# Report of the National Marine Fisheries Service/Pacific Fishery Management Council Workshop on Pacific Sardine Distribution

NOAA Fisheries, Southwest Fisheries Science Center, La Jolla, California
August 17-19, 2015

**Table of Contents**



Jacobson, Parrish, and MacCall at the source for the Scripps Institution of Oceanography pier temperature.

## 1. OVERVIEW

A workshop to examine the Distribution parameter in the harvest control rule (HCR) for the northern subpopulation of Pacific sardine, and to examine potential alternative means of accounting for the fact that some portion of the U.S. stock is present and subject to harvest outside U.S. waters was held at the Southwest Fisheries Science Center (SWFSC), during 17-19 August 2015 (see Appendix A for the draft Agenda). The participants (see Appendix B) included three members of the Pacific Fishery Management Council (PFMC; Council) Scientific and Statistical Committee (SSC), representatives of the PFMC Coastal Pelagic Species (CPS) Advisory Subpanel, and representatives of the PFMC CPS Management Team, as well as other scientists with knowledge of the data and methods pertinent to specifying the amount of northern subpopulation of Pacific sardine in U.S. waters.

Dr. André Punt, the workshop chair, called the meeting to order, and Dr. Cisco Werner (SWFSC) welcomed the participants. Dr. Punt outlined the purpose of the workshop and the process for developing and agreeing on the report.

Mr. Kerry Griffin then provided an overview of the Terms of the Reference for the Workshop (Appendix C). He noted that the workshop is one part of the settlement agreement related to *Oceana, Inc. v. Penny Pritzker, et al*. (Ninth Circuit No. 13-16183; District Court No. C-11-6257 EMC (N.D. Cal.)). The purpose of this workshop as specified in the settlement agreement is:

> *To examine and discuss the DISTRIBUTION parameter in the Pacific sardine harvest control rule used in setting management reference points to account for the presence of sardine in the waters of the United States, Mexico, and Canada. Workshop participants are expected to compile the best available scientific information on the distribution of Pacific sardines along the North American Pacific coast as well as examine potential alternative means of accounting for the fact that some portion of Pacific sardine stock exists and is subject to catch outside of U.S. waters.*

In opening the workshop, the Chair emphasized that the focus of the workshop was on the Distribution term in the U.S. HCR for the northern subpopulation of Pacific sardine. He noted that there are several topics of interest related to Pacific sardine and its management, such as stock structure, the form of the HCR, and the way assessments are conducted. However, he noted that this workshop was focused on Distribution, so the discussions would be focused on that topic and this workshop report would not focus on issues unrelated to Distribution.

This workshop report is organized primarily around the five alternatives identified in the Terms of Reference:

1. Setting the value for the Distribution parameter annually as part of the specifications process based on the most recent data on the actual mean distribution of the Pacific sardine stock in U.S. waters.
2. Using landings information from Canada and Mexico to account for catch in the waters of those nations in estimating the Distribution parameter in the HCR, using work from recently published scientific studies regarding Pacific sardine management.
3. Estimating the stock biomass in U.S. waters only, instead of the total sardine biomass, in the stock assessment.
4. Using a numerical-based Distribution parameter as an alternative to the existing percent-based Distribution parameter.

5. Using a temperature-based model to predict the proportion of Pacific sardines in U.S. waters for a particular year.

The workshop also considered a sixth topic proposed by representatives of Oceana, a conservation organization:

6. Considerations for revising the Pacific Sardine Distribution Parameter.

The report of this workshop will be provided to the Council, who will then determine whether to take further action regarding the Distribution parameter at its November 2015 meeting.

The first section of this report provides background regarding Pacific sardine, the HCRs used to set overfishing limits (OFLs), acceptable biological catches (ABCs), and harvest guidelines (HGs), as well as the basis for the current value of Distribution. Each subsequent section summarizes the presentations provided for each alternative (see Appendix D for a list of documents), and the discussion among the workshop participants.

The Chair appointed rapporteurs for each section of the report

- Background: Dr. André Punt.
- Setting Distribution annually and survey approaches for estimating Distribution: Mr. Tom Jagielo.
- Using landings data: Dr. Owen Hamel.
- Estimating the stock biomass in U.S. waters only: Dr. Cleridy Lennert-Cody.
- Using a numerical-based Distribution parameter: Mr. Kirk Lynn.
- Using a temperature-based model, Dr. Lennert-Cody.
- Overall report preparation and coordination: Dr. Punt.

In closing the Workshop, the Chair thanked the SWFSC for hosting the Workshop and the SWFSC staff, who provided logistical support to the workshop. The Chair also thanked the participants for the work they did prior to the workshop in developing the background material, especially given the limited time available prior to the workshop, and for the constructive way the discussions were conducted. He thanked the rapporteurs.

## 2. BACKGROUND

There is general agreement that there are three stocks of Pacific sardine off the west coast of North America: the Gulf of California stock, the southern subpopulation of Pacific sardine, and the northern subpopulation of Pacific sardine (Felix-Uraga *et al.*, 2005; Smith, 2005). The workshop focused on the northern subpopulation of Pacific sardine, which is managed in the U.S. under the CPS Fishery Management Plan (CPS FMP). It is known that some of the catch of sardine off the U.S. includes animals from the southern subpopulation, while some of the catch of sardine off Mexico includes animals from the northern subpopulation (Demer and Zwolinski, 2014a; Hill *et al.*, 2015). The stock assessment for the northern subpopulation of Pacific sardine was previously based on all of the catches from Ensenada north, but the most recent two assessments (the 2014 benchmark assessment and the 2015 update) were based on catches designated to be from the northern subpopulation using the method of Demer and Zwolinski (2014a). In recent years, the designation of which subpopulation a catch is taken from have been based on the method of Demer and Zwolinski (2014a), and several of the approaches outlined in this report are based on that method.

Management of northern subpopulation of Pacific sardine is based on three HCRs: (a) the OFL HCR, (b) the ABC HCR, and (c) the HG HCR. The OFL and ABC HCRs were revised during 2014, and the Council recommended revising the HG HCR. Changes to the HCRs were based on research undertaken during a 2013 workshop (PFMC, 2013) that showed that temperature measured during the California Cooperative Oceanic Fisheries Investigation (CalCOFI) surveys has a stronger relationship with the deviations about the stock-recruitment relationship for the northern subpopulation of Pacific sardine than the Scripps Pier index of temperature that had been used earlier. The exploitation rate (Fraction) in these HCRs depends on CalCOFI temperature, with maximum and minimum limits imposed on Fraction. The focus for the current workshop was the Distribution parameter that is used in the OFL and ABC control rules, as well as the HG control rule:

$$\text{OFL} = \text{Biomass} * \text{Fraction} * \text{Distribution} \tag{1a}$$
$$\text{ABC} = \text{Biomass} * \text{Fraction} * \text{Distribution} * \text{Buffer}_{\text{pstar}} \tag{1b}$$
$$\text{HG} = (\text{Biomass} - \text{Cutoff}) * \text{Fraction} * \text{Distribution} \tag{1c}$$

where Biomass is the estimate of the biomass of Pacific sardine aged 1 and older at the start of the season; Cutoff is 150,000 mt, and is the escapement threshold below which fishing is prohibited; Distribution is the average proportion of the biomass of the northern subpopulation in U.S. waters; and $\text{Buffer}_{\text{pstar}}$ is a factor to account for scientific uncertainty. In addition, there is a maximum allowable catch regardless of biomass such that: HG $\leq$ Maxcat, where Maxcat is 200,000 mt. The purpose of Cutoff (presently 150,000 mt) is to protect the stock when biomass is low. The purpose of Fraction is to specify how much of the stock is available to the fishery when Biomass exceeds Cutoff.

As stated above, Biomass (minus Cutoff in the HG control rule) used in three primary control rules for setting U.S. catch levels of Pacific sardine is prorated by an "estimate of the portion of the stock resident in U.S. waters" through the use of Distribution, which has been set at 0.87 (PFMC, 1998). This approach is described in the CPS FMP, and is intended to account for the fact that some level of the sardine stock exists outside of U.S. waters and can therefore be subject to harvest by fisheries in neighboring countries. The 0.87 was chosen based on the best information available when Amendment 8 to the CPS FMP (PFMC, 1998) was created, and in light of the absence of an international agreement governing management of Pacific sardine off the North American west coast. Distribution, as defined in the CPS FMP, is an estimate of the long-term average of the portion of total stock biomass of the northern subpopulation occurring in U.S. waters, and is a simple way to prorate the biomass estimate used to calculate U.S. catch limits; it is not a prescription of actual catch levels by the combined fishing vessels of the U.S., Canada, and Mexico in any given year. All sardines caught in U.S. waters count against the U.S. catch limit, including those from the southern subpopulation.

Pacific sardine exhibit annual and inter-annual migratory patterns that depend on the attributes of the populations as well as oceanographic effects, and the actual portion of the northern subpopulation of Pacific sardine in U.S. waters at any given time is highly variable. While the Council's policy has been to account for the migratory and international nature of the sardine stock through the use of the Distribution parameter, Amendment 8 recognized that it is impractical to accurately gauge the precise proportional distribution at any given time. Therefore, although the original estimate of the Distribution was informed by the best scientific information available, the determination of the value of Distribution is ultimately a policy decision rather than solely a scientific one. Recognizing this, the Council considered two data sources (spotter data and CalCOFI data) for estimating Distribution as part of Amendment 8. The Council chose a fixed factor of 0.87 as the best available science regarding a long-term average, for use in the HCRs based on the recommendations of the Amendment 8 analysis. Ultimately, the Amendment 8 analysts recommended using the spotter pilot estimate because they considered that it was a more realistic number than the CalCOFI index or a combination of the two.

Josh Lindsay stated that although the Magnuson-Stevens Act (MSA) does not mandate a harvest reduction to account for fishing on the same stocks by fisheries beyond the jurisdiction of the U.S., for stocks such as Pacific sardine for which there is no international management, if the stock becomes "...overfished, or is approaching a condition of being overfished due to excessive international fishing pressure, ... then the Secretary and/or the appropriate Council shall take certain actions..." (Section 304(i) of the MSA). Such actions include the Secretary or appropriate Council developing recommendations to end overfishing and/or to rebuild the stock, taking into account the relative impacts of the U.S. fishery. For Pacific sardine, he stated that this would likely look something like what is already done under the CPS FMP using the Distribution parameter to unilaterally reduce the level of U.S. fishing.

**2.1 Oceana Presentation**

Primary Document 5 outlined some concerns and requested further analyses related to the Distribution parameter. The authors of Primary Document 5 stated that the basic function of Distribution is to unilaterally determine the portion of sustainable coastwide fishing levels that can be taken by the U.S. fleet. The authors interpret this such that this fixed parameter E means that Canada and Mexico can only catch the remaining 13 percent or risk exceeding sustainable levels. The problems with Distribution and the current management framework identified by Primary Document 5 were (a) there is no common policy for managing Pacific sardine between the U.S., Canada, and Mexico, therefore no assurance that Canada and Mexico will determine catch levels according to the U.S. estimation of the portion of the stock in respective waters; (b) the current Distribution value is based on outdated science, and that science gave no consideration to the portion of the stock in Canadian waters, or the variability in sardine distribution; and (c) a fixed 87 percent Distribution value risks coastwide overfishing, it risks ecosystem effects, and undermines the goals of the CPS FMP when a large proportion of the population is present and fished in the Mexican and/or Canadian Exclusive Economic Zone (EEZ). Primary Document 5 also noted that, while Mexico and Canada do not follow the U.S. HG HCR, its modeled performance - which managers have used as a basis for the selection of the HCR to achieve optimum yield - is highly sensitive to the assumption that those countries actually do follow it (Hurtado-Ferro and Punt, 2014). Primary Document 5 stated that the purpose of Distribution, and the problems with the current value necessitate its reevaluation, including the current definition in the CPS FMP. Hence, in the absence of a cooperative international agreement, alternative approaches to Distribution should be considered such as a higher Cutoff (as suggested in the CPS FMP and the Amendment 8 analysis) or an approach that accounts for recent landings by Mexico and Canada (*e.g.*, Demer and Zwolinski, 2014b and Primary Document 1), which may more optimally determine ecologically sustainable U.S. fishing levels. Similarly, the authors of Primary

Document 5 stated that subtracting predicted foreign landings from a total OFL to set U.S. OFL may be more effective at preventing coastwide overfishing.

The workshop noted in discussion that the HG HCR for Pacific sardine applies to all catches in U.S. waters. In several years, the catch of sardine designated to be southern subpopulation animals using the approach of Demer and Zwolinski (2014a) in U.S. waters equals or exceeds the difference between the catch by Mexico and Canada and 13 percent of the value from Equation 1 if the Distribution term is ignored.

