CWPA Methods Description

Prepared for

Pacific Fisheries Management Council

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Title:

CWPA Methods Review Proposal: aerial photographic surveys with lidar and hydroacoustic components for calibration.

Names of Proposers:

California Wetfish Producers Association
Diane Pleschner-Steele
Doyle Hanan
James Churnside
David Demer
Don LeRoi

How proposed methodology will improve assessment and management for CPS species.

Current aerial sardine assessment techniques for estimation of biomass photographed are dependent on capture of sardine schools that have been photographed immediately prior to capture by purse seine (termed a point set in this survey). School surface areas (m^2) are regressed against the landing weights (biomass in mt) for all schools captured to develop an expected relationship. Only those schools captured and meeting stringent criteria (>90% of school captured, series of pictures that delineate or identify the school captured) are used in the analysis. During the 2009 and 2010 aerial surveys, a total of 69 "acceptable" purse seine sets were made, but they represented a very small portion (3%) of the total schools photographed and measured (2,523). For the California portion of the two surveys, only 17 of 81 sets were qualified for use in the regression and in Oregon/Washington 52 of 70 were used. Because of these issues as well as others, this point set method of determining school density is difficult to accomplish, varies by location, and is expensive.

We are proposing the use of additional methods to enhance measurements of school density and to calibrate these techniques for use with aerial surveys. The methods we propose (lidar and hydroacoustics) have been tested in numerous studies and have demonstrated their effectiveness for providing quantifiable results. There are advantages and disadvantages to each method, but either method, or both, should yield results superior to the point set method alone. Lidar provides a third dimension (actual thickness of schools) and hydroacoustics also provides that third dimension, which is missing in the aerial survey utilizing surface photogrammetry alone (hydroacoustic sound return gives a 3-D view/analysis of schools). Lidar can be run simultaneously from the same airplane that conducts the photographic survey; therefore all schools sampled by lidar will also have corresponding photographs. Schools found near the ocean surface sampled by hydroacoustics can also be photographed.

Better estimates of density for large numbers of schools during photographic surveys will be very useful for improving sardine assessment and management. Sampling by airplane, or multiple planes, can cover large areas of the sardine habitat relatively quickly, but weather, clouds and fog can seriously hamper aerial surveys, Ships and hydroacoustics can cover areas further offshore and can sample when airplanes are restricted by weather.

Airplanes are less expensive for the area surveyed and much faster; therefore, we are proposing a coordinated survey utilizing all three techniques.

We are also proposing that this survey be conducted in the fall (October-November) when the marine layer, low clouds, and fog, that greatly restricted the aerial survey for the past two years in California during the summer, are less prevalent. Fall is also a season when the seas tend to be calmer and clearer, thus allowing better photographic conditions. This time period is also a season when sardines have returned to California from the PNW, and there will be a greater chance of sampling the stock with reduced variability using the combined techniques discussed above. When combined with the summer aerial survey, hydroacoustics, and DEPM, a fall survey should contribute significantly to our understanding of Pacific sardine abundance, migratory patterns and trends. Based on result from this pilot project we will be submitting an EFP application to be submitted in early January, as outlined in the Recommendations for Research Set Asides in 2011.

Outline of methods (field and analytical).

We are proposing a survey method that utilizes aerial survey methodology that has already been approved by the Council. To this methodology we will add simultaneous lidar use in the transect airplanes. We also plan point sets on targeted sardine schools to calibrate with CalCOFI and SWFSC shipboard hydroacoustics, which will augment and enhance the aerial survey by comparison with those hydroacoustic surveys.

LIDAR FIELD LOGISTICS AND ANALYSIS:

Use of Lidar Resource

We will be incorporating and following closely assessment methods developed by Dr. Jim Churnside for comparison of lidar to photogrammetric techniques (high definition video[1]) and acoustics (BioSonics 208 kHz splitbeam transducer[2]). In the video study, Dr. Churnside counted fish schools for analysis, but we intend to measure surface area and density of fish schools for comparison to the photographs we will collect, adopting and expanding his survey methods to correspond with our existing STAR panel approved photographic analysis. We expect to use lidar gear, techniques, and settings very similar to (Churnside, et al., 2001): "frequency-doubled, Q-switched Nd:YAG laser that produced 120 mJ of green (532 nm), linearly polarized light in a 12 nsec pulse at a rate of

[1] Churnside, J. H., A. F Sharov, R. Richter. (Submitted for publication). Aerial Surveys of Fish in estuaries: A Case Study in Chesapeake Bay. 27 pages.

