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99 Pacific Street, Suite 155C
Monterey, CA 93940 USA

+1.831.643.9266
OCEANA.ORG

March 30, 2017

Mr. Herb Pollard, Chair
Pacific Fishery Management Council
7700 NE Ambassador Place, Suite 101
Portland, OR 97220

RE: Pacific Sardine Assessment, Specifications, and Management Measures

Dear Mr. Pollard and Council members:

The 2017 Pacific sardine assessment shows the northern subpopulation of Pacific sardine will have declined more than 95 percent between 2006 and July 2017.[1] At a projected 86,586 metric tons (mt) at the start of the fishing year (July 1, 2017 – June 30, 2018), the sardine population remains below the 'cutoff' threshold and thus too low to allow for a directed fishery. As a result, the Pacific Fishery Management Council ("Council") and National Marine Fisheries Service (NMFS) must keep the non-tribal directed fishery closed for the 2017-18 fishing year, and only minimal incidental catch should be allowed in other fisheries. In addition we request that the Council amend its Pacific sardine management framework to prevent future coastwide overfishing, minimize depletion, rebuild the population to healthy levels, and account for the foraging needs of dependent marine wildlife. We also request the Council and NMFS take steps to address the southern subpopulation of Pacific sardine that is fished off southern California and is a shared resource with Mexico.

1. The Pacific sardine population remains collapsed and too low to allow fishing

The 2017 assessment finds that the northern sardine subpopulation declined roughly 97 percent between 2007 and the start of 2017, to a recent low point of 57,427 mt—a 3.8 billion pound decline in biomass.[2] The age 1+ biomass of the northern subpopulation of Pacific sardine is estimated to increase between the start of the year and July 2017, when it is expected to be approximately 86,586 mt.[3] Assessment authors note caution, however, in estimating recruitment as "the 2011-15 year classes have been among the

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[1] Hill, K.T., P.R. Crone, J.P. Zwolinski. 2017. Assessment of the Pacific sardine resource in 2017 for U.S. management in 2017-18. Pacific Fishery Management Council, April 2017 Briefing Book, Agenda Item G.5.a, Portland, Oregon. 146 p.
[2] *Id.* at 67.
[3] *Id.* at. 34.

weakest in recent history," and a, "small increase in recruitment was observed in 2016, albeit a highly variable estimate (CV=79%) based on limited data."[4]

As you are aware, the Pacific sardine harvest control rule includes a cutoff factor of 150,000 mt, below which directed fishing is prohibited.[5] This assessment finds the population likely dropped below cutoff in early 2014. In April 2015, the Council took swift action to recommend that NMFS close the directed fishery, and it has remained closed since. Given this 2017 assessment, the Council must take action to keep the non-tribal directed fishery closed during the 2017-18 fishing year.

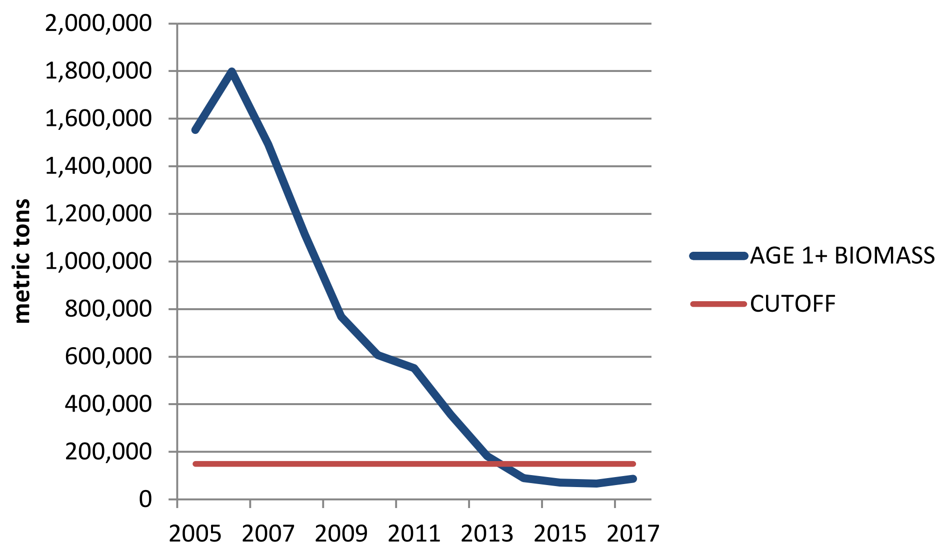

Figure 1. Pacific sardine biomass (age 1+) 2005 to 2017 in relation to 'cutoff'.[6]