## 3. SETTING THE VALUE FOR THE DISTRIBUTION PARAMETER ANNUALLY AS PART OF THE SPECIFICATIONS PROCESS

### 3.1 Spotter data

Primary Document 2 reviewed the original analysis conducted for Amendment 8. In the original work, an estimate of 0.87 was reported for the proportion of the schooling biomass of the northern subpopulation of Pacific sardine in U.S. waters. This estimate was obtained from fish spotter logbook data for 1963-92 using delta log linear models originally developed for northern anchovy (Lo *et al.,* 1992). Primary Document 2 reported the results of new work, prepared for this workshop, which was conducted with the objective of re-checking the original estimates of the Distribution parameter. The new analysis of the fish spotter data used data from the years 1985-2001, because the original data set for 1963-92 could not be located in the time available. The new estimates of Distribution ranged from 0.84-0.89, providing, in the view of the authors of Primary Document 2, support for the original 0.87 estimate in PFMC (1998). Technical issues, including an estimation bias in the original analysis, the lack of an intercept term, and a modification of the parameterization to avoid negative proportions did not appear to have a large impact on the final results.

In the discussion, it was noted that a key assumption of the Amendment 8 analysis and the re-analyses for this meeting is that the spotter pilots were observing only animals from the northern subpopulation. Also discussed were the effects of movement, time, and biomass on sardine distribution, and the fact that the spotter pilot data do not extend into the Pacific Northwest, and thus were limited spatially relative to the distribution of the northern subpopulation. This is relevant because the years considered in Primary Document 2 and PFMC (1998) did not include years when the northern subpopulation was known to be in the Pacific Northwest and Canada. A strength of this analysis is that it potentially integrates the estimate of the Distribution parameter across the entire year, which is important given seasonal migrations.

The raw spotter data were not available to the analysts in advance of this meeting (Caruso [1977] and Caruso *et al*. [1979] provide a summary of the data and methods for data collection), so additional analyses could not be undertaken. Further analysis could include improved analytical methods, estimation of error, and consider using an approach such as that of Demer and Zwolinski (2014a) for assigning fish schools to the northern and southern subpopulations, along with the potential of recovering the original data and extending the time series beyond 2001. It was noted that the actual distribution of the population depends on a number of factors, including: season, weather/climate, size of fish, and stock size. Because of changes in stock size over time, the use of estimates of the Distribution parameter from analyses of older data for the present time period could be problematic. It was also noted that the method of Lo *et al*. (1992) assumes that area is a proxy for habitat, which may be incorrect because of inter- and intra-annual variation in potential habitat for Pacific sardine. Furthermore, these spotter data are no longer being collected in ways comparable to the earlier data, precluding using these data to estimate Distribution for recent years.

**3.2 Acoustic-trawl data**

Primary Document 1 estimated the proportions of the northern subpopulation of Pacific sardine in the U.S. EEZ using data from acoustic-trawl surveys. The estimate of the proportion in U.S. waters was always ~1 for the spring surveys and ranged between 0.94 and 0.99 for the summer surveys. The workshop noted that surveys did not cover Mexican waters because of a lack of an international agreement. However, Dr. Demer noted that there is little northern subpopulation habitat off Mexico in spring; the observed distributions of northern subpopulation biomass generally exhibit a gap between their southern extent and the U.S.-Mexico border; and other studies have shown that there is relatively little northern subpopulation sardine spawning off Baja California in spring. Furthermore, Dr. David Demer noted that the spring and summer estimates of abundance were not statistically different, suggesting that there must be little biomass of the northern subpopulation in Mexico in spring. However, without further work to examine the catchability parameter for both the spring and summer, the validity of that conclusion is an open question.

**3.3 Ichthyoplankton data (off Mexico and the USA)**

Primary Document 6 summarized CalCOFI survey methods for eggs and ichthyoplankton relevant to the spawning distribution of sardine. The methods used to collect eggs and larvae, including plankton nets and the Continuous Underway Fish Egg Sampler (CUFES), were presented. Additionally, the historical and current spatial domain for egg and larval sampling was reviewed, and the frequency and spatial coverage of core CalCOFI surveys, spring CPS and CalCOFI surveys, the SaKe survey, and Investigaciones Mexicanas de la Corriente de California (IMECOCAL) surveys were contrasted. Three datasets with potential for analyzing sardine distribution in U.S. and Mexican waters were discussed.

It was noted that, while not informative regarding year-round distribution of sardine, these data could potentially be used to examine the relative proportion of spawning in the U.S. and Mexico. The chief limitations are: 1) the spatial coverage of the data has reduced over time (CalCOFI no longer collects data from Mexican waters), 2) egg data reflect spawning only (data on immature and non-spawning fish are not collected), 3) data are not available for north of San Francisco, 4) the data are seasonal and not useful for computing a year-round spatial estimate of the proportion of sardine, 5) the data do not distinguish between northern and southern subpopulation sardine, and 6) the data do not allow comparison of sardine distribution between years of high and low abundance. The most promising dataset discussed (referred to as Dataset 1 in the presentation) extended from roughly San Francisco to Southern Baja, when sampling was conducted in spring. It is possible that this dataset could be used to address whether the proportion of the population in the waters off Mexico and southern California changes between periods of low (1951-64) and very low abundance (1965-84).

**3.4 Ichthyoplankton data (off Mexico)**

Primary Document 7 examined the variability in the movement and character of sardine spawning over the annual cycle from CUFES data in January-April-July-October 2000. It focused on the difference in sardine biomasses in the CalCOFI and IMECOCAL regions between April of 2002 and 2003. It was found that roughly 20 percent of the egg abundance of the northern subpopulation was found in waters off northern and central Baja California during April 2002, while only 2 percent was found during April 2003. This is explained by the difference in the equatorward flow of the California Current determined by differences in dynamic height that was nearly three times stronger in 2002, a relatively cool year, than in 2003, which was an El Niño year. As a result of this inter-annual variability, the utility and appropriateness of a static estimate of Distribution is in question. The estimation and application of annual estimates of Distribution should be explored. The authors of Primary Document 7 stated that the value of 0.87 for Distribution in the U.S. HCR should be abandoned since it is surely almost never true (and has antagonized Mexican scientists resulting in poor binational collaboration) and suggested that the landings in Canada and Mexico should be estimated by formulating a mean or weighted value of the previous three years of landings.

In discussion, it was noted that the estimates of abundance on which the estimates of 2 percent and 20 percent were based are uncertain, so the precision of these estimates needs to be evaluated and accounted for.

Primary Document 8 examined the distribution of sardine spawning during the months of April and May from years 2000 through 2013 using a random forest model to determine the area of spawning. The model employs: 1) chlorophyll, 2) CalCOFI and IMECOCAL positions (line and station numbers), 3) date and year of sampling, and 4) pumping time of CUFES for collection of the egg samples. Given the results for the area of spawning, then sea surface temperature (SST) $\leq 16.4^{o}$C was used to distinguish the presence of the northern subpopulation within the CalCOFI region in the U.S. compared to that in the IMECOCAL region in Mexico. Results from the model indicate (1) optimal spawning conditions are found in the CalCOFI region; (2) 4.1 percent of the area occupied by the northern subpopulation was found in the IMECOCAL region in April 2002, while only 1.1 percent was found there in April 2003. This is consistent with the results in Primary Documents 7; and 3) there exists a mixture of the northern and southern subpopulations habitats as defined by the SST threshold of $16.4^{o}$C. The authors of Primary Document 8 inferred that the southern subpopulation potential habitat (inferred by SST) extends northward into U.S. waters during the summer-fall period, with a different spawning schedule than the northern subpopulation (with the southern subpopulation spawning mainly in winter and summer indicated by the CUFES data off Baja California), whereas the northern subpopulation potential habitat extends southward during spring during its peak spawning season.

**3.5. Canadian data**

Linnea Flostrand (Department of Fisheries and Oceans, Canada; DFO) gave a presentation with background information and maps from Canada, indicating variation in mid-summer trawl locations and relative sardine catch densities from 1999-2014 off the west coast of Vancouver Island (WCVI). Between years, there are differences in sampling designs and coverage, especially the switch from primarily day trawling (up until 2004) to solely night trawling in 2006. A declining trend in densities is evident from the night survey data and no sardines were caught during the 2013 and 2014 surveys. Examples of other DFO surveys that have detected sardines were briefly described. However, sardine data from these other surveys were not provided, largely because of time and data access limitations. Also, there are some known confounding issues with some of the sampling designs so data would be expected to be useful mainly for inferences based on sardine presence/absence. Summaries of annual Canadian sardine landings from the commercial seine fishery (2002-14) and approximate catch locations were provided. In 2013 and 2014, the fishery did not locate fishable schools so no sardines were landed. Sardine fork length distributions by mid-summer WCVI trawl survey and commercial fishery year were shown (2000-12), and greater than 50 percent of all sardine measured annually were longer than 20 cm. The presentation also included a brief summary of HCRs for the British Columbia sardine fishery, and fishery management issues that have regulated annual fishing allowances, with a focus on the history, intent, and calculation of the migration rate parameter in the HCRs, which acts in a similar way to the Distribution parameter in the U.S. HCRs. The migration rate parameter was dropped from the Canadian HCRs after 2012.

## 4. USING LANDINGS INFORMATION FROM CANADA AND MEXICO TO ACCOUNT FOR CATCH IN THE WATERS OF THOSE NATIONS

### 4.1 Estimating distribution from landings data

Primary Document 3 evaluated the use of landings information to estimate the distribution of the northern subpopulation of Pacific sardine in U.S. waters relative to the subpopulation's total distribution. In this approach, catch is assumed to represent the abundance of the northern subpopulation in U.S. waters relative to the total abundance. Important caveats to this approach are: 1) sardine fisheries operate in a relatively small portion of the overall habitat, so catch is a biased representation of total population; 2) catch is a function of both regional abundance and fishing effort (however, effort information was not available for any of the three national sardine fisheries, so effort must be assumed equal in each country across space and time); 3) regulations; and 4) economic factors can affect effort in the regional fisheries, but these cases were undocumented here.

The author of Primary Document 3 stated that he is not a proponent of this approach for deriving an estimate of Distribution for the U.S. sardine management. Monthly landings data from 1981 to 2014 were filtered using the method of Demer et al. (2014a) to omit the purported southern subpopulation. If any fishery was subject to regulatory closure in a given region and month, then all data for that year were excluded from the analysis. Years included in the final analysis were 1992, 1995, and 1997-2007. These criteria had the effect of excluding certain years (2010-11) when the proportion of U.S. landings were even lower (0.46, 0.54). The proportion of U.S. to total (domestic + foreign) catch was taken to represent the U.S. 'distribution' of sardine. There was a notable seasonal trend in U.S. proportions, ranging from 0.63 in winter to 1.00 in summer. No yearly trend was apparent in the annual time series. Annual proportions based on the average of monthly values ranged from 0.68 in 2003 to 0.97 in 1992. The average U.S. proportion across all years examined was 0.82. Sardine distribution, and the portion of sardine in U.S. waters, depends on abundance as well as high frequency (*e.g.* seasonal, El Niño Southern Oscillation; ENSO) and low frequency (decadal scale) environmental conditions. Information regarding fishing effort would be required to make inference about abundance in the U.S. waters relative to Mexico and Canada. U.S. proportions estimated in this study (aggregate catch=0.78, average proportion=0.82) are generally similar in magnitude to estimates made using spotter logbook data (U.S. =0.87; PFMC, 1998). However, these results should be interpreted in the light of all caveats noted above.

Primary Document 1 compared proportions of sardine biomass, monthly landings, and modeled potential sardine habitat for the northern subpopulation of Pacific sardine in the U.S. EEZ (Fig. 1). The landings distribution differed markedly from the distributions of biomass from the acoustic-trawl survey. The author noted that a key reason for this relates to the fact that fishing effort is not equally distributed spatially. U.S. landings were subject to closures during 2008-14, so the proportions in Table 1 are biased low compared to what would have occurred had those closures had not been in effect.

The workshop agreed with the authors of Primary Documents 1 and 3 that landings data on their own provide little information about relative abundance spatially. This is because while landings data are related to the distribution of biomass, they also reflect the distribution of effort (which will be driven by the location of ports and not the biomass of one target species, as well as socioeconomic and regulatory factors), fishing efficiency spatially, oceanographic effects, and management regulations. However, landings data do indicate the presence of sardines in the vicinity of certain ports, which may be useful in determining whether sardines are present off Canada.

**4.2 A harvest control rule for Pacific sardine that accounts for harvests by Mexico and Canada**

Primary Document 1 noted that the northern subpopulation of Pacific sardine is exploited by Mexico, the U.S., and Canada. The U.S. sets its annual fishing quotas using an HCR that, through Distribution, deems a constant proportion of the stock to be in the U.S. EEZ. However, the use of a constant value of Distribution may not protect the stock from combined Mexican-U.S.-Canadian exploitation. To annually optimize Distribution, Demer and Zwolinski (2014b) proposed a method to explicitly account for total landings by estimating this year's catch in Mexico and Canada by that from the previous year; or that from the previous year, modified by the error in estimating the foreign catch in that year (Primary Document 1). This approach is intended to ensure that the total fishing fraction approximates Fraction. The authors of Primary Document 1 noted that this method for annually estimating Distribution (an annual average) could be applied irrespective of the HCR formulation.

The workshop noted that the concept of a 'total fishing fraction' as described in Primary Document 1 does not exist in the CPS FMP. However, the formula for Fraction was developed (Hurtado-Ferro and Punt, 2014) to maximize yield over the entire stock, accounting for the impact of CalCOFI temperature on recruitment success as well as error when conducting assessments.

