Southern California Coastal Pelagic Species Aerial Survey Methodology Review

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1) Overview

The review of the Southern California Coastal Pelagic Species Survey (SCCPSS) was conducted by a Methodology Review Panel that met at the Southwest Fisheries Science Center, La Jolla, CA, from April 17-18, 2017. The SCCPSS involves two projects that are planned to inform the assessments for the Northern Subpopulation of Pacific sardine and the Central Subpopulation of northern anchovy. Project 1 involves a nearshore index of relative (or a [minimum] estimate of absolute) abundance based on density, while Project 2 pertains to an inshore correction factor for the acoustic-trawl method (ATM) survey to account for nearshore areas not surveyed due to operational constraints. Project 2 was an approach recommended by the SSC in November 2015 (Agenda Item H.4.a, Supplemental SSC Report).

Introductions were made (see list of attendees, Appendix 1), and the agenda was adopted. A document outlining the aerial survey, the design of the sampling procedures, preliminary results, and background materials, including the Pacific Northwest aerial survey review report, were provided at the request of the Panel in advance of the usual deadline for a meeting on a Council FTP site.

Mr. Kirk Lynn presented the methodology and current results. He also outlined work to validate the observer species compositions and the biological data collected during the surveys. The Panel raised questions for the technical team, with a view to drawing conclusions focused on sampling design and analyses, taking account of results obtained from data collected during sampling from 2012-2016. The results of the Panel deliberations are summarized in Sections 2 (general considerations), 3 (Project 1), and 4 (Project 2). Section 6 lists the overall conclusions of the review.

The main Panel conclusions are:

- Project 1 is closer to being ready to provide information for use in stock assessments for Pacific sardine (2019-20 or earlier) or northern anchovy. In particular, a negatively biased estimate of biomass can be obtained from the estimates of biomass from surveyed transects. However, it will be necessary to develop and apply a method for estimating the variance of the biomass inshore of the ATM survey area. The estimates of biomass from surveyed transects can be extrapolated to unsurveyed areas, but this will require additional sampling to ensure that the extent of between-area differences in density can be quantified to inform proper stratification of expansions and to allow variance to be estimated.
- The SCCPSS cannot at present be used to develop an index of recruitment for Pacific Sardine or northern anchovy.
- Project 2 is unlikely to be successful given the aerial survey and ATM survey are sampling different parts of the water column, and there is high sampling error.

The Panel recommends that another Methodology Review be undertaken if biomass is estimated by extrapolating into unsurveyed areas (i.e. by assuming the density in the surveyed areas applies to the unsurveyed areas) or if the survey is expanded north of the current survey area (unless the survey is used to provide a minimum estimate of biomass by basing the estimate of biomass only on areas surveyed).

The Panel thanked the technical team for their hard work and willingness to respond to Panel requests, and the staff at the Southwest Fisheries Science Center La Jolla laboratory for their usual exceptional support and provisioning during the Panel meeting.

2. General issues

Projects 1 and 2 depend on use of aerial survey techniques in nearshore waters to estimate biomass, either along the coast and off islands (Project 1), or along transects (Project 2). Thus, the two projects are subject to common sources of uncertainty. This section outlines issues common to both projects.

2.1 Requests

A. Request: Update Tables 1 and 2 from the report of the June 2009 Methodology Panel on the Northwest Aerial Survey (PFMC: Agenda Item H.2.A. Attachment 3, June 2009).
Rationale: The Panel wished to have a single summary of the key sources of uncertainty, how the estimates of biomass were likely to be impacted by each source, and whether it would be possible to address each uncertainty, and estimate its magnitude.
Response: Table 1 lists the sources of uncertainty associated with species identification, school detection and biomass estimation. It also lists the likely direction of bias and data / methods to overcome each source of uncertainty.

B. Request: Show the variance estimates and how they are calculated. Ideally, quantified uncertainty would account for within-transect error (replicate sampling) that might indicate depth variation and movement in schools plus surveyor error. Between-transect variance and the variance estimator for the biomass estimate were requested. There also appears to be rounding since there appears to be an improbable set of numbers divisible by five given the numbers presented. Would that contribute to the variance? Is there an estimate of surveyor bias or survey condition bias? A table listing the sources of variance, how they are calculated, and how they are combined to estimate biomass estimation error would be helpful.
Rationale: The estimates of variance of total Coastal Pelagic Species (CPS) biomass included in the documentation accounted only for survey bias error derived from the point set data.
Response: The Panel and proponents agreed that the current approach to quantifying uncertainty is inadequate. Appendix 2 outlines a generic approach for quantifying uncertainty for Project 1 estimates. Variance estimation is discussed further in Section 6.2.

C. Request: Define the standard for "synoptic" needed to reduce the risk of double counting schools from the ATM survey or vice versa. Optimally, it would be good to see comparisons (aerial to aerial and aerial to acoustic) for overlapping data with increasing time gaps between results. If the comparisons between methods worsen over time, that information might be useful for estimating method error.
Rationale: The effect of fish movement, whether lateral or vertical, has not been accounted for in the survey analysis. Schools of sardine or anchovy can travel 10 nm during 24 hours, which can bias estimates from combined aerial-acoustic survey data. The probability of counting the same schools twice may increase with the time interval between the aerial and ATM surveys.
Response: The proponents highlighted that aerial surveys are generally conducted very quickly (1-2 days), and attempts are made to conduct aerial surveys synoptically with the ATM survey. The Panel supports the strategy adopted by the proponents.