2. **Only minimal incidental catch should be allowed to prevent further depletion and support sardine recovery**

The Coastal Pelagic Species (CPS) Fishery Management Plan (FMP) states that the purpose of cutoff is "to protect the stock when biomass is low."[7] The CPS FMP also states,

> "By the time BIOMASS falls as low as CUTOFF, the harvest rate is reduced to zero. The CUTOFF provides a buffer of spawning stock that is protected from fishing and available for use in rebuilding if a stock becomes overfished."[8]

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[4] *Id.* at 10.
[5] PFMC 2016. CPS FMP, at 37: Harvest Guideline = (BIOMASS-CUTOFF) x FRACTION x DISTRIBUTION.
[6] Data from Hill et al. 2017, *supra note* 1.
[7] PFMC CPS FMP, at 38.
[8] *Id.*

While stating that the harvest rate is reduced to zero when biomass is below cutoff, the CPS FMP simultaneously envisions that a small fishery will continue to supply recreational and commercial fisheries with bait.[9] Accordingly, the simulation model used to justify the Pacific sardine harvest control rule considered that there may be sardine harvest after the population drops below cutoff. That simulation model, however, only considered that up to 2,000 metric tons of sardine would be harvested after this point.[10] The analysis also assumes that Mexico and Canada fish within the U.S. defined coastwide harvest rate. Catch data presented in the 2017 stock assessment demonstrates that this is not true.[11] The Hurtado and Punt analysis found that when Mexico and Canada do not follow the U.S. HCR, the sardine population could actually be "rendered extinct."[12]

The Council, therefore, should set a Pacific sardine ACL of no more than 2,000 mt, which would be divided among the live bait and Tribal sectors and accommodate limited bycatch in other sectors. A 2,000 mt ACL would provide for limited directed sardine catch while acting as a strong incentive to avoid bycatch. It would also account for the likelihood that Mexico may also harvest the northern sardine subpopulation, would conform to the harvest strategy analyzed[13] and adopted by the Council in 2014, and is similar to actual sardine landings over the past two years.[14]

Commensurate with the proposed ACL, we recommend an incidental landing allowance of 40 percent Pacific sardine until a total of 800 mt of Pacific sardine are landed across all West Coast CPS and non-CPS fisheries. If 800 mt are landed, the incidental per landing allowance should be reduced to 20 percent until a total of 1,600 mt of Pacific sardine are landed. If 1,600 mt of sardine are landed, the incidental per landing allowance should be reduced to 10 percent for the remainder of the 2017–2018 fishing year.

3. The role of fishing during the collapse

It is clear that forage fish, like Pacific sardine, experience dramatic changes in abundance even in the absence of fishing.[15] The science also shows that increasing fishing pressure

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[9] *Id.* at 40.
[10] Hurtado-Ferro, F. and A.E. Punt. 2014. Revised analyses related to Pacific sardine harvest parameters. PFMC Agenda Item I.1.b Revised Analysis. March 2014, Pg 28 ("The catch is always assumed to be at least 2,000t to cover catches in the live bait fishery.").
[11] Hill et al. 2017, *supra note* 1, *at 9*.
[12] Hurtado-Ferro, F and and A.E. Punt, 2014, *supra note* 10, stating, "However, the results are sensitive to Mexico and Canada not following the US control rule (case S14 in Table 6). This is the only case in which the resource is rendered extinct."
[13] Hurtado-Ferro, F. and A.E. Punt. 2014, *supra note* 10.
[14] Hill et al. 2017, at 55. U.S. total landings in 2015-16 were 2,012 mt (259 mt NSP). To date 956 mt (98 mt NSP) of sardine have been landed in the 2016-17 fishing year.
[15] McClatchie, S., I. L. Hendy, A. R. Thompson, and W. Watson (2017), Collapse and recovery of forage fish populations prior to commercial exploitation, *Geophys. Res. Lett.*, *44*, doi:10.1002/2016GL071751.