Testing of the methods in Primary Document 1 assumed perfect knowledge of the population status in every year based on the 2012 (Demer and Zwolinski, 2014b) or the 2015 (Primary Document 1) assessment. These results, with both perfect knowledge of the population and the proposed use of the "optimal" method, were compared to the fishing mortality (F) rates implied by the actual landings (limited by the actual quotas, not those that would have been applied given perfect knowledge), and given the biomass time series estimated in the 2012 or 2015 assessments for the F calculation. This leads to an implication of great improvement in results with the "optimal" method, when, in fact, the gain is certainly almost entirely due to the assumption of perfect knowledge of the stock biomass. In addition, the absolute scale of the results for exploitation rate is highly dependent upon the assessment used to define the "actual" biomass time series (which is evident from Table 1 of the 2014 paper and Table 2 of Primary Document 1). A more correct application of the method to the actual time series of quotas and landings (see Appendix E for technical details) would have led to alternative U.S. quotas, total catch streams, and exploitation rates (Figs 2-3; Figs 4-5, assuming the biomass time series estimates from the 2015 assessment; and Fig 6, assuming the biomass time series estimates from the 2012 assessment). This approach provides the appropriate comparison, but does not account for changes in stock status due to the alternative catch streams.

Implementation of the Demer and Zwolinksi (2014b) approach might reduce the instance or severity of catches exceeding 'total' or 'coastwide' HGs and OFLs, but could also have severe negative implications for the U.S. fishery. Therefore, if this approach is to be considered for adoption, its implications in terms of reduction in risk to the stock from foreign catches and its consequences for the U.S. fishery would need to be fully evaluated using a management strategy evaluation (MSE).

However, considering the merits of making recommendations about changes to U.S. harvest policy, aside from the Distribution term, was outside the scope of the Workshop.

The workshop also noted that the method proposed in Primary Document 1 could be developed in terms of an autoregressive model such as an AR(1) process.

## 5. ESTIMATING THE STOCK BIOMASS IN U.S. WATERS ONLY, INSTEAD OF THE TOTAL SARDINE BIOMASS

The goal of this agenda item was to determine whether it is possible to estimate sardine biomass in U.S. waters only and circumvent the need for a Distribution parameter in HCRs, which is suggested in the CPS FMP as an alternative to specifying Distribution.

Primary Document 4 noted that the stock assessment model used for the northern subpopulation of Pacific sardine currently pools fishery data (landings and size/age compositions) into two regional fleets to account for differences in selectivity/availability driven by seasonal north-south migrations (Hill *et al*., 2015). The 'MexCal' fleet includes data from California and Mexico (Ensenada, Baja California), and the 'PacNW fleet' represents data from Oregon, Washington, and Canada (Vancouver Island, British Columbia). The model excludes catches attributed to the purported southern subpopulation (southern California and Ensenada) using satellite-based environmental data and the method of Demer and Zwolinski (2014a). The model would require a spatially-explicit design and a seasonal structure, with a minimum of four areas representing Mexico, California, Oregon-Washington, and Canada for the assessment to estimate sardine biomass in 'U.S. waters only'. The model would require data on fishery compositions and abundance from each region and, optimally, information on movement rates among the four areas. These types of information are not fully available for Pacific sardine, so it is not currently possible to estimate sardine biomass in U.S. waters only using fully-integrated methods such as Stock Synthesis. At present, the best scientific information available regarding sardine abundance in 'U.S. waters only' are estimates derived from the SWFSC's acoustic-trawl surveys.

There was considerable discussion regarding the utility of conducting an assessment that would ignore catches outside U.S. waters (*i.e.*, ignore the catches off Canada and Mexico). The motivation behind the suggestion was that ignoring the catches of other countries may be no worse than some of the assumptions required by some of the other methods that are being considered for estimation of Distribution. It was commented that conducting an assessment ignoring catches by Canada and Mexico would not be good assessment practice because the purpose of stock assessment is to assess populations, and given that sardine migrate, ignoring the catches outside U.S. waters would result in biased estimates of abundance, which in turn would probably lead to higher exploitation rates because there would be apparently lower mortality; *i.e*., the stock would probably appear more productive as a result of ignoring the catches of Canada and Mexico in a U.S.-only assessment. It was observed, however, that other sources of unknown mortality exist that are not presently accounted for in the assessment. A suggestion was made that instead of conducting such an assessment, the biomass estimates from the acoustic-trawl surveys might be used directly to apply the HCR, as is done in some South African fisheries. However, the workshop agreed that prior to use of an assessment that ignores catches off Canada and Mexico or basing catch limits on estimates of abundance from the acoustic trawls surveys, the effects of setting catch limits this way needs to be explored using MSE.

## 6. USING A NUMERICAL-BASED DISTRIBUTION PARAMETER AS AN ALTERNATIVE TO THE EXISTING PERCENT-BASED DISTRIBUTION PARAMETER

Mr. Josh Lindsay noted that the CPS FMP states that the default method of accounting for the fact that some level of the sardine stock exists outside of U.S. waters does not preclude the development of other approaches. For instance, the CPS FMP provides the example of using "a high Cutoff in the MSY control rule to compensate for stock biomass off Mexico or Canada." Under this scenario, an estimate of the proportion of stock biomass off the U.S. would no longer be used in the various control rules; instead, an amount of biomass would just be subtracted from the total biomass. For instance, as it relates to the current sardine HG control rule, this would likely not involve increasing or modifying the existing Cutoff in the control rule that has its own explicit function, but may look something like the re-construction of the control rule shown below:

$$\text{HG} = \{(\text{Biomass} - \text{Cutoff}) - \text{Distribution}\}{*}\text{Fraction} \tag{2}$$

Here, Distribution becomes some amount of biomass that is subtracted from the total biomass before applying the applicable harvest rate for setting U.S. catch levels.

No suggestions for how to compute Distribution in Equation 2 were included in the primary documents and presentations to the workshop. However, in discussion, suggestions included a value that differed depending on whether the biomass was larger than some threshold so that migration to Canada occurs [Zwolinski and Demer (2012) estimate 740,000 mt, but this value is sensitive to the choice of the assessment], and a number that depends on past catches.

It was noted that substituting a fixed value representing Distribution that essentially increases Cutoff may result in years where the U.S. fishery would operate under comparatively higher HGs at relatively high stock biomass levels, and conversely operate under lower HGs when stock biomass is small. Alternatively, a time-varying value based on predictions from recent catch could be used. For example, the foreign catch could be taken as the additional biomass to be subtracted from the Biomass and Cutoff. It was also noted that at low stock size there will be no expected fishery in Canada, whereas there is likely to be a Mexican fishery at all stock sizes. Finally, it is appropriate for management to consider and evaluate potential impacts to the fishery resulting from these changes to the HG HCR.

**7. USING A TEMPERATURE-BASED MODEL TO PREDICT THE PROPORTION OF PACIFIC SARDINES IN U.S. WATERS FOR A PARTICULAR YEAR**

Primary Document 1 (and Fig. 1) compared proportions of northern-stock sardine biomass, monthly landings, and modelled potential sardine habitat (based on approach of Zwolinski *et al*. (2011) in the EEZs of Mexico, the U.S., and Canada. The results showed that the proportion of the northern subpopulation in the U.S. EEZ varies seasonally and annually. Also, the proportion of the stock biomass in the U.S. EEZ at any given time is generally not equal to the proportions of either the potential habitat or the landings of the northern subpopulation in the U.S. EEZ. The author of Primary Document 1 highlighted that the proportion of the total potential habitat that is utilized will depend on factors such as the size of the stock.

There was discussion as to whether environmental data existed for earlier years that could be used to estimate habitat of the northern subpopulation prior to 1998. Satellite estimates of environmental predictors may be available from about 1993. A comment was made that if just SST values were used to predict habitat, there may be estimates available from reconstructed time series of SST for years prior to 1993, but that those estimates are at a fairly low spatial resolution (2° x 2°). The workshop noted that the western extent of offshore potential habitat may be too far to the west. However, it was noted that sardine has been observed 300 nautical miles from the coast during a Russian survey in the 1980s (Macewicz and Abramenkoff, 1993).

Dr. Richard Parrish was invited to the workshop to present a mechanistic model that incorporates both environmental and stock size effects on the distribution of the northern subpopulation of Pacific sardine. However, Dr. Parrish was unable to attend the workshop, so the workshop could not evaluate this method. This model should be presented to the PFMC SSC for evaluation if the Council chooses to further explore the possibility of using a method that uses environmental data to estimate Distribution.

8. **GENERAL CONCLUSIONS**

The workshop noted that all of its deliberations are conditional on there being a northern subpopulation of Pacific sardine, and most of the methods considered during the workshop relied on the method developed by Demer and Zwolinski (2014a) to assign catches to the northern and southern subpopulations of Pacific sardine. Research recommendations 1-3 (see Section 9) pertain to stock structure and the Demer and Zwolinksi (2014a) method for designating catches as either southern or northern subpopulation.

A. Alternative 1 (*Setting the value for the Distribution parameter annually as part of the specifications process based on the most recent data on the actual mean distribution of the Pacific sardine stock in U.S. waters*).
   All of the methods for estimating the proportion of the biomass of the northern subpopulation of Pacific sardine in U.S. waters are subject to considerable uncertainty owing to how the data were collected (none of the data sets considered in the workshop except for the acoustic trawl survey estimates were collected with the specific intent to estimate this proportion). Moreover, the proportion changes seasonally, inter-annually, and due to oceanographic factors and likely as a function of stock size. None of the data sets considered provide information on Distribution across the year (*e.g*. quarterly), for all regions where the northern subpopulation is predicted to occur (Mexico, the U.S., and Canada), and for a sufficient number of years to allow the effects of factors such as stock

size on Distribution (*e.g*. from 1950 to present to cover periods when stock biomass was high, low, and very high; Fig. 7) to be explored. Table 1 provides a summary of the advantages and disadvantages of the information types considered during the workshop. The data sources considered during the workshop relate to different components of the population (spawning biomass, fishable biomass, total biomass, etc.), which will lead to differences in the estimates of Distribution even for the same year and season.

Of the data sets considered during the workshop, the ichthyoplantkton data sets cover the longest period of time (the first ichthyoplantkton survey to cover Mexican and U.S. waters took place in 1939; Hewitt, 1988; Fig. 1). However, the ichthyoplantkton surveys do not sample north of San Francisco. Some (often not a substantial fraction of the total) spawning occurs north of San Francisco. The ichthyoplantkton data have yet to be analyzed to estimate year-specific values for Distribution (it will likely be necessary to pool ichthyoplantkton data for years of very low abundance owing to low sample size).

Of the other data sets, if the U.S. and Mexican acoustic-trawl surveys can be made comparable, it should be possible to estimate sardine biomass across the entire range of northern subpopulation using this data source, at least for spring and summer. In addition, the spotter data could be re-analyzed to estimate yearly values of Distribution.

Use of the habitat model (Zwolinski *et al.*, 2011) to estimate sardine in the U.S. EEZ is more problematic, as potential habitat does not equate to biomass, and the potential habitat pertains to the potential presence of sardine rather than the actual presence of sardine biomass. The last of these problems could be overcome by modelling density of eggs and larvae, or by modelling the presence/absence of density above a threshold value. However, the fact that potential sardine habitat may not reflect abundance may mean this data source will never be able to provide reliable estimates of Distribution. The same concern pertains to landings. In principle, landings can be corrected for factors such as effort. However, defining effort for CPS is known to be very difficult and catch-per-unit-effort for CPS is generally hyperstable (MacCall, 1976; Csirke, 1989).

Given the limited data, the workshop identified three options for accounting for inter-annual variation in the proportion of the biomass of the northern subpopulation of Pacific sardine in U.S. waters:

1. Ignore it and estimate a single value – this option acknowledges the challenges in determining an overall mean using the currently available data let alone annually-varying estimates. However, this may be problematic in years where a larger or smaller than average portion of the biomass or catch occurs outside U.S. waters.
2. Identify various categorical variables (*e.g.*, stock biomass divided into levels corresponding to very low abundance, low abundance, and high abundance) and estimate the proportion of biomass present at each level of the categorical variable. This method requires fewer data than option 3; it is not necessary that the same method be used to estimate the proportion for each level of the categorical variable.
3. Estimate the proportion of biomass on an annual basis.

No analyses were presented to the workshop that estimated Distribution for recent years that were not likely to provide biased estimates (habitat model and landings) or which were based on data for the entire range of the subpopulation (acoustic-trawl surveys). However, with further analysis, it should be possible to develop time series of the proportion of the northern subpopulation biomass in U.S. waters (with estimates for different periods potentially based on different data types, *e.g*. spotter for 1963-2001; ichthyoplantkton thereafter).

In regards to option 2 above, the workshop identified the following variables that could be explored when defining Distribution using categorical variables: (a) ENSO, (b) stock biomass, (c) average age of the catch, (d) whether a fishery took place in Canada, and (e) sea surface temperature. The workshop noted that any analyses to implement option 2 will need to convert the continuous variables (a), (b), (c) and (e) to categorical variables.