D. Request: Explain the relationship between the estimates obtained during the spring and summer surveys and which subpopulations of anchovy and sardine are observed during those surveys.
Rationale: The Panel was concerned that the summer estimates of biomass likely pertain to the Southern Subpopulation of Pacific sardine.

Response: Table 2 suggests that most of the summer surveys were not conducted in environmental conditions consistent with the presence of the Northern Subpopulation of Pacific sardine. The Southern California Bight is an area of overlap for the two subpopulations, and the summer data would not provide usable information on the northern subpopulation. Sampling could, however, be shifted northward according to the distribution of the northern subpopulation from the model of Demer and Zwolinski to focus minimum abundance estimates away from the region of sympatry in the summer months. Northern anchovy may occur in the southern California bight in summer, thus surveying in the Bight is still worthwhile to provide an estimate of minimum abundance therein, but estimation of Pacific sardine could not be used for management purposes until the latitude of distribution of the northern population is reached.

2.2 Conclusions

I). The sample sizes (Table 5 of the survey report) are generally far too small to allow demographic structure in the survey region to be estimated. This means that it is not feasible to compute biomass by age-class, especially for Pacific sardine and northern anchovy, which are target species for the survey. Additional sampling, perhaps in collaboration with the fishing industry, needs to be conducted if age-based estimates of biomass are desired. The level of additional sampling could be selected to achieve a desired level of precision.

II). The present limited age-composition data for Pacific sardine suggests that the animals in nearshore waters are not only "recruits" (age-0 and age-1 animals), but also older age classes, suggesting that the data from the aerial survey do not currently provide a true estimate of recruitment, for Pacific sardine at least.

III). The summer estimates of Pacific Sardine are not likely to provide information on the Northern Subpopulation of Pacific sardine alone, due to the presence of the southern subpopulation in all or part of the Southern California Bight at that time of year.

IV). The approach proposed for estimating variance is inadequate. Further work is needed to develop a variance estimator to more fully account for the various sources of uncertainty.

V). The point set data are limited and hard to collect in Southern California waters, but are a core source of information to validate the survey estimate of biomass. Noting the difficulty for collecting point sets, the Panel nevertheless recommends that additional point set data be collected (or an alternative approaches for groundtruthing survey estimates be applied, such as using the volume of schools combined with estimates of packing density).

3. Project 1: Development of a nearshore index of relative abundance based on density

3.1 Requests

E. Request: Plot (a) the point set data and (b) the ratio data vs. pilot-estimated tons (Table 2 of the survey report). Assess the variance structure of the ratio data to determine whether it matches the assumptions of the analyses or whether another analysis provides a better match. Update the analysis based on most appropriate approach for representing variance.

Rationale: The estimate of "r" (and its variance) depends on how the ratio data are weighted.

Response: An initial regression suggested that variance is independent of the pilot estimate of biomass. However, it was noticed that the observer biomass estimates rather than the boat-based biomass estimates were corrected, i.e. the observer estimates of school biomass were reduced to better match the actual portion of the school captured, but the relationship that should be explored is that of the observer estimates to the true size of the school, as measured by capture, so the capture amounts should be scaled up instead. See Request K.

F. Request: Consider and analyze potential stratifications (e.g., coastal vs. island) to reduce bias in the index/estimate when areas are missed during the survey.
Rationale: The Panel was interested in knowing whether densities differed spatially.
Response: Results indicate that the nearshore (<40m depth) densities around the islands are substantially smaller than those by the coast. No anchovy were seen in any of the surveys around the islands. This indicates that conducting the aerial survey around the islands is unlikely to yield useful results in summer. In spring, when the Northern Subpopulation of Pacific sardine is present, the island areas could be surveyed and treated as a separate stratum from the coastal areas.

G. Request: Describe how a recruitment index would be developed given (the lack of) compositional data?
Rationale: There is very little age-composition data for Pacific sardines and northern anchovy. However, young-of-year anchovy, as opposed to sardine, do aggregate in the nearshore, and a coast-wide nearshore aerial survey with directed net sampling may be able to provide an index.
Response: The proponents agree that it is currently infeasible to construct an index of recruitment.

H. Request: Provide more information on species/amounts for split schools to estimate the proportion of schools with mixed species
Rationale: The Panel wished to assess the extent to which it is necessary to estimate the precision associated with estimates of species composition by school.
Response: Table 3 lists the breakdown of the observations (sampling events that consist of multiple schools) by whether the observation is of a single species or mixed species. It also shows the number of schools within the single-species or mixed-species observations and the corresponding biomass that is from single-species or mixed-species observations. The Panel noted that interpretation of these data is complicated because of the way mixed species schools and biomass are defined. However, there is evidence that mixed species cannot be ignored, when computing measures of precision. Row 3 of the table shows a small number of observations leading to a large number of schools, contributing the dominant tonnage of mixed schools. This could indicate anomalous conditions affecting interpretation of these few observations.

I. Request: Exactly how are transects flown? Does the pilot always circle and descend to observe schools? Document the criteria used by the surveyor to identify species.
Rationale: The Panel wished to better understand the survey protocol.
Response: The technical team noted “Distinguishing CPS schools from the plane is based on structure, color, shine, and movement of schools. For sardine, they’re black-greenish, with a little twinkle. Schools can be either long and stringy or frequently boomerang-shaped (especially when moving) and also balls; often hard-edged. Anchovy are a generic brown color without much shine, and schools are dull-shaped (rounded) of any shape, often blotchy. Mackerel schools are shinier, and individual fish in the school can be detected (especially with binoculars). The big Pacific or blue mackerels can look silver, the smaller Spanish or jack mackerels brownish-green. The shapes of schools are similar to sardine. Large Pacific mackerel are obvious, but it’s hard to distinguish between jack and smaller Pacific mackerel. Also, mackerels break the surface more often than other species, and schools move much faster.”

