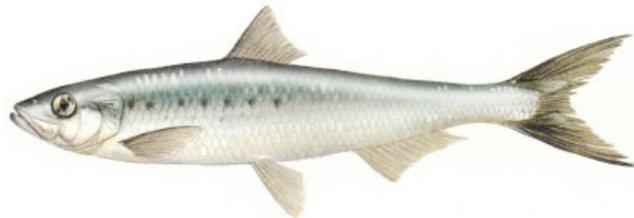




# **WORKSHOP ON ENHANCING STOCK ASSESSMENTS OF PACIFIC SARDINE IN THE CALIFORNIA CURRENT THROUGH COOPERATIVE SURVEYS**

**June 1-3, 2010  
La Jolla, California**



**Sponsored by NOAA Fisheries Southwest Fisheries Science Center and Northwest Fisheries Science Center.**

## ACKNOWLEDGMENT

Organizing and staging this Workshop on Enhancing Stock Assessments of Pacific Sardine in the California Current Through Cooperative Surveys took a lot of personal dedication and commitment on the part of a number of individuals. The sponsors wish to thank Robert Emmett, Doyle Hanan, Tom Jagielo, Gary Sakagawa, Sarah Shoffler and Russ Vetter for serving on the Steering Committee and Diane Pleschner-Steele and Mike Okoniewski for serving as sardine industry advisers to the Committee.

James Churnside, David Demer, Tom Jagielo, Dayle Hanan, Kevin Hill, Nancy Lo, Jake Schweigert, Dale Sweetnam and Jerry Thon graciously agreed to prepare and present working papers on different survey methods. Their contributions were appreciated.

Finally, the services of Bev Macewicz, Dawn Graham and Rose Sanford for various important tasks for smooth execution of the event were appreciated. A special thanks is owed to Gerard DiNardo for expertly facilitating the workshop to its objectives.

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**LIST OF DOCUMENTS**

Annex I	List of Participants
Annex II	Agenda
Document 1	Current Management and Fishery-Dependent Sampling of the U.S. Pacific Sardine Fishery by <i>D. Sweetnam, California Department of Fish and Game</i>
Document 2	Assessment of the Pacific Sardine Resource in 2009 for U.S. Management in 2010 by <i>K.T. Hill, N.C.H. Lo, B.J. Macewicz, P.R. Crone, and R. Felix</i>
Document 3	A Description of the West Coast Aerial Sardine Survey by <i>T. Jagielo and D. Hanan, West Coast Sardine Survey</i>
Document 4	Daily Egg Production Method Survey by <i>N.C.H. Lo and B. Macewicz</i>
Document 5	Acoustic-Trawl Surveys of Pacific Sardine ( <i>Sardinops sagax</i> ) in the California Current Ecosystem by <i>D.A. Demer, J.P. Zwolinski, K.A. Byers, G.R. Cutter, J.S. Renfree, and T.S. Sessions, NOAA Southwest Fisheries Science Center</i>
Document 6	Fishery Logbook Data for Pacific Sardine by <i>K.T. Hill, NOAA Southwest Fisheries Science Center</i>
Document 7	Airborne LIDAR for Pacific Sardine Surveys by <i>J. Churnside, NOAA Earth System Research Laboratory</i>
Document 8	Considerations Regarding the Use of Satellite Imagery for West Coast Sardine Surveys by <i>J. Thon, Northwest Sardine Survey</i>

Document 9 Pacific Sardine Trawl Surveys – Canada *by J. Schweigert, Department  
of Fisheries and Oceans Canada*

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## **I. OPENING AND INTRODUCTION**

The Southwest Fisheries Science Center (SWFSC) and Northwest Fisheries Science Center (NWFSC) of NOAA Fisheries, in partnership with stakeholders in the Pacific sardine (*Sardinops sagax caerulea*) fisheries of the United States, held the Sardine Workshop, June 1-3, 2010, in La Jolla, California. The objectives of this Workshop were to achieve common understandings among stakeholders regarding the: (1) advantages, limitations and challenges with, and possible improvements to, survey methods relevant to estimating biomass for stock assessments in 2011 and beyond; (2) identity of current investigators and users of each method; and (3) opportunities for collaboration. Participation was by invitation only.

The workshop began with participants introducing themselves (see Annex 1 Participants List). Usha Varanasi, Director of Science and Research at the NWFSC and Acting Director of the SWFSC welcomed the participants to the workshop. She noted that it was the first time stakeholders have met to discuss available sardine survey methods. She reiterated the objectives of the workshop and added that the workshop results should show who will work on each relevant survey method and indicate when results will be available. She thanked participants for making the workshop possible: those who traveled, the steering group, and others. She also extended a special thanks to Don Hansen who has been a proponent of collaboration among stakeholders and to the California Wetfish Producers Association (CWPA) for sponsoring the ice breaker reception.

## **II. ARRANGEMENTS AND PROCESS**

Gary Sakagawa, Chair of the Sardine Workshop, reviewed the logistics and the role of facilitator. The facilitator, Gerard DiNardo, promoted constructive dialogue among all parties to ensure that various views were presented. He also ensured that presenters adhered to their allotted 15 minutes per presentation. The participants provided the content. The purpose of this forum was not to debate the merits and limitations of each method, but to promote a common understanding of the methods. The principal investigators for each method were invited to discuss their method, plans for their survey and explore opportunities for collaboration with other stakeholders. It was noted that for the purpose of this workshop collaborations are limited to surveys conducted in U.S. waters. Potential collaborations with foreign partners are necessary and will need review at a later date. Sarah Shoffler, with assistance from Beverly Macewicz, was appointed rapporteur.

The agenda (Annex 2) and general schedule were reviewed and accepted.

### **III. REVIEW OF THE FISHERIES AND STOCK ASSESSMENT MODEL REQUIREMENTS**

#### ***1. Fisheries coast-wide (D. Sweetnam, Doc. 1)***

Dale Sweetnam presented a review of: 1) the U.S Pacific sardine fishery; 2) recent changes in management of the sardine resource; 3) a description of the current sardine fleet; 4) an overview of fishery-dependent sampling techniques; and 5) the effect of harvest constraints on the fishery in 2008 and 2009.