[2] Churnside, J. H., Demer, D. A., and Mahmoudi, B. 2003. A comparison of lidar and echosounder measurements of fish schools in the Gulf of Mexico. ICES Journal of Marine Science, 60:147–154.

30 pulses per second. The beam from the laser will be diverged, using a lens in front of the laser, to be eye-safe at the surface (laser spot diameter of approximately 8 m) from the flight altitude of 600 m. The diverged beam will be directed by a pair of mirrors to be parallel to the axes of the two receiver telescopes, which collected the two orthogonal polarizations of the backscattered light. The first receiver channel uses a 7 cm diameter refracting telescope with a polarizer aligned with the laser polarization to measure the co-polarized lidar return. The other channel uses a 17 cm diameter telescope with a polarizer oriented perpendicular to the laser polarization to measure the cross-polarized lidar return. Each of the telescopes collects light onto an interference filter to reject background light. An aperture at the focus of the primary lens also limits background light by limiting the field of view of the telescope to match the divergence of the transmitted laser beam. A photomultiplier behind each telescope converts the lidar return into an electronic signal, which is passed through a logarithmic amplifier to improve the dynamic range. This signal is digitized at a rate of 109 samples per second during the return from each laser pulse. The computer records the digitized returns, along with the position and time from a GPS receiver, and displays the data to the operator. Sardine schools will be identified by visual examination of the photographs and lidar data and then lidar data will be plotted in grey scale. Return from water near the school will be estimated and subtracted from the sardine school returns to account for water scattering between fish. This return will also be used to estimate lidar attenuation and the signal will be corrected by multiplying with the inverse of attenuation. In addition, the penetration depth of lidar will be estimated as the depth at which the lidar signal reaches the same level as from background light in the absence of sardine schools. Length of each school along the flight track will be estimated from the number of lidar pulses across the school, the time between pulses, and the speed of the aircraft. The school area will then be estimated by assuming the measurement passes through the center of a circular school. Average distance between sea surface and maximum lidar return within schools is assumed to be a measure of school depth for calculating school volume."

The following steps will be applied to processing of the lidar data:

1. Identify fish schools by visual inspection of the data.

2. Measure the optical properties of the water near the schools. The important properties are the lidar attenuation, α, and the volume backscatter function, β_w. The lidar signal in homogenous water has the form

$$S_w = C\beta_w \exp(-2\alpha z), \qquad (1)$$

where C is the calibration constant of the lidar, S_w is the lidar signal near the school, and z is depth. A is obtained from a laboratory calibration and the other two parameters are found from the lidar signal at several depths using Eq. (1).

3. Calculate the corrected volume backscatter from the school according to the following equation

$$\beta_f = (CS - \beta_w)\exp(2\alpha z), \tag{2}$$

where β_f is the volume backscatter coefficient of fish within the school.

4. Estimate the density of fish within the school using the equation

$$N = \frac{\beta_f}{\sigma}, \tag{3}$$

where σ is the backscatter cross section of a single fish. The average backscatter cross section of a collection of 480 sardines was measured in a tank (Churnside et al., 1997), with the result

$$\sigma = (9.7 \pm 0.9) \times 10^{-3} A, \tag{4}$$

where A is the cross sectional area of a single fish as seen from above. The area is generally proportional to length squared, and a linear relationship between backscatter cross section and length squared is also used in fisheries hydroacoustics. For sardines, we expect the area to be about 0.1 times the length squared. If lidar to be used as an absolute measure of biomass, more work will be needed to refine the relationship between backscatter cross section and fish length.

5. Estimate the total number of fish in the school from the product of the number density and the total volume. School volume will be estimated in two different ways. The first will use the thickness of the school inferred from the lidar and the area from the camera images. The other will use the length of the school along the lidar track to estimate its area under the assumption of a circular school. This technique worked very well in estimating the area of menhaden schools in Chesapeake Bay (Churnside et al., 2010), but it is not clear yet how well it will work for sardines.

6. Perform a regression analysis comparing the lidar results with hydroacoustics, point sets, and images. This will involve binning of the data to account for time differences between observations. The spatial scale of that binning will be determined during processing, based on the scales of variability in the data.

