Daily Egg Production Methods for Pacific Sardine

Report of STAR Panel Meeting

NOAA / Southwest Fisheries Science Center
La Jolla, California
May 4-8, 2009

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)
Ken Burnham, External Reviewer, Colorado State University

Pacific Fishery Management Council (Council) Representatives:
Greg Krutzikowsky, Coastal Pelagic Species Management Team (CPSMT)
Mike Okoniewski, Coastal Pelagic Species Advisory Subpanel (CPSAS)
Mike Burner, Council Staff

Sardine Daily Egg Production Method (DEPM) Technical Team:
Nancy Lo, NMFS, SWFSC
Beverly Macewicz, NWFS, SWFSC
Kevin Hill, NMFS, SWFSC

1) Overview

The review of the Daily Egg Production Method (DEPM) as it is applied to Pacific Sardine was conducted by a Stock Assessment Review Panel ((Panel) which met at the SWFSC, La Jolla, CA, from May 4-8, 2009. The membership of the Panel was broader than is normal for assessment reviews in order to include expertise on survey methodology and design as well stock assessment. Material documenting the methodology used for DEPM generally, and as it has been applied to Pacific Sardine, 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 and the additional analyses that were conducted during the course of the meeting.

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 DEPM.
- 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.
- Use of DEPM estimates in stock assessments for Pacific Sardine.

2) Design of the Sampling Scheme

The sampling scheme follows a design originally developed for northern anchovy in the early 1980s, and which has since found widespread use in fisheries around the world. The most important difference from the anchovy DEPM and that for sardine is the much larger geographic scope of the sardine population, which ranges from Mexico to Canada. The survey consists of concurrent and complementary surveys of pelagic egg abundance and of adult spawning rates conducted in a relatively short period of time, e.g., one month. The estimate of adult biomass is the number of pelagic eggs spawned per day divided by the average daily quantity of eggs produced per unit weight of mature adult sardines.

2.1) Pelagic Egg Abundance

The egg survey uses an adaptive sampling scheme based on near-surface egg densities measured by a continuous underway sampling system (CUFES). The survey is generally conducted during April, which is a peak time of spawning activity. Eggs have been sampled using a vertically-retrieved plankton net of relatively small diameter (CalVet: CalCOFI Vertical Egg Tow). Since 1997, high egg abundance areas are sampled more intensely than low density area, and the subsequent calculations are based on a two-stratum (high vs. low) estimation scheme. Egg age is determined by stage of development, and the production rate of freshly spawned eggs is calculated from a regression of daily egg and yolksac larvae production on age. The most substantial problem with the egg abundance portion of the DEPM is incomplete coverage of the spawning area, which is unavoidable due to the current inability to access ichthyoplankton data from Mexican waters in a timely manner. The attempts to cover the full geographic range of spawning in U.S. waters have been commendable, and the lack of complete coverage is usually due to factors beyond control, such as adverse weather, equipment malfunction, and limited ship time and staff. The review did not identify any serious problems with operational aspects of the pelagic egg survey portion of the sardine DEPM.

2.2) Adult Spawning Rate
The Panel considered several issues and potential problems with sampling and calculation of adult spawning rate and its component parameters. Unfortunately, many of the necessary data were unavailable for use during the review, preventing the Panel from reaching some conclusions or from recommending appropriate changes in procedures and calculations (see "Data Accessibility" below).

Population Heterogeneity: The present methodology treats each trawl sample as being equally representative of the population, with the main pattern of heterogeneity being related to the high and low egg density strata, as described in Section 2.1. There appear to be other patterns of heterogeneity which could result in recommended methodological changes. Specifically, there is clear evidence for spatial heterogeneity in average fish weight, with larger fish tending to occur to the north and offshore, suggesting a possible benefit from further stratification of the adult samples. Although the limited available data appeared to indicate that the size composition of sampled fish approximately reflected regional size patterns in fishery-caught sardines, there remained some concern within the Panel that the northernmost portion of the stock may not be adequately represented in the adult samples. It also appears that this northern segment may not be spawning as actively as the better-sampled more southerly portion of the population at the time of the DEPM survey. If this is the case, the estimated population spawning rate would be somewhat lower if these northern fish were represented, and the DEPM estimate of spawning biomass would be somewhat larger. Available data did not allow evaluation of this hypothesis.