J. Request: Explain where fish are if they are not seen by the surveyor on nearshore transects (to consider bias). For example, are they (a) too dispersed in nearshore waters shallower than 40 m to

be detected (b) to deep in nearshore waters to be detected, or (c) deeper than 40m (i.e., not in the nearshore zone, and therefore not in this survey)?
Rationale: The Panel wished to better understand the survey protocol because of the apparent relationship between the number of schools in a cluster and the percentage of schools identified as sardine versus anchovy. Species identification should not be density-dependent. As with the overcounting risk resulting from lateral fish movement, vertical fish movement can lead to undercounting bias for aerial estimates.
Response: Sampling error can be examined using repeated surveys and by repeating transects. The magnitude of bias due to dispersed schools and fish deeper than 10m could be consequential (negative bias), but there are currently no data to estimate the magnitude of this bias. The Panel did not consider fish deeper than 40m and offshore a major concern because the nearshore is a strip survey.

K. Request: Re-plot (a) the point set data and (b) the ratio data vs. pilot-estimated tons, but adjusting the boat-based landed tons rather than the pilot (observer) based biomass estimates.
Rationale: The data used for analysis should be adjusted landed tons to pilot total school biomass estimates, as the goal is to quantify the relationship between the survey-based estimates of entire school biomass and the estimates from point sets, accounting for proportion captured.
Response: The analysts adjusted to the data to reflect the recommendation of the Panel. The Panel noted that three of the point sets were estimated to have caught only half of the observed school, while all others were estimated to have caught at least 90% of the school. Since these three points represented extreme outliers either in the ratio or both in estimated biomass and size of the residual, the Panel ultimately recommended removing them from the data set, leaving 26 data points. Figures 1 and 2, which plot the remaining 26 data points, confirm the need to conduct a regression through the origin and also that assuming constant coefficient of variation (CV) is not supported by the data. Constant variance or a relationship between observer estimated biomass and variance that is intermediate between constant variance and constant CV should be used when estimating the total variance of the resultant biomass index or estimate. Appendix 3 outlines another method for estimating the variance of biomass from the surveys.

L. Request: Estimate the extent of between-island variance in density
Rationale: The amount of between-islands variance in density is needed to estimate the variance of density for unsampled areas.
Response: There was insufficient information from previous surveys to evaluate consistency in densities among the island areas.

3.2 Conclusions and recommendations

I). Add the plot of the point set data used to estimate "r" to the report to be presented to the Council.
II). Conduct replicate transects and surveys to allow estimation of variance for density.
III). Conduct more sampling of islands if there is interest in extrapolating observed island densities to unsurveyed islands.
IV). The data should be stratified by island vs coast if they are to be used to extrapolate to unsurveyed areas.
V). The surveyor bias should be based on a regression through the origin with either a constant variance assumption, or variance proportional to observer estimated size, rather than the square of observer estimated size. Use the original observer estimates of school biomass and corrected point

sets for analysis of observer bias and variance, and remove the data points where only half of the school was estimated to be caught in the point set.
VI). It is currently infeasible to create an index of recruitment using the SCCPSS data.
VII). The effects of error estimating species biomass in mixed schools could be non-trivial.

4. Project 2: Development of an inshore correction factor for the acoustic-trawl method (ATM) survey to account for nearshore areas not surveyed by ships due to operational constraint

M. Request: Provide synoptic, transect-specific acoustic data to compare with the aerial data.
Rationale: There is considerable variation among transects and the overall variance of any correction factor depends on the variance of the ATM-based estimates of biomass.
Response: Dr. Juan Zwolinski (SWFSC) provided acoustic data for transects that overlap with the aerial survey. However, direct comparisons are difficult to make because the aerial observations occur in the upper 10 m while this represents a "dead zone" with no observations for the acoustic survey. Plots of ATM density and aerial survey biomass for the transects surveyed during 2016 also confirmed that the variation is very high.

5. Comments by Advisory Subpanel and Management Team Representatives
5.1 Comments by the Advisory Subpanel Representative
The CPSAS representative is thankful to the CDFW for their perseverance, dedication of substantial resources and staff time over the past five years to develop a scientific method to quantify the abundance of sardine, anchovy and potentially other CPS in the nearshore area inshore of NOAA CPS surveys.

CPSAS members have repeatedly commented that a substantial volume of fish is missed using current survey methods. We are encouraged that this omission is now acknowledged as a priority research and data need.

The SCCPSS modified the methodology approved for the Northwest Sardine Aerial Survey in an effort to recreate the spotter pilot survey, once used as an index of abundance in sardine stock assessments in California. The SCCPSS expanded its scope to include anchovy in 2013 because both resources are important to California's wetfish industry. Currently, NOAA survey transects do not extend into nearshore waters, 1-2 miles from the mainland and Channel Islands, where the majority of fishing takes place.

One issue identified during this review was that the California CPS fisheries typically take place at night unlike the sardine fishery in the Northwest, yet the aerial survey is conducted in daylight. CPS do surface during daylight in California. Experienced spotter pilots, including the spotter who serves as an observer in the CDFW aerial survey, know the conditions when fish are likely to surface. It will be important to account for the fish that are present, but not seen in aerial surveys. This requires flexibility to fly when fish are likely to be "up".

