Center for Independent Experts Independent Peer Review of the Acoustic Trawl Methodology (ATM)

A REPORT BY THE REVIEWER DR. PAUL G. FERNANDES

27 MARCH 2018
ABERDEEN, SCOTLAND, UK

Declaration: The opinions expressed in this report are entirely the author's own. They are based on: his own experience with acoustic surveys, trawl surveys, and stock assessments; the relevant literature; examination of material provided for the review; and discussions with the administrators, scientists and industry representatives present at the San Diego meeting. Some of the report is taken from the Panel's report which the author co-authored.

Front cover: *An image of La Jolla Shores, San Diego, taken on 31 January 2018 showing the pier at Scripps Institute of Oceanography, viewed from the South West Fisheries Science Centre where the review took place*

Contents

Executive summary

1. The Acoustic Trawl Method (ATM) consists of surveys of multiple Costal Pelagic fish Species (CPS) carried out along the US west coast by the South West Fisheries Science Center (SWFSC). Two surveys are conducted annually which produce biomass estimates for Pacific sardine (*Sardinops sagax*) stock assessments. The surveys also provide biomass estimates of northern anchovy (*Engraulis mordax*), jack mackerel (*Trachurus symmetricus*) and Pacific mackerel (*Scomber japonicas*).
2. A review of the ATM took place from 29 January to 2 February 2018 at a meeting at the SWFSC, with administrators, scientists and representatives of industry. The purpose was to: review survey documentation; consider the target strengths (TS) used; examine survey design; examine the trawl survey design; consider the use of the EK80 echosounder; consider effects of vessel avoidance; consider unsampled areas; and ultimately, to determine how the results from the survey should be used.
3. The documentation provided was inadequate to address the TOR. The ATM Team were, however, very forthcoming and diligent in providing further information: a more comprehensive document is in preparation. There is clearly a lot of good practice, particularly in the technical detail associated with the operation of the acoustic instruments. The team are exceptionally well qualified and well equipped to carry out effective surveys. The summer surveys, in particular, seem to contain most of the stocks pretty well. However, survey precision is generally poor (CV's > 20%) and is not [inversely] proportional to the effort applied (as it should). The former may be related to the very challenging problem of species identification, which despite significant progress in signal processing, has been difficult to advance from the expert-based methods of the 1970's (Mais 1974).
4. The application of target strength to length relationships of other species from other parts of the world is one of the factors which inhibits the estimates of biomass for the ATM surveys being used as absolute values. Specific TS/L relationships should be determined for each stock, and these should be depth dependent where appropriate.
5. The survey sampling frame should be set with reference to the habitat model and results from former surveys, and surveyed in full. Adaptive sampling should not prejudice completing the survey design. Enhanced precision should not be sought at the cost of potentially significant bias, notwithstanding the problems highlighted of poor precision: it is better to be vaguely right than exactly wrong.
6. The time delay between acoustic detection and verification of species composition and size by trawling introduces several significant uncertainties. Chief amongst these is the differential selectivity given the different sizes of the animals concerned; but differential vertical distribution by species or by size may also have an effect. Such a delay is not standard practice, and in most cases, trawling to determine or verify species and size composition takes place as soon as significant echotraces are detected. In conjunction with efforts to improve species identification, methods to improve the biological sampling are needed.
7. The new Simrad EK80 broadband echosounder has several interesting features which may enhance the identification of CPS. The Team is well equipped and very well versed in broadband technology. Efforts to develop the system are encouraged.
8. Due to the epi-pelagic nature of the ATM target species, avoidance of the survey vessel is possible during the day and likely at night during trawling. Various approaches to investigating avoidance have been adopted throughout the world and the Team have all the necessary equipment and expertise to try one or more of these. They need to

demonstrate that avoidance is not a source of bias if their estimates are to be considered absolute.

9. There are fish in the inshore areas that are not surveyed by the ATM. There are legitimate concerns from the fishing industry, who fish extensively in these areas, that these fish are not accounted for. However, evidence points to the bias (as per the area) being small. This could be examined retrospectively by extrapolation, but in future, additional efforts should be made to survey inshore areas.
10. It is recommended that ATM survey estimates of sardine, Pacific mackerel, Jack mackerel, the Northern sub-population of northern anchovy, and the Central sub-population of northern anchovy be used in an integrated stock assessment as indices of relative abundance. The use of the ATM biomass estimates as absolute estimates of biomass in assessments is not recommended. This is chiefly due to the aforementioned uncertainties related to target strength, target species identification, unsampled areas (inshore & south of the survey area) and potential avoidance. Many of these uncertainties can be addressed with research which the Team is eminently qualified and well equipped to tackle. Improvements in age reading are essential to improve the quality of the estimates at age.

1 Background

The Acoustic Trawl Method (ATM) is the name given to the survey of multiple Costal Pelagic fish Species (CPS) carried out along the Californian coast by the South West Fisheries Science Center (SWFSC) of the United States National Marine Fisheries Service (NMFS). The survey is currently used annually, to produce biomass estimates for Pacific sardine (*Sardinops sagax*) stock assessments, which in turn are used to provide advice on the management of the stock. The survey also provides estimates of the biomass of three other species: northern anchovy (*Engraulis mordax,* of which there are two sub-stocks), jack mackerel (*Trachurus symmetricus*) and Pacific mackerel (*Scomber japonicas*). NMFS works with the Pacific Fishery Management Council (PFMC) to improve the advice associated with management of these stocks and to this end, they commissioned an independent peer review to determine the usefulness of the ATM for all of these stocks. Pacific herring (*Clupea pallasii*) also occur in the area, although the species is predominantly distributed further north, so this species was not included in the review's terms of reference (TOR).

The ATM review took place from 29 January to 2 February 2018. The independent review was conducted by the Center for Independent Experts (CIE) and examined 8 TOR. This report details the individual views of one of the four reviewers, Dr. Paul G. Fernandes (see Appendix 3 for contact details, and for details of the other three reviewers). The report, as stipulated in the statement of work (Appendix 2), includes a description of the reviewer's role, a summary of findings for each TOR, and conclusions and recommendations in accordance with the TOR. A full list of references, including those provided as background material, and those cited in this report appears in Appendix 1 and was posted in ftp://ftp.pcouncil.org/pub/

2 Description of the Individual Reviewer's Role in the Review Activities

The reviewer, Dr 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.

3 Summary of Findings for each TOR

3.1 TOR 1. ATM survey documentation.

Document the ATM survey design, protocols (sampling, data filtering, etc.), and estimation methods, including the following: a) delineate 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; e) specify the rules for adaptive sampling (including the stopping rule); and f) 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 (PFMC 2017). g) Describe how echogram backscatter is analyzed to exclude non-CPS backscatter.

A document entitled Acoustic-Trawl Methods for Surveying Coastal Pelagic Fishes in the California Current Ecosystem (Demer et al. 2018) was provided. This document describes the sampling domain, sampling process, survey time series and, briefly, highlights measurement bias. It makes reference to a number of peer-reviewed articles, which were provided for the review, along with survey and assessment reports (see bibliography in Appendix 1). The document fell short on detail and failed to describe many of the essential processes, notably the identification of CPS backscatter, the specific target strength to length relationships used, the limits to the survey design, details of the trawl, the trawling strategy, and how the trawl clusters are determined. These points were described during the course of the meeting and a more comprehensive document describing the survey methods is being prepared.

3.1.1 The survey area (sampling frame).

The survey area is defined according to the expected distribution of the target species. The area is seasonally dynamic in terms of its oceanography (Figure 1), and the CPS distribution is similarly seasonal. In summer and fall, sardine feed in the productive coastal upwelling areas north of Oregon, whereas in winter and spring they migrate south off central and southern California. Mackerel follow a similar latitudinal pattern but are located further offshore. Anchovy are divided into a northern stock off Washington and Oregon and a central stock off California.

The spring survey takes place in spring (March to May), and it lasts ~30 days. The given design covers an area from about 32°N to 42°N with systematic transects orientated perpendicular to the coast extending about 80 nautical miles, although the offshore extent is adaptively set according to the CPS distribution at the time (up to 200 n.mi). Survey bounds are set to include sardine potential habitat at the beginning of the survey, although it is not clear how this varies and is planned in terms of actual survey design according to Demer et al. (2018). The individual survey reports indicate that this design is rarely achieved in spring and that potential habitat extends beyond the realm of the survey (e.g. Figure 2), in both a latitudinal and offshore extent (particularly in 2016).