The Pacific sardine fishery was the largest in North America in the 1930s and 1940s with peak landings of over 700,000 metric tons (t) in 1936. Then, in 1967, after approximately fifty years of fishing, a moratorium on fishing was imposed by the California Legislature. However, by the time the moratorium was imposed, most of the fisheries along the west coast of the U.S. had collapsed, even in southern California. In the early 1980s, sardine was once again observed with increasing regularity in other coastal pelagic species (CPS) and live bait fisheries. In 1986, the first directed fishery in 20 years was conducted with a 1,000 short ton quota, and, in 1999, the California Department of Fish and Game (CDFG) declared that the Pacific sardine resource was officially recovered. U.S. management responsibility of the Pacific sardine resource was transferred from CDFG to the National Marine Fisheries Service (NMFS) with the Coastal Pelagic Species Fishery Management Plan (CPS FMP) which was implemented by the Pacific Fishery Management Council (PFMC) in January 2000.

The majority of sardine on the Pacific coast are landed by vessels with roundhaul gear, primarily purse seines. In 2009, the federal CPS limited entry program in California consisted of 65 permits and 61 vessels; the state-managed Oregon limited-entry fleet consisted of 25 permits; and the Washington limited-entry program consisted of 16 permits and six active vessels.

All three states monitor the commercial Pacific sardine catch utilizing fishery-dependent port sampling programs. The goals of the sampling program are to: 1) provide age from otoliths and length data to NMFS for Pacific sardine and Pacific mackerel for use in stock assessment modeling; 2) determine sex and maturity; 3) estimate the species composition of the CPS catch; and 4) estimate by-catch and incidental catch.

In 2008, the U.S. harvest guideline (HG) was set at 89,093 t, a 42% decline from the 2007 HG of 152,564 t. However in 2007, the U.S. fishery landed 127,764 t of Pacific sardine, 43% larger than the projected 2008 HG, setting the stage for landings to be constrained by management restrictions for the first time since the 1999 recovery declaration. In California, as well as the Pacific Northwest, the potential for early closures during the allocation periods resulted in a derby style fishery in which there was a race to catch Pacific sardine. In 2008, the Pacific sardine fishery was open for 199 days (55%) and closed 166 days (45%), the amount landed per day roughly doubled in each

allocation period, and number of landings per day increased. In 2009, the Pacific sardine fishery was only open for 78 days (21%) and closed 287 days (79%). Since 2008, the directed fishery has been closed from October-December, the peak harvest season in California.

### **Discussion**

Sweetnam also mentioned a report by Hunter and Hanan, written in 2000, summarizing the results of the “Stock Assessment and Management Workshop” held at Scripps Institution of Oceanography May 23-25, 2000 that describes management and monitoring recommendations for enhancing the sardine stock assessment. It was pointed out that many of the issues outlined in the 2000 report persist today.

Several details about which landings are available and used in the assessment were discussed and clarified by Sweetnam: Port samples were based on tonnage of landings; CDFG currently samples about one in 10 landings. Oregon and Washington conduct similar sampling which has been assembled and used in the stock assessment model. Canadian samples have been available since the last assessment. That fishery was relatively small until 2008 and was 15,000 t in 2009. Accounting for the sizes of that catch is important and it is hoped that the Canadian data will be a regular contribution. As for Mexican data, updated length compositions series for 1989-2000 and new data for 2001-2009 were obtained earlier this year and are hoped to be incorporated in future assessments.

The length-frequency data show periods when the Pacific sardine enter the fishery. It was pointed out that it would be useful to the assessment to have consistency in who conducts the analyses and maintains the data.

### **2. *Stock assessment model requirements and improvements (K. Hill, Doc. 2)***

Kevin Hill reviewed the Pacific sardine stock assessment model and requirements currently implemented. The northern subpopulation of Pacific sardine is assessed each year to establish a harvest guideline for the U.S. fishery. The current assessment was conducted using the Stock Synthesis model. The model included landings and biological sample data from commercial fisheries in Ensenada (Mexico), southern California, central California, and the Pacific Northwest (1981 to present), and abundance estimates from three fishery-independent surveys. The daily egg production method (DEPM) and total egg production (TEP) indices of spawning stock biomass were based on the SWFSC's egg production survey conducted each spring from San Diego to San Francisco (1986 to 2009). The third index was an estimate of biomass from the 2009 aerial survey. The 2009 aerial survey observation was considerably higher than recent biomass from the DEPM and TEP surveys (e.g., 2006-2008), and this scaled the model estimates of biomass upward. Due to the contrast in scale among survey estimates, the base model was tuned without the aerial spotter estimate. The estimate was then included to derive final base model results. Stock biomass increased rapidly through the 1980s and 1990s, starting at 8,210 t in 1981 and peaking at 1.69 million t in 2000. Stock biomass has subsequently declined to the present, July 1, 2009, level of 702,024 t. Stock biomass from

the 2009 final model, including the aerial survey estimate, was very similar to the results from the final 2007 assessment. Both the 2009 and 2007 final models were scaled higher than the 2008 update and the 2009 base model that excluded the aerial survey estimate. Based on results from the final 2009 model, the PFMC's 2010 HG for the U.S. fishery was set at 72,039 t. The total exploitation rate for the combined Pacific sardine fisheries is currently less than 16 %.

## **Discussion**

It was noted that the biomass trajectory of the 2007 assessment was similar to that in the 2009 assessment with the aerial data and that the 2008 update model scaled considerably lower than both. Hill explained that the 2008 model trajectory was influenced by two changes: One was that there was a lower DEPM estimate of spawning biomass, and the other was that sample sizes for the combined Oregon and Washington fisheries were large, increasing the weight of the data in the model. There were no changes to the model structure, only changes to input data.

Variation in scale across different models was reflected by the catchability coefficients. Female spawning stock biomass was one of the model inputs. The catchability for the DEPM and TEP indices was much higher without the aerial survey data. It was pointed out that the Pacific sardine assessment is unique in that it starts with a severely depleted population, whereas most begin with an unexploited one. This means that the initial population in the stock assessment must be estimated by an additional parameter.