Species composition was another issue discussed during the review: how to validate the spotter pilot's estimates of composition in mixed schools as well as estimated tonnage. CDFW aerial surveys have found a high degree of accuracy in spotter observations of species composition and estimated tonnage in individual schools. Quantifying tonnage of schools in aerial photographs is based on point sets conducted in 2010 industry-sponsored surveys. However, in California fish behaviour is different from that in the Northwest and point sets capturing 100% of schools were very difficult to achieve, so other methods to quantify school volume are needed.

Panel members offered helpful recommendations to improve the CDFW aerial survey method to allow it to be used in future stock assessments. One recommendation was the need to increase survey sample size. Live bait fishermen are willing to assist in capturing a portion of schools identified by the spotter pilot in 2017. Another method suggested was photographing screen shots of the sonar and fathometer of the capture vessel to document school depth and density.

The CWPA representative, in public comment, described another related cooperative survey now in the planning stages for summer 2018, when the SWFSC plans to utilize a skiff with an acoustic array to survey the inshore area now missed in NOAA surveys. The survey plan for this "proof of concept" includes an aerial component, with transects flown by the spotter pilot. He will photograph schools, and an Exempted Fishing Permit will be requested that will enable purse seine fishermen to capture schools observed in the backscatter. Biological and species composition sampling will be conducted onboard the purse seiner, and the processor receiving the fish will also fully sort the loads, validating the species composition of the sets.

The CPSAS also thanks the SWFSC for recognizing the problems with current surveys as well as helping to provide funding for cooperative surveys that will hopefully improve the accuracy of future stock assessments.

The CPSAS representative is encouraged that progress is being made to develop a survey methodology for the nearshore, an area where the majority of the fishery occurs in California.

5.2 Comments by the Management Team Representative

The CPSMT representative commends the proponents for the initiative in undertaking this effort and the substantial amount of work by CDFW to address the need to estimate nearshore anchovy and sardine biomass to better inform management of these fish. The current NOAA ship cannot access nearshore areas where CPS stocks are known to reside and the majority of California commercial fishing occurs, and thus the ATM surveys may produce negatively biased estimates. In periods of declining or lower biomass particularly, this can raise concerns as to whether fishing exploitation exceeds appropriate management limits, if based solely on offshore surveys. Conversely, by not accounting for what could be a substantial biomass, the relative harvest level could be overestimated.

This review identified significant logistical challenges with both projects presented, but suggested that of the two, Project 1 shows more promise, and could produce an estimate of biomass if a variance estimation procedure is endorsed and other deficiencies are addressed. For sardine, review of the variance estimator could be accomplished during the next full sardine STAR Panel scheduled for 2019/20. Incorporating a variance estimator for anchovy will depend on a review process that does not yet exist because stocks categorized in the CPS Fishery Management Plan as monitored by definition are not regularly assessed and are not subject to annual management. Full utility of a nearshore biomass estimate for anchovy also will only be achieved if the ATM survey is endorsed for estimating anchovy biomass in offshore waters.

Given limited agency resources, it seems preferable to direct survey efforts to most fully achieve Project 1 and resolve the deficiencies noted by the Panel. More sampling is needed to address the lack of necessary biological data from the survey to validate species identification and collect life history information. The collection of age data in particular is needed for sardine for an age-structured assessment model. Anchovy age data would be useful in the event a model approach is pursued for assessing anchovy biomass. These issues are all described in this review panel report.

There also is the issue of how to resolve lack of coast-wide coverage, as Project 1 is limited to surveying areas in the Southern California Bight. This leaves unknown the amount of CSNA biomass in nearshore areas to the north of the Bight. If the aerial survey methodology is approved for use in the Bight, expanding this effort north should be considered.

Finally, as noted above, presently the next opportunity to evaluate the aerial survey methodology for sardine will be at the sardine STAR Panel in 2019/20. In the meantime, the proponents will be investing a significant amount of time and money to conduct the survey. The Management Team representative recommends a review or similar evaluation that could provide them feedback and further guidance in the interim such that there would be an opportunity to refine survey methodology or analyses. Proponents of future methodologies would benefit from a pre-review, perhaps by the SSC or SSC CPS subcommittee, to address some concerns prior to investing significant time and resources before a formal methodology review.

6. Summary of Conclusions and General Recommendations

6.1 Management use

The Panel identified various potential uses of the data collected from the nearshore survey

1. An index of recruitment.
2. A (negatively-biased) estimate of biomass based on the surveyed areas only, which would be added to the ATM estimate of biomass.
3. An estimate based on the surveyed areas plus an estimate for the unsurveyed nearshore areas in the Southern California Bight based on extrapolating densities to unsurveyed areas.
4. An estimate based on the surveyed areas plus an estimate for the unsurveyed nearshore areas off the California coast based on extrapolating densities to unsurveyed areas.
5. An estimate based on the surveyed areas plus an estimate for the unsurveyed nearshore areas off the entire west coast (but based on additional sampling north of the current survey area).

Table 4 lists the research needs (short- and long-term) for each management use. The main Panel conclusions are:

- Project 1 is closest to being ready to provide information for use in stock assessments for Pacific sardine (2019-20 or earlier) or northern anchovy. In particular, a negatively biased estimate of biomass can be obtained from the estimates of biomass from surveyed transects. However, it will be necessary to develop and apply a method for estimating the variance of the biomass inshore of the ATM survey area. The estimates of biomass from surveyed transects can be extrapolated to unsurveyed areas, but this will require additional sampling to ensure that the extent of between-area differences in density can be quantified to inform proper stratification of expansions and to allow variance to estimated.

