METHODOLOGY REVIEW PANEL REPORT:
ACOUSTIC TRAWL METHODOLOGY REVIEW FOR USE
IN COASTAL PELAGIC SPECIES STOCK ASSESSMENTS

National Marine Fisheries Service (NMFS)
Southwest Fisheries Science Center (SWFSC)
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OVERVIEW

A review of the acoustic-trawl method (ATM), developed by the National Oceanic and Atmospheric Administration's (NOAA) 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 from 29 January – 2 February 2018. The Panel followed the Terms of Reference for Stock Assessment Methodology Reviews (June 2016). This is the second review of the ATM sponsored by the Pacific Fishery Management Council (Council). The previous review took place in 2011

The meeting began with a welcome by Dr. Gerard DiNardo, SWFSC. The Chair then identified the eight topics that provided a focus for discussions during the review as identified in the TOR: (a) ATM survey documentation; (b) target strength of CPS from the California Current, (c) trawl survey design protocols for using a CPS preferred habitat model to determine adaptive sampling areas, (d) effects of trawl survey design, (e) effects of upgrading from the Simrad EK60 to EK80, (f) effects of vessel avoidance for the upper water column, (g) ATM survey design in areas where the ATM vessel is currently not sampling, and (h) ATM data analysis and quantification of uncertainty. The Chair noted that it was agreed that topic (e) should not take up a large amount of time during the review, and should focus on summarizing the conclusions of workshops on comparing outputs from the EK60 and EK80 echosounders.

Dr. Paul Crone gave an overview of the CPS assemblage, and the management system currently in place for CPS. He indicated that the SWFSC considered the ATM survey as the highest quality data available and that the aim is to develop survey- and model-based assessments for CPS stocks. Dr. David Demer, Leader of the Advanced Survey Technologies Program, SWFSC, provided a summary of the objectives of the ATM program, overviewed the basic methodology and provided a summary of results and papers arising from data collected by the ATM program. Dr. Kevin Stierhoff outlined how the process of analyzing the acoustic data in conjunction with the trawl data has been automated.

This report first summarizes the Panel's requests to the acoustic-trawl survey team (Team) and the discussions, recommendations, and conclusions related to the eight key topics (the text in italics at the start of each Items 1-8 is excerpted from the TOR). It then summarizes areas of disagreement, lists key unresolved problems, summarizes comments by the CPSAS and CPSMT representatives, 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 is a list of the primary background documents that were provided to the Panel in advance of the meeting, via email and on an ftp site. These documents included descriptions of the ATM; peer-reviewed scientific papers and technical reports; reports of previous reviews of the ATM; cruise reports from recent ATM surveys; and various supporting references. Appendix 4 provides a summary of progress relative to the recommendations from the 2011 review.

The Panel **commends** the Team for their thorough presentations, and willingness to respond to the Panel requests. As was the case during the previous review, the Panel wishes to emphasize that the Team had already identified most of the issues and were well prepared to discuss them. This Panel **concludes** that 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, northern anchovy, and Pacific mackerel, although several key uncertainties remain, many of which were identified during the 2011 review. In comparison to 2011, more is known about the distribution of CPS, the approaches used to analyze the acoustic

data have improved and research has been conducted with state agencies and industry to quantify the biomass inshore of the survey area.

The Panel **concluded** that the ATM survey can be used to provide relative indices of biomass for all CPS finfish for use in integrated stock assessments, subject to caveats. Although the estimates from the survey are reported in absolute terms (i.e. biomass), the Panel **concluded** that they should not be used as such in assessments where catchability, Q, and selectivity (at size and/or age) are estimated. These two quantities determine the ratio between the biomass estimated by the assessment and the biomass observed by the survey. It is, however, useful to consider these estimates in the absolute units they are reported when the value of Q is of the order of 1. The estimates of biomass from the ATM surveys can be used to directly inform management, but appropriate harvest control rules for using such estimates will need to be developed using Management Strategy Evaluation. In the case of northern anchovy there is need to adjust the ATM biomass estimates for the biomass inshore of the survey area, ideally using directed sampling, before the estimates can be used in assessments and management.

The Chair thanked the 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.

1. ATM SURVEY DOCUMENTATION
Document the ATM survey design, protocols (e.g., sampling, data filtering), and estimation methods, including the following: (a) define the survey area (sampling frame); (b) specify the spatial stratification (if any) and transect spacing within strata planned in advance (true stratification); (c) specify the rule for stopping a transect (offshore boundary by species); (d) specify the rules for conducting trawls to determine species composition; (d) specify the rules for adaptive sampling (including the stopping rule); (e) specify the rules for post-stratification, and in particular how density observations are taken into account in post-stratification. Alternative post-stratification without taking into account densities should be considered; and (f) Describe how backscatter is analyzed to exclude non-CPS backscatter.

1.1 Requests for the Team
1.A. Request: Document the strategy used to select and cluster the trawl stations and how that strategy has changed over time. Summarize how the trawl clusters are included in later analyses.
Rationale: The documentation provided to the Panel did not fully specify the trawling strategy.
Response: The Panel heard several presentations that outlined aspects of how the trawl stations were selected and clustered, but there was insufficient time for the Team to assemble the requested document.

1.B. Request: Document the strategy used to decide when to stop the acoustic sampling in the offshore area.
Rationale: The documentation provided to the Panel did not fully specify this aspect of the acoustic survey methodology.
Response: The Panel was informed that the transects continue until no CPS are encountered, but there was insufficient time for the Team to assemble the requested document.

1.C. Request: Provide more information about the trawl system being applied. Specifically provide (a) drawings giving the main properties of the trawl; (b) drawings of trawl rigging. including sweep wires, flotation and doors; (c) measurements of trawl geometry; and (d) trawl sonar of echosounder data from the trawl opening (if available).

Rationale: Sampling efficiency of trawls depends on the behavior of the fish in front of the trawl, the filtering capacity of the trawl and the mesh selection. The mesh selection and the filtering capacity are determined by the trawl construction, such as mesh sizes in the various panels, and the cutting angle of the panels (determining the overall length of the trawl). Low filtering capacity will amplify the impact of fish behavior in front of codend as well as in front of the trawl, such as size- and species- dependent behavior.

Response: The Team provided trawl drawings and information about rigging as requested (Appendix 5). The opening of the trawl is stated to be ~20x15 m, but might be slightly smaller. The flotation is attached to the trawl headline in front of the ropes where the vertical opening of the breast is ~35 m. Thus, while the headline of the breast part will be at surface, the net headline will probably be at about 5-10 m depth. The mesh sizes decrease from 1,600 mm in the front of the net to 100 mm in the end. The codend (100 mm netting) is 8.5 m long and has a liner with 8 mm square mesh netting. The trawl design indicates a good filtering capacity due to the large meshes in the front. Mesh selection for small individuals must be expected due to their limited swimming capacity. The Team also mentioned some constraints that could impact trawl efficiency such as the operation of trawl instrumentation to monitor trawl performance. There are some issues related to the trawl that require attention (see recommendations).

1.D. Request: Provide examples of the coherence of daytime acoustic data and night-time trawl results using Echoview outputs.

Rationale: The Panel wished to better understand the rationale for basing species and size compositions from night-time trawling and to explore how variable the density of epipelagic species is at night-time.

Response: The Team showed the Panel several Echoview outputs, and the Panel and Team examined them. There is evidence of schools (which could have been CPS) during the day that reside below the 70 meter depth limit assumed as the lower limit of CPS. The evidence for surface schools in the output at night was particularly noteworthy and was confirmed by industry members present at the review.

1.E. Request: Provide an outline (e.g. for 2017) for how the objectives for a survey are determined, and how those objectives lead to the acoustic survey-trawl design.

Rationale: The Panel wished to more fully understand the approach used for survey design.

Response: The Team stated that the summer surveys tend to be coast-wide because they target the epipelagic assemblage and that the spring surveys have targeted primarily Pacific sardine. However, there was insufficient time to provide a document by end of the meeting.

1.F. Request: Document the approach used to process the acoustic data, including filtering algorithms and algorithms for removing non-CPS "epipelagic" fish (Echoview and R-based approaches).

Rationale: The documentation provided to the Panel did not fully specify the strategy to process the acoustic data.

Response: The Panel heard presentations that outlined several aspects of how the acoustic data were processed, but there was insufficient time for the Team to assemble the requested document.

1.G. Request: Construct a plot of the distribution of CPS at the trawl level that includes bathymetry and represents the magnitude of the catches.
Rationale: These plots will provide additional information on species distribution, which relates to survey design.
Response: The plots were produced for spring and summer separately. However, it was hard to interpret the plots because of the presence of one large catch of sardine. This led to request 1.I.

1.H. Request: Provide plots of histograms of the distance from a trawl cluster to the 100 m Equivalent Distance Sampling Units (EDSUs) (and the cumulative distribution), restricting the data to (a) transects with non-zero CPS Nautical Areas Scattering Coefficients (s_A; m^2 nmi^{-2}) and (b) transects with a non-negligible CPS s_A.
Rationale: The Panel wished to more fully understand the distribution of the CPS relative to trawl catches.
Response: The plot (Figure 1) showed that the most of the biomass is based on trawl samples whose centroid is less than 25 miles from associated EDSUs.

1.I. Request: Construct a plot of the distribution of the CPS at the trawl level that includes bathymetry and represents the magnitude of the catches where the catches are square-root transformed
Rationale: These plots will provide additional information on species distribution, which relates to survey design.
Response: The request plot was created (Figure 2).

1.J. Request: Evaluate variability among trawls in a cluster for species proportions.
Rationale: If the trawl species compositions are dissimilar, then there is high uncertainty in species composition, even assuming that the night trawl sampling approach is perfectly unbiased.
Response: Plots of variability in species proportions against species catch for the summer 2016 survey, provided to the Panel, showed the expected pattern, with higher variability for lower biomass. This was most evident for anchovy, which constituted the bulk of the biomass in the survey concerned. This type of information should be reported routinely in survey reports.

1.K. Request: Provide zoomed-in graphics of how close the survey transects get to the shore, with bathymetry lines if possible.
Rationale: The Panel needed a visual to demonstrate how close the ATM vessel can approach the coastline.
Response: These figures are given as Figure 3.

1.L. Request: Provide a table that lists the ATM surveys conducted to date, with start date (dd/mm/yyyy), duration (days), principal objective (target species), sardine biomass estimate (mt, CV), anchovy biomass estimate (mt, CV), area covered (n.mi.^{2}), total cruise track length (n.mi.), number of trawls conducted, numbers of trawl clusters, and number of non-zero clusters.
Rationale: This is core information needed to fully understand the survey results.
Response: This information is given as Table 1.

1.2 Discussion
a. delineate the survey area (sampling frame)
The survey area is defined given the objectives for the survey, in particular the priority target species, and taking into account the number of days available for sampling. The survey area is

also selected given information from the habitat model (for Pacific sardine in the spring) to some extent, as well as using information from industry. The Team recognizes that this will lead to the surveys not fully covering the distribution of all CPS finfish, although an effort is made to cover the distributions of Pacific sardine and northern anchovy to the maximum extent possible (see also Item 7). The Panel supports the approach used to select the survey area, which attempts to keep the bias of estimates of abundance constant, but at the cost of lower precision. Trends and variability of the spatial distribution of the CPS might lead to unpredictable changes in the survey efficiency given the present approach.

b. specify the spatial stratification (if any) and transect spacing within strata planned in advance (true stratification);
The stratification of the acoustic component of the survey is related in part to the selection of high- and low-density transect areas. The selection of the high-density sampling areas is based partially on historical data on density as well as on the objectives of the survey (e.g. greater effort in the Pacific Northwest if the aim is to survey the northern subpopulation of northern anchovy). Adaptive sampling occurs, but there would be value in examining the benefits of making the current process more dynamic i.e. include flexibility in the effort distribution to ensure adequate spatial coverage when distribution changes.

c. specify the rule for stopping a transect (offshore boundary by species);
The Panel was informed that transects continue until there is no evidence for further signs of CPS.

d. specify the rules for conducting trawls to determine species composition;
In general, trawl sampling is conducted each night by returning to positions where CPS schools were acoustically detected earlier that day, where CUFES samples indicated the presence of eggs, and from reports on the locations of CPS catches by the industry. The first set is ~1 h after sunset, and the last set is concluded prior to sunrise. As noted above, the Team was unable to provide a fully specified protocol for how trawls are conducted.

e. specify the rules for adaptive sampling (including the stopping rule);
The Panel was informed that adaptive transects are added when a large change in density is detected. At least three additional transects are added as transects with lower inter-transect distances are pooled into a stratum for biomass estimation

f. specify the rules for post-stratification, and in particular how density observations are taken into account in post-stratification
The aim of the post-stratification process is two-fold: (a) to identify strata for which the assumption of approximate stationarity is valid, and (b) to create strata for which the number of transects per unit area is constant. The aim is to distinguish regions with 'structural zeros' from regions (which may include transects with observed zero acoustic density) for which density is likely non-zero. Juan Zwolinski explored the validity of the approach to post-stratification taken by the Team by computing autocorrelation functions (there was no evidence for significant autocorrelation within the post-stratified strata at any lag when transect means were considered). He also compared the variance estimates when they were computed using the current post-stratification approach and a simpler approach that defined strata without reference to density and found the estimates of variance to be similar (Appendix 6), suggesting that the expected negative bias in the variance estimates due to post-stratification is not likely to be substantial.

g. Describe how echogram backscatter is analyzed to exclude non-CPS backscatter
The Team presented the approaches behind the processing and evaluation of the data in detail. In general, the approach is a combination of automatic and manual processes. The methods applied are consistent with those applied elsewhere. However, in common with analysis of acoustics data elsewhere, they involve some semi-subjective judgments. The background documentation for the meeting did not include specifications for the processes used to make these judgments. Subjective evaluation takes place after, instead of during, the survey, which is more common practice. Making decisions when most information is recent and available activates the learning-while-doing principle, a helpful tool for enhancing memory and securing future improvements.

Noise removal and calculation of frequency response for species identification is conducted in accordance with current practice. The Panel noted that account is not taken of the reduction of estimates of biomass from dense schools due to shadowing. It also noted that masking bubbles could also potentially mask biomass.

More importantly, it was noted that the approach used to eliminate non-CPS epipelagic fishes during day-time acoustic sampling may lead to some species (e.g. herring) being excluded from the acoustic data used to estimate total CPS biomass, but that such species are likely included in the trawl catches used to apportion total CPS.

1.3 Recommendations (*H=high priority; M=medium priority; L=low priority*)
1. (H) Construct a document, ideally a NOAA Technical Memo that lists all of the aspects of the ATM survey, including design and analysis. This document should be updated regularly given new information and decisions.
2. (H) Study the vertical distribution of fish close to surface to determine if fish in the very surface layer may be lost. This could be done using vessel sonars, acoustic moorings or Autonomous Underwater Vehicles (AUVs) where available.
3. (L) Study fish behavior in front of the codend and measure flow inside/outside the trawl using a high frequency Acoustic Doppler Current Profiler (ADCP). This will allow an evaluation of the frequency with which fish escape. Such work is needed because the codend is relatively short with a small mesh liner, and has probably insufficient filtering capacity at 4 knots. This might "block" the entrance of the codend and lead to an increased flow of water through the meshes in front of the codend where some fish will probably escape.
4. (M) Use net monitoring devices to monitor the trawl during all hauls. The most critical element of the trawl is probably its overall size and performance during operation. This trawl requires perfect performance to fish target species, but there is no information available to evaluate that. Even at night, the trawl might be highly visible to the fish due to bioluminescence (Jamieson et al., 2006). Thus, the target species will have no problem avoiding the net. The optimal instrumentation to monitor the net is trawl sonar, which is available to the Team, and gives the full geometry of the trawl opening, including its variability as well as the distribution of fish within and outside the trawl opening.
5. (M) Develop methods (or adapt from the literature) to extract information from the acoustic data about numbers of schools and their size and spacing. Time series of school statistics, along with other stock characteristics, might become useful in studies of state and interaction dynamics of stocks. In addition, given that the shapes of schools of different species appear to look different, school shape should be considered as part of the system for deciding which schools are CPS. Having this information will also allow

for easier back-calculation should a depth-dependent target strength model ever be adopted.

6. (L) Utilize time series of survey data, including school statistics, to explore if changes in species dominance in the ecosystem causes changes in behavioral characteristics, such as vertical and horizontal distribution dynamics, which ultimately will impact survey efficiency for those species.

1.4 Conclusion

The ATM involves many stages and steps, including decisions related to survey design, operational decisions during cruises, and analysis options. This is not unexpected for a methodology that is complex and involves multiple data sources. However, the overview document did not provide sufficient detail for the Panel to fully understand the entire process (see requests 1.A, 1.B, 1.E, and 1.F). Moreover, detailed documentation is currently in multiple documents and, for some matters, only known to the Team. Consequently, the Panel was not provided with full documentation and this needs to be addressed as a matter of urgency.

2. ESTIMATED TARGET STRENGTHS OF CPS FROM THE CALIFORNIA CURRENT

2.1 Requests for the Team

2.A. Request: What are the target strength to length functions that are used for each species and what is the basis for using these? Of those that include a depth-dependent component, how were the coefficient(s) derived? What experiments have been done, or which observations have been made, to determine or validate the selected model coefficients? Document the calculations that are carried out to estimate the mean backscattering cross section from the trawl information.

Rationale: The Panel wished to see a summary of the pertinent information in a single location

Response: The equations used for sardine and mackerel come from Barange et al. (1996); the pilchard model is applied to sardine and Pacific herring, while the horse mackerel equation is used for Pacific and jack mackerel (Table 2). For anchovy, the target strength is described in a technical memorandum (Zwolinski et al., 2017) and is based on the target strength of another anchovy species (Japanese anchovy) from Kang et al. (2009), with an added (fixed) term for depth-dependence. The validity of this model was tested against empirical target strength data collected from three trawls within a single transect in southern California where anchovy were abundant and estimated to constitute 99% of all CPS finfish. The target strength (TS) measurements at each location were combined with the associated total length (TL) distribution from each catch and resulted in an estimate of the b_{20} parameter of 67.3 dB. Given the mean depth of the schools during this measurement at 13 m and estimated compression of the swim bladder, this value is in agreement with the value for b_{20} estimated for the Japanese anchovy (67.2). The frequency distribution of the measured target strength was broader than would be expected from the length frequency distributions, but this is likely due to added variability from the tilt angle distribution, a commonly observed phenomenon echoed by the experts in the room. For the summer surveys, when the mean depth of schools increased to 21 m, the b_{20} value was adjusted to 68.1 dB. This is the value used throughout the surveys. To apply target strength models for estimation of biomass, individuals of each species are randomly sampled from each trawl and the length frequencies are weighted by the catch sizes.

2.2 Discussion

The discussion focused largely on the impacts of depth on target strength of species with open swim bladders (physostomes). Target strength is impacted by compression or expansion of the swim bladder over the vertical range. Vertical distribution of Pacific herring has been

documented to 200 m (*Pers comm. Stephane Gautier*), and fishermen have observed vertical migrations of both sardine and anchovy below 70 m (*pers comm. David Crabbe*). Depth-dependent target strength has been documented for Atlantic herring (e.g. Ona, 2003). Models of depth-dependent target strength have not been applied to date in the North Sea herring assessments, mostly due to the impracticality in updating long time-series. While depth-dependent models have been discussed widely, especially in Europe, they are not routinely implemented. It was acknowledged that maintaining consistency in the method applied is critical, irrespective of whether a depth-varying target strength is applied or a target strength applied to a mean depth. Notwithstanding issues of depth-dependence, there are some published target strength models for Pacific herring (Thomas et al., 2002; Gauthier and Horne, 2004). These may be more appropriate than the current model used, which is based on pilchard.

Measuring target strength at night when fish are acoustically resolved in single targets either in layers or at the outskirts of schools might give a biased estimate of target strength because such individuals are not necessarily representative for the bulk for fishes in daytime school recordings both in terms of size and tilt angle distribution.

The current method for estimating biomass is to link backscatter with cluster-specific trawl catches. Error from low sample sizes translates to error in mean target strength, reducing confidence in the biomass estimates. An alternative method would be to define a region across multiple transects where the length-frequencies are not significantly different and pooling the data at this scale.

2.3 Recommendations
1. (H) The team should continue to collect target strength data using best available technology with associated relevant biological information to improve current target strength models.
2. (M) A comparison should be made between the area (e.g. over several transects) and the current trawl cluster approach to convert backscatter data to biomass when catch sample sizes for a particular species are insufficient.

2.4 Conclusion
Target strength remains a key uncertainty in the analysis of the acoustic data. Research to evaluate and improve target strength to length models should continue. However, the Panel supports the current choices for target species models while the Team continues to improve *in situ* TS measurement methodology.

