risen in the last several years. DFO has done off shore swept trawl surveys with some estimates of abundance for the west side of Vancouver Island. Canadian fishermen anecdotal reports suggest there are heavy concentrations as far north as the Queen Charlottes. No effort is made in the US acoustic-trawl survey to measure this phenomenon. Per California (CA) fishermen the greatest amount of sardine harvest and concentration occurs within 3 miles of the shore. Per NW fishermen a great amount of the NW fishing effort and observed concentrations occur inshore of 10KM. It is worrisome to industry that the acoustic-trawl survey does not encompass the entire range of the population or go inshore in US waters in areas where fishermen see large aggregations of fish.
2. Acoustic-trawl survey timing: (no specific reference): Fishery data and anecdotal reports suggest that the greatest concentrations of fish are concurrently seen in both the PNW and Canada from early August/late September. CPUE rates support this time range. The acoustic-trawl survey relies heavily on habitat modelling and migration theory to support the idea that the A-T survey can successfully observe all fish by doing the survey in a June-July time frame before the fish theoretically migrate north into Canadian waters. Industry members wish to point out that the migration theory is based on tagging studies that occurred over 70 years ago. There is no conclusive evidence to suggest that the entire population migrated back to CA waters in the winter during the last expansion cycle or the current one. In fact there has been anecdotal evidence that at least a portion of the population over-winters in Canada and off the NW. To some extent this has been reinforced by fisheries data from landings in Canada in December and in NW landings that have occurred in every month except January.
3. Vessel Avoidance: Ref: 2.2.4: This topic was debated at length by the Panel: It was concluded that "there was no evidence for substantial avoidance effects." This is a point that industry is not willing to concede on a wholesale basis. Fishing vessels employing both fishing caliber sonar and echo sounding equipment simultaneously have reported that often they will observe sardines with the sonar but see nothing in the echo-sounders. This is by no means conclusive, but the prevailing consensus amongst NW and Canadian fishermen is that most often schooling sardines move laterally away from the vessel and not below it. This has been supplemented from a report and colored sonar recording graphs at the last sardine Tri National.

Conclusions: The CPSAS representative believes that the use of the acoustic-trawl survey represents an important step forward and that the Team has done an amazing amount of work in development of this survey. I believe the Panel has done an excellent job identifying and elucidating the issues.

CPSAS Future Recommendations:

1. Change timing of the survey to early August.
2. Extend the survey inshore and into Canada.
3. Use of sonar to better document vessel avoidance issues.
4. Use of Northwest Sardine Survey airplanes and cameras to do over-flights when acoustic-trawl survey vessels are doing transects in NW (Canadian?) waters.
5. Use of fishery data and fishermen knowledge to better understand whether sardines are behaving in accordance with migration and habitat theories.
6. Reevaluation of trawl equipment and technique.

Final question: Should the survey be used to formulate a relative or absolute measure of sardine abundance? I do not have the expertise to argue this question but I do have concern that the acoustic-trawl survey at this level of development is not observing all areas where there are substantial amounts of fish and that fish avoidance behavior may not be adequately understood.