Pacific Sardine

STAR Panel Meeting Report

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1. **Overview**

The STAR Panel (hereafter the Panel) reviewed the assessment documents prepared by the STAT for Pacific sardine. The entire STAT was available to present and discuss aspects of the report.

The Panel focused exclusively on assessment models for Pacific sardine. The Terms of Reference for CPS STAR panels includes consideration of management recommendations. The Harvest Guideline for Pacific sardine is currently based on the catch control rule specified in the CPS Fishery Management Plan. The STAR Panel did not review the basis for this catch control rule but noted that the SSC has identified that a future STAR Panel could evaluate the catch control rule for Pacific sardine (and Pacific mackerel). Public comment on the issue on the control rule (verbal and written) was presented to the Panel. The written public comment will be forwarded to the Council.

The "wetfish" purse-seine fleet in California historically has taken CPS (market squid, Pacific sardine, northern anchovy, Pacific mackerel, jack mackerel, bonito), and tunas on an opportunistic basis. The fishery has progressed from one focused primarily on squid and Pacific mackerel in the early 1980s to one that focuses substantially on squid and sardine, although the fishery still relies to some degree on all target species. A CPS purse-seine fishery focused primarily on sardine has developed in the Pacific northwest in recent years.

The results from the assessment models presented to the Panel were preliminary and based on data through 2003. The Panel did not focus on the consequences of the results, and instead focused on the most appropriate framework for conducting future assessments of Pacific sardine. The first occasion that any new assessment for Pacific sardine could be used to provide management advice will be November 2004.

The STAT provided results for two assessment frameworks: CANSAR-TAM (catch-at-age analysis for sardine – two area model) and ASAP (age structured assessment program). CANSAR-TAM has provided the basis for the assessment of Pacific sardine since 1998. CANSAR-TAM is an extension to the CAGEAN approach to fisheries stock assessment that explicitly allows for migration of the northern component of the Pacific sardine population from southern California to the Pacific northwest. The assessment relies on indices of abundance for southern California to infer the status of the total population size.

The migration model underlying CANSAR-TAM is simple, and the values for the parameters related to migration are largely arbitrary. The treatment of the fisheries in Pacific northwest in CANSAR-TAM is also *ad hoc*. In contrast, ASAP is a multi-fleet model that can deal relatively straightforwardly with the component of the population in the Pacific northwest, both in terms of its contribution to the spawning biomass and to the catches. Both the STAT and Panel agreed that ASAP provides a more defensible basis for conducting assessments of Pacific sardine.

The Panel commended the STAT for their excellent presentations, well-written and complete documentation, and their willingness to respond to the Panel's requests for additional analyses.

2. Requests made and comments to the STAT during the meeting (Table 1 provides a summary of the alternative models considered during the workshop).

a) **Assemble a table of the sample sizes on which the catch-at-age matrix is based**.
The sample sizes for the USA-California fishery range from 432 (1984) to 3887 (1995). The Panel agreed that, given that the sample sizes are all fairly large, and the fact that there are several sources of uncertainty associated with the catch-at-age data other than sampling error, there is no need to assign year-specific weights to the catch age-composition data when fitting the population dynamics model.

b) **Examine the implications of different assumptions about selectivity in the USA-California using "bubble plots" of residuals.**
The residual patterns for the baseline case in the assessment document provide no evidence for trends in residuals within cohorts but several "runs" of residuals within age-classes are evident. The Panel highlighted the continuing importance of reviewing the residuals about the fits to the catch age-composition data, particularly once these data have been revised.

c) **Examine the trends in *q* for the CalCOFI percent positive index and the spawning area index.**
There are noteworthy trends in *q* (increasing for the percent positive index / decreasing for the spawning area index). These trends were expected given percent positive indices will saturate at high population size while square miles of spawning area would under-estimate spawning stock size if there is a "basin effect". See Section 3.2 for further discussion in terms of the utility of these indices for tuning purposes.

d) **Examine the sensitivity of the results to setting the population weights-at-age from 1990 equal to the weights-at-age in the catch.**
The results of this sensitivity test were broadly similar to those for the baseline case. The most notable difference between the results of this sensitivity test and those from the baseline case were that the estimates of recruitment for 1990-99 were greater for baseline case. The Panel and the STAT agreed that this was expected given that the fishery weights-at-age are higher than the population weights-at-age for these years. The value of a sensitivity test along these lines will be enhanced once the assessment software can include separate fishery and population weight-at-age matrices.