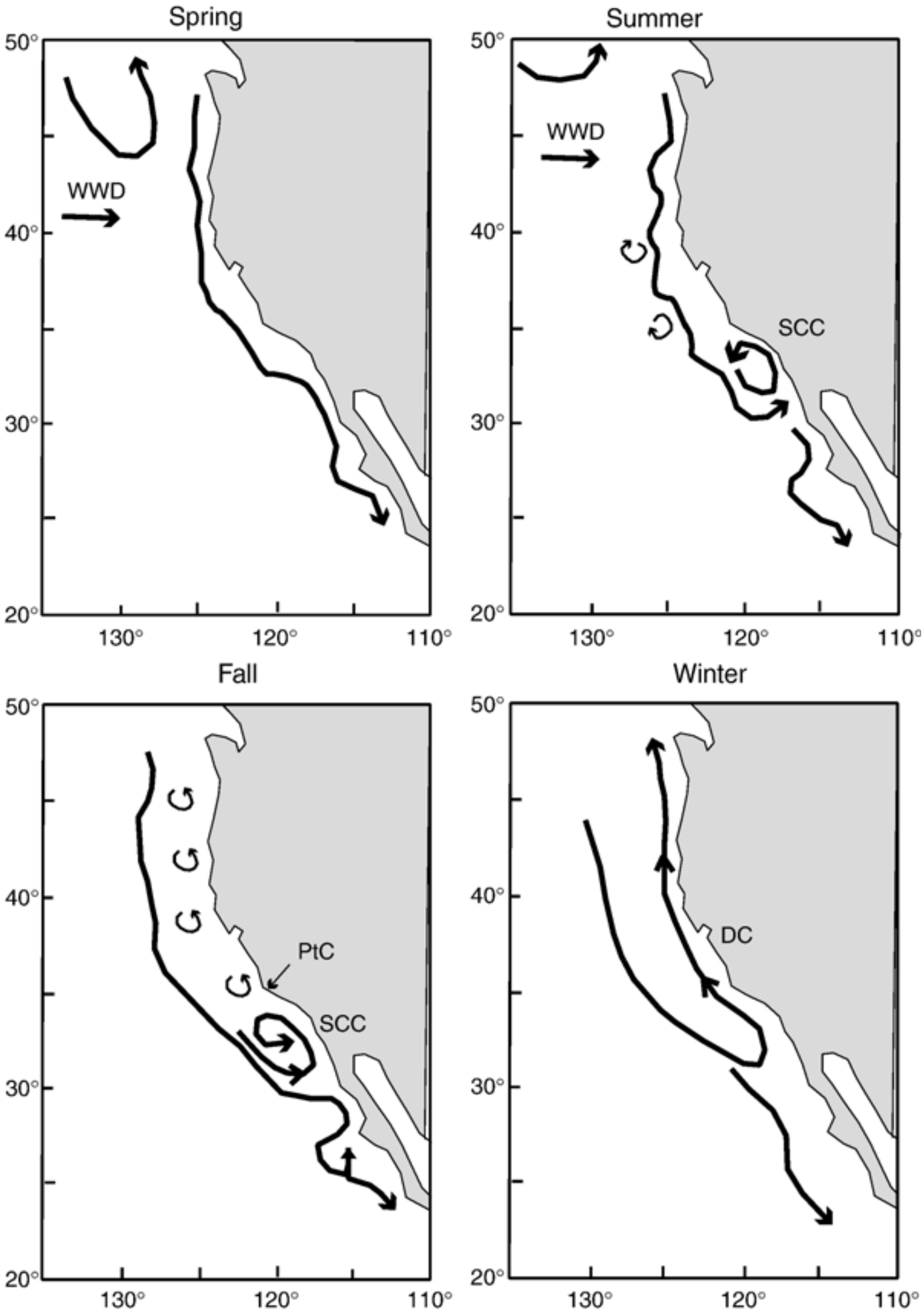

Figure 1. Maps of the western seaboard of the United States of America showing the seasonal circulation of the California current, reproduced from Barron and Bukry (2007). WWD = West Wind Drift; SCC = Southern California Countercurrent; PtC = Pt. Conception; DC = Davidson Current.

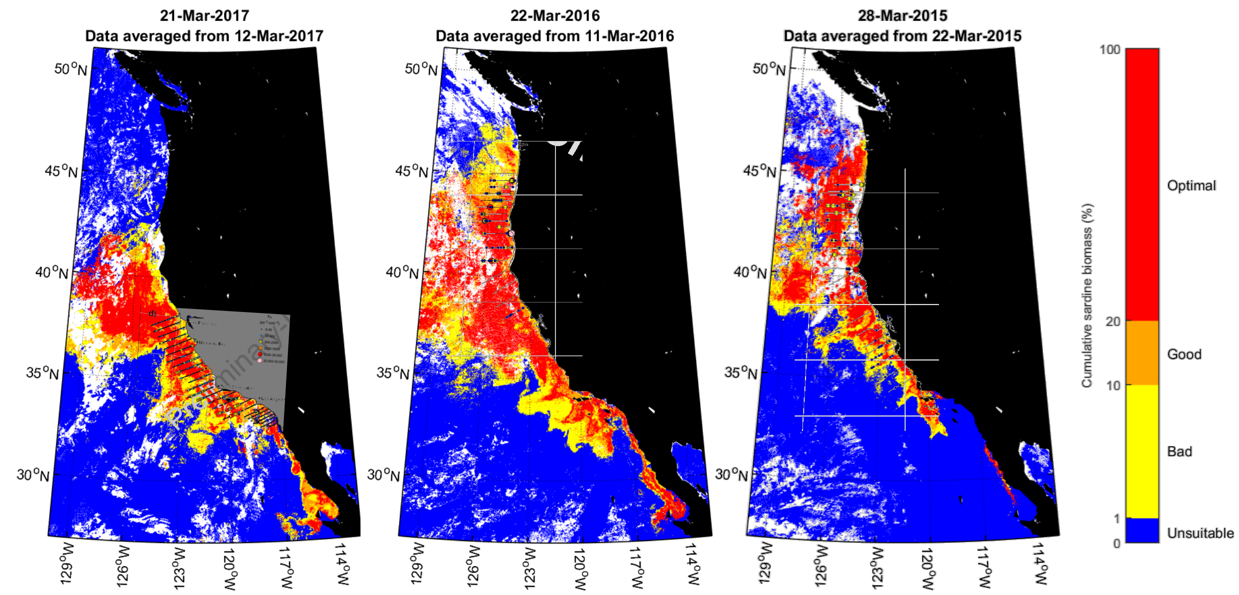

Figure 2. Maps of western North America with suitable coastal pelagic species (CPS) habitat for the spring ATM surveys of 2017, 2016 and 2015, with the final survey design superimposed and acoustic backscatter attributed to CPS.

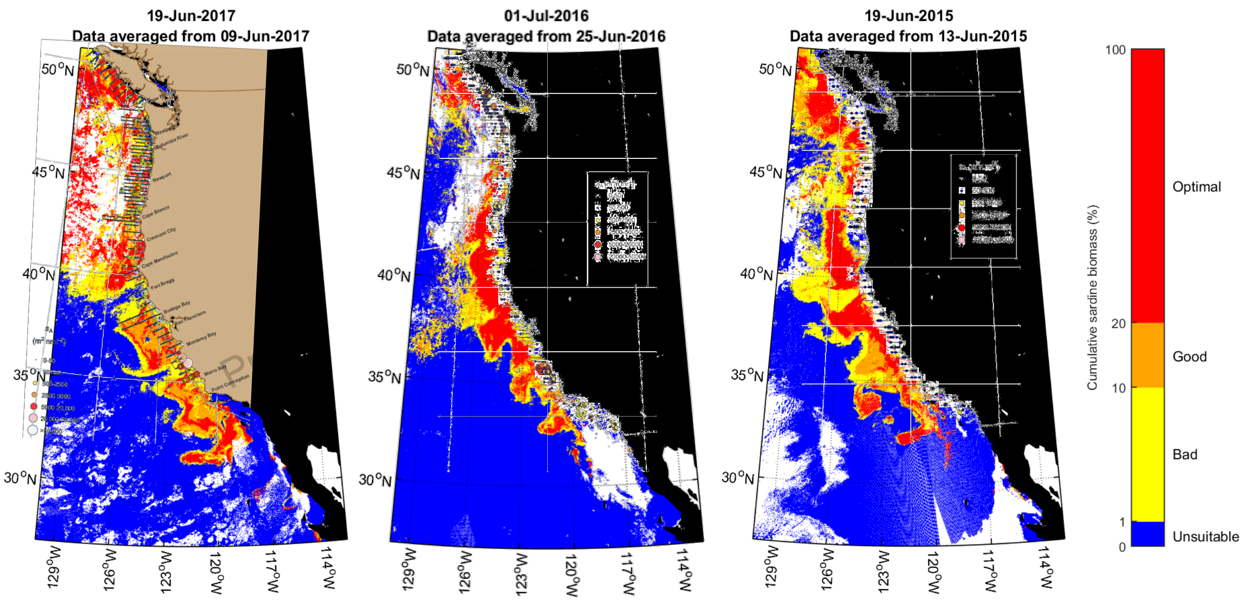

Figure 3. Maps of western North America with suitable coastal pelagic species (CPS) habitat for the summer ATM surveys of 2017, 2016 and 2015, with the final survey design superimposed and acoustic backscatter attributed to CPS.

In 2017 & 2016 the area surveyed in spring was small relative to the potential habitat (see Fig. 2) and CPS were detected at the offshore end of transects indicating a potential bias as fish may have been missed. It is apparent that due to the adaptive nature of the acoustic sampling, the sampling frame may not be completely covered as time runs out. This prioritizes precision over bias and should be avoided.