B. Alternative 2 (*Using landings information from Canada and Mexico to account for catch in the waters of those nations in estimating the Distribution parameter in the HCR, using work from recently published scientific studies regarding Pacific sardine management*)
Landings data are only measures of biomass under assumptions including a uniform effort distribution, no market impacts on catches and targeting, and no spatial management-related restrictions on catches. These assumptions are unlikely to be valid for Pacific sardine. Therefore, the workshop agreed that landings data should not be used to estimate Distribution.

The approach for accounting for the transboundary nature of the stock by subtracting foreign landings from U.S. OFLs, U.S. ABCs., and U.S. HGs aims to achieve different objectives (to prevent coastwide overfishing and achieve a target coastwide fishing rate; Demer and Zwolinksi, 2014b and Primary Document 1) than the current Distribution term. This approach appears to better meet these objectives than the current approach. However, concerns were raised that this approach could also have severe negative implications for the U.S. fishery, and whether this is the case was not analyzed during the workshop.

C. Alternative 3 (*Estimating the stock biomass in U.S. waters only, instead of the total sardine biomass, in the stock assessment*)
   a. Estimating the biomass in U.S. waters using a stock assessment method that is spatially- and seasonally-structured is currently infeasible, owing to an absence of key data sources such as tagging data and indices of abundance for Mexico and Canada.
   b. Estimating the biomass in U.S. waters by conducting an assessment that uses only U.S. data (*i.e.*, ignoring the catches off Canada and Mexico) will lead to biased estimates of biomass. However, the extent of bias may not be substantial – if this option is to be pursued, the implications of the bias need to be evaluated, using, for example, MSE.
   c. Estimating the biomass in U.S. waters by basing the HG on the estimate of biomass from the acoustic-trawl survey would need to be evaluated using MSE, if it is to be considered for possible implementation.

D. Alternative 4 (*Using a numerical-based Distribution parameter as an alternative to the existing percent-based Distribution parameter*)
The HG HCR could be modified to remove a numerical Distribution from the biomass before applying Cutoff and multiplying by Fraction. Several ideas for how such a

numerical value for Distribution could be calculated were discussed at the workshop (see Section 6).

E. Alternative 5 (*Using a temperature-based model to predict the proportion of Pacific sardines in U.S. waters for a particular year*)
The environmental-based model estimate of potential sardine habitat does not appear to be a good way to predict the realized distribution of the northern subpopulation of Pacific sardine because this subpopulation is not likely to utilize all of its potential habitat, particularly when abundance is low.

Of the methods considered at the workshop, the approaches proposed by Demer and Zwolinksi (2014b) and Primary Document 1 were the only that intended to help avoid total catches exceeding a 'total' or 'coastwide' HG or 'total' or coastwide' OFL, and analyses conducted during the workshop (Figs 2-3) show that the Demer and Zwolinksi (2014b) and Primary Document 1 approaches may help to keep the total catch below the 'total' or 'coastwide' HG in some circumstances. However, for particular years, it could result in higher catch and fishing mortality rates than the current rule, even exceeding the 'total or 'coastwide' HCRs, if the entire U.S. HG is taken. Those calculations also showed that this approach does not keep exploitation rates at the values used to calculate 'total' or 'coastwide' HGs and OFLs, given updated retrospective information on population biomasses (Figs 4-6). Implementation of the Demer and Zwolinksi (2014b) approach might reduce the instance or severity of catches exceeding 'total' or 'coastwide' HGs and OFLs, but could also have severe negative implications for the U.S. fishery. Therefore, if this approach is to be considered for adoption, its implications in terms of reduction in risk to the stock from foreign catches and its consequences for the U.S. fishery would need to be fully evaluated using a management strategy framework that includes realistic models of the fisheries off Mexico and Canada.

While not examined at the workshop, workshop participants generally agreed that there would be benefit in initiating discussions with Mexico and Canada toward more coordinated management to address the transboundary nature of the stock, which would be preferable to the status quo. The workshop participants encourage the National Marine Fisheries Service and the PFMC to work with the State Department to initiate such discussions of potential trinational management.

## 9. KEY RESEARCH RECOMMENDATIONS

### 9.1 General

1. There is still uncertainty regarding stock structure of Pacific sardine. The present workshop was based on the current working hypothesis of a northern and a southern subpopulation that can be distinguished using environmental data (*e.g.*, sea surface temperature, chlorophyll-a, etc.). Research should continue to focus on stock structure of Pacific sardine. If that stock structure is changed, it will be necessary to re-evaluate Distribution so that its calculation is consistent with the stock structure hypothesis.
2. Re-evaluate some of the details of the landings differentiation methodology outlined in Demer and Zwolinski (2014a) in the context of its current use. The method of Zwolinski *et al*. (2011) was developed to improve sampling design, and from Figure 5 of that paper, it appears that the definition of habitat ('optimal + good') results in an effectively much higher misclassification error rate for negatives (i.e., proportion of negatives that were predicted to be positives) than for positives (i.e., the proportion of positives that were

predicted to be negatives). This may be appropriate for survey design. However, it is not clear that it is appropriate for the purpose of allocation of habitat for estimation of landings by subpopulation and country, particularly as the spatial extent of the habitat of the northern stock appears to be sensitive to the levels of the two types of classification errors (per Figure 6 of Zwolinski *et al*., 2011). There are two specific suggestions:

a) Re-evaluate the relative importance (costs) of the two types of mistakes that can be made by a two-class classifier (false positives and false negatives) (e.g., Berk, 2008), given that the results of the classification algorithm are being used to allocate habitat for estimation of landings by stock and country. This may require a modified definition of habitat (with the current method) or that a new classification algorithm be developed (per suggestion below). For example, in the context of the current use, would it be more appropriate to put equal importance on the two types of classification errors?
b) Explore whether there are other techniques (e.g. random forests) that might yield a better overall classifier, given that the goal of the analysis is prediction. For example, there are machine learning techniques that may result in a better classification algorithm (e.g., Berk, 2008; Hastie *et al.*, 2009), perhaps reducing the apparent current false positive rate. As part of this, it would be important to obtain estimates of the false positive and false negative rates that are based on cross-validation or a test data set.

3. The analyses conducted to evaluate HCRs for the northern subpopulation of Pacific sardine examine one case in which Canada and Mexico did not follow the U.S. HCRs. However, that case was not very realistic. The MSE analyses should be repeated using realistic models for the catches off Canada and Mexico to better understand the consequences of the fisheries in these countries not being based on the HCRs used in the U.S. Specifically, future catches for Canada (assuming that there is biomass in Canadian waters) should be based on the most recent control rule (DFO, 2014, 2015).

**9.2 Alternative 1**

4. Assemble the raw spotter data and re-analyze these data using the current definition for the northern subpopulation. Use the results of the analysis to investigate whether sardine distribution changes with environmental variables such as SST, time, and abundance. The analysis should be based on a Generalized Linear Model (GLM) rather than log-linear regression, which will reduce the need to add 1 to the absence/presence data and remove the need to correct for bias in the constant terms.
5. Conduct additional comparisons between IMECOCAL and CalCOFI estimates of spawning stock biomass to better understand the extent of variation in sardine distribution in spring among years.
6. Make the U.S. and Mexican acoustic trawl surveys comparable, and use the resulting data to estimate Distribution.
7. Develop a time series of estimates of Distribution using the CalCOFI and IMECOCAL data.
8. Integrate the estimates of Distribution to construct a time series of estimates and evaluate whether those estimates differ among levels for categorical variables such as stock biomass, ENSO, temperature, whether a catch occurred off Canada, and the average age of the catch. Use these estimates to construct a table that relates Distribution to categorical variables.

### 9.3 Alternative 2

9. Develop an alternative formulation of the Demer-Zwolinski approach (Demer Zwolinski, 2014b or Primary Document 1) that assumes an AR(1) error formulation.
10. Evaluate HCRs for the northern subpopulation of Pacific sardine that include the Demer-Zwolinski approach (Demer Zwolinski, 2014b or Primary Document 1) using MSE. A key component of the MSE would be a model of how catches occur off Mexico and Canada as a function of environmental conditions and stock biomass.

### 9.4 Alternative 3

11. Conduct an MSE to evaluate the implications, in terms of achieving the goals for CPS, when the HCRs are based on (a) an assessment that ignores catches outside of the U.S., and (b) the estimate of abundance from the acoustic-trawl survey. The results of this MSE should be based on realistic models of catches off Canada and Mexico and be compared with the results for the status quo in which U.S. management is based on Distribution set to 0.87 and the assessment covers the entire northern subpopulation.
12. Conduct tagging of Pacific sardine to enable a ‘U.S. waters only’ spatial assessment model to be developed.

### 9.5 Alternative 4

13. Further develop, then test, approaches for setting Distribution based on a numerical value (see Section 6).

### 9.6 Alternative 5

14. Modify the habitat model so that the response variable is density, or presence/absence of density above a threshold level. The latter analyses should be more robust to the highly variable nature of egg and larval abundance data.
15. Richard Parrish has developed a model of Pacific sardine that incorporates both environmental and stock size effects on distribution. This paper should be updated to reflect the latest understanding of stock structure and presented to the Council.

## 10. REFERENCES


Berk, R.A. 2008. *Statistical Learning from a Regression Perspective*. Springer.

Caruso, J.P. 1977. Aerial marine resource monitoring system: Explanation and examples of the coding forms for the effort and sighting records. SWFSC Administrative Report LJ-77-07.

Caruso, J.P., Meyer, C.A. and S. Iacometti. 1979. Aerial marine resources monitoring system. SWFSC Administrative Report LJ-79-09.

Csirke, J. 1989. Changes in the catchability coefficient in the Peruvian anchoveta (*Engraulis ringens*) fishery. pp. 207-219 *In:* Pauly, D., P. Muck, J. Mendo and I. Tsukayama, Editors. The Peruvian upwelling ecosystem: dynamics and interactions. *ICLARM Conference Proceedings* 18.

Demer, D.A. and J.P. Zwolinski. 2014a. Corroboration and refinement of a method for differentiating landings from two stocks of Pacific sardine (*Sardinops sagax*) in the California Current. *ICES Journal of Marine Science* 71: 328–335.

Demer, D.A. and J.P. Zwolinski. 2014b. Optimizing fishing quotas to meet target fishing fractions of an internationally exploited stock of Pacific sardine. *North American Journal of Fisheries Management* 34: 1119–1130.

DFO (Department of Fisheries and Oceans, Canada) 2014. Pacific Region Integrated Fisheries Management Plan for Pacific Sardine (June 1, 2012 to February 9, 2015) Amended June 1, 2014. Department of Fisheries and Oceans, Government of Canada.

DFO (Department of Fisheries and Oceans, Canada) 2015. Pacific Region Integrated Fisheries Management Plan for Pacific Sardine (June 1, 2015 to February 9, 2018). Department of Fisheries and Oceans, Government of Canada.

Felix-Uraga, R., Gómez-Muñoz, V.M., Quiñónez-Velázquez, C., Neri Melo-Barrera, F., Hill, K.T. and W. García-Franco. 2005. Pacific sardine stock discrimination off the west coast of Baja California and southern California using otolith morphometry. *CalCOFI Reports* 46: 113–121.

Hastie, T., Tibshirani, R. and J. Friedman. 2009. The Elements of Statistical Learning, 2nd Edition. Springer.

Hewitt, R.P. 1988. Historical review of the oceanographic approach to fishery research. *CalCOFI Reports* 29: 27-41.

Hill, K., Lo, N., Macewicz, B., Crone, P.R. and R. Felix-Uraga. 2010. Assessment of the Pacific sardine resource in 2010 for US management in 2011. NOAA Technical Memorandum NOAA-TM-NMFS-SWFSC-469.

Hill, K.T., Crone, P.R., Dorval, E. and B.J. Macewicz. 2015. Assessment of the Pacific sardine resource in 2015 for USA management in 2015-16. Pacific Fishery Management Council, 7700 NE Ambassador Place, Portland, OR 97220.

Hurtado-Ferro, F. and A.E. Punt. 2014. Revised analyses related to Pacific sardine harvest parameters. Pacific Fishery Management Council, 7700 NE Ambassador Place, Portland, OR 97220.

Lo, N.C.H., Jacobson, L.D. and J.L. Squire. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. *Canadian Journal of Fisheries and Aquatic Sciences* 49: 2515–2526.

Lo, N.C.H., Green, Y.A., Cervantes, M.J., Moser, H.G. and R.J. Lynn. 1996. Egg production and spawning biomass of Pacific sardine (sardinops sagax) in 1994, determined by the Daily Egg Production Method. *CalCOFI Reports* 37: 160–174.

MacCall, A.D. 1976. Density dependence of catchability coefficient in California Pacific sardine, *Sardinops sagax* caerulea, purse seine fishery. *CalCOFI. Reports* 18: 136-148.

MacCall, A.D. 1979. Population estimates for the waning years of the Pacific sardine fishery. *CalCOFI Reports* 20: 72-82.

Macewicz, B.J. and D.N. Abramenkoff. 1993. Collection of jack mackerel, *Trachurus symmetricus*, off southern California during 1991 cooperative US-USS.R. cruise. Southwest Fisheries Science Center, National Marine Fisheries Service, Admin. Rep. LJ-93-07. 13pp.