e) **Plot indices against each other in the form of an X-Y plot.**
These plots suggest that the relationships among the DEPM (Daily Egg Production Method), CalCOFI percent positive and spawning area indices are, in general, not linear. There does appear, however, to be a linear relationship between the DEPM and spotter plane indices, even though these indices relate to different components of the population.

f) **Conduct a sensitivity test in which the only abundance indices are the DEPM estimates and the spotter plane index.**
The results of this sensitivity test were not statistically different to those for the baseline case, although the variances were slightly larger owing to the reduction in

the number of data points. The Panel agreed that this sensitivity analysis should form the baseline case for the November 2004 assessment.

g) Conduct a preliminary evaluation of estimation uncertainty using the Markov chain Monte Carlo (MCMC) module.

The results of a preliminary application of the MCMC algorithm (1,000,000 cycles) indicated evidence for lack of convergence (see Fig. 1). The Panel advised the STAT to examine the .COR matrix from ADMB and to use this to guide how the model should be re-parameterized in future to reduce the correlations among the model parameters. It is likely that modifying the parameterization of selectivity in the first year should lead to reduced correlation among the selectivity parameters.

h). **Examine the sensitivity of the results of the assessment to having a single selectivity pattern for entire 1983-2003 period and to there being three periods of selectivity (1983-91, 1992-97, and 1998-2003).**

The fit to the data deteriorates markedly if selectivity for the southern California fishery is assumed to be time-invariant, providing support for having at least two periods of fishery selectivity. There is little improvement in fit if three periods of fishery selectivity are assumed for the southern California fishery. The Panel agreed that the baseline case for the November 2004 assessment should include two selectivity periods for the southern California fishery.

3. Technical merits and/or deficiencies of the assessment

The STAT identified three areas of considerable (but largely unquantifiable) uncertainty in its initial presentation to the Panel:

- Stock structure and migration are not well understood
- Fishery-independent data are limited to central and southern California, even though spawning occurs off Mexico and limited spawning has been reported to the north.
- The biological data for the Mexican, Canadian and Pacific northwest fisheries are limited.

3.1 Stock structure

There are several hypotheses regarding the stock structure of Pacific sardine. The current stock assessment is based on the working hypothesis that Pacific sardine off northern Mexico, southern California, northern California and the Pacific northwest constitute a single biological stock with substantial mixing / migration. However, there is considerable uncertainty regarding this hypothesis. Evidence that may support an alternative stock structure hypothesis includes:

- The presence in the Pacific northwest of some spawning and some zero-year-old fish.
- The marked differences in mean weight-at-age among fish in the Pacific northwest and those off southern California (the fish tend to be much larger and have higher weight-at-age off the Pacific northwest).

There is also uncertainty regarding the relationship between the fish found offshore of where the fishery off California is prosecuted and those elsewhere, and between the Mexican fish and those elsewhere. The Panel emphasized the considerable importance of research to resolve issues related to stock structure, and to develop abundance indices for areas in addition to southern California. The latter aspect is as important as the former because, if data are collected which provide support for an alternative stock structure hypothesis (e.g. separate California and Pacific northwest stocks), abundance data for the Pacific northwest will be required to conduct an assessment for the population in this area. Even if additional data confirm the present working hypothesis, there is still considerable value in obtaining abundance information for regions other than for which the DEPM and spotter plane indices are available.

The importance of resolving stock structure uncertainty was also emphasized during the period of public comment.

The Panel, the STAT and members of the public identified several areas of research which might shed light on the issue of stock structure (see Section 6.1). It was agreed that for the present time, the assessment should be based on a single coastwide assessment.

3.2 Input data

The variant of the assessment presented initially to the Panel included four indices of abundance: a) the CalCOFI percent positive index, b) the DEPM index, c) the spawning area index, and d) the spotter plane index (see Table 1 for the basic data for the first three indices). The STAR panel noted that the three fishery-independent indices are correlated with each other because they are based on the some of the same underlying data and that the DEPM estimates of abundance are correlated among years because of the way the biological information for 1994 is used to construct the DEPM estimates for several years.

The Panel noted that the DEPM estimates used in the assessment are based on biological data (from which the estimates of daily fecundity per gram are computed) from 1994 and 2002[1]. Although the estimates of fecundity per gram are fairly similar for 1994 and 2002, the values for the biological parameters that are used to estimate fecundity per gram differ markedly between 1994 and 2002. For example, percentage spawning was 7% for 1994 and 17% for 2002. The Panel agreed that biological data for use in the DEPM should be collected more routinely in the future than has been the case in the past.