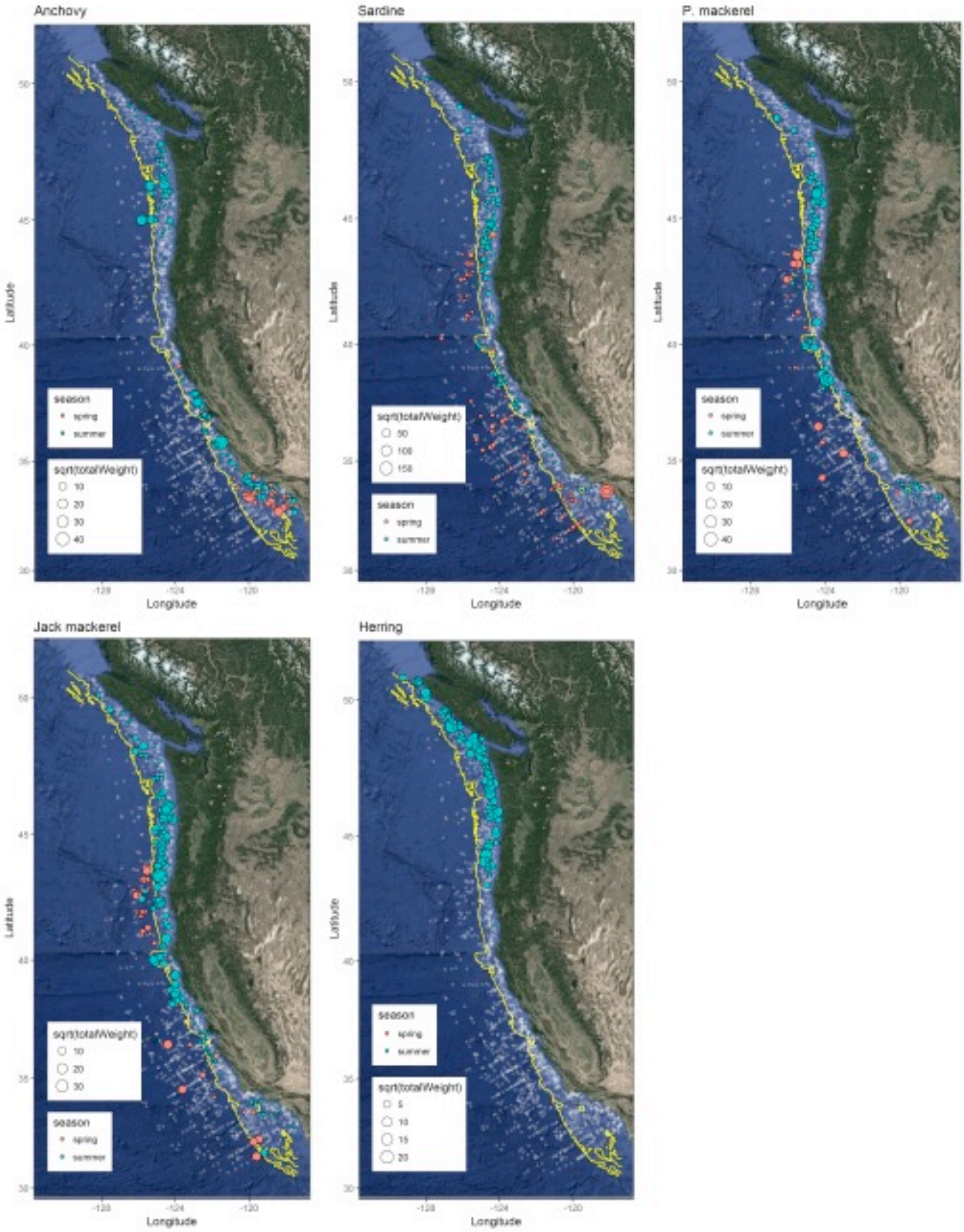

Figure 4. Maps of the west coast of North America showing the locations (circles) of all trawl catches of coastal pelagic species (labelled at the top of each panel) during all of the ATM surveys conducted since 2006. The circles are sized according to the square root of the total catch (kg) and colored by survey (red = spring, blue = summer). The yellow line is the 500 fathom bathymetric contour, which, in summer (blue circles), contains most of the distributions of each species.

The summer surveys are much more extensive in terms of the latitude covered (Fig. 3): in fact, they often cover the entire seaboard of the western USA and include parts of Canadian coastline. The offshore extent of these surveys is much less than that of the spring surveys, but results indicate that the sardine are contained closer to the coast in summer. In fact, the summer surveys seem to contain all of the main species considered by this review (Fig. 4).

It was clear that the survey sampling frame may change due to different survey objectives (target species). Table 1 provides a summary of the surveys to date with the essential elements, such as survey objectives, biomass estimates, precision, length of transects and survey area.

There are two observations of note from this table. Firstly, the values and range of coefficients of variation (CV) are quite high for acoustic surveys (Fig. 5). Rose et al. (2000) reported CVs for cod and redfish between 7 and 13% (once recalculated as the reported standard error divided by the mean, as their reported values make no sense); Demer (2004) estimated a total CV of 10-11% for Antarctic krill surveys; Simmonds et al. (2009) CVs in Peruvian anchoveta surveys were mostly between 5-25% (although one was 149% for a very low stock size); and Woillez et al. (2009) CVs for herring were between 5 and 17%. Many of these are estimates of the total error but all (with the exception of Simmonds) indicate that the sampling variance of the acoustic measurements dominate. A more interesting observation from Table 1 is the lack of relationship between the precision (CV), and the degree of coverage (DOC) (Aglen 1989), which is the effort relative to area (specifically, the total length of transect divided by the square root of the survey area). One would expect the CV to decline with an increase in DOC (see, for example, Aglen's Figure 8) as this is equivalent to increasing sample intensity [size, accounting for area]. Notwithstanding the DOC measure, 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, however, if the figures in Table 1 are correct, then the precision is invariant with increased sampling intensity (Fig. 5). This points to a source of error not related to survey effort, such as for example species allocation, which typically is the larger source of error (up to 50%), particularly when there are species mixtures (Simmonds and MacLennan 2005).

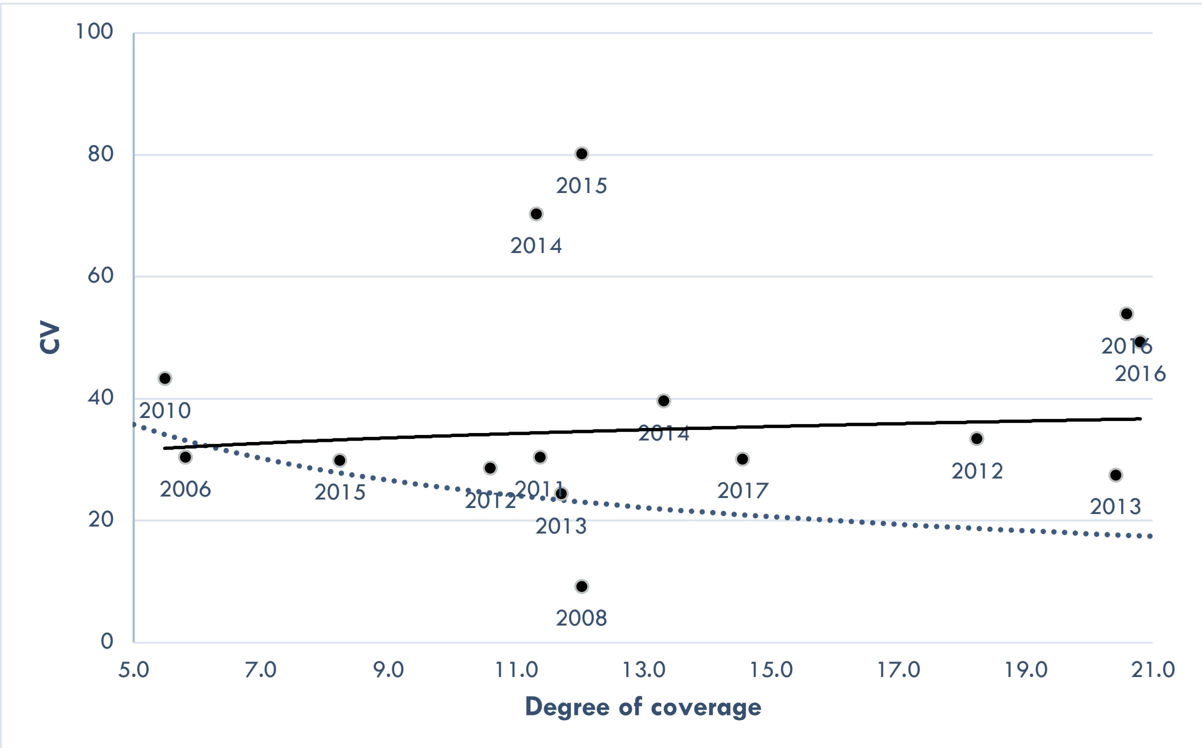

Figure 5. ATM survey precision (CV) against sampling intensity (DOC). Aglen's (1989) Degree of Coverage is N/√A, where N = total transect distance, and A = survey area , both taken from Table 1; CV is the Coefficient of Variation for the ATM surveys. Individual point labels are survey years. The black 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.

3.1.2 Spatial stratification (if any) and transect spacing within strata planned in advance (true stratification)

The survey design consists of systematic parallel transects orientated perpendicular to the average coastline. There is no mention of a randomized start point which is required to ensure that all elements in the area have an equal probability of being sampled over the time series. The argument given in defense of this omission was that because these are pelagic species, their point of [spatial] reference is not fixed as it is likely to be determined by dynamic oceanographic currents. This, therefore, results in a dynamic positioning of the resource relative to the fixed transect design which in effect is the same as a randomized start point. This may be partly or even wholly true, but there may still be areas with unknown specific effects, close to canyons for example. Given that a random start point is not an onerous logistical requirement, the team should consider implementing it.

Transect spacing is default to 20 n.mi., with 10 n.mi. spacing "…in areas with historically high CPS densities and diversity". These areas (strata) were described as "…off Washington and Oregon during the summer" but not specifically identified in Demer et al. (2018): they should be specified (mapped) in the detailed survey protocol document being prepared. A map of mean abundance and variance over the time series should be prepared to determine the validity of these "…historic high CPS densities…"; see for example, Figures 1 and 2 in Simmonds (1995). This would provide a documented and valid justification of the high density strata.