- The SCCPSS cannot at present be used to develop an index of recruitment for Pacific sardine or northern anchovy, due to the lack of sufficient age composition data for the observed biomass.
- Project 2 is unlikely to be successful given the aerial survey and ATM survey are sampling different parts of the water column, and there is high sampling error.

The Panel recommends that another methodology review be undertaken if biomass is estimated by extrapolating into unsurveyed areas (i.e. by assuming the density in the surveyed areas applies to the unsurveyed areas) or if the survey is expanded north of the current survey area (unless the survey is used to provide a minimum estimate of biomass by basing the estimate of biomass only on areas surveyed, in which case a review by a STAR panel would be adequate rather than a full methodology review).

6.2 Variance estimation

The Panel notes that no adequate estimates of variance exist. Table 5 lists various components of variance identified for Project 1 and the data needed to allow quantification of uncertainty. It will be necessary to develop and implement a variance estimation method before estimates from Project 1 could be used for management. Review of a variance estimation method could be accomplished during a STAR Panel.

6.3 General recommendations

I). Consideration should be given to use of relevant technical developments for remote sensing of fish schools using satellites and drones. For example, Sentinel 2 satellites are now providing (at no cost) multi-spectral images at 10m resolution with five day repeat intervals, suggesting that it should now be possible to rapidly scan large areas for apparent schools. A drone-mounted camera could give coverage of a relatively small coastal area, showing how school visibility changes in repeat observations.

II). Undercounting bias, due to depth distribution of schools below the visible range, could be estimated from school metrics (i.e. school depth, thickness, general shape, etc.) derived from sonars on fishing vessels assisting with the surveys. The sampling effort required to produce a robust estimate of bias would depend on the variability of vertical depth distribution within a defined survey period.

III). Given the effort and difficulty of obtaining point sets to calibrate aerial biomass estimates, especially for larger schools, an alternative might be estimation of packing density. Literature- or observation-based fish spacing is generally length-dependent and can be used, given fish size, school thickness, and surface area, to estimate school biomass.

IV). Acoustic versus aerial surveys are not comparable as the data collection, speed, transect width, transect depth, sources of bias, and type of observational data are completely different. While a stratified survey design is the preferred survey design for acoustics, an adaptive survey design with clearly defined strata or grids might be better for aerial surveys. What is not optimal is forcing an aerial survey program to acoustic survey protocols.

V). It is critical to comprehensively document criteria used to decide when to survey and how experts distinguish species to properly extrapolate data to unsurveyed areas as well as deriving the appropriate variance estimates of biomass and density estimates. Although the sea state and weather condition criteria were defined for the method reviewed here as well as species-specific school characteristics, other expert knowledge used to predict when surface schools might be visible were not documented. This expert knowledge transforms the survey design to adaptive and has ramifications on estimates of variance for abundance indices.

Table 1. Summary of the sources of uncertainty in estimating biomass of CPS using aerial observations.

Source of uncertainty or bias	Direction	Ways of Addressing the Issue
Species misidentification		
Type 1: Target species misidentification	Under- or overestimation	Boat sampling; plane circling
Type 2a: Other spp. misidentified as target species	Overestimate	Boat sampling; plane circling
Type 2b: Other features misidentified as target species	Overestimate	Plane circling; avoid cloudy and poor weather conditions
Density-dependent misidentification (a nonlinearity)	Hyperstability?	N/A (nearshore survey)
Surveyor bias (allocation of CPS biomass to species)	Under- or overestimation	Comparative flight observation studies
School detection		
Schools too deep	Underestimate	Nearshore acoustic studies
Schools lost in glare	Underestimate	Plane circling; flight direction
Schools too diffuse (hypothetical)	Unknown	Not typical fish behavior; daytime survey
Marginal cloud cover, reduced visibility	Underestimate	Survey conducted under optimal conditions
Sea state	Underestimate	Survey conducted under optimal conditions
Turbidity reducing detection depth	Underestimate	Survey conducted under optimal conditions
Biomass estimation (total CPS)		
Surveyor bias	Under- or overestimation	Comparative flight observation studies

Table 2. Relationship between the surveys of nearshore waters and sardine potential habitat identified using the habitat model developed by Zwolinski and Demer. Survey dates were compared with corresponding habitat model indications of favorable sardine habitat.

Year	Season	Dates	Sardine Potential Habitat
2012	Summer	7/30 - 8/17	Yes (partial)
2013	Spring	4/22 - 5/21	Yes
	Summer	8/1 - 10/4	Yes (partial)
2014	Spring	5/13 - 6/20	Yes (partial)
	Summer 1	8/4 - 8/18	Yes (partial)
	Summer 2	8/25 - 8/26	No
2015	Spring	NO SURVEY	
	Summer 1	8/7 - 8/29	No
	Summer 2	10/1 - 10/6	No
2016	Spring 1	4/16 - 5/2	Yes (partial)
	Spring 2	5/23 - 6/23	Yes (partial)
	Summer	8/11 - 9/6	No
	Overflight	9/7 - 9/15	Yes (partial)
2017	Overflight	3/24 - 3/30	Yes

Year	Season	Dates	Sardine Potential Habitat
2012	Summer	7/30 - 8/17	Yes (partial)
2013	Spring	4/22 - 5/21	Yes
	Summer	8/1 - 10/4	Yes (partial)
2014	Spring	5/13 - 6/20	Yes (partial)
	Summer 1	8/4 - 8/18	Yes (partial)
	Summer 2	8/25 - 8/26	No
2015	Spring	NO SURVEY	
	Summer 1	8/7 - 8/29	No
	Summer 2	10/1 - 10/6	No
2016	Spring 1	4/16 - 5/2	Yes (partial)
	Spring 2	5/23 - 6/23	Yes (partial)
	Summer	8/11 - 9/6	No
	Overflight	9/7 - 9/15	Yes (partial)
2017	Overflight	3/24 - 3/30	Yes

Table 3. Breakdown of the ‘observations’ sampled during 2012-16 including pure samples (S, A, PM, and JM) and mixed schools.