3. TRAWL SURVEY DESIGN PROTOCOLS FOR USING A CPS PREFERRED HABITAT MODEL TO DETERMINE ADAPTIVE SAMPLING AREAS
In relation to a preferred habitat model for Pacific sardine, as well as other coastal pelagic species: (a) to the extent possible, address the fact that low population size likely affects the probability of acoustic detection in a non-linear way. This could create a negatively biased estimate at low population levels and potentially a non-detection threshold below which the stock size cannot be reliably assessed; and (b) evaluate the costs and benefits of targeting sampling effort based on the preferred habitat model for Pacific sardine in terms of biomass estimates for Pacific sardine and for other CPS stocks.

3.1 Requests for the Technical team
None

3.2 Discussion

In relation to a preferred habitat model for Pacific sardine, as well as other coastal pelagic species:

a. *To the extent possible, address the fact that low population size likely affects the probability of acoustic detection in a non-linear way. This could create a negatively biased estimate at low population levels and potentially a non-detection threshold below which the stock size cannot be reliably assessed.*

Low stock abundance may potentially lead to higher relative observation variability and thus greater uncertainty in population size. The abundance index will be hyperstable if the relative proportion of a stock that occurs outside of the sampling frame has an inverse relationship with stock size (e.g. if a larger proportion of the anchovy stock is closer to shore than the inshore boundary of the acoustic survey). Additional inshore transects conducted by the *FV Lisa Marie* in the Pacific Northwest during summer 2017 indicated that only a small portion of the stock (1.6%) of anchovy occurred in the nearshore in the summer in that area during that season. In contrast, the summer 2017 aerial survey off central California is suggestive that a substantial portion of both anchovy and sardine may be shoreward of the shoreside limit of the acoustic survey in the summer in California.

Uncertainty in the estimates of stock biomass at small stock size also can be affected by changes in species composition, either within schools or in the areas for which species composition is assigned to a particular trawl cluster. Further, interaction and competition among species undergoing large changes in abundance might lead to behavioral changes, including altered distribution patterns. At small stock size, there is a greater chance of completely missing a species in the trawls or capturing a substantially higher proportion of that species than is actually in that area, and thus assigning a substantially wrong proportion to the estimated biomass (as well as calculating a somewhat incorrect target strength relationship). Further investigation into these potential sources of bias is needed.

b. *Evaluate the costs and benefits of targeting sampling effort based on the preferred habitat model for Pacific sardine in terms of biomass estimates for Pacific sardine and for other CPS stocks.*

The focus of sampling effort depends on the goal of a particular survey. Most surveys have been focused on surveying Pacific sardine. However, the 2017 summer survey was focused primarily on the northern subpopulations of northern anchovy and Pacific sardine. The habitat model for Pacific sardine is used to help determine the sampling for those surveys focused on Pacific sardine (all surveys except that for summer 2016). The amount of ship time available for the survey influences the northern and/or southern boundaries of a particular survey. In principle, the summer surveys extend from the northern end of Vancouver Island to the U.S. Mexico border. When survey time was limited, the surveys extended as far south as necessary to survey the entire northern stock of Pacific sardine. The summer survey typically moves from north to south, and uses various sources of information to determine the southern boundary of the survey.

The survey design includes areas with 20 nmi and others with 10 nmi inter-transect distances, based on previous observations of where CPS are expected to occur in substantial numbers. Additional transects are held in reserve, and added between the 20 nmi interval transects when substantial biomass is seen on a transect. However, there are a limited number of these additional transects allotted.

3.3 Recommendations

1. (H) Analyze the effect of the adaptive sampling through simulation or through reanalyzing various subsets of conducted transects for any given year, including a standard set at 20 nmi spacing, with either randomly assigned (equal numbers of) extra transects or extra transects assigned according to the rule that is actually used. In order to do this, a fixed number extra transects (i.e. those conducted in between the 20 nmi spaced transects) will have to be set, at say half of the actual number of transects conducted in addition to the 20 nmi spaced transects already included. There is a concern about bias in the scheme used to determine transect spacing since it is not truly random sampling, but the magnitude of such bias is not clear. Francis (1984) addressed a similar issue for a survey for orange roughy. He concluded that although there is a bias associated with such strategy, the benefit from reduced variance overrules this problem.

2. (M) Transects have a standard length, but can be extended if CPS are seen at the end. However, there is a limited amount of time for performing transects, which limits the ability to extend the survey offshore. The tradeoffs of allocating time to extra length vs. extra transects should be explored.

4. EFFECTS OF TRAWL SURVEY DESIGN

In relation to trawl survey design, the following should be considered and addressed: (a) The consequences of the time delay and difference in diurnal period of the acoustic surveys versus trawling need to be understood; validation or additional research is critical to ensure that the fish caught in the trawls from the night time scattering layer share the same species, age and size structure as the fish ensonified in the daytime clusters. To the extent possible, the Team should conduct paired trawls during daytime acoustic sampling, to validate (or to generate a correction factor for) nighttime species composition trawls. (b) Consider suitable sample sizes of CPS in the ATM survey. The ability of a single vessel following fixed transects along the entire northern sardine subpopulation region over a single period to sufficiently observe and sample a highly mobile schooling species that exhibits high variability in recruitment, migratory patterns and timing, school structure, and depth distribution, remains a core challenge. The relatively small sample size of sardine for biological analysis remains a concern related to acoustic expansions, population model estimates, and projection forecasts that depend on age composition and size-at-age information. Conduct an analysis of effect of fish sample size on the uncertainty in the ATM biomass estimates and model outputs. Use this information to re-evaluate and revise the sampling strategy for size and age data that includes target sample sizes for strata. (see Pacific Sardine STAR Panel [Meeting Report](#), PFMC, April 2017). (c) Test the efficiency (relative catchability) and selectivity of the trawl among and within species by comparing samples from the same area taken with the survey trawl and purse seine. (d) Estimate trawl selectivity by species. Cameras attached to the trawl in front of the cod end have been developed and used extensively since the 2013 surveys to observe and quantify fish behavior and Marine Mammal Excluder Device (MMED) performance. The Team should report on findings from the camera research and quantify the selectivity of the trawl. If unquantifiable, describe state-of-the-art acoustic and optic technology to investigate fish behavior and escapement at various critical positions of the trawl, and how the data would be incorporated into the biomass estimation process.

4.1 Requests for the Team

None

4.2 Discussion

In relation to trawl survey design, the following should be considered and addressed:

a. *The consequences of the time delay and difference in diurnal period of the acoustic surveys versus trawling need to be understood; validation or additional research is critical to ensure that the fish caught in the trawls from the nighttime scattering layer share the same species, age and size structure as the fish ensonified in the daytime clusters. To the extent possible, the Team should conduct paired trawls during daytime acoustic sampling, to validate (to generate a correction factor) nighttime species composition trawls.*

Trawls are conducted during an acoustic survey to obtain biological information (notably length and age) and to verify the species composition of the echotraces. The latter is often referred to as ground-truthing, analogous to other remote sensing techniques that require validation (see McClatchie et al., 2000). Therefore, in a typical acoustic survey, trawls are conducted shortly after detecting fish and/or fish schools. There are few pre-defined design criteria to the allocation of trawl samples, instead time is usually allocated for trawling, and trawls are conducted as and when targets are detected (Simmonds 1995). In relation to the issue of using the trawls for species allocation, Simmonds and MacLennan (2005) state the following: *"Although it is often the best available, pelagic trawling is a poor method of sampling fish densities, and substantial errors may arise in estimating the proportions of species in mixed aggregations. If there is any possibility of partitioning the echo-integrals to species level from examination of the echograms, this should be attempted in preference to the catch-partitioning technique described by Nakken and Dommasnes (1975). Even if the interpretation of the echogram is uncertain, the error in acoustic partitioning may well be less than that based on the catch analysis…".* In their analysis of the requirements for ground truthing (McClatchie et al. 2000) go further, stating that "*It must be feasible to direct the sampler to capture a "mark" seen on the echogram, and the sampler should have the capacity to capture a series of discrete marks without contamination between the catches. It is necessary to be able to locate the sampler precisely in relation to the targets during its deployment.*" They go on to conclude that "*Correlations between acoustic and ground truth observations are always best when they are synoptic.*"

In similar circumstances, i.e. an acoustic survey for sardine, anchovy and mackerels, Petitgas et al. (2003) compared four methods of allocating echotraces to species with information from trawl hauls conducted shortly after echotrace detection: i) nearest haul; ii) expert; iii) a post-stratified acoustic image classification method (AICASA); and iv) a post-stratified trawl-haul classification method (THC). Very little difference was found between these in terms of the abundance estimates, with the exception of mackerel (which was a different species, without a swimbladder, and so had a very different target strength). However, the ATM practice does not conform to any of these methods, largely because of the time delay between the respective components (acoustic data during the day allocated to trawl hauls at night). Trawling at night based on daytime recordings is not a generally used approach to estimating species proportions and their lengths, but has been used in the Mediterranean, apparently without negative consequences (Tugores et al 2010). In the present case, it is a practical approach to addressing logistical difficulties in a multispecies survey when trawling by day is problematic, but consequences are unknown. The sampling takes place in the surface layer (top 15 m) at night under the assumption that all CPS finfish spread out at the surface, but this requires validation.

Several approaches were discussed, including spending a full day and night at a location with a variety of schools observed during the daytime and then following them at twilight and at night using for example, a multi-beam sonar.

Validating the identity of fish seen on the echosounder by fishing or otherwise observing the fish during the day is desirable. While fishing was previously attempted using auxiliary vessels, it was not successful. This could be a gear issue, however (see Item 1 discussion of trawl design). Experiments to understand and improve the trawl presently in use, as well as testing a larger and more efficient trawl are relevant approaches. To conduct such an experiment, it would be useful to consult with industry in the choice of approach, equipment, and experimental design. Several European nations engage with industry specialists (skippers) to assist with fishing operations during acoustic surveys on research vessels, recognizing that this is a specialized activity with which research vessel crew often have little experience. It would not only be directly useful to the ATM survey to include such experience by inviting a skipper on board to advise on fishing practices, but indirectly this would contribute greatly to improved relations between scientists and industry stakeholders.

There are several surveys for small pelagic species around the world, most of which do both acoustics and net sampling during the day, indicating that identification along with the acoustic sampling is possible when using the proper gear.

b. *Consider suitable sample sizes of CPS in the ATM survey. The ability of a single vessel following fixed transects along the entire northern sardine subpopulation region over a single period to sufficiently observe and sample a highly mobile schooling species that exhibits high variability in recruitment, migratory patterns and timing, school structure, and depth distribution, remains a core challenge. The relatively small sample size of sardine for biological analysis remains a concern related to acoustic expansions, population model estimates, and projection forecasts that depend on age composition and size-at-age information. Conduct an analysis of effect of fish sample size on the uncertainty in the ATM biomass estimates and model outputs. Use this information to re-evaluate and revise the sampling strategy for size and age data that includes target sample sizes for strata. (See Pacific Sardine STAR Panel* [Meeting Report]*, PFMC, April 2017).*
No results were reported, but the Panel raised a recommendation.

c. *Test the efficiency and selectivity of the trawl by comparing samples from the same area taken with the survey trawl and purse seine.*
There were no results to report.

d. *Estimate trawl selectivity. Cameras attached to the trawl in front of the cod end have been developed and used extensively since the 2013 surveys to observe and quantify fish behavior and Marine Mammal Excluder Device (MMED) performance. The Team should report on findings from the camera research and quantify the selectivity of the trawl. If unquantifiable, describe state-of-the-art acoustic and optic technology to investigate fish behavior and escapement at various critical positions of the trawl, and how the data would be incorporated into the biomass estimation process.*
No results were reported.

4.3 Recommendations

1. (H) Conduct night trawls at different depths in the same area, with the headrope at the surface, at 15 m, and at 30 m depth, for example to compare estimates of species and length composition.
2. (H) Develop approaches and methodologies to verify that what is detected with the echosounder during the day and what is caught in the net at night are the same in terms of species and size compositions. Such approaches would include alternative trawling strategies (e.g. curved trajectories), purse seining by day (either using the research vessels or industry vessels), or alternative sampling techniques such as dropped cameras.
3. (M) Examine the effects of the sample size of fish collected in trawls in terms of uncertainty and variability in indices and size and age compositions, and if necessary consider ways to increase sample size. Low sample size affects estimates of species proportions, and therefore abundance estimates more than length distributions, but the latter is important for estimating size and age structure. While increasing the length of trawls will help to some extent, other approaches may be more efficient.
4. (M) Design and execute field experiments (for example by tracking fish schools with sonars over 24 hrs) to study movements of fish between time of registration and time of sampling, to validate that the current sampling strategy is adequate to reflect the size and species composition of daytime acoustic records.

5. EFFECTS OF UPGRADING FROM THE SIMRAD EK60 TO EK80

After 10+ years of service, Simrad discontinued the EK60 series and introduced the EK80 series of transceivers and control software, which shifts from narrow-bandwidth transmit pulses to wide-bandwidth pulses using existing hull-mounted transducers. The Team should review the initial outcomes of the EK80 and provide information on the proposed benefits including: (a) fish echoes captured from more complete band of frequencies allowing improvement in species identification; (b) increased range resolution allowing detection of fish close to the bottom and individual fish within an aggregation; (c) increased signal-to-noise ratio allowing improvements in detection capabilities and effective range; and (d) extension and miniaturization of wide-band technology allowing autonomous deployment on smaller vessels (i.e., rigid hull inflatables which could sample nearshore areas, surface buoys, deep moorings, and ROVs).

5.1 Requests for the Team
None

5.2 Discussion
Discussion focused on summarizing the relevant conclusions of a 2016 workshop that evaluated the performance of the new Simrad EK80 broadband echosounder (Demer et al., 2017). It should be noted that the workshop was hosted by the Team, and the ensuing report's lead author was the Team leader: the SWFSC is, therefore, at the leading edge of this technology.

The Simrad EK60 scientific echosounder has been the standard instrument used worldwide to collect acoustic survey data since ~2000. Simrad's EK series typically gets updated every 20 years or so, and in 2016/17, Simrad introduced the next generation of EK echosounders, the EK80. The EK80, when used in conjunction with the appropriate transducer, has the capability of generating broadband signals: these may also be referred to as wideband, or frequency modulated (FM) signals, and are distinguished from the continuous wave (CW) narrowband signals generated by the EK60. As an example, a typical EK60 echosounder may transmit signals

(simultaneously) at three narrowband frequencies of (approximately) 38 ± 0.35 kHz, 120 ± 1.5 kHz and 200 ± 1.5 kHz; an EK80 with similar center frequency transducers may, in FM mode, transmit frequencies of 34-45 kHz, 90-170 kHz and 160-260 kHz respectively. The EK80 is also capable of generating CW pulses. The benefits of transmitting FM pulses are reflected in the following four topics as listed in the Terms of Reference.

1. *Improvement in species identification.* Different objects and animals produce different quantities of sound at different frequencies depending on their size, material properties, geometrical dimensions and behavior. Generally, objects that are small relative to the wavelength scatter more sound with increasing frequency (Rayleigh scatterers), whereas objects that are large relative to the wavelength scatter a similar quantity of sound regardless of frequency (geometric scatterers). This is a generalization, and depends on several other factors, notably the material properties of the object, which may allow for resonance to occur that leads to a scattering peak at a particular (resonance) frequency. These frequency-dependent properties have hitherto been exploited using several CW signals transmitted simultaneously, which provide four points on a frequency spectrum (scattering on the y-axis and frequency on the x-axis). These spectra can be used to distinguish various classes of objects and are used, for example, in the ATM CPS filters to distinguish CPS schools. The transmission of FM signals, with their wider bandwidths, allows for many more points to be determined in the spectrum. In the aforementioned example, using transducers at the three center frequencies, a CW EK60 system would provide three data points on a spectrum, whereas the EK80 with equivalent transducers would have 191 data points. This allows for a much greater characterization of the spectrum and potentially aids species identification. Demer et al. (2017) allude to this potential, but the ICES workshop did not collect any data to support it: rather, the ICES workshop focused on issues related to the consistent operation of the instrument, such as data volume and processing, power output, noise and calibration. At the range of frequencies employed, it is yet to be established if having the additional information across a more complete spectrum will provide an enhanced ability to distinguish objects. Although this is certainly possible for certain objects in the Rayleigh region, CPS are largely in the geometric region which means that their spectrum should be flat. Exceptions might be small anchovy, which have a resonance peak between 1 and 2 kHz (Holliday, 1977), such that the downwards slope of the spectrum may be detectable at the range of frequencies deployed. The approach is not yet used much and there is a need for validation.

2. *Increased range resolution.* The ability to separate objects in a smaller vertical space is also a feature of a broadband signal (Demer et al., 2017). This may potentially allow for the detection of fish close to the bottom and of individual fish within an aggregation. The latter was not examined, but has been demonstrated elsewhere, e.g. Stanton et al. (2010). Demer et al. (2017) did consider detection close to the seabed by making measurements using an EK80 from the RV "Reuben Lasker" of ten ~4 cm diameter spherical lead targets spaced 1 m apart in a vertical array deployed on a rocky seabed substrate. They found that short CW pulses better resolved targets near the seabed, compared to FM pulses. This was because processing the FM signal introduces side lobes (scattering to the side of the main beam) and if the echo from one target is much weaker than another, e.g. a fish near the seabed, the side lobes from the seabed echo may eclipse the fish echo. However, their measurements were carried out on a rocky substrate, which is more susceptible to side lobe interference so it remains to be seen if improvements are possible

on other, notably flatter, substrates. The improved range resolution will improve sampling of individual in schools and thus strengthen the *in situ* target strength estimates.

3. *Signal to noise ratio*. Broadband systems, such as the EK80, allow for increased signal-to-noise ratio, allowing improvements in detection capabilities and effective range. In the case of CPS, this feature is unlikely to provide significant benefits because the schools are relatively shallow (range is not an issue), large and dense (signal to noise ratio is good). Although this is mentioned as a feature of the EK80 in Demer et al. (2017), nothing further is elaborated.

4. *Extension and miniaturization*. The wide-band technology contained in the EK80 can be packaged in a number of different products, some of which are small and allow for autonomous operation (see Table 1.1. in Demer et al. (2017)). The ATM has three wideband autonomous transceiver (WBAT) systems that are battery powered autonomous EK80's which can be deployed on moorings, surface buoys, Remotely Operated Vehicles and small vessels such as AUVs and inflatables. The Team has access to this equipment, and is therefore extremely well equipped to deploy this technology for a variety of applications (see, for example, Item 6). Such instrumentation might substantially improve target strength measurements of *in situ* CPS.

6. EFFECTS OF VESSEL AVOIDANCE FOR THE UPPER WATER COLUMN

Multibeam systems (Simrad EK80s, ME70, MS70, and SX90) are now available on the FSV Reuben Lasker. These represent state-of-the-art instrumentation that will improve overall survey effectiveness and clarify issues related to school behavior around the survey vessel. These systems must be fully utilized to clarify vessel impact factors, and the Team should estimate what proportion of biomass is missed with the standard down-looking sonar.

6.1 Requests for the Team
6.1 Requests: What work has been conducted by the Team to address this issue?
Rationale: The document provided to the Panel did not include information relative to Topic 6.
Response: Some data have been collected during surveys using the multibeam system, but those data have not been processed or looked at so far.

6.2 Discussion and conclusions
If fish avoid the vessel by moving away from its path during the day, this could lead to bias in acoustic estimates of biomass. Similarly, if differential avoidance by species or size occurs at night, this could bias catches and consequently biomass estimates by species or size. All agree that there is a potential for species avoidance of the vessel, and experience tells us that avoidance behavior is species-, life stage-, and situation-dependent (De Robertis and Handegard 2012). For example, avoidance behavior of a species may change during spawning or when predators such as marine mammals are present and actively foraging. The sound profile of the ship can potentially affect avoidance behavior and, in some instances the pressure wave formed by the moving platform may be a factor, especially for larger vessels. The ICES specification for "quiet" vessels is based on herring avoidance at 30-m depth. It should not be expected that fish at the surface have the same reaction even to vessels with sound signatures below the ICES recommendation. It was also stated that avoidance during cruising may be different from avoidance during trawling. Avoidance during trawling might be minimized by running the vessel around a school at the same time as navigating the trawl through the school, a technique that has been used in other surveys.

Several approaches have been used to study avoidance. Using an AUV in front of a quiet vessel, some have found no signs of avoidance (e.g. Fernandes et al., 2000). Other studies using an instrumented buoy or comparisons among vessels found varying effects (Ona et al. 2007; De Robertis et al., 2008, 2010; De Robertis and Wilson, 2010, 2011), pointing to the complexity of the issue. There are no universal approaches on this topic, but there are a number of methods that could be used to estimate vessel avoidance. These involve technologies attached to the front or side of the vessel (sonar, LIDAR, spectral cameras), using relatively quiet instrumented platforms (buoys, moorings, AUVs, surface drones) or aerial platforms equipped with various optical sensors (spotter planes, aerial drones). Some of these instruments can be operated as part of or in conjunction with the acoustic survey, while other would require dedicated experimental time.