3.1.3 Rule for stopping a transect (offshore boundary by species)

According to (Demer et al. 2018), transect length is adaptively extended offshore to map CPD based on the CPS echoes, eggs, or CPS in survey and/or commercial catches. This is a rather vague description and an inspection of the data reveals CPS to be present at the end of some transects. A single map of the entire time series of CPS, egg and commercial catch would have been instructive in this regard, although the former were available in the individual survey reports. Information on the location of commercial catches was not available despite a specific request which infers it is not easy to obtain.

3.1.4 Rules for conducting trawls to determine species composition

Trawl sampling is conducted each night by returning to positions where either: i) CPS schools were acoustically observed earlier that day; ii) CUFES samples indicated egg presences; iii) reports on the locations of CPS catches by the industry. The ATM team's initial experiences with attempting to fish during the day has been bad because schooling fish avoid the net during the day. The temporal mismatch may cause problems if there is no spatial pattern in the school's length or age makeup. More detail on this point is provided in Section 4.4.

3.1.5 Rules for adaptive sampling (including the stopping rule)

Adaptive sampling is included in the offshore extent of the individual transects, as well as adding interlaced transects. (Demer et al. 2018) states that "in areas with CPS, a minimum of three interstitial transects are added to the compulsory transects": but no mention is made of what the threshold is which invokes the decision to add transects. There is no evidence of 3.3 n.mi. spacing transects in some of the survey reports where CPS was detected.

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.

Survey ID	Date start	Date end	Duration (d)*	Target Species	Sardine biomass (10^3 t) [CV]	Anchovy biomass (10^3 mt) [CV]	Number of transects (n)	Length of transects (n.mi.)	Area covered (n.mi.^{2})	Acoustic equipment	Number of trawls (n)	Total number of trawl Clusters (n)	Number of positive trawl cluster (n)
0604OD	4/12/2006	5/8/2006	26	Sardine/CPS	1,947 [30.4]	n.a.	18	2,563	194,543	EK60	40	n.a.	n.a.
0804JD	4/12/2008	4/28/2008	16	Sardine/CPS	751 [9.2]	n.a.	15	3,489	84,095	EK60	30	n.a.	n.a.
0804MF	4/12/2008	4/30/2008	18				18	2,458	106,879	EK60	42	n.a.	n.a.
1004FR	3/30/2010	4/27/2010	28	Sardine/CPS	357 [43.3]	n.a.	9	1,360	61,435	EK60	55	n.a.	n.a.
1004MF	4/3/2010	4/20/2010	17				15	1,780	70,936	EK60	43	n.a.	n.a.
1104FR/ 1104SH	3/25/2011	4/25/2011	31	Sardine/CPS	494 [30.4]	n.a.	21	2,919	65,741	EK60	105	19	16
1204SH/ 1204OS	3/17/2012	4/30/2012	44	Sardine/CPS	470 [28.6]	n.a.	19	3,230	92,823	EK60/ME70	95	35	14
1206SH	6/24/2012	8/30/2012	67	Sardine/hake /CPS	341 [33.4]	n.a.	85	3,509	36,991	EK60/ME70	98	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
1306SH	6/6/2013	8/30/2013	85	Sardine/hake /CPS	314 [27.5]	n.a.	62	4,420	46,865	EK60/ME70	147	56	39
1404SH	4/13/2014	5/7/2014	24	Sardine/CPS	35 [39.6]	n.a.	10	3,890	85,265	EK60/ME70	39	16	8
1406SH	6/24/2014	8/5/2014	42	Sardine/CPS	26 [70.3]	n.a.	22	2,278	40,513	EK60/ME70	85	36	29
1504SH	3/28/2015	5/1/2015	34	Sardine/CPS	29 [29.9]	n.a.	13	1,843	50,038	EK60/ME70	54	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
1604RL	3/22/2016	4/22/2016	31	Sardine/CPS	83 [49.3]	n.a.	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

3.1.6 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 (PFMC 2017).

The post stratified method applied here was described at length [on request] at the meeting. 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, suggesting that the expected negative bias in the variance estimates due to post-stratification is not likely to be substantial. Essentially it purports to follow the methods of Fewster et al. (2009) but the selection of strata is not as indicated in Fewster et al.: they post stratify systematically across the entire survey design, whereas in the ATM the strata are ad hoc selections to isolate largely positive values. It is unknown what the effects of this strategy are but it is irregular. There is almost certainly some autocorrelation in the data which, because the design is systematic, will contribute to an improvement in precision (Rivoirard et al. 2000); however, it was undetectable at the transect level and given the highly zero inflated data, may also be at the EDSU level. This is not unusual (see for example (Fernandes and Simmonds 1997), but the team might be encouraged to try the methods described in Woillez et al. (2009) which are now more amenably described in Petitgas et al. (2017) and cater for zero inflation.

3.1.7 How echogram backscatter is analyzed to exclude non-CPS backscatter.

The statement, "The echo energy attributed to CPS, based on empirical echo spectra (Demer et al., 2012), are apportioned to species using trawl-catch proportions" (Zwolinski et al., 2014), summarizes the approach but hides much of the detail which, eventually, was revealed. The data are corrected for local sound speed and filtered to reduce noise in accordance with standard practice. The Sv data are averaged (11 samples vertically and 3 transmissions horizontally) and then filtered based on empirical predictions of CPS according to Demer et al. (2018) as : $-13.85 \leq Sv\ 70\ kHz - Sv\ 38\ kHz < 9.89$; $-13.5 \leq Sv\ 120\ kHz - Sv\ 38\ kHz < 9.37$; and $-13.51 \leq Sv\ 200\ kHz - Sv\ 38\ kHz < 12.53$ dB. The stated references "For more details are…" Demer et al. (2009) and Demer et al. (2012), but the former relates to demersal fish (rockfish) and reports no multifrequency thresholds, and the latter, not only has a different set of thresholds, but provides no justification whatsoever of the derivation of thresholds. No explanation was given as to where these values have come from and the stated references do not provide any detail. The data are then further filtered according to the standard deviation of each averaging bin, and a simple Sv threshold (< 60 dB). The outcome of this process is to isolate strong scatterers across all frequencies, characteristic of geometric scatterers, in a manner analogous to multifrequency thresholding described in Fernandes (2009); in common with the latter technique, areas of intense unknown midwater scattering (Mair et al. 2005) can remain (not documented, but very evident when the panel inspected echograms). The data are then selected from 10 m down to the depth of the bottom of the "surface mixed layer (typically between 10 and 12°C)" or to the maximum logging range (350 m). Manual adjustment then takes place by inspection of each EDSU to remove any scattering from the unknown midwater scattering layer or demersal fish. So the process is neither objective nor automatic, but it does make use of some spectral and statistical properties of fish schools.

A major drawback here is that despite this complex processing, what is taken into the next stage of analysis is CPS backscatter as opposed to species specific backscatter. So 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.*" As a consequence, CPS backscatter is then apportioned to species according to the night time trawl catch compositions. This has implications for the precision of the abundance estimate and is considered further in Section 4.4.

3.2 TOR 2. Estimated target strengths of CPS from the California Current

Current ATM estimates rely on target strengths of similar CPS species identified in other studies around the world. The ability to measure target strengths of live fish collected from the survey area can now be conducted at the Technology Tank at the SWFSC, La Jolla, CA. Target strengths of CPS from the California Current should be provided for the review meeting.

Target strength is a vital component of an acoustic survey that purports to be absolute. Generally, uncertainties in TS estimation are the major determinant in stipulating whether the survey estimates are used as absolute or relative indices of abundance. There are very few acoustic surveys where the surveys are considered as absolute abundance estimates: Icelandic capelin being one of the few in north-east Atlantic. So an absolute estimate would be expected to have very specific evidence of the TS of the fish from the stock in question. Demer et al. (2018) state that length distributions "…are input to TS-versus-length models for sardine (*Sardinops ocellatus*/*Sardinops sagax*) (Barange et al. 1996), horse mackerel (*Trachurus trachurus*) (Barange et al. 1996)…", which was rather cryptic. After some discussion it was clear that the Barange et al. relationship for South African pilchard (*Sardinops ocellatus*), is used for California sardine (*Sardinops sagax*) and Pacific herring; while their horse mackerel equation is used for the Pacific and jack mackerel. These are not the same species, never mind the same stock.

All of these species have open swim bladders (physostomes), so their target strength is impacted by compression or expansion of the swim bladder over the vertical range. Fishermen have observed vertical migrations of both sardine and anchovy below 70 m (*pers. comm.* David Crabbe). However, no depth compensation is applied to sardine TS. Depth-dependent target strength has been documented for Atlantic herring (Ona 2003, Fässler et al. 2009). However, 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. Such considerations are consistent with the use of the resulting estimates as indices rather than absolute estimates.

For anchovy, the target strength 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, which again is consistent.

The impact of depth may also be significant for herring because vertical distribution of Pacific herring has been documented to 200 m (pers. comm. Stephane Gauthier). Notwithstanding issues of depth-dependence, there are some published target strength models for Pacific herring (Thomas et al. 2002, Gauthier and Horne 2004) which may be more appropriate than the current model used, which is based on pilchard.

The last review recommended that efforts should be made to obtain TS measurements for in situ CPS. However, with the exception of anchovy, no progress has been made. Given the desire to use the estimates as absolute, the continued use of the TS relationships from other species (Barange *et al*. 1996) is curious. Several suggestions for making measurements were discussed. 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. Little discussion was had about the excellent facility, the acoustic technology tank, available at SWFSC. This can accommodate fish and would be an excellent facility to make controlled experiments and observations of species and stock specific TS.

