COASTAL PELAGIC SPECIES MANAGEMENT TEAM REPORT ON
SARDINE HARVEST FRACTION

## Introduction

The harvest guideline (HG) control rule for Pacific sardine includes a sea surface temperature (SST) parameter measured off the Scripps Institution of Oceanography (SIO) pier. Recent research indicates that the California Cooperative Oceanic Fisheries Investigations (CalCOFI) temperature index is a better indicator of the California Bight SST and a better predictor of Pacific sardine recruitment and productivity. The Council already adopted the CalCOFI temperature index and productivity relationship for use in the overfishing limit (OFL) control rule. The purpose of this report is to assess the effect of changing the temperature index from SIO to CalCOFI for the FRACTION component of the Pacific sardine harvest guideline (HG) control rule, and to recommend changes to FRACTION based on this assessment.

In March and September 2014, the Coastal Pelagic Species Management Team (CPSMT) presented reports that considered how use of a SST index for Pacific sardine management would affect existing Pacific Council harvest and management policy. In addition to recommending use of the CalCOFI temperature index to replace the SIO pier index, the CPSMT recommended modifying the FRACTION bounds for the HG harvest control rule (HCR) from 5-15% to 10-20%. The March report analyzed two options for FRACTION: 5-15% and 10-20%; the September report included Council requested analyses of alternate HG FRACTION bounds of 5-20% and 0-20%.

At its September meeting, the Council considered a preliminary draft Environmental Assessment (EA) describing preliminary alternatives for the SST index and four variations on the harvest FRACTION range: 5-15 percent, 5-20 percent, 0-20 percent, and 10-20 percent (September 2014 Agenda Item C.1.a Attachment 1). To meet the Council's desire for more direct comparison to what is in place now, this report expands the information and analyses presented to further characterize the transition to CalCOFI and the new temperature-recruitment relationship. Performance measures with SIO informing the FRACTION term are included, along with a retrospective view of harvest control rule outputs with both the SIO and CalCOFI temperature time series, and a series of hypothetical scenarios illustrating the suite of harvest control outputs over a range of biomasses and SSTs.

## How this report is organized

Before describing the alternatives under consideration, this report begins with a brief review of the events leading to reevaluation of the temperature index for the sardine control rules, and the formulas and current policy framing the control rules. Next, a description comprising simulation modeling performance measures, retrospective views and hypothetical scenarios for the alternatives is presented. Embedded in the description and conclusion is the CPSMT's recommendation for the FRACTION term.

A number of appendices include new supporting information, as well as material submitted in previous reports for reference. Appendix 1 adds descriptive text, and depicts simulation modeling performance measures for Alternatives 1 and sub-alternatives 2a-d. Likewise, the complete table of fifteen hypothetical scenarios is found in Appendix 2. Additional runs of the Hurtado-Ferro and Punt (2014) simulation model were done for sub-alternatives 2a-d with varying P-star and Tier values; these are depicted in Appendix 3. Scripps Pier and CalCOFI mean annual temperatures are repeated from earlier reports in Appendix 4. Appendix 5 presents additional retrospective harvest levels based on observed temperatures with hypothetical biomass estimates.

In addition to this report, the CPSMT, National Marine Fisheries Service (NMFS) staff, and Council staff prepared a draft environmental assessment (EA) for this action, included as Agenda Item E.2.a, Attachment 1.

## Harvest Control Rule Framework

To effectively evaluate the alternatives presented in this report, it is important to recognize the interplay between the set of Pacific sardine HCRs under current policy, which is informed by both Amendments 8 and 13 of the CPS FMP.

A Maximum Sustainable Yield (MSY) Control Rule and the HG for Pacific sardine were first established in Amendment 8 of the Coastal Pelagic Species Fishery Management Plan (CPS FMP) (PFMC 1998). The HG includes a FRACTION term, which is a proxy for $E_{MSY}$ [1] and which specifies how much of the sardine stock is available for harvest when the biomass is above CUTOFF (i.e. the lowest biomass at which harvest is allowed). FRACTION has been dependent on a linear relationship between oceanic water temperature and stock productivity, with sardines being more productive at higher ocean temperatures (Jacobsen and MacCall 1995).

Up until Amendment 13 of the CPS FMP (PFMC 2011), the HG was the only sardine harvest control rule and it described the overfishing limit, the annual harvest policy, and the annual catch limit. Amendment 13 adopted Overfishing Limit (OFL) and Acceptable Biological Catch (ABC) as additional harvest control rules. The formulas for the three HCRs are displayed below.

| **Harvest Control Rule (HCR) Formulas** |
|---|
| OFL = BIOMASS * $E_{\mathrm{MSY}}$ (0-25) * DISTRIBUTION<br><br>$\mathrm{ABC}_{\text{P-star}}$ = BIOMASS * $\mathrm{BUFFER}_{\text{P-star}}$ * $E_{\mathrm{MSY}}$ * DISTRIBUTION<br><br>HG = (BIOMASS - CUTOFF) * FRACTION ($E_{\mathrm{MSY}}$ 5-15) * DISTRIBUTION |

[1] As a point of clarification, Overfishing Limits (OFLs) for CPS are based on $F_{MSY}$ or $E_{MSY}$ proxy harvest rates applied to the best available estimate of biomass. $F_{MSY}$ is an instantaneous measure of fishing mortality rate for deterministic equilibrium MSY. In reality, an annual exploitation rate, $E_{MSY}$, is used as a proxy for $F_{MSY}$ as the appropriate measure of fishing mortality for a particular year. $E_{MSY}$ is used to determine OFL and is also equal to FRACTION in the HG Harvest Control Rule, subject to lower and upper bounds.

All three control rules (OFL, ABC, and HG) incorporate $E_{MSY}$, an estimate of the exploitation rate at MSY. $E_{MSY}$ is dependent upon SST and serves as a proxy for the influence of environmental conditions on stock biomass, so that harvest levels (rates) are adjusted in relation to different oceanic conditions. In both the OFL and ABC control rules $E_{MSY}$ is bounded at 0 and 25% (Figure 1)[2]. In the HG control rule, $E_{MSY}$ is more narrowly bounded, from 5-15%, and is represented by the FRACTION parameter. These bounds – 0, 5, 15 and 25% – reflect Council policy to set the portion of stock available to the fishery depending on, and within a range of environmental conditions.

The upper bounds constrain the exploitation rate when temperature and $E_{MSY}$ increase, as SSTs get warmer. Similarly, the lower bound of 5% in the HG reflects a policy decision to allow the exploitation rate to remain constant at this level regardless of further declines in temperature and $E_{MSY}$. Analyses conducted during the Amendment 13 scoping process showed that there were times when the ABC control rule fell below the HG at some P-star (probability of overfishing) values during years with lower SSTs. This outcome is in part due to fixing the lower bound for FRACTION at 5%. To address this, Amendment 13 implemented an additional policy that specifies the lowest HCR be used for annual management, effectively overriding FRACTION's lower bound at lower SSTs. The result was that sardine management post-Amendment 13 became more precautionary, particularly in cooler and low biomass conditions.

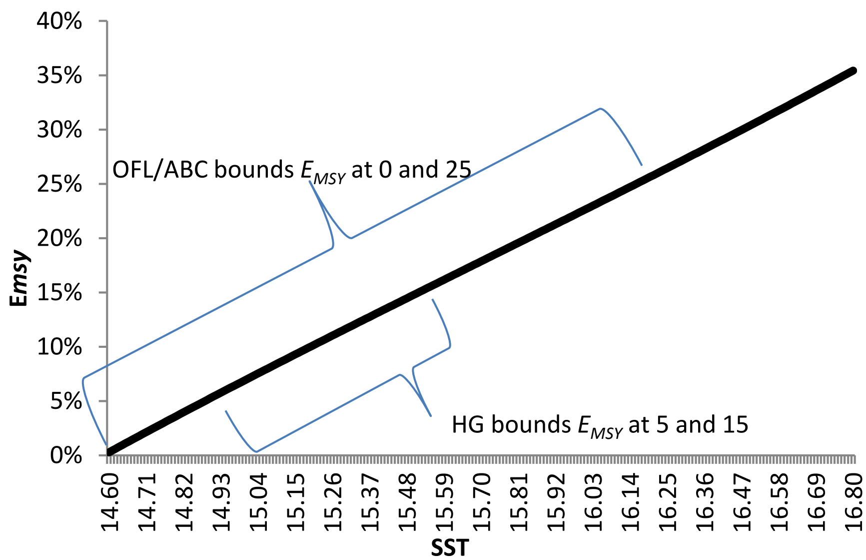



Figure 1. CalCOFI $E_{MSY}$ relationship to SST, with current OFL/ABC and HG bounds on $E_{MSY}$.

[2] The upper bound of 25% was recommended by the SSC because it nearly corresponds to the upper quartile of observed CalCOFI temperatures, 1984-2008. Actual upper quartile value is 26% (Figure 3); Hurtado-Ferro and Punt simulation modeling utilized 25%.

In 2010, McClatchie et al. questioned whether the SIO sardine stock–recruit and temperature–recruit relationships underpinning the FRACTION term in the sardine HG formula were still valid. Subsequently, the CalCOFI temperature time series was identified as a better indicator of ocean temperatures off southern California and a better predictor of Pacific sardine recruitment/productivity (Lindegren and Checkley 2013). To incorporate this new scientific information, at the behest of the Council, Felipe Hurtado-Ferro and André Punt developed a new simulation harvest model and conducted an analysis of sardine management scenarios (Hurtado-Ferro and Punt 2014). The simulation model and sensitivity tests developed by Hurtado-Ferro and Punt enabled the examination of the risks associated with the current harvest control rules using this new index, as well as comparison of stock and fishery performance measures for alternative OFL and HG control rules.

The following information and analyses of alternatives characterize the transition to the CalCOFI temperature index and the new temperature-recruitment relationship. Performance measures with SIO informing the FRACTION term are included, along with a retrospective view of harvest control rule outputs with both the SIO and CalCOFI temperature time series, and a series of hypothetical scenarios illustrating the suite of harvest control outputs over a range of biomasses and SSTs.

## Description of Alternatives for Temperature Index and FRACTION Bounds, and CPSMT Recommendation

### Alternative 1 – SIO Temp Index; HG FRACTION 5-15 (NO ACTION)

This alternative retains the Scripps Institution of Oceanography (SIO) pier temperature index to describe the relationship between ocean conditions and sardine stock productivity and the bounds around the FRACTION harvest control rule parameter as adopted in Amendment 8 of the CPS FMP.

### Alternative 2 – Use the New Temp Index (CalCOFI)

The purpose of this alternative is to switch from the SIO temperature index to a CalCOFI SST-based index for computing the harvest control rules, while evaluating whether and how this transition can occur while maintaining current harvest policy. Alternative 2 examines four different scenarios for bounding FRACTION, which are defined below:

***Sub-alternative 2a – Maintain existing bounds on FRACTION, of 5-15%***
This sub-alternative retains the existing HG FRACTION bounds of 5-15% adopted originally in Amendment 8 to implement a temperature-based harvest control rule, but adopts the CalCOFI temperature index.

***Sub-alternative 2b – Revise bounds on FRACTION to 10-20%***
This sub-alternative adjusts the HG FRACTION range in the harvest guideline control rule to 10-20%.

***Sub-alternative 2c – Revise bounds on FRACTION to 5-20%***
This sub-alternative maintains a lower bound of FRACTION at 5% and increases the upper bound to 20%.

***Sub-alternative 2d – Revise bounds on FRACTION to 0-20%***

Under this sub-alternative the bounds for FRACTION in the HG control rule are the broadest of all the options, and are set at 0-20%.

There are several choices for incorporating an environmental co-variate into the HG policy for Pacific sardine. The first decision point is whether to use SIO (Alternative 1 or No Action) or CalCOFI as the temperature index (Sub-alternatives 2a-d). Secondarily, sub-alternatives 2a-d present a range of $E_{MSY}$ bounds (FRACTION) for the HG.

***CPSMT Recommendation***

The CPSMT **recommends** adopting sub-alternative 2b, use of the CalCOFI SST temperature index with a harvest FRACTION of 10-20% in order to better 1) adhere to the goals and maintain policies for sardine management previously adopted under Amendments 8 and 13; 2) cover the range of CalCOFI temperatures similar to the past use of SIO temperatures; and 3) provide for adaptive management under a broad range of sardine resource and environmental conditions. The 20% upper bound of the FRACTION range will allow greater harvest opportunities in some cases, when SSTs are favorable and the stock is abundant. The 10% lower limit ensures that at least a small amount will be available especially for incidental harvest in other commercial fisheries and for live bait.

Regarding the decision to move from the SIO-based temperature index and temperature-productivity relationship, the CPSMT recognizes the CalCOFI SST index is presently the most appropriate indicator of sardine recruitment/productivity and **recommends** its use. The results of the harvest policy workshop demonstrated the CalCOFI index had the best fit to recruitment measures of all available environmental variables evaluated (PFMC 2013). And the SSC approved using the CalCOFI SST index as best available science, to compute the Overfishing Limit (OFL).

1) Adherence to Goals and Policies

Sub-alternative 2b is consistent with the Council's goals and policies. The specific HG formula adopted under Amendment 8 was selected from among many potential HCR rules analyzed because it optimally met the following CPS FMP goals:

1. Promote efficiency and profitability in the fishery, including stability of catch.
2. Achieve optimum yield.
3. Provide adequate forage for predator species.
4. Prevent overfishing.

A variety of performance measures were estimated over the long-term with a simulation model and then compared against the goals for each HCR variant. A similar approach was used to evaluate various FRACTION bounds under Alternative 2 with the new CalCOFI SST temperature index (Hurtado-Ferro and Punt 2014). The performance measure results for the Alternatives are presented in Appendix 1 of this report, and in Table 1 of the draft EA (November Briefing Book Agenda Item E.1.a Attachment 1). Under the No Action alternative, FRACTION in the HG would continue to rely on SIO which has been deemed less representative of current ocean conditions and not the best available science.

Sub-alternative 2b maintains a precautionary management approach. Depletion refers to the portion of the population remaining after harvest (i.e., the percentage of fish left in the ocean after harvest). The CPSMT notes that the depletion rate (% mean biomass compared to the unfished case) rose from 64% based on the existing HG rule in Amendment 8 to ≥75% for sub-alternatives 2a-d (Appendix 1, Table A-1). This means that under all scenarios under Alternative 2, a higher percent of biomass is being left in the ocean compared to what was expected under the status quo.

Further, the updated analysis/new model shows an increase from stochastic $E_{MSY}$ of 0.12 in Amendment 8 to 0.18 (Hurtado-Ferro and Punt 2014). The increase in $E_{MSY}$ reflects statistically identified increased productivity and therefore a higher fishing rate at MSY that maximizes mean catch.

For sub-alternatives 2a-d, biological and economic performance measures are similar, differing by less than 5% except for mean and median catch (Appendix 1). Mean and median catch are approximately 5% and 9% lower, respectively, for sub-alternative 2a than the other sub-alternatives. Other economic performance indicators are generally comparable. All of the sub-alternatives have similar frequencies of years with no catch (i.e., no fishery), ranging from 4.7% to 5.1%, and the frequency of years with catch <50 mt is identical: 31% for all Alternatives. For biological performance measures, all the Alternatives have a population biomass over 400,000 mt more than 91 percent of the time. These results show 2a (FRACTION bounds of 5-15) provides less catch than the other scenarios, but does not produce higher biomass levels than those other scenarios with higher catches.

<u>2) Range of Observed CalCOFI Temperatures</u>

Sub-alternative 2b best represents, and is best aligned with, the range of observed CalCOFI temperatures. In the relationship between SST and $E_{MSY}$, a FRACTION that ranges from 10-20% better reflects the range of observed CalCOFI temperatures in a comparable manner to the 5-15% range for SIO temperatures. Figure 2 depicts the current policy from Amendment 8, using SIO temperature and FRACTION bounded at 5-15%, with median and quartile observed temperatures noted. Figure 3 similarly depicts FRACTION bounded at 5-15% and 10-20% using CalCOFI temperatures, with median and quartile observed temperatures noted. FRACTION at 5-15% for the CalCOFI SST index encompasses fewer than half the observed temperatures.