6.3 Recommendation:
1. (M) Explore options to quantify potential fish avoidance under a range of survey conditions. This could involve combining systematic collection of additional data during surveys, as well as dedicated experiments.

6.4 Conclusion
Issues of potential fish avoidance should be addressed, either as part of ongoing survey efforts or under controlled designs. Collecting additional data during surveys allows spreading of the information in space and time and understanding potential overall impact of fish behavior on the acoustic-trawl abundance estimates. Survey vessels with MS and ME 70 multibeam systems can collect 3-D data under and on the side of the vessel that can be used to estimate distribution statistics, thus detecting potential impact of the vessel on fish distribution (see Patel and Ona, 2009). On the other hand, experimental approaches require dedicated time, but may offer clearer and independent quantification of vessel effects. Experiments could include use of instrumentation such as Lidar, spectral camera, or stationary acoustics, which are capable of measuring distribution patterns or trends in the absence and presence of the survey vessel.

7. ATM SURVEY DESIGN IN AREAS WHERE THE ATM VESSEL IS CURRENTLY NOT SAMPLING
The 2017 Council STAR Panel concluded that lack of nearshore coverage by the ATM survey persists. The Team should, to the extent possible, describe ways (e.g., cooperative sampling, use of drones, etc.) to achieve the goal of providing an estimate of abundance or correction factor for those unsurveyed areas. The Team should also address the potential effects of reduced sea days, relative to generating estimates of un-sampled areas, as well as relative to the conduct of the overall survey itself. The Team should provide information on what a sufficient number of sea days is, and information on tradeoffs between spatial coverage and transects.

7.1 Requests for the Team
None

7.1 Discussion
During the 2011 ATM method review for CPS (Agenda Item C.3.a, Attachment 1, April 2011), the topic of survey design in areas not surveyed was reviewed, requests were presented, and recommendations were provided. One request concerned providing an estimate of the area between the eastern ends of transects and the coastline by survey and strata. Using data from the 2008 survey in a region north of Cape Mendocino, an inshore area correction factor was estimated, CPS density was shown to increase towards the inshore ends, and the analysis

provided indicated a survey abundance increase of 15% if this inshore higher density was applied to the inshore area outside the normal survey expansion region. The recommendation related to this request suggested examining trends in density from the inshore ends of the survey transects to provide best available information for expansion of estimates to un-surveyed inshore regions.

Results from the 2016-2017 California Department of Fish and Wildlife (CDFW) aerial survey program were presented. This survey aims to produce minimum estimates of anchovy and sardine tonnage or an index of abundance in the nearshore region surveyed out to a maximum of 1.3 nm offshore, along with digital photo documentation of schools. Data from an August 2017 aerial survey off northern California at the same time as ATM surveys offshore show anchovy and sardine biomass inshore of ATM transects. Also shown were data from synoptic survey efforts from 2016-2017 where CDFW conducted aerial transects overlapping the inshore sections of several ATM transects conducted over the same time period. The aerial surveys were inshore of the ATM survey transects, with some overlap with the ATM transects at the extreme inshore end. The results from this effort were inconclusive because binned acoustic data had not yet been compared. Although a thorough analysis has not been completed, few schools were identified by both methods and a preliminary conclusion was that the two survey methods observe different schools. It is possible that the aerial survey observes surface schools in the dead zone of the area ensonified by the acoustic survey, whereas deeper schools observed by the ATM were not visible to aerial observations. It is unclear if further analysis of these data will be useful.

The California Wetfish Producers Association (CWPA) presented qualitative information showing large aggregations of anchovy in nearshore regions off southern California from digital images, photos of fishing boat sonar images, video footage of schools at the surface, and stomach contents of bluefin tuna full of anchovy. The group collected 26 point sets in 2010 where 90 to 100% of sardine schools were captured and weighed, although those data were not shown. The CWPA presentation also included aerial photos and photos of fishermen's electronics documenting large schools of both anchovy and sardine near Pismo Beach, Morro Bay, Monterey and Half Moon Bay. The fishermen from this group expressed their opinion that the biomass of both sardine and anchovy they observed has exceeded NOAA's ATM survey estimates at least since 2015, when fishermen began seeing a significant increase of both species in nearshore waters. Fishermen reported large aggregations north to Cape Mendocino as well as large aggregations of sardines "switching places with anchovy over the thermocline". This industry group requested that ATM survey results be treated as indices rather than absolute abundance estimates for all CPS finfish, largely because of under-represented nearshore aggregations. The majority of commercial catches in California are inside 3 miles or within state waters.

The Panel stated that exclusion of nearshore CPS distribution is a global problem and it is up to managing bodies as well as assessment groups to solve the issue. Data from the targeted nearshore survey off of Oregon and Washington conducted from the F/V *Lisa Marie* in June of 2017 were presented. The nearshore transects were 5 nmi, and extended inshore from the ATM survey tracks. 3-D visualization of the data did not suggest a higher biomass within the inshore region, although, fishermen noted that the cooperative survey timing in June may have been a little early. Except for the example provided in the 2011 review and work conducted in 2017 in the Pacific Northwest, no further efforts or examination of the acoustic backscatter in the nearshore portion of transects has been performed.

Other data sources and methods were discussed. The CPSMT representative reminded the Panel that fishermen's catch log book data have been digitized, which can provide catch data within the

polygons. This information may be useful in examining the relative magnitude of fish available to fishers offshore versus onshore. Saildrones, able to collect acoustic information nearshore or to extend ship transects, may provide an important tool in the future to extend survey regions.

7.3 Recommendations
1. (H) Continue to explore and expand independent nearshore survey methods and efforts to estimate the proportion of the populations not currently surveyed by the ATM surveys.
2. (H) Develop extrapolation methods from the existing data that would extend biomass estimates to the coastline. Two potential methods would be relatively easy to implement:
   a. extend the existing polygons to the coastline and assume the same mean density; and
   b. use backscatter information collected nearshore (in-between transects) to extrapolate to the coastline.
3. Examine trends in density from the inshore ends of the survey transects to provide best available information for expansion of estimates to un-surveyed inshore regions.

The following text from Simmonds and MacLennan (2005) provides further insight on option b:
"There may be practical considerations near the coast that result in a lack of coverage in the shallow water. At first sight, excluding the inter-transect data seems the best choice. However, this implies that the average of the transect values is the most appropriate evidence to evaluate the unsurveyed region. This is not the most reasonable solution. The best method would be to extrapolate from the transect data over the unsurveyed region. One way to do this is to map the data by kriging (a geostatistical concept, cf. Chapter 9). Simpler analysis methods might suggest that on a coastal boundary, the inter-transect sections should provide a good estimate by extrapolation. In that case a small section of the inter-transect record, equivalent in length to the distance from the coast, could be used to estimate the unsurveyed region."

7.4 Conclusions
The nearshore distribution information needs to be included as part of the abundance estimation process. The best way forward is to survey the inshore areas (e.g. with smaller vessels or other platforms). For existing (historical) data there are three options: 1) assume that there is no biomass in unsurveyed area (current status), 2) extrapolate biomass linearly into the unsurveyed inshore area, and 3) have an estimator with trend to estimate the biomass in the unsurveyed inshore area. The latter requires more information (from independent surveys or other sources) to estimate the nature of this trend.

The Panel **emphasizes** that doing extrapolation should not be adopted at the expense or in lieu of expanding efforts to survey inshore areas, but rather as a way to account for this bias in existing survey data and with the absence of better information. The extrapolated amount should always be explicitly reported along with un-extrapolated biomass estimates.

8. ATM DATA ANALYSIS AND QUANTIFICATION OF UNCERTAINTY
Provide the appropriate level of documentation of data analysis and the degree to which the proposed methods describe and quantify the major sources of uncertainty. For each CPS stock under consideration (Pacific sardine, central subpopulation of northern anchovy, northern subpopulation of northern anchovy, Pacific mackerel, and jack mackerel), and to the extent possible, provide sufficient information for the Panel to determine whether the results of ATM survey as reviewed are suitable for (a) inclusion as an index of relative abundance as one of multiple inputs into an integrated stock assessment; (b) inclusion as an index of

absolute abundance (i.e. survey Q = 1) as one of multiple inputs into an integrated stock assessment; and (c) use the most recent estimate of absolute biomass to directly inform harvest management without the use of a formal integrated assessment. In addition, the Team should describe how echogram backscatter is analyzed to exclude non-CPS backscatter.

8.1 Requests for the Team

8.A. Request: Summarize the approaches used to age the CPS finfish for which ATM-based estimates of biomass are computed (sardine, anchovy, Jack mackerel, Pacific mackerel) and outline efforts to validate the ageing and quantify ageing error.

Rationale: The Panel wished to understand the nature of the ageing data that could be used in stock assessments.

Response: Emmanis Dorval provided a summary of an evaluation of the consistency of the age-determination for Pacific sardine. There is no formal validation of the ageing process using for example tagging studies. However, age-reading error has been quantified based on otoliths that have been double read. Ageing of Pacific sardine is conducted by a variety of laboratories, including CICIMAR-INP in Mexico. The same basic method (surface ageing) is used, but there are some differences among laboratories. The precision of the age estimates depends on ager, with ageing error increasing with age (Figure 4). The same approach is taken for Pacific mackerel (Figure 5). The anchovy in the survey have not been aged, although CDFW has started ageing anchovy using surface ageing (whole otoliths), but no agreement on ageing method has been achieved among ageing laboratories. Jack mackerel otoliths have been collected on the survey since 2012, but ageing of this species has not yet commenced.

8.B. Request: Summarize how the ATM estimates are used to inform the age-structured stock assessment model for Pacific sardine.

Rationale: The Panel wished to understand the context in which ageing data are used in assessments.

Response: The ATM biomass estimates are treated as relative indices of abundance (although Q is estimated to be close to 1 (log(Q)=0.113, SD=0.109) and the age data from the survey (based on applying a pooled age-length key) are assumed to be multinomially distributed. Selectivity for the ATM survey was assumed to be uniform (fully-selected) above age 1 and zero for age 0.

8.C. Request: Calculate ratios of age x+1 in year t+1 to age x in year t to look for consistency in age estimates across years. Across 3 years = 2 points per cohort.

Rationale: This should show if the age compositions across years are consistent or not.

Response: The Team showed plots of estimated length and age compositions from the summer surveys, where the age compositions were based on an age-length key in which data were pooled over years, as well as the raw age-compositions (no weighting). There appears to be some selectivity (age-0 animals appear to be under-sampled, although they have been caught during trawls, e.g. during 2015). The animals in the size-range 20-24cm are assigned to ages 2-4 and there is no clear evidence that the age-compositions track over time, even though the mode of the size-composition moves to the right as expected. There was insufficient time during the review to complete this request in detail. However, a figure was prepared for sardine shortly after the meeting (following Figure 6). This indicates no agreement between estimates of the number of fish between the ages of 1 and 2, and very little between ages 2 and 3, and 3 and 4; there is better agreement between ages 0 and 1; and at older ages up to 6. This may reflect uncertainties in age reading. Further, misallocation of the acoustic data to species or size based on the use of night time trawls might add similar noise to the data.

8.2 Discussion and conclusions

The 2011 Panel conclusions regarding the use of the ATM results were:

> *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.*

Substantial new information on abundance and distribution has been obtained since the 2011 Methodology Review. However, to date, ATM results (biomass and age-composition) are only included in the assessment for Pacific sardine (biomass as a relative index). These results are not used in the model-based assessment of Pacific mackerel and no integrated stock assessments are available for jack mackerel and the two stocks of northern anchovy. The results of the Panel's evaluation of the use of ATM data in assessments and management are summarized in Table 3. Table 3 also lists an evaluation of whether it will be possible to obtain estimates of abundance by age, which could be included in an integrated assessment. The Panel **strongly recommends** that ageing techniques be improved to allow use of age composition data for the survey in assessments.

The Panel does not support the use of the ATM biomass estimates as absolute estimates of biomass (Q=1) in assessments because of the uncertainties related (a) to target strength (borrowed from relationships for other areas), (b) the proportion of the biomass inshore, offshore and to the north and south of the survey area, (c) target species identification, avoidance, migration during the survey, and (d) the surface blind zone, all lead to Q values that may differ substantially from 1. These are multispecies surveys with total CPS backscatter converted to biomass by species. This implies that if Q differs from 1 for any of the species / stocks, the estimates for all other species / stocks will be biased. The Panel noted that the 2011 Panel supported use of the estimates of Pacific sardine as absolute biomass in assessments. However, it identified several research tasks that needed to be conducted, but little progress has been made on some key issues (see Appendix 4 and Items 3, 4 and 6).

The Panel highlights the importance of the survey aiming to cover the range of all stocks. It identified periods when jack mackerel and Pacific mackerel appear to be substantially in the survey frame, i.e. summer (Figure 2). It is likely that a substantial proportion of the biomass of the central subpopulation of northern anchovy is in Mexican waters, particularly in spring – extending the survey to Mexican waters should be an aim for the future. The ATM and stock assessment analysts should review each survey to decide whether to use the associated estimates in assessments.

It is beyond the Terms of Reference for the Panel to specify exactly how an ATM biomass index should be used directly in management. Specifying harvest control rules that directly use ATM biomass index is complicated because the Panel does not support use of estimates of biomass as absolute in assessments. However, harvest control rules that use indices of biomass have been developed for other fisheries using Management Strategy Evaluation and generally involve examining changes in biomass indices, with lesser focus on the absolute value of the biomass index.

9. AREAS OF DISAGREEMENT REGARDING PANEL RECOMMENDATIONS

There were no major disagreements among Panel members. The Panel summary of the major disagreements between the Panel and Team is:

- The Team believes that nighttime trawling is effective and efficient at providing the information that is needed from the trawl catches. The Team questions what specific scientific information is there that daytime trawling is more effective and accurate at providing this information? Moreover, the Team states that they do acoustic sampling during the day and trawling at night in the same areas, and the survey results, for multiple species, are more coherent than most acoustic-trawl surveys conducted elsewhere.
- The Team states that Panel refuses to recognize that surveys repeated during spring (when sardine are offshore and deeper) and summer (when nearshore and shallow) over six years, produced biomass estimates that are not statistically different from each other -- which logically indicates there is no significant bias due to avoidance or lack of near-surface and nearshore sampling?
- The Team questions whether the Panel has scientific evidence that avoidance or lack of near-surface and nearshore sampling is a problem.
- The Team believes that there is no scientific justification for extrapolating observations into areas where observations were not made.
- The Team states that if the Panel concludes that the results of the ATM surveys cannot be used as so-called "absolute" estimates, and the assessments should estimate Q, then why does the Panel also mostly concern itself with components of potential sampling and measurement bias? In other words, if the Panel believes that the ATM results can be considered "relative", then it inherently believes that the biases are either constant, or their variability is insignificant compared to the variability in the true stock biomass. In either case, the Panel makes the case that studying and correcting biases (e.g., from species ID, TS, behavior, sampling area) would be wasting resources. The Team argues that when the assessments estimates Q=1 for ATM estimates, the potential biases are not significant and the Team should better aim to reduce sampling variance.
- The Team states that several of the recommendation are not sufficiently clearly stated.

10. UNRESOLVED PROBLEMS AND MAJOR UNCERTAINTIES
Table 4 lists a summary of the major uncertainties, the recommendations related to each from the 2011 review, and this Panel's recommendations.

11. MANAGEMENT, DATA OR FISHERY ISSUES RAISED BY THE CPSMT AND CPSAS REPRENTATIVES
11.1 CPSMT Statement
On behalf of the CPSMT, the MT representative thanks the Team and Panel for preparing and conducting this extensive review. We also thank the SWFSC for hosting this review and appreciate the support of the Pacific Fishery Management Council. Nearly the entire CPSMT was able to attend and benefit first-hand from the participants' experience and expertise.

For each of the elements listed in the Terms of Reference, the Panel spent considerable time considering the merits and limitations of the ATM surveys as currently conducted. They suggested a number of research projects and data analyses to address uncertainties and potential deficiencies in the spring and summer surveys. The reviewers noted that the Team could develop a multi-year research program and allocate some time during each survey to address field research questions recommended by the Panel and others that may arise in the future.

Given the difficulties and significant complexities in achieving the survey goals, the CPSMT strongly supports allocating survey resources during each survey to conduct research on potential survey improvements, even at the expense of adaptive sampling currently conducted when significant acoustic biomass is detected on a transect. The CPSMT recommends the following research be considered among the highest priorities for the current survey design (in no particular order):

a) minimize or account for vessel avoidance,
b) document and account for fish catchability,
c) evaluate and conduct appropriate sampling (e.g., trawling) for species and size composition corresponding to acoustic signals, and
d) develop a means to reliably assess species composition, abundance and size composition within the areas not currently sampled during the ATM survey, such as inshore areas.

The CPSMT notes that for species such as anchovy that can aggregate in shallow waters, projecting biological density from nearshore ends of the current ATM survey transects to unsurveyed nearshore areas may produce biased population biomass estimates, likely underestimates. A management strategy evaluation, including a comparison to current monitored management of these species, would be needed before such biomass estimates may be used for active management. Other research, which may not require involvement by the Team, such as ageing studies, should also be conducted.

The CPSMT also supports the Panel recommendation for full documentation of methods and the decision process involved in field operations and data processing of the acoustic and trawl components of the current surveys, in providing a complete reference for future consideration and evaluation of the AT survey methodology. For example, a table including the goals, design, and significant operational decisions and changes, for past surveys and updated with future surveys, would be very useful.

11.2 CPSAS Statement
On behalf of the Coastal Pelagic Species Advisory Subpanel, the CPSAS representative commends the ATM Methods Review Panel, with special thanks to the three CIE acoustic scientists, for sharing their expertise and providing very helpful recommendations throughout the weeklong review. We also thank the Southwest Fisheries Science Center for hosting the meeting, the Pacific Fishery Management Council for sponsoring it, and the Team for their work to provide information on survey design, strategic decisions and analyses requested by the Panel during the meeting. Overall, the meeting was highly informative.

Throughout the 2018 review, CIE scientists expressed concerns with the same general issues found in 2011, also noted in the 2017 sardine STAR Panel and CIE Reports.

Target strength as well as the other problems stated– survey coverage, biological sampling, stratification and aging – and the scaling problem that has haunted sardine Star Panel reviews for many years, again were discussed at length. Two CIE comments in particular concerned this CPSAS representative: the current ATM trawl procedure seemed to focus on precision at the expense of accuracy, and the protocol is repeatable but not necessarily objective.

CIE scientists offered several recommendations for further study to resolve these problems that both the CPSMT and CPSAS unanimously support. In addition, the CPSAS, as well as the CPSMT, also support the Panel recommendation for full documentation of methods and the

decision process involved in field operations and data processing of the acoustic and trawl components of the survey, in providing a complete reference for future consideration and evaluation of the ATM methodology.

The fishery representatives on the CPSAS greatly appreciate the support and recommendations of the CIE scientists for collaborative research involving the fishing industry, and we also appreciate the support of the SWFSC and willingness of the Team to work with fishermen to resolve outstanding questions, such as:

- validating that the fish caught in the trawls from the night time scattering layer share the same species, age and size structure as the fish ensonified in the daytime clusters
- expanding sample size by testing the efficiency (relative catchability) and selectivity of the trawl among and within species by comparing samples from the same area taken with the survey trawl and purse seine.
- cooperating in inshore surveys to provide an estimate of abundance or correction factor for those unsurveyed areas.

Resolving these issues will lead to better surveys and more accurate stock assessments.

The fishing industry in both the Pacific Northwest and California is ready and willing to cooperate with NOAA to improve CPS surveys, and stock assessments, if adequate funding can be secured to help support such cooperative research ventures.

Appendix 7 provides details on concerns raised by CPSAS fishing representatives.

12. RECOMMENDATIONS FOR FUTURE RESEARCH AND DATA COLLECTIONS (IN PRIORITY ORDER)

A long-term strategy is needed to address the various issues discussed in this report. Experimental work to improve the results should be an integral part of conducting the survey. A systematic approach over years starting with the crucial elements will support survey efficiency as well as ecological understanding. It was recognized that some of the field seasons are joint surveys with multiple goals (e.g. 2018 summer survey is a joint CPS and marine mammal and turtle survey), which adds complexity to the operational strategy as well as the methodology.