Murphy, G.I. 1966. Population biology of the Pacific sardine (*Sardinops caerulea*). *Proceedings of the California Academy of Sciences* 34: 1-84.

PFMC (Pacific Fishery Management Council). 1998. Amendment 8, appendix B, options and analyses for the coastal pelagic species fishery management plan. PFMC, Portland, Oregon.

PFMC (Pacific Fishery Management Council). 2011. Acoustic-Trawl Survey Method for Coastal Pelagic Species: Report of Methodology Review Panel Meeting. PFMC, Portland, Oregon.

PFMC (Pacific Fishery Management Council). 2012. Canada (Department of Fisheries and Oceans) Swept-Area Trawl Survey Report of Methodology Review Panel Meeting. PFMC, Portland, Oregon.

PFMC (Pacific Fishery Management Council). 2013. Report of the Pacific Sardine Harvest Parameters Workshop. PFMC, Portland, Oregon.

Smith, P.E. 2005. A history of proposals for subpopulation structure in the Pacific sardine (*Sardinops sagax*) population off western North America. *CalCOFI Reports* 46: 75–82.

Zwolinksi, J.P. and D.A. Demer. 2012. A cold oceanographic regime with high exploitation rates in the Northeast Pacific forecasts a collapse of the sardine stock. *Proceedings of the National Academy of Sciences* 109: 4175–4180.

Zwolinski, J.P., Emmett, R.L. and D.A. Demer. 2011. Predicting habitat to optimize sampling of Pacific sardine (*Sardinops sagax*). *ICES Journal of Marine Science* 68: 867–879.

Table 1. Summary of the advantages and disadvantages of each information type for estimating the proportion of the biomass of the northern subpopulation of Pacific sardine in U.S. waters relative to the entire biomass of this subpopulation, along with the years and areas for which data are available, and the estimates of this proportion presented to the workshop. None of the data can be assigned directly to the northern or southern subpopulation; rather, the assignment of catches to subpopulation for the acoustic and landings data are based on the habitat model.

| Information Type | Advantages | Disadvantages | Year / Areas | Current use in the estimation of DISTRIBUTION | Estimates of DISTRIBUTION (% in U.S. waters) |
|---|---|---|---|---|---|
| Spotter data | 1. Data are available for the whole year.<br>2. Data are available for much of the southern range of the northern subpopulation. | 1. Spotter data have not been collected since 2001.<br>2. There are no spotter data for the Pacific Northwest; data are being collected, but these data are not comparable with the data for 1963-2001.<br>3. The estimates in Primary Document 2 and PFMC (1998) are based on a fixed latitudinal cut-off for the northern subpopulation of Pacific sardine.<br>4. Data are not available for high abundance years.<br>5. The data are not spatially finely resolved, making it difficult to designate observations to the northern or southern subpopulations using the approach of Demer and Zwolinski (2014a). | San Francisco – Punta Eugenia (1963-2001) | Data modelled with a GLM-type approach. The methodology, as used, produces one overall estimate. | 1963-92: 0.87 (PFMC, 1998)<br>1985-97: 0.84 - 0.89 (Primary Document 2) |
| Acoustic-trawl data[2] | 1. Provides information on abundance spatially using standard monitoring methods.<br>2. Ongoing.<br>3. Survey program was reviewed (PFMC, 2011). | 1. Survey data are not available for Mexico during spring when some of the catches are attributed to the northern subpopulation<br>2. Data are only available from 2006 – 2014, and hence not when the population was at very low abundance (i.e. the levels during the 1970s).<br>3. Data are only available for two seasons (spring and summer).<br>4. The Mexican and U.S. surveys have yet to be made comparable. | Vancouver Island – U.S.-Mexico border (2006 – present) | Estimates are based on the proportion of biomass that falls within the U.S. EEZ | Spring: ~1 (Primary Document 1)<br>Summer: 0.94 - ~1 (Primary Document 1) |

| | | | | | |
|---|---|---|---|---|---|
| Ichthyoplankton data | 1. High resolution data are available for southern California for each season.<br>2. Could be used to address whether the distribution between Mexico and southern California changes between low (1951-64) and very low abundance (1965-84) periods.<br>3. Some comparisons between individual recent years are possible (*e.g.*, Primary Document 7). | 1. The spatial coverage of the data has reduced over time and CalCOFI no longer collects data from Mexico or north of Point Conception.<br>2. Egg data reflect spawning -immature and non-spawning fish are not recorded.<br>3. Data are not available north of San Francisco<br>4. Yet to be used to compute the proportion of sardine spatially for all seasons (other than spring).<br>5. The analyses data do not distinguish between northern and southern subpopulation sardine<br>6. Data from Mexican IMECOCAL program are not freely available for analysis. | USA: 1951 onwards (various resolutions); currently<br>• Quarterly: Point Conception to San Diego.<br>• Spring: San Francisco to San Diego.<br>Mexico: IMECOCAL 1997-present. | 1994 & 2002-03: Daily Egg Production Method estimates.<br>1951-85: Estimates are based on smoothing spatial estimates of biomass and obtaining the proportion of that smoothed biomass that was north of the Mexico-U.S. border. | 1994: 0.9 (Lo *et al.*, 1996)<br>1951-85: 31% (PFMC, 1998)<br>2002-03: 80-98% (Primary Document 7) |
| Canadian Surface trawl | 1. Based on a design that has been reviewed by the PFMC SSC (PFMC, 2012) (night time series now more standardized). | 1. The data are not comparable with surveys south of Vancouver Island.<br>2. The surveys only occur in summer. | West Coast of Vancouver Island.<br>Day time series (1999-2003) has considerable variation in sampling design.<br>Night time series more standardized (2006-2014, with future biennial even years plans 2016, 2018 etc.). | Data have not been analyzed to estimate the proportion. | N/A |
| Habitat model[1] | 1. Can be applied to compute potential sardine habitat for a range of seasons, regions, and years. | 1. Sardine may not use all of the potential habitat so estimates of potential habitat may not relate well to abundance.<br>2. Measure of habitat not abundance.<br>3. The western extent of potential habitat is less certain that the north-south extent.<br>4. The ability to estimate potential habitat for the early years may be limited owing to lack of high resolution environmental data. | Vancouver Island – U.S.-Mexico border (2006 – present) [could be extended back to 1981 or perhaps earlier] (Primary Document 1)<br>Vancouver Island – Mexico border (2000 – present) (Primary Document 7) | Model built using icthyoplankton and concurrent environmental data.<br>Estimates of proportions in U.S. waters are based on using the current year's environmental data to predict annual (or overall) spatial | Spring: 0.68 – 0.95 (Primary Document 1)<br>Summer: 0.79 – 0.87 (Primary Document 1)<br>April: 0.97 – 0.99 (primary Document 7)<br>May: 0.96 – 0.99 (Primary Document 7) |

| | | | | | |
|---|---|---|---|---|---|
| | | | | distribution of potential habitat. | |
| Landings data[2] | 1. Most comprehensive data set available to estimate Distribution (estimates for a range of seasons, regions, and years). | 1. The relationship between landings and relative abundance is complex, and depends on factors including effort distribution, oceanographic conditions, market conditions, the availability of other fished species, and regulations. | Entire range of the northern subpopulation of Pacific sardine (1981-present). | | 0.68-0.97 (1992-2007) (Primary Document 3) 0.46-0.92 (1993-2014) (Primary Document 1) |

[1]: Relies on the CUFES data to estimate the parameters of the habitat model; [2]: Relies on the habitat model

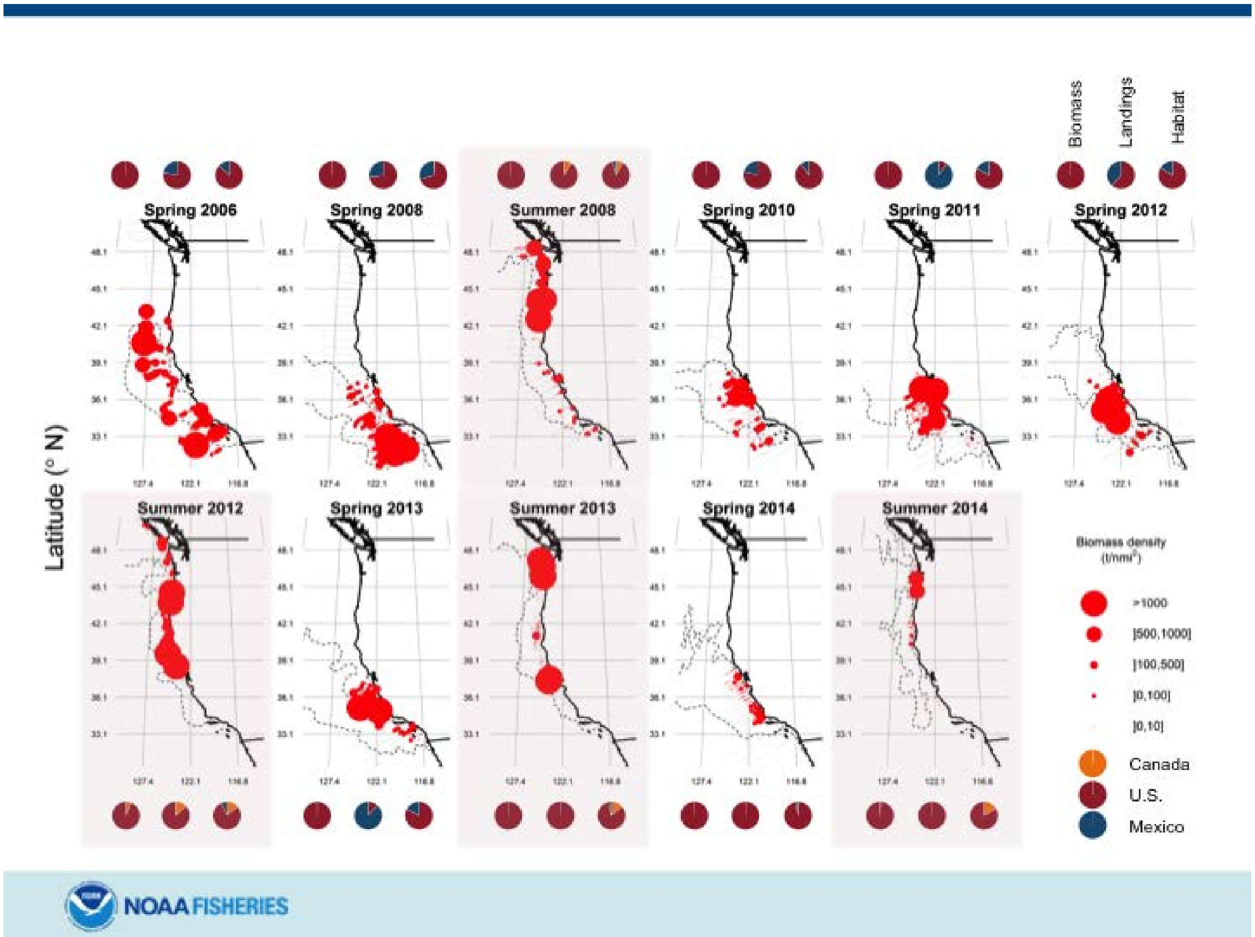


Figure 1. Densities of Pacific sardine observed during the acoustic trawl surveys overlaid on boundaries of good+optimal potential northern-stock habitat (see Zwolinski *et al.*, 2011) and estimates of the proportion of biomass, landings, and habitat in Canada, the U.S. and Mexico (source: Primary Document 1).