The current understanding of stock structure of the Pacific sardine population was discussed. Two stocks exist along the West Coast from outer Baja California, Mexico to Canada. Their degree of separation is unclear. The southern and northern stocks may mix in the Southern California Bight (SCB), but the degree to which the southern stock contributes to the southern California fishery or the assessment is unclear. It was noted that University of Washington was recently awarded California Sea Grant funding to develop a model accounting for the separation between southern and northern stocks, and to evaluate the importance of including spatial structure in the stock assessment model.

What can be done to improve surveys to address stock mixing issues and measure recruitment was discussed. Biological samples (tissues, otoliths) and oceanographic data can potentially be used to determine stock source, particularly for areas and times when there is a high likelihood of stock mixing. Some surveys have collected samples, but how to analyze them or work up data are not planned. Sampling of the live bait fishery catch could be another source for collecting biological samples and addressing questions about stock mixing.

Juvenile rockfish surveys being conducted by the SWFSC were discussed as a potential source of data on Pacific sardine abundance. The survey is conducted in May/June and uses a different gear from those used on sardine surveys, and catches some sardine. The group agreed it should explore the usefulness of this source of sardine data.

Some information regarding recruitment is obtained from the length composition and age composition data from the Pacific sardine fisheries. However, because the California fishery operates within a narrow band of coast relative to the entire region where recruitment occurs, data on recruits from this source are variable. Nonetheless, the data set could be improved upon by directing sampling on young-of-the-year (when present) by the fleet. It was noted that power plants impinge and entrain sardine during normal operations and may provide an additional source of recruitment data. However, the utility of recruitment data in the assessment model requires further investigation, particularly because these data normally exhibit high variability and surveys to collect sufficient data are expensive.

The live bait fishery, which targets both northern anchovy and Pacific sardine, could potentially provide samples for estimating recruitment abundance in a small local area. For the 0-age fish collected, birth date can be back-calculated with analysis of hard parts.

#### **IV. REVIEW OF SURVEY METHODS CURRENTLY PROVIDING DATA FOR THE STOCK ASSESSMENT MODEL**

##### ***1. Aerial survey (T. Jagielo, Doc. 3)***

Tom Jagielo presented an overview of the survey design and methodologies of the aerial survey. He noted the industry's application for an exempted fishing permit of the PFMC in 2010 includes both a repeat of the summer aerial survey conducted in 2009, with an extension in 2010 into southern California, and a pilot project in the fall, in conjunction with the fall CalCOFI cruise, intended to test various assessment methodologies including LIDAR and acoustics both day and night, at a time when Pacific sardine are abundant in southern California.

He focused his presentation on the summer aerial survey, noting that the survey method was reviewed by the PFMC STAR Panels in both May and September of 2009, where it was concluded that the method provides a minimum estimate of absolute abundance, and should be included in the 2009 stock assessment of Pacific sardine. The chief advantage of the method over other techniques is that it provides a synoptic, direct estimate of abundance. It also makes use of the extensive "on the grounds" expertise of spotter pilots and fishermen. Uncertainty in the estimate of biomass was evaluated via the method of bootstrapping, which showed that at current sampling levels, the method can produce biomass coefficient of variation (CV) values within the range useful for stock assessment modeling.

##### **Discussion**

A number of points regarding why the method provides a minimum estimate, and perhaps an underestimate, of abundance were discussed. For instance, some schools are too deep below the ocean surface to be seen from the air. Also, factors that obscure the view of the ocean surface, such as sea state and glare (depending on weather conditions and time of day) can cause problems in detecting schools with the aerial survey method. Jagielo pointed out that one factor that could introduce a positive bias would be if schools of

other species were mis-identified as sardine schools. In 2009, sardine were virtually the only species observed in the point set samples used to estimate the biomass of individual schools; however, it is possible that sampling in the future could result in multi-species school encounters where this issue could be of concern.

It was pointed out that airplanes can rapidly cover large areas of the ocean surface relative to vessels at sea, and satellites even more so. More discussion of satellites was tabled until the satellite survey methods presentation.

Jagiello noted that the project has been building a library of photographs for analysts to use to improve species identification skills. Additionally, double blind tests and similar methods are planned to evaluate and monitor photo-analyst performance.

Various methods for verifying school species identification were discussed, including: 1) conducting more synoptic point sets, and 2) conducting surface trawls.

The group also discussed issues related to school detection. The question was raised if reducing the plane altitude could be expected to improve school-species identification. It was noted that there is a tradeoff between survey altitude and the amount of area swept by the camera, not to mention safety considerations. To keep point set sampling representative of transect sampling, the STAR panel recommended that pilots first identify schools at 4,000 feet before the sets are made. Current procedure provides for pilots to identify schools at the nominal transect height, then descend, as necessary, to direct the set. To date, all of the schools selected for point-set sampling at an altitude of 4,000 feet were sardine schools.

Finally, it was noted that the fall 2010 aerial survey will use LIDAR, acoustics, and aerial photography both day and night, and also evaluate flying at 2,000 feet, to explore alternative methods that may facilitate improvements in aerial survey techniques.

### **3. *Daily Egg Production Survey (N. Lo, Doc. 4)***

Nancy Lo presented a summary of the DEPM. The DEPM was developed by the SWFSC in the early 1980s to estimate the absolute spawning biomass of northern anchovy off central and southern California and has been applied to anchovy, sardine, sprat, mackerel, horse mackerel, snapper, and hake in 16 locations around the world. The DEPM is suitable for multiple-spawning fishes with eggs distributed in the upper layers of the ocean and mature females for whom the spawning rates can be measured. Eggs are the preferred stage for sampling because they do not avoid the nets. However the patchy distribution of eggs requires a sound survey design, like adaptive sampling. Processing of adult reproductive specimens requires intensive laboratory work and a large number of trawl samples to achieve reliable estimates. A complication is that a small portion (<10%) of adults may reside and spawn north of the standard DEPM survey area, from San Diego to San Francisco in April.

The DEPM requires just a single survey conducted for at most a month, preferably during the peak spawning time. The cost of such a survey is about half million dollars. The cost would be double for a survey from San Diego to the US-Canadian border, expanded to 43°N and starting from the northern end of the survey area; this would enable sampling of that portion of the stock spawning in the northern area. If extra vessel time is needed, commercial fishing vessels are a potential source for collecting adult fish samples through the cooperative research funding as suggested by the May 2009 STAR panel. Long time series of spawning biomass, and biomass estimates from other survey methods, like acoustic and/or aerial surveys, can be used to compare with and calibrate DEPM results.