3.3 TOR 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. 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.

3.3.1 Low population effects.

Low stock abundance may potentially lead to higher relative observation variability and thus greater uncertainty in population size, e.g. see Simmonds et al. (2009). 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.

3.3.2 Costs and benefits of targeting sampling effort

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 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. However, the southern boundary may fall short of the likely distribution of sardine, as evidenced from the presence of fish on the most southerly transect (Figs. 2 and 3).

The survey design includes areas with 20 n.mi. and others with 10 n.mi. 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 n.mi. interval transects when substantial biomass is seen on a transect. However, even though there are a limited number of these additional transects allotted, the practice may limit the southern boundary because the time taken to conduct these transects impinges on completing the southern order and hence the entire sampling frame, even when designated by the habitat model.

3.4 TOR 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 ATM 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 ATM 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. Cannot see any information relating to this?*

3.4.1 Time delay between trawling and acoustic detection of CPS

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.*"

There are many 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. 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.

In the ATM surveys there is substantial time lag [and some distance lag] between trawling and acoustically detected CPS. This raises an obvious concern that the proportions of fish species and the length distributions detected by day may not be the same as those which are trawled on by night. This may occur for several reasons:

a) Differential horizontal distribution due to movement.
b) Differential vertical distribution. The trawl has a vertical opening of 15 m and the headline is at 5-10 m, at best the trawl samples down to 25 m; epipelagic CPS occur at greater depths than this and individuals may segregate vertically by size at night (Stockwell et al. 2010, Jensen et al. 2011, Busch and Mehner 2012). 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 as they migrate into upper waters also.
c) Differential species trawl selectivity. There are considerable size differences between the species: anchovy ranges from 9 to 16 cm; sardine from 9 to 26 cm; and the mackerels from 6 to 61 cm (Demer et al. 2012). So the smaller fish (anchovy) are more likely to pass through the anterior meshes than successively larger species such as sardine and more so mackerel. O'Driscoll (2003) document such effects and account for species vulnerabilities in the mixture allocation: this approach might be considered here.
d) Differential dispersal of fish. Fish are concentrated in schools, potentially monospecific, by day, and mixtures of individuals by night. The concentration of individuals may not reflect those of schools. During the course of the review it was evident that some schooling was maintained at night although it was not clear which species these were likely to be.

Other than consistency of results, the team provided no evidence to dispute that any of these effects could be occurring. Furthermore, the wide confidence intervals associated with each survey would mean that statistically significant differences are difficult to determine.

Several approaches to dealing with these issues 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, perhaps due to inappropriate gear. However, a midwater trawl is used in the hake (aka Pacific whiting) surveys, and it is capable of catching Pacific herring.

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, which at the present time seem strained.

3.4.2 Consider suitable sample sizes of CPS in the ATM survey

No results were reported, but this should be taken forward. 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. The effects of the sample size of fish collected in trawls in terms of uncertainty and variability in indices and size and age compositions, should be examined. Well informed length distributions are important for estimating size and age structure. While increasing the length of trawls will help to some extent, other approaches may be more efficient (weighted pooling where similarities are confirmed). There were examples of very low sample sizes which should be avoided.

3.4.3 Efficiency (relative catchability) and selectivity of the trawl

No results were reported. But comparisons with alternative ground truth devices (purse seine, gillnet, cameras) would help to understand the selectivity of the trawl.

3.4.4 Estimate trawl selectivity by species.

No results were reported, but as noted above (4.4.1.c) this should be investigated, as suggested, with camera work, but also by considering alternative approaches (O'Driscoll 2003).

3.5 TOR 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 ATM 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; 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).

This response to this TOR 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.

3.5.1 *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.

3.5.2 *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.

3.5.3 *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.

3.5.4 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.

3.6 TOR 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 ATM team should estimate what proportion of biomass is missed with the standard down-looking sonar.

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. Given the nature of the epi-pelagic species surveyed here, 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 (Mitson 1995). It should not be expected that fish at the surface have the same reaction, even to vessels with sound signatures quieter than 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 (Fernandes et al. 2000a, Fernandes et al. 2000b). Other studies using an instrumented buoy or comparisons among vessels found varying effects (Ona et al. 2007, De Robertis et al. 2008, De Robertis et al. 2010, De Robertis and Wilson 2011, De Robertis et al. 2012), with one example providing evidence of vessel attraction (Røstad et al. 2006); 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 others would require dedicated experimental time. Survey vessels with multibeam sonar systems can collect 3-D data under and on the side of the vessel that can be used to estimate distribution statistics, detecting the potential impact of the vessel on fish distribution (Patel and Ona 2009). Experimental approaches require dedicated time, but may offer clearer and independent quantification of vessel effects. Experiments could include use of instrumentation such as Lidar (Gauldie et al. 1996), spectral camera (Borstad et al. 1992), or stationary acoustics, which are capable of measuring distribution patterns or trends in the absence and presence of the survey vessel.

3.7 TOR 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 ATM 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 ATM 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 ATM team should provide information on what a sufficient number of sea days is, and information on tradeoffs between spatial coverage and transects, etc.*

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 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 n.mi., and extended inshore from the

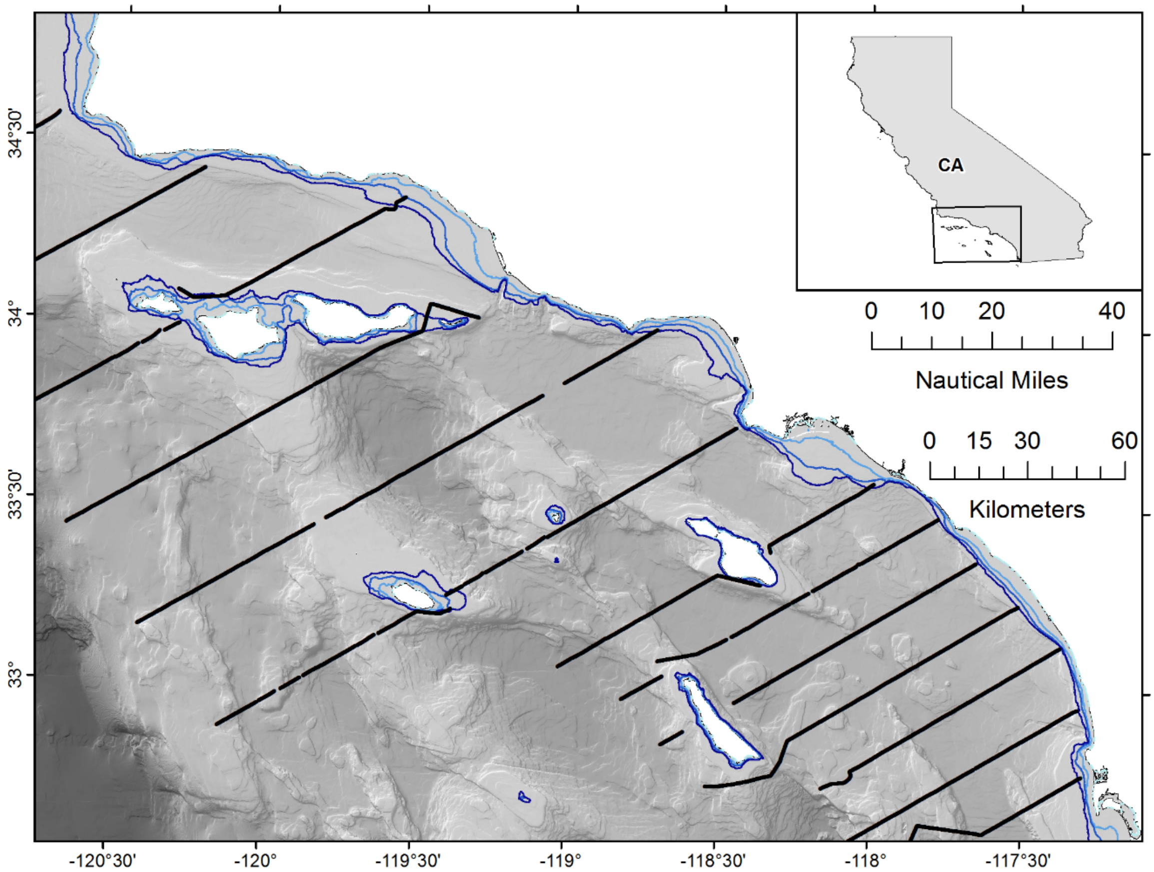

Figure 6 Map of the coast of California showing how close the acoustic survey transects (black lines) approach the coast, and bathymetric contours (blue lines at 20, 40, and 60 m seabed depth, respectively darker).

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. A map was provided (Fig. 6) which indicates that the inshore areas that are not sampled by the ATM survey are relatively small. Nevertheless, 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, not recommended); 2) extrapolate biomass into the unsurveyed inshore area using the intertransect data (see below); 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 following text from Simmonds and MacLennan (2005) provides further insight on the latter options: "*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 tool (Rivoirard et al. 2000). 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.*"

3.8 TOR 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 review 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; 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 ATM team should describe how echogram backscatter is analyzed to exclude non-CPS backscatter.

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, where the biomass is used 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 current panel's evaluation of the use of ATM data in assessments and management are summarized in Table 2.

This reviewer does not support the use of the ATM biomass estimates as absolute estimates of biomass in assessments; i.e. where Q, the ratio between the assessed biomass and the ATM survey biomass, is 1. This is because of the uncertainties related to: (a) target strength (determined from relationships for other species in other areas, see Section 4.2); (b) the proportion of the biomass inshore (see Section 4.7), and to the north and south of the survey area (see Section 4.3.2); (c) target species identification (see Section 4.1.7); (d) avoidance (see Section 4.6); (e) migration during the survey (limited discussion); and (f) the surface blind zone (limited discussion). These factors may 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. It was 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.