References

Churnside, J. H., J. J. Wilson, and V. V. Tatarskii (1997) Lidar profiles of fish schools, Appl. Opt. **36**, 6011-6020.

Churnside, J. H., A. F. Sharov, and R. A. Richter (2010) Aerial surveys of fish in estuaries: a case study in Chesapeake Bay, ICES J. Mar. Sci. doi: 10.1093/icesjms/fsq138

HYDROACOUSTICS FIELD LOGISTICS AND ANALYSIS:

Methods

Aerial surveys are to be conducted for schools of sardine. The remote observations of near-surface fish schools will be used to estimate fish abundance. These estimates are to be validated by purse-seine capture of a number of schools. Here we propose to augment these measurements with active-hydroacoustic measurements made with a multi-frequency split-beam echosounder system (Simrad EK60), and a single-frequency multi-beam sonar (Kongsberg-Mesotech SM20/2000). After a fish school is spotted, and before it is netted, a vessel equipped with hydroacoustic instrumentation will drive around the school to hydroacoustically estimate the size and shape of the school; a subset of schools will be measured by driving over the school multiple times to hydroacoustically estimate the fish density. Schools measured by sonar will also be photographed and observed to evaluate fish avoidance behavior during these transects.

EK60 multi-frequency echosounder

Throughout the survey, volume backscattering strengths (S_v; dB re 1 m) and *in-situ* target strengths (*TS*; dB 1 m^2) will be measured continuously by four calibrated Simrad EK60 split-beam echosounders operating at frequencies of 38, 70, 120, and 200 kHz. The echosounders will be configured with Simrad ES38-12, ES70-7C, ES120-7C, and ES200-7C transducers. The four split-beam transducers will be pole mounted on the side of the ship's hull, and positioned approximately 2m beneath the water surface. Synchronized pulses of 1024 µs will be transmitted downward every 0.5 seconds, received with bandwidths of 0.8745, 1.6375, 2.3435, 2.7785, and 2.986 kHz, respectively, digitized to a range of 150 m, and stored in .raw-data format. Except for the EK60 sounders being used for these surveys, all other echo sounders and sonars operating at or near the survey frequencies will be secured.

SM20/SM2000 Multi-beam sonar

A Kongsberg-Mesotech SM2000 200 kHz multi-beam sonar (180 degree-head with a nominal 155 degree usable swath) and an SM20 processor will be used. The system forms 128 beams that insonify a 180 degree swath. The SM2000 has two transducers: a cylindrical array that can be used to both transmit and receive when operating in imaging mode; and a long stave that can be used as the transmitter, when operated in echosounding mode, with receiving on the cylindrical array. This survey will be conducted in echosounding mode only. The SM2000 sonar head will also be mounted on a pole, attached at an angle of 30 degrees off vertical at a depth of approximately 2 m below the mean water surface.

Triggering

One of the EK60s and the SM2000 both operate at 200 kHz. Therefore, the EK60s and the SM20 processor surface telemetry board (STB) will be triggered using a multiplexer unit. Triggering will be synchronous for all EK60s, and asynchronous (alternating) between the EK60s and the SM20 to prevent interference. That is, a trigger pulse will be sent to the EK60s every second; one-half second after the pulse is sent to the EK60s, a pulse will be sent to the SM20.

AERIAL SURVEY FIELD LOGISTICS AND ANALYSIS:

I. Aerial Transect Survey

Overall Aerial Survey Design

The 2010 California Aerial Sardine Survey design consists of 36 (?) aerial transects spanning the area from 15 miles north of CalCOFI line 86.7 in the north to 15 miles south of CalCOFI line 90 in the southern California Bight (Figures 1 and 2). These transects will extend on or parallel to the CalCOFI lines and run from shore to 75 miles offshore. Each 6-transect series will be conducted as a SET, and will make up one replicate. We intend to fly these transects during both day and night to determine optimum observation time for sardines. The survey will strive to complete three replicate SETS, or 18 transects in total, to the degree possible.

Location of Transects

Transects and corresponding shoreline positions are mapped in Figure 2. The transects start at shore and extend westward for 75 statute miles in length; they are spaced approximately 15 nautical miles (15 minutes) apart in latitude.