Given that the stock is more productive than previously estimated, and assuming use of the CalCOFI temperatures, FRACTION at 10-20% is a more conservative policy than a FRACTION range of 5-15% (using SIO temperatures). Under the 10-20% range, FRACTION is better aligned with the median CalCOFI temperatures, but the range still falls in the lower temperature range than the 5-15% using SIO temperatures.

CalCOFI FRACTION at 10-20% manages the stock at lower prescribed $E_{MSY}$/FRACTION levels compared to SSTs commonly observed, while SIO FRACTION at 5-15% manages at roughly the $E_{MSY}$/FRACTION levels corresponding to most of the SSTs observed. Hence, using a CalCOFI 10-20% FRACTION results in a smaller FRACTION relative to what the $E_{MSY}$/SST relationship calls for, i.e., at an exploitation rate less than MSY. Use of the SIO 5-15% FRACTION results in generally falling in line with exploitation at MSY, based on the $E_{MSY}$/SST relationship.

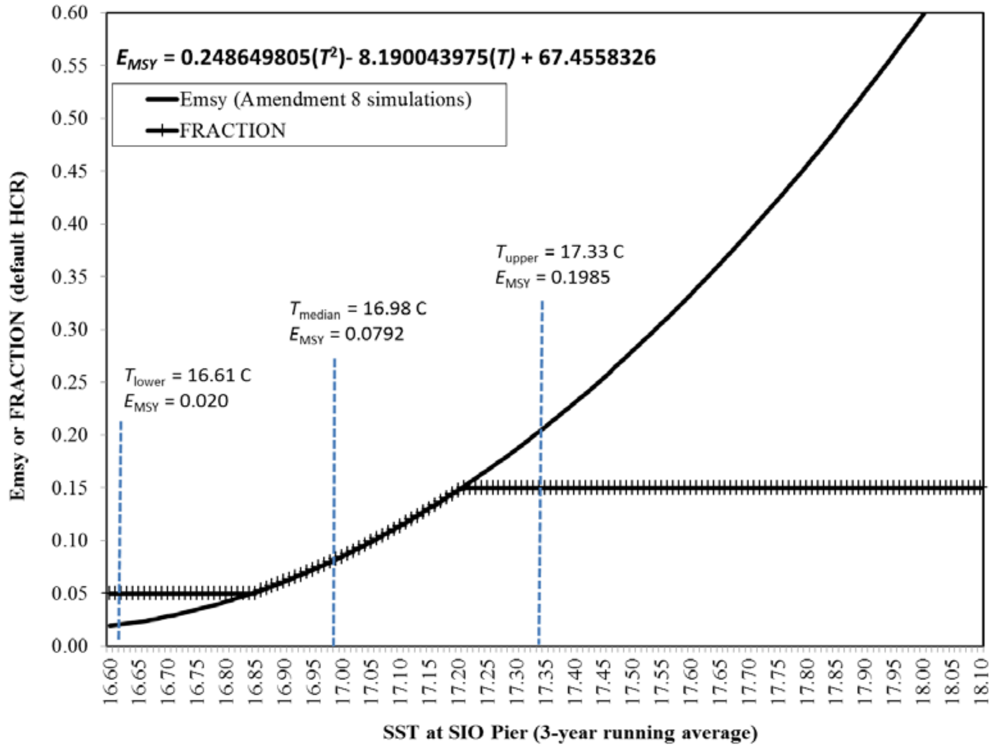



Figure 2. $E_{MSY}$ and FRACTION based on SST at SIO pier (Amendment 8). Vertical lines represent quartile and median SSTs from years used to develop the $E_{MSY}$ -SST relationship (1916-1997).

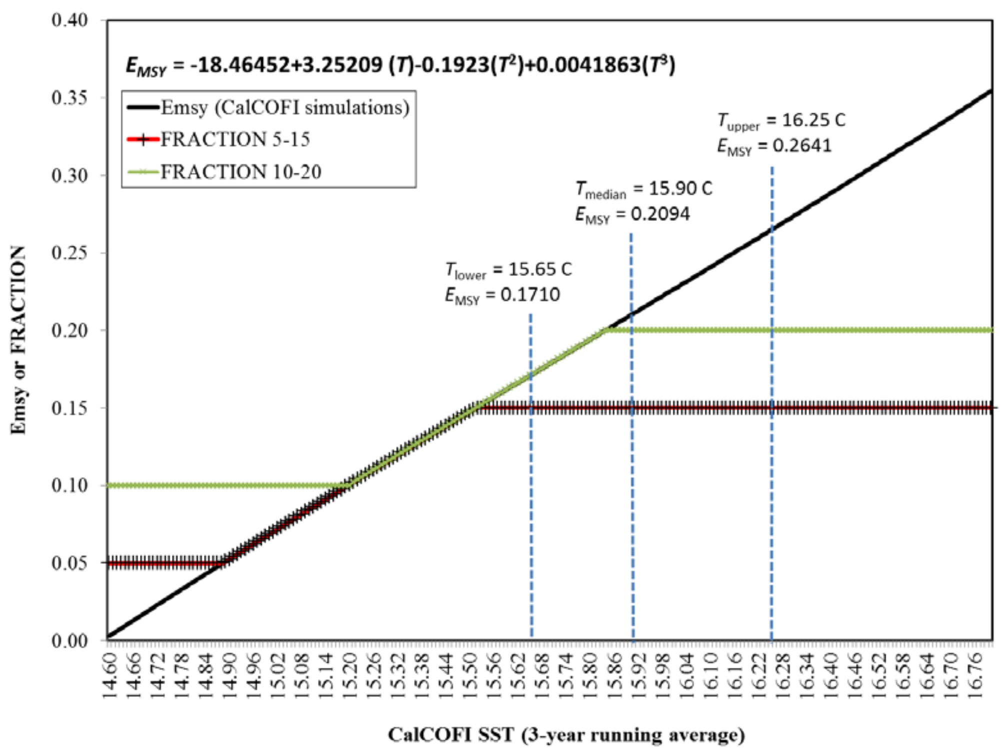



Figure 3. $E_{MSY}$ and FRACTION based on CalCOFI (Hurtado-Ferro and Punt 2014). FRACTION bounded at 5-15% and 10-20%. Vertical lines represent quartile and median SSTs from years used to develop the $E_{MSY}$-SST relationship (1984-2008).

3) Management under Diverse Conditions

Sub-alternative 2b allows for adaptive management under a variety of conditions. The original intent of the HG under the CPS FMP was to have a FRACTION that varied based on temperature to allow higher harvest rates and more catch during good conditions and lower harvest rates and less catch during unfavorable environmental conditions. The bounding of FRACTION was a Council policy decision based on social, economic, and biological criteria.

Under Amendment 13, additional Harvest Control Rules afforded the Council the assurance that allowed harvests would not exceed the OFL or the ABC, for a given P-star value (probability of overfishing). The Council adopted a policy to set the allowable harvest no higher than the lowest of the HCRs. In addition, the Council may set an Annual Catch Target (ACT) at any level below the lowest ABC or HG but not higher, giving the Council the ability to adapt to adverse social, economic, environmental or biological conditions not already accounted for in the three HCRs.

For the HG, the lower FRACTION bound of 10% is a minimum harvest level under cooler SST conditions. It allows for some harvest opportunity in cooler conditions, although the ABC control rule can still be lower than an HG with FRACTION at 10%. The net result is that a lower bound at 10%, couched in the current policy to select the lowest HCR output, is not substantially different than a lower bound at 5% (Appendix 2/Table A-2, panels 1, 6 and 11). Selecting a FRACTION with an upper bound of 20 preserves a greater level of fishing opportunity while still retaining the ability to set lower harvest limits. Alternative 2b (10-20%) thus 1) affords the most flexibility to select harvest limits at the lower bound, since Annual Catch Target levels can always be selected below (but not above) the prescribed ABC or HG to protect the stock, and 2) provides more opportunity during warmer more productive conditions.

## Hypothetical Scenarios and Control Rule Analysis

To compare and evaluate FRACTION Alternatives 2a-d under a wide range of biomass and temperature conditions, the CPSMT estimated allowable harvests for the HCRs and each Alternative for 15 sample conditions (Appendix 2, Table A-2). Three levels were selected to indicate low (250,000 mt), moderate (700,000 mt) and high (1,500,000 mt) biomass. Five temperature conditions, as indicated by $E_{MSY}$ values, were analyzed: 0-5% for low temperatures, 5-10% for moderately low temperatures, 10-15% for moderate temperatures, 15-20% for moderately warm temperatures, and 20-25% for warm temperatures. These example ranges were selected to reflect the potential differences in upper and lower bounds of FRACTION sub-alternatives 2a-d, as well as the OFL/ABC bounds (0-25%). The HCRs included OFL, ABC with P-star=0.4, ABC with P-star=0.05, and HG under each of the FRACTION sub-alternatives 2a-d. For each example (panel in table), the computed harvest control rule (whether ABC or HG) and its associated harvest rate (harvest/biomass of age 1+ fish) are listed in order of low to high harvest level.

For a given biomass level and HCR, allowable harvests increase with increasing temperatures, until the upper bound of FRACTION or MAXCAT (200,000 mt) is reached. At all biomass levels and moderately warm and warm temperatures, allowable harvests under sub-alternatives 2b, c, and d are the same because their upper FRACTION bound is 20%. Allowable harvest under all the alternatives is below the ABC at P-star = 0.4 and even below ABC at P-star = 0.05 when biomass is low.

At low and moderately low temperatures and all biomass levels, the lower bound of FRACTION determines the level of allowed harvest. Allowed harvest under these conditions is the same for Alternatives 2a and 2c (lower bound of 5%), and Alternative 2d (lower bound of 0%) allows the least harvest of all the sub-alternatives. However, at all three biomass levels (panels 1, 6 and 11), ABC at P-star = 0.4 is lower than the HG for sub-alternative 2b (lower bound of 10%), and therefore, the ABC would be used for management.

At moderate temperatures and all three biomass levels, the sub-alternatives 2a-2d do not differ. All alternatives provide the same allowable harvest and it is lower than ABC at P-star = 0.4. The difference between allowable harvest and the ABC value decreases as stock size increases so that at high biomass levels, the allowable harvest and ABC are nearly the same.

In the following figures, 4a-d, which correspond to the FRACTION sub-alternatives 2a-d, harvest rates as a function of SST are shown for different levels of stock biomass (low = 250,000 mt, moderate = 700,000 mt, high = 1,500,000 mt). These figures pictorially present information similar to Table A-2 with hypothetical examples of harvest rates and harvests under a range of biomass and temperatures. However, Table A-2 presents information tabulated to easily compare among Alternatives at a given biomass and temperature level, whereas each of the Figures 4a-d presents information to readily compare harvest rates and interplay among control rules for a single Alternative under different biomass and temperature conditions. To provide an indication of how often these temperature conditions have been observed historically, quartile and median values for 3-year averaged CalCOFI temperatures from 1950-2013 are denoted by dashed and solid vertical lines, respectively. HG and ABC (P-star 0.4) harvest rates are constrained by the 200,000 mt maximum catch allowance (MAXCAT). ABC values are also restricted by the $E_{MSY}$ upper bound of 0.25. At the lower end of SSTs, ABC harvest rates go to zero, while HG harvest rates are limited by each alternative's lower FRACTION bound for $E_{MSY}$. Negative harvest rates at lower SSTs are set to 0 on the figures. Also note that the lines are the same for ABCs at low and medium biomass levels on all the figures.

For **sub-alternative 2a** (Figure 4a), harvest rates for the HG are lower than those for ABC above the lower SST quartile, when biomass is at medium or high levels. At temperatures below 14.8 degrees, harvest rates are determined by the ABC and are less than 5% at all biomass levels. At approximately the median SST, harvest rates reach their maximum: 12% for high biomass, 10% for medium biomass, and 5% for low biomass levels.

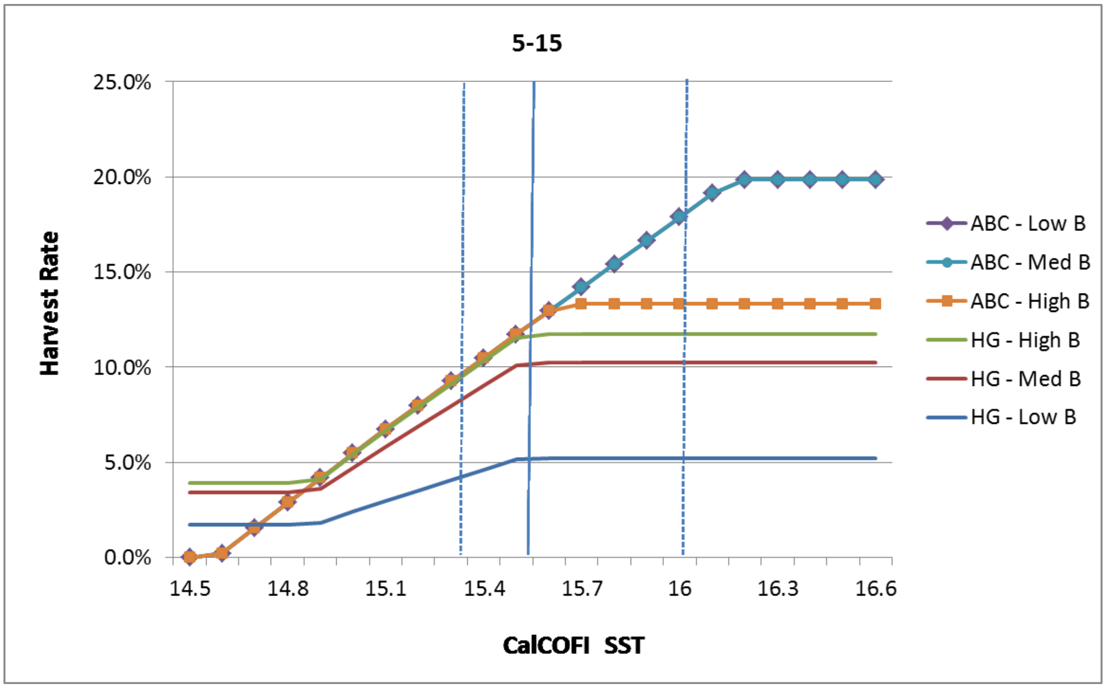



Figure 4a. Harvest rates as a function of CalCOFI SST under different levels of stock biomass (low = 250,000 mt, medium = 700,000 mt, high = 1,500,000 mt) for **sub-alternative 2a** (FRACTION = 5-15%).

For **sub-alternatives 2b-d** (Figures 4b-d), harvest rates for a given biomass level are identical at temperatures above 15.3 degrees (the lower SST quartile), and harvest rates for the HG are lower than the ABC rates. Under these scenarios, harvest rates reach their maximum at temperatures above the median, ranging from approximately 14% for medium and high biomass levels to about 7% for low biomass levels. Because these sub-alternatives differ only in the lower bounds for FRACTION, their harvest rates diverge from each other at progressively lower temperatures as the lower FRACTION bound is reduced. For example, under sub-alternative 2b (FRACTION 10-20%), the lower bound for the HG at all biomass levels is reached at temperatures below about 15.2 degrees. Similarly, under **sub-alternative 2c** (FRACTION 5-20%), the lower HG bound is reached at about 14.9 degrees, whereas it is reached at 14.6 degrees for **sub-alternative 2d** (FRACTION 0-20%). The point at which the ABC is lower than the HG and therefore, determines allowable harvest likewise occurs at progressively lower temperatures. Consequently, harvest rates at low temperatures range from a maximum of about 8% for Alternative 2b at high biomass levels down to zero for sub-alternative 2d at all biomass levels.

For the sub-alternatives, at cooler temperatures between about 14.6 – 15.1 $^{0}$C, the ABC begins to override the HG. Below about 14.6 $^{0}$C harvest rates are reduced to zero regardless of biomass level.

