Aerial Survey Methods for Pacific Sardine

Report of STAR Panel Meeting

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1) Overview

This review was specifically of an aerial survey being proposed by the sardine fishing industry, and not of aerial methods in general, nor of any specific alternative approach.

The review of a new aerial survey method as it could be applied to Pacific Sardine was conducted by a Stock Assessment Review Panel (Panel) which met at the Southwest Fisheries Science Center, La Jolla, CA, from May 4-8, 2009. The membership of the Panel was broader than is normal for assessment reviews to include expertise on survey methodology and design as well stock assessment. Material documenting the methodology used for west coast aerial surveys was provided to the Panel in advance of the meeting. A file server was provided at the meeting room to provide common access to all presentation material.

The Panel reviewed the available material in terms of the following key questions:

- The design of sampling scheme used to collect the basic data used in the proposed aerial survey.
- The analytical treatment of the data in terms of the ability to estimate (A) absolute abundance and (B) trends in abundance.
- Consequences of the implementation of survey protocols.
- Evaluation of precision and bias.
- Use of aerial survey abundance estimates in stock assessments for Pacific Sardine.

Only minor requests were made of the Technical Team, for additional information and description, and for minor clarifications. These requests were not recorded formally, and are not listed here. In all cases these minor requests were well-received, and the responses were satisfactory. Appendix 2 is a voluntary response by the Technical Team to issues raised during the review, including those listed in Table 1 (which provides an overview of the various uncertainties the Panel identified, and which provided a focus for the discussion).

2) Design of the Sampling Scheme

The survey consists of an aerial photogrammetric survey (Stage 1) to determine the school surface area, and a calibration study (Stage 2) intended to determine the relationship between school surface area and school biomass (Stage 2 involves the physical capture of schools by purse seine). A small proof-of-principle survey (henceforth referred to as the "2008 pilot survey") was conducted in 2008 off the northern Oregon coast, with promising results.

2.1) "Stage 1" School Surface Area Survey

Three replicate sets of aerial survey transects (two groups of 26 transects, from 3 to 35 nautical miles offshore) will be conducted. The transects will be 15 nautical miles apart during each replicate. The Panel **recommended** establishing three alternative fixed starting points five miles apart, and choosing one of the three without replacement at the start of each replicate survey. The northern group of transects will be off Washington and Oregon, and the southern group will be off northern California down to Monterey. These two groups of transects will be conducted semi-independently. Each group will be conducted by separate observers/planes/pilots (but with the possibility of exchanging pilots and/or equipment for purposes of inter-calibration).

The aircraft will be fitted with high resolution digital cameras, which take a continuous sequence of photographs. The aircraft will normally fly at 8000 feet, with a photographed strip width of

12,000 feet, and 60 percent overlap of successive images. Photos will be time-stamped with Global Positioning System (GPS) position, GPS altitude, and possible observer comments. It is anticipated that the aircraft may have to fly lower sometimes due to clouds etc., but the Panel **cautions** that this flexibility would necessitate appropriate calibration.

The digital photographs will be software enhanced (Adobe Photoshop) following the survey to reveal schools, help identify probable species, measure surface areas and other attributes (e.g., irregularity or an index of circularity) of detected fish schools. The Panel noted that image enhancement involves many case-by-case decisions, and may not be an easily standardized process. The Panel also **cautioned** that it is also important to be sure that informative features (e.g., edge properties) are not removed from the images during image processing.

The schools and their attributes will be recorded in a processing log/database for statistical processing. The Panel **recommended** that the log include a record of qualitative information regarding the processing and the difficulty in assigning species and calculating school areas.

The Panel discussed a number of specific issues, summarized below and also in Table 1.