There is an overlap between the data on which the DEPM estimates are based and the data on which the spawning area and CalCOFI percent positive indices are based. Furthermore, unless allowance is made for time-varying catchability, the fit of the model to the latter two indices is very poor. The Panel and STAT considered three ways to resolve this problem:

- Ignore the CalCOFI percent positive and the spawning area indices and base the assessment solely on the DEPM and spotter plane indices.
- Include the CalCOFI percent positive and the spawning area indices in the assessment but restrict them to years for which the assumption that these indices

[1] Data for 2004 are still being processed so were not available to the Panel.

are linearly proportional to abundance appears to be most valid (e.g. prior to 1998 for the CalCOFI index and after 1998 for the spawning area index).

- Use a mixed effects model to fill in years with no DEPM data.

The Panel and STAT agreed that the assessment to be presented to the Council in November 2004 should be based on ignoring the CalCOFI percent positive and the spawning area indices.

The Panel and STAT were concerned about relying substantially on the DEPM estimates when it is known that these can vary markedly from one year to the next. The Panel agreed that an attempt should be made to extend the DEPM method so that constraints are placed on the extent to which the estimate of P_0 (the number of eggs spawned) can vary over time to avoid biologically unrealistic changes in this quantity. One approach that could be investigated is to force a time-series structure on the values for P_0 over time.

3.3 Biological data

The model makes use of the weight-at-age data for the population (in addition to that for the fishery). Weight-at-age in the catches off southern California are lower than weight-at-age in the population because the larger individuals appear to be located outside the areas that are fished primarily. Survey data are used to infer post-1990 population weight-at-age. However, this is a crude approach and efforts should be made to include data on weight-at-age from the fisheries in the Pacific northwest when constructing population weight-at-age. This problem can not, however, be resolved easily without sampling of offshore and northern areas to determine the relative proportion of the population in different areas, such as through the use of a synoptic survey of the entire west coast.

3.4 Other

The catch control rule relies on the estimate of 1+ biomass for the start of the last year of the assessment period. The STAT currently bases this estimate on population weight-at-age. However, the alternative of basing it on the fishery weight-at-age may be more appropriate. This issue should be considered when the catch control rule is reviewed at a future STAR Panel.

The weightings given to the various data sources and penalties (the lambdas) impact the sizes of the variances calculated using asymptotic (Hessian and delta method) and Bayesian approaches. The Panel noted that it would be desirable to develop an overall scaling parameter so that the residuals about the data are not over-dispersed relative to the variances implied by the lambda values.

4. Areas of disagreement

There were no areas of major disagreement between the STAT and the Panel[2].

[3] The Panel was unable to reach agreement on the correct way to pronounce certain letters of the Latin and Greek alphabets. The Panel therefore recommends that future Panels include not only LANs but also translators who can translate from American “English” into English as it is used elsewhere.

5. Unresolved problems and major uncertainties

Problems unresolved at the end of the meeting form the basis for the recommendations in Sections 6.0 - 6.3.

6. Recommendations

The following recommendations are not given in priority order.

6.0 General

The Tri-national Sardine Forum should be utilized to share fishery, survey and biological information among researchers in Mexico, Canada, and the U.S. The long-term benefits of this forum will be greatly enhanced if it can be formalized through international arrangements.

6.1 Stock structure

a) Growth data for Mexico, southern California, northern California, the Pacific northwest and the offshore areas should be collected and analyzed to quantitatively evaluate differences in growth among areas. This evaluation would need to account for differences between Mexico and the U.S. on how birthdates are assigned, and the impact of spawning on growth.
b) The timing and magnitude of spawning off California and the Pacific northwest should be examined.
c) The likelihood of various stock structure hypotheses should be examined using existing tagging data and additional tagging experiments or (preferably) techniques such as analyses of trace element composition.
d) Information which could be used in an assessment of the Pacific northwest component of a single coastwide population or of a separate Pacific northwest stock should be obtained. Synoptic surveys of Pacific sardine on the entire west coast have the potential to provide such information as well as the basic data needed to address research questions 1) and 2) above.