Observations	
S	226
A	44
AS	8
SP	9
P	9
J	1
U	1
AU	1
SUA	1
Single	281
Mixed	19

Schools	
S	1520.5
A	550
AS	593
SP	64.5
P	16
J	1
U	2
AU	1
SUA	3
Single	2089.5
Mixed	661.5

Tons	
S	30976.1
A	11418
AS	21987.5
SP	1518.1
P	507.5
J	15
U	10
AU	25
SUA	21.5
Single	42926.6
Mixed	23552.1

Abbreviations for first column:

S – sardine
A – anchovy
AS – combined anchovy-sardine
SP – combined sardine-Pacific mackerel
P – Pacific mackerel
J – jack mackerel
U – unidentified mackerel
AU – combined anchovy – unidentified mackerel
SUA – combined sardine-unidentified mackerel-anchovy

Table 4. Summary of the five management uses and the research (short-term and long-term) needed prior to such use.

Management Use	Status	Short term research/activity	Long term research/activity
1. Index of recruitment	No	Not feasible in the short-term	Requires collection of age-data; calibration of any index to a measure of recruitment (e.g., YOY series along entire coast)
2. Biomass from survey transects only			
Project 1	Yes (but needs variance)	Calculate variance estimate (may require replicate sampling)	Additional validation of assumptions (point sets or equivalent, e.g., using fisher's estimates of school metrics from sonar.)
Project 2	No	Not feasible in the short-term	Not feasible in the longer-term
3. Biomass estimated for the entire southern California Bight (by extrapolation)			
Project 1	No	As 2, but also strata need to be defined and the variance of extrapolation estimated	As for Project 1 above (may have less bias, but higher variance)
Project 2	No	N/A	N/A
4. Biomass estimated for the entire California coast (by extrapolation)	No	Not recommended	
5. Biomass estimated for the entire stock distribution (through additional sampling)	No	Not feasible in the short-term	Expand survey effort and sampling Incorporate new technologies (e.g. high res satellite imaging and/or drones)

Table 5. Sources of variance, how each could be quantified, and whether the source is current quantified.

Sources of Variance	How calculated	Status
Within-transect error	Variance would be calculated from multiple (>2) replicates of coastal and island transects flown at a time interval that provides comparable estimates	Insufficient transects at present
Between-transect variance	Variance calculated from observation data among surveyed transects.	Insufficient transects at present
Rounding	Unknown effect on variance, would depend on whether biased high or low. Not expected for observers to avoid rounding, there are limitations to precision above a certain tonnage.	Not accounted for at present
Estimate of surveyor bias	If multiple surveyors used, would need to do comparative field studies to determine relative bias and precision. If point set data available can use those data as ground truthing.	2010 point set data are used to estimate surveyor bias and precision
Survey Condition bias	Information on survey conditions are not consistently noted. Surveys flown in generally similar conditions, suitable for visual surveys. Observations could be analyzed at different quantified conditions (estimated sea state, cover) to quantify this source.	Not accounted for at present