<u>School Identification:</u> Species identification of schools is one of the most controversial aspects of the survey. The Panel was assured by the Technical Team that the results of the 2008 pilot study indicate that species identification is sufficiently reliable in the north so as not to pose a problem in that region. Although work has yet to be conducted in the south, spotter pilots are able to detect and identify fish schools, which suggests that species identification from enhanced photographs should be possible. The 2008 pilot survey demonstrated that fish schools can be identified from the photographic records, and the Technical Team is confident that species identification will not be a problem. Work on the spectral criteria for species identification will be ongoing. The airplane pilot is an experienced professional fish spotter, and also will contribute to the identification process by means of comments and observations recorded while underway. Overflights at low altitude can provide better observation for identification purposes, but such overflights are not possible during Stage 1 transects. The targeted purse seine sets in Stage 2 will also provide a practical test of species identification.

Some forms of supplementary information, such as species composition from concurrent trawl surveys or from commercial fishing in the area, are not directly useful for abundance estimation as part of the aerial survey. However, the need to carefully evaluate the potential to see and recognize non-sardine schools will be further emphasized if these sources indicate the presence of species other than sardines.

The species identification issue can only be evaluated by practical experience. The Technical Team is most concerned about how often schools thought to be sardine are in fact not sardine (referred to as “Type 2 error” in Table 1), which is associated with a tendency to overestimate sardine abundance. There are presently no plans to sample schools that are not thought by the pilot to be sardines during Stage 2 sampling. Such sampling could have been used to determine the extent of “Type 1 error” (where schools of sardines fail to be recognized as such, an error that would lead to an underestimate of sardine abundance). The Panel noted that the frequency of Type 2 error is likely to be related to the relative abundance of sardine schools. At high relative abundances of sardines, the prior (i.e., uninformed by any observational data) probability that a school is not sardines is low. However, at relatively low sardine abundances, schools thought to be sardine have a higher prior probability of not being sardines. Ultimately this phenomenon could result in a nonlinear relationship between survey estimates and true local abundance, and merits careful attention.

The survey plan emphasizes species identification primarily from the enhanced photographic images without auxiliary information. Image processing technicians will be trained by processing a library of images with known species composition. In this regard it is vitally important that the identification of the species in the training set be known.

Image Size Calibration: Initial calibration of image size suggests a bias toward overestimating the size of observed schools, but this bias may cancel if the tonnage of fish caught in Stage 2 is calibrated directly to a representative camera image. However, accurate calibration is always desirable so that different equipment can be used interchangeably, and changes to new equipment do not pose a problem.

Although the images appear to have relatively little edge distortion[1], a trigonometric argument suggests that this is probably not negligible. At a height of 8,000 ft, the left and right edges of the photographic field are 6,000 ft from the track line. Therefore schools at the edge of the frame are 10,000 ft from the observer (this being congruent to a 3-4-5 triangle), or 25 percent farther away than schools directly beneath the aircraft (Fig. 1). While a theoretical calibration curve could easily be derived, the Panel **recommends** that an empirical calibration curve may be more reliable and robust. Both approaches should be attempted and compared, but the Panel favors the empirical approach. In this respect, the Panel suggested that having both planes fly a small number of transects 6,000 ft apart would provide an additional source of information to quantify the impact of edge distortion.

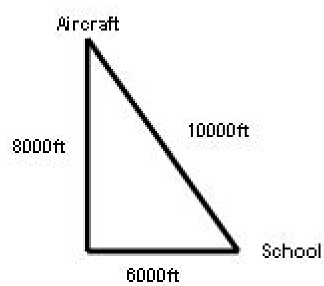

Figure 1. Distance to a school that is a perpendicular distance of 6,000 ft from the aircraft.

School Area Determination: The Panel agrees that total school area is a useful summary statistic related to abundance for long-term comparisons, and is better than alternative metrics such as a numerical count of schools.

Consistency Issues: The criteria of how and when to do the survey should be consistent over time, so there is no unintended change in *q*. Although the best weather and visibility conditions

[1] Distortion is defined in this report as being when an image appears different (or has a different detection probability) than it would have had had the image been directly beneath the aircraft.

occur in the fall, the surveys will have to be conducted several months earlier so that the results are available for use in the sardine stock assessment.