### **Discussion**

Data indicate that the proportion of females spawning off the Pacific northwest in July is small (3% female per day) on a per day basis compared to off the Pacific southwest in April (13% of females per day). Because Pacific sardine are multiple spawners they continue to produce eggs, depending on the environment, food, and size of the fish over a period of time. They typically spawn in the south, off California, and travel northward. After about a month, they may spawn again off the Pacific northwest. Hence, those spawning off the Pacific northwest may be repeat spawners or they may be fish spawning only in the north. It is suspected, though, that primary spawning occurs in the south and a second spawning occurs in the north. Size at maturity is smaller in the southern range than off the Pacific northwest.

Lo noted that this northward movement pattern of Pacific sardine was determined years ago and should be investigated again with advanced tagging methods that are currently available. She suggested using acoustical archival tags such as those used for inshore salmon studies in the Pacific Northwest.

It was mentioned that the fishery caught about 16 t of Pacific sardine off Coos Bay in 2009. The fish averaged 90-200 g and 220-240 mm long. The smaller fish had low fat content and females had no eggs. The bigger fish were more mature and had more fat. If samples from this catch are available, the females could be analyzed for spawning activity by the SWFSC.

Lo noted that DEPM projects trends in spawning biomass. There are a few reproductive biology factors that could affect the estimate from this method. For example, the DEPM method assumes the survey covers the total spawning area, but migration and spawning outside of the survey area can contradict this assumption. In addition, more work is needed to update the temperature-dependent egg development relationships because temperature affects the rate of degeneration of post-ovulatory follicles, as well as the percentage of fish spawning.

It was pointed out that the timing and duration of the survey are important aspects of the current survey. The best survey time is during the peak spawning period because fewer samples (eggs and adults) are needed. However, if the area is large, it may take three

weeks to survey the entire spawning area. Therefore a good survey design is necessary, and for a coast-wide survey, two vessels are needed.

The group discussed augmenting the DEPM with acoustics, swept-area trawls or other methods if the trawls are inefficient. It was pointed out that the swept-area trawl method has a different objective from the DEPM. Also pointed out was that acoustics have been used in combination with trawls to augment the DEPM in past surveys.

In response to questions on the Continuous Underway Fish Egg Sampler (CUFES), Lo responded that it effectively samples the top three meters only and gives a good indication of presence and absence of eggs. This is useful information for guiding adaptive sampling. Lo also noted that bongo net samples are also taken at fixed stations during the DEPM surveys.

## **V. REVIEW OF OTHER SURVEY METHODS OR POTENTIAL DATA SOURCES**

### ***1. Acoustics survey (D. Demer, Doc. 5)***

David Demer described acoustic-trawl surveys. Acoustic-trawl methods have been used to survey Pacific sardine off the west coast of the U.S. for more than a half century. The methods provide estimates of biomass and distribution. They have also been used by France, Spain, Portugal, Peru, Chile, South Africa, Namibia, and other countries to estimate distributions and abundances of CPS in other ecosystems, and the operational methods and results have been reviewed and published extensively. The main benefits of acoustic sampling is that it can be conducted continuously while a survey vessel is underway; the sampling range, volume, and resolution are greater than those of alternative techniques; and the data provide quantitative information about the distributions, densities and interactions of the various species in a survey area. The challenges of acoustic-trawl surveys are to first survey the potential habitat of the target species; identify the target species' contribution to the total acoustic backscatter; estimate the mean acoustic backscatter per individual fish, and combine this information to estimate their biomass densities and total biomass. Total uncertainty, including random and systematic components of measurement and sampling error, is then estimated. Total biomass of sardine was estimated from the summer 2008 survey data as 0.8 million t with a CV of 29%. The biomass was located mostly off the coasts of Oregon and Washington as predicted in summer by a generalized additive model of Pacific sardine habitat. The model also indicates that surveys of sardine may be most efficiently conducted during the months of June and July when: (1) the habitat is compressed along the coasts of Oregon and Washington, (2) the fish are generally north of Point Conception and south of the Strait of Juan de Fuca, (3) daytime survey effort is maximum, and (4) the survey analysis can be augmented with fishery catch data from the same general time and place. Collecting these data as part of the NWFSC biennial hake survey, which is conducted in this time and place, may offer additional survey efficiencies. Further analyses are required to assess the utility of these data.

## **Discussion**

In response to a question, Demer indicated that acoustic observations are best conducted during daylight because the Pacific sardine observed by echosounders are deeper and thus available to acoustic sampling.

Additional challenges to the method were also discussed: One challenge to acoustic sampling is that the fish may react to the ship. Pacific sardine and other coastal pelagics have been observed during the day in acoustical tracings at depths of between approximately 10 and 70 m with mean depth of 20 m. One possibility is that when the vessel approaches Pacific sardine schools, they dive and become more available to acoustic sampling. The depth distribution of Pacific sardine changes depending on their position relative to shore, the season, and the surface conditions (e.g. turbulence).

The Simrad MS70 sonar has the capability to create a three-dimensional image of a near-surface school within 500 m perpendicular to a vessel. This tool, slated to be installed on FSV6, may help to explain the vertical distributions of sardine schools and to quantify error associated with acoustically estimated biomasses of epi-pelagic fish.

Another challenge is attributing the acoustics data to other coastal pelagic species, given that some organisms may have similar frequency responses. There is also the possibility of underestimating diffuse aggregations or individual fish.

It was noted that the NWFSC has been conducting a regular hake survey using trawling and acoustics methods along the West Coast to estimate hake abundance. Data collected from that survey contain information on Pacific sardine. Demer suggested that the data be analyzed for possible use for measuring Pacific sardine abundance and the group agreed this would be a possible data source to explore.

Demer also explained that habitat modeling and acoustics sampling could be used to guide other Pacific sardine surveys. Acoustics and the habitat optimization model could be used to stratify and reduce variance in other surveys. Predicting the habitat reduces the number of zero observations in sampling and also reduces costs. His model was tested against data from CUFES, fishery landings, and scientific catches around the Columbia River mouth. The predicted habitat is consistent with historical records and recent observations.