High priority
1. Construct a document, ideally a NOAA Technical Memo that lists all of the aspects of the ATM survey, including design and analysis. This document should be updated regularly given new information and decisions.
2. Study vertical distribution of fish to determine if CPS in the surface blind-zone represent a stable and/or variable portion of the overall density of significance to the stock assessment. This could be done using vessel sonars or acoustic moorings.
3. The team should continue to collect target strength data using best available technology with associated relevant biological information to improve current target strength models.
4. Use net monitoring devices to monitor the trawl during all hauls. The optimal instrumentation is trawl sonar, which monitors the variable geometry of the trawl opening, and the distribution of fish within and outside the trawl opening
5. Continue to explore and expand independent nearshore survey methods and efforts to estimate the proportions of the populations that may not currently be surveyed by the ATM surveys.

6. Develop extrapolation methods from the existing data that would extend biomass estimates to the coastline, or, alternatively, document why such approaches are not needed for certain areas. Two potential methods include:
   a. extend the existing polygons to the coastline and assume the same mean density; and
   b. use backscatter information collected nearshore (in-between transects) to extrapolate to the coastline.
7. Analyze the effect of the adaptive sampling of the bias of estimates of biomass using simulation or through reanalyzing various subsets of conducted transects.
8. Improve ageing of survey and fisheries samples to allow age composition data to be used in assessments.
9. Test efficiency (and suitability) of the existing trawl. This can be done either by comparing acoustic density measures with swept volume densities of the trawl or compare swept volume densities with similar measures from larger trawls and other gear types.
10. Develop methods to verify that daytime sound scatterers are the species and sizes caught in nighttime trawls; i.e. verify that efficient day time sampling of the acoustic record gives similar results as present nigh time sampling strategy. Such approaches could include alternative day-time sampling strategies (e.g. curved trawling trajectories) and/or different trawl gear, purse seining by day (either using research or industry vessels), or alternative sampling techniques such as drop cameras.
11. The assumption that all CPS finfish spread out at the surface needs to be validated.

Medium priority
1. Conduct night trawls at different depths in the same area, with the headrope at the surface, at 15 m, and at 30 m depth, for example to compare estimates of species and length composition.
2. Develop methods to extract information from the acoustic data about numbers of schools and their size and spacing. Time series of school statistics, along with other stock characteristics, might become useful in studies of state and interaction dynamics of stocks.
3. Compare the area (e.g. over several transects) and the current cluster approach to convert backscatter data to biomass when sample sizes for a particular species are insufficient.
4. Examining certain school characteristics (e.g. frequency response) by day and by night may be instructive. In the case of "pure" species compositions the latter may also be instructive to detect species-specific characteristics that could be latter apply for acoustic mark classification
5. Examine the effects of the sample size of fish collected in trawls in terms of uncertainty and variability in indices and size and age compositions, and consider ways to increase sample size. Low sample size to estimate relative abundance by species affects indices more than the sizes collected, but the latter is important for estimating size and age structure. While increasing the length of trawls will help to some extent, other approaches may be more efficient.
6. Explore options to quantify potential fish avoidance under a range of survey conditions. This could involve combining systematic collection of additional data during surveys, as well as dedicated experiments.
7. Examine trends in density from the inshore ends of the survey transects to provide best available information for expansion of estimates to un-surveyed inshore regions.

8. In relation to ageing, evaluate the trade-offs between ageing more animals, but with lesser precision vs. ageing more animals with greater precision. Consider polishing otoliths before reading them.
9. Design and execute field experiments (for example by tracking fish schools with sonars over 24 hrs) to study movements of fish between time of registration and time of sampling, to validate that the current sampling strategy is adequate to reflect the size and species composition of daytime acoustic records.
10. Utilize time series of survey data, including school statistics, to explore if changes in species dominance in the ecosystem causes changes in behavioral characteristics, such as vertical and horizontal distribution dynamics, which ultimately will impact survey efficiency for those species.

Lower priority
1. Study fish behavior in front of the codend and trawl opening and measure flow inside/outside the trawl using a high frequency Acoustic Doppler Current Profiler (ADCP). This will allow an evaluation of the frequency with which fish escape. Such work is needed because the codend is relatively short with a small mesh liner, and has probably insufficient filtering capacity at 4 knots. This might "block" the entrance of the codend and lead to an increased flow of water through the meshes in front of the codend where some fish will probably escape.

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Table 1. Summary of the characteristics of the surveys conducted to date. Note that the values reported are preliminary. The Team should be contacted for updates prior to citing these values.

Response:

Survey ID	Date start	Date end	Duration (d)*	Target Species	Sardine biomass (10³ mt) [CV]	Anchovy biomass (10³ mt) [CV]	Number of transects (n)	Length of transects (nmi)	Area covered (nmi²)	Acoustic equipment	Number of trawls (n)	Total number of trawl Clusters (n)	Number of positive trawl cluster (n)
			26		1,947	n.a.						n.a.	n.a.
0604OD	4/12/2006	5/8/2006		Sardine/CPS	[30.4]		18	2,563	194,543	EK60	40		
0804JD	4/12/2008	4/28/2008	16		751	n.a.	15	3,489	84,095	EK60	30	n.a.	n.a.
0804MF	4/12/2008	4/30/2008	18	Sardine/CPS	[9.2]		18	2,458	106,879	EK60	42	n.a.	n.a.
1004FR	3/30/2010	4/27/2010	28		357	n.a.	9	1,360	61,435	EK60	55	n.a.	n.a.
1004MF	4/3/2010	4/20/2010	17	Sardine/CPS	[43.3]		15	1,780	70,936	EK60	43	n.a.	n.a.
			31		494	n.a.							
1104FR/1104SH	3/25/2011	4/25/2011		Sardine/CPS	[30.4]		21	2,919	65,741	EK60	105	19	16
			44		470	n.a.						35	14
1204SH/1204OS	3/17/2012	4/30/2012		Sardine/CPS	[28.6]		19	3,230	92,823	EK60/ME70	95		
				Sardine/hake/CPS	341	n.a.					98		
1206SH	6/24/2012	8/30/2012	67	PS	[33.4]		85	3,509	36,991	EK60/ME70		38	31
1304OS/1304SH	4/10/2013	5/4/2013	24	Sardine/CPS	305 [24.4]	n.a.	17	2,791	56,804	EK60	70	26	15
				Sardine/hake/CPS	314	n.a.					147		
1306SH	6/6/2013	8/30/2013	85	PS	[27.5]		62	4,420	46,865	EK60/ME70		56	39
					35	n.a.					39		
1404SH	4/13/2014	5/7/2014	24	Sardine/CPS	[39.6]		10	3,890	85,265	EK60/ME70		16	8
					26	n.a.					85		
1406SH	6/24/2014	8/5/2014	42	Sardine/CPS	[70.3]		22	2,278	40,513	EK60/ME70		36	29
					29	n.a.					54		
1504SH	3/28/2015	5/1/2015	34	Sardine/CPS	[29.9]		13	1,843	50,038	EK60/ME70		22	15
1507SH	6/15/2015	9/10/2015	87	CPS	16 [80.2]	n.a.	32	2,614	47,188	EK60/ME70	160	58	50
						n.a.							
1604RL	3/22/2016	4/22/2016	31	Sardine/CPS	83 [49.3]		12	3,849	34,223	EK60/EK80/ME70/MS70/SX90	43	18	9
1607RL	6/28/2016	9/22/2016	86	CPS	79 [53.9]	152[41]	54	4,627	50,477	EK60/EK80/ME70/MS70/SX90	121	49	40
1706RL	6/21/2017	8/10/2017	50	CPS	37 [30.1]	n.a.	68	3,313	51,743	EK60/EK80/ME70/MS70/SX90	86	36	34

*Includes in-port days

Table 2. Parameters of the regression equations fitted to target strength data for anchovy, pilchard (sardine) and horse mackerel (s.e.m. denotes standard error of the mean; s.e. of Y indicates the standard error of the dependent variable). Source: Barange et al. (1996).

| | (dB individual^{-1}) | | (dB kg^{-1}) |
	$Y=20 \log TL - b_{20}$	$Y=a \log TL - b$	$Y=a \log TL - b$
Anchovy	$n=18$	$a=19.50$	$a=-12.15$
	$b_{20}=76.10$	$b=75.57$	$b=21.12$
	s.e.m.$=0.15$	$r^2=0.81$	$r^2=0.59$
		s.e. of $Y=0.66$	s.e. of $Y=0.70$
Pilchard	$n=13$	$a=17.07$	$a=-14.90$
	$b_{20}=70.51$	$b=66.73$	$b=13.21$
	s.e.m.$=0.10$	$r^2=0.87$	$r^2=0.87$
		s.e. of $Y=0.35$	s.e. of $Y=0.30$
Horse mackerel	$n=21$	$a=14.66$	$a=-15.44$
	$b_{20}=66.80$	$b=58.72$	$b=7.75$
	s.e.m.$=0.16$	$r^2=0.78$	$r^2=0.80$
		s.e. of $Y=0.63$	s.e. of $Y=0.63$

Table 3. Evaluation of possible use of ATM results in assessments and management. Q denotes the catchability coefficient between the biomass estimate and biomass in the model. This table does not discuss option (c) of TOR 8 given the Panel did not support using the ATM estimates as measures of absolute abundance, but provides options for how biomass estimates from the survey could be used to directly inform management.

Species / stock	Inclusion in an integrated stock assessment		Use of biomass estimates from the survey to directly inform management (following an MSE)[4]	Ability to estimate abundance at age
	Relative abundance (Q estimated)[1]	Absolute abundance (Q=1)[2]		
Pacific Sardine	Yes	No	Yes	Yes, but there are concerns with aging
Pacific mackerel	Yes, summer surveys only	No	Yes, summer only	Yes, but there are concerns with aging
Jack mackerel	Yes, summer surveys only	No	Yes, summer only	In principle, but there is currently no ageing program
Northern sub-population of northern anchovy	Yes, summer surveys only, if inshore area is addressed[3]	No	Yes, summer surveys only, if inshore area is addressed	Yes – no current ageing program that is ready to be used
Central sub-population of northern anchovy	Yes, but only, if inshore areas is addressed[3]	No	Yes, but only, if inshore areas is addressed	Yes – no current ageing program that is ready to be used

1: option (a) in the TOR 8
2: option (b) in the TOR 8
3: Only available from 2015.
4. Only with MSE. Harvest control rules that use indices of biomass that are not considered absolute have been developed for other fisheries using Management Strategy Evaluation and generally involve examining changes in biomass indices.

Table 4. Major sources of uncertainty, the recommendations from the 2011 panel, and the current status.

| Source of uncertainty	2011 Review recommendation	2018 recommendations (see Section 12)
Proportion of the biomass inshore		H.5, H.6, M.7
Proportion of the biomass offshore		
Proportion of the biomass north and south of the survey area		
Uncertainties in target species identification	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	
Uncertainties in target strength	Make efforts to obtain TS measurements for *in situ* CPS in the California Current Ecosystem.	H.3
Avoidance		M.6
Migration during the survey		M.9
Surface blind zone		H.2, H.4, H.11
Efficiency and selectivity of trawls	1. Test the efficiency and selectivity of the trawl by comparing samples from same area taken with the survey trawl and purse seine 2. Investigate potential species selectivity effects by comparing the ratios of catch rates and acoustically-estimated densities in areas where single species dominate.	H.3, H.4, H.9, H.10, M.1, M.4, M.9, M.10, L.1
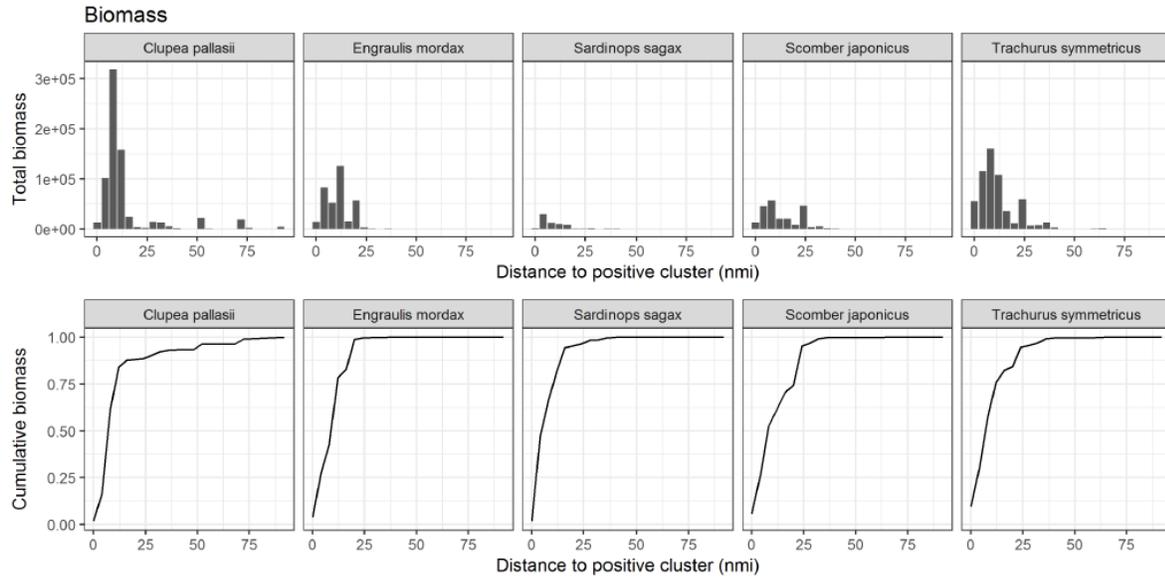
Figure 1. Acoustic biomass (upper panel) and cumulative relative biomass (lower panel) by the distance to the nearest positive trawl cluster.
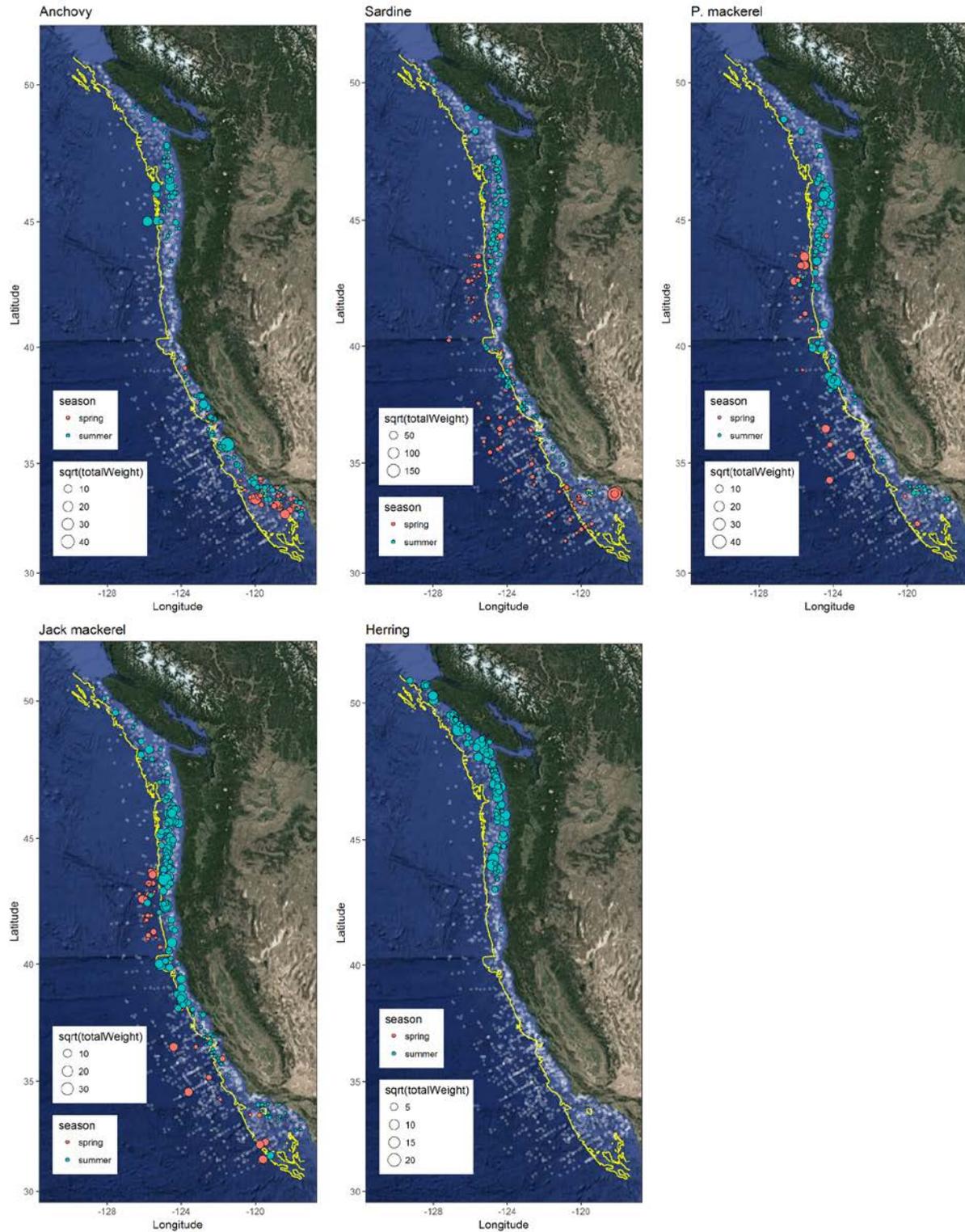
Figure 2. Maps of the west of the North America showing the total catch (square-root kg) of each CPS by season (spring ≤ May, summer > May) for ATM surveys conducted since 2006.
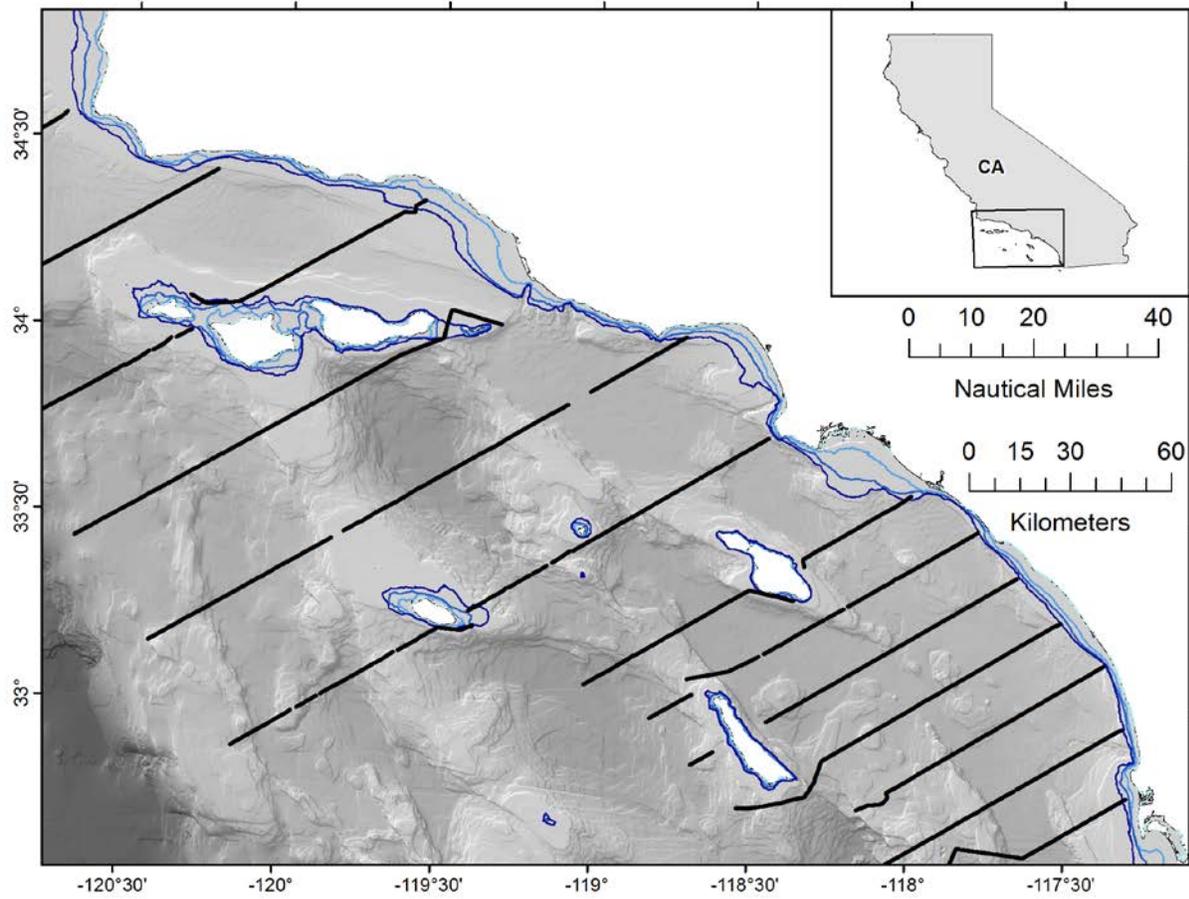
Figure 3. Map of the coast of California showing the acoustic survey transects (black lines) and bathymetric contours (blue lines at 20, 40, and 60 m seabed depth, respectively darker).
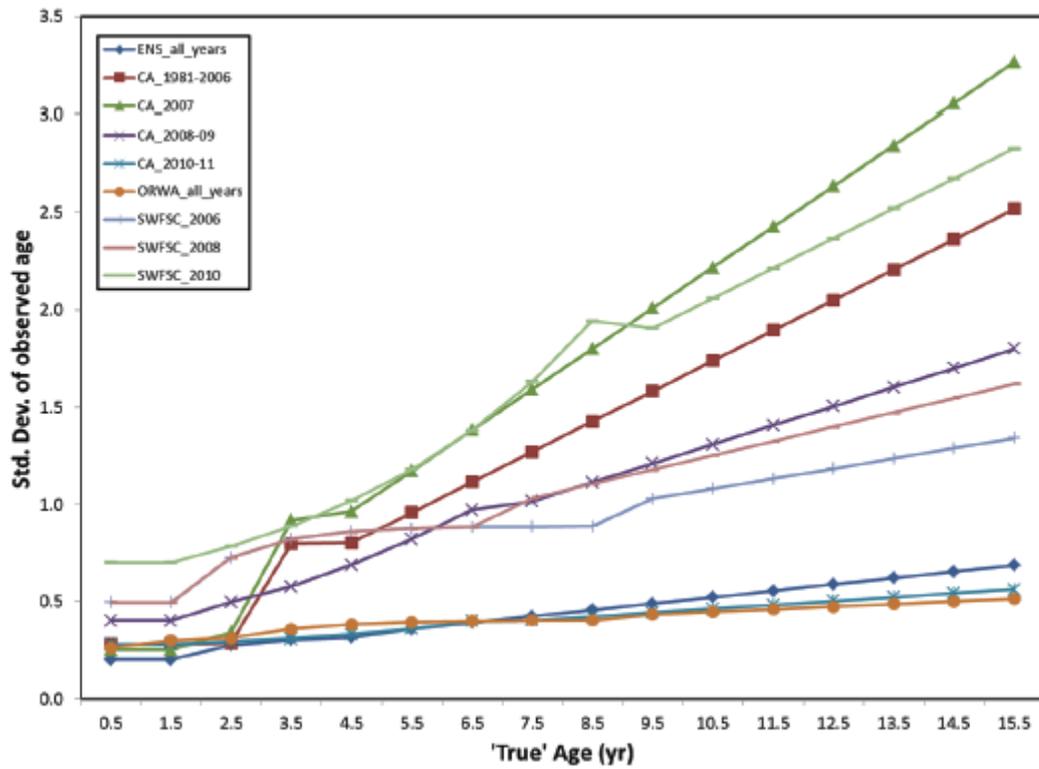
Figure 4. Laboratory and year-specific ageing errors for Pacific sardine. The 'True' age was a reference age estimated using a mixed effects model.
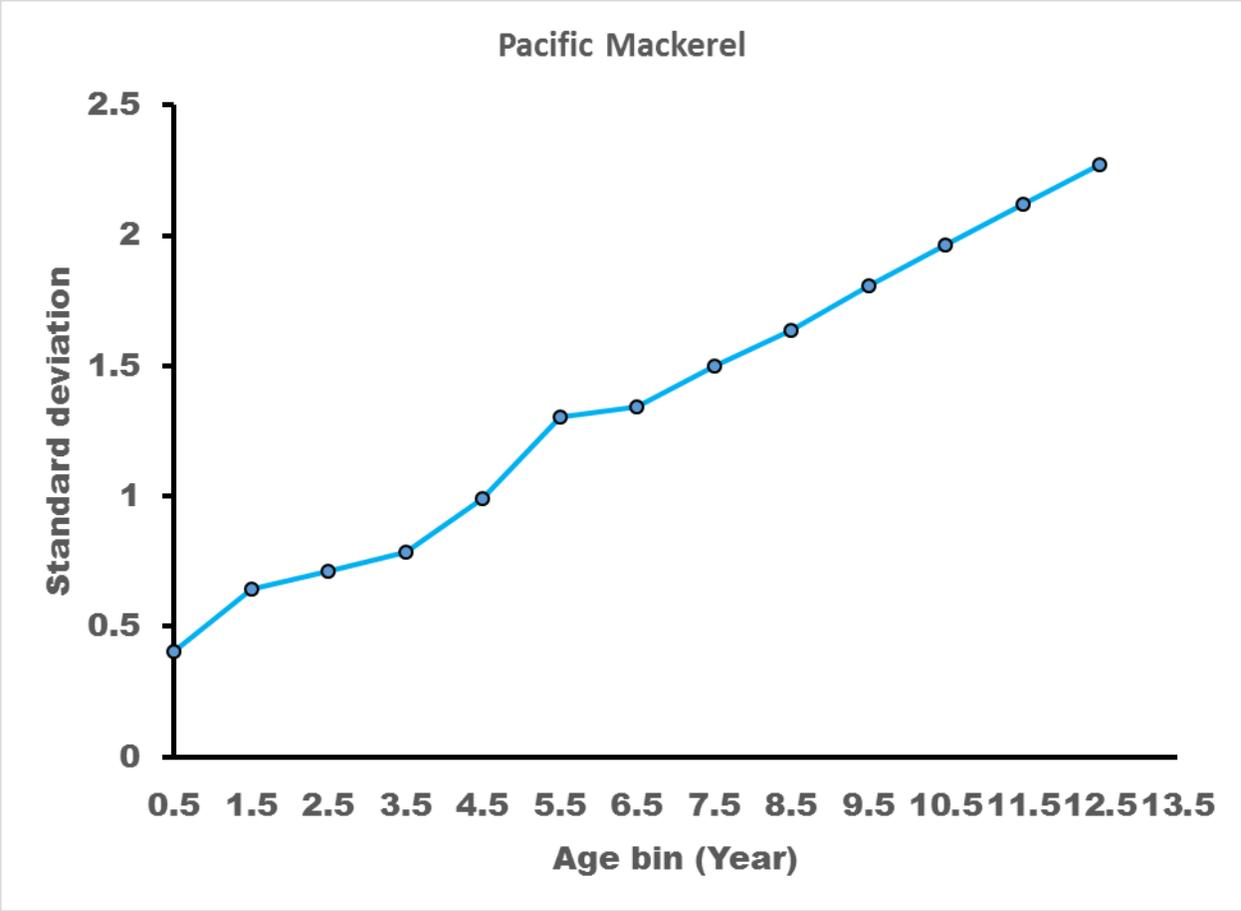
Figure 5. The standard deviation of age-reading error for Pacific mackerel (E. Dorval, SWFSC).
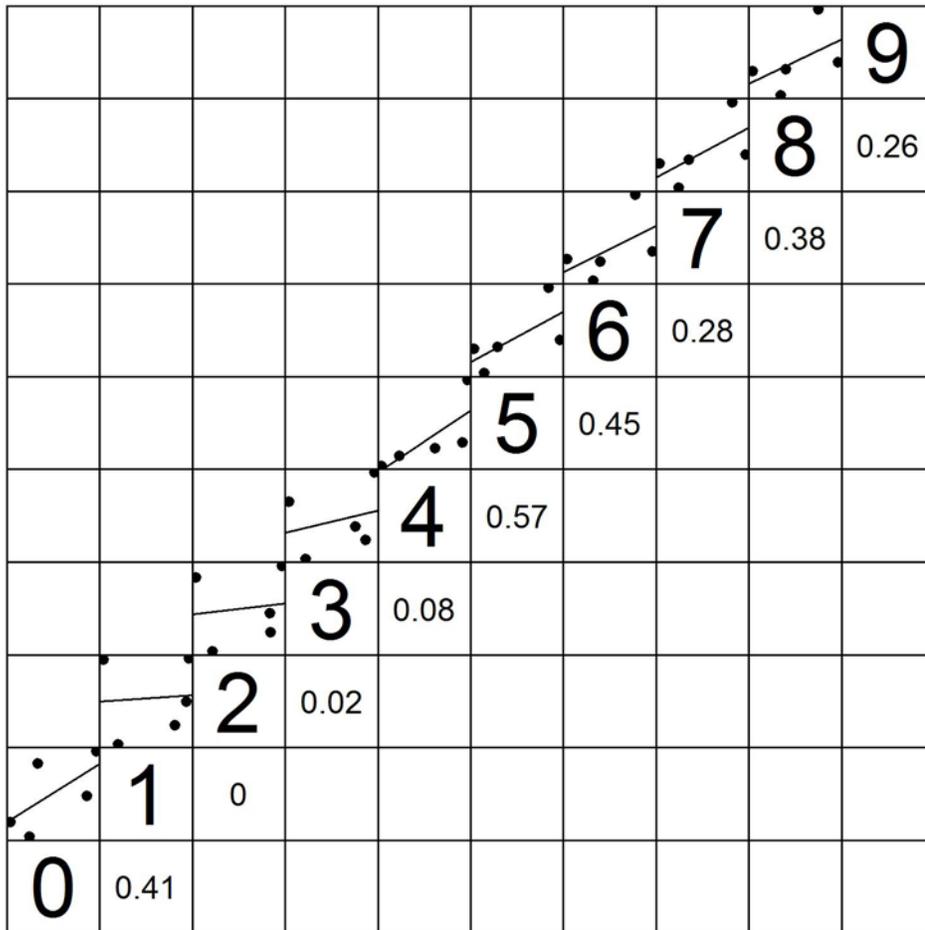
Figure 6. North Sea herring. Internal consistency plot (log of numbers at age x in year t against numbers at age x+1 in year t+1) of the acoustic survey for sardine. Above the diagonal the linear regression is shown including the observations (in points) while under the diagonal the r^2 value that is associated with the linear regression is given.