Currently the assessment incorporates a single estimate of biomass for each species from the ATM survey and, to comply with the model ALT formulation, estimates of abundance at length are converted into abundance at age using a pooled age length key. Estimates of abundance at age are a key component of many acoustic survey outputs (Simmonds 2003). A summary of an evaluation of the consistency of the age-determination for Pacific sardine was provided by Emmanis Dorval. There is no formal validation of the ageing process using, for example, tagging studies or otolith microstructure. However, age-reading error has been quantified based on

Table 2. 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. 1option (a) in the TOR 8; 2option (b) in the TOR 8; 3Only available from 2015; 4Only 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.

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

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.

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.

A key performance metric in the evaluation of an abundance at age estimate from any survey is a plot of internal consistency: this was provided for sardine at the end of the meeting (Fig. 7). One would expect a good survey, allied to an effective age reading program, to have consistent positive correlations between the number of any aged fish one year and the numbers of that same year group the following year. In the case of sardine, the age 0 versus age 1 correlation is indicative of fairly positive relationship ($r2=0.41$, $r=0.64$), but clearly age 1 versus age 2 are very poor, as are 2 versus 3, and 3 versus 4. This may reflect the age reading errors described above, but curiously things settle down again after 4 vs 5 (all subsequent

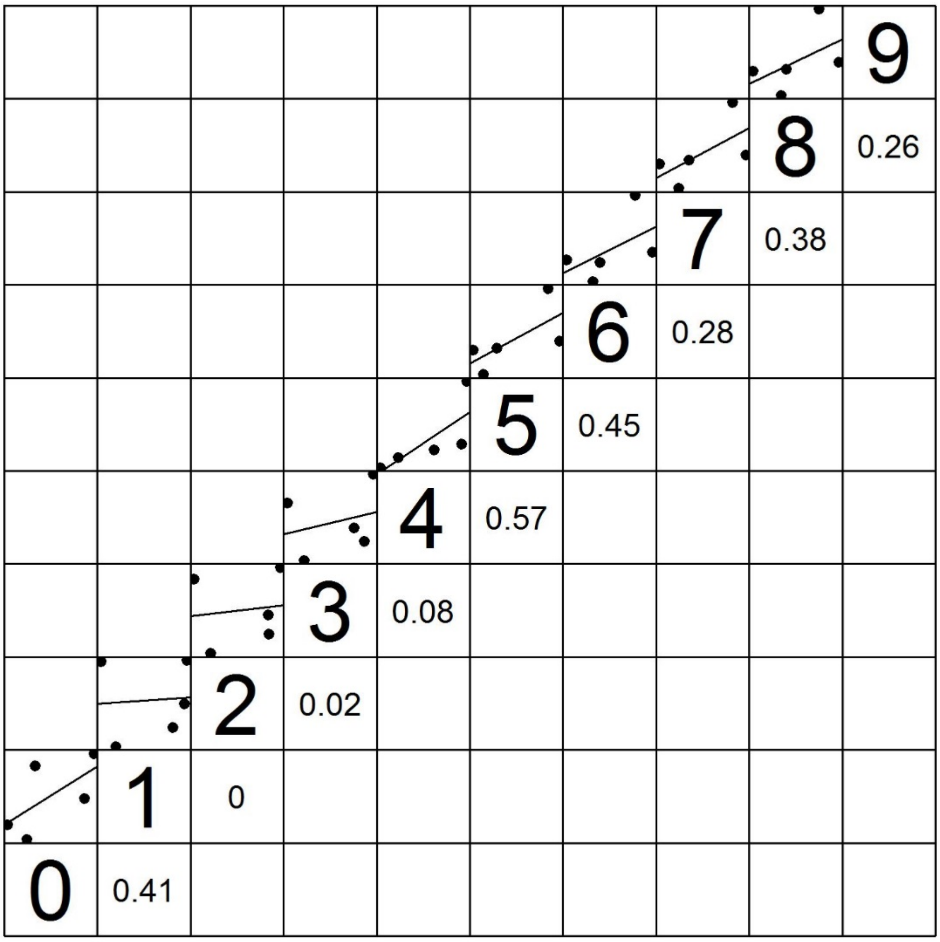

Figure 7 Internal consistency plot (log of numbers at age x in year t against numbers at age x+1 in year t+1) of the acoustic survey for sardine. Above the diagonal the fitted linear regression is shown including the observations (in points) while under the diagonal the r^2 value that is associated with the linear regression is given.

correlation coefficients, r, are greater than 0.5, indicating a moderate positive relationship). If age reading across all ages was so bad these might have expected to be equally bad, so this could also be a sign that the species or size allocations are astray.

Table 2 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. This reviewer **strongly recommends** that ageing techniques be improved to allow use of age composition data for the survey in assessments.

It is important to highlight that the survey aims to cover the range of all four stocks. There are periods when jack mackerel and Pacific mackerel appear to be substantially in the survey frame, i.e. summer (Fig. 4). It is likely that a substantial proportion of the biomass of the central subpopulation of northern anchovy is in Mexican waters, particularly in spring, so 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.

The same approach to ageing is taken for Pacific mackerel so this should also be encouraged and developed. 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.

It is beyond the current Terms of Reference to specify exactly how an ATM biomass index should be used directly in management. Specifying harvest control rules that directly use the ATM biomass index is complicated because the use of the estimates of biomass as absolute in assessments is not recommended. 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.

4 Recommendations

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.

4.1 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. The team should continue to collect target strength data using best available technology with associated relevant biological information to improve current target strength models.
3. Improve ageing of survey and fisheries samples to allow age composition data to be used in assessments.
4. 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 night 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.
5. 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.
6. 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.
7. 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.
8. 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.
9. Analyze the effect of the adaptive sampling of the bias of estimates of biomass using simulation or through reanalyzing various subsets of conducted transects.

10. 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.
11. The assumption that all CPS finfish spread out at the surface needs to be validated.

4.2 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 applied 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.

4.3 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.

5 Conclusions

TOR 1. ATM survey documentation. The documentation provided was inadequate to address the TOR. The ATM Team were, however, very forthcoming and diligent in providing further information: a more comprehensive document is in preparation. There is clearly a lot of good practice, particularly in the technical detail associated with the operation of the acoustic instruments. The summer surveys, in particular, seem to contain most of the stocks pretty well. Survey precision is generally poor (CV's > 20%) and is not [inversely] proportional to the effort applied (as it should). The former may be related to the major problem of species identification. The former may be related to the very challenging problem of species identification, which despite significant progress in signal processing, has been difficult to advance from the expert based methods of the 1970's (Mais 1974).

TOR 2. Target strength. The application of target strength to length relationships of other species from other parts of the world is one of the factors which inhibits the estimates of biomass for the ATM surveys being used as absolute values. Specific TS/L relationships should be determined for each stock, and these should also be depth dependent where appropriate (i.e. for physostomes).

TOR 3. Survey design. The sampling frame should be set with reference to the habitat model and results from former surveys, and surveyed in full. Adaptive sampling should not prejudice completing the survey design. Enhanced precision should not be sought at the cost of potentially significant bias, notwithstanding the problems highlighted of poor precision: it is better to be vaguely right than exactly wrong (Read 1906).

TOR 4. Trawl survey design. The time delay between acoustic detection and verification of species composition and size by trawling introduces several significant uncertainties. Chief amongst these is the differential selectivity given the different sizes of the animals concerned, but differential vertical distribution by species or by size may also have an effect. Such a delay is not standard practice, and in most cases, trawling to determine or verify species and size composition takes place as soon as significant echotraces are detected. In conjunction with efforts to improve species identification, methods to improve the biological sampling need to be pursued.

TOR 5. Use of the broadband EK80 echosounder. The EK80 has several interesting features which may enhance the identification of CPS species. The Team is well equipped and very well versed in broadband technology and are in as good a position to exploit it as anyone else in the world. Efforts to develop the systems are encouraged.

TOR 6. Vessel avoidance. Due to the epi-pelagic nature of the ATM target species, avoidance of the survey vessel is possible during the day and likely at night during trawling. Various approaches to investigating avoidance have been adopted throughout the world and the Team have all the necessary equipment and expertise to try one or more of these. They need to demonstrate that avoidance is not a source of bias if their estimates are to be considered absolute.

TOR 7. Unsampled (inshore) areas. There are fish in the inshore areas that are not surveyed by the ATM. There are legitimate concerns from the fishing industry, who fish extensively in these areas, that these fish are not accounted for. However, evidence points to the bias (as per the area) being small. This could be examined retrospectively by extrapolation, but in future, additional efforts should be made to survey inshore areas.

TOR 8. Suitability of ATM results for inclusion in assessments. It is recommended that ATM survey estimates of sardine, Pacific mackerel, Jack mackerel, the Northern sub-population of northern anchovy, and the Central sub-population of northern anchovy be used in an integrated stock assessment as indices of relative abundance. The use of the ATM biomass estimates as absolute estimates of biomass in assessments is not recommended. This is chiefly due to the aforementioned uncertainties related to target strength, target species identification, unsampled areas (inshore & south of the survey area) and potential avoidance. Many of these uncertainties can be addressed with research which the Team is eminently qualified and well equipped to tackle. Improvements in age reading are essential to improve the quality of the estimates at age.

Appendix 1: Bibliography of materials, including those provided for the review.

Aglen, A. (1989). Empirical results on precision - effort relationships for acoustic surveys. **B:** 28.