Aerial Resources Available

The airplane used for this survey will be equipped with a Canon EOS 1Ds camera with laptop control computer and Lidar equipment ((1) laser and beam-control optics, 2) receiver optics and detector, and 3) data collection and display computer))[3] to survey the transects. The camera will be mounted in an *Aerial Imaging Solutions* FMC mount system installed inside the fuselage and utilizing one of the downward ports (belly port). The Lidar will use a 2nd downward viewing port. Experimental photography of nighttime bioluminescence also will be attempted with a Nikon D700 camera and intensifier, which offers an extremely high ISO along with larger pixel size to reduce noise. It may be sensitive enough to capture usable images at a reasonable shutter speed (1/10th)

[3] Churnside, J. H., J. J. Wilson, and V. V. Tatarskii. 2001. Airborne lidar for fisheries applications. Opt. Eng. 40:406-414.

Use of Aerial Resources

The survey pilot will begin with the most northward transect, flying to the off shore end then move to the next transect and survey to shore. The pilot will repeat this pattern until each transect is surveyed. The pilot will repeat this patter three times thus will attempt to fly a total of 18 transect lines both day and night.

Hydroacoustic Resources Available

Drs. David Demer and Sam McClatchie, NMFS, SWFSC, will direct the hydroacoustic portion of this research project. We propose to augment these measurements with active-hydroacoustic measurements made with a multi-frequency split-beam echosounder system (Simrad EK60), and single-frequency multi-beam sonar (Kongsberg-Mesotech SM20/2000). After a fish school is spotted, and before it is netted, a vessel equipped with the hydroacoustic instrumentation will drive around the school to hydroacoustically estimate the size and shape of the school to hydroacoustically estimate the fish density.

Use of Hydroacoustic Resources

We propose to estimate a function which relates aerially-observed fish school area to fish biomass, including error bounds; and estimate the target strength of sardine (and perhaps other fish species) versus hydroacoustic frequency and fish length, including error bounds.

Conditions Acceptable for Aerial Surveying

At the beginning of each potential survey day, the survey pilot will confer with Dr. Doyle Hanan, Co-principal Investigator, and will jointly judge if conditions will permit safe and successful surveying that day. Considering local conditions, they will also jointly determine the optimal time of day for surveying the area slated for coverage that day. Factors will include sea condition, time of day for best sardine visibility, presence of cloud or fog cover, and other relevant criteria as determined by the survey pilot and Dr. Hanan.

Transect Sampling

Prior to beginning a survey flight, the Pre-Flight Survey Checklist will be completed. This will ensure that the camera system settings and Lidar equipment are fully operational for data collection. For example, it is important to have accurate GPS information in the log file. It is also crucial that the photograph number series is re-set to zero.

The decision of when to start a new SET of transects will be determined jointly by the pilot and the principal investigator. Transects will be flown at the nominal survey altitude of 1,500 – 2,000 ft if possible. If conditions require a lower altitude for acceptable ocean surface visibility, transects (or portions of transects) may be flown at a lower altitude, when necessary. Transects may be flown starting at either the east end or the west end.

A Transect Flight Log Form will be kept during the sampling of each transect for the purpose of documenting the observations of the pilot and/or onboard observers. Key notations will include observations of school species ID and documentation of any special conditions that could have an influence on interpreting photographs taken during transects.

It will be acceptable to skip portions of transects as conditions require (e.g. fog covering a small transect portion). The goal is to cover a full 6-transect SET in one day and two replicate SETS of transects in as few days as possible.

Data Transfer
Photographs and FMC camera log files will be downloaded and forwarded for analysis and archival as soon as practicable. Dr. Hanan will collect photographic data and provide to Zachary Hanan to analyze and archive, with supervision by Don LeRoi. Dr. Hanan will also coordinate collection of the Lidar data and provide to Dr. Churnside to archive and analyze.

II. Point Set Sampling

Location of Point Sets
Point sets are the actual capture of fish by purse seiners approved and permitted for this research. Each set by a purse seiner will be directed by the spotter pilot. Attempts will be made to conduct point sets over as wide an area as feasible; however, point sets may occur in any area covered by aerial transects that are not restricted to purse seine fishing and where sardine schools of the desired size are found.