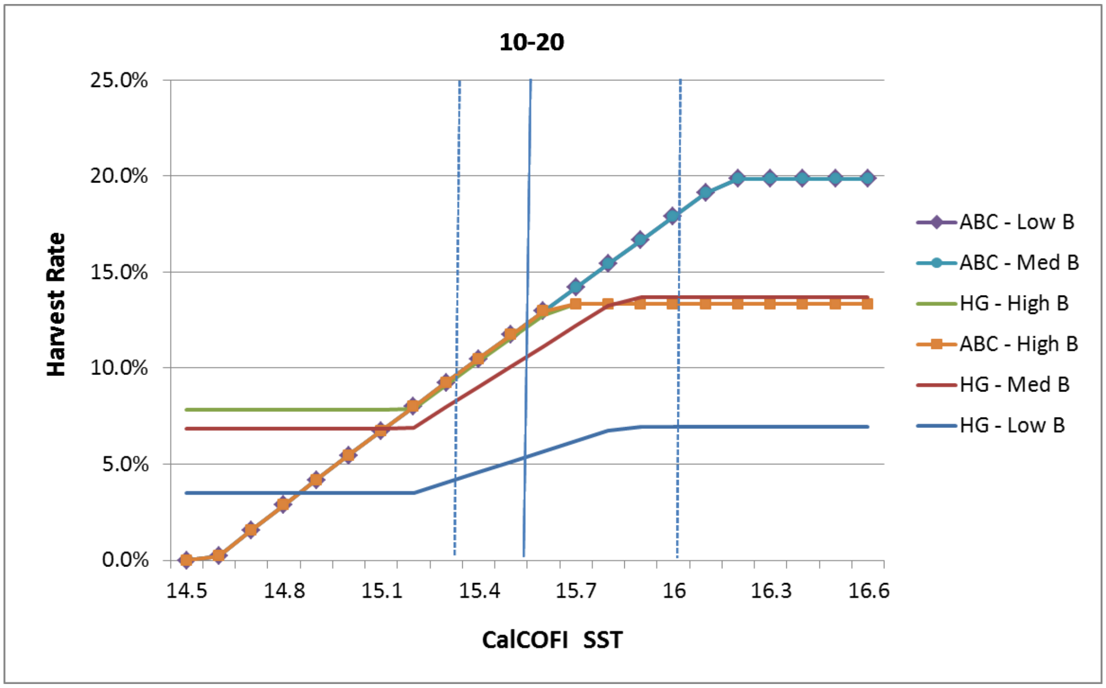



Figure 4b. Harvest rates as a function of CalCOFI SST under different levels of stock biomass (low = 250,000 mt, medium = 700,000 mt, high = 1,500,000 mt) for **sub-alternative 2b** (FRACTION = 10-20%).

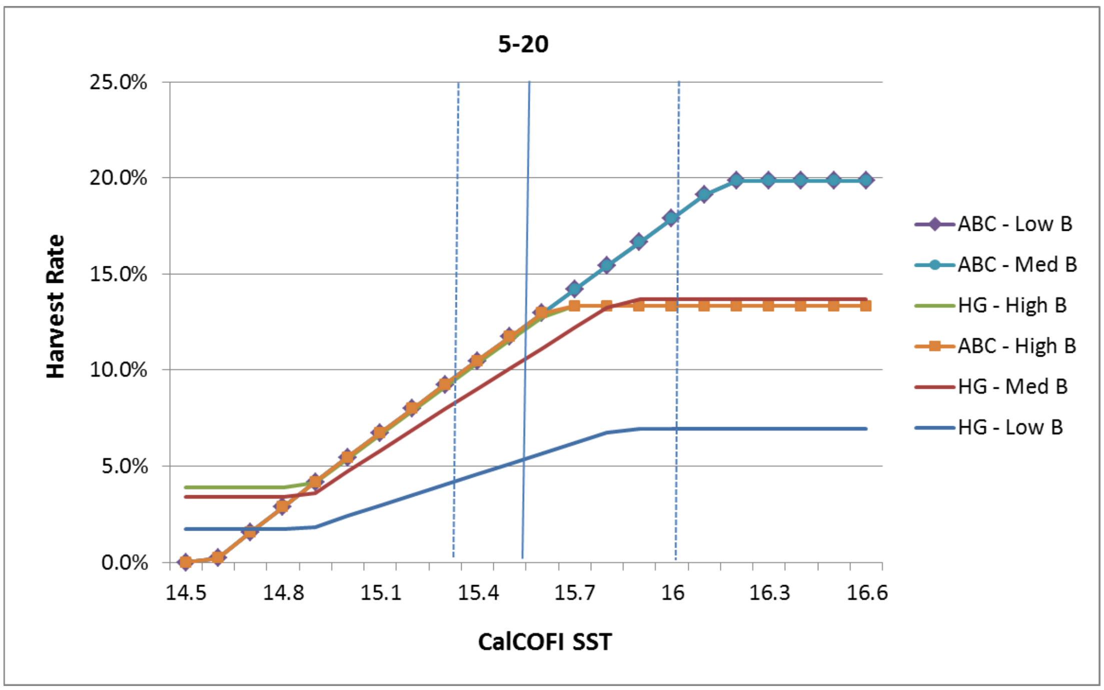



Figure 4c. Harvest rates as a function of CalCOFI SST under different levels of stock biomass (low = 250,000 mt, medium = 700,000 mt, high = 1,500,000 mt) for **sub-alternative 2c** (FRACTION = 5-20%).

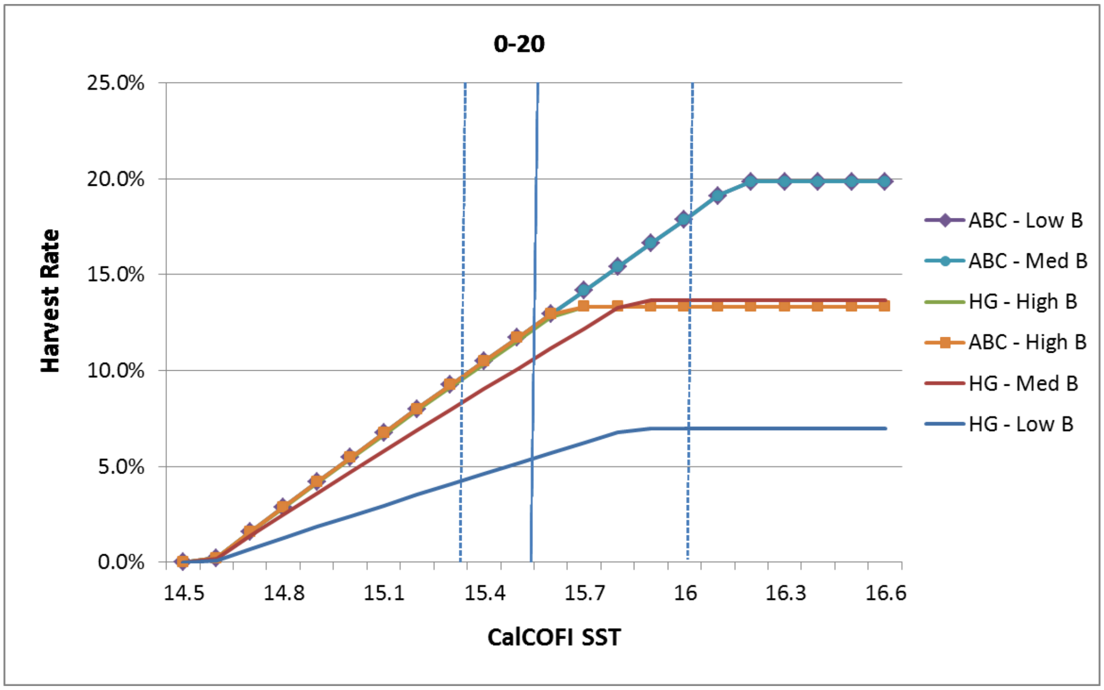



Figure 4d. Harvest rates as a function of CalCOFI SST under different levels of stock biomass (low = 250,000 mt, medium = 700,000 mt, high = 1,500,000 mt) for **sub-alternative 2d** (FRACTION = 0-20%).

In summary, at low temperatures (unfavorable conditions), harvest rates and harvests estimated for FRACTION sub-alternative 2b (10-20%) are overridden by a lower ABC value, as intended under the HCR policies adopted under Amendment 13. At moderate temperatures, all the Alternatives perform similarly. At higher temperatures (favorable environmental conditions), sub-alternatives 2b, c, and d perform similarly and allow greater harvest rates and harvests compared to sub-alternative 2a. At moderate and high biomasses, the difference can be substantial, as much as 25,000 mt until MAXCAT is reached. If sub-alternative 2a is adopted, this additional harvest opportunity is foregone. If one of the other sub-alternatives is adopted, this opportunity is preserved, and the Council may choose to set a more conservative ACT as environmental, socioeconomic or resource conditions warrant.

## Retrospective Analysis

The application of the CalCOFI index and the alternatives for FRACTION are shown retrospectively in the following table and figures. Caution should be used in evaluating these illustrations. First, removals in any year affect biomass in subsequent years and this view assumes no difference in biomass regardless of difference of catch between the two indices. Secondly, biomass estimates are not fixed. With each stock assessment, biomass estimates are updated reflecting new understanding as more biological and catch data are added. For this evaluation, biomasses for the period prior to federal management (i.e. 2000) are taken from the 2010 sardine update assessment (Hill et al. 2010). The biomasses for subsequent years are those adopted for annual management each year. This approach is consistent with that used in the Harvest Parameters Workshop (Lindegren and Checkley 2013).

The differences in HG control rules and true harvest rates (HR) for years 1992-2014 are shown below using different FRACTION bounds for SIO and CalCOFI (Table 2). The HG values are subscripted: Alternative 1 (SIO 5-15% FRACTION bounds) or sub-alternatives 2a-2d (CalCOFI FRACTION bounds 5-15%, 10-20%, 5-20%, 0-20%). Note the minimum CalCOFI $E_{MSY}$ value for 1992-2014 was 0.11 (11), so all HG and HR values for sub-alternatives 2b-2d are identical. Harvest rates are the HG value divided by the coastwide biomass (1+ years). In year 2000, $HG_{2b-d}$ values are constrained by the 200,000 mt maximum allowable catch.

Figure 5 shows biomasses (low, median, and high) CalCOFI temperatures (low, median, and high) since 1992. Figure 6 compares harvest rates for all Alternatives since 1992.

**Table 1.** Pacific sardine HG control rules and true HRs for years 1992-2014, with SIO and CalCOFI temperature indices. HGs are bounded by Alternatives 1 (SIO) and 2a-d (CalCOFI) specifications, with temperature-dependent OFL/ABC FRACTION of 0-25%, and CUTOFF and MAXCAT at status quo.

| | | SIO | | | | | CalCOFI | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Biomass (1+) | SST | Emsy | HG FRAC$_1$ | HG$_1$ | SIO HR | SST | Emsy | HG FRAC$_{2a}$ | HG$_{2a}$ | HG FRAC$_{2b\text{-}d}$ | HG$_{2b\text{-}d}$ | CC$_{2a}$ HR | CC$_{2b\text{-}d}$ HR |
| 1992 | 168,037 | 17.35 | 0.207 | 0.150 | 2,354 | 1.4% | 15.75 | 0.187 | 0.150 | 2,354 | 0.187 | 2,930 | 1.4% | 1.7% |
| 1993 | 250,493 | 17.61 | 0.340 | 0.150 | 13,114 | 5.2% | 16.17 | 0.251 | 0.150 | 13,114 | 0.200 | 17,486 | 5.2% | 7.0% |
| 1994 | 329,328 | 17.84 | 0.482 | 0.150 | 23,402 | 7.1% | 16.31 | 0.273 | 0.150 | 23,402 | 0.200 | 31,203 | 7.1% | 9.5% |
| 1995 | 562,105 | 17.97 | 0.575 | 0.150 | 53,780 | 9.6% | 16.53 | 0.310 | 0.150 | 53,780 | 0.200 | 71,706 | 9.6% | 12.8% |
| 1996 | 821,223 | 18.04 | 0.631 | 0.150 | 87,595 | 10.7% | 16.27 | 0.268 | 0.150 | 87,595 | 0.200 | 116,793 | 10.7% | 14.2% |
| 1997 | 819,628 | 18.07 | 0.649 | 0.150 | 87,386 | 10.7% | 16.24 | 0.263 | 0.150 | 87,386 | 0.200 | 116,515 | 10.7% | 14.2% |
| 1998 | 771,761 | 18.08 | 0.659 | 0.150 | 81,140 | 10.5% | 16.31 | 0.275 | 0.150 | 81,140 | 0.200 | 108,186 | 10.5% | 14.0% |
| 1999 | 1,095,610 | 18.47 | 1.015 | 0.150 | 123,402 | 11.3% | 16.60 | 0.320 | 0.150 | 123,402 | 0.200 | 164,536 | 11.3% | 15.0% |
| 2000 | 1,581,346 | 18.08 | 0.660 | 0.150 | 186,791 | 11.8% | 16.25 | 0.264 | 0.150 | 186,791 | 0.200 | 200,000 | 11.8% | 12.6% |
| 2001 | 1,182,465 | 17.75 | 0.421 | 0.150 | 134,737 | 11.4% | 15.95 | 0.217 | 0.150 | 134,737 | 0.200 | 179,649 | 11.4% | 15.2% |
| 2002 | 1,057,599 | 17.24 | 0.162 | 0.150 | 118,442 | 11.2% | 15.54 | 0.154 | 0.150 | 118,442 | 0.154 | 121,816 | 11.2% | 11.5% |
| 2003 | 999,871 | 17.31 | 0.191 | 0.150 | 110,908 | 11.1% | 15.43 | 0.137 | 0.137 | 100,938 | 0.137 | 100,938 | 10.1% | 10.1% |
| 2004 | 1,090,587 | 17.46 | 0.259 | 0.150 | 122,747 | 11.3% | 15.51 | 0.149 | 0.149 | 121,863 | 0.149 | 121,863 | 11.2% | 11.2% |
| 2005 | 1,193,515 | 17.60 | 0.334 | 0.150 | 136,179 | 11.4% | 15.62 | 0.166 | 0.150 | 136,179 | 0.166 | 150,737 | 11.4% | 12.6% |
| 2006 | 1,061,391 | 18.03 | 0.618 | 0.150 | 118,937 | 11.2% | 15.79 | 0.193 | 0.150 | 118,937 | 0.193 | 152,802 | 11.2% | 14.4% |
| 2007 | 1,319,072 | 18.11 | 0.685 | 0.150 | 152,564 | 11.6% | 15.75 | 0.187 | 0.150 | 152,564 | 0.187 | 190,001 | 11.6% | 14.4% |
| 2008 | 832,706 | 18.12 | 0.693 | 0.150 | 89,093 | 10.7% | 15.51 | 0.149 | 0.149 | 88,560 | 0.149 | 88,560 | 10.6% | 10.6% |
| 2009 | 662,886 | 17.83 | 0.477 | 0.150 | 66,932 | 10.1% | 15.45 | 0.139 | 0.139 | 62,231 | 0.139 | 62,231 | 9.4% | 9.4% |
| 2010 | 702,024 | 17.84 | 0.483 | 0.150 | 72,039 | 10.3% | 15.26 | 0.110 | 0.110 | 53,033 | 0.110 | 53,033 | 7.6% | 7.6% |
| 2011 | 537,173 | 17.90 | 0.522 | 0.150 | 50,526 | 9.4% | 15.39 | 0.131 | 0.131 | 44,185 | 0.131 | 44,185 | 8.2% | 8.2% |
| 2012 | 988,385 | 17.64 | 0.358 | 0.150 | 109,409 | 11.1% | 15.49 | 0.146 | 0.146 | 106,624 | 0.146 | 106,624 | 10.8% | 10.8% |
| 2013 | 659,539 | 17.36 | 0.213 | 0.150 | 66,495 | 10.1% | 15.47 | 0.143 | 0.143 | 63,325 | 0.143 | 63,325 | 9.6% | 9.6% |
| 2014 | 369,506 | 17.22 | 0.156 | 0.150 | 28,646 | 7.8% | 15.34 | 0.122 | 0.122 | 23,293 | 0.122 | 23,293 | 6.3% | 6.3% |