Acoustics are best augmented with targeted-trawl sampling to determine species and to estimate their sizes. Fishery landings can also be used to obtain length data. Catch information can be used if it is spatially and temporally coincident with the acoustic sampling.

It was noted that CWPA has acquired a BioSonics scientific echosounder (a portable system) which will be used opportunistically to measure Pacific sardine schools (see Section VII). The goal is to use the system to measure the same school as the LIDAR and aerial camera.

In discussion of point sets (Doc. 3) used in aerial surveys to determine the relationship between surface area of observed Pacific sardine schools from aircrafts (photos) and the actual tonnage of the schools from capture (purse seine) of the observed schools, the concept of using acoustics to determine tonnage instead of capture was discussed. The concept was described as “virtual point-sets” and could increase the sample size for the surface area to tonnage relationship without capturing schools that are too large for available purse seine vessels to handle or schools that avoid the vessels.

## ***2. Fishery-dependent (logbook) survey (K. Hill, Doc. 6)***

Kevin Hill reviewed the use of logbook information for estimating an abundance index for Pacific sardine. Stock assessment scientists often use fishery logbook data to infer changes in population abundance over time. Before utilizing logbook or survey data in an assessment one must first ask: 1) does the survey/fishery sample a sufficient amount of the population to accurately represent overall trends; 2) do changes in the index represent changes in population size or just local availability; 3) is the catchability coefficient ‘ $q$ ’ constant over time, or has it changed due to fishing practice or survey technique?; and 4) does  $q$  remain constant as population density changes? MacCall (1976) examined catch-per-unit-effort (CPUE) and abundance data from the historic Pacific sardine fishery and estimated that  $q$  was inversely proportional to population abundance, i.e., the catchability of sardine increased as the population declined. An inverse relationship between catchability and population size means that CPUE will most likely remain stable as the population declines. This phenomenon has been observed during collapse of other major coastal pelagic fish stocks such as Atlantic menhaden, Norwegian herring, and the Peruvian anchoveta. This is a highly undesirable characteristic for a stock assessment time series as it will result in misinformed management decisions. While logbook data may not provide useful time series for the current Pacific sardine stock assessment, there are other potential uses for the data, including: indices of local abundance for spatially-explicit research models; data for improving ongoing Pacific sardine habitat prediction models; optimizing survey design; economic data for PFMC or other regulatory analyses; documenting fishing grounds in the event that MPAs are proposed for those areas; improving Total Catch Accounting, including by-catch and discards.

### **Discussion**

Hill reiterated that CPUE as a index of Pacific sardine abundance from logbooks is well known to be misleading as an indicator of abundance because CPUE tends to remain constant when abundance decreases because of increasing catchability. However, it was noted that because catchability is related to improvements in the fishing capability of a unit of fishing effort, after a period of efficiency improvements, efficiency stabilizes. For the sardine boats, this may already have occurred and hence, CPUE may be currently useful as a measure of local abundance, especially with the data stratified by small areas.

Hill noted that Oregon and Washington require logbook recording by the northwest sardine fishery, although the data requirements are not standardized, whereas California does not. Although logbook data might not be useful for measuring total population abundance, Hill reminded the group that logbook data are useful for tracking catch

location, verifying landing information, estimating school size and monitoring expansion and contraction of the population. Other uses are for studying preferred habitat, economics of the fishery and by-catch in the fishery. The group agreed it would be worthwhile to establish a consistent logbook along the entire West Coast.

### **3. LIDAR survey (J. Churnside, Doc. 7)**

James Churnside reviewed the airborne LIDAR survey method for estimating biomass. Airborne LIDAR uses a laser to probe the upper ocean and readily detects schools of fish like Pacific sardine. The presentation described the results of experimental surveys of Pacific sardine in the Pacific northwest and menhaden in Chesapeake Bay. The main strengths of this technique are the high speed and low cost with which surveys can be performed. The main weaknesses are limitations to identification of species and limited depth penetration. These strengths and weaknesses were discussed.

#### **Discussion**

Churnside elaborated on limitations and advantages of the LIDAR method. He noted that the surface footprint of the LIDAR beam is five meters, an OSHA standard for occupational use of laser beams. There is some scattering of the beam's energy because of sea state and time of day. For example, the top two meters of the ocean is observed when sea state is rough. He noted that when it is rough, not many fish are found in the top two meters of the surface. Best depth penetration is during the night, but the day-night difference is not large.

### **4. Satellite (as augmentation to aerial surveys) (T. Jagielo, Doc. 8)**

Tom Jagielo described use of satellite photography for assessing location, number, and size (area) of Pacific sardine schools. An example of satellite-derived photography collected for Pacific sardine school analysis off the southern Washington coast in August of 2009 was presented. Considerations of the advantages and limitations or challenges of using satellite photography for Pacific sardine school analysis were discussed.

#### **Discussion**

Satellite data may be used to assist in the planning and design of surveys employing other methods, or as a primary tool for estimating densities of schools throughout the Pacific sardine spatial distribution. Survey effort can be stratified before an acoustical or aerial survey using satellite information on school location and size.

It was pointed out that NASA or others should have powerful analytical tools to enhance satellite images to accurately detect schools in the images. GeoEye currently does visual imaging and is in the business of developing products for users. GeoEye might be approached to explore development of an inexpensive tool for enhancing current available images to more accurately identify Pacific sardine schools. Expertise in photo image enhancement is available at the SWFSC and it was suggested that that expertise should be consulted.