Aerial Photography of Point Sets
Sardine schools to be captured for point sets will be first selected by the spotter pilot and photographed at the nominal survey altitude of 1,500 – 2,000 ft. Following selection, the spotter pilot will descend to a lower altitude to better photograph the approach of the seiner to the school and set the seiner for capture of the school. The camera system will be running during the whole point set thus allowing photographs before and during the vessels approach to the school for the point set capture. Each school selected by the spotter pilot and photographed for a potential point set will be logged on the spotter pilot’s Point Set Flight Log Form. The species identification of the selected school will be verified by the captain of the purse seine vessel conducting the point set and will be logged on the Fisherman’s Log Form. These records will be used to determine the rate of school mis-identification by the spotter pilot in the field and by analysts viewing photographs taken.

Vessel Point Set Capture
The purse seine vessel will encircle (wrap) and fully capture the school selected by the spotter pilot for the point set. Any schools not “fully” captured will not be considered a valid point set for analysis. If a school is judged to be “nearly completely” captured (i.e. over 90% captured), it will be noted as such and will be included for analysis. Both the spotter pilot and the purse seine captain will independently make note of the “percent captured” on their survey log forms for this purpose. Upon capture, sardine point sets

will be held in separate holds for separate weighing and biological sampling of each set after landing.

Biological Sampling

Biological samples of individual point sets will be collected at the landing docks or at the fish processing plants upon landing. Fish will be systematically taken at the start, middle, and end of a delivered set. The three samples will then be combined and a random subsample of fish will be taken. The sample size will be n = 50 fish for each point set haul.

Length, weight, maturity, and otoliths will be sampled for each point set haul and will be documented on the Biological Sampling Form. Sardine weights will be taken using an electronic scale accurate to 0.5 gm. Sardine lengths will be taken using a millimeter length strip attached to a measuring board. Standard length will be determined by measuring from sardine snout to the last vertebrae. Sardine maturity will be established by referencing maturity codes (female- 4 point scale, male- 3 point scale) supplied by Beverly Macewicz NMFS, SWFSC. Otolith samples will be collected from n = 25 fish selected at random from each n = 50 fish point set sample for future age reading analysis.

Hydroacoustic Sounding of School Height

School height will be measured for each point set. This may be obtained by using either the purse seine or other participating research vessels' hydroacoustic gear. The school height measurements to be recorded on the Fisherman's Log Form are: 1) depth in the water column of the top of the school, and 2) depth in the water column of the bottom of the school.

Number and Size of Point Sets

Point sets will be conducted for a range of school sizes (Table 1). Each day, the spotter pilot will operate with an updated list of remaining school sizes needed for analysis. The spotter pilot will use his experience to judge the biomass of sardine schools from the air, and will direct the purse seine vessel to capture schools of appropriate size. Following landing of the point sets at the dock, the actual school weights will be determined and the list of remaining school sizes needed from Table 1 will be updated accordingly for the next day of fishing. If schools are not available in the designated size range, point sets will be conducted on schools as close to the designated range as possible. Dr. Hanan will oversee the gathering of point set landing data and will update the list daily. The total landed weight of point sets sampled will not exceed **800 mt**. The number of point set samples needed for the Southern California pilot sardine aerial survey in 2010 (Table 1), were distributed to obtain adequate data points for the area-biomass regression in the region between 2,000 and 10,000 m^2 of school surface area (Figure 3).

Landing Reporting Requirements

Cumulative point set landings will be maintained and updated by Ms. Diane Pleschner-Steele or Dr. Hanan and will be reported daily to NMFS, as per the terms of the Exempted Fishing Permit. Also included in this daily report will be an estimate of the weight of all by-catch by species.

Other EFP Reporting Requirements
Ms. Pleschner-Steele or Dr. Hanan will be responsible for providing the other required reporting elements (as specified in the EFP permit) to NMFS. For example, a daily notice will be provided for enforcement giving 24 hour notice of vessels to be conducting point sets on any given day and will include vessel name, area to be fished, estimated departure time, estimated return time.

III. Calibration and Validation

Aerial Measurement Calibration
A series of photographs have been collected from both participating planes, depicting a feature of known size (e.g. a football field or tennis court) on the ground, from the altitudes of 1,000 ft, 1,500, and 2,000 ft. For each altitude series, an aerial pass was made to place the target onto the right, middle, and left portions of the photographic image.