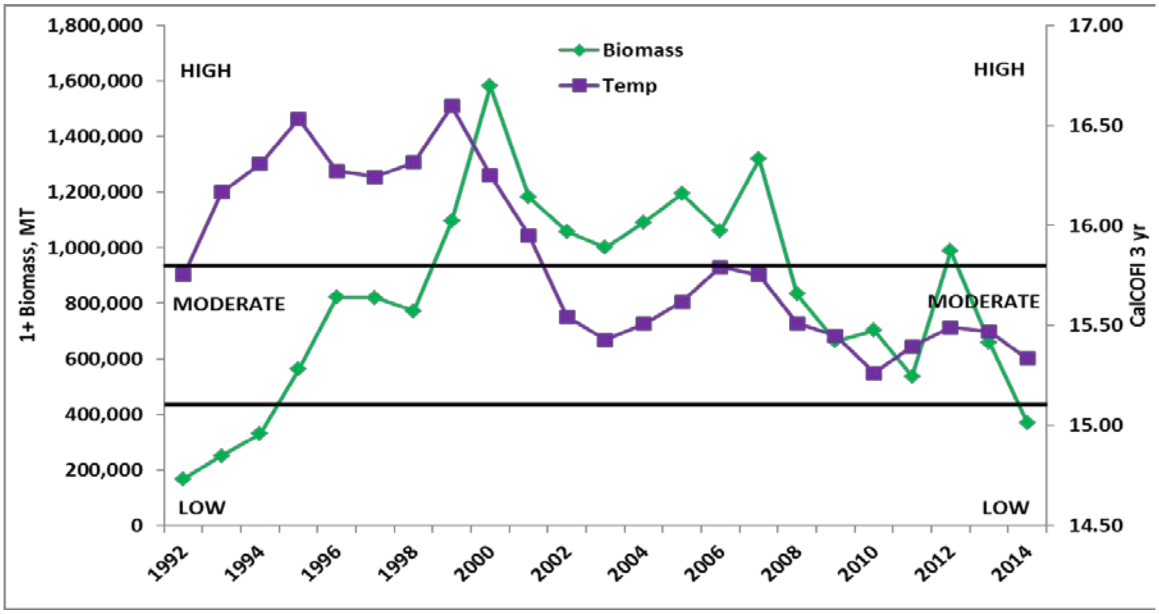



Figure 5. Sardine biomass (1+ years) and CalCOFI 3-yr averaged SST from 1992-2014; represents a retrospective view of years with high, moderate, and low biomass and temperatures.

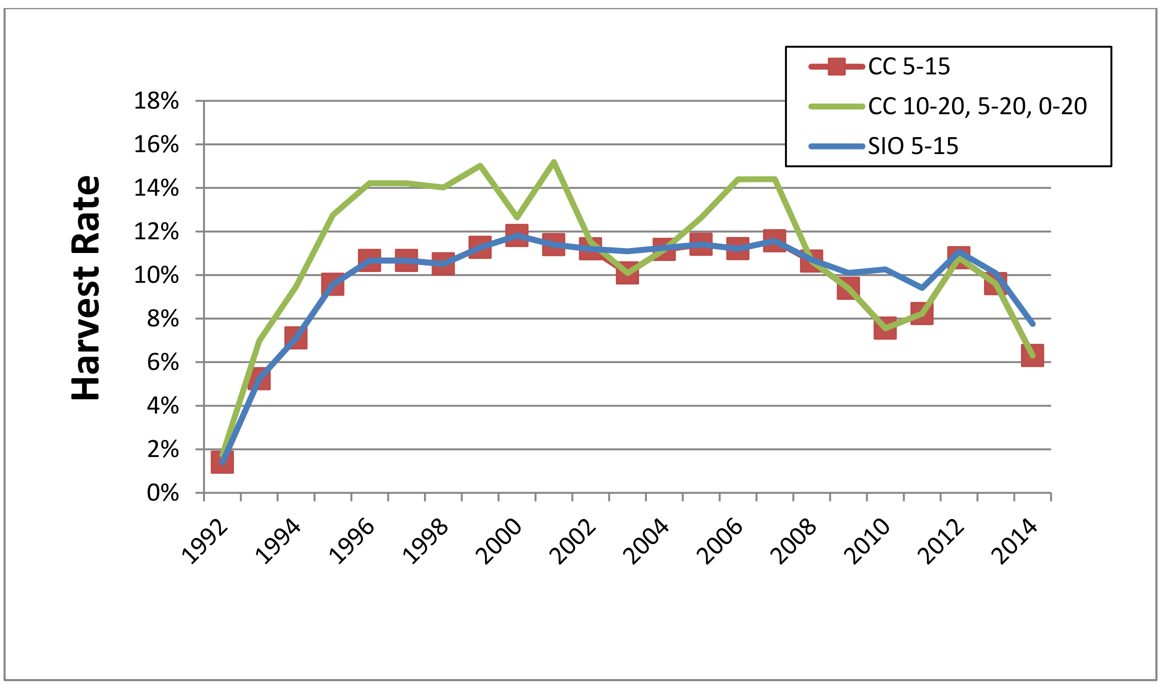



Figure 6. Retrospective comparison of harvest rates from Table 1. Note elevated harvest rates and increased opportunity for fishing during warmer years under CalCOFI Alternatives 2b-2d (FRACTION 10-20%, 5-20%, 0-20%).

# Conclusion

The CPSMT supports the continued inclusion of temperature as an environmental variable in the harvest guideline (HG) control rule for sardine management, because it is an indicator of stock productivity. The CPSMT recognizes the CalCOFI index is presently the most appropriate indicator of sardine recruitment/productivity and recommends its use. Use of the CalCOFI temperature time series, along with the change from a production to an age-structured model, incorporates best available science into the management of sardines and maintains a precautionary management policy over the long-term as evidenced by the simulation model performance measures, comparing sub-alternatives 2a-d with each other, and in comparison to the No Action Alternative.

The choice of values used to define or bound the HG FRACTION is a policy decision. The No Action option would be to continue to use SIO with FRACTION bounded at 5-15%. Another option is to use CalCOFI and FRACTION bounded at 5-15% (Alternative 2a). However, if CalCOFI is used going forward, and with the calculated stochastic $E_{MSY}$ changing from 0.12 (using SIO SST) to 0.18 (using CalCOFI SST), the CPSMT believes it would be appropriate to adjust the HG FRACTION bounds accordingly. The original intent of the HG under the CPS FMP was to have a FRACTION that varied based on temperature to allow more catch during good conditions and less during unfavorable conditions.

Placing a lower bound on FRACTION was a policy decision taken by the Council based on social, economic, and biological criteria to allow a small, but directed fishery when biomass and temperature were low, but above CUTOFF. Additionally, a FRACTION that ranges up to 20% also better reflects the mid-range of temperature vs $E_{MSY}$ and aligns with CalCOFI temperatures in manner that is similar to where the 5-15% range fell relative to SIO temperatures. Figure 2 depicts the current policy from Amendment 8, using SIO temperature and FRACTION bounded at 5-15%, compared to Figure 3 which depicts FRACTION bounded at 5-15% and 10-20% using CalCOFI temperature. This shift in FRACTION to up to 20% is a more conservative approach when looking at where the bounds lie with regard to the median temperature.

Among all the Alternatives, selection of FRACTION bounds of 10-20%, under existing policy, allows comparatively more Council discretion to set harvest levels, adaptively managing based on current information on recruitment, environmental conditions, or the trajectory of the stock biomass. The suite of HCRs (OFL, ABC, and HG) account for scientific and management uncertainty; the HG is but one control rule, used in conjunction with the others to manage the stock. Additionally, Annual Catch Target levels can always be selected below (but not above) the prescribed ABC or HG to address more immediate concerns. This option, with the cap at 20%, would preserve a greater level of fishing opportunity but does not limit the ability to set lower harvest limits as warranted to protect the stock. Additionally, a lower cap is not necessary to protect sardine because that is specifically what the ABC control rule does.

**Appendix 1: Modeled Performance Measures**

Table 1A below presents the performance measures from Amendment 8, HG-J and selected model harvest scenarios conducted by Hurtado-Ferro and Punt (2014), to compare values informing the FRACTION parameter.

Under the No Action alternative, OFL and ABC control rules would utilize the CalCOFI SST time series, whereas the FRACTION term in the HG would continue to rely on SIO. Performance measures for this alternative are not available; no single operating model exists that incorporates both SST time series. Development of such an operating model would first require analysis correlating the two SST time series. Such analysis would require oceanographic expertise and an approach similar to the Harvest Parameters Workshop (PFMC 2013).

As a substitute, performance metrics for the HCR policy adopted under Amendment 8 are presented in Table 1A. Care should be taken in evaluating the performance measures of the No Action alternative (1) with Alternatives 2a-d. The former are the output from the simulation modeling conducted under Amendment 8 (Jacobsen and MacCall 1995), whereas the latter were produced from the most recent simulation modeling Hurtado-Ferro, F. and A. E. Punt (2013). Because the results for the No Action alternative derive from a different data set and operating model, direct comparison between Alternatives 1 and 2a-d is not appropriate. However, a more general approach that considers the policy implications relative to the context, or scientific understanding of the two simulations, is reasonable.

The new operating model by Hurtado-Ferro and Punt (age-structured) is structurally different than the simulation model used in Amendment 8 (production model), and incorporates a revised recruitment time series that better represents sardine population dynamics over the past several decades. The updated model produces a higher stochastic $E_{MSY}$ ($SE_{MSY}$) than Amendment 8 (0.18 vs 0.12) due to the bulk of the intermediate and low biomass years when Amendment 8 was developed and a period when sardine biomass was declining because of the numerous cold water years. The new time series with more recent data includes a large number of years at low and intermediate biomass levels when the biomass was expanding because it was a warm water period (Dr. Richard Parrish, pers. comm.).

All the scenarios used a three-year averaged CalCOFI SST time series because this moderates inter-annual fluctuations in temperature and therefore harvest. A three-year average also spans temperature conditions from the year preceding spawning, the birth year and the year prior to recruitment to the adult population. This is consistent with present policy for FRACTION, which currently uses a three-year average temperature variable, but from SIO temperatures. For the purpose of analysis Hurtado-Ferro and Punt (2014) set DISTRIBUTION to 1.0, as was done originally in Amendment 8, and thus this parameter was not a factor in the scenarios.

Under Alternative 2, plain shaded cells (green) represent values within 5% of the best value; dotted/shaded cells represent values in excess of 5% of the best value.

**Table A-1.**

| Alternative | 1 "No Action" | 2a | 2b | 2c | 2d |
|---|---|---|---|---|---|
| Simulation Model | Original Amend. 8 Analysis | Hurtado-Ferro and Punt, 2014 | | | |
| Temperature Index | SIO | CalCOFI | | | |
| $E_{MSY}$ Bounds (FRACTON): | 5-15 | 5-15 | 10-20 | 5-20 | 0-20 |
| | | | | | |
| OFL $E_{MSY}$ (%) | - | 0-25 | 0-25 | 0-25 | 0-25 |
| CUTOFF | 150 | 150 | 150 | 150 | 150 |
| MAXCAT | 200 | 200 | 200 | 200 | 200 |
| | | | | | |
| **Performance Measure** | | | | | |
| ***Biological*** | | | | | |
| Mean B1+ (SD) | 1952 (49) | 1220 (888) | 1182 (883) | 1186 (882) | 1187 (881) |
| Mean SSB (SD) | - | 945 (757) | 911 (753) | 915 (752) | 916 (751) |
| Median B1+ | 1648 | 991.8 | 945.1 | 948.6 | 949.5 |
| %B1+>400 | 96 | 92 | 91 | 92 | 92 |
| Depletion (B1+ % of Unfished B1+) | 64% | 78% | 75% | 75% | 76% |
| | | | | | |
| ***Economic*** | | | | | |
| %No catch | 0.5 | 4.7 | 4.7 | 4.8 | 5.1 |
| %Catch<50 | - | 31 | 31 | 31 | 31 |
| Median catch | 182 | 97 | 107 | 107 | 107 |
| Mean catch all (SD) | 145 (67) | 106 (73) | 112 (75) | 111 (75) | 111 (76) |

**Appendix 2: Hypothetical Harvest Control Rule Scenarios**

In Table A-2 three biomass levels were selected to indicate low (250,000mt), moderate (700,000mt) and high (1,500,000mt) biomass. Five temperature conditions, as indicated by $E_{MSY}$ values, were analyzed: 0-5% for low temperatures, 5-10% for moderately low temperatures, 10-15% for moderate temperatures, 15-20% for moderately warm temperatures, and 20-25% for warm temperatures. These example ranges were selected to reflect the potential differences in upper and lower bounds of FRACTION Alternatives 2a-d, as well as the OFL bounds (0-25%).

The HCRs include OFL, ABC with P-star=0.4, ABC with P-star=0.05, and HG under each of the FRACTION Alternatives 2a-d. For each example (panel in table), the computed harvest (whether ABC or HG) and its associated harvest rate (harvest/biomass of 1+ fish) are listed in order of low to high harvest level.

In this illustration, the hypothetical biomass is analogous to total 1+ biomass. The ABC or HG output is US catch. The harvest rates are calculated as ABC or HG output divided by biomass. Therefore, the harvest rates here represent US catch of total 1+ biomass.

## Table A-2

Yellow highlight indicates management "driver."
Under Panels 1 and 6 - ABC P.40 is lower than Alt 2b so it would be used for management.
Under Panel 11, ABC P.40 would be used for management in lieu of Alts 2a-c.
ABC P.05 and P.40 are in red font reflecting current Council choice (P.40) and something lower (P.05).
Within each panel - outputs are ranked low to high based on harvest rate.

**Low Biomass (250,000 mt)** | **Moderate Biomass (700,000 mt)** | **High Biomass (1,500,000 mt)**

**"Low" Temp**
**Emsy between 0 and 5%**
**Emsy used for scenario: 2.5%**
Temp Range: 14.58 to 14.88
Temp Used for Scenario: 14.73

| 1 | Harvest rate | ABC or HG | 6 | Harvest rate | ABC or HG | 11 | Harvest rate | ABC or HG |
|---|---|---|---|---|---|---|---|---|
| 2d. 0-20 | 0.87% | 2,175 | ABC 0.05 | 1.20% | 8,421 | ABC 0.05 | 1.20% | 18,044 |
| ABC 0.05 | 1.20% | 3,007 | ABC 0.10 | 1.37% | 9,597 | ABC 0.10 | 1.37% | 20,566 |
| ABC 0.10 | 1.37% | 3,428 | ABC 0.20 | 1.61% | 11,245 | ABC 0.20 | 1.61% | 24,096 |
| ABC 0.20 | 1.61% | 4,016 | 2d. 0-20 | 1.71% | 11,962 | ABC 0.30 | 1.80% | 27,011 |
| 2a. 5-15 | 1.74% | 4,350 | ABC 0.30 | 1.80% | 12,605 | 2d. 0-20 | 1.96% | 29,361 |
| 2c. 5-20 | 1.74% | 4,350 | ABC 0.40 | 1.99% | 13,897 | ABC 0.40 | 1.99% | 29,780 |
| ABC 0.30 | 1.80% | 4,502 | ABC 0.45 | 2.08% | 14,551 | ABC 0.45 | 2.08% | 31,181 |
| ABC 0.40 | 1.99% | 4,963 | 2a. 5-15 | 3.42% | 23,925 | 2a. 5-15 | 3.92% | 58,725 |
| ABC 0.45 | 2.08% | 5,197 | 2c. 5-20 | 3.42% | 23,925 | 2c. 5-20 | 3.92% | 58,725 |
| 2b. 10-20 | 3.48% | 8,700 | 2b. 10-20 | 6.84% | 47,850 | 2b. 10-20 | 7.83% | 117,450 |