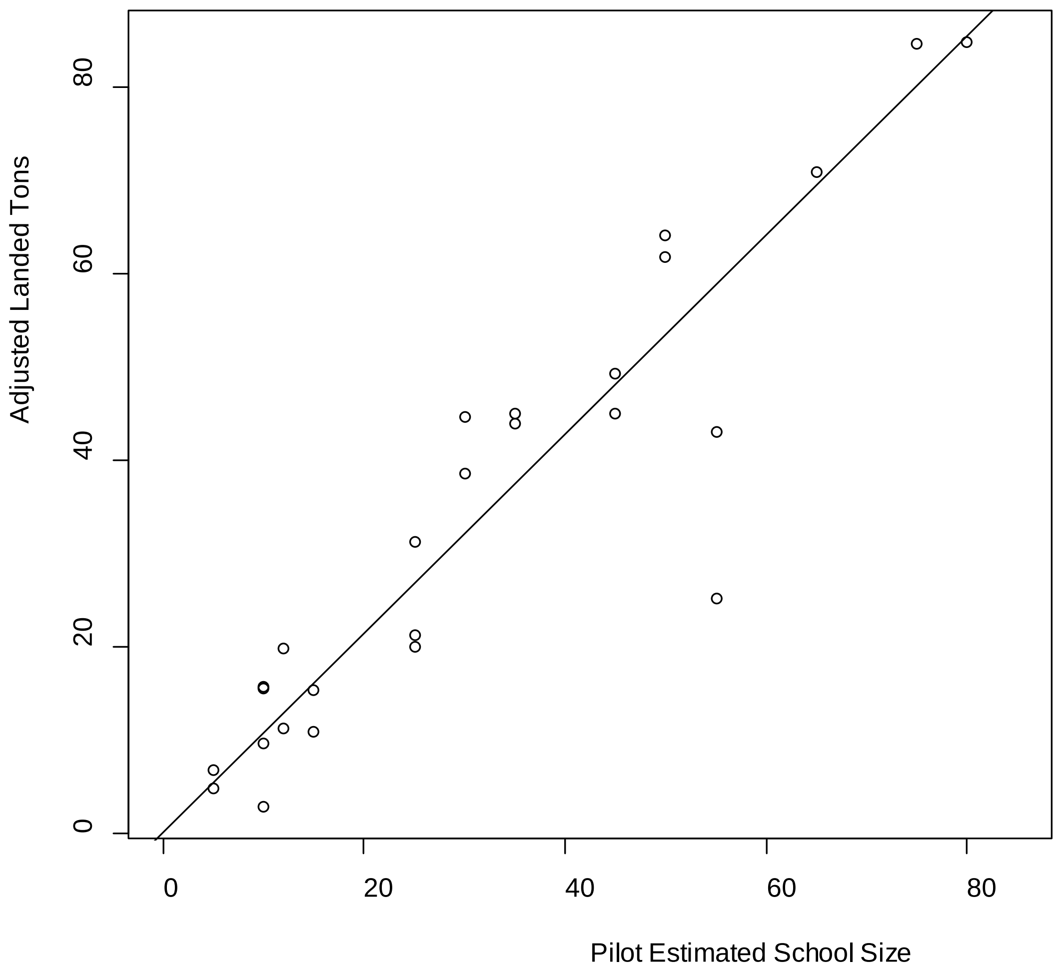

Figure 1. Adjusted landed tons versus the pilot-estimated school size.

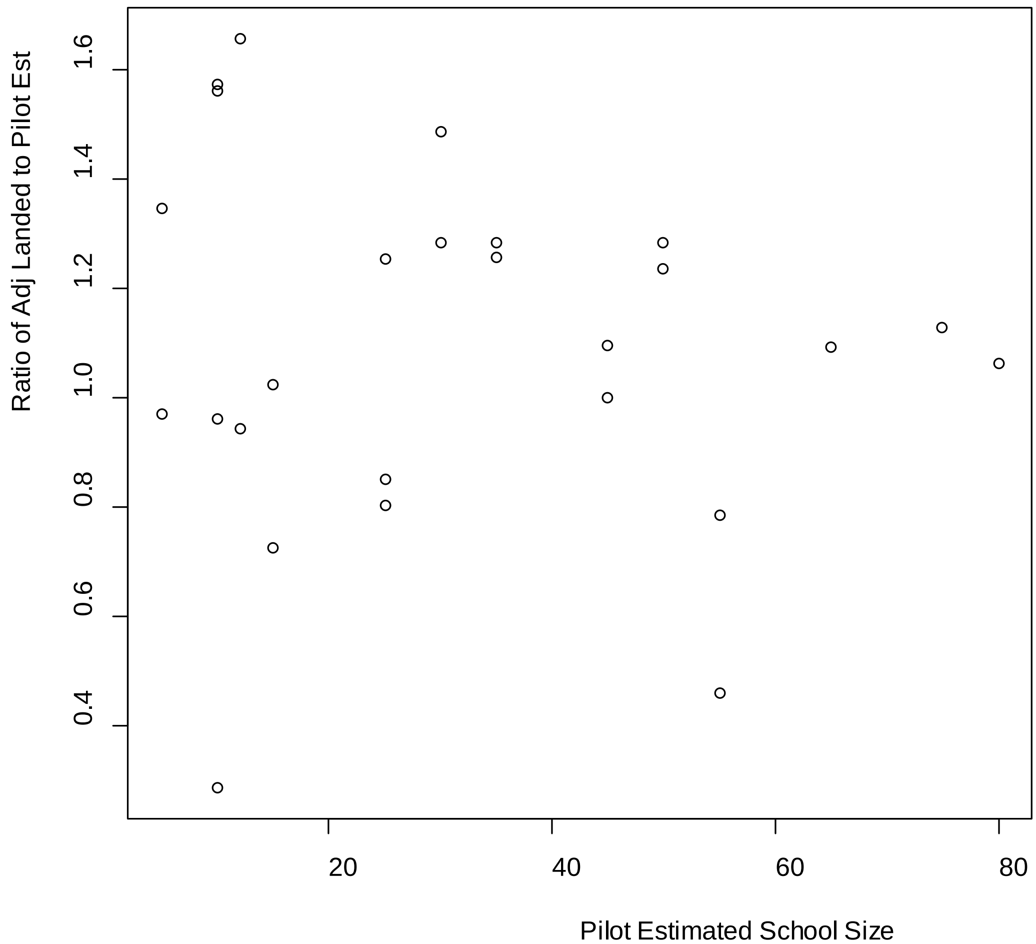

Figure 2. Ratio of adjusted landed tons to pilot estimates as a function of the pilot-estimated school size.

Appendix 1

Panel Members:
André Punt (Chair), Scientific and Statistical Committee (SSC), Univ. of Washington
Owen Hamel, SSC, Northwest Fisheries Science Center
Evelyn Brown, SSC, Lummi Natural Resources, LIBC
Jim Gower, Department of Fisheries Oceans, Canada (Retired)

Pacific Fishery Management Council (Council) Representatives:
Kerry Griffin, Council Staff
Steve Crooke, CPSAS Advisor to the Panel
Lorna Wargo, CPSMT Advisor to the Panel

CDFW Aerial Survey Technical Team:
Kirk Lynn, California Department of Fish and Wildlife
Dan Averbuj, California Department of Fish and Wildlife
Dianna Porzio, California Department of Fish and Wildlife
Trung Nguyen, California Department of Fish and Wildlife