Appendix 1: List of Participants

Attendance List – ATM Review
Methodology Review Panel
André Punt, SSC, University of Washington, Chair
Evelyn Brown, SSC, Lummi Indian Nation
Owen Hamel, SSC, NWFSC
Stéphane Gauthier, CIE, Institute of Ocean Sciences, Canada
Paul Fernandes, CIE, University of Aberdeen
Olav Rune Godø, CIE, Institute of Marine Research, Norway

Pacific Fishery Management Council (Council) Representatives
David Crabbe, PFMC
Cyreis Schmitt, Coastal Pelagic Species Management Team (CPSMT)
Diane Pleschner-Steele, Coastal Pelagic Species Advisory Subpanel (CPSAS)
Kerry Griffin, Council Staff

Acoustic-Trawl Method Technical Team:
David Demer, SWFSC
Juan Zwolinski, SWFSC
Kevin Stierhoff, SWFSC
Josiah Renfree, SWFSC
David Murfin, SWFSC
Steve Sessions, SWFSC
Dan Palance, SWFSC
Scott Mau, SWFSC

Other:
Josh Lindsay, NMFS WCR
Gerard DiNardo, SWFSC
Emmanis Dorval, SWFSC
Briana Brady, CDFW
Kirk Lynn, CDFW
Kevin Hill, SWFSC
Mike Okoniewski, Pacific Seafood
Steve Marx, Pew Trusts
Bev Macewicz, SWFSC
Alan Sarich, Quinault Indian Nation
Dale Sweetnam, SWFSC
Paul Crone, SWFSC
Roger Hewitt, SWFSC
Ed Weber, SWFSC
Sam McClatchie, SWFSC
James Hilger, SWFSC
Noelle Bowlin, SWFSC
Geoff Shester, Oceana

Kristen Koch, SWFSC
Toby Garfield, SWFSC
Trung Nguyen, CDFW
Phill Dionne, WDFW
Katie Grady, CDFW
Bill Watson, SWFSC
Dan Averbuj, CDFW
Kim Boone, CDFW
Steven Teo, SWFSC
Michael Kinney, SWFSC
Sharon Charter, SWFSC
Magumi Enomoto, Tokyo University
Anne Freire, SWFSC
Megan Human, SWFSC
Luke Thompson, 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 340 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.

Evelyn Brown joined the SSC at the beginning of 2016 and serves on the CPS and Ecosystem Indicator subcommittees. She currently works as the stock assessment lead and fisheries analyst for the Lummi Nation, a consortium of five tribes associated with a usual and accustomed fishing region that stretches from northern Puget Sound to central Salish Sea ending at the US border. Her main focus currently is improving salmon population metrics and models, including life history, for the Nooksack River stocks, monitoring and modeling Dungeness crab recruitment, assisting with other shellfish assessment topics, and providing metrics and models for salmon and shellfish enhancement. She was formerly a stock assessment biologist with the Alaska Department of Fish and Game (15 years), and research associate at the University of Alaska Fairbanks focusing on aerial surveys and remote sensing of forage species and ecology. She obtained her Masters in Fisheries from Oregon State in 1980 and her PhD from University of Alaska in 2003 with a dissertation topic of Pacific herring stock assessment.

Paul G. Fernandes, is a fisheries scientist at the University of Aberdeen in Scotland UK. Dr Fernandes has a BSc in Marine Biology and a PhD in Marine Ecology from Liverpool University's Port Erin Marine Laboratory. He worked overseas in Bolivia on the artisanal fisheries of Lake Titicaca and in the Republic of Ireland, before embarking on a 17-year stint at the Marine Laboratory in Aberdeen, Scotland (now Marine Scotland Science). Initially, he worked on fisheries surveys (acoustics and trawl), then on fish stock assessment, and latterly he managed over 20 scientists in the Sea Fisheries group; this group was responsible for the assessment of Scotland's internationally managed fish stocks. He took up his current position as reader in Fisheries Science at the University of Aberdeen in July 2011 partly funded by the Marine Alliance for Science and Technology Scotland (MASTS). He has a small (8) research group, FEAST (Fisheries Ecosystems and Advanced Survey Technologies), working on topics such as ecosystem modelling, acoustic surveys (active and passive), trawl surveys, visual surveys and stock assessments. He also convenes the MASTS Fisheries Forum, which pools all of Scotland's expertise in marine fisheries across academic, government and industry sectors. Dr Fernandes role in the review activities was specified according to matching experience and expertise in: (1) the design and application of fisheries underwater acoustic technology to estimate fish abundance for stock assessments; (2) the design and execution of fishery-independent surveys for use in stock assessments, preferably with coastal pelagic fishes; (3)

expertise in the application of fish stock assessment methods, particularly, length/age-structured modeling approaches, e.g., 'forward-simulation' models (such as Stock Synthesis, SS) and how fishery-independent surveys can be incorporated into such models; (4) expertise in the life history strategies and population dynamics of coastal pelagic fishes. This reviewer does not have experience in the design and application of aerial surveys to estimate fish abundance for stock assessments.

Stéphane Gauthier is a research scientist and head of the fisheries acoustics program at the Institute of Ocean Sciences (Sidney, British Columbia). His research program focuses on the development of acoustics and complementary technologies to improve fisheries management and knowledge of ecosystem dynamics. Before joining Fisheries and Oceans Canada in 2011 he was a fisheries scientist with the National Institute of Water and Atmospheric research in New Zealand, where he worked on a wide range of ecosystems, from the Arabian Sea to the Antarctic Ocean. Stéphane holds a Ph.D. in biology from Memorial University of Newfoundland, as well as postdoctoral experience from the University of Washington and Université de Montréal.

Olav Rune Godø retired from his senior scientist position at Institute of Marine Research and is now senior advisor at Christian Michelsen Research. He received his Cand. real. in fisheries biology and his Ph.D. in marine survey methodologies, both at 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 group in survey methodology, all duties at the Institute of Marine Research. In recent year his focus has been development of in marine ecosystem acoustics. His research interests include trawl-acoustic survey methodology, fish behavior, biophysical interaction and fisheries-induced evolutionary changes. During the last 5 years he has been Norwegian representative to CCAMLR (Commission for Conservation of Antarctic Marine Living Resources). He has published about 100 publications in peer-reviewed journals and in addition to several book chapters and a number of 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 Census of Marine Life and a member of a SCORE WG on observation methods. He also has been a member of several ICES working groups.

Owen S. Hamel leads the Integrated Fisheries Stock Assessment Team at the Northwest Fisheries Science Center (NOAA Fisheries) in Seattle, Washington. He holds a B.A. in Mathematics from Brandeis University, and an M.S. in Applied Mathematics and Ph.D. in Quantitative Ecology and Resource Management from the University of Washington. Owen's current research interests include stock assessment methods, survey and sampling approaches and analysis, otolith ageing validation, fishing impact metrics, and development of Bayesian priors for life-history parameters. Previously, he worked in fish disease modeling. Owen is an Affiliate Professor in the School of Aquatic and Fisheries Sciences at the University of Washington, a member (and former chair) of the Scientific and Statistical Committee (SSC) of the Pacific Fisheries Management Council (PFMC), and current chair of the NOAA Fisheries Assessment Methods Working Group.

Appendix 3: Documents provided to the Panel before the meeting

Document prepared for the meeting

Demer, D.A, Zwolinski, J.P., Stierhoff, K.L., Renfree, J.S, Palance, D., Mau, S., Murfin, D. and Stevens, S. Acoustic-Trawl Methods for Surveying Coastal Pelagic Fishes in the California Current Ecosystem

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Appendix 4 : Progress related to the recommendations from the 2011 ATM-survey review
David Demer

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, and catch information) to provide estimates for the biomass outside of the survey area, as well as the range of possible biomass levels.

Response: The ATM survey results are for the survey area. If some biomass for particular species resides outside of the survey area, this should bias should be estimated by the associated stock assessment. If the bias is significant, the survey sampling should be refined appropriately.

The Pacific sardine assessments have either assumed Q=1 or estimated Q≈1, indicating no or insignificant bias in the ATM results for this species. This finding is supported by analyses of data collected outside of the ATM survey area. These include eggs counts obtained from the continuous underway fish egg samples (CUFES) offshore off Southern California (https://swfsc.noaa.gov/textblock.aspx?Division=FRD&id=1121) and aerial observations in the nearshore region of the Southern California Bight (Lynn et al., 2014). Prior to 2016, the biomass of Pacific sardine residing in those areas was negligible in relation to the biomass observed in the survey area. In 2017, the biomass in schools of fish observed nearshore off southern California, putatively Pacific sardine and northern anchovy, may have increased (unpublished data; Lynn, pers. Comm.). Also in 2017, the ATM survey area was extended to the nearshore region off Washington and Oregon, facilitated by a collaboration with the fishing industry, and the biomass there was insignificant compared to the anchovy biomass sampled offshore (unpublished data; Team). Nearshore sampling is expected to continue in 2018.

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

Response: The between-transect CV approximates the overall sampling variability and is insensitive to trawl sampling error when a species is abundant and geographically separate from others species.

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.

Response: The FRD trawl group initiated catch selectivity experiments in 2017.

b. Compare total CPS backscatter along transects to trawl catch rates using statistical techniques.

Response: Positive trawls were associated with acoustic samples with significantly higher than average backscatter (Zwolinski et al., 2012).

c. Conduct sensitivity tests in which stations are pooled and allocated to acoustic values over a larger area.

Response: The trawl catches from each night are pooled. Species and size composition data from these "trawl clusters" are associated to the nearest acoustic samples (see Appendices A and B in Hill et al., 2012).

d. Consult experts in trawl design to evaluate the current trawl design in relation to the survey objectives.
Response: The FRD trawl group will consult the report of the 2018 ATM review for recommendations from independent experts on the current trawl design.

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.
Response: The Echoview algorithm includes a set of filters, but not the VMR, to retain backscatter of schooling, swimbladder fishes. Echo classification to species is not presently possible, but improved classification of CPS using wideband signals will continue to be explored.

f. Evaluate the potential use of the echosounder in a non-vertical position.
Response: FSV Reuben Lasker is equipped with Simrad EK60 and ME70 echosounders (vertical beams or beam swath) and MS70 and SX90 sonars (horizontal beams), to sample fish behaviors and abundances throughout the water column. Since 2016, data have been collected routinely from these instruments. Dedicated personnel are needed to analyze these data.

g. Check the filtering algorithm every year to ensure that it is still suitable under changing conditions.
Response: The efficacy of the filtering algorithm is evaluated for each survey, and refined as necessary (see 2e Response).

h. Study trends in the frequency response over depth strata in schools.
Response: The frequency responses of CPS aggregations within the mixed layer do not vary significantly versus depth in areas with sardine, anchovy, or mackerels in the associated catches.

i. Compare results from the 18-kHz and other transducers to examine possible avoidance reactions.
Response: The possibility that near-surface CPS may move to the side of the vessel and therefore negatively bias estimates of their biomass could perhaps be evaluated by comparing data from wide- versus narrow-beam echosounders. However, comparison of data from an 18-kHz, 11-degree beamwidth transducer and that from a 38-kHz, 7-degree beamwidth transducer, as proposed, requires accurate knowledge of the relative frequency response which may vary with any changes in incidence angle resulting from possible reaction of fish to the survey vessel. The analysis may be better done with a dual-beam 38-kHz transducer, e.g., if the narrowband narrow-beam ES38B is replaced by the new wide-band, dual-beam ES38-7, or by comparing data from an ME70 70-kHz wide-beam (e.g., 20 degree beamwidth) to that from an EK60 70-kHz narrow beam (7 degree beamwidth). Even using the same frequency, however, any differences in volume backscatter may be caused by either avoidance reaction or scattering directivity.

j. Continue to consider the advantages and disadvantages of conducting ATM surveys at different times of the year.
Response: The Winter/Spring ATM survey is conducted during ~30 days and targets sardine or anchovy aggregated and spawning offshore of southern and central California; and the results are complemented by those from concomitant DEPM surveys. In comparison, the Summer ATM

survey is conducted during ~50-80 days and targets the CPS assemblage when the species are typically closer to shore and more geographically separate, the days are longer and the weather is generally better, and the survey area overlaps more or all of the regional fisheries.