**"Low-Mod" Temp**
**Emsy between 5 and 10%**
**Emsy used for scenario: 7.5%**
Temp Range: 14.88 to 15.20
Temp Used for Scenario: 15.04

| 2 | Harvest rate | ABC or HG | 7 | Harvest rate | ABC or HG | 12 | Harvest rate | ABC or HG |
|---|---|---|---|---|---|---|---|---|
| 2a. 5-15 | 2.61% | 6,525 | ABC 0.05 | 3.61% | 25,262 | ABC 0.05 | 3.61% | 54,134 |
| 2c. 5-20 | 2.61% | 6,525 | ABC 0.10 | 4.11% | 28,793 | ABC 0.10 | 4.11% | 61,699 |
| 2d. 0-20 | 2.61% | 6,525 | ABC 0.20 | 4.82% | 33,735 | ABC 0.20 | 4.82% | 72,290 |
| 2b. 10-20 | 3.48% | 8,700 | 2a. 5-15 | 5.13% | 35,887 | ABC 0.30 | 5.40% | 81,036 |
| ABC 0.05 | 3.61% | 9,022 | 2c. 5-20 | 5.13% | 35,887 | 2a. 5-15 | 5.87% | 88,086 |
| ABC 0.10 | 4.11% | 10,283 | 2d. 0-20 | 5.13% | 35,887 | 2c. 5-20 | 5.87% | 88,086 |
| ABC 0.20 | 4.82% | 12,048 | ABC 0.30 | 5.40% | 37,817 | 2d. 0-20 | 5.87% | 88,086 |
| ABC 0.30 | 5.40% | 13,506 | ABC 0.40 | 5.96% | 41,693 | ABC 0.40 | 5.96% | 89,342 |
| ABC 0.40 | 5.96% | 14,890 | ABC 0.45 | 6.24% | 43,654 | ABC 0.45 | 6.24% | 93,544 |
| ABC 0.45 | 6.24% | 15,591 | 2b. 10-20 | 6.84% | 47,850 | 2b. 10-20 | 7.83% | 117,450 |

**"Mod" Temp**
**Emsy between 10 and 15%**
**Emsy used for scenario: 12.5%**
Temp Range: 15.20 to 15.52
Temp Used for Scenario: 15.35

| 3 | Harvest rate | ABC or HG | 8 | Harvest rate | ABC or HG | 13 | Harvest rate | ABC or HG |
|---|---|---|---|---|---|---|---|---|
| 2a. 5-15 | 4.35% | 10,875 | ABC 0.05 | 6.02% | 42,105 | ABC 0.05 | 6.02% | 90,225 |
| 2b. 10-20 | 4.35% | 10,875 | ABC 0.10 | 6.86% | 47,990 | ABC 0.10 | 6.86% | 102,835 |
| 2c. 5-20 | 4.35% | 10,875 | ABC 0.20 | 8.03% | 56,227 | ABC 0.20 | 8.03% | 120,487 |
| 2d. 0-20 | 4.35% | 10,875 | 2a. 5-15 | 8.54% | 59,813 | ABC 0.30 | 9.00% | 135,064 |
| ABC 0.05 | 6.02% | 15,038 | 2b. 10-20 | 8.54% | 59,813 | 2a. 5-15 | 9.79% | 146,814 |
| ABC 0.10 | 6.86% | 17,139 | 2c. 5-20 | 8.54% | 59,813 | 2b. 10-20 | 9.79% | 146,814 |
| ABC 0.20 | 8.03% | 20,081 | 2d. 0-20 | 8.54% | 59,813 | 2c. 5-20 | 9.79% | 146,814 |
| ABC 0.30 | 9.00% | 22,511 | ABC 0.30 | 9.00% | 63,030 | 2d. 0-20 | 9.79% | 146,814 |
| ABC 0.40 | 9.93% | 24,818 | ABC 0.40 | 9.93% | 69,490 | ABC 0.40 | 9.93% | 148,907 |
| ABC 0.45 | 10.39% | 25,985 | ABC 0.45 | 10.39% | 72,759 | ABC 0.45 | 10.39% | 155,911 |

**"Mod-Warm" Temp**
**Emsy between 15 and 20%**
**Emsy used for scenario: 17.5%**
Temp Range: 15.52 to 15.84
Temp Used for Scenario: 15.68

| 4 | Harvest rate | ABC or HG | 9 | Harvest rate | ABC or HG | 14 | Harvest rate | ABC or HG |
|---|---|---|---|---|---|---|---|---|
| 2a. 5-15 | 5.22% | 13,050 | ABC 0.05 | 8.42% | 58,947 | ABC 0.05 | 8.42% | 126,314 |
| 2b. 10-20 | 6.09% | 15,225 | ABC 0.10 | 9.60% | 67,185 | ABC 0.10 | 9.60% | 143,968 |
| 2c. 5-20 | 6.09% | 15,225 | 2a. 5-15 | 10.25% | 71,775 | ABC 0.20 | 11.25% | 168,680 |
| 2d. 0-20 | 6.09% | 15,225 | ABC 0.20 | 11.25% | 78,717 | 2a. 5-15 | 11.75% | 176,175 |
| ABC 0.05 | 8.42% | 21,052 | 2b. 10-20 | 11.96% | 83,738 | ABC 0.30 | 12.61% | 189,088 |
| ABC 0.10 | 9.60% | 23,995 | 2c. 5-20 | 11.96% | 83,738 | 2b. 10-20 | 13.70% | 205,538 |
| ABC 0.20 | 11.25% | 28,113 | 2d. 0-20 | 11.96% | 83,738 | 2c. 5-20 | 13.70% | 205,538 |
| ABC 0.30 | 12.61% | 31,515 | ABC 0.30 | 12.61% | 88,241 | 2d. 0-20 | 13.70% | 205,538 |
| ABC 0.40 | 13.90% | 34,745 | ABC 0.40 | 13.90% | 97,285 | ABC 0.40 | 13.90% | 208,468 |
| ABC 0.45 | 14.55% | 36,379 | ABC 0.45 | 14.55% | 101,861 | ABC 0.45 | 14.55% | 218,274 |

**"Warm" Temp**
**Emsy between 20 and 25%**
**Emsy used for scenario: 22.5%**
Temp Range: 15.84 to 16.16
Temp Used for Scenario: 16.00

| 5 | Harvest rate | ABC or HG | 10 | Harvest rate | ABC or HG | 15 | Harvest rate | ABC or HG |
|---|---|---|---|---|---|---|---|---|
| 2a. 5-15 | 5.22% | 13,050 | 2a. 5-15 | 10.25% | 71,775 | ABC 0.05 | 10.83% | 162,404 |
| 2b. 10-20 | 6.96% | 17,400 | ABC 0.05 | 10.83% | 75,789 | 2a. 5-15 | 11.75% | 176,175 |
| 2c. 5-20 | 6.96% | 17,400 | ABC 0.10 | 12.34% | 86,381 | ABC 0.10 | 12.34% | 185,101 |
| 2d. 0-20 | 6.96% | 17,400 | 2b. 10-20 | 13.67% | 95,700 | ABC 0.20 | 14.46% | 216,875 |
| ABC 0.05 | 10.83% | 27,067 | 2c. 5-20 | 13.67% | 95,700 | 2b. 10-20 | 15.66% | 234,900 |
| ABC 0.10 | 12.34% | 30,850 | 2d. 0-20 | 13.67% | 95,700 | 2c. 5-20 | 15.66% | 234,900 |
| ABC 0.20 | 14.46% | 36,146 | ABC 0.20 | 14.46% | 101,208 | 2d. 0-20 | 15.66% | 234,900 |
| ABC 0.30 | 16.21% | 40,519 | ABC 0.30 | 16.21% | 113,453 | ABC 0.30 | 16.21% | 243,113 |
| ABC 0.40 | 17.87% | 44,672 | ABC 0.40 | 17.87% | 125,081 | ABC 0.40 | 18.71% | 268,030 |
| ABC 0.45 | 18.71% | 46,773 | ABC 0.45 | 18.71% | 130,964 | ABC 0.45 | 18.71% | 280,638 |

For slashed cells in Panels 14 and 15, HCRs exceed and revert to MAXCAT value of 200,000:

| Harvest rate | ABC or HG |
|---|---|
| 13.33% | 200,000 |

## Appendix 3: Additional Model Simulations

Additional runs of the Hurtado-Ferro and Punt simulation model were done for Alternative 2 with P-star 0.4 Tier 2 and P-star 0.2 Tier 2.

Table A-3. Performance measures for alternatives 2a-d using alternative tiers and P-stars.

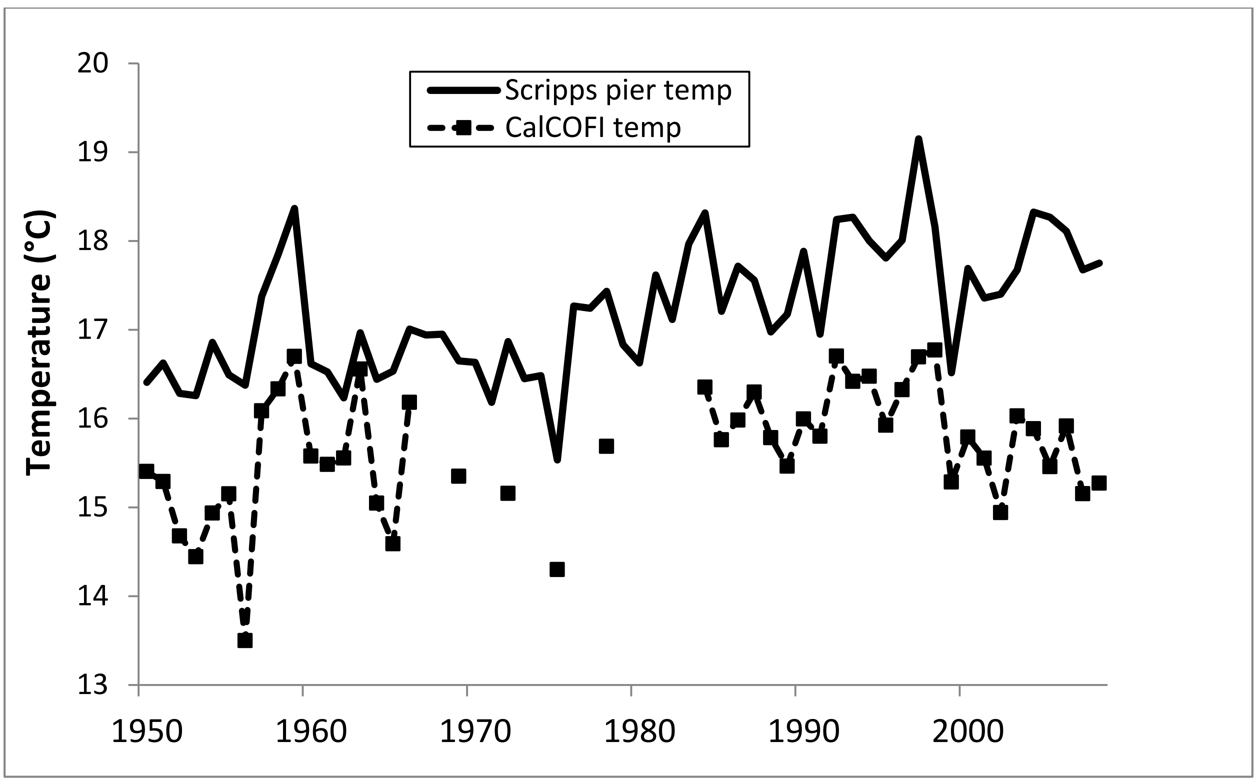
| Scenario | R1 | R2 | R3 | R4 | R5 | R6 | R7 | R8 | R9 | R10 | R11 | R12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| HG Fraction | | 5-15 | | | 10-20 | | | 5-20 | | | 0-20 | |
| Tier | 1 | 2 | 2 | 1 | 2 | 2 | 1 | 2 | 2 | 1 | 2 | 2 |
| P* | 0.2 | 0.2 | 0.4 | 0.2 | 0.2 | 0.4 | 0.2 | 0.2 | 0.4 | 0.2 | 0.2 | 0.4 |
| Buffer | 0.7381 | 0.54555 | 0.83326 | 0.7381 | 0.54555 | 0.83326 | 0.7381 | 0.54555 | 0.83326 | 0.7381 | 0.54555 | 0.83326 |
| | | | | | | | | | | | | |
| Performance Measure | | | | | | | | | | | | |
| Biological | | | | | | | | | | | | |
| Mean B1+ | 1231.5 | 1272.2 | 1222.5 | 1204.2 | 1268.8 | 1190.3 | 1204.2 | 1268.8 | 1190.3 | 1204.2 | 1268.8 | 1190.3 |
| SD B1+ | 885.2 | 877.1 | 887.5 | 879.1 | 876.5 | 880.8 | 879.1 | 876.5 | 880.8 | 879.1 | 876.5 | 880.8 |
| Mean SSB | 957.3 | 995.2 | 949.0 | 931.4 | 992.0 | 918.6 | 931.4 | 992.0 | 918.6 | 931.4 | 992.0 | 918.6 |
| SD SSB | 755.0 | 749.2 | 756.6 | 750.0 | 748.9 | 751.1 | 750.0 | 748.9 | 751.1 | 750.0 | 748.9 | 751.1 |
| %B1+>400 | 93.0 | 94.8 | 92.6 | 92.5 | 94.7 | 91.9 | 92.5 | 94.7 | 91.9 | 92.5 | 94.7 | 91.9 |
| Depletion | 78.3 | 80.9 | 77.8 | 76.6 | 80.7 | 75.7 | 76.6 | 80.7 | 75.7 | 76.6 | 80.7 | 75.7 |
| | | | | | | | | | | | | |
| Economic | | | | | | | | | | | | |
| %No catch | 4.7 | 4.6 | 4.7 | 5.0 | 4.7 | 5.0 | 5.0 | 4.7 | 5.0 | 5.0 | 4.7 | 5.0 |
| %Catch<50 | 31.5 | 35.2 | 31.2 | 30.8 | 34.6 | 30.7 | 30.8 | 34.6 | 30.7 | 30.8 | 34.6 | 30.7 |
| Median catch | 93.8 | 82.9 | 96.9 | 101.6 | 84.6 | 106.5 | 101.6 | 84.6 | 106.5 | 101.6 | 84.6 | 106.5 |
| Mean catch all | 104.1 | 97.8 | 105.4 | 108.9 | 98.3 | 110.9 | 108.9 | 98.3 | 110.9 | 108.9 | 98.3 | 110.9 |
| SD catch all | 72.0 | 71.1 | 72.3 | 74.3 | 70.9 | 75.1 | 74.3 | 70.9 | 75.1 | 74.3 | 70.9 | 75.1 |

## Appendix 4: SIO and CalCOFI Temperature Series

The temperature time series from both the Scripps Pier and CalCOFI surveys shows that the Scripps Pier information tracked similarly with the CalCOFI information from approximately 1950-1998 but diverged after 1998, with CalCOFI temperatures mostly declining but Scripps Pier temperatures mostly increasing after this year (Figure A-1).