Weather variability and associated operational constraints are necessarily a problem for consistency. It is important to have pre-determined and quantifiable criteria for deciding when a portion of a transect cannot be used, or when a transect must be shortened or abandoned altogether. Such decisions should be thoroughly documented so that consistency and lack of bias can be evaluated.

There is a potential for observer (or equipment) differences in several aspects of the survey. Such differences include: (a) changes over time in personnel and equipment, and (b) differences among pilots, and among photographic processing technicians during a single survey. The Panel notes that periodic refresher training can be used to reduce those differences in some cases, but **recommends** that ultimately it may be most effective to quantify any consistent differences by means of double-blind comparisons and similar techniques.

2.2) "Stage 2" Area to Tonnage Calibration by Targeted Fishing

The relationship between school surface area and school tonnage will be estimated using directed purse seine sets on example schools. The target school will be photographed before the vessel interacts with it, and will also be photographed continuously while it is being caught. It is important to take the reference photograph under standard survey conditions, including the standard 8,000 ft altitude, to obtain comparable photographic images and nominal identifications of the target school before descending to a lower altitude if it is necessary to direct the set. Although the photographic processing technician will be aware that the target was initially thought to be sardine, maintaining comparability requires that the technician is not aware of the definitive identification from actual capture.

The Panel **recommends** that the targeted schools should be representative of the types and sizes of schools observed in the Stage 1 transects. To the extent practicable, captured schools should attempt to include representative samples from areas that are distant, both offshore and alongshore, from the base fishing port.

There would be value in following individual schools photographically for a period of time before catching them. This would reveal useful aspects of the variation in school area for schools of known tonnages. Together with photographic monitoring during the capture, this would help assure that the initially observed school is captured in its entirety.

3) Analytic Treatment of the Data

In principle, the estimate of survey biomass is straightforward to calculate, i.e. biomass = area of cover*(biomass/area) where the first quantity is obtained from Stage 1, and the ratio is obtained from Stage 2. The Technical Team initially intended to estimate total school surface area before estimating biomass, but the Panel **recommends** that each school be converted to an estimated tonnage before integrating over the survey area, because this allows for nonlinearity in the relationship between school tonnage and school surface area. The Panel expects this relationship will be nonlinear, and notes that quantification of the extent of nonlinearity is an important objective of Stage 2 sampling. Another problem related to nonlinearity is extrapolation uncertainty for the biomass/area of schools much larger than those that were sampled.

If the area to tonnage relationship is nonlinear, "edge effects" (schools that extend outside the photographic frame) pose a special problem. Edge effects are much less severe along the fore and aft direction of travel because of the extensive overlap of successive images, and the "edge effects" of concern mainly involve the "right" and "left" edges of the photographic images. There are a variety of techniques for addressing edge effects, but one simple approach might be to end the accounting frame somewhat short of the edge of the photograph, so that full images of most "edge schools" are available for analysis and quantification.

4) Implementation of Survey Protocols

An important question is whether the total exempted fishing permit (EFP) allocation (and how it is allocated to each area) is sufficient to achieve a useful survey.

- At 1,200 tons from each area, the suggestion of the Technical Team (i.e., a total EFP allocation of 2400 tons), the Panel concluded that there is a good outlook for successful calibration.
- The Panel doubts whether sufficient precision would be achieved if only 600 tons were taken from each area (a total of 1,200 tons is currently allocated for an EFP). In the case where a total of only 1,200 tons was available, the Panel **recommends** that the entire 1,200 tons be used in only one of the two possible survey areas. Moreover, the Panel saw no compelling reason to recommend that the tonnage be assigned to a particular area of the two areas, and would prefer that the Technical Team decide how they would best use the allocation, were it only 1,200 tons. However, the Panel would not expect that an estimate based on a small number of point sets would provide a sufficient basis for a robust and precise estimate of abundance. If all of the allocation was taken from one area, this would provide a basis to estimate the relationship between school size and tonnage for that area, but it could not be used to estimate abundance for the entire survey area (Canadian border to Point Conception).