The Panel agreed with the Technical Team that annual adult sample sizes (both in terms of positive sites and number of fish) are undesirably small. The Panel **recommends** that efforts should be made to increase the number of adult samples.

3) Analytic Treatment of the Data
Stratification: The Panel **recommends** more extensive use of stratification in estimation of the adult spawning rate parameters, but recognizing that small sample sizes place a constraint on the amount of stratification that should be considered (also see Section 4 in this regard). A first level of stratification would be to estimate the adult reproductive parameters using the same high and low production regions identified by the pelagic egg sampling survey. This approach has been presented in recent DEPM reports, but with an unweighted stratification scheme. The Panel **recommends** that the two strata (regions 1 and 2) should be weighted by their relative adult abundance. Trawl catch rates appear to be too variable to serve as a basis for this weighting. However, an approximate measure of the adult abundance is given by the present unweighted stratified calculation of DEPM estimates of spawning biomass, therefore a single iteration of reweighting should suffice. Other patterns of heterogeneity could provide motivation for further stratification of adult spawning rate estimates.

Hierarchical (Random Effects) Modelling: The present and historical treatment of DEPM estimates has been to rely entirely on contemporary sample-based measurements of parameters as much as possible. In years when sampling has failed to produce a reliable estimate of a parameter, there has been a pattern of *ad-hoc* borrowing of needed quantities from previous years. Importantly, the present practice is to produce a DEPM estimate (which, should be noted, is done under severe time pressure), with no explicit intent to revise the entire time-series of estimates on a regular basis.

The Panel **recommends** that a hierarchical modelling approach (a.k.a. random effects modelling) should be adopted for estimation of spawning rate parameters. Each new annual estimate would be based both on new data and on the historical data, with substantial improvement in precision. If new data are lacking, the *ad-hoc* "borrowing" would be replaced by a well-documented statistical basis for estimating missing parameters. This would allow construction of estimates of spawning biomass for all years for which estimates of egg production (P_0) are available. At present, estimates of egg production for such years are treated as a separate data series in the stock assessment (referred to as Total Egg Production [TEP]). It should be noted that the entire estimated time series of spawning rate parameters would change somewhat with each new year of samples. Once the statistical model has been developed and implemented (there are relevant procedures in many commonly-used statistical packages such as *R, SAS*, WinBUGS, and *SPLUS*), annual updates would require very little time and effort. Initial development would require more work, and probably should not be attempted for 2009 unless help can be obtained from a statistician who has experience in this specialty.

There also may be an opportunity to improve the precision of the estimated fraction spawning. The present procedure is to use only day 1 post-ovulatory follicles, but day 2 and day 3 follicles should be informative, and a properly specified model should provide a basis for using the additional information. This would in effect increase the sample size without additional sampling effort and the Panel **recommends** that this approach be explored further.

It was noted that there are some fish at depths deeper than those depths sampled by the trawl. The Panel **recommends** that the relative abundance of these deeper fish be determined (perhaps by means of acoustics) and an evaluation conducted to assess whether they are a significant source of uncertainty.

4) Implementation of Survey Protocols
Operationally, one of the major difficulties facing the DEPM for sardines is the ability to obtain a sufficiently large number of adult samples over a sufficiently large portion of the adult range, all in the relatively short time window of the survey. The Panel **recommends** that additional sources of adult fish samples should be explored. Commercial fishing vessels are a potential source of adult samples, and cooperative research with the fishing industry would be worth pursuing. The latter may require an exempted fishing permit (EFP) from the Council, and the project would be a good candidate for NMFS cooperative research funding.

5) Use of DEPM in Stock Assessments of Sardine
The original DEPM methodology estimated the biomass of mature males and females combined, based on an estimated sex ratio parameter. In the historical context of DEPM usage for anchovy management, the abundance estimate was used directly in setting annual harvest levels, and this combined-sex treatment was appropriate for that purpose. However, the present usage for sardine assessment differs in that the DEPM is one of many data inputs to a demographic model Stock Synthesis (SS). In SS, it is more suitable to input the female spawning biomass (or more accurately, the population egg production), in which case the sex ratio parameter is not a necessary part of the DEPM calculation. Because the sex ratio parameter is an estimated parameter that is subject to sampling error, its deletion should also result in some improvement in the relative precision of the abundance estimate. However, the DEPM estimates are treated as relative indexes (q is estimated, and is less than 1), so use of female-only spawning biomass estimates would have less benefit than would be the case for an estimate of absolute estimate.