Other Attendees
Dale Sweetnam, SWFSC
Emmanis Dorval, SWFSC
Chelsea Protasio, CPSMT/CDFW
Paul Crone, SWFSC
Erin Kincaid, Oceana
Juan Zwolinski, SWFSC
Jason Dunn, Everingham Bait Bros
Matt Everingham, Everingham Bait Bros
Kevin Piner, Esq., SWFSC
John Budrick, CDFW
Briana Brady, CDFW
Diane Pleschner-Steele, CWPA
David Demer, SWFSC
Uwe Send, Univ. of San Diego
Noelle Bowlin, SWFSC
Kimberli Boone, CDFW

CDFW – California Department of Fish and Wildlife
CPSAS - Coastal Pelagic Species Advisory Subpanel
CPSMT - Coastal Pelagic Species Management Team
CWPA – California Wetfish Producers Association
SSC - Scientific and Statistical Committee (of the Pacific Fishery Management Council)
SWFSC - Southwest Fisheries Science Center (National Oceanic and Atmospheric Administration)

Appendix 2
Outline of a procedure for estimating biomass and its variance

The estimate of biomass, $\hat{B}$, can be defined as the sum over strata of the stratum biomass, i.e.:

$$\hat{B} = r\sum_{s} D_i \, A_i \tag{1}$$

where D_i is the density in stratum *i*, A_i is the area of stratum *i* (surveyed and unsurveyed areas), and *r* is the factor to account for error in estimates of total biomass by surveyors.

The estimate of density is the sum over transects of the biomass recorded by the surveyor, accounting for the proportion that is the species of interest divided by the transect length, i.e.:

$$D_i = \sum_{t} T_{t,i} \,/\, A_{t,i} \; p_{t,i} \tag{2}$$

where $T_{t,i}$ is the total CPS biomass on transect *t* of stratum *i*, and $p_{t,i}$ is the proportion of the species of interest for transect *t* of stratum *i*.

Each of $T_{t,i}$, $p_{t,i}$, and *r* are subject to estimation error that needs to be quantified (or the error associated with D_i estimated directly). Methods for estimating the variance of D_i include conducting replicate surveys while the uncertainty associated with $T_{t,i}$ could be estimated using transects and that associated with $p_{t,i}$ by comparing species proportions from the surveyor with those from independent boat-based sampling.

Appendix 3
Calculation of variance in estimated biomass from aerial observations.

(A) The variance analysis used by the aerial survey analysts for the point sets suggests that more small schools (or observations) results in a more precise overall biomass index (without expansion outside of the observed area) than fewer large schools (or observations) in particular the variance structure assumed in calculating total variance is:

$$Var = V \sum_{i=1}^{N} C_i^2$$

This is based upon the idea that the CV for estimating the size of individual schools (or observations) is constant. The CV for the overall biomass index is then:

$$CV = \frac{\sqrt{V \sum_{i=1}^{N} C_i^2}}{B}$$

So that more small schools results in a **smaller** variance and CV than a few large schools given the same total biomass.

(B) However, the point set data indicate that the estimation variance itself may be closer to constant and independent of the size of the school. If we assume that that is the case, we can calculate the variance about the line, and then the total variance for an overall biomass index is simply a function of the number of schools (or observations) N.

$$Var = NV$$

with the CV of the biomass index being:

$$CV = \frac{\sqrt{NV}}{B}$$

So that more schools results in a **larger** variance and CV than a few schools given the same total biomass.

(A) and (B) are in some sense opposite assumptions. The constant variance assumption of (B) may be closer to what the data says, but there really isn't enough data to be secure in that result, and with observations rather than schools, this may be less true. Therefore, an intermediate approach may be preferred.

(C) An intermediate assumption would be that the total variance around the regression line is **independent** of the number of observations or schools:

$$Var = v \sum_{i=1}^{N} C_i = vB$$

The CV for the biomass index around the line is then:

$$CV = \frac{\sqrt{vB}}{B} = \sqrt{\frac{v}{B}}$$

v is calculated from the point set data (as displayed in the report) in this case by first conducting a regression assuming that the variance has this form, and then calculating the total variance of the data about the line and dividing by the sum of the pilot estimated biomass.

A regression analysis in R, weighting the data* by the inverse of the pilot estimated biomass, found a correction factor of 1.0696 and a *v* of 2.6321.

Note, however, that when using this as a basis for an expanded biomass estimate (for example to add to the ATM estimate of abundance), one has to account for the uncertainty in the correction factor itself as well. The SE of the correction factor when calculated in this way is 0.0540, so the estimated biomass and CV for the total biomass estimate are:

$$Estimate\ as\ basis\ for\ expansion\ to\ total\ biomass\ estimate = rB$$

$$CV = \sqrt{\frac{v}{B}} + \frac{SE}{r} = \sqrt{\frac{2.6321}{B}} + 0.0540$$

This can be combined with the uncertainties associated with expansion.

When using as a time series of indices and not as the basis for a biomass estimate, the uncertainty in the correction factor can be omitted, since the scale of the values does not matter but only the relative values. In that case, each index and CV are simply:

$$Index = rB$$

$$CV = \sqrt{\frac{v}{B}} = \sqrt{\frac{2.6321}{B}}$$

Note that the correction factor (1.0696) is the same as would be found using Cochran's approach. However the variance for the slope by that calculation is 0.00330, providing a somewhat larger standard error (0.0575) than the one I found using the weighted regression approach (0.0540).

Since it was not clear in the other document:

$$Cochran's\ CV = \sqrt{\frac{n}{n-1}}\sqrt{\left(\frac{x_i(r_i - r_0)}{\sum_{i=1}^{n} x_i}\right)^2}$$

* The data referred to here are the pilot estimated biomass and the adjusted point set data for which 90% or more of the school was estimated to have been captured in the point set, i.e. the 26 data points which were suggested to be used by the review panel.