The 2008 pilot survey involved 13 point sets, eight of which were usable; the rest of which were unusable due to partial escapement. The Technical Team is hoping for about 32 sets in each of the two areas in 2009. There is substantial room for optimizing the information that can be obtained from a fixed allocation of catch biomass, including maximizing the precision of the calibration and detecting and quantifying nonlinearity in the relationship. Special considerations apply to the high end of school tonnages. The maximum school size that a single vessel can accommodate is about 95 tons (hold capacity), but a purse seine net can take up to about 300 tons, which would require multiple vessels to receive the fish. These large schools are likely to be important in the biomass/area calibration, but quickly use up tonnage and would require a substantially larger EFP allocation. Larger schools may also be more difficult to catch in their entirety.

5) Evaluation of Precision and Bias

An overview of issues regarding precision and bias is given in Table 1[2], and some further thought from the Technical Team are given in Appendix 2. The Panel notes that the survey is well enough described/designed that it is amenable to close study of component details and procedures.

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[2] This report uses the informal terms "overestimate" and "underestimate" rather than the technically correct equivalents of "positive bias" and negative bias."

Two of the largest sources of bias are expected to result in underestimates: (a) the survey does not cover the entire region occupied by Pacific sardine, and (b) there will also be no correction factor for undetectable (e.g., deep) schools, so the estimate of biomass will probably be an underestimate, even within the survey area. Moreover, although the Technical Team and the Panel have identified sources leading to both over- and underestimates of abundance, the survey plan will only attempt to correct for overestimates (see Appendix 2). Consequently, the Panel expects that the overall result will be an underestimate of the total biomass of northern subpopulation of Pacific sardine. This conclusion is consistent with experience from analogous surveys.

6) Use of Aerial Survey in Stock Assessments of Sardine

The 2008 data were from a pilot study, and the Panel notes that it should not be used for stock assessment purposes. The first usable data will presumably be collected during 2009.

The proposed survey presents a problem of how to utilize an absolute estimate for an uncertain portion of the total area. It is “an estimate of a minimum”, at least. One somewhat analogous example is the use of an absolute estimate of the biomass of cowcod in the Cowcod Conservation Area of southern California, in the Pacific Fishery Management Council cowcod assessment. The abundance estimate was based on strip transect observations from a submersible. The assessment combined the precision estimate from the submersible survey with uncertainty in the value of q, which in this case was the estimated fraction of the cowcod population that resides in the survey area.

It is important to get accurate size composition data for the surveyed fish, so that a selectivity curve can be estimated with the assessment model, and so that the survey biomass estimate can be compared with an appropriate demographic subset of the assessment stock. Age-composition data would be even more useful in this regard.

There will be ongoing and probably increasing benefit from continuing the survey for many years. Also the cumulative sampling and experience will result in progressive improvement in precision of the survey.

It is anticipated that if the surveys continue over multiple years, it would provide a basis for a new relative index of abundance.