Aerial Photographs and Sampling for Species Validation
A set of reference photographs will be compiled which will be taken at the nominal survey altitude of 1,500 – 2,000 ft for the purpose of species identification. The spotter pilot will find and photograph schooling fish other than sardine (e.g. mackerel, herring, smelt, anchovy, etc). For the actual schools photographed, a vessel at sea will collect a jig sample to document the species identification. This set of reference photographs will be used by the photograph analysts to learn how to discern between sardine and other species as they appear on the aerial transect photographs.

IV. Photograph Data Reduction and Analysis

Digital images will be analyzed by Zachary Hanan, under the supervision of Don LeRoi, to determine the number, size, and shape of sardine schools on each transect. Adobe *Photoshop Lightroom 3.0* software will be used to bring the sardine schools into clear resolution and measurements of sardine school size (m^2) and shape (circularity) will be made using Adobe *Photoshop CS5-Extended*. Transect width will be determined from the digital images using the basic photogrammetric relationship:

$$\frac{I}{F} = \frac{GCS}{A}$$

and solving for *GCS*:

$$GCS = \frac{I}{F}A$$

where I = Image width of the camera sensor (e.g. 36 mm), F = the focal length of the camera lens (e.g. 24mm), A = altitude, and GCS = "ground cover to the side" or width of the field of view of the digital image. Transect width will be obtained by taking the average of *GCS* for all images collected on the transect. Transect length will be obtained from the distance between start and stop endpoints using the GPS data logged by the data acquisition system.

V. Data Analysis

Total Biomass

Principal Investigator, Dr. Hanan, assisted by Tom Jagielo, will estimate total sardine biomass for the survey area with a 3 step process, and requiring 1) measurements of individual school surface area on sampled transects, 2) estimation of individual school biomass (from measured school surface area and estimated school density), and 3) transect sampling design theory for estimation of a population total. The calculations described below will be implemented using the R statistical programming language.

Individual school surface area (a_i) will be measured on the photo-documented transects using the measurement tool feature of *Adobe Photoshop*, and employed the photogrammetric relationships described above. Individual school density (d_i) will be specific to school size and will be determined from the empirical relationship between surface area and biomass obtained from Stage 2 (point set) sampling (described below). Individual school biomass (b_i) will be estimated as the product of school density and surface area ($b_i = d_i a_i$). The sum of individual school biomass (b_u) will then be determined for each transect (u). The mean sampled biomass for the study area ($\bar{b}$) will be computed as

$$\bar{b} = \sum_{u=1}^{n} b_u \ / n \ ,$$

where n = the number of transects sampled. Total biomass for the study area $(\hat{B})$ will be estimated using the unbiased estimator for a population total (Stehman and Salzer 2000),

$$\hat{B} = N\bar{b} \ ,$$

where N = the total number of transects that could possibly be sampled in the survey area without overlap. In 2011, we intend to fly three replicate sets of transects (SET A, SET B, and SET C) and thus three estimates of $\hat{B}$ will be calculated: $\hat{B}_A$, $\hat{B}_B$, and $\hat{B}_C$, respectively. The point estimate of total biomass for the study area ($\hat{B}_T$) will be obtained by averaging these three estimates of biomass.

Individual School Biomass

The biomass of individual schools observed on the transects (b_i) will be calculated using 1) measurements of school surface area, and 2) the relationship between school surface area and biomass, obtained from point sets. The three parameter Michaelis-Menten (MM) model assuming log-normal error will be used to describe the sardine surface area–density relationship

d_i = (yint * cc + asymp * a_i) / (cc + a_i)

where

d_i = school density (mt/m^2)
a_i = school area (m^2)
yint = y intercept
asymp = asymptote as x -> infinity
asymp/cc = slope at the origin .

As noted above, individual school biomass (b_i) will then be estimated as the product of school density and surface area ($b_i = d_i a_i$).