Barange, M., I. Hampton and M. Soule (1996). "Empirical determination of in situ target strengths of three loosely aggregated pelagic fish species." *ICES Journal of Marine Science* **53**(2): 225-232.

Barron, J. A. and D. Bukry (2007). "Development of the California Current during the past 12,000 yr based on diatoms and silicoflagellates." *Palaeogeography, Palaeoclimatology, Palaeoecology* **248**(3): 313-338.

Borstad, G. A., D. A. Hill, R. C. Kerr and B. S. Nakashima (1992). "Direct digital remote sensing of herring schools." *International Journal of Remote Sensing* **13**(12): 2191-2198.

Busch, S. and T. Mehner (2012). "Size-dependent patterns of diel vertical migration: smaller fish may benefit from faster ascent." *Behavioral Ecology* **23**(1): 210-217.

Cochran, W. G. (1977). *Sampling Techniques (third edition)*. New York, John Wiley & Sons.

De Robertis, A. and N. O. Handegard (2012). "Fish avoidance of research vessels and the efficacy of noise-reduced vessels: a review." *ICES Journal of Marine Science: Journal du Conseil* **70**(1): 34-45.

De Robertis, A., V. Hjellvik, N. J. Williamson and C. D. Wilson (2008). "Silent ships do not always encounter more fish: comparison of acoustic backscatter recorded by a noise-reduced and a conventional research vessel." *ICES Journal of Marine Science* **65**(4): 623-635.

De Robertis, A., D. R. McKelvey and P. H. Ressler (2010). "Development and application of an empirical multifrequency method for backscatter classification." *Canadian Journal of Fisheries and Aquatic Sciences* **67**(9): 1459-1474.

De Robertis, A. and C. D. Wilson (2011). "Silent ships do not always encounter more fish (revisited): comparison of acoustic backscatter from walleye pollock recorded by a noise-reduced and a conventional research vessel in the eastern Bering Sea." *ICES Journal of Marine Science* **68**(10): 2229-2239.

De Robertis, A., C. D. Wilson and N. J. Williamson (2012). Do Silent Ships See More Fish? Comparison of a Noise-Reduced and a Conventional Research Vessel in Alaska. The Effects of Noise on Aquatic Life. A. N. Popper and A. Hawkins. New York, NY, Springer New York: 331-334.

Demer, D. A. (2004). "An estimate of error for the CCAMLR 2000 survey estimate of krill biomass." *Deep Sea Research Part II: Topical Studies in Oceanography* **51**(12): 1237-1251.

Demer, D. A., L. N. Andersen, C. Bassett, L. Berger, D. Chu, J. Condiotty, G. R. C. Jr., et al. (2017). "2016 USA–Norway EK80 Workshop Report: Evaluation of a wideband echosounder for fisheries and marine ecosystem science." *ICES Cooperative Research Report* **336**: 69.

Demer, D. A., G. R. Cutter, J. S. Renfree and J. L. Butler (2009). "A statistical-spectral method for echo classification." *ICES Journal of Marine Science: Journal du Conseil* **66**: 1081-1090.

Demer, D. A., J. P. Zwolinski, K. A. Byers, G. R. Cutter, J. S. Renfree, T. S. Sessions and B. J. Macewicz (2012). "Prediction and confirmation of seasonal migration of Pacific sardine (Sardinops sagax) in the California Current Ecosystem." *Fishery Bulletin* **110**(1): 52-70.

Demer, D. A., J. P. Zwolinski, K. L. Stierhoff, J. S. Renfree, D. Palance, S. Mau, D. Murfin, et al. (2018). "Acoustic-Trawl Methods for Surveying Coastal Pelagic Fishes in the California Current Ecosystem." *Report to the CIE review group.*

Fässler, S. M. M., P. G. Fernandes, S. I. K. Semple and A. S. Brierley (2009). "Depth-dependent swimbladder compression in herring *Clupea harengus* observed using magnetic resonance imaging." *Journal of Fish Biology* **74**: 296-303.

Fernandes, P. G. (2009). "Classification trees for species identification of fish-school echotraces." *ICES Journal of Marine Science* **66**: 1073-1080.

Fernandes, P. G., A. Brierley, E. J. Simmonds, N. W. Millard, S. D. McPhail, F. Armstrong, P. Stevenson, et al. (2000b). "Addendum to Fish do not avoid survey vessels." *Nature* **407**: 152.

Fernandes, P. G., A. S. Brierley, E. J. Simmonds, N. W. Millard, S. D. McPhail, F. Armstrong, P. Stevenson, et al. (2000a). "Fish do not avoid survey vessels." *Nature* **404**: 35-36.
Fernandes, P. G. and E. J. Simmonds (1997). "Variographic refinement of North Sea herring acoustic survey data." *Quantitative geology and geostatistics* **9**: 451-462.
Fewster, R. M., S. T. Buckland, K. P. Burnham, D. L. Borchers, P. E. Jupp, J. L. Laake and L. Thomas (2009). "Estimating the encounter rate variance in distance sampling." *Biometrics* **65**(1): 225-236.
Gauldie, R. W., S. K. Sharma and C. E. Helsley (1996). "LIDAR applications to fisheries monitoring problems." *Canadian Journal of Fisheries and Aquatic Sciences* **53**: 1459-1468.
Gauthier, S. and J. K. Horne (2004). "Acoustic characteristics of forage fish species in the Gulf of Alaska and Bering Sea based on Kirchhoff-approximation models." *Canadian Journal of Fisheries and Aquatic Science* **61**(1839-1850): 836-845.
Holliday, D. V. (1977). Extracting bio-physical information from the acoustic signatures of marine organisms. Oceanic sound scattering prediction. N. R. Andersen and B. J. Zahuranec. New York, Plenum Press: 619-624.
Jensen, O. P., S. Hansson, T. Didrikas, J. D. Stockwell, T. R. Hrabik, T. Axenrot and J. F. Kitchell (2011). "Foraging, bioenergetic and predation constraints on diel vertical migration: field observations and modelling of reverse migration by young-of-the-year herring Clupea harengus." *Journal of Fish Biology* **78**(2): 449-465.
Kang, D., S. Cho, C. Lee, J.-G. Myoung and J. Na (2009). "Ex situ target-strength measurements of Japanese anchovy (Engraulis japonicus) in the coastal Northwest Pacific." *ICES Journal of Marine Science* **66**(6): 1219-1224.
Mair, A. M., P. G. Fernandes, A. Lebourges-Dhaussy and A. Brierley (2005). "An investigation into the zooplankton composition of a prominent 38-kHz scattering layer in the North Sea." *Journal of Plankton Research* **27**(7): 623-633.
Mais, K. F. (1974). "Fish Bulletin 162. Pelagic Fish Surveys In The California Current."
McClatchie, S., R. E. Thorne, P. Grimes and S. Hanchet (2000). "Ground truth and target identification for fisheries acoustics." *Fisheries Research* **47**: 173-191.
Mitson, R. B. (1995). "Underwater noise of research vessels. Review and recommendations." *ICES Co-operative Research Report* **209**: 61.
Nakken, O. and A. Dommasnes (1975). "The application of an echo integration system in investigations on the stock strength of the Barents Sea capelin (Mallotus villosus, Müller) 1971-1974." *ICES CM 1975/B:25*: 20.
O'Driscoll, R. L. (2003). "Determining species composition in mixed-species marks: an example from the New Zealand hoki (*Macruronus novaezelandiae*) fishery." *ICES Journal of Marine Science* **60**: 609-616.
Ona, E. (2003). "An expanded target-strength relationship for herring." *ICES Journal of Marine Science* **60**(3): 493-499.
Ona, E., O. R. Godø, N. O. Handegard, V. Hjellvik, R. Patel and G. Pedersen (2007). "Silent research vessels are not quiet." *The Journal of the Acoustical Society of America* **121**(4): EL145-EL150.
Patel, R. and E. Ona (2009). "Measuring herring densities with one real and several phantom research vessels." *ICES Journal of Marine Science* **66**(6): 1264-1269.
Petitgas, P., M. Woillez, J. Rivoirard, D. Renard and N. Bez (2017). "Handbook of geostatistics in R for fisheries and marine ecology." *ICES Cooperative Research Report* **338**: 177.
Read, C. (1906). *Logic deductive and inductive*, A. Moring, Limited.
Rivoirard, J., J. Simmonds, K. F. Foote, P. Fernandes and N. Bez (2000). *Geostatistics for estimating fish abundance*. Oxford, Blackwell Science Ltd.
Rose, G., S. Gauthier and G. Lawson (2000). "Acoustic surveys in the full monte:simulating uncertainty." *Aquatic Living Resources* **13**: 367-372.
Røstad, A., S. Kaartvedt, T. A. Klevjer and W. Melle (2006). "Fish are attracted to vessels." *ICES Journal of Marine Science* **63**(8): 1431-1437.

Simmonds, E. J. (1995). "Survey design and effort allocation: a synthesis of choices and decisions for an acoustic survey. North Sea herring is used as an example." *ICES CM 1995* /**B:9**: 20.

Simmonds, E. J. (2003). "Weighting of acoustic- and trawl-survey indices for the assessment of North Sea herring." *ICES Journal of Marine Science* **60**: 463-471.

Simmonds, E. J., M. Gutiérrez, A. Chipollini, F. Gerlotto, M. Woillez and A. Bertrand (2009). "Optimizing the design of acoustic surveys of Peruvian anchoveta." *ICES Journal of Marine Science: Journal du Conseil* **66**(6): 1341-1348.

Simmonds, E. J. and D. N. MacLennan (2005). *Fisheries acoustics: theory and practice. 2nd edition*. Oxford, Blackwell Publishing.