Table1: Sources of uncertainty in proposed aerial survey for sardines

Stage 1 – Estimation of sardine school area

Source of Uncertainty or Bias	Direction	Ways of Addressing the issue
Category: Species misidentification		
Type 1: Sardine misidentified as other spp./features	Underestimate	Directed sets, jigging, include low overflight
Type 2a: Other spp. misidentified as sardines	Overestimate	Directed sets, jigging
Type 2b: Other features misidentified as sardine	Overestimate	Avoid cloudy conditions??
Density dependent misidentification (a nonlinearity)	Hyperstability?	Long-term comparisons
Variability among pilots		
Category: School detection (note: timing needed for assessment schedule is not optimal for survey conditions)		
Schools too deep	Underestimate	Quantify water clarity (e.g. secchi depth), Echo sounder evidence
Schools lost in glare	Underestimate	Time of day, compare adjacent frames
Schools too diffuse (hypothetical)	Unknown	Relate to behavioral patterns?
Marginal cloud cover, reduced visibility	Underestimate	Determine range of acceptable conditions
Sea state	Underestimate	Determine range of acceptable conditions
Technician variability–image enhancement	Unknown	Double-blind re-analyses
Weather is consistently prohibitive	Unknown	Use better season and delay input one year
Category: School area determination		
Calibration of scale (photogrammetry)	Overestimate (maybe neutral)	Continue calibration
Calibrate distortion at edge of frame	Unknown	Continue calibration
Precision and repeatability	Unknown	Repeat photos of same school over time; Compare morning and afternoon views
Schools extending outside visual frame	Depends on B/A relationship	Problem mainly if nonlinearity exists
Diffuse school boundary	Overestimate?	Disturb with vessel and compare area?
Complex shape or diffuse	Overestimate?	Repeat photos of same school over time; Disturb with vessel and compare
Technician variability–image enhancement	Unknown	Blind" reanalyses of photos, within and among technicians.

Stage 2 – Estimation of biomass per unit area

Source of Uncertainty or Bias	Direction	Ways of Addressing the issue
Comparability to images in Stage 1	Unknown	Choose conditions and school types similar to aerial survey. Use similar altitude.
Pro-sardine target selection	Overestimate	Select schools only on size criterion
Nonlinear biomass/area relationship	Variance issue	Increase sample size, contrast
Statistical imprecision	Variance issue	Increase sample size
Regional differences	Unknown	Compare northern and southern cases
Behavioral patterns		
Feeding, spawning, transiting	Variance issue	Stratification
Mixed species	Unknown	
Response to fishing vessel	Overestimate	Get photo before vessel approaches
Oceanographic conditions (e.g., El Niño)	Overestimate (contraction)	Caution in among-year data sharing
Distance offshore	Unknown	
Present but undetectable–directed sets impossible	Underestimate	Conduct blind sets (e.g., Pearcy's work)
Variable relationship depending on school thickness	Variance issue	Voluntary logbooks at time of survey to compare school thicknesses among years
Density-dependent mixed schooling	Unknown	Long-term fishery catch compositions

Source of Uncertainty or Bias	Direction	Ways of Addressing the issue
Abundance estimation		
Pre-integrate area–works if there is linearity	Unknown	Depends on Stage 2 results; Edge effect is neutral if linear
Integrate biomass over schools–works best if nonlinear	N/A	Need to deal with edge effects
Other		
Survey stratification (transect density depends on school density)	N/A	Possible with further experience, but not currently proposed
Survey does not cover whole area	Underestimate	Maybe extend transects offshore; Go into Canada, Mexico

Appendix 1. List of Participants

STAR Panel Members:
André Punt (Chair), Scientific and Statistical Committee (SSC), Univ. of Washington,
Owen Hamel, SSC, NMFS, Northwest Fisheries Science Center
Gary Melvin, Center for Independent Experts (CIE),
Alec MacCall, External Reviewer, Southwest Fisheries Science Center (SWFSC)
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Appendix 2. Technical Team Response to Various Issues

Response to comments following review of the survey design at the May, 2009 STAR Panel

Stage 1: Estimation of sardine school surface area

Species misidentification

Prior to the onset of production scale photo analysis, we will investigate the potential for school misidentification by photo analysis personnel. Images will be collected from areas where sardine are intermixed with other species (e.g. anchovy). Spotter pilots experienced with the problem of discriminating between species in aerial surveys of schooling fishes will aid in the preparation of a reference set of photographs with "known" species images. Photo analysis personnel will be trained to discriminate between species using the reference set of images. A set of test images will be compiled to evaluate within and between reader error in the parameters measured by the photo analysis personnel. The test images will be used in a double-blind experiment to measure variability in the entire process of image analysis, including: image enhancement, species identification, school enumeration, and area measurement. The development of a reference collection of photographs will be made carefully and validated, with the consideration that they will be used by photo analysis personnel for training purposes. Additional photos may be added to the reference collection in future years.