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.
Response: As the veracity of age estimation improves, year-specific age-length keys will be derived and used to estimate age-based abundances from the ATM surveys.

l. Conduct standard (ICES) vessel noise measurements for all vessels.
Response: Measurements of vessel noise have been made for all NOAA FSVs and the results have been compared to the ICES standard. Since 2016, recordings of underwater sound have been made using hydrophones mounted on the survey-vessel hull.

3. Long-term
a. Evaluate if different trawling practices or gears, or both would be beneficial.
Response: The FRD trawl group continues to evaluate different trawling practices and gears for their benefits.

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.
Response: Nighttime trawl catches are used to apportion the closest CPS backscatter to species and their sizes. Additional nighttime trawling in an area may be achieved by reducing the transect spacing. However, unless the survey duration is increased, this approach will reduce the total survey area. Consequently, reductions in variance through additional trawling may increase estimation bias.

c. Use a trawl/vessel configuration that can support directed trawl sampling.
Response: Directed trawling may be used to achieve spatial-temporal matches between echoes and catches, to perhaps elucidate frequency responses for each species. If the frequency responses are sufficiently unique, they may be used to accurately apportion echoes to target species, even for schools not trawled. However, sardine, anchovy, jack mackerel, Pacific mackerel and herring have presently indistinguishable frequency responses, so nighttime trawl catches must be used to apportion the closest CPS backscatter to species and their sizes. The accuracy of this apportioning is related to their geographic separations and relative abundances.

d. Conduct repeated trawl sampling experiments to obtain a better understanding of small-scale variability.
Response: Typically, a maximum of three trawls are conducted per night, each separated by less than 10 nmi. Small-scale variability can be evaluated by comparing species proportions and length distributions estimated from nightly trawl clusters including data from 1, 2, or 3 trawls. An analysis with additional trawl samples from the same area will require an assumption of stationarity and additional ship time necessary to remain in and trawl more in one location.

e. Test the efficiency and selectivity of the trawl by comparing samples from same area taken with the survey trawl and purse seine.

Response: The FRD trawl group will consider the merits of this recommendation and whether it can be practically facilitated by future collaboration with the fishing industry.

f. Apply state-of-the-art acoustic and optic technology to investigate fish behavior and escapement at various critical positions of the trawl.

Response: Video data were collected inside the trawl net to observe the performance of the marine mammal excluder device. During successive trawls, the light-source was randomly changed between white, red, or no illumination. These data and the associated catches could be analyzed to glean some information about fish behavior inside the net. Additional personnel is needed to analyze these data. The FRD trawl group is pursuing other methods to investigate fish escapement.

g. Conduct validation tows on various kinds of backscatter to assure that the filtering algorithm is performing as intended to apportion backscatter to CPS.

Response: The FRD trawl group will investigate the net and trawl gears needed for such investigations.

h. Make efforts to obtain TS measurements for in situ CPS in the California Current Ecosystem.

Response: TS measurements of in situ CPS are made during nighttime trawls. Results for northern anchovy served to refine the TS(L) model used. Analyses of these data continue for anchovy and other CPS.

i. Focus on utilizing more advanced instrumentation and resource-demanding research for studying vessel impacts.

Response: See response to 2f. These data will be analyzed as priorities and resources permit.
References:

Lynn, K., Porzio, D., and Kesaris, A. 2014. Aerial sardine surveys in the Southern California Bight. California Fish and Game, 100: 260-275.

Appendix 5 : Trawl drawings

49

200mm(8") CENTER HOLE FLOATS
SPIKED TO TOP RIBLINE WITH #333 NYLON
20 TOTAL

9mm(3/8"x2") GALVANIZED STEEL RINGS x 6/PANEL
CLOSE WITH 16mm(5/8") DURALON x 9.14m(30')
PUCKER LINE AND 20mm(3/4") TRAWL RELEASE

88.0MD
APPROX 8.49m(27'10")

18.0MD
APPROX 1.65m(5'5")

LINER: SEE NOTE #4
AND DETAIL DIAGRAM

NOTES:

1. DIMENSIONS: 92(23x23) MESHES AROUND x 88.0 MESHES DEEP

2. NETTING: 100mm(4") D5.0mm PE

3. LINER: RASCHEL NYLON NOAA LINER

CONTAINER LINES
18mm(3/4") ULTRA LINE x 4.27m(14')
SPLICED EYE TO EYE, 0.76m(30") SPACING
5 TOTAL FROM AFT END

23M

LIFTING STRAPS
24mm(1") ULTRA LINE x 6.10m(20')
2 TOTAL

FRONT
END

20mm(3/4") SLING LINK
LASHED TO RIBLINES

23M

RIBLINES
16mm(5/8") DURALON
LENGTH 5% LESS THAN NETTING
COLOR CODE: STBD=GREEN, PORT=RED

THIS END SEWN ONTO
AFT END OF INTERMEDIATE

0.61m
(2')

LINER DETAIL

370.0MD

97M

97M

RASCHEL NYLON NOAA LINER

SAMPLING CODEND		
CUSTOMER: NMFS (LA JOLLA)		
JOB NO.—ORIGINAL: 25096/CODD40592/5448,5449		
REVISED: --		
ENGINEER— ORIGINAL: NETS STAFF	04/13/97	
REVISED: NETS STAFF	05/18/04	
DRAWN BY: K. TAMURA	VERSION: 02	
DWG NO.: O88CO4NM	SHEET 1 OF 1	

NET SYSTEMS USA

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Appendix 6: Evaluation of the ATM post-stratification protocol and variance estimation

Acoustic surveys methods sampling

- Parallel systematic surveys
  - Even spacing (multiples of 10 miles)
  - Provide the most precise estimates for spatially structured stocks (not my words)
- Transects are perpendicular to the isobaths
  - There is a strong gradient inshore-offshore
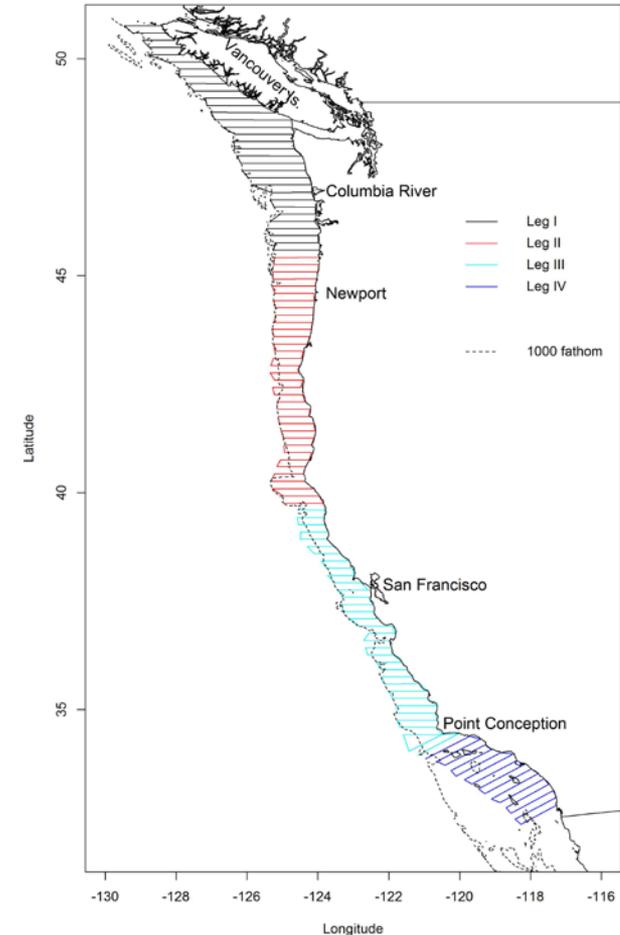
Abundance estimation

- The goal is to estimate the abundance of a species in the survey area

$$N = A * \hat{D}$$

- Transects are typically short, placed normal to the coast, strong density gradient
  - Use of transect means as sampling units - the literature is full of references justifying this approach
- Ratio estimator

$$\hat{D} = \frac{\rho l}{L},$$

where $\rho l = \sum_{i=1}^{k} \overline{\rho}_i l_i$ and $L = \sum_{i=1}^{k} l_i,$

and $\overline{\rho}_i =$ mean biomass density of the *i-th* transect, $l_i =$ length of the *i-th* transect

- Ratio estimator is equivalent to the mean biomass density calculated from all EDSUs

NOAA FISHERIES

Precision of the abundance estimate

- Precision – the reproducibility of an estimator under repeated observations
    - Repeated surveys are not common
    - Ergodic theorem states that the precision of a survey quantity can be done through a "one-off" large sampling realization of the process – if the process is ergodic
        - We can use the survey samples to calculate the precision of our estimator
    - Variance of the estimator

$$var(N) = A^2 * var(\widehat{D})$$

$var(\widehat{D}) = var(\frac{\rho l}{L})$, if $l_i = constant$, $var(\widehat{D})$ is proportional to $var(\overline{\rho}_i)$

- Bootstrap – "the bootstrap provides a powerful yet simple method for variance and interval estimation" – (Buckland et al 1993)

Bootstrap requires independent and identically distributed (IID) data

NOAA FISHERIES

Identically distributed data

- Identically distributed data means that the data arise from the same probability distribution
  - Stationary in mean and variance (weaker condition)

- By design, the surveys will encounter transects with 0-mean outside the area of distribution – "external" or "structural" zeros

- Due to fish aggregative behavior, areas of presence will exhibit a right-skewed distribution (e.g. log-normal) and a certain amount of "internal" zeros

Transect means are non-identically distributed

- Post-sample stratification creates strata with approximate stationarity through step functions
  - Post-sample stratification does not change the abundance estimate
 - Post-sample stratification provides the correct variance to evaluate precision in the repeated-survey sense

NOAA FISHERIES

Post-sample stratification

Post-sample stratification

NOAA FISHERIES
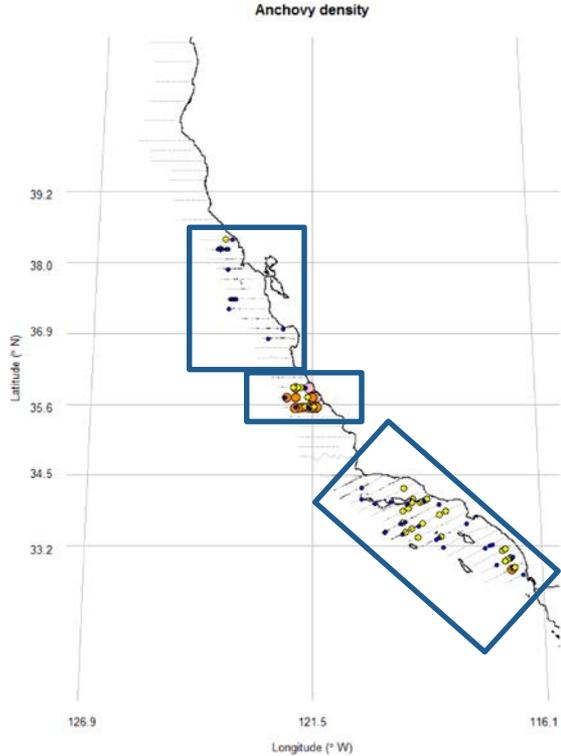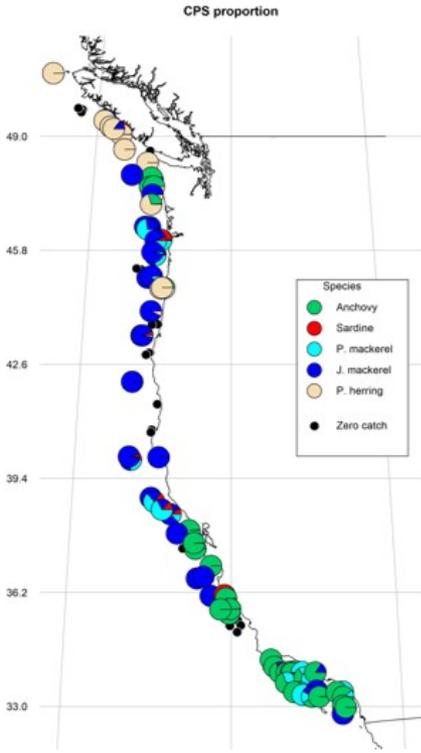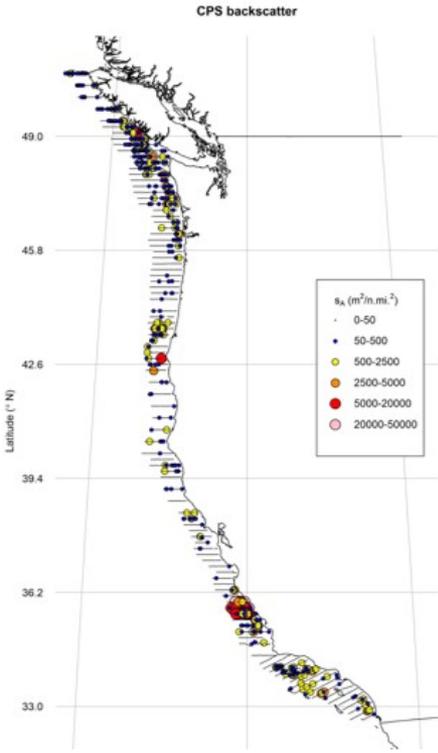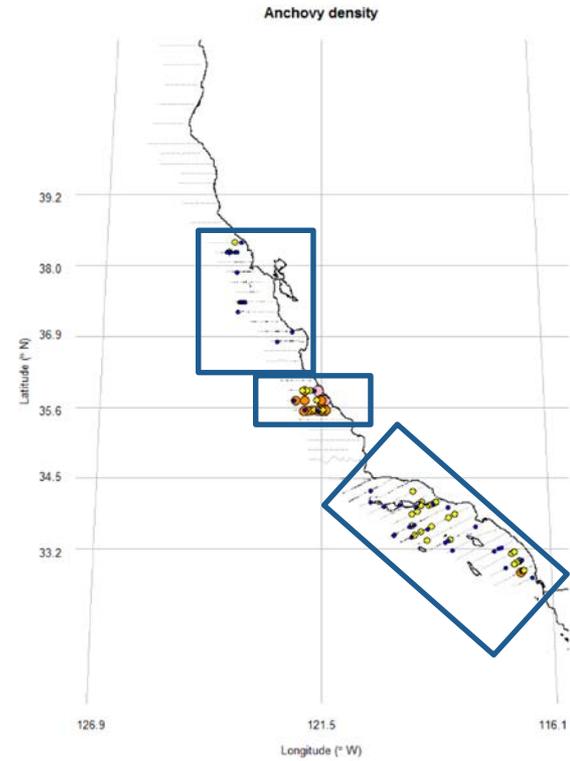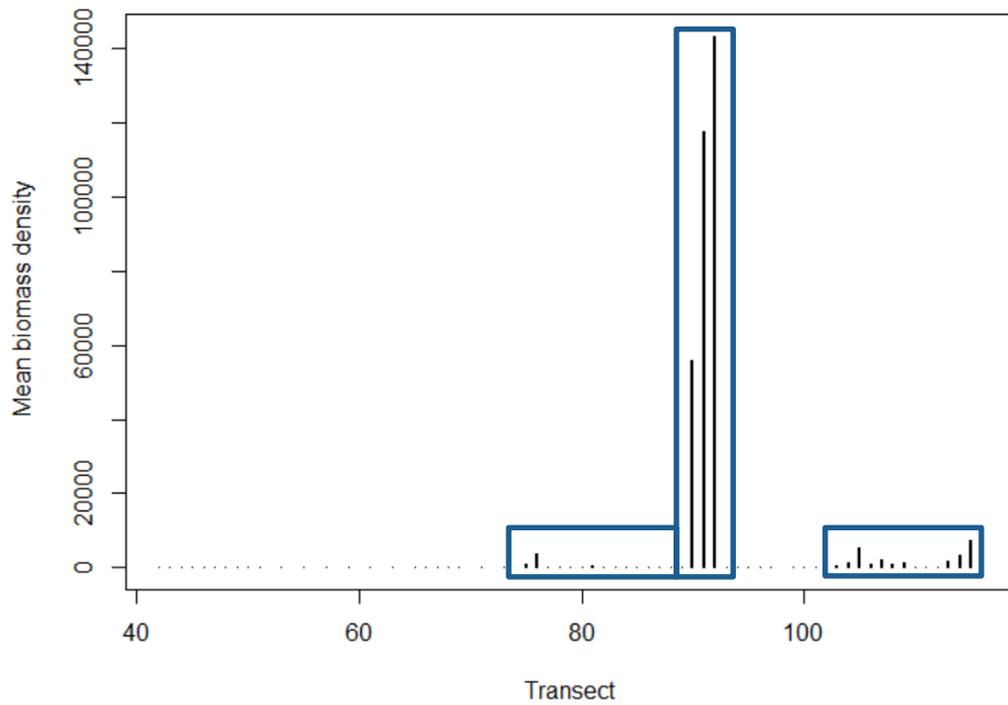
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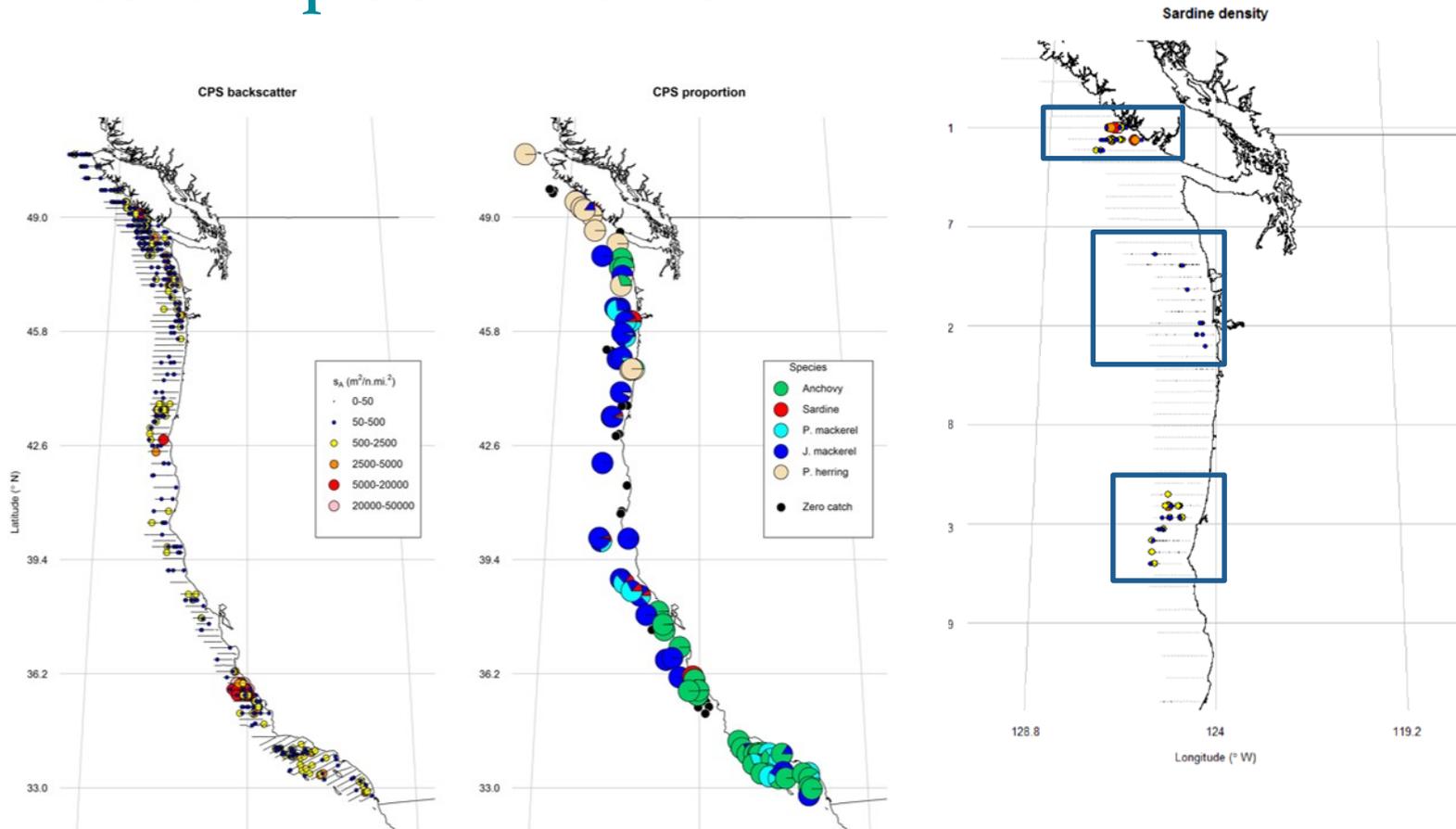
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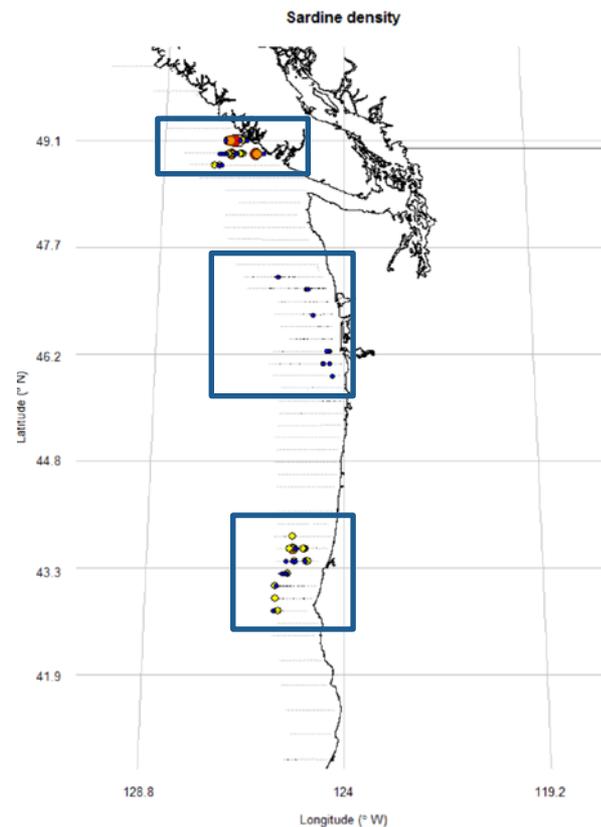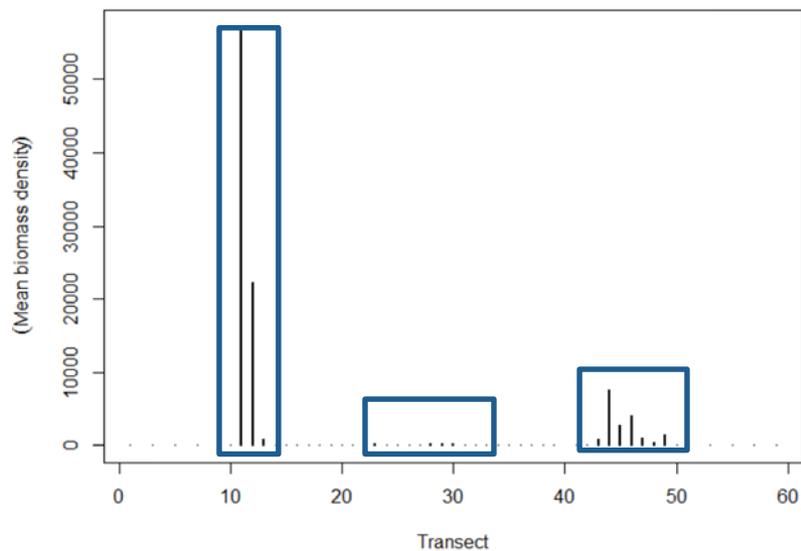
Independence of data