## 5. *Trawl survey (swept area) (J. Schweigert, Doc. 9)*

Jake Schweigert presented a summary of swept-area trawl surveys off Vancouver Island, Canada. Swept-area trawl surveys provide a method for estimating population abundance if the distribution and density of the target species can be estimated. It assumes unbiased and representative sampling of the population. Factors such as vessel avoidance and gear selectivity can result in biased sampling. Surveys employing mid-water trawls near the surface have been conducted on the west coast of Vancouver Island from 1997 to present to examine the distribution and relative abundance of sardine. Abundance estimates were calculated using representative trawl catches from the surface to 30 m depth, collected during surveys in late June, July, and August. The July surveys have generally been most indicative of the relative sardine biomass in Canadian coastal and offshore waters. Biomass estimates were calculated from data collected during cruises from 1997 to 2009. In general, the trawl surveys provide an empirical estimate of relative sardine abundance in Canadian waters. An issue that remains is describing the northerly extent of the annual feeding migration. A considerable portion of the fishery occurs in areas not surveyed north of Vancouver Island where an abundance of Pacific sardine is clearly present. Another issue is the abundance of Pacific sardine in inlets on Vancouver Island and in mainland inlets which are not surveyed routinely. The annual survey is constrained by the availability of survey vessels which has restricted the survey to key strata along the west coast of Vancouver Island that have historically contained the bulk of the Pacific sardine. Some experimental trials have been conducted with aerial surveys but to date these have not been very successful. Nevertheless, aerial surveys could be used in future to augment trawl surveys in areas north of Vancouver Island. Similarly, there has been limited capacity to conduct acoustic surveys during the swept-area survey and this could be augmented in future.

### **Discussion**

The group raised some questions regarding limitations and challenges the survey method faces: In response to a question, Schweigert indicated that the estimates from his survey reflect limits of the survey range. This issue is recognized and needs to be addressed. Regarding differences in performance owing to change from day to night trawling in 2006, Schweigert indicated that in 2005, Canada DFO conducted comparative day and night surveys. The day catch was 21% greater than the night catch. Schweigert noted that the age composition of Pacific sardine from the 2009 survey is preliminary and the aging needs to be reviewed.

In response to a question about whether fishermen are involved in the survey, Schweigert indicated that Canadian fishermen have not yet been involved but they are interested in collaborating. The question being reviewed by DFO is how to conduct joint surveys with the involvement of the fishing fleet. Schweigert also explained that there is currently 10% observer coverage of the fishery.

Regarding how the Canadian trawl surveys differ from the SWFSC trawl sampling, it was indicated that the gears (especially the trawl doors) and trawling speed are different. A comparative survey to test the performances of the different gears would be useful.

Schweigert was asked whether his trawl survey has been combined with other survey technologies. Schweigert explained that satellite SST data have not been used to estimate the distribution of Pacific sardine. Also, while acoustic technology has not yet been used, he is interested in utilizing that technology to augment the trawl results.

Extending the U.S. aerial survey into Canada to cover the northern limits of the stock beyond the U.S. northwest was discussed. It was noted that there is interest in extending the survey but there is a lack of experienced pilots and the costs are prohibitive for such an extension; hence, future application of aerial methods is unknown.

## **VI. REVIEW OF PLANS AND PARTNERSHIP OPPORTUNITIES: 2010-2011**

The group reviewed the advantages and limitations/challenges of each survey method particularly with respect to the current Pacific sardine stock assessment method; these are summarized in Table 1. The group also reviewed existing and proposed survey plans, which are summarized in Table 2.

Stock assessment of the Pacific sardine resource is regularly produced for the PFMC and is currently highly dependent on abundance information from two surveys, DEPM and aerial, that provide an estimate of total abundance and a minimum estimate of abundance, respectively. Plans for these surveys are in place for 2010 and 2011 with each planned for execution with overlap in area but not time. The 2010 surveys are underway with the SWFSC responsible for the DEPM survey and the Pacific northwest and California sardine industries responsible for the aerial survey. Plans for 2011 surveys are to repeat the 2010 survey designs. The group engaged in a useful discussion on various collaborative projects that can assist in minimizing the limitations and/or augment the objectives of these two surveys.

The group concluded that both 2010 and 2011 surveys should proceed as planned but should incorporate testing of other methods with the proviso that additional methods incorporated into the surveys should not distract from the objectives of the surveys. The group identified two immediate benefits from piggyback collaboration. One is increased efficiency in designing and executing the surveys by taking into account the dynamic seasonal changes in the preferred habitat of Pacific sardine through use of satellite data. The other is validation of tonnage, species composition and sizes of fish in observed schools from the aerial survey through augmentation with acoustics and LIDAR methods as well as with use of purse seine sets.

The group agreed that the following opportunities for collaboration should be pursued for the 2010 surveys:

1. Testing of acoustics and LIDAR methods in the “point sets” experiment (Doc. 3) in the Pacific northwest and southern California fishing areas during the aerial survey. Echosounders might be deployed aboard vessels used by the NWFSC on its annual NWFSC salmon juvenile cruise and by the sardine industry in the Pacific northwest. LIDAR should be deployed on an aircraft used in the Pacific northwest aerial survey.

Similarly for the southern California fishing area, echosounders should be deployed on the SWFSC’s annual CalCOFI cruise. Plans by CWPA to deploy LIDAR are already in place for an aircraft to be used in the aerial survey in southern California. SWFSC (R. Vetter) will be responsible for arrangements for deploying acoustic instruments on the CalCOFI cruises; D. Hanan (CWPA) will be responsible for arrangements to deploy a portable Biosionics scientific echosounder opportunistically on targeted sardine schools during the fall aerial survey; and NOAA/ESRL (J. Churnside) will be responsible for deploying LIDAR in the fall aerial survey. D. Hanan (CWPA) will take the lead for the analyses.

2. Satellite imagery and data should be compiled and tested for estimating the preferred habitat of Pacific sardine, and for forecasting that habitat to optimize efficiencies in designing (optimum sample size) and operating (cost savings) of surveys. The SWFSC (R. Vetter) will take lead.
3. A budget of \$10K was identified to serve as “challenge awards” to encourage collaboration, including work to analyze sardine data contained in records of the regularly conducted NWFSC hake acoustics-trawl survey. The SWFSC (K. Koch) will take lead on exploring whether this data can be used.

Similar opportunities for collaboration are available for the 2011 surveys. Because planning for the 2011 surveys is not yet in final form, collaborations should be more easily incorporated in the survey plans at the outset and thus, enable enhanced efficiencies. Priority should be given to

replicating tests conducted in the 2010 surveys, but also to looking for opportunities for augmenting trawl sampling and increasing sample sizes for biological data. A budget of \$625K was estimated as required for incorporating piggyback methods on the two surveys in 2011; this assumes that a 2011 EFP with similar provisions as the 2010 EFP (Doc. 3) will be approved.