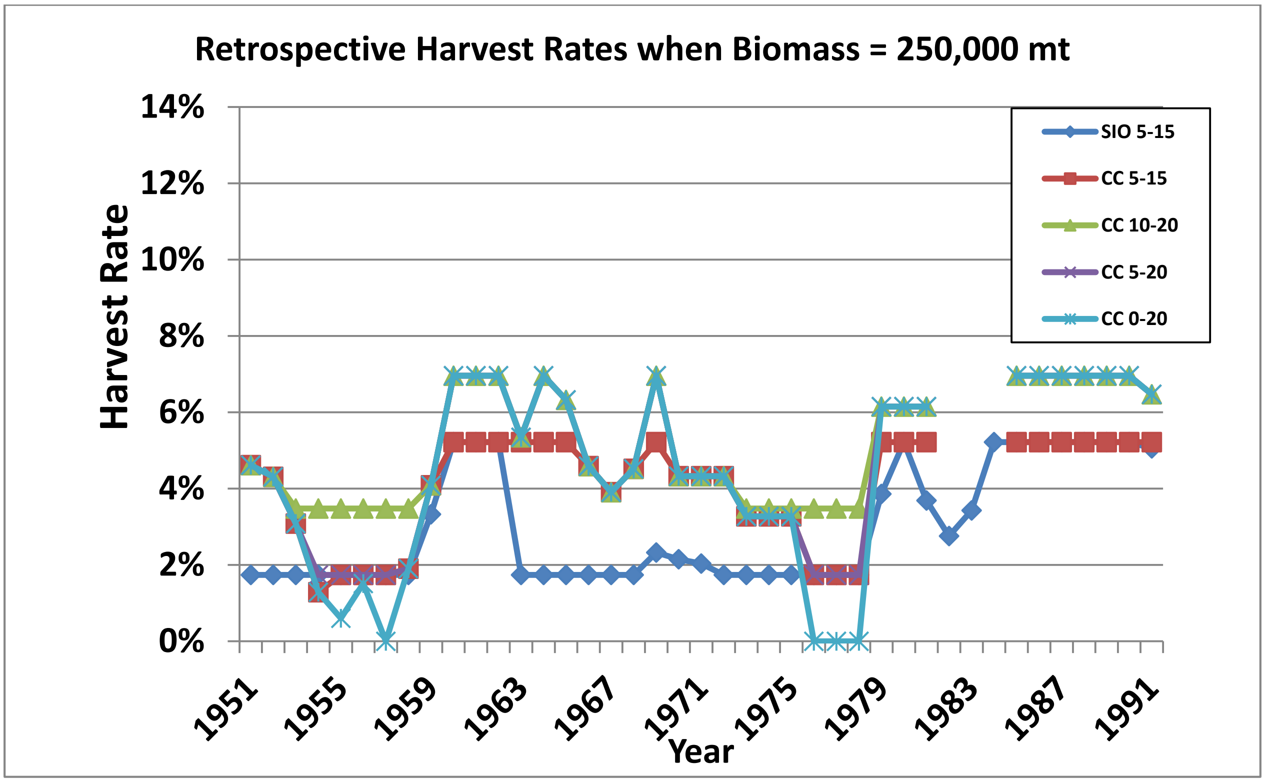
The 1984-2008 CalCOFI SST time series replaces the 1916-1998 SIO SST used in the Amendment 8 model and in the relationship to define $E_{MSY}$ ($F_{msy}$). The annual CalCOFI SST time series provides the best fit for the sardine recruitment – environment relationship, as indicated by $R^2$ of 0.72 from Table 10 in the Hurtado-Ferro and Punt report (March 2014 Briefing Book Agenda Item I.1.b, Attachment 1).

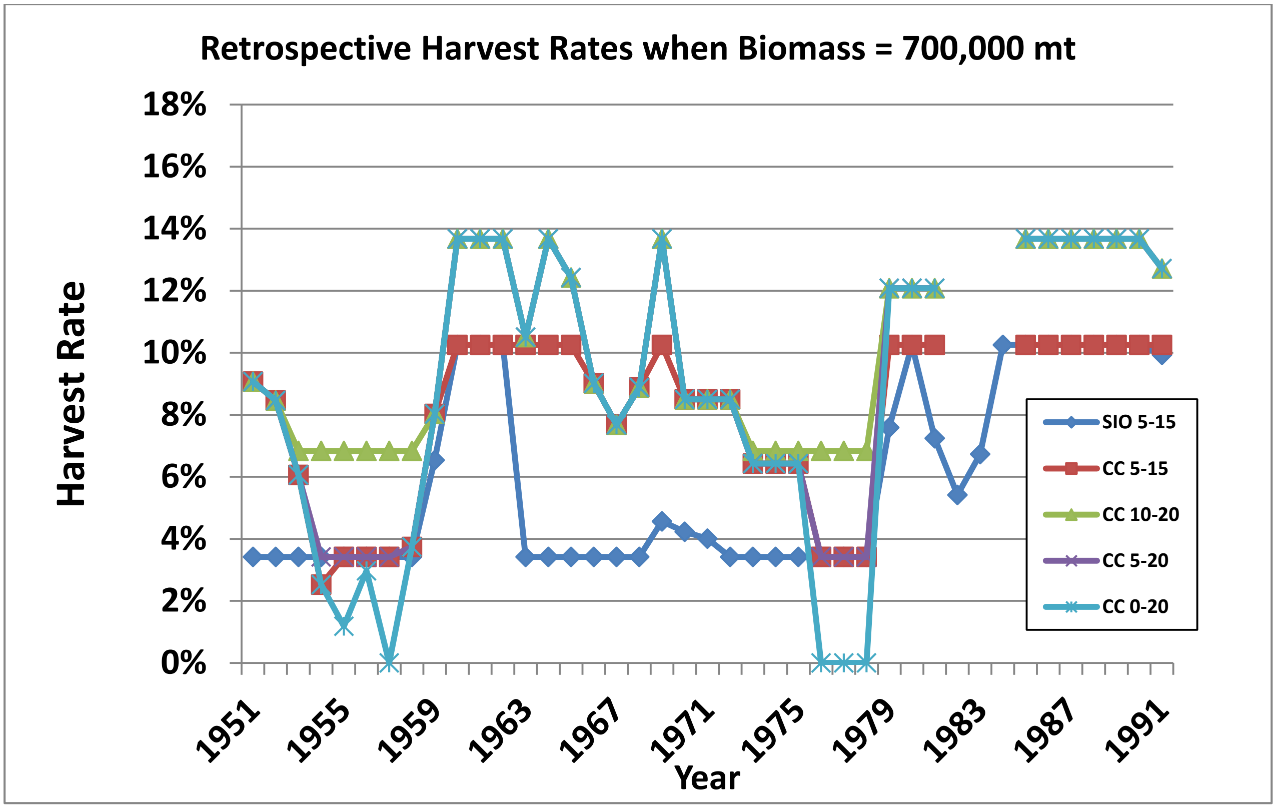
**Figure A-4.** Mean annual temperatures from Scripps Pier and from the California Cooperative Oceanic Fisheries Investigation surveys.

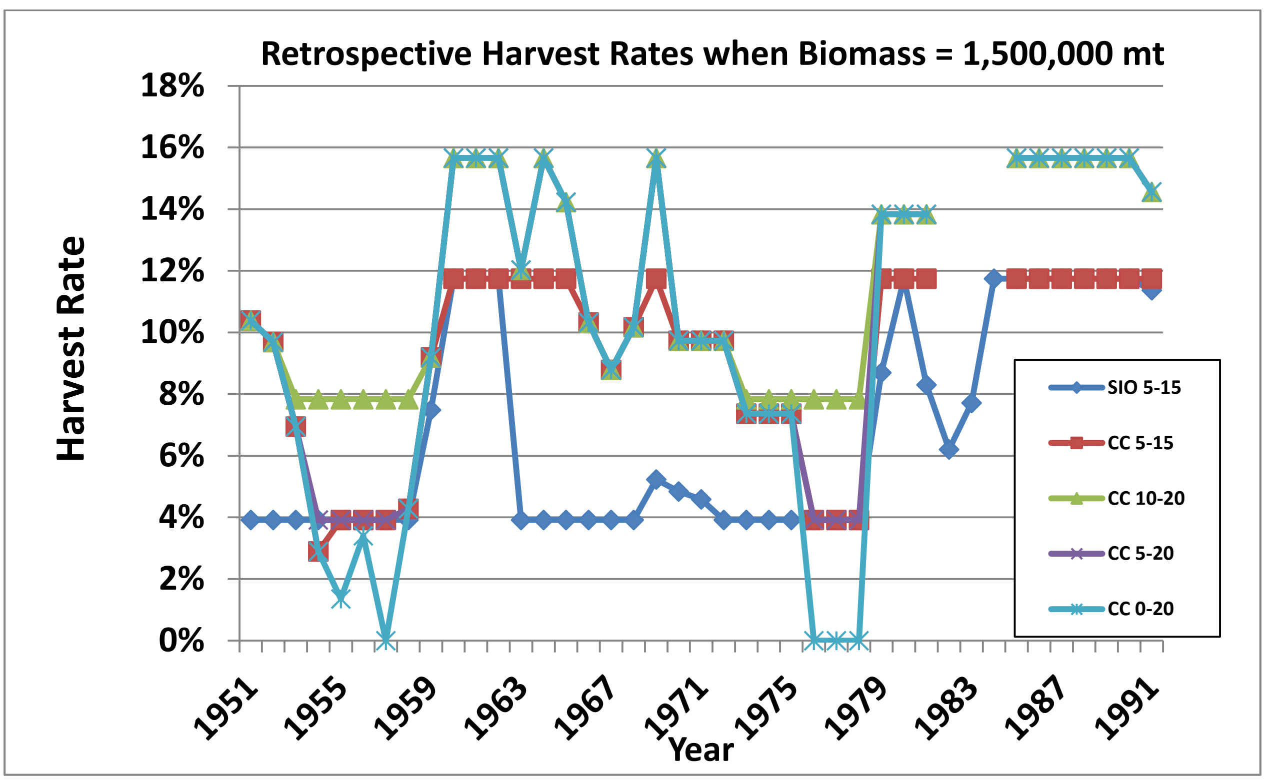


**Appendix 5: Additional Retrospective Harvest Rates**

Below are retrospective harvest rates based, in graph and table format, on CalCOFI and SIO temperatures from 1950 to 1991. Biomass estimates were not available, so this Appendix uses three hypothetical biomass estimates: 250,000 mt, 700,000 mt, and 1,500,000 mt, representing low, medium, and high biomasses.




Retrospective Harvest Rates when Biomass = 700,000 mt
Harvest Rate
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
1951
1955
1959
1963
1967
1971
1975
1979
1983
1987
1991
Year
SIO 5-15
CC 5-15
CC 10-20
CC 5-20
CC 0-20


Retrospective Harvest Rates when Biomass = 1,500,000 mt
Harvest Rate
18%
16%
14%
12%
10%
8%
6%
4%
2%
0%
1951
1955
1959
1963
1967
1971
1975
1979
1983
1987
1991
Year
SIO 5-15
CC 5-15
CC 10-20
CC 5-20
CC 0-20