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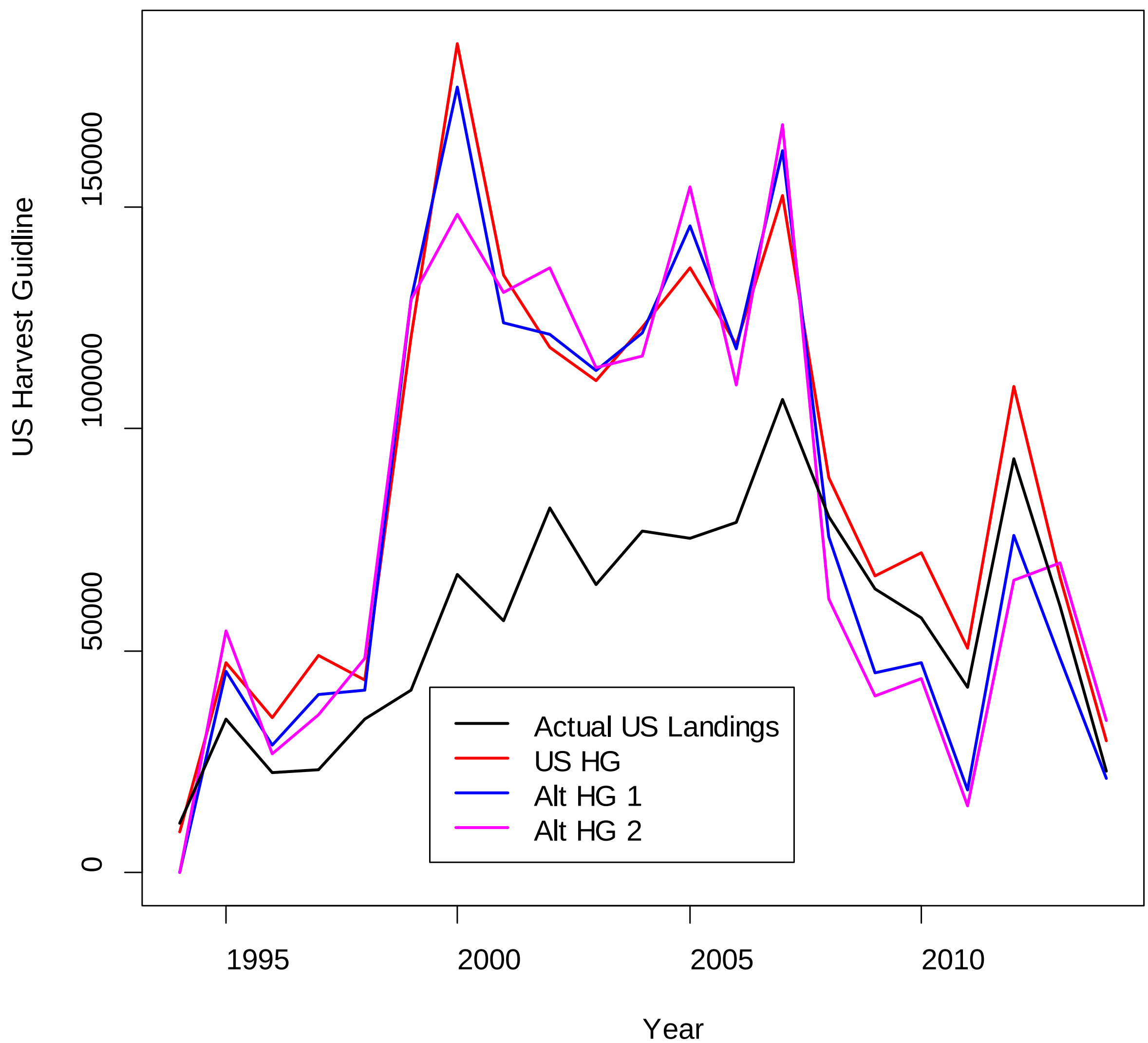


Figure 2: Actual U.S. Harvest Guidelines (HG = quotas) and Landings, and Alternative U.S. HGs (Alt HG 1 and 2) which would have been assigned if the Optimal D values of Demer and Zwolinski (2014b) had been implemented.

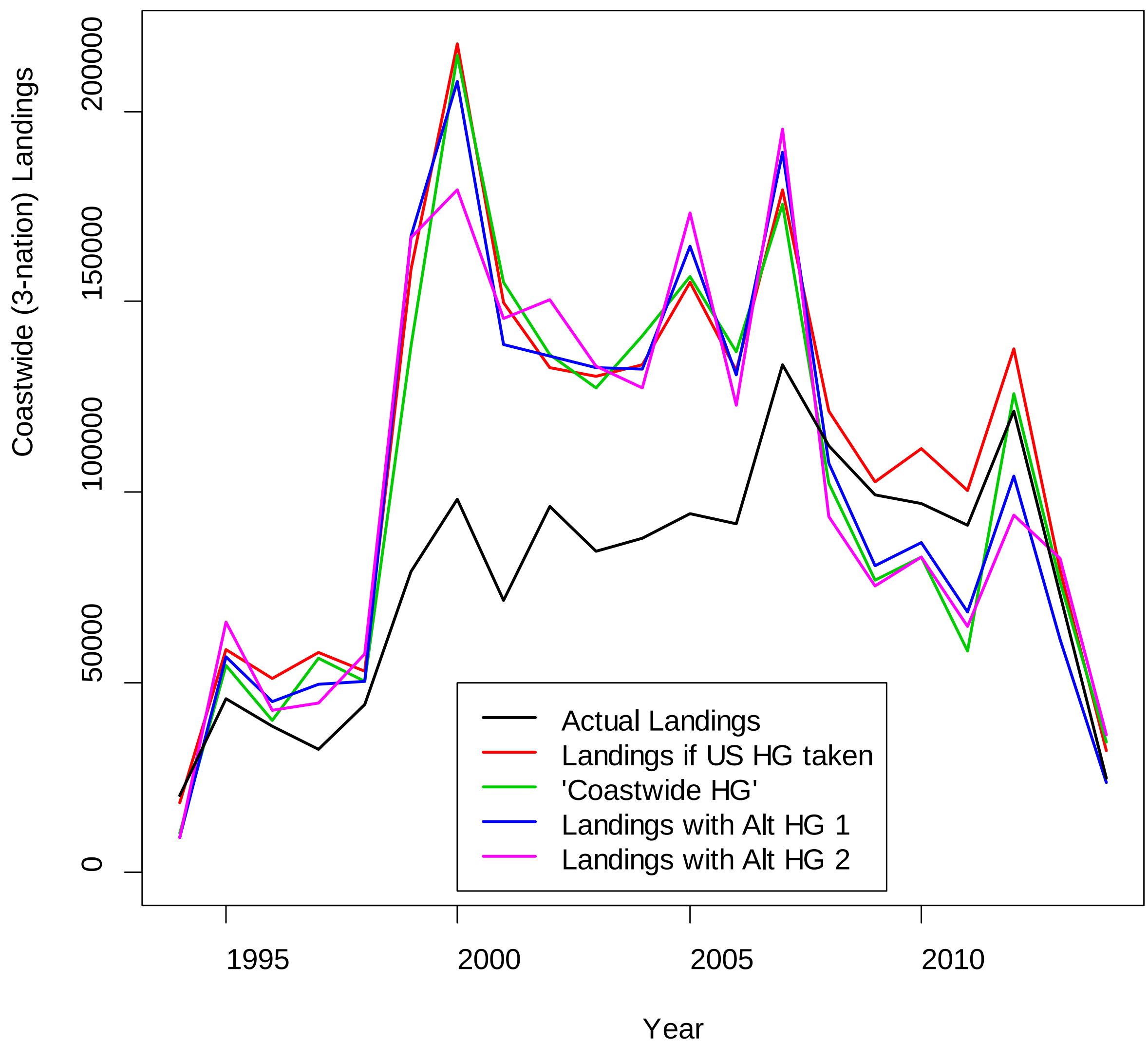


Figure 3. Results of analysis of alternative setting of U.S. Harvest Guidelines (HG) as suggested by Demer and Zwolinski (2014b), but ignoring impact of alternative catch streams on the population. Actual Catch: total 3-nation catch. "Coastwide Q": U.S. Q divided by 0.87. Catch USQ: Catch if U.S. quota achieved (along with observed foreign catch). Alt1: 3-nation catch if U.S. quota is based on "coastwide" harvest fraction with foreign catch predicted to be previous year's foreign catch. Alt 2: As in Alt 1, but with foreign catch predicted to be last year's catch modified by error in predicting last year's foreign catch. All U.S. catch is assumed to be from the northern subpopulation – *i.e.* U.S. catches of southern subpopulation sardine are not removed from the "Actual Catch" stream.

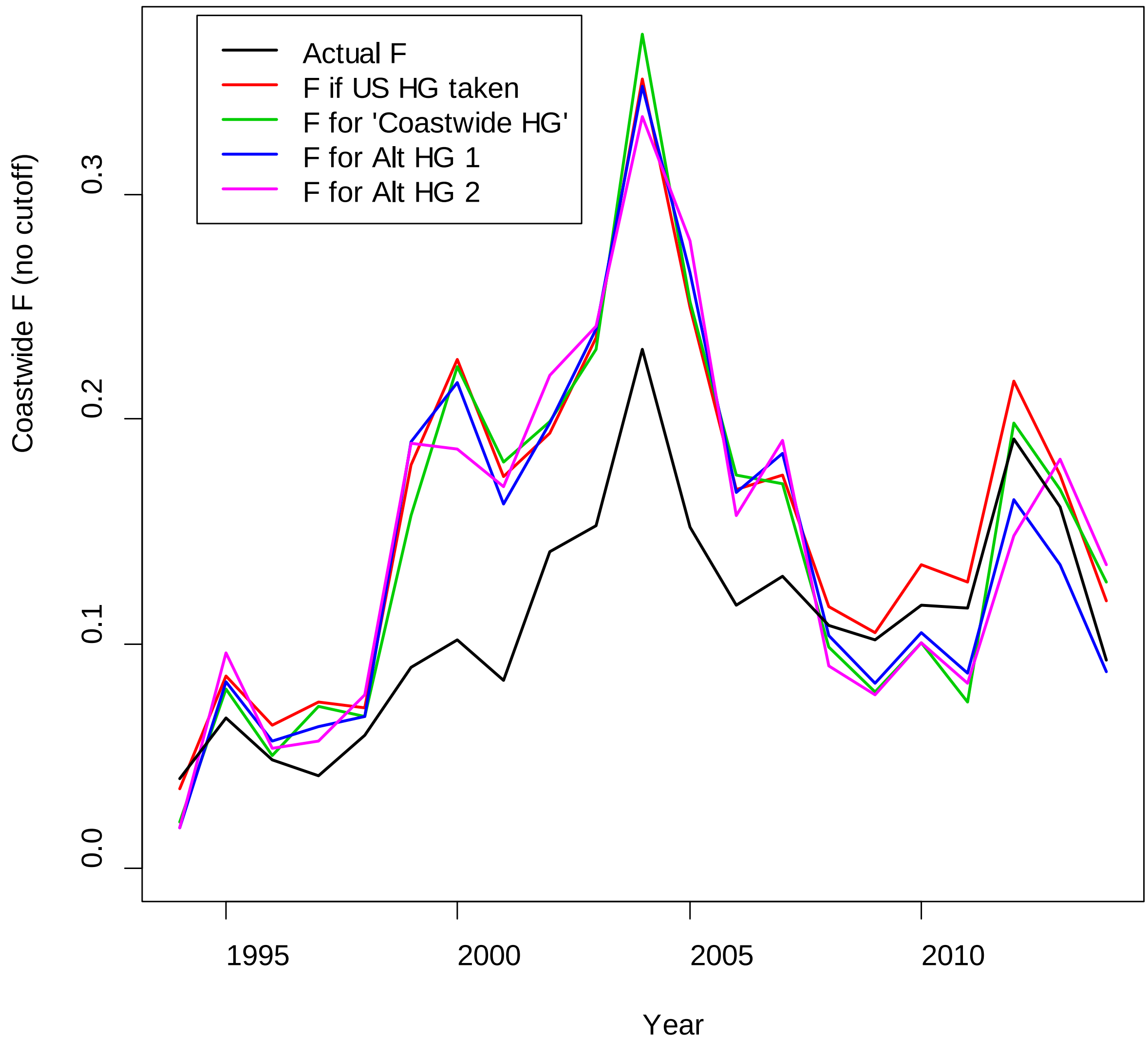


Figure 4. F (actually: exploitation) rates associated with catch levels in Figure 3, assuming biomass time series from the 2015 assessment, without feedback and without accounting for the cutoff.

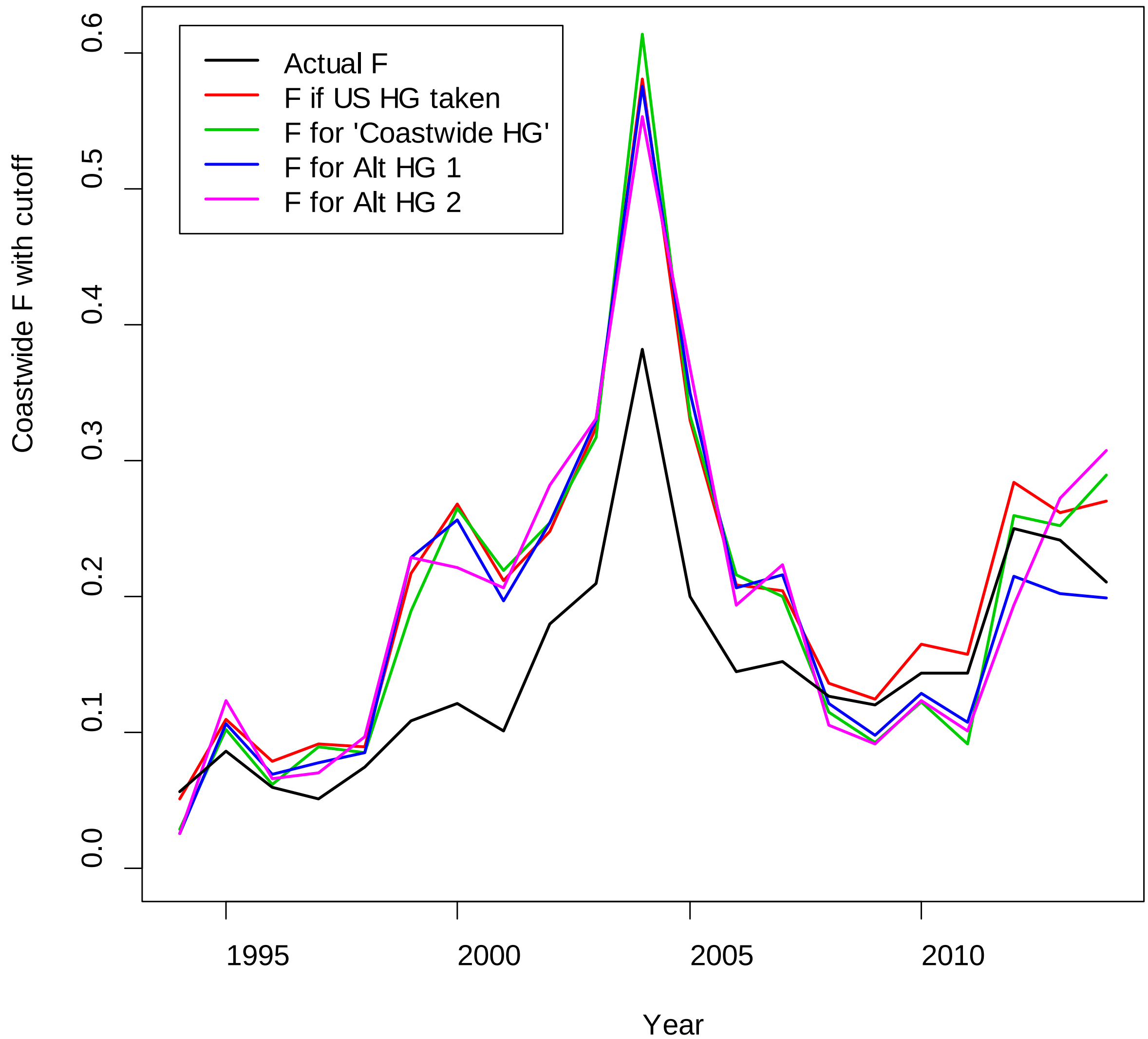


Figure 5. F (actually: exploitation) rates associated with catch levels in Figure 3, assuming biomass time series from the 2015 assessment, without feedback but accounting for the cutoff.