4

The Panel **recommends** that the DEPM estimates should be input to the stock assessment in the form of the biomass of spawning females (i.e. ignore the sex-ratio of mature animals when computing the indices).

Trawl data are effectively missing for 2006 (i.e. the trawl and the egg samples were not synchronized in that year due to operational reasons), therefore the Panel **recommends** that this estimate should not be treated as a DEPM estimate. The 1995 survey only collected ichthyoplankton data from the standard CalCOFI grid. The Panel **recommends** this estimate not be included in the stock assessment at all, because it not comparable with the remainder of the time-series and to re-specify the SS model accordingly.

The Panel **recommends** that a complete and annotated table similar to Table 3 in the 2008 report, including the information from the 1980s CDFG surveys, should be available (and included in the stock assessment report) for the upcoming sardine assessment.

6) Data Accessibility
The Panel was not able to fully evaluate the sensitivity of the estimates of spawning biomass from the DEPM to important methodological assumptions because much of the raw data from the trawl surveys were not available to the analysts (and hence the Panel) during the review meeting. While the analysts attempted to address the Panel's requests for additional analyses to the extent possible given the available data (essentially the summary data published in previous reports), the lack of raw data constrained the Panel's ability to examine issues and to draw definitive conclusions.

The Panel **strongly recommends** that the Terms of Reference for Stock Assessments for CPS (and other Council fishery management plan (FMP) species) be modified to require raw data for key model inputs be available at STAR Panels to allow for further analyses. The need for raw data is critical for any future STAR Panel tasked with reviewing survey methodology. Although some data sources may be excessively large, and other data sources may not yet be in machine-readable format, suitable database management systems exist, and are within all agencies' capability to employ and maintain. Moreover, use of formal databases is nearly always beneficial to research programs that require extensive data collection.

7) Areas of Disagreement
There were no major areas of disagreement between the Technical Team and Panel.

8) Summary of Research Recommendations
General
   • The Terms of Reference for Stock Assessments for CPS (and other Council FMP species) should be modified to require raw data for key model inputs be available at STAR Panels to allow for further analyses.

Tasks to be Completed Prior to the September 2009 Sardine Assessments
   • The estimates of spawning biomass for 1985, 1986 and 1988 should be re-calculated using a statistical system that is consistent with the more recent DEPM estimates.
   • Estimate the adult reproductive parameters using the same high and low production regions identified by the pelagic egg sampling survey.
   • The two strata (regions 1 and 2) should be weighted by their relative adult abundance.

- The DEPM estimates should be input to the stock assessment in the form of the biomass of spawning females (i.e. ignore the sex-ratio of mature animals when computing the estimates).
- The data for 2006 should be used in the assessment as an estimate of TEP rather than as part of the DEPM series.
- Estimates of abundance based on the 1995 survey should not be included in the stock assessment at all and re-specify the SS model accordingly.
- A complete and annotated table similar to Table 3 in the 2008 report, including the information from the 1980s CDFG surveys, should be available (and included in the stock assessment report) for the upcoming sardine assessment.

Longer-term research priorities
- Efforts should be made to increase the number of samples of adults.
- A hierarchical modelling approach (a.k.a. random effects modelling) should be adopted for estimation of spawning rate parameters.
- The use of day 2 and day 3 follicles should be explored as a way to estimate the spawning fraction.
- The relative abundance of fish deeper than can be sampled by the trawls should be determined (perhaps by means of acoustics) and an evaluation conducted whether these fish represent a significant source of uncertainty.
- Additional sources of adult fish samples should be explored.

Appendix 1

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)
Ken Burnham, External Reviewer, Colorado State University

Pacific Fishery Management Council (Council) Representatives:
Greg Krutzikowsky, Coastal Pelagic Species Management Team (CPSMT)
Mike Okoniewski, Coastal Pelagic Species Advisory Subpanel (CPSAS)
Mike Burner, Council Staff

Sardine Daily Egg Production Method (DEPM) Technical Team:
Nancy Lo, NMFS, SWFSC
Beverly Macewicz, NWFS, SWFSC
Kevin Hill, NMFS, SWFSC