In addition to the above procedures, we will review the available data from other surveys to get a sense of species other than sardine that we may expect to see in our aerial survey. Data sources include: 1) trawl survey data (Emmett et al.) and historical spotter data (Squire et al.).

We also plan to evaluate the effect of altitude on species identification in the aerial survey. An experiment will be conducted with two airplanes to evaluate the altitude effect. One pilot will fly along a pre-designated test transect at the nominal survey altitude of 8,000 ft and will keep a log of schools observed, by species. The second airplane will fly at a lower altitude (e.g. 500 ft) with an observer on board for detailed note taking. There will be no communication between pilots regarding schools observed during the transect, in order to keep the two sets of observations independent. Photographs taken from the two airplanes will be analyzed and schools will be identified and compared between the two sets of images on a school by school basis. Pilots will be permitted to use their logbooks and notes made during the transect to assist in analyzing the photographs collected for the comparison. The rate of between-pilot agreement in school identification will be determined from the comparison of the two sets of photographs. To eliminate the pilot effect from the test, the pilots will switch altitude positions and will repeat the procedure on subsequent transects.

School detection

We recognize that an unknown proportion of schools in any given area will be too deep to detect via the proposed aerial survey method, and thus we acknowledge that the method will tend to underestimate total school surface area. Data collected from Stage 2 of the survey will include measurements of school height and vertical distribution in the water column. These data are a sample of schools visible from the aerial survey, and will be photographed at the nominal survey altitude of 8,000 ft. During the fishery, two vessels in each region (north and south) will be operating with ES-60 sounders logging data onto hard disks in continuous-operation mode.

These data will be processed to obtain a sample distribution of school height measurements (location of the top and bottom of the school in the water column). We expect that some of these schools will be distributed below the surface such that they would be too deep for aerial detection. Comparison of these data with the range of school height measurements from the 64 schools captured in Stage 2 point set sampling will give us a qualitative look at the rate of encountering schools not likely to be detected by the aerial survey method.

Weather conditions (e.g. marginal cloud cover, haze, elevated sea state) can conspire to create situations where schools would be likely to go undetected with the aerial survey method. We will determine a range of acceptable conditions for survey commencement (and termination). The survey pilots will judge whether or not conditions are acceptable for conducting surveys on a day to day basis. A detailed log will be kept to document when and why transects are terminated early due to prevailing weather conditions. From the Pilot Study we found that conditions such as glare and scattered cloud shadows over the ocean surface can be handled operationally by increasing the overlap rate of the photographic coverage. We have found that an image overlap rate of 60 percent is effective for dealing with this issue under most circumstances.

School area determination

Calibration of aerial images to measure the size of known objects was conducted during the pilot study in 2008 and will be continued in the 2009 survey year. We will extend the calibration experiments to evaluate the level of distortion on the periphery of the digital images. It is possible to address this issue by either a theoretical or an empirical approach. For example, a theoretical approach could involve collecting measurements from photographs to determine if objects on the image edge are on average smaller than objects found in the image center, and then deriving a theoretical relationship from this information. Alternately, an empirical approach could involve comparing real-world measurements of objects photographed in the image periphery with the sizes of the same objects as determined from the software analysis procedure.

Stage 2: Estimation of sardine biomass per unit surface area

Comparability to images in Stage 1

To ensure that the surface area measurements collected in Stage 2 are comparable to those collected in Stage 1 of the survey, we will collect the point set images at the same nominal altitude of the survey (i.e. 8,000 ft). Measurements of school surface area for point sets will be taken prior to purse seine vessel approach. Photographs will be taken throughout the point set process to examine potential school responses to the fishing vessel.