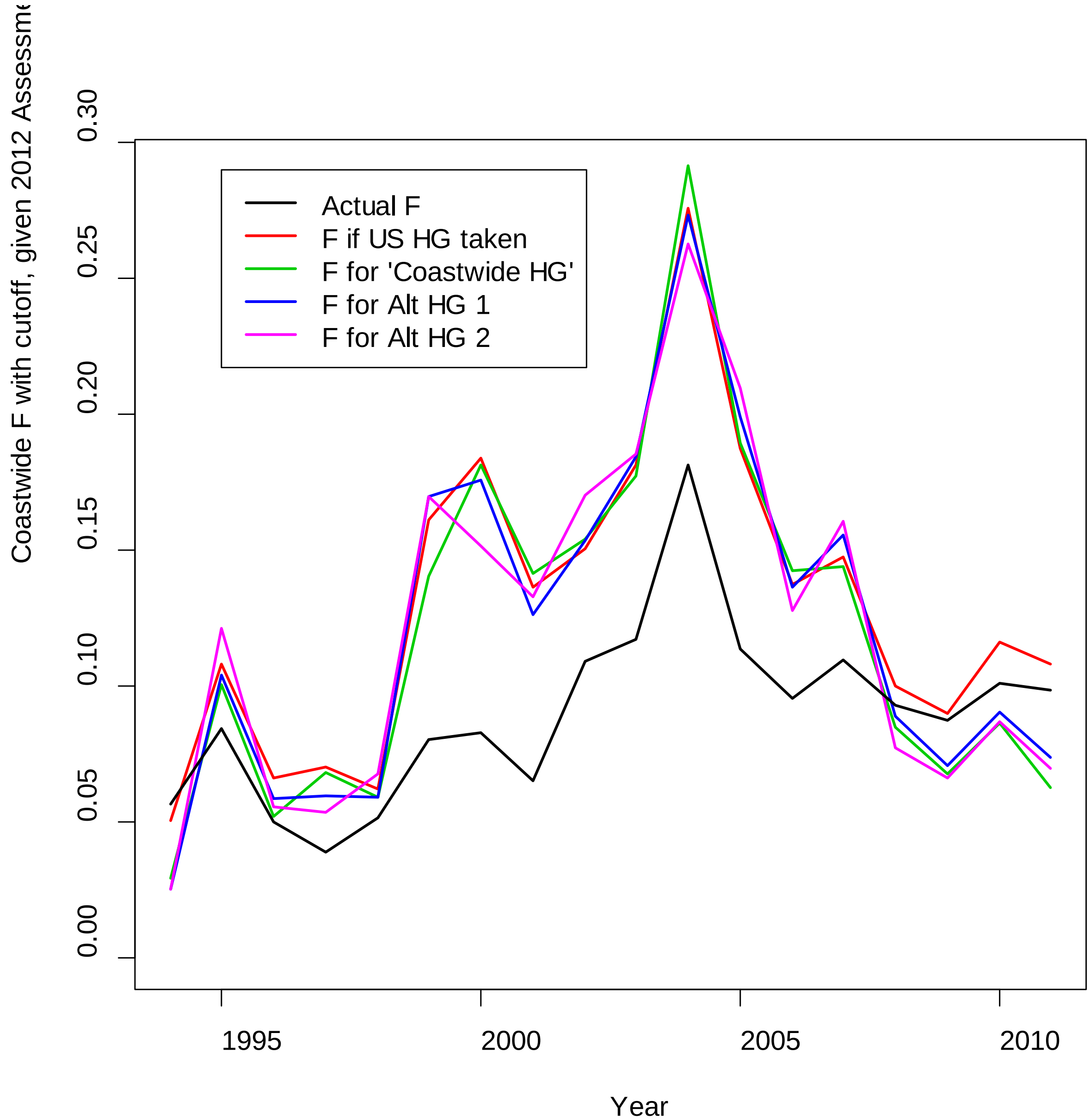


Figure 6. F (actually: exploitation) rates associated with catch levels in Figure 3, assuming biomass time series from the 2012 assessment (and thus graph ends in 2011), without feedback but accounting for the cutoff. Comparison of this figure to Figure 5 demonstrates the sensitivity of the estimated absolute values (and to a lesser extent, relative values across years) of F to the choice of assessment as the basis for the biomass time series.

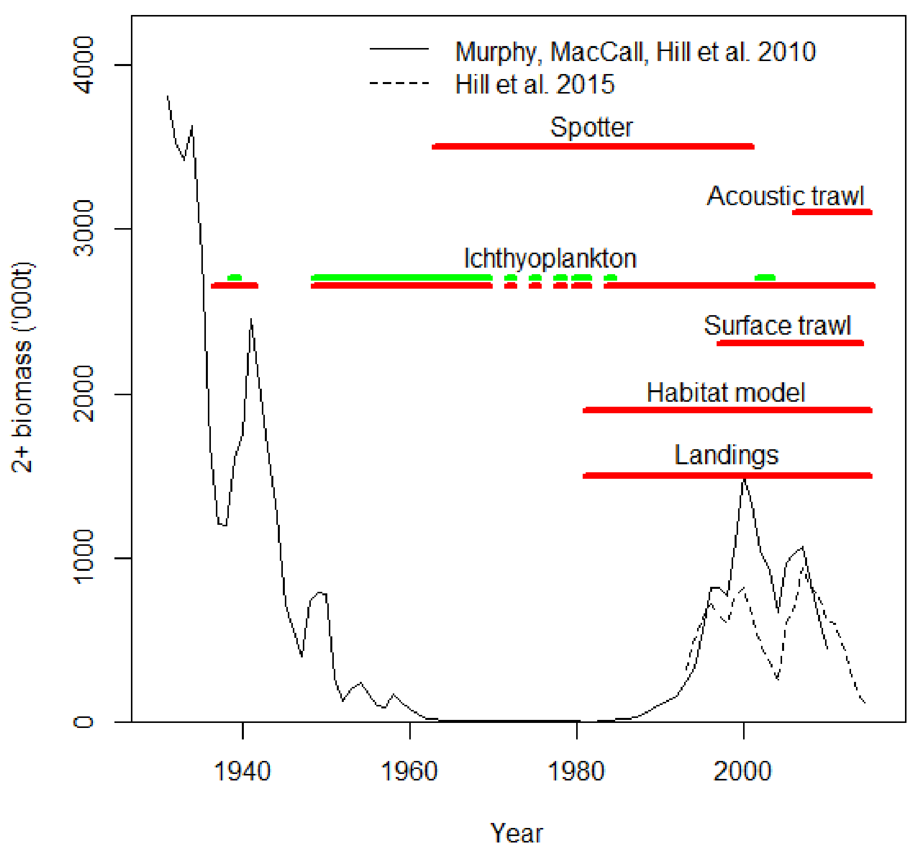


Figure 7. 2+ biomass trajectories from three historical assessments (Murphy, 1966; MacCall, 1979; Hill *et al.*, 2010) (solid line) and the most recent assessment (Hill *et al.*, 2015). The horizontal lines denote the years for which various sources of information on Distribution are available. The green points for the ichthyoplankton surveys denote years when surveys were conducted in both U.S. and Mexican waters (at least once during the year concerned), and the red points denote years when surveys were conducted in U.S. waters. The landings line indicates the years for which landings data have been assigned to the northern and southern subpopulations.

# Appendix A

## PROPOSED AGENDA
## PACIFIC FISHERY MANAGEMENT COUNCIL
## WORKSHOP ON PACIFIC SARDINE DISTRIBUTION
**August 17-19, 2015**

Pacific Room
Southwest Fisheries Science Center
8901 La Jolla Shores Dr., La Jolla, CA 92037
La Jolla, CA 92037
858-334-2800

The Pacific Fishery Management Council (Council), the National Marine Fisheries Service (NMFS), and the National Oceanic and Atmospheric Administration's (NOAA) Southwest Fisheries Science Center (SWFSC) are convening this workshop to examine the Distribution parameter in the Pacific sardine harvest control rule (HCR), including potential alternative means of accounting for the fact that some portion of the U.S. stock is present and subject to harvest outside U.S. waters. The workshop will review the best available scientific information on the Distribution parameter and is not intended as a review of other aspects of the HCR or Pacific sardine harvest management policy. The workshop is a requirement of the Oceana vs Pritzker Settlement Agreement[1], and a workshop results report will be considered by the Pacific Fishery Management Council at its November 2015 meeting.

The workshop is open to the public, and public comments will be accepted during the scheduled public comment period. Public comment at times other than the established public comment period will be taken at the discretion of the Workshop Chair.

Notes:

1. Meeting materials are available on the Workshop ftp site: ftp://ftp.pcouncil.org/pub/2015_Sardine_Distribution_Workshop/
2. The Workshop Terms of Reference is available on the ftp site, or by request.
3. Agenda item C will also briefly summarize the current stock structure hypothesis compared to that on which the current value for Distribution is based.
4. Agenda items D, K and M will address Objective 1. These agenda items will also address whether the current value for Distribution could be updated basis on more recent data and whether data are available which could set Distribution annually or only as an average over several years.
5. Agenda item O will address Objective 4
6. Agenda item N will address Objective 3
7. Agenda items E and F will address Objective 2
8. Agenda item G will address Objective 5
9. The report will be finalized as per the Terms of Reference, after the Workshop concludes

*Italicized names indicate co-author who is not present.*

[1] *Oceana, Inc. v. Penny Pritzker, et al*. (Ninth Circuit No. 13-16183; District Court No. C-11-6257 EMC (N.D. Cal.)). The Settlement Agreement requires a scientific workshop to examine the Distribution parameter of the Pacific sardine harvest control rule, including consideration that catch can occur in the U.S., Mexican, and Canadian waters. The results of the workshop are to be presented at the Council's November 2015 meeting, at which time the Council will determine whether further action regarding this item is warranted.