Others in Attendance
Alexandre Aires-da-Silva, Inter-American Tropical Tuna Commission (IATTC)
Briana Brady, California Department of Fish and Game (CDFG), CPSMT
Ray Conser, SWFSC, SSC
Doyle Hanan, Hanan and Associates
Sam Herrick, SWFSC, CPSMT
Roger Hewitt, SWFSC
Ryan Kapp, Astoria Fisherman
Josh Lindsay, NMFS, Southwest Regional Office
Mark Maunder, IATTC
Sam McClatchie, SWFSC
Jonathan Phinney, SWFSC
Kevin Piner, SWFSC
Diane Pleschner-Steele, California Wetfish Producers Association, CPSAS
Rosa Runcie, SWFSC
John Rutter, SWFSC
Bob Seidel, Astoria Holdings Inc.
Sarah Shoffler, SWFSC
Dale Sweetnam, CDFG, CPSMT
Akinori Takasuka, SWFSC
Russ Vetter, SWFSC
Ed Weber, SWFSC

Appendix 2 Requests and Responses

A. Compare the size-composition of the trawl samples with the assessment model estimates of the size-composition of the total population. Do the same comparison for ages, if possible. Possibly divide the trawl samples into northern and southern segments.
Reason: Is there evidence for biased selection in the trawl samples? Is there evidence for north/south population heterogeneity that is somehow a problem?
Response: The DEPM Technical Team (TEAM) didn't have access to the size-composition data from the trawl samples. Data are partially in figures in the Team report–forthcoming.

B1. For some of the years, re-calculate adult spawning parameters and the biomass estimate using samples weighted by trawl catch.
B2. Correlate/scattergram of biological values vs trawl catch size.
B3. Do alternative B2 using Table 2 in the 2007 document to compare biological values with number sampled.
Reason: Possibility of better statistical treatment of sample data.
Response: Sex ratio and spawning fraction don't seem to vary with latitude, but average fish weight does. This suggests that latitudinal population structure merits more investigation. The plot of spawning fraction against sample size shows possible (but not conclusive) correlation of trawl catch with spawning fraction. These patterns need larger sample sizes to confirm. The existence of high and low egg density regions suggests possible spatial differences in sex ratio and spawning fraction. Weighting by catches was influenced by a single outlier in the case that was examined. This does not allow determination of an optimal weighting system. The subject would benefit from a meta-analysis to determine the best weighting scheme, based on variance as a function of trawl catch size.

C. Drop, or expand the 1995 survey to include the probable central California segment.
Reason: The 1995 survey covered a small area and there were no trawls; the survey result is based on CalCOFI eggs, not DEPM.
Response: No response was necessary during the review. This applies to the upcoming assessment.

D. Summarize information on the 1986, 1987, and 1988 surveys using a format similar to Tables 4 and 6 of the 2008 report. Also document any peculiarities.
Reason: These surveys are poorly documented.
Response: The Team found the original CDFG reports. The egg data exist, but it is unclear whether all of the adult data still exist. The 1980s CDFG surveys were conducted later in the year than is the case now (fish were thought to spawn during the summer, based on historical experience). If the original data can be obtained, the Panel **recommends** that the estimates should be re-calculated using a statistical system that is consistent with the more recent DEPM estimates.

E. Re-stratify trawl balance in high and low density areas consistently.
Reason: Too many changes make it difficult to do comparisons. Also, methodological changes can be a source of estimation variability.
Response: The Team revisited the high-low area stratification. There is a precision benefit from stratified estimation of adult parameters

F: Do separate DEPM calculations for high and low density regions, at least for 2007, but preferably for several different years. Compare the results with the original estimates (and their precisions).
Reason: There is a possible heterogeneity of adult parameters in the high and low egg density regions. How does the estimate change if we stratify the adult parameters similarly?
Response: The Team revisited the high-low area stratification. There is a precision benefit from stratified estimation of adult parameters

G: Re-calculate the 1998 estimate using conventional stratification and statistical treatment.
Reason: The original estimate used region 1 only -- We don't know what the consequences were of treating it differently, and this will allow us to compare estimates. Consistent methodology is desirable, other things equal. This is an extension of request E.
Response: This was done.

H: Reweight the 2007 and 2008 stratified estimates by abundances
Reason: Weighting by area is an approximation, but can be improved by iterative reweighting based on the estimated spawning population in each area (one-time iterative reweighting). The ideal approach is to weight by actual abundance in the two areas, however, we were unable to get an index from trawl catch rates.
Response: The Team presented the results, which suggested that stratification improved the precision of the estimates.