| | | SIO | | | | | CalCOFI | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Biomass (1+) | SST | Emsy | HG $FRAC_1$ | $HG_1$ | SIO HR | SST | Emsy | HG $FRAC_{2a}$ | $HG_{2a}$ | HG $FRAC_{2b}$ | $HG_{2b}$ | HG $FRAC_{2c}$ | $HG_{2c}$ | HG $FRAC_{2d}$ | $HG_{2d}$ | $CC_{2a}$ HR | $CC_{2b}$ HR | $CC_{2c}$ HR | $CC_{2d}$ HR |
| 1951 | 250,000 | 16.31 | 0.021 | 0.050 | 4,350 | 1.7% | 15.40 | 0.133 | 0.133 | 11,540 | 0.133 | 11,540 | 0.133 | 11,540 | 0.133 | 11,540 | 4.6% | 4.6% | 4.6% | 4.6% |
| 1952 | 250,000 | 16.42 | 0.015 | 0.050 | 4,350 | 1.7% | 15.35 | 0.124 | 0.124 | 10,769 | 0.124 | 10,769 | 0.124 | 10,769 | 0.124 | 10,769 | 4.3% | 4.3% | 4.3% | 4.3% |
| 1953 | 250,000 | 16.55 | 0.016 | 0.050 | 4,350 | 1.7% | 15.12 | 0.089 | 0.089 | 7,715 | 0.100 | 8,700 | 0.089 | 7,715 | 0.089 | 7,715 | 3.1% | 3.5% | 3.1% | 3.1% |
| 1954 | 250,000 | 16.43 | 0.015 | 0.050 | 4,350 | 1.7% | 14.80 | 0.037 | 0.037 | 3,215 | 0.100 | 8,700 | 0.050 | 4,350 | 0.037 | 3,215 | 1.3% | 3.5% | 1.7% | 1.3% |
| 1955 | 250,000 | 16.40 | 0.016 | 0.050 | 4,350 | 1.7% | 14.69 | 0.017 | 0.050 | 4,350 | 0.100 | 8,700 | 0.050 | 4,350 | 0.017 | 1,503 | 1.7% | 3.5% | 1.7% | 0.6% |
| 1956 | 250,000 | 16.42 | 0.015 | 0.050 | 4,350 | 1.7% | 14.84 | 0.043 | 0.050 | 4,350 | 0.100 | 8,700 | 0.050 | 4,350 | 0.043 | 3,778 | 1.7% | 3.5% | 1.7% | 1.5% |
| 1957 | 250,000 | 16.51 | 0.015 | 0.050 | 4,350 | 1.7% | 14.53 | 0* | 0.050 | 4,350 | 0.100 | 8,700 | 0.050 | 4,350 | 0.000 | 0 | 1.7% | 3.5% | 1.7% | 0.0% |
| 1958 | 250,000 | 16.65 | 0.023 | 0.050 | 4,350 | 1.7% | 14.91 | 0.055 | 0.055 | 4,756 | 0.100 | 8,700 | 0.055 | 4,756 | 0.055 | 4,756 | 1.9% | 3.5% | 1.9% | 1.9% |
| 1959 | 250,000 | 17.04 | 0.096 | 0.096 | 8,316 | 3.3% | 15.31 | 0.117 | 0.117 | 10,215 | 0.117 | 10,215 | 0.117 | 10,215 | 0.117 | 10,215 | 4.1% | 4.1% | 4.1% | 4.1% |
| 1960 | 250,000 | 17.62 | 0.346 | 0.150 | 13,050 | 5.2% | 16.37 | 0.284 | 0.150 | 13,050 | 0.200 | 17,400 | 0.200 | 17,400 | 0.200 | 17,400 | 5.2% | 7.0% | 7.0% | 7.0% |
| 1961 | 250,000 | 17.81 | 0.462 | 0.150 | 13,050 | 5.2% | 16.20 | 0.257 | 0.150 | 13,050 | 0.200 | 17,400 | 0.200 | 17,400 | 0.200 | 17,400 | 5.2% | 7.0% | 7.0% | 7.0% |
| 1962 | 250,000 | 17.41 | 0.233 | 0.150 | 13,050 | 5.2% | 15.92 | 0.213 | 0.150 | 13,050 | 0.200 | 17,400 | 0.200 | 17,400 | 0.200 | 17,400 | 5.2% | 7.0% | 7.0% | 7.0% |
| 1963 | 250,000 | 16.79 | 0.040 | 0.050 | 4,350 | 1.7% | 15.54 | 0.154 | 0.150 | 13,050 | 0.154 | 13,367 | 0.154 | 13,367 | 0.154 | 13,367 | 5.2% | 5.3% | 5.3% | 5.3% |
| 1964 | 250,000 | 16.44 | 0.015 | 0.050 | 4,350 | 1.7% | 15.87 | 0.204 | 0.150 | 13,050 | 0.200 | 17,400 | 0.200 | 17,400 | 0.200 | 17,400 | 5.2% | 7.0% | 7.0% | 7.0% |
| 1965 | 250,000 | 16.54 | 0.016 | 0.050 | 4,350 | 1.7% | 15.72 | 0.182 | 0.150 | 13,050 | 0.182 | 15,813 | 0.182 | 15,813 | 0.182 | 15,813 | 5.2% | 6.3% | 6.3% | 6.3% |
| 1966 | 250,000 | 16.61 | 0.020 | 0.050 | 4,350 | 1.7% | 15.40 | 0.132 | 0.132 | 11,472 | 0.132 | 11,472 | 0.132 | 11,472 | 0.132 | 11,472 | 4.6% | 4.6% | 4.6% | 4.6% |
| 1967 | 250,000 | 16.68 | 0.026 | 0.050 | 4,350 | 1.7% | 15.27 | 0.112 | 0.112 | 9,766 | 0.112 | 9,766 | 0.112 | 9,766 | 0.112 | 9,766 | 3.9% | 3.9% | 3.9% | 3.9% |
| 1968 | 250,000 | 16.62 | 0.021 | 0.050 | 4,350 | 1.7% | 15.39 | 0.130 | 0.130 | 11,302 | 0.130 | 11,302 | 0.130 | 11,302 | 0.130 | 11,302 | 4.5% | 4.5% | 4.5% | 4.5% |
| 1969 | 250,000 | 16.93 | 0.067 | 0.067 | 5,811 | 2.3% | 16.18 | 0.254 | 0.150 | 13,050 | 0.200 | 17,400 | 0.200 | 17,400 | 0.200 | 17,400 | 5.2% | 7.0% | 7.0% | 7.0% |
| 1970 | 250,000 | 16.90 | 0.062 | 0.062 | 5,378 | 2.2% | 15.35 | 0.124 | 0.124 | 10,812 | 0.124 | 10,812 | 0.124 | 10,812 | 0.124 | 10,812 | 4.3% | 4.3% | 4.3% | 4.3% |
| 1971 | 250,000 | 16.89 | 0.059 | 0.059 | 5,096 | 2.0% | 15.35 | 0.124 | 0.124 | 10,812 | 0.124 | 10,812 | 0.124 | 10,812 | 0.124 | 10,812 | 4.3% | 4.3% | 4.3% | 4.3% |
| 1972 | 250,000 | 16.52 | 0.015 | 0.050 | 4,350 | 1.7% | 15.35 | 0.124 | 0.124 | 10,812 | 0.124 | 10,812 | 0.124 | 10,812 | 0.124 | 10,812 | 4.3% | 4.3% | 4.3% | 4.3% |
| 1973 | 250,000 | 16.48 | 0.015 | 0.050 | 4,350 | 1.7% | 15.16 | 0.094 | 0.094 | 8,182 | 0.100 | 8,700 | 0.094 | 8,182 | 0.094 | 8,182 | 3.3% | 3.5% | 3.3% | 3.3% |
| 1974 | 250,000 | 16.64 | 0.022 | 0.050 | 4,350 | 1.7% | 15.16 | 0.094 | 0.094 | 8,182 | 0.100 | 8,700 | 0.094 | 8,182 | 0.094 | 8,182 | 3.3% | 3.5% | 3.3% | 3.3% |
| 1975 | 250,000 | 16.57 | 0.017 | 0.050 | 4,350 | 1.7% | 15.16 | 0.094 | 0.094 | 8,182 | 0.100 | 8,700 | 0.094 | 8,182 | 0.094 | 8,182 | 3.3% | 3.5% | 3.3% | 3.3% |
| 1976 | 250,000 | 16.42 | 0.015 | 0.050 | 4,350 | 1.7% | 14.30 | 0* | 0.050 | 4,350 | 0.100 | 8,700 | 0.050 | 4,350 | 0.000 | 0 | 1.7% | 3.5% | 1.7% | 0.0% |
| 1977 | 250,000 | 16.10 | 0.049 | 0.050 | 4,350 | 1.7% | 14.30 | 0* | 0.050 | 4,350 | 0.100 | 8,700 | 0.050 | 4,350 | 0.000 | 0 | 1.7% | 3.5% | 1.7% | 0.0% |
| 1978 | 250,000 | 16.60 | 0.019 | 0.050 | 4,350 | 1.7% | 14.30 | 0* | 0.050 | 4,350 | 0.100 | 8,700 | 0.050 | 4,350 | 0.000 | 0 | 1.7% | 3.5% | 1.7% | 0.0% |
| 1979 | 250,000 | 17.09 | 0.111 | 0.111 | 9,657 | 3.9% | 15.69 | 0.177 | 0.150 | 13,050 | 0.177 | 15,372 | 0.177 | 15,372 | 0.177 | 15,372 | 5.2% | 6.1% | 6.1% | 6.1% |
| 1980 | 250,000 | 17.32 | 0.194 | 0.150 | 13,050 | 5.2% | 15.69 | 0.177 | 0.150 | 13,050 | 0.177 | 15,372 | 0.177 | 15,372 | 0.177 | 15,372 | 5.2% | 6.1% | 6.1% | 6.1% |
| 1981 | 250,000 | 17.07 | 0.106 | 0.106 | 9,220 | 3.7% | 15.69 | 0.177 | 0.150 | 13,050 | 0.177 | 15,372 | 0.177 | 15,372 | 0.177 | 15,372 | 5.2% | 6.1% | 6.1% | 6.1% |
| 1982 | 250,000 | 16.98 | 0.079 | 0.079 | 6,891 | 2.8% | | | | | | | | | | | | | | |
| 1983 | 250,000 | 17.05 | 0.098 | 0.098 | 8,569 | 3.4% | | | | no CalCOFI data available | | | | | | | | | | |
| 1984 | 250,000 | 17.25 | 0.167 | 0.150 | 13,050 | 5.2% | | | | | | | | | | | | | | |
| 1985 | 250,000 | 17.58 | 0.320 | 0.150 | 13,050 | 5.2% | 16.35 | 0.281 | 0.150 | 13,050 | 0.200 | 17,400 | 0.200 | 17,400 | 0.200 | 17,400 | 5.2% | 7.0% | 7.0% | 7.0% |
| 1986 | 250,000 | 17.80 | 0.454 | 0.150 | 13,050 | 5.2% | 16.06 | 0.234 | 0.150 | 13,050 | 0.200 | 17,400 | 0.200 | 17,400 | 0.200 | 17,400 | 5.2% | 7.0% | 7.0% | 7.0% |
| 1987 | 250,000 | 17.87 | 0.501 | 0.150 | 13,050 | 5.2% | 16.03 | 0.230 | 0.150 | 13,050 | 0.200 | 17,400 | 0.200 | 17,400 | 0.200 | 17,400 | 5.2% | 7.0% | 7.0% | 7.0% |
| 1988 | 250,000 | 17.71 | 0.395 | 0.150 | 13,050 | 5.2% | 16.01 | 0.227 | 0.150 | 13,050 | 0.200 | 17,400 | 0.200 | 17,400 | 0.200 | 17,400 | 5.2% | 7.0% | 7.0% | 7.0% |
| 1989 | 250,000 | 17.55 | 0.308 | 0.150 | 13,050 | 5.2% | 16.02 | 0.228 | 0.150 | 13,050 | 0.200 | 17,400 | 0.200 | 17,400 | 0.200 | 17,400 | 5.2% | 7.0% | 7.0% | 7.0% |
| 1990 | 250,000 | 17.24 | 0.164 | 0.150 | 13,050 | 5.2% | 15.85 | 0.202 | 0.150 | 13,050 | 0.200 | 17,400 | 0.200 | 17,400 | 0.200 | 17,400 | 5.2% | 7.0% | 7.0% | 7.0% |
| 1991 | 250,000 | 17.19 | 0.145 | 0.145 | 12,637 | 5.1% | 15.75 | 0.186 | 0.150 | 13,050 | 0.186 | 16,180 | 0.186 | 16,180 | 0.186 | 16,180 | 5.2% | 6.5% | 6.5% | 6.5% |

| | | SIO | | | | | CalCOFI | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Biomass (1+) | SST | Emsy | HG FRAC$_{1}$ | HG$_{1}$ | SIO HR | SST | Emsy | HG FRAC$_{2a}$ | HG$_{2a}$ | HG FRAC$_{2b}$ | HG$_{2b}$ | HG FRAC$_{2c}$ | HG$_{2c}$ | HG FRAC$_{2d}$ | HG$_{2d}$ | CC$_{2a}$ HR | CC$_{2b}$ HR | CC$_{2c}$ HR | CC$_{2d}$ HR |
| 1951 | 700,000 | 16.31 | 0.021 | 0.050 | 23,925 | 3.4% | 15.40 | 0.133 | 0.133 | 63,471 | 0.133 | 63,471 | 0.133 | 63,471 | 0.133 | 63,471 | 9.1% | 9.1% | 9.1% | 9.1% |
| 1952 | 700,000 | 16.42 | 0.015 | 0.050 | 23,925 | 3.4% | 15.35 | 0.124 | 0.124 | 59,230 | 0.124 | 59,230 | 0.124 | 59,230 | 0.124 | 59,230 | 8.5% | 8.5% | 8.5% | 8.5% |
| 1953 | 700,000 | 16.55 | 0.016 | 0.050 | 23,925 | 3.4% | 15.12 | 0.089 | 0.089 | 42,434 | 0.100 | 47,850 | 0.089 | 42,434 | 0.089 | 42,434 | 6.1% | 6.8% | 6.1% | 6.1% |
| 1954 | 700,000 | 16.43 | 0.015 | 0.050 | 23,925 | 3.4% | 14.80 | 0.037 | 0.037 | 17,681 | 0.100 | 47,850 | 0.050 | 23,925 | 0.037 | 17,681 | 2.5% | 6.8% | 3.4% | 2.5% |
| 1955 | 700,000 | 16.40 | 0.016 | 0.050 | 23,925 | 3.4% | 14.69 | 0.017 | 0.050 | 23,925 | 0.100 | 47,850 | 0.050 | 23,925 | 0.017 | 8,264 | 3.4% | 6.8% | 3.4% | 1.2% |
| 1956 | 700,000 | 16.42 | 0.015 | 0.050 | 23,925 | 3.4% | 14.84 | 0.043 | 0.050 | 23,925 | 0.100 | 47,850 | 0.050 | 23,925 | 0.043 | 20,777 | 3.4% | 6.8% | 3.4% | 3.0% |
| 1957 | 700,000 | 16.51 | 0.015 | 0.050 | 23,925 | 3.4% | 14.53 | 0* | 0.050 | 23,925 | 0.100 | 47,850 | 0.050 | 23,925 | 0.000 | 0 | 3.4% | 6.8% | 3.4% | 0.0% |
| 1958 | 700,000 | 16.65 | 0.023 | 0.050 | 23,925 | 3.4% | 14.91 | 0.055 | 0.055 | 26,155 | 0.100 | 47,850 | 0.055 | 26,155 | 0.055 | 26,155 | 3.7% | 6.8% | 3.7% | 3.7% |
| 1959 | 700,000 | 17.04 | 0.096 | 0.096 | 45,739 | 6.5% | 15.31 | 0.117 | 0.117 | 56,182 | 0.117 | 56,182 | 0.117 | 56,182 | 0.117 | 56,182 | 8.0% | 8.0% | 8.0% | 8.0% |
| 1960 | 700,000 | 17.62 | 0.346 | 0.150 | 71,775 | 10.3% | 16.37 | 0.284 | 0.150 | 71,775 | 0.200 | 95,700 | 0.200 | 95,700 | 0.200 | 95,700 | 10.3% | 13.7% | 13.7% | 13.7% |
| 1961 | 700,000 | 17.81 | 0.462 | 0.150 | 71,775 | 10.3% | 16.20 | 0.257 | 0.150 | 71,775 | 0.200 | 95,700 | 0.200 | 95,700 | 0.200 | 95,700 | 10.3% | 13.7% | 13.7% | 13.7% |
| 1962 | 700,000 | 17.41 | 0.233 | 0.150 | 71,775 | 10.3% | 15.92 | 0.213 | 0.150 | 71,775 | 0.200 | 95,700 | 0.200 | 95,700 | 0.200 | 95,700 | 10.3% | 13.7% | 13.7% | 13.7% |
| 1963 | 700,000 | 16.79 | 0.040 | 0.050 | 23,925 | 3.4% | 15.54 | 0.154 | 0.150 | 71,775 | 0.154 | 73,519 | 0.154 | 73,519 | 0.154 | 73,519 | 10.3% | 10.5% | 10.5% | 10.5% |
| 1964 | 700,000 | 16.44 | 0.015 | 0.050 | 23,925 | 3.4% | 15.87 | 0.204 | 0.150 | 71,775 | 0.200 | 95,700 | 0.200 | 95,700 | 0.200 | 95,700 | 10.3% | 13.7% | 13.7% | 13.7% |
| 1965 | 700,000 | 16.54 | 0.016 | 0.050 | 23,925 | 3.4% | 15.72 | 0.182 | 0.150 | 71,775 | 0.182 | 86,972 | 0.182 | 86,972 | 0.182 | 86,972 | 10.3% | 12.4% | 12.4% | 12.4% |
| 1966 | 700,000 | 16.61 | 0.020 | 0.050 | 23,925 | 3.4% | 15.40 | 0.132 | 0.132 | 63,098 | 0.132 | 63,098 | 0.132 | 63,098 | 0.132 | 63,098 | 9.0% | 9.0% | 9.0% | 9.0% |
| 1967 | 700,000 | 16.68 | 0.026 | 0.050 | 23,925 | 3.4% | 15.27 | 0.112 | 0.112 | 53,714 | 0.112 | 53,714 | 0.112 | 53,714 | 0.112 | 53,714 | 7.7% | 7.7% | 7.7% | 7.7% |
| 1968 | 700,000 | 16.62 | 0.021 | 0.050 | 23,925 | 3.4% | 15.39 | 0.130 | 0.130 | 62,162 | 0.130 | 62,162 | 0.130 | 62,162 | 0.130 | 62,162 | 8.9% | 8.9% | 8.9% | 8.9% |
| 1969 | 700,000 | 16.93 | 0.067 | 0.067 | 31,960 | 4.6% | 16.18 | 0.254 | 0.150 | 71,775 | 0.200 | 95,700 | 0.200 | 95,700 | 0.200 | 95,700 | 10.3% | 13.7% | 13.7% | 13.7% |
| 1970 | 700,000 | 16.90 | 0.062 | 0.062 | 29,578 | 4.2% | 15.35 | 0.124 | 0.124 | 59,464 | 0.124 | 59,464 | 0.124 | 59,464 | 0.124 | 59,464 | 8.5% | 8.5% | 8.5% | 8.5% |
| 1971 | 700,000 | 16.89 | 0.059 | 0.059 | 28,029 | 4.0% | 15.35 | 0.124 | 0.124 | 59,464 | 0.124 | 59,464 | 0.124 | 59,464 | 0.124 | 59,464 | 8.5% | 8.5% | 8.5% | 8.5% |
| 1972 | 700,000 | 16.52 | 0.015 | 0.050 | 23,925 | 3.4% | 15.35 | 0.124 | 0.124 | 59,464 | 0.124 | 59,464 | 0.124 | 59,464 | 0.124 | 59,464 | 8.5% | 8.5% | 8.5% | 8.5% |
| 1973 | 700,000 | 16.48 | 0.015 | 0.050 | 23,925 | 3.4% | 15.16 | 0.094 | 0.094 | 45,002 | 0.100 | 47,850 | 0.094 | 45,002 | 0.094 | 45,002 | 6.4% | 6.8% | 6.4% | 6.4% |
| 1974 | 700,000 | 16.64 | 0.022 | 0.050 | 23,925 | 3.4% | 15.16 | 0.094 | 0.094 | 45,002 | 0.100 | 47,850 | 0.094 | 45,002 | 0.094 | 45,002 | 6.4% | 6.8% | 6.4% | 6.4% |
| 1975 | 700,000 | 16.57 | 0.017 | 0.050 | 23,925 | 3.4% | 15.16 | 0.094 | 0.094 | 45,002 | 0.100 | 47,850 | 0.094 | 45,002 | 0.094 | 45,002 | 6.4% | 6.8% | 6.4% | 6.4% |
| 1976 | 700,000 | 16.42 | 0.015 | 0.050 | 23,925 | 3.4% | 14.30 | 0* | 0.050 | 23,925 | 0.100 | 47,850 | 0.050 | 23,925 | 0.000 | 0 | 3.4% | 6.8% | 3.4% | 0.0% |
| 1977 | 700,000 | 16.10 | 0.049 | 0.050 | 23,925 | 3.4% | 14.30 | 0* | 0.050 | 23,925 | 0.100 | 47,850 | 0.050 | 23,925 | 0.000 | 0 | 3.4% | 6.8% | 3.4% | 0.0% |
| 1978 | 700,000 | 16.60 | 0.019 | 0.050 | 23,925 | 3.4% | 14.30 | 0* | 0.050 | 23,925 | 0.100 | 47,850 | 0.050 | 23,925 | 0.000 | 0 | 3.4% | 6.8% | 3.4% | 0.0% |
| 1979 | 700,000 | 17.09 | 0.111 | 0.111 | 53,114 | 7.6% | 15.69 | 0.177 | 0.150 | 71,775 | 0.177 | 84,544 | 0.177 | 84,544 | 0.177 | 84,544 | 10.3% | 12.1% | 12.1% | 12.1% |
| 1980 | 700,000 | 17.32 | 0.194 | 0.150 | 71,775 | 10.3% | 15.69 | 0.177 | 0.150 | 71,775 | 0.177 | 84,544 | 0.177 | 84,544 | 0.177 | 84,544 | 10.3% | 12.1% | 12.1% | 12.1% |
| 1981 | 700,000 | 17.07 | 0.106 | 0.106 | 50,712 | 7.2% | 15.69 | 0.177 | 0.150 | 71,775 | 0.177 | 84,544 | 0.177 | 84,544 | 0.177 | 84,544 | 10.3% | 12.1% | 12.1% | 12.1% |
| 1982 | 700,000 | 16.98 | 0.079 | 0.079 | 37,899 | 5.4% | | | | | | | | | | | | | | |
| 1983 | 700,000 | 17.05 | 0.098 | 0.098 | 47,129 | 6.7% | | | | no CalCOFI data available | | | | | | | | | | |
| 1984 | 700,000 | 17.25 | 0.167 | 0.150 | 71,775 | 10.3% | | | | | | | | | | | | | | |
| 1985 | 700,000 | 17.58 | 0.320 | 0.150 | 71,775 | 10.3% | 16.35 | 0.281 | 0.150 | 71,775 | 0.200 | 95,700 | 0.200 | 95,700 | 0.200 | 95,700 | 10.3% | 13.7% | 13.7% | 13.7% |
| 1986 | 700,000 | 17.80 | 0.454 | 0.150 | 71,775 | 10.3% | 16.06 | 0.234 | 0.150 | 71,775 | 0.200 | 95,700 | 0.200 | 95,700 | 0.200 | 95,700 | 10.3% | 13.7% | 13.7% | 13.7% |
| 1987 | 700,000 | 17.87 | 0.501 | 0.150 | 71,775 | 10.3% | 16.03 | 0.230 | 0.150 | 71,775 | 0.200 | 95,700 | 0.200 | 95,700 | 0.200 | 95,700 | 10.3% | 13.7% | 13.7% | 13.7% |
| 1988 | 700,000 | 17.71 | 0.395 | 0.150 | 71,775 | 10.3% | 16.01 | 0.227 | 0.150 | 71,775 | 0.200 | 95,700 | 0.200 | 95,700 | 0.200 | 95,700 | 10.3% | 13.7% | 13.7% | 13.7% |
| 1989 | 700,000 | 17.55 | 0.308 | 0.150 | 71,775 | 10.3% | 16.02 | 0.228 | 0.150 | 71,775 | 0.200 | 95,700 | 0.200 | 95,700 | 0.200 | 95,700 | 10.3% | 13.7% | 13.7% | 13.7% |
| 1990 | 700,000 | 17.24 | 0.164 | 0.150 | 71,775 | 10.3% | 15.85 | 0.202 | 0.150 | 71,775 | 0.200 | 95,700 | 0.200 | 95,700 | 0.200 | 95,700 | 10.3% | 13.7% | 13.7% | 13.7% |
| 1991 | 700,000 | 17.19 | 0.145 | 0.145 | 69,501 | 9.9% | 15.75 | 0.186 | 0.150 | 71,775 | 0.186 | 88,989 | 0.186 | 88,989 | 0.186 | 88,989 | 10.3% | 12.7% | 12.7% | 12.7% |