<u>MONDAY AUGUST 17 – 1 P.M.</u>

***A. Call to order, Administrative Matters*** — André Punt, Chair
*Facilities, Adoption of Agenda, Appointment of Rapporteurs* — Dale Sweetnam
*(1 p.m., 0.5 hours)* — Kerry Griffin

***B. Terms of Reference and Objectives*** — Josh Lindsay/Kerry Griffin
*(1:30 p.m., 0.5 hours)*

*The following five afternoon presentations will be approximately 30-60 minutes including questions. The Chair will call a break at an appropriate time.*

***C. Basis for the current value for distribution*** — Josh Lindsay/Nancy Lo/*Larry Jacobson*

***D. Survey-based data for estimating distribution (acoustic-trawl data)*** — David Demer

***E. Landings data for estimating distribution I*** — Kevin Hill

***F. Landings data for estimating distribution II*** — David Demer

***G. Temperature-based data for estimating distribution*** — David Demer *(tentative)*

***H. Requests for analyses*** — Participants
*(5:30 p.m., 0.5 hours)*

<u>TUESDAY AUGUST 18</u>

***I. Public Comment*** — André Punt
*(8 a.m., 0.5 hours)*

***J. Responses to requests for analyses*** — Participants
*(8:30 a.m., 1 hour)*

BREAK

***K. Survey-based data for estimating distribution (CalCOFI data)*** — Sam McClatchie
*(10 a.m., 1 hour)*

***L. Canadian approaches and data for estimating distribution and migration*** — Linnea Flostrand
*(11 a.m., 1 hour)*

LUNCH

***M. CUFES Survey data off Southern California and Baja California, Mexico*** — Tim Baumgartner/
*(1 p.m., 1 hour)* — *Augusto Valencia-Gasti/Ed Weber*

***N. Estimating stock biomass in U.S. waters only*** — Kevin Hill
*(2 p.m., 0.5 hours)*

BREAK

***O. Using a numerical vs percent-based distribution parameter*** — Josh Lindsay

*(3 p.m., 0.5 hours)*

***P. General discussion and requests for additional analyses*** Participants
*(3:30 p.m., 1 hour)*

WEDNESDAY AUGUST 19

***Q. Responses to overnight requests / review of report status*** Participants
*(8 a.m., 1 hour)*

***R. Consideration of any new approaches (tentative, at Chair's discretion)*** André Punt
*(9 a.m., 1 hour)*

BREAK

***S. Chair's summary and initial conclusions*** André Punt
*(10:30 a.m., 1 hour)*

***T. Final assignments and meeting wrap-up*** André Punt
*(11:30 a.m., 0.5 hours)*

*If needed, there will be additional Workshop discussion after a lunch break*

ADJOURN

# Appendix B

**2015 Pacific Sardine Distribution Workshop**

**Principal Participants**
André Punt (Chair), SSC, University of Washington
Tom Jagielo, SSC
Owen Hamel, SSC, NWFSC
Cleridy Lennert-Cody, IATTC
Cyreis Schmitt, ODFW/CPSMT
Kirk Lynn, CDFW/CPSMT
Alan Sarich, Quinault Indian Nation/CPSMT
Sam McClatchie, SWFSC
Kevin Hill, SWFSC
David Demer, SWFSC
Paul Crone, SWFSC

**Other Invited Participants**
Mike Okoniewski, CPSAS
Diane Pleschner-Steele, CWPA
Geoff Shester, Oceana
David Crabbe, Council member
Corey Niles, Council member, WDFW
Linnea Flostrand, Canada DFO
Tim Baumgartner, CICESE, Mexico
Frank Lockhart, Council Member, NMFS WCR

**Workshop Coordinators**
Josh Lindsay, NMFS WCR
Dale Sweetnam, SWFSC
Mike Burner, PFMC
Kerry Griffin, PFMC

**Other Attendees**
Russ Vetter, SWFSC
Cisco Werner, SWFSC
Sarah Shoffler, SWFSC
Mark Maunder, IATTC
Don Hansen, PFMC
Gerard DiNardo, SWFSC
Ben Enticknap, Oceana
Suzanne Manugian, SWFSC
Kevin Stierhoff, SWFSC
Josiah Renfree, SWFSC
Andrew Richards, commercial fisherman
Scott Mau, SWFSC
Roger Hewitt, SWFSC
Russ Vetter, SWFSC
Nancy Lo, SWFSC (retired)
Larry Jacobson, NEFSC
Gilly Lyons, PEW

**Acronyms**
CDFW – California Department of Fish and Wildlife
CICESE - Centro de Investigación Científica y de Educación Superior de Ensenada
CPSAS - Coastal Pelagic Species Advisory Subpanel
CPSMT - Coastal Pelagic Species Management Team
CWPA – California Wetfish Producers Association
DFO – Department of Fisheries and Oceans (Canada)
IATTC – Inter-American Tropical Tuna Commission
NMFS - National Marine Fisheries Service
ODFW – Oregon Department of Fish and Wildlife
NWFSC - Northwest Fisheries Science Center (National Oceanic and Atmospheric Administration)
SSC - Scientific and Statistical Committee (of the Pacific Fishery Management Council)
SWFSC - Southwest Fisheries Science Center (National Oceanic and Atmospheric Administration)
WDFW – Washington Department of Fish and Wildlife
WCR – West Coast Region

**Appendix C**

# TERMS OF REFERENCE

**I. Purpose**

A workshop to examine the Distribution parameter in the Pacific sardine harvest control rule (HCR), and to examine potential alternative means of accounting for the fact that some portion of the U.S. stock is present and subject to harvest outside U.S. waters. The workshop will review the best available scientific information on the Distribution parameter and is not intended as a review of other aspects of the HCR or Pacific sardine harvest management policy. The workshop is a requirement of the *Oceana vs Pritzker* Settlement Agreement[2], and the workshop report will be considered by the Council at the November 2015 meeting, to determine whether further action is warranted.

The current Distribution parameter of the Pacific sardine HCR was estimated in Amendment 8 to the Coastal Pelagic Species (CPS) fishery management plan (FMP) (PFMC 1998). The Distribution term was reviewed at a 2013 technical workshop that concluded that synthesis and further evaluation of existing data was an important step in evaluating whether the value of the Distribution parameter should be revised. The Distribution term is used to account for the fact that some proportion of sardine biomass may at times not be in U.S. waters. The Pacific sardine harvest control rule is:

HARVEST = (BIOMASS – CUTOFF) * FRACTION * DISTRIBUTION

Pacific sardines exhibit annual and interannual migratory patterns, and the actual portion of sardines in U.S. waters at any given time is highly variable. While the Council’s policy has been to account for the migratory and international nature of the sardine stock, it also recognized that it is impossible to accurately gauge the precise proportional distribution at any given time. Therefore, although the estimate of the Distribution value is informed by the best scientific information available, the determination of the value is ultimately a policy decision rather than a scientific one. Recognizing this, the Council considered a range of options for estimating the Distribution parameter, and chose a fixed factor of 0.87 as the most reasonable long-term average, for use in the HCR. This 0.87 value was derived after examining spotter pilot data and larval distribution data. Ultimately, the Amendment 8 analysts recommended using the spotter pilot estimate because it was a more realistic number than the CalCOFI index or a combination of the two. A primary purpose of the workshop is to consider whether new or newly-evaluated information warrants consideration of changing the value of the Distribution parameter.

**II. Objectives**

The workshop participants are expected to compile the best available scientific information on the distribution of the northern subpopulation of Pacific sardines along the North American Pacific

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[2] *Oceana, Inc. v. Penny Pritzker, et al*. (Ninth Circuit No. 13-16183; District Court No. C-11-6257 EMC (N.D. Cal.)). The Settlement Agreement requires a scientific workshop to examine the Distribution parameter of the Pacific sardine harvest control rule, including consideration that catch can occur in the US, Mexican, and Canadian waters. The results of the workshop are to be presented at the Council’s November 2015 meeting, at which time the Council will determine whether further action regarding this item is warranted.

Coast, and to consider potential alternatives for estimating or specifying the value of the Distribution parameter of the Pacific sardine harvest control rule in the CPS FMP. These are listed on page 2 of the Settlement Agreement. The workshop participants may consider additional methods such as #5 below. Additional methods may be considered by Workshop participants, at the discretion of the Workshop Chair, if submitted to the Chair no later than August 10, 2015. The Workshop Chair will determine if the method is sufficiently described and is reasonable for inclusion in the Workshop agenda. Alternatives to be considered include:

7. Setting the value for the Distribution parameter annually as part of the specifications process based on the most recent data on the actual mean distribution of the Pacific sardine stock in U.S. waters. Primary presenters: SWFSC.
8. Using landings information from Canada and Mexico to account for catch in the waters of those nations in estimating the Distribution parameter in the HCR, using work from recently published scientific studies regarding Pacific sardine management. Primary presenters: SWFSC.
9. Estimating the stock biomass in U.S. waters only, instead of the total sardine biomass, in the stock assessment. Primary presenters: SWFSC.
10. Using a numerical-based Distribution parameter as an alternative to the existing percent-based Distribution parameter. Primary presenter: NMFS WCR Staff.
11. Using a temperature-based model to predict the proportion of Pacific sardines in U.S. waters for a particular year. Primary presenter: SWFSC.

**II. Outcomes**

1. A workshop report, including:
   a. A summary of the analyses of each alternative considered by the workshop participants;
   b. Recommendations on which, if any, alternative would represent an improvement over the current term of 0.87, for use in the Pacific sardine HCR;
   c. Recommendations on statistical or methodological shortcomings and data gaps, relative to each of the alternatives considered by the workshop participants;
   d. Other appropriate records of the workshop.
2. The final workshop report will be considered by the Council, and is to be submitted for the advance briefing book deadline for the November, 2015 Council meeting.

**III. Responsibilities**

1. The Workshop Chair is responsible for overall facilitation and order of the Workshop. The Chair will make rapporteur assignments, delegate tasks to presenters and Principals, and will be responsible for assigning section authors, and preparing the final report.
2. Workshop Principals are responsible for reviewing alternatives and other presentations, for making requests to presenters, and to make sincere attempts to resolve disagreements and discrepancies among Principals, presenters, and other workshop attendees.
3. Workshop presenters are responsible for providing meaningful presentations that describe the data available that may be used to inform Distribution, or if possible, describe potential alternatives to the current Distribution value.
4. It is the expectation that all Workshop attendees will provide information, advice, and dialog relative to the alternatives being considered.

# Appendix D

**PRIMARY DOCUMENTS**

- Demer, D.A., and J.P. Zwolinski. Variations in the spatial distribution of an internationally exploited migrating stock of Pacific sardine (*Sardinops sagax*) for consideration in the U.S. Harvest Control Rule (primary document 1)
- Jacobson, L. and N.C.H. Lo. Proportions of sardines in U.S. waters from fish spotter and CalCOFI data (primary document 2)
- Hill, K.T. using sardine landings to estimate the 'Distribution' parameter (primary document 3)
- Hill, K.T. Estimating sardine stock biomass in U.S. waters only (primary document 4)
- Shester, G. and B. Enticknap. Problem Statement, Requests for Analysis, and Considerations for Revising the Pacific Sardine Distribution Parameter (primary document 5)

**PRIMARY DOCUMENTS (PRESENTATIONS ONLY)**

- McClatchie, S. Survey-based methods for estimating distribution (CalCOFI data) (primary document 6)
- Baumgartner, T., Valencia, A. and R. Durazo. Distribution of transboundary movement of sardine stocks in the California Current (primary document 8)
- Valencia-Gasti, J., Baumgartner, T. and R. Durazo. Distribution of Pacific Sardine Spawning Habitat within the Waters of the Mexican and U.S. Exclusive Economic Zones (primary document 8)

# Appendix E

## Description of the calculations underlying each curve in plots 2-6

Owen Hamel (NWFSC)

In all cases "catch" refers to catch of the Northern Subpopulation of Pacific Sardine (NSP).

Figure 2:

i. *Actual U.S. Landings*: U.S. landings of the NSP as reported in Table 2 of Primary Document 1.

ii. *U.S. HG*: Actual U.S. Harvest Guidelines (HG; or quotas) by year as reported in Table 2 of Primary Document 1. The amount that would have been caught had the entire U.S. HG been taken and the entire U.S. catch been from the northern population.

iii. *Alt HG 1*: The U.S. HGs that would have been adopted had the method described in Demer and Zwolinski (2014b) been implemented. This equals:

    ((the U.S. HG (see ii) in current year)/0.87) – (catch in Mexico and Canada last year)

iv. *Alt HG 2*: The U.S. HGs that would have been adopted had the additional method described in Primary Document 1 been implemented. This has an additional adjustment for the prediction error for foreign catch in the previous year. See Primary Document 1. The total adjustment was limited to be less than or equal to zero, such that the Alt HG 2 for the U.S. could not exceed the 'coastwide HG' (see iii under Figure 3.)

Figure 3.

i. *Actual Landings*: Coastwide (U.S., Mexico and Canada) landings of the NSP as reported in Table 2 of Primary Document 1.

ii. *Landings if U.S. HG taken*: The coastwide harvest had the entire U.S. HG been taken and the entire U.S. catch been from the NSP (and assuming this had no impact on catch of the NSP in Mexico or Canada).

iii. *'Coastwide HG'*: The implied coastwide HG (= (U.S. HG)/0.87). This can be thought of as the harvest if everything went exactly "right" under management.

iv. *Landings with Alt HG 1*: The coastwide harvest had the entire U.S. ALT HG1 been taken given the caveats in ii.

v. *Landings with Alt HG 2*: The coastwide harvest had the entire U.S. ALT HG1 been taken given the caveats in ii.

Figure 4:

i.-v. under Figure 3 above divided by the age 1+ NSP biomass as reported in Table 2 of Primary Document 1. This is the exploitation rate on the 1+ biomass assuming the 2015 assessment reflects actual historical biomass.

Figure 5:

i.-v. under Figure 3 above divided by [(age 1+ NSP biomass as reported in Table 2 of Primary Document 1) – 150,000 mt]. This is the exploitation rate on the 1+ biomass after the cutoff is excluded, assuming the 2015 assessment reflects actual historical biomass.

Figure 6:
i.-v. under Figure 3 above divided by [(age 1+ NSP biomass as reported in Table 1 of Demer and Zwolinski 2014b) – 150,000 mt]. This is the exploitation rate on the 1+ biomass after the cutoff is excluded, assuming the 2012 assessment reflects actual historical biomass.

Further caveats (which apply to the original analysis in Demer and Zwolinski (2014b) and Primary Document 1 as well):

1. This assumes that all catch in the U.S. under the U.S. HG and Alt HG 1 and 2 are from the NSP and none from the SSP, or, alternatively, that the U.S. is able to differentiate and take the right amount of the NSP.
2. There is no feedback in this analysis, so a larger catch in one year does not affect the population in the following year.