Stanton, T. K., D. Chu, J. M. Jech and J. D. Irish (2010). "New broadband methods for resonance classification and high-resolution imagery of fish with swimbladders using a modified commercial broadband echosounder." *ICES Journal of Marine Science* **67**: 365–378.

Stockwell, J. D., T. R. Hrabik, O. P. Jensen, D. L. Yule and M. Balge (2010). "Empirical evaluation of predator-driven diel vertical migration in Lake Superior." *Canadian Journal of Fisheries and Aquatic Sciences* **67**(3): 473-485.

Thomas, G., J. Kirsch and R. E. Thorne (2002). "Ex situ target strength measurements of Pacific herring and Pacific sand lance." *North American Journal of Fisheries Management* **22**(4): 1136-1145.

Woillez, M., J. Rivoirard and P. G. Fernandes (2009). "Evaluating the uncertainty of abundance estimates from acoustic surveys using geostatistical conditional simulations." *ICES Journal of Marine Science* **66**: 1377-1383.

Appendix 2: A copy of the CIE Statement of Work

Statement of Work
National Oceanic and Atmospheric Administration (NOAA)
National Marine Fisheries Service (NMFS)
Center for Independent Experts (CIE) Program
External Independent Peer Review

Acoustic Trawl Methodology Review for use in Coastal Pelagic Species Stock Assessments

Background

The National Marine Fisheries Service (NMFS) is mandated by the Magnuson-Stevens Fishery Conservation and Management Act, Endangered Species Act, and Marine Mammal Protection Act to conserve, protect, and manage our nation's marine living resources based upon the best scientific information available (BSIA). NMFS science products, including scientific advice, are often controversial and may require timely scientific peer reviews that are strictly independent of all outside influences. A formal external process for independent expert reviews of the agency's scientific products and programs ensures their credibility. Therefore, external scientific peer reviews have been and continue to be essential to strengthening scientific quality assurance for fishery conservation and management actions.

Scientific peer review is defined as the organized review process where one or more qualified experts review scientific information to ensure quality and credibility. These expert(s) must conduct their peer review impartially, objectively, and without conflicts of interest. Each reviewer must also be independent from the development of the science, without influence from any position that the agency or constituent groups may have. Furthermore, the Office of Management and Budget (OMB), authorized by the Information Quality Act, requires all federal agencies to conduct peer reviews of highly influential and controversial science before dissemination, and that peer reviewers must be deemed qualified based on the OMB Peer Review Bulletin standards. (http://www.cio.noaa.gov/services_programs/pdfs/OMB_Peer_Review_Bulletin_m05-03.pdf).

Further information on the CIE program may be obtained from www.ciereviews.org.

Scope

The three CIE reviewers will serve on a Methodology Review (MR) Panel and will be expected to participate in the review of Acoustic Trawl Method (ATM) currently used to produce biomass estimates for Pacific sardine stock assessments. The Pacific sardine stock is assessed regularly (currently, every 1 year) by Southwest Fisheries Science Center (SWFSC) scientists and the Pacific Fishery Management Council (PFMC) uses the resulting biomass estimate to establish an annual harvest guideline (quota). Currently, ATM biomass estimates for three other coastal pelagic species—Pacific mackerel, northern anchovy (two sub-stocks) and jack mackerel have not been approved for use in PFMC stock assessments (see 2011 ATM Methodology Review). It is the intent of this review to evaluate usefulness of the ATM for these stocks even though portions of the population may be outside the range of the ATM survey either in international waters or in shallow nearshore waters that cannot be sampled by the ATM in its present configuration.

The Methods Review Panel will review current ATM survey results and associated stock assessment documents and any other pertinent acoustic information for coastal pelagic species, work with the ATM Stock Assessment (STAT) team to make necessary revisions, and produce a MR Panel report for use by the PFMC and other interested persons for developing management recommendations for these fisheries. The ATM Terms of Reference (TORs) provides the scope and range of issues that this methodology review should cover is provided in **Appendix 1** for the benefit of both the reviewers and the ATM STAT team. Additionally, the overarching PFMC TORs for the methodology review process for groundfish and coastal pelagic species for 2017 and 2018 are available at: https://www.pcouncil.org//wp-content/uploads/2017/01/Methodology_ToR_CPSGF-2017-18.pdf. The tentative agenda of the Panel review meeting is attached in **Appendix 2**. Each CIE reviewer shall complete the independent peer review according to required format and content as described in **Appendix 3**. Finally, a Panel summary report template is included as **Appendix 4**.

Requirements

Three CIE reviewers shall participate during a panel methodology review meeting in La Jolla, California during 29 January-2 February 2018, and shall conduct impartial and independent peer review accordance with this Statement of Work (SoW) and ToRs herein. The CIE reviewers shall have the expertise as listed in the following descending order of importance:

- The CIE reviewer shall have expertise in the design and application of fisheries underwater acoustic technology to estimate fish abundance for stock assessments.
- The CIE reviewer shall have expertise in the design and execution of fishery-independent surveys for use in stock assessments, preferably with coastal pelagic fishes.
- The CIE reviewer shall have 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.
- The CIE reviewer shall have expertise in the life history strategies and population dynamics of coastal pelagic fishes.
- It is desirable for the CIE reviewer to be familiar with the design and application of aerial surveys to estimate fish abundance for stock assessments.

Tasks for reviewers

Pre-review Background Documents

Review the following background materials and reports prior to the review meeting. Two weeks before the peer review, the NMFS Project Contact will send by electronic mail or make available at an FTP site to the CIE reviewers all necessary background information and reports for the peer review. In the case where the documents need to be mailed, the NMFS Project Contact will consult with the CIE on where to send documents. The CIE reviewers shall read all documents in preparation for the peer review, for example:

- *Recent Acoustic Trawl Method documents and journal articles completed* *since 2010 provided for this review; Stock Assessement Review (STAR) Panel- and* Scientific and Statistical Committee *(SSC)-related documents pertaining to reviews of past ATM survey results and; CIE-related summary reports pertaining to past methodology reviews; and miscellaneous documents, such as ToRs, logistical considerations, etc.*

Panel Review Meeting

Each CIE reviewer shall conduct the independent peer review in accordance with the SoW and ToRs, and shall not serve in any other role unless specified herein. Each CIE reviewer shall actively participate in a professional and respectful manner as a member of the meeting review panel, and their peer review tasks shall be focused on the ToRs as specified herein. The meeting will consist of presentations by NOAA and other scientists to facilitate the review, to provide any additional information required by the reviewers, and to answer any questions from reviewers.

Contract Deliverables - Independent CIE Peer Review Reports

The CIE reviewers shall complete an independent peer review report in accordance with the requirements specified in this SoW and OMB guidelines. Each CIE reviewer shall complete the independent peer review addressing each ToR as described in **Appendix 1**. Each CIE reviewer shall complete the independent peer review according to required format and content as described in **Appendix 3**.

Other Tasks – Contribution to Summary Report

The CIE reviewers may assist the Chair of the panel review meeting with contributions to the Summary Report, based on the ToRs. The CIE reviewers are not required to reach a consensus, and should provide a brief summary of each reviewer's views on the summary of findings and conclusions reached by the review panel in accordance with the ToRs. The Panel summary report template is attached as **Appendix 4.**

Foreign National Security Clearance

When reviewers participate during a panel review meeting at a government facility, the NMFS Project Contact is responsible for obtaining the Foreign National Security Clearance approval for reviewers who are non-U.S. citizens. For this reason, the reviewers shall provide requested information (e.g., first and last name, contact information, gender, birth date, passport number, country of passport, travel dates, country of citizenship, country of current residence, and home country) to the NMFS Project Contact for the purpose of their security clearance, and this information shall be submitted at least 30 days before the peer review in accordance with the NOAA Deemed Export Technology Control Program NAO 207-12 regulations available at the Deemed Exports NAO website: http://deemedexports.noaa.gov/ and http://deemedexports.noaa.gov/compliance_access_control_procedures/noaa-foreign-national-registration-system.html. The contractor is required to use all appropriate methods to safeguard Personally Identifiable Information (PII).

Place of Performance

The place of performance shall be at the contractor's facilities, and at the Southwest Fisheries Science Center in La Jolla, California.

Period of Performance

The period of performance shall be from the time of award through April 30, 2017. Each reviewer's duties shall not exceed 14 days to complete all required tasks.

Schedule of Milestones and Deliverables: The contractor shall complete the tasks and deliverables in accordance with the following schedule.

Within two weeks of award	Contractor selects and confirms reviewers
No later than January 15, 2018	Contractor provides the pre-review documents to the reviewers
January 29 - February 2, 2018	The reviewers participate and conduct an independent peer review during the panel methods review meeting
No later than February 23, 2018	Contractor receives draft reports
No later than March 23, 2018	Contractor submits final reports to the Government

Applicable Performance Standards

The acceptance of the contract deliverables shall be based on three performance standards: (1) The reports shall be completed in accordance with the required formatting and content (2) The reports shall address each ToR as specified (3) The reports shall be delivered as specified in the schedule of milestones and deliverables.

Travel

All travel expenses shall be reimbursable in accordance with Federal Travel Regulations (http://www.gsa.gov/portal/content/104790). International travel is authorized for this contract. Travel is not to exceed $12,000.

Restricted or Limited Use of Data

The contractors may be required to sign and adhere to a non-disclosure agreement.

NMFS Project Contact:
Dale Sweetnam
8901 La Jolla Shores Drive
La Jolla, CA 92037-1509

Appendix 3: Panel Membership and contact details.

Andre Punt (Chair)
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Appendix 4: Participants **in the ATM review.**

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