| | | SIO | | | | | CalCOFI | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Biomass (1+) | SST | Emsy | HG FRAC$_1$ | HG$_1$ | SIO HR | SST | Emsy | HG FRAC$_{2a}$ | HG$_{2a}$ | HG FRAC$_{2b}$ | HG$_{2b}$ | HG FRAC$_{2c}$ | HG$_{2c}$ | HG FRAC$_{2d}$ | HG$_{2d}$ | CC$_{2a}$ HR | CC$_{2b}$ HR | CC$_{2c}$ HR | CC$_{2d}$ HR |
| 1951 | 1,500,000 | 16.31 | 0.021 | 0.050 | 58,725 | 3.9% | 15.40 | 0.133 | 0.133 | 155,792 | 0.133 | 155,792 | 0.133 | 155,792 | 0.133 | 155,792 | 10.4% | 10.4% | 10.4% | 10.4% |
| 1952 | 1,500,000 | 16.42 | 0.015 | 0.050 | 58,725 | 3.9% | 15.35 | 0.124 | 0.124 | 145,384 | 0.124 | 145,384 | 0.124 | 145,384 | 0.124 | 145,384 | 9.7% | 9.7% | 9.7% | 9.7% |
| 1953 | 1,500,000 | 16.55 | 0.016 | 0.050 | 58,725 | 3.9% | 15.12 | 0.089 | 0.089 | 104,157 | 0.100 | 117,450 | 0.089 | 104,157 | 0.089 | 104,157 | 6.9% | 7.8% | 6.9% | 6.9% |
| 1954 | 1,500,000 | 16.43 | 0.015 | 0.050 | 58,725 | 3.9% | 14.80 | 0.037 | 0.037 | 43,398 | 0.100 | 117,450 | 0.050 | 58,725 | 0.037 | 43,398 | 2.9% | 7.8% | 3.9% | 2.9% |
| 1955 | 1,500,000 | 16.40 | 0.016 | 0.050 | 58,725 | 3.9% | 14.69 | 0.017 | 0.050 | 58,725 | 0.100 | 117,450 | 0.050 | 58,725 | 0.017 | 20,285 | 3.9% | 7.8% | 3.9% | 1.4% |
| 1956 | 1,500,000 | 16.42 | 0.015 | 0.050 | 58,725 | 3.9% | 14.84 | 0.043 | 0.050 | 58,725 | 0.100 | 117,450 | 0.050 | 58,725 | 0.043 | 50,997 | 3.9% | 7.8% | 3.9% | 3.4% |
| 1957 | 1,500,000 | 16.51 | 0.015 | 0.050 | 58,725 | 3.9% | 14.53 | 0* | 0.050 | 58,725 | 0.100 | 117,450 | 0.050 | 58,725 | 0.000 | 0 | 3.9% | 7.8% | 3.9% | 0.0% |
| 1958 | 1,500,000 | 16.65 | 0.023 | 0.050 | 58,725 | 3.9% | 14.91 | 0.055 | 0.055 | 64,200 | 0.100 | 117,450 | 0.055 | 64,200 | 0.055 | 64,200 | 4.3% | 7.8% | 4.3% | 4.3% |
| 1959 | 1,500,000 | 17.04 | 0.096 | 0.096 | 112,269 | 7.5% | 15.31 | 0.117 | 0.117 | 137,901 | 0.117 | 137,901 | 0.117 | 137,901 | 0.117 | 137,901 | 9.2% | 9.2% | 9.2% | 9.2% |
| 1960 | 1,500,000 | 17.62 | 0.346 | 0.150 | 176,175 | 11.7% | 16.37 | 0.284 | 0.150 | 176,175 | 0.200 | 234,900 | 0.200 | 234,900 | 0.200 | 234,900 | 11.7% | 15.7% | 15.7% | 15.7% |
| 1961 | 1,500,000 | 17.81 | 0.462 | 0.150 | 176,175 | 11.7% | 16.20 | 0.257 | 0.150 | 176,175 | 0.200 | 234,900 | 0.200 | 234,900 | 0.200 | 234,900 | 11.7% | 15.7% | 15.7% | 15.7% |
| 1962 | 1,500,000 | 17.41 | 0.233 | 0.150 | 176,175 | 11.7% | 15.92 | 0.213 | 0.150 | 176,175 | 0.200 | 234,900 | 0.200 | 234,900 | 0.200 | 234,900 | 11.7% | 15.7% | 15.7% | 15.7% |
| 1963 | 1,500,000 | 16.79 | 0.040 | 0.050 | 58,725 | 3.9% | 15.54 | 0.154 | 0.150 | 176,175 | 0.154 | 180,455 | 0.154 | 180,455 | 0.154 | 180,455 | 11.7% | 12.0% | 12.0% | 12.0% |
| 1964 | 1,500,000 | 16.44 | 0.015 | 0.050 | 58,725 | 3.9% | 15.87 | 0.204 | 0.150 | 176,175 | 0.200 | 234,900 | 0.200 | 234,900 | 0.200 | 234,900 | 11.7% | 15.7% | 15.7% | 15.7% |
| 1965 | 1,500,000 | 16.54 | 0.016 | 0.050 | 58,725 | 3.9% | 15.72 | 0.182 | 0.150 | 176,175 | 0.182 | 213,477 | 0.182 | 213,477 | 0.182 | 213,477 | 11.7% | 14.2% | 14.2% | 14.2% |
| 1966 | 1,500,000 | 16.61 | 0.020 | 0.050 | 58,725 | 3.9% | 15.40 | 0.132 | 0.132 | 154,877 | 0.132 | 154,877 | 0.132 | 154,877 | 0.132 | 154,877 | 10.3% | 10.3% | 10.3% | 10.3% |
| 1967 | 1,500,000 | 16.68 | 0.026 | 0.050 | 58,725 | 3.9% | 15.27 | 0.112 | 0.112 | 131,843 | 0.112 | 131,843 | 0.112 | 131,843 | 0.112 | 131,843 | 8.8% | 8.8% | 8.8% | 8.8% |
| 1968 | 1,500,000 | 16.62 | 0.021 | 0.050 | 58,725 | 3.9% | 15.39 | 0.130 | 0.130 | 152,579 | 0.130 | 152,579 | 0.130 | 152,579 | 0.130 | 152,579 | 10.2% | 10.2% | 10.2% | 10.2% |
| 1969 | 1,500,000 | 16.93 | 0.067 | 0.067 | 78,446 | 5.2% | 16.18 | 0.254 | 0.150 | 176,175 | 0.200 | 234,900 | 0.200 | 234,900 | 0.200 | 234,900 | 11.7% | 15.7% | 15.7% | 15.7% |
| 1970 | 1,500,000 | 16.90 | 0.062 | 0.062 | 72,601 | 4.8% | 15.35 | 0.124 | 0.124 | 145,957 | 0.124 | 145,957 | 0.124 | 145,957 | 0.124 | 145,957 | 9.7% | 9.7% | 9.7% | 9.7% |
| 1971 | 1,500,000 | 16.89 | 0.059 | 0.059 | 68,799 | 4.6% | 15.35 | 0.124 | 0.124 | 145,957 | 0.124 | 145,957 | 0.124 | 145,957 | 0.124 | 145,957 | 9.7% | 9.7% | 9.7% | 9.7% |
| 1972 | 1,500,000 | 16.52 | 0.015 | 0.050 | 58,725 | 3.9% | 15.35 | 0.124 | 0.124 | 145,957 | 0.124 | 145,957 | 0.124 | 145,957 | 0.124 | 145,957 | 9.7% | 9.7% | 9.7% | 9.7% |
| 1973 | 1,500,000 | 16.48 | 0.015 | 0.050 | 58,725 | 3.9% | 15.16 | 0.094 | 0.094 | 110,459 | 0.100 | 117,450 | 0.094 | 110,459 | 0.094 | 110,459 | 7.4% | 7.8% | 7.4% | 7.4% |
| 1974 | 1,500,000 | 16.64 | 0.022 | 0.050 | 58,725 | 3.9% | 15.16 | 0.094 | 0.094 | 110,459 | 0.100 | 117,450 | 0.094 | 110,459 | 0.094 | 110,459 | 7.4% | 7.8% | 7.4% | 7.4% |
| 1975 | 1,500,000 | 16.57 | 0.017 | 0.050 | 58,725 | 3.9% | 15.16 | 0.094 | 0.094 | 110,459 | 0.100 | 117,450 | 0.094 | 110,459 | 0.094 | 110,459 | 7.4% | 7.8% | 7.4% | 7.4% |
| 1976 | 1,500,000 | 16.42 | 0.015 | 0.050 | 58,725 | 3.9% | 14.30 | 0* | 0.050 | 58,725 | 0.100 | 117,450 | 0.050 | 58,725 | 0.000 | 0 | 3.9% | 7.8% | 3.9% | 0.0% |
| 1977 | 1,500,000 | 16.10 | 0.049 | 0.050 | 58,725 | 3.9% | 14.30 | 0* | 0.050 | 58,725 | 0.100 | 117,450 | 0.050 | 58,725 | 0.000 | 0 | 3.9% | 7.8% | 3.9% | 0.0% |
| 1978 | 1,500,000 | 16.60 | 0.019 | 0.050 | 58,725 | 3.9% | 14.30 | 0* | 0.050 | 58,725 | 0.100 | 117,450 | 0.050 | 58,725 | 0.000 | 0 | 3.9% | 7.8% | 3.9% | 0.0% |
| 1979 | 1,500,000 | 17.09 | 0.111 | 0.111 | 130,370 | 8.7% | 15.69 | 0.177 | 0.150 | 176,175 | 0.177 | 207,516 | 0.177 | 207,516 | 0.177 | 207,516 | 11.7% | 13.8% | 13.8% | 13.8% |
| 1980 | 1,500,000 | 17.32 | 0.194 | 0.150 | 176,175 | 11.7% | 15.69 | 0.177 | 0.150 | 176,175 | 0.177 | 207,516 | 0.177 | 207,516 | 0.177 | 207,516 | 11.7% | 13.8% | 13.8% | 13.8% |
| 1981 | 1,500,000 | 17.07 | 0.106 | 0.106 | 124,474 | 8.3% | 15.69 | 0.177 | 0.150 | 176,175 | 0.177 | 207,516 | 0.177 | 207,516 | 0.177 | 207,516 | 11.7% | 13.8% | 13.8% | 13.8% |
| 1982 | 1,500,000 | 16.98 | 0.079 | 0.079 | 93,024 | 6.2% | | | | | | | | | | | | | | |
| 1983 | 1,500,000 | 17.05 | 0.098 | 0.098 | 115,680 | 7.7% | | | | | no CalCOFI data available | | | | | | | | | |
| 1984 | 1,500,000 | 17.25 | 0.167 | 0.150 | 176,175 | 11.7% | | | | | | | | | | | | | | |
| 1985 | 1,500,000 | 17.58 | 0.320 | 0.150 | 176,175 | 11.7% | 16.35 | 0.281 | 0.150 | 176,175 | 0.200 | 234,900 | 0.200 | 234,900 | 0.200 | 234,900 | 11.7% | 15.7% | 15.7% | 15.7% |
| 1986 | 1,500,000 | 17.80 | 0.454 | 0.150 | 176,175 | 11.7% | 16.06 | 0.234 | 0.150 | 176,175 | 0.200 | 234,900 | 0.200 | 234,900 | 0.200 | 234,900 | 11.7% | 15.7% | 15.7% | 15.7% |
| 1987 | 1,500,000 | 17.87 | 0.501 | 0.150 | 176,175 | 11.7% | 16.03 | 0.230 | 0.150 | 176,175 | 0.200 | 234,900 | 0.200 | 234,900 | 0.200 | 234,900 | 11.7% | 15.7% | 15.7% | 15.7% |
| 1988 | 1,500,000 | 17.71 | 0.395 | 0.150 | 176,175 | 11.7% | 16.01 | 0.227 | 0.150 | 176,175 | 0.200 | 234,900 | 0.200 | 234,900 | 0.200 | 234,900 | 11.7% | 15.7% | 15.7% | 15.7% |
| 1989 | 1,500,000 | 17.55 | 0.308 | 0.150 | 176,175 | 11.7% | 16.02 | 0.228 | 0.150 | 176,175 | 0.200 | 234,900 | 0.200 | 234,900 | 0.200 | 234,900 | 11.7% | 15.7% | 15.7% | 15.7% |
| 1990 | 1,500,000 | 17.24 | 0.164 | 0.150 | 176,175 | 11.7% | 15.85 | 0.202 | 0.150 | 176,175 | 0.200 | 234,900 | 0.200 | 234,900 | 0.200 | 234,900 | 11.7% | 15.7% | 15.7% | 15.7% |
| 1991 | 1,500,000 | 17.19 | 0.145 | 0.145 | 170,594 | 11.4% | 15.75 | 0.186 | 0.150 | 176,175 | 0.186 | 218,427 | 0.186 | 218,427 | 0.186 | 218,427 | 11.7% | 14.6% | 14.6% | 14.6% |

*Negative CalCOFI fraction

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