Target selection by pilot

Pilots will be given a daily schedule of school sizes to be targeted for capture. The pilots will maintain a logbook which will contain a record of every school identified for point set capture. To ensure Stage 2 sampling frame comparability to the set of images collected in Stage 1 of the survey, pilots will identify point set targets from the nominal survey altitude of 8,000 ft. In the event that the pilot identifies a school for point set capture at 8,000 ft, and the school is subsequently found to be a species other than sardine (e.g. when the pilot descends to a lower altitude for a better look, and after the vessel has approached the school for capture and is capable of making on the water observations and jigging), this information will be duly recorded and used to estimate the sardine mis-identification rate of pilots in Stage 2 sampling.

Non-linear biomass to area relationship
A simple ratio estimator of biomass is not desirable if a pronounced non-linear relationship is observed in the biomass to area relationship. During the data analysis phase of the survey, we will evaluate the alternative of integrating biomass over the size range of schools observed. It will be important to ensure sufficient contrast in the sizes of schools sampled for this purpose. During the data analysis phase, we will look for non-linearity in the surface area to biomass relationship, and will also make the determination whether a standard regression vs. an errors-in-variables approach is more appropriate for survey data analysis.

Regional differences
We anticipate regional differences will be observed in the parameters associated with both Stage 1 and Stage 2 sampling; however, we have no a prior information for effective stratification beyond a simple north-south treatment at this time. Thus, in this first survey year, we are distributing the sampling effort such that 1) an equal amount of area will be surveyed in the north and the south, and 2) an equal number of point sets will be collected in the north and the south. With the information we seek to collect in 2009, we may be able to reduce the variance on our parameter estimates by alternative stratification schemes going forward.

This survey design is limited to the area extending from Cape Flattery to Monterey Bay and nominally to 35 miles offshore. Sardine distribution is known to extend into Canada to the north, and into Mexico to the south, and may extend further offshore than 35 miles in some areas. Thus, we recognize that the survey will underestimate sardine abundance for this reason. We do not anticipate sampling north or south of the area specified; however, we will examine the east-west distribution by systematically extending a set of transect beyond 35 miles to determine the offshore distribution of sardine and the utility of the 35 mile cut-off for the design of future surveys.

Behavioral patterns
We recognize that sardine behavioral patterns will influence the variability of measurements that we will record during the aerial survey. For example, feeding, spawning, and transiting behaviors can be expected to result in different levels of aggregation/dispersion and thus will increase the variability in the surface area to biomass relationship. We expect that our ability to classify schools by behavioral category will improve as we obtain observations over a period of years and under a variety of conditions. The parameters we will be examining in our 2009 survey that have potential for beginning the development of a school classification scheme include: 1) school height (from ES-60 data) and 2) school shape (i.e. perimeter to area; circularity).

Abundance Estimation
Edge effects – procedure for handling schools not completely within the photograph
Edge effects are not a problem on the top and bottom of the images because image overlap provides for multiple observations of schools in the direction of aircraft travel; however, the images of schools could from time to time have the edges cut off (i.e. not photographed in their entirety. This is a problem because of the potential for non-linearity in the surface area to biomass relationship. This situation is not uncommon in quadrate based sampling and methods for dealing with it are available in the survey design literature. We will review the literature and will establish an appropriate procedure for data reduction and analysis to deal with this issue.

Two methods were suggested by the Panel. One method would involve drawing lines some distance from the edge (e.g. 1 inch) and re-defining the area-swept using the new (reduced) width. This approach allows for empirical measurements of schools straddling the edges. Another method would involve drawing a line down the middle of the image and studying the edge effect by examining schools that are split by the line.

Calculation of total biomass
As noted above, we will evaluate non-linearity in the surface area to biomass relationship. If deemed appropriate, we will integrate biomass over the range of observed school sizes.

Other
Comparison of pilot estimate vs. measured point set tonnage
In the survey logbook to be maintained by the pilots, the estimate of school tonnage prior to each point set will be recorded. This information will be summarized and compared to actual landed point set tonnage.