## **VII. CLEARING OF REPORT AND COMMITMENTS FOR FOLLOW THROUGH**

### **1. Commitments for follow through**

During the review and discussion of available survey methods, it was evident that because of the characteristics of the methods or different areas where they have been deployed, they provide data that yield different estimates of abundance. The group concluded that this is troublesome and that the methods need to be tested and compared under similar conditions and standards. The group agreed that a technical design team should be organized to design an experiment that will compare all of the Pacific sardine survey methods (aerial, DEPM, LIDAR, trawl, satellite, acoustic) under similar conditions, such as season, area, environmental conditions, and sizes of sardine. The design team would draw upon available information on sardine stock structure and biology, information gained from the DEPM and aerial surveys conducted to date, and fishery information, to design the experiment for small areas and a short period. The experiment should be planned for 2012, to not disrupt existing survey plans for 2010 and 2011, and with consideration for the need to replicate in subsequent years. The SWFSC should take lead in organizing the team in consultation with stakeholders. The objective would be to have the team's design, budget estimate and plan for execution available by March 2011, for budget considerations and for execution in 2012.

### **2. Clearing of report.**

Sections I-VI of the workshop report were reviewed and approved by the group before the close of the workshop. Sakagawa explained that notes for the remaining Sections VII-IX of the report would be used to draft those sections. The entire draft report would then be made available to participants for review and comments before finalizing. For this process, the group provided Sakagawa with the authority to make decisions on incorporating comments and to finalize the report as soon as possible.

## **VIII. CLOSE OF WORKSHOP**

In closing, Gary Sakagawa thanked everyone for contributing to the workshop and expressed his opinion that the interactions were productive. He thanked the CWPA for sponsoring the social and participants, especially those who traveled long distances to be in La Jolla, for their contributions.

Usha Varanasi also thanked everyone for their participation, including the SWFSC support staff and acknowledged that this was a valuable effort by the stakeholders. She expressed her expectation that valuable collaborations and products would result from this meeting and the spirit of cooperation developed at this workshop will continue.

**TABLE 1**  
**SUMMARY OF ADVANTAGES AND LIMITATIONS & CHALLENGES\* OF**  
**SURVEY METHODS**

### **Aerial Survey**

#### *Advantages*

- Provides an empirical estimate (fishery-independent) of minimum abundance
- Makes use of experienced spotter pilots and their observations
- Surveys are conducted in optimal weather conditions
- Could be used to provide estimates of other species, boats, etc.

#### *Limitations and Challenges*

- Speed at which the plane can fly
- Time – may take several days or even weeks to complete a “SET” due to prohibitive weather
- Species identification – need to confirm
- Schools extending outside of visual frame (edge effects)
- Conversion of aerially estimated school area to sardine biomass
- Probability of detection is affected by depth, school size, sea state, etc.

### **Daily Egg Production Method**

#### *Advantages*

- Eggs are non-evasive,
- Provides estimates of egg production, egg mortality, reproductive parameters, and spawning biomass with the measurements of precision, e.g. the coefficient of variation (CV).
- A short cruise time
- Data of other species and oceanographic measurements, valuable for other coastal pelagic species
- Provides fishery-independent long-term time series of relative abundance for the stock assessment model

#### *Limitations and Challenges*

- Patchy distribution of eggs requires large number of net tows or a well-designed survey
- Adult samples require intensive lab work and a good number of trawls with mature fish
- Adult sardine migrate and spawning habitat can move outside current DEPM survey area biasing the abundance estimates
- Some biological parameters require regular updating

### **Acoustics**

#### *Advantages*

- Estimates distribution and abundance of multiple species
- Conducted concomitant with other ship-based sampling
- Continuous sampling, depth and distance
- Refined methods accepted and used worldwide
- Multi-species observations - ecosystem surveys

- Can be conducted synoptically
- Pending review, ready for use in stock assessment

*Limitations and Challenges*

- Optimized sampling - define habitat and optimally allocate survey effort
- Animal behavior including avoidance
  - Horizontal migration
  - Vertical migration
  - Aggregation variation
- Species identification
- Target Strength estimation

**Logbook**

*Advantages*

- Catch location, quantity, and SST data provide input for habitat prediction models. This could be used to optimize survey design
- Important to document fishing ground utilization in event closures are proposed
- Improving Total Catch Accounting including bycatch and discards.
- Economic data for regulatory impact reviews and other analyses
- Potentially can provide index of local abundance for use in spatially-explicit research models.
- Oregon and Washington already have logbooks which are likely standardized
- Logbooks are collected in Canada

*Limitations and Challenges*

- Catchability coefficient is inversely proportional to population size; highly problematic for catch-per-unit effort (CPUE) time series in an assessment
- No logbooks currently exist for the directed commercial fishery in California
- No logbooks currently provide trip target data and detailed effort information
- Canadian and existing US logbooks are not standardized

**LIDAR**

*Advantages*

- Low platform cost (aircraft)
- No vessel avoidance
- Synoptic surveys
- Potentially estimates biomass
- Provides additional information on school density, shape and depth

*Limitations and Challenges*

- Target identification
- Target strength estimation
- Observational range (depth penetration)
- Narrow swath width
- Technology not yet commercially available

**Satellite Photography (private)**

*Advantages*

- Only pay for data used

- Specific ocean and weather conditions can be requested (i.e. % cloud cover, % water vapor, ocean surface conditions)
- Time – These satellites travel the entire coast in a matter of minutes
- Extensive synopticity
- Single platform reduces potential for equipment bias
- Reduced possibility of “double counting” of sardine schools
- Fewer personnel needed to acquire data

*Limitations and Challenges*

- Species identification
- Image processing
- Weather may preclude sampling at specific times
- Ground truthing

**Trawl survey (swept area)**

*Advantages*

- Simple to conduct
- Provides direct identification of targets and ground truthing of other methods
- Less weather dependent
- Provides critical biological information on the target population
- Widely accepted, provides ancillary data on other cohabiting species
- Can provide a direct biomass estimate

*Limitations and Challenges*

- Expensive, requires vessel and staff resources
- Data analysis can be complex (have to incorporate gear efficiency, etc.)
- Difficult to account for vessel and gear avoidance
- Generally not possible to confirm the entire spatial distribution of the target population
- Unable to sample some areas (nearshore, untrawlable areas, potential protected species interactions)

\*Limitations and challenges common to all or most methods (such as mechanical problems) are not listed.