Total Biomass Coefficient of Variation (CV) for the 2010 PILOT Survey
The CV of the total biomass estimate will be obtained by employing a bootstrapping procedure implemented with the R statistical programming language (Appendix I). The intent of the procedure will be to propagate error from the point of school density estimation forward -- to the ultimate goal of total biomass estimation from the three replicate sets of transect data. The steps of the procedure are:

1) The MM model will be fit to the point set data.
2) A variance-covariance matrix will be derived for the MM model fit to the data, using the R library "MSBVAR" .
3) A matrix of simulated MM parameters will be derived from the MSBVAR output, using the R function "rmultnorm".
4) For n = 100,000 bootstraps:
   a. One realization of the MM parameters will be selected from the matrix of simulated parameters.
   b. The predicted MM curve will be calculated.
   c. Total biomass for the study area will be estimated for each of the three replicate transect sets.
   d. The three replicate estimates of total biomass will be sampled with replacement.
   e. The mean of the sampled replicates will be calculated, and stored as the bootstrap estimate of biomass.
5) The standard error (SE) will be calculated from the stored bootstrap estimates of biomass (4e).
6) CV will be calculated as CV = SE/$\hat{B}_T$.

Table 1. Size and Number of Point Sets needed during 2010 EFP survey for the Southern California Pilot Sardine Survey area. Total landed weight of point sets will not exceed 800 mt.

Surface Area (m2/set)	mt/set	Number of point sets	Total mt
100	3.8	3	11.4
500	10.6	4	42.4
1000	17	5	85
2000	26.5	6	159
4000	51.9	4	207.6
8000	70.5	3	211.5
10000	82.1	1	82.1
Total		26	799

Figure 1. Transects

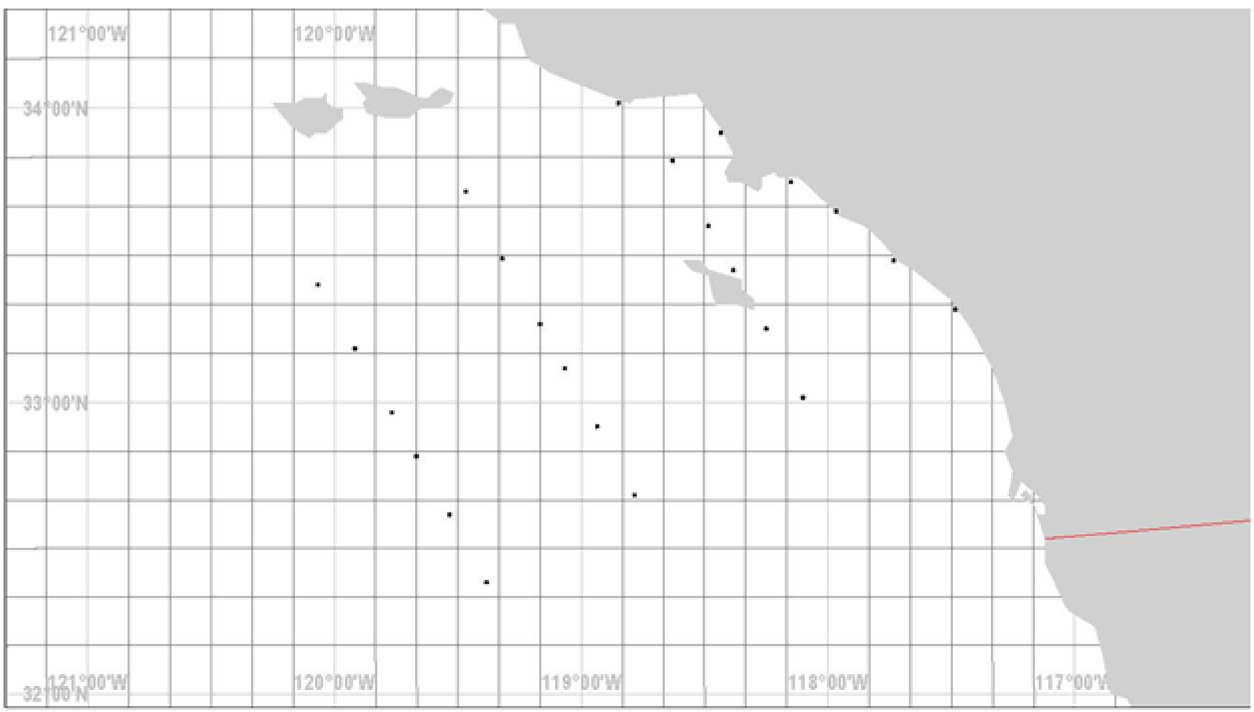

Figure 2. Relationship of surface area (m^2) (x axis) vs. density (y axis) determined from point sets sampled in 2008, 2009, and 2010 (From: West Coast Aerial Sardine Survey Sampling Results in 2010, Jagielo, et al, 2010).