6.2 Data and monitoring needs

a) The Panel endorsed the aerial survey which started during 2004 and emphasized the value and importance of a rigorous survey protocol. It suggested that the surveys be augmented to estimate schooling areas and distinguish schools. It also supported the collection of data (e.g. bearing and distance to schools) which could be used in line transect-type estimation methods. ‘Sea-truthing’ of the species identification of the aerial surveys will enhance the value of any resulting index of abundance.
b) An aerial survey program should be started in the Pacific northwest. Such a survey program would provide data for a component of the population currently not surveyed. However, it would take several years before any index based on such a survey could be included in the assessments.
c) The current abundance indices provide data which can be used to fit a population dynamics model. However, alternative methods for indexing the population (e.g. acoustics) should continue to be evaluated. Acoustic methods are a qualitatively different approach to indexing relative abundance and are the primary fishery-independent method for obtaining abundance indices for many of the world’s major

pelagic fish stocks. Acoustic methods have been applied to northern anchovy off California. Acoustic data have the potential to provide information on the relative abundance of the populations off southern California and the Pacific northwest.

d) The catch-at-age data should be updated so that ages are defined in terms of a calendar year lifecycle (if the model continues to be based on a calendar year). At present the catch-at-age matrix combines animals from different cohorts into the same age-class because no account is taken of the assumed 1 July birthdate.
e) Biological data for use in the DEPM must be collected and analyzed more routinely in the future than has been the case in the past.
f) The DEPM method should be extended so that constraints are placed on the extent to which the estimates of P_0 vary over time.
g) The impact of environmental variability on the CalCOFI percent positive data should be examined.
h) The data on maturity-at-age should be reviewed to assess whether there have been changes over time in maturity-at-age, specifically whether maturity may be density-dependent.
i) The algorithm used to determine the catch proportion-at-age data from the raw data collected from the fishery should be documented and included in the assessment report.

6.3 Modeling and assessment issues

a) The November 2004 assessment for Pacific sardine should be based on an extension of ASAP in which:
    - allowance is made for fleet-specific weights-at-age (specifically the fishery weights-at-age for the fishery in the Pacific northwest);
    - spawning biomass is defined in terms of the numbers at the end of the year;
    - explicitly include a zero age-class;
    - a log-normal bias-correction factor is included in the component of the objective function related to deviations about the stock-recruitment relationship; and
    - parameter uncertainty is quantified using the MCMC algorithm.
b) The data on which the November 2004 assessment will be based will differ from those on which the analyses reviewed during the Panel meeting:
    - only the DEPM and spotter plane indices will be used as abundance indices when fitting the model;
    - the latest fishery and abundance index data will be included in the assessment;
    - substantial additional catch-at-age data for the Mexican fisheries for 1983-2002 will be included in the assessment;
    - additional catch-at-age data for the fisheries in the northwest will be included in the assessment; and
    - the DEPM estimate will be enhanced using new biological data.
c) An attempt should be made move from a model that is based on a calendar year to one based on a biological year. This may improve the fits of the model to catch-at-age data but may lead to the catch-at-age data being overweighted relative to the abundance indices.
d) The extent of ageing error should be quantified and included in future assessments.

e) The sensitivity of the results of the assessment to the assumption that recruitment is related to spawning biomass by a Ricker stock-recruitment relationship should be examined.
f) The sensitivity of the results of the assessment to the weight assigned to each data point / abundance index (e.g. equal weight, weight based on the sampling standard error) should be explored.
g) Environmental covariates should be considered when fitting the stock-recruitment relationship.
h) Confidence intervals for the data should be added to the time-series plots which compare observed *versus* model-predicted values.
i) The values for the lambdas should be chosen so that these are consistent with variances of the residuals.
j) Data that may be included in assessments for years beyond November 2004:
    - additional indices of abundance for Oregon / British Columbia / Mexico.
    - the results of the new spotter plane index (if the new index can be related to the historical index).
    - an index based on the spawning volume for Pacific sardine (if such an index can be developed).
k) Sensitivity should be examined to different southern boundaries for the "stock" (i.e. if there is a separate stock off northern Mexico, how does it mix with the stock(s) exploited in the U.S.).