TABLE 2 (continued): EXISTING AND PROPOSED SURVEYS TO COLLECT DATA FOR STOCK ASSESSMENTS OF PACIFIC SARDINE IN THE CALIFORNIA									
CURRENT*									
Methods	Objective: Primary (biomass/index)	Objective: Fish age group	Location	Duration in years	Time Period (length)	Platform	PI	Collaborators	Needs
Aerial	Summer: Min.estimate of absolute abundance	Adults	Synoptic - Cape Flattery to southern California	2009, 2010	[during close of directed fishery]late July - Sep 14; 35 days)	4 Airplanes, 8 fishing vessels	NWSS/CWPA - T. Jagielo/D. Hanan	Industry, PFMC	Expedite exempted fishing permit mechanism, NOAA real time habitat estimates, Twin-engine plane[s]
	Fall: Evaluate alternate survey methods; i.e. aerial photogrammetry, lidar, acoustics, day vs. night	Adults in southern California	Southern California Bight, centered on Catalina Island to 75nm offshore	2010	Concurrent w/ fall CalCOFI - late Oct-Nov (10-14 days)	2 Airplanes, 4 purse-seine fishing vessels	CWPA - D. Hanan/J. Churnside	Industry, CalCOFI, SWFSC	Expedite exempted fishing permit mechanism, NOAA real time habitat estimates, Twin-engine plane[s]
Acoustic	Biomass and distribution of sardine, other CPS, and their zooplankton prey	Adults	San Diego to San Francisco	1986-present (most years) (1986-88 conducted by CDFG)	Late March to Early May (22 days)	NOAA research vessel, SIO RV, fishing vessel	SWFSC - David Demer	Industry	Trawl samplers, Fishery catch data, Lidar, aerial observations
	Biomass and distribution of sardine, other CPS, and their zooplankton prey	Adults	Predicted habitat - between Pt. Conception and Strait of Juan de Fuca	n/a	June-July	NOAA vessel and charters	SWFSC - David Demer	Industry	Trawl samplers, Fishery catch data, Lidar, aerial observations
Daily Egg Production	Spawning biomass	All ages of adult fish All eggs and yolk-sac larvae	San Diego to San Francisco	1986-present (most years) (1986-88 conducted by CDFG)	Late March to Early May (22 days)	NOAA research vessel, SIO RV, fishing vessel	SWFSC - Nancy Lo	CDF&G	Verify lab experiments of temperature dependent egg development rates
	Spawning biomass	All ages of adult fish; All eggs and yolk-sac larvae	coastwide survey from San Diego to US-Canada boarder	2006, 2008 (2), 2010	Late March, April, Early May; sometimes in July (35 days)	NOAA research vessel and chartered fishing vessel	SWFSC - Nancy Lo and Bev Macewicz	CDF&G, NWFSC	Verify lab experiments of temperature dependent egg development rates; semi-annual occurrence
	April 2011, basic area biomass	1+ years	US-Mexican Border to San Francisco, CA	n/a	April 2011, basic area	NOAA vessel	SWFSC - Sam McClatchie	NWFSC, SIO	better adaptive sampling, better trawling, better lab expts, better coordination, better forward looking sonar, fast tow cam
	April 2012 coastwide-biomass	1+ years	Mexico to Canada		April 2012 coastwide	NOAA vessel	SWFSC - Sam McClatchie	NWFSC, SIO	better adaptive sampling, better trawling, better lab expts, better coordination, better forward looking sonar, fast tow cam
	July 2012 coastwide-biomass	1+ years	Mexico to Canada		July 2012 coastwide	NOAA Vessel	SWFSC - Sam McClatchie	NWFSC, SIO	better adaptive sampling, better trawling, better lab expts, better coordination, better forward looking sonar, fast tow cam

TABLE 2 (continued): EXISTING AND PROPOSED SURVEYS TO COLLECT DATA FOR STOCK ASSESSMENTS OF PACIFIC SARDINE IN THE CALIFORNIA									
CURRENT*									
Methods	Objective: Primary (biomass/index)	Objective: Fish age group	Location	Duration in years	Time Period (length)	Platform	PI	Collaborators	Needs
<b>Fishery Independent</b>	live bait log - California (voluntary after 1998) - Purpose: fishery monitoring	Commercial fish available in California livebait fishery	California	1933-present		commercial purse seines	CDFG		incorporated as part of federal CPS logbook; size sampling to provide potential recruitment index
<b>LIDAR</b>	biomass; feasibility studies; spatial distribution and env factor relationships	adult	Washington and Oregon	2003, 2005, 2006	July (03), Aug (05), May (06), (~14days)	light aircraft	NOAA ESRL - James Churnside	SWFSC (03), NWFSC, Uni W., OR state (05, 06), industry, U AK fairbanks	
	biomass; collaboration with aerial survey	adult	S. California		Oct. 2010 (~14 days)	light aircraft	NOAA ESRL - James Churnside	CWPA	
<b>Satellite</b>	Evaluate alternate survey methods (biomass)	0-3 years	Synoptic - Cape Flattery to southern California	n/a	consistent with aerial	Satellite, fishing vessels, planes	NWSS/CWPA-T. Jagielo/D. Hanan	Industry, PFMC, SWFSC, Can DFO, NESDIS	NASA? or private Satellite data
<b>Trawl survey</b>	Biomass	All, primarily >2 years	British Columbia	1997-present	July - Aug (~10days)	WE Ricker	Canada DFO - Jake Schweigert	Possibly Aerial, high seas salmon	Plane
	Biomass	All, primarily >2 years	British Columbia		July - Aug (~10days)	plane	Canada DFO - Jake Schweigert	trawl	Plane

*Proposed surveys are shaded	
Acronyms	
Can DFO	Department of Fisheries and Oceans Canada
CDF&G	California Department of Fish and Game
CWPA	California Wetfish Producers Association
ESRL	NOAA Earth Systems Research Laboratory
NESDIS	NOAA Environmental Satellite, Data, and Information Service
NWFSC	NOAA Northwest Fishery Science Center
PFMC	Pacific Fishery Management Council
SIO	University of California, Scripps Institution of Oceanography
SWFSC	NOAA Southwest Fishery Science Center