- The value of a transect mean does not depend on the value of the other transects, however it might be close to it if it's being generated by the same probability density function

- Trend is not autocorrelation

  - Auto-correlation measures the degree of similarity as a function of sample separation

    - Auto correlation function is only meaningful in stationary process

  - IF the auto-correlation function of the transects means is flat, bootstrap estimates of variance can be applied

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# Transect independence - ACF anchovy
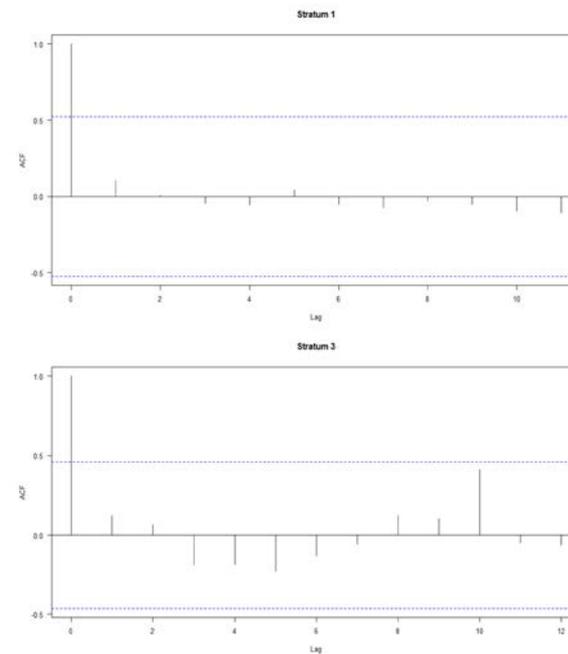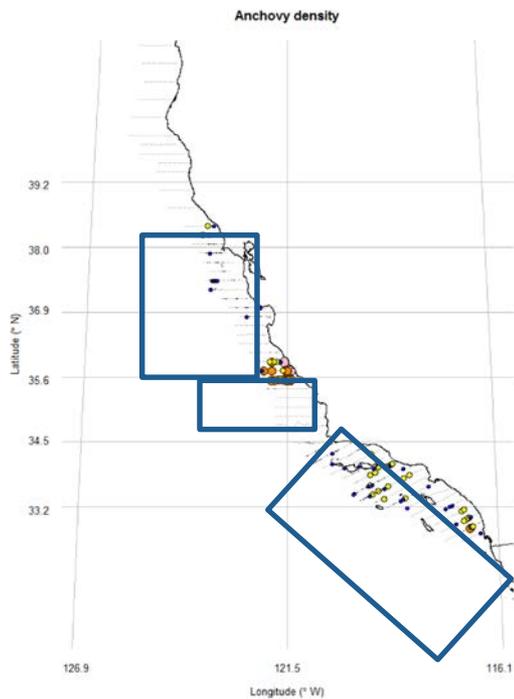
# Comparison to other systematic surveys estimators of variance

- Estimators
  - Random (R1, R2, Fewster et al 2009)
- Overlapping stratified estimators – partitions the area into overlapping strata, estimator (O1, Fewster et al 2009)

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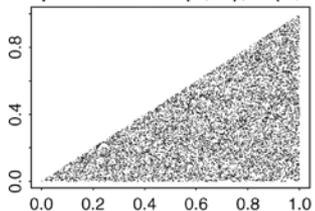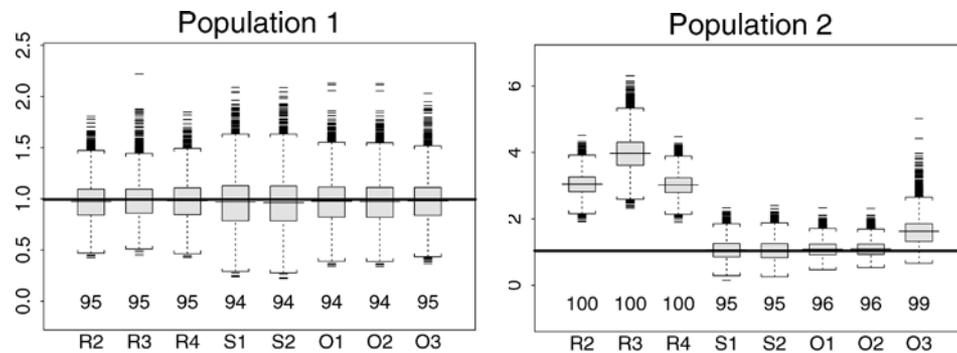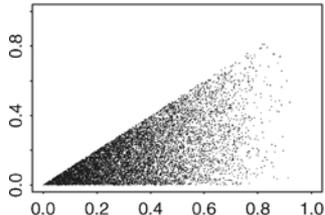
Comparison to other systematic surveys estimators of variance

Figures 2–4 show that random-based estimators $R2$ to $R4$ are not suitable for systematic designs when the object density has strong trends (populations 2–6).
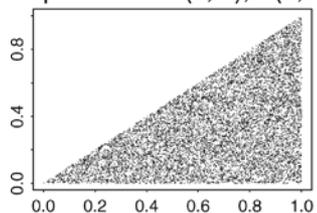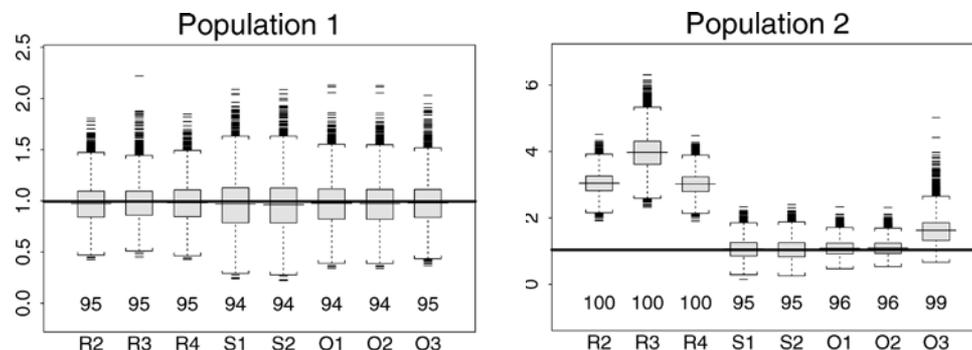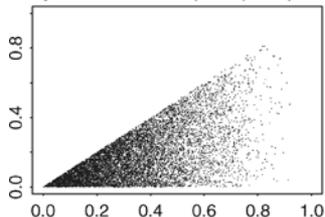
The simple strategy of poststratification can greatly reduce bias in variance estimation for systematic designs. The

Bootstrap are calculated inside the small boxes.

O1, R1 and R2 are calculated with all the transects inside the large boxes.
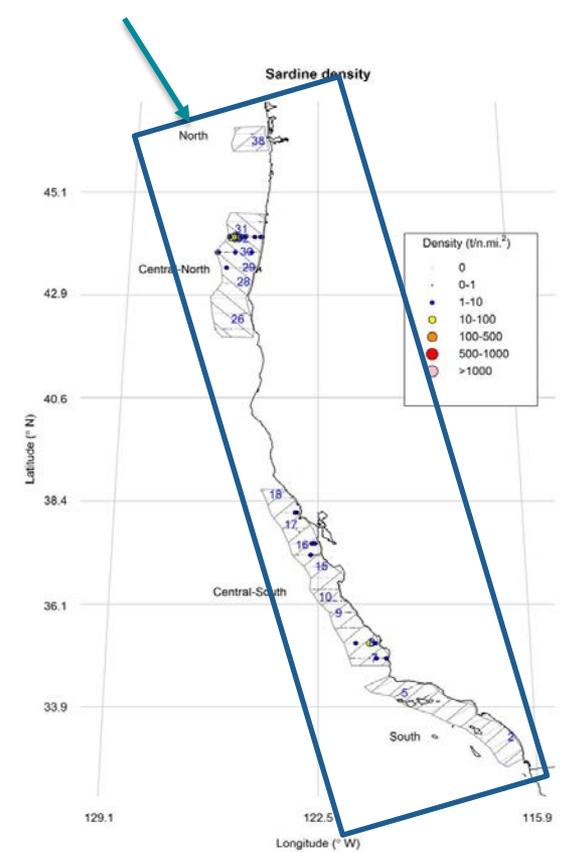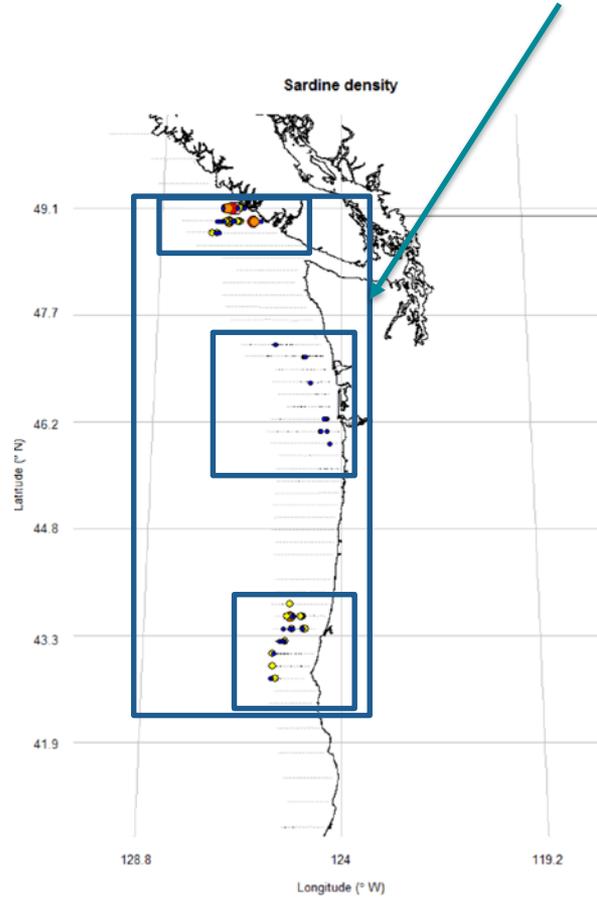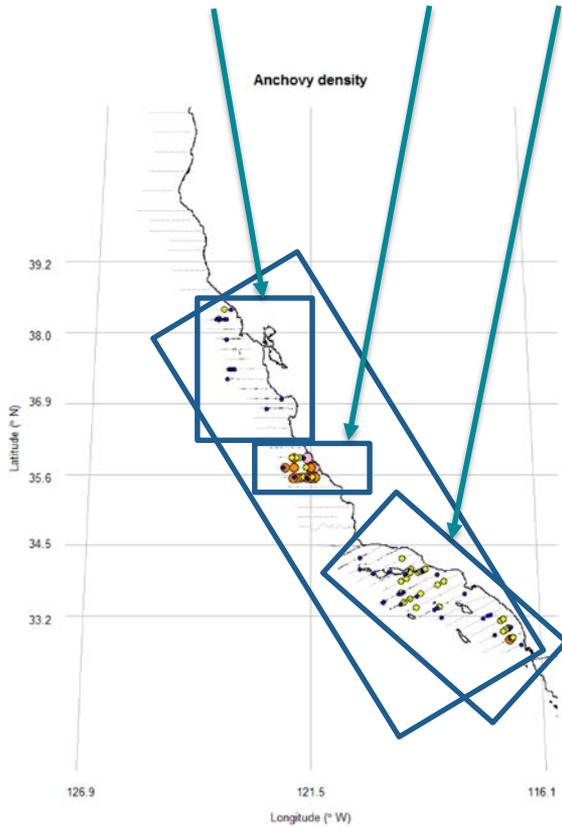
# Comparison to other systematic surveys estimators of variance
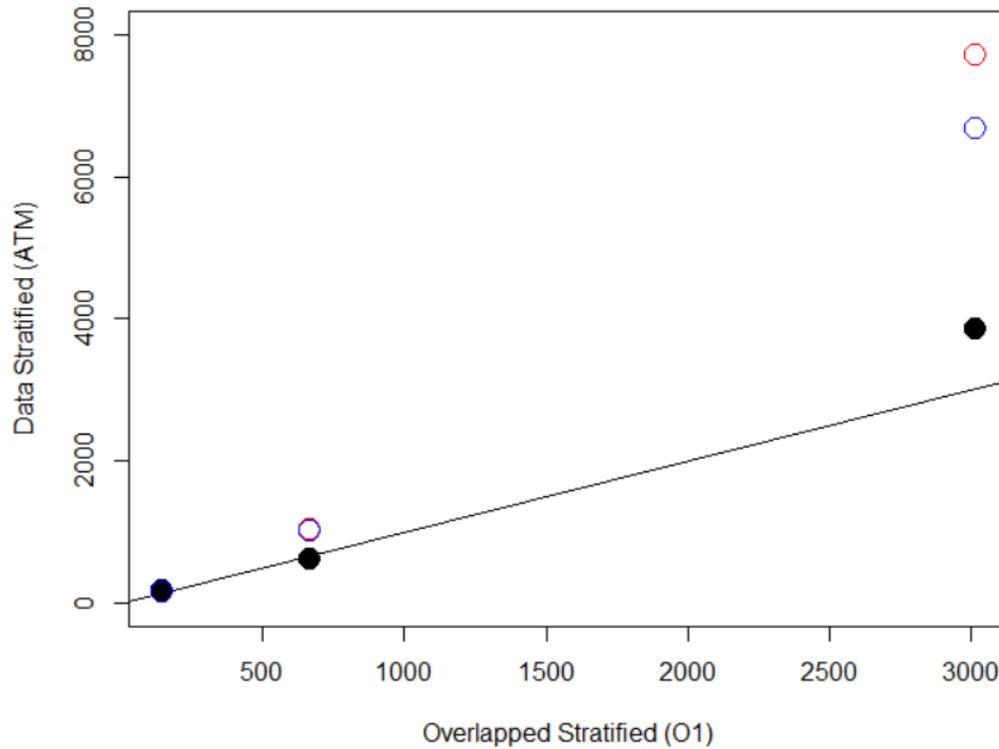
Brief notes

For stocks with patchy distributions, systematic, parallel-transect sampling designs (page 1) provide the most precise estimates of abundance. But because the SWFSC multi-species surveys extend far beyond the spatial extent of any single stock, the biomass density over the survey footprint is often non-stationary (page 4). In these cases, variance estimators for random-sample designs are positively biased. Unbiased estimates of variance for abundance, can be obtained by post-stratifying the survey area into stationary, statistically independent strata. Generally, the natural patchiness in the transect densities is conspicuous and the assignments of post-sampling strata boundaries is unequivocal (pages 5 through 8).

Within each stratum, provided that there is no auto-correlation (pages 9 and 10), the transect-mean densities can be treated as replicates and the variance can be calculated using random sampling estimators. Using non-parametric bootstrap (Efron, 1981) we calculate the variance of the mean density per stratum, which is then raised to the variance of abundance by multiplying it by the square of the stratum area (page 3). For stocks spanning multiple strata, the variance of the collective abundance estimate (page 2) is the sum of the strata variances.

The variance of the estimates using the above approach was compared in three instances to the variance obtained with the designed-based, post-stratified variance estimator O1, and the random sampling estimators R1 and R2 described in Fewster et al. (2009). From those, Fewster et al. concluded that O1 was unbiased when used in systematic designs with strong density trends, whereas R1 and R2 showed strong positive biases (pages 11 and 12). The three case-studies presented here (page 13), two for Pacific sardine and one for northern anchovy, have their bootstrap variances estimated using at least 3 post-strata (page 13). These ATM data-stratified variances of the overall abundances, were plotted against the estimator O1 (full dots; page 14). The ATM data-stratified variances were similar or slightly higher than O1. The R1 and R2 estimates (blue and red circles, respectively) were in one instance substantially higher than both O1 and the ATM data-stratified variance. This analysis suggests that the ATM data-stratified variance estimator accurately depicts the variance of the abundance estimate for the survey region.

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Appendix 7: Expanded comments of the CPSAS fishery representatives

Overall, the ATM Methods Review was highly informative. However, as the Report states, detailed documentation was not included in materials provided before the review for many key questions identified in the Terms of Reference, and there was insufficient time for the Team to assemble such information during the meeting. This hampered the comprehensiveness of the review, although, as the report states, in comparison with 2011, "more is known about the distribution of CPS, the approaches used to analyze the acoustic data have improved and research has been initiated with state agencies and industry to quantify the biomass inshore of the survey area."

Notwithstanding progress, many of the recommendations from the 2011 Methods Review had not yet been completed, including the two tasks required before allowing estimates from acoustic trawl surveys to be included in the sardine stock assessment as "absolute estimates" with a catchability quotient (Q) of 1. For that reason and several others, the 2018 Review Panel **recommended against** using ATM surveys as minimum absolute estimates of abundance (Q=1) for any of the CPS stocks considered: sardine, the northern and central populations of anchovy, Pacific and jack mackerel.