Table 1. Sardine models considered during the STAR Panel

Run	Description	Number of Parameters	Total Likelihood	SSB Virgin (1000 MT)	SSB 2003 (1000 MT)	Recruits 2003 (Billions)
R06-9	Baseline in paper	131	381	2,038	1,490	9.4
R08-0	Remove 2 indices: CalCOFI and Spawn Area. New Baseline	129	281	2,100	1,609	9.9
R08-1	Use USA-CA fishery WAA as population WAA. R08-0 is still new baseline	129	268	1,628	1,836	8.2
R08-2	No time varying selex R08-0 is still new baseline	111	359	1,676	1,365	13.7
R08-3	3 selex blocks for USA-CA 1983-92 / 1993-97 / 1998-2003 R08-0 is still new baseline ???	135	276	2,086	1,510	7.8

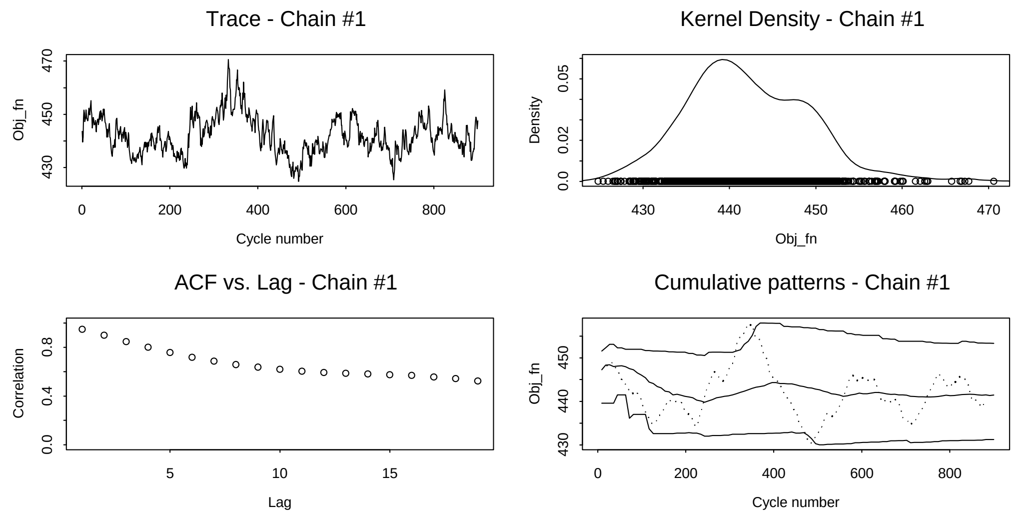
Table 2. Raw data used to construct the DEPM estimates and the indices of abundance based on the positive stations in the CalCOFI surveys and the spawning area.

Year	***P*₀**	***Z***	**Area (km^2)**	**SSB (CV)**	**Positive Stations**	**Spawning Area index**	**Spotter Plane**
1983					-	40	-
1984					4.9	480	-
1985					3.8	760	-
1986				7,659	1.9	1,260	22,049
1987				15,704	4.0	2,120	11,498
1988				13,526	7.9	3,120	55,882
1989					7.2	3,720	32,929
1990					3.7	1,760	21,144
1991					16.7	5,550	40,571
1992					8.8	9,697	49,065
1993					6.1	7,685	84,070
1994	0.193 (0.21)	0.12 (0.91)	380,175	127,102 (0.32)	17.8	24,539	211,293
1995	-	-	-	-	13.4	23,816	188,924
1996	0.415 (0.42)	0.105 (4.15)	235,960	83,176 (0.48)*	28.0	25,890	119,731
1997	2.77 (0.21)	0.35 (0.14)	174,096	409,579 (0.31)*	27.3	40,591	66,943
1998	2.279 (0.34)	0.255 (0.37)	162,253	313,986 (0.41)*	24.3	33,446	118,492
1999	1.092 (0.35)	0.10 (0.6)	304,191	282,248 (0.42)*	16.7	55,171	50,506
2000	4.235 (0.4)	0.42 (0.73)	295,759	1,063,837 (0.67)*	7.8	32,784	48,373
2001	2.898 (0.39)	0.37 (0.21)	321,386	790,925 (0.45)*	12.5	31,663	-
2002	0.728 (0.17)	0.4 (0.15)	325,082	206,333 (0.35)	7.1	61,753	-
2003	1.52 (0.18)	0.48 (0.08)	365,906	485,121 (0.36)	14.2	41,702	-

* $CV = (CV^2(P_0) + 0.054CV_{1994}^2)^{1/2}$

Figure 1. Example MCMC diagnostics for two model outputs. The panels for each quantity show the trace, the posterior density function (estimated using a normal kernel density), the correlation at different lags, the 50-point moving average against cycle number (dotted line in the rightmost panels), and the running mean and running 95% probability intervals (solid lines in the rightmost panels).

(a) The objective function



(b) The second selectivity parameter