Fishery representatives agree with this finding, in light of the fact that current acoustic trawl (ATM) surveys do not cover the full range of CPS stocks, including Mexico, the upper water column 'dead zone', and the area below 70 meters where potential CPS schools were observed on echograms but were not sampled due to the Team assumption that all CPS finfish occur above 70 meters depth. But fishermen report that both anchovy and sardine are found deeper at times. Further, NOAA surveys exclude the nearshore area inside 50 meters depth, where fishermen have reported an abundance of both anchovy and sardine in southern and northern California since at least 2015.

CIE scientists noted this omission as a serious problem worldwide. They recommended that surveys be extended inshore as the preferred approach, and supported the cooperation offered by the fishing industry as a practical and effective long-term solution. In the short term, they suggested at least estimating abundance in the area missed by applying a correction factor. Fishery representatives on the CPSAS agree with the CPS Management Team (MT) comment noting that for species like anchovy that always live in shallow waters inside 50 meters at ages 0 and 1 and older ages may be found inshore as well, the recommendation of applying density from current [deep water] transect segments to unsurveyed areas to estimate biomass relies on many assumptions that can greatly underestimate nearshore abundance. However, that procedure seems better than the current approach, which excludes the nearshore altogether under the assumption that the inshore biomass is "insignificant." Fishermen strongly disagree.

During the 2018 review CIE scientists expressed concern with the same general issues found in 2011, also noted in the 2017 sardine STAR Panel CIE Report, which stated:
*"While the detailed discussion of the acoustic methods were deferred until the 2018 methods review, several areas of weakness in the survey approach were discussed (**survey coverage, biological sampling, stratification, and aging**). Factors such as **TS** [target strength] were not investigated but could have had a significant impact on the estimated biomass (assumed to be absolute)."*

Target strength as well as the other problems stated earlier – survey coverage, biological sampling, stratification and aging – and the scaling problem that has haunted sardine Star Panel reviews for many years, again were discussed at length. Two CIE comments in particular concerned this ATM review's CPSAS representative: the current ATM trawl procedure seemed to focus on precision at the expense of accuracy, and the protocol is repeatable but not objective.

CIE scientists offered several recommendations for further study to resolve these problems that both the MT and CPSAS unanimously support. In addition, the CPSAS, as well as the MT, also support the Panel recommendation for full documentation of methods and the decision process involved in field operations and data processing of the acoustic and trawl components of the survey, in providing a complete reference for future consideration and evaluation of the ATM methodology.

The fishery representatives on the CPSAS greatly appreciate the support and recommendations of the CIE scientists for collaborative research involving the fishing industry, and we also appreciate the support of the SWFSC and willingness of the Team to work with fishermen to resolve outstanding questions, such as:
  – validating that the fish caught in the trawls from the night time scattering layer share the same species, age and size structure as the fish ensonified in the daytime clusters
  – expanding sample size by testing the efficiency (relative catchability) and selectivity of the trawl among and within species by comparing samples from the same area taken with the survey trawl and purse seine.
  – cooperating in inshore surveys to provide an estimate of abundance or correction factor for those unsurveyed areas.
Resolving these issues will lead to better surveys and more accurate stock assessments.

This methods review has found that ATM surveys may be used as in index of abundance, along with other indices, in integrated stock assessments for all CPS finfish, including both sardine and anchovy. At present an integrated stock assessment is not available for anchovy because of a lack of data, including recent aging information in addition to incomplete survey coverage. However, recent ATM surveys, although unable to estimate total anchovy biomass accurately due to the omissions noted above, do indicate a significantly increasing trend in anchovy abundance, corroborating the observations of fishermen. This is encouraging news.

The CPSAS conservation representative agrees that the recent increase in anchovy abundance is encouraging; however, her perspective differs in part from the majority of the CPSAS regarding the Panel's findings. She notes panel agreement that ATM survey data may now be utilized as an index of relative abundance in an integrated stock assessment, or to generate biomass estimates (with some additional considerations) to directly inform management for CPS. While the panel identified sources of uncertainty and bias (both positive and negative) that should be addressed, the panel's evaluation of how ATM survey data can be utilized going forward represents a significant opportunity to improve management of all CPS finfish stocks, including monitored stocks such as northern anchovy.

In contrast, fishery representatives on the CPSAS recommend that the Council continue its stepwise approach to gather the data necessary for an accurate assessment. They also point out that anchovy was designated a "monitored" stock due to very low landings (averaging under

10,000 mt annually) continuing over several decades and projected to remain low into the future. In light of the extreme variability in anchovy biomass estimated over time, the intent of the catch rule was to provide management advice based on long-term average biomass, not a single stock assessment.

DETAILED CONCERNS OF CPSAS FISHERY REPRESENTATIVES

General concerns expressed by CPSAS fishery representatives include the following issues, which were also highlighted in CIE scientists' discussion during the ATM Methods Review:

Scale is not quantified or verified with another survey. Making changes to target strength changes outputs exponentially.

Target strength is based on other species in other regions and has not been validated by comparable studies of CPS in the California Current.

The rationale for acoustic trawl survey design changes and trawl cluster design is not well defined or documented. CIE scientists' comments indicated that survey design may be repeatable, but is not objective. Moreover, survey objectives appear to focus on precision at the expense of accuracy.

Assumptions that CPS occur only above 70 meters depth, with no samples taken of schools ensonified below 70 meters, was questioned by both CIE scientists and fishermen who have observed CPS, particularly sardine and anchovy, at lower depths at times.

Assigning species composition and estimated biomass to acoustic backscatter by trawling at night in general areas where backscatter had been identified during daylight uses unquantified assumptions of fish behavior. Fishermen note that species composition may change day vs. night.

Catchability of the acoustic trawl has not been verified. Questions remain about biomass density in areas not covered in ATM surveys.

Vessel avoidance is still unresolved and unknown. Fish not counted, particularly in the upper water column "dead zone", would skew the biomass outcome downward.

The following concerns are expressed by CPS fishermen, particularly in the Pacific Northwest (PNW), and these comments also are echoed by Canadian CPS fishermen.

1. Down-sounder alone without use of sonar will not give true measure of fish behavior in proximity to survey vessel. The assumption that fish dive straight under the vessel when the survey ship passes overhead is challenged by fishermen who report that schools will split away from the vessel and many will be missed by the acoustic beam. John Lenic, sardine seiner in British Columbia, played a video demonstrating this fact at a Tri-National Sardine Forum. Extent of vessel avoidance is currently not documented with sonar or camera. Sonar can be used to see schools at distance and can help determine how

many fish actually are caught by the down-sounder. Sonar can capture volumetric measurement. Species composition can be determined as it presently is for the down-sounder. As an example, in 2012 when the RV Shimada surveyed near Westport, almost every boat loaded up and many of them twice, and yet very few sardines were acoustically recorded by the NOAA survey vessel.

2. Sardines in PNW and Canada often stay in large schools – some over 10,000MT –usually near the surface in daylight hours. Vessels sometimes will chase schools for some distance before they can set (if at all). As a rule, sardines do not go deep in daylight hours.

3. Some years the majority of the fish in the PNW are caught inside of 35 fathoms where the survey vessel does not go.

4. While sardine in the PNW do tend to stay on the surface day and night, they go into 5mt +/- "bait balls" at night. In many cases other CPS come to the surface. This is the primary reason most PNW fishermen do not fish at night.

5. PNW night trawl species composition trawls are not compared to other catch methods such as seine. Some of us believe that slower "weaker" species such as anchovies will be captured at a higher rate than sardines and mackerel, that can swim much faster than the anchovies, creating a target bias.

6. It is not known if there is a species composition differential or a density / scale differential inside of 35 fathoms as the survey vessel does not go inside 35 fathoms.

7. For many years we have sent pictures of very mature PNW females in the late spring or summer. Per SWFSC estimates these could be spawning within several days. This period has been from May through July but usually in late June and early July. We have also sent samples of unbiased catch harvest that were caught randomly. Speaking to other processors, it was rare that these fish ever fell out of a 60 gram range any one day. I have never heard of any of these samples having been tested for age at the SWFSC, although we have sent several tons on occasion. Usually no later than July 15th all females no longer have mature eggs – they have spawned…..there usually was a very high % of mature females – well over 50% at the height of the fishery. All appear to have spawned within the stated period. Yet we hear the spawning is "weaker" in the PNW. While recruiting may be weaker, we do not believe the spawning has been weak in the PNW, with the exception of a few years after the 2003 super recruitment event.

8. Sardines were reported to ADFG in catches of salmon and perhaps herring in SE AK. Anecdotal reports were for large fish over 250g. AK was talking about an experimental permit for sardines at one point, and yet we do not know if anyone ever contacted ADFG as recommended. This would suggest the range may have extended much farther north than recognized and that this area may have harbored year classes that were have thought to be deceased. In the last cycle in the 1930's there were reportedly sardines in SE AK. (may also have been some canning of sardines there).

9. No scientists went out on fishing vessels, spotter planes and / or visited processing plants where they could have examined first-hand hundreds of thousands of tons of sardines and seen where they were, what they fed on, and how they behave.

10. Migration theory is not always true and some years sardines will overwinter in colder latitudes. Fish were caught off Newport OR in March of 2004 and again in 2010 off Coos Bay in early February. The fish caught in 2010 ranged from 80g to 210g. In 2012, fish

were being harvested in Mid-December off the Columbia River. CR Buoy temps were 50*F. Fishing shut down when crab season got underway, not due to lack of fish.

In conclusion, it should be noted that CPS are very adaptive animals that live over a large range with many different environmental parameters. They do not always behave predictably.

Appendix 8: SWFSC ATM Team Supplemental Statement

The SWFSC ATM Team provides the following responses to the Panel report:

- **Section 4.2 -** Team claims that nighttime trawling efficiently and accurately provides species proportions and length distributions. Team has no scientific information that daytime trawling provides this information more efficiently or accurately.
- **Section 6.2 -** Team showed that ATM estimates of Pacific sardine biomass are not statistically different for spring, when sardine are offshore and deeper, versus summer, when sardine are near shore and shallower, for all six years with bi-annual surveys. Therefore, Team claims there is no significant bias in ATM estimates of Pacific sardine biomass due to posited fish avoidance of the survey vessel, biomass above the acoustic sampling volume, or biomass shoreward of the survey transects.
- **Section 7.2 -** Team showed negligible anchovy biomass near shore off Oregon and Washington during summer 2017. Therefore, Team claims there is no significant bias in the ATM estimates of biomass for the northern stock of anchovy in 2017 due to posited biomass shoreward of the ship's survey transects.
- **Section 7.3 -** Team claims that it has no scientific justification for extrapolating observations into areas where observations were not made. However, Team acknowledges that any scientific evidence of biomass outside of past survey areas may serve to prioritize mitigation strategies in future sampling.
- **Section 11 -** Team claims that all survey results are estimates with uncertainty. All components of sampling and measurement bias are non-random variables, so their effects must be either negligible or their estimates must be considered in the accounting. If they are negligible or accounted, then the estimates are unbiased. If they are not negligible, and their variable magnitudes are unknown or unaccounted, then the estimates cannot be statistically evaluated for change. Therefore, Team will continue to investigate potential sources of bias but, until scientific evidence indicates significant estimation bias, adaptive sampling to improve estimate precision should remain the Team's priority for resource allocation.

APPENDIX 9: PANEL REBUTTAL TO TEAM SUPPLEMENTAL STATEMENT

Background: The Panel provided the Team with a near-final draft of the report on 16 February 2018 and a series of comments were received from the Team on 23 February 2018 in response to the report draft. The report was then updated based on those comments and a final report was issued on 28 February. The Team then provided a supplementary report [Appendix 8] referencing disagreements with specific sections of the final report. The Panel wishes to express its appreciation to the Team for their comments on the near-final draft, which corrected some factual errors in that version.

The disagreements between the Panel and Team pertain to some of the Panel's conclusions regarding sources of bias and the need to implement some of its recommendations for future work. The Team does not disagree with the two core management-related recommendations: (a) 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, northern anchovy, and Pacific mackerel, although several key uncertainties remain, and (b) the ATM survey can be used to provide relative indices of biomass for all CPS finfish for use in integrated stock assessments, subject to caveats, although the Team implicitly disagrees with the suggestion that the estimates of biomass for anchovy inshore of the survey area should involve extrapolation to inshore areas. The latter is, however, not the Panel's preferred approach, which is rather to sample such areas.

Section 4.2. We agree with the Team that they have no scientific information that daytime trawling provides species proportions and length distributions more efficiently or accurately than nightime trawling. In fact, it is not possible to evaluate the validity of the present sampling procedures given current information. However, given samples sizes from some trawls, there is evidence that the current trawl method is likely not efficient; possible sources of inefficiency relate to gear type and method or frequency of deployment. An experimental approach along the lines proposed is needed to understand trawl efficiency. The Team's methods in relation to estimating species proportions and length distributions are not standard practice, as stated in the accepted textbook: see Section 4.2 text in italics taken from Simmonds and MacLennan (2005). Furthermore, despite the progress made in signal processing, these surveys seem to have regressed in their ability to identify echotraces from the 1970s, when, for example, Mais (1974) states: "*Fish school targets detected by sonar and echo sounder were identified by a variety of methods which included visual observation, echogram characteristics, midwater trawling, and commercial catches. Echogram characteristics was the prevalent method of identification. Characteristics of species previously identified by other means were used as criteria. These include depth below surface or in relation to bottom, school thickness, shape and density of echogram, aggregation of schools into school groups, location of school groups from shore, and orientation to bottom topography. The characteristics of individual species are based on confirmation of echogram identification by a wealth of midwater trawl catch data, extensive experience and knowledge by commercial fishermen, and direct visual observation of schools. The problem of confusing two or more species when schooled together was not as serious as expected. Commercial catch records and midwater trawl data indicate none of the major species under survey school in the same manner and localities simultaneously in appreciable quantities.*"

Section 6.2. This section pertains to avoidance behaviour for all species and not just Pacific sardine. The Panel were aware of the similarity of estimates, which clearly increases confidence in the biomass estimates (at least for Pacific sardine). However, even if the biomass estimates

for Pacific sardine are not statistically different, that does not mean they are the same, nor that effects of avoidance behaviour, fish above the acoustic sample volume or the biomass shoreward of the survey vessel is negligible, nor that the estimates are unbiased. Additionally, the impact of distribution and vessel avoidance may be dynamic or non-constant, with varying and unknown impacts on estimates if not corrected for (Ona et al. 2007; Godø and Wespestad 1994).

The values and range of coefficients of variation (CV) are quite high for acoustic surveys (Figure 1). CVs from Rose et al. (2000), for cod and redfish; Demer (2004) for Antarctic krill; Simmonds et al. (2009) for Peruvian anchoveta surveys; and Woillez et al. (2009) for herring, all generally ranged between 5% and 25%, with most between 5% and 17%. The CVs for the ATM surveys range from 10% to 80% for sardine indices, with only 1 of 15 below 20%, and 5 above 40%. An interesting observation from Table 1 of the Panel report (Fig. 1) is the lack of relationship between the precision (CV) and the degree of coverage (DOC) (Aglen 1989), which is a measure of the effort relative to survey area. One would expect the CV to decline with an increase in DOC as precision generally increases with sample size (Cochran 1977), which in the case of an acoustic survey is usually dominated by the acoustic data (Demer 2004; Woillez et al. 2009). In the case of ATM surveys, however, the precision appears invariant with increased sampling intensity (Fig. 1). This points to a source of error not related to survey effort, such as species allocation, which typically is the larger source of error (up to 50%) particularly for mixed-species aggregations (Simmonds and MacLennan 2005).

Section 7.2. Based on Team's evidence, the bias may not be significant for the northern subpopulation of northern anchovy in Summer 2017 and the Panel did not conclude that there was bias due to anchovy inshore of the survey frame during that survey for that subpopulation. However, this result cannot be used to infer that such bias may not be significant in other years and/or areas. This section raised the generic issue of nearshore presence, which needs to be investigated further as the Panels notes "*Except for the example provided in the 2011 review and work conducted in 2017 in the Pacific Northwest, no further efforts or examination of the acoustic backscatter in the nearshore portion of transects has been performed*". Fish missed inshore is a legitimate concern of the fishers that operate in shallow water close to the coast and hence have anecdotal evidence to the contrary.

Section 7.3. The suggestion for extrapolation is standard practice, as described by reference to the standard text (Simmonds and MacLennan 2005). Equally, there is no justification for the team's subjective delineation of the polygons used to convert density to abundance: the polygons seem to have been drawn by hand rather than, for example, having design-based criteria (with equal sampling per unit area, for the areas represented by each transect).
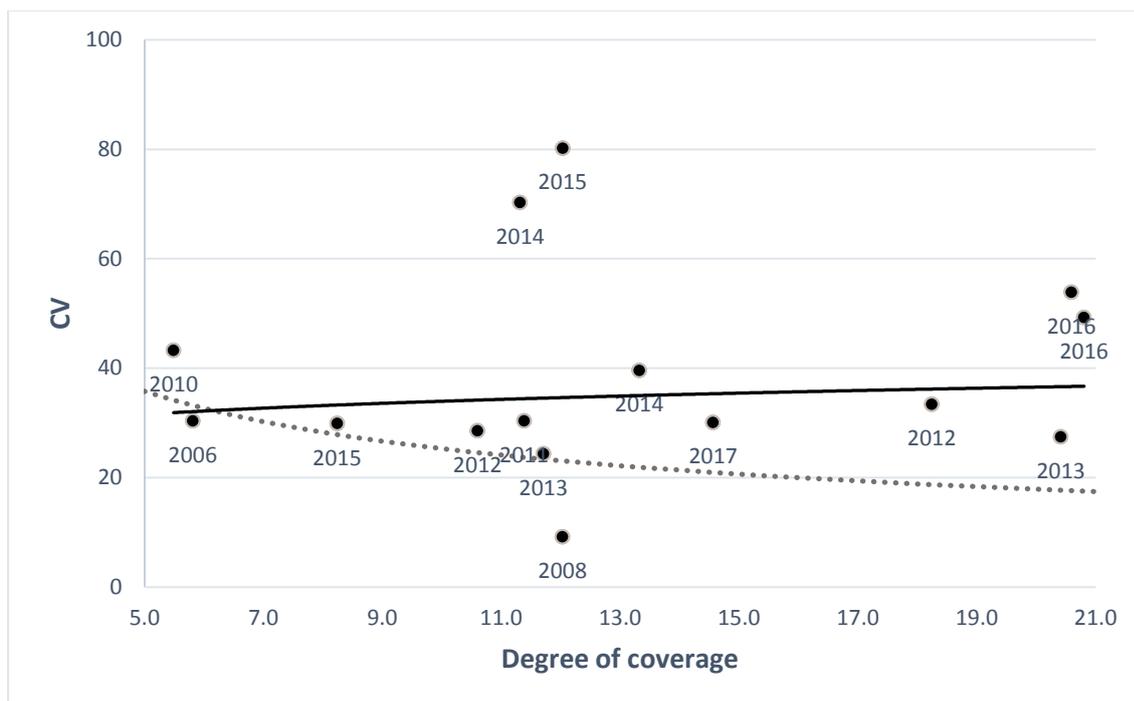
Figure 1. ATM survey precision (CV) against sampling intensity (DOC). Aglen's (1989) Degree of Coverage is $N/\sqrt{A}$, where N = total transect distance, and A = survey area , both taken from the report's Table 1; CV is the Coefficient of Variation for the ATM surveys. Individual point labels are survey years. The black solid line is the fitted power function of the form $CV = 26.6\ DOC^{0.1}$, and the grey dotted line is Aglen's empirical form for contagious fish schools where $CV = 0.8\ DOC^{-0.5}$ and, therefore, represents the expected relationship.

Section 11. As described above, uncertainty is high, hence there is some justification for the team's priority that adaptive sampling to improve precision should be the priority; However, other major causes of high levels of error, such as difficulty in species identification, have been discussed in past reviews. The Team state that they will continue to investigate potential sources of bias, a decision that the Panel supports. However, sufficient emphasis needs to be placed on such investigation otherwise the "null hypothesis" of no significant estimation bias cannot be rejected. The amount of effort required to address some of the issues should not impact the recognized need to address them. Rather, exploring more creative ways to share the burden of effort, such as increasing partnerships with outside entities (as recommended in the Panel report), should be considered. The Team can straightforwardly deal with certain components, such as target strengths (TS). All of their TS to length relationships are derived from different species in a different area (South African pilchard, Japanese anchovy, South African horse mackerel). Absolute abundance estimates from any fisheries survey are rare, and the reviewers know of only two cases where an acoustic survey it is considered absolute (Icelandic and Barents Sea capelin). There are far too many instances of irregular practice and potential sources of bias for this ATM survey to be considered as absolute, notwithstanding the fact that the bias cannot be detected through the lack of statistical difference between survey estimates.

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