during a collapse increases the magnitude and frequency of collapse.[16] As such, the 2017 Pacific sardine assessment shows fishing rates significantly increased during the northern subpopulation collapse to a high of 40 percent in 2013 (figure 2). U.S. West Coast and coastwide fishing far exceeded sustainable levels, on a continuing basis, and this likely amplified the severity of the sardine crash.

The assessment reports that from 2005-2016, 851,955.5 mt (over 1.8 billion pounds) of Pacific sardine (northern subpopulation) were directly removed by commercial fishing.[17] During the collapse, many ocean animals like California sea lions, which depend on sardine and anchovy for food starved to death.[18]

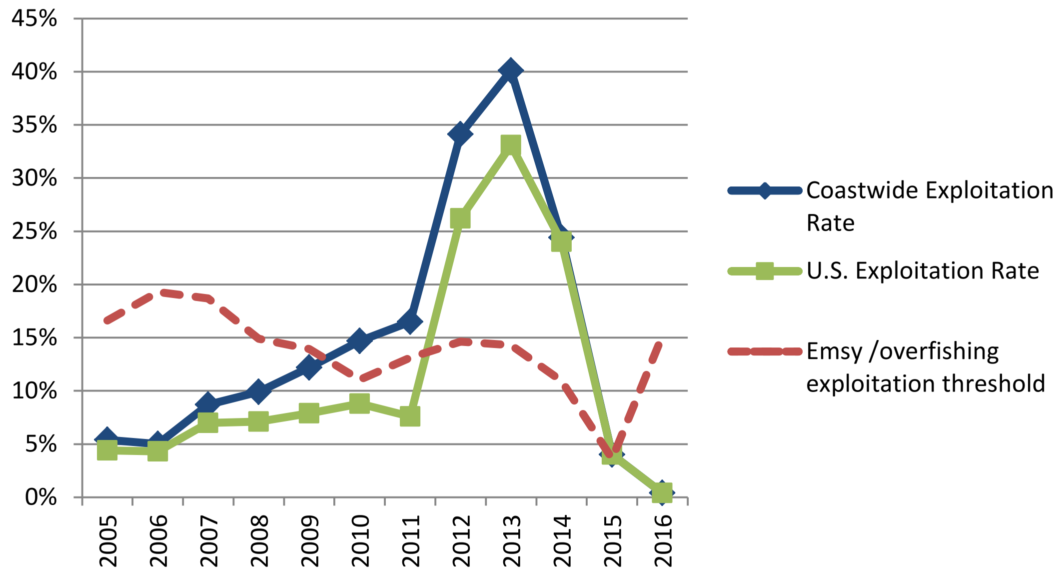

Figure 2. Coastwide (U.S., Canada and Mexico) and U.S. Pacific sardine exploitation rates compared with the E_{MSY} fishing rate.[19] E_{MSY} is the maximum sustainable yield (MSY) fishing rate which fluctuates based on the three-year average temperature in the CalCOFI sampling area. Fishing rates exceeded E_{MSY} from 2010-2014 based on data provided in the 2017 Pacific sardine assessment.

Under the Magnuson-Stevens Fishery Conservation and Management Act (MSA), "'overfishing and overfished' mean a rate or level of fishing mortality that jeopardizes the capacity of a fishery to produce the maximum sustainable yield on a continuing basis."[20]

[16] Essington et al. 2015. Fishing amplifies forage fish population collapses, PNAS Early Edition, available at http://www.pnas.org/content/early/2015/04/01/1422020112.full.pdf.
[17] Hill et al. 2017, *supra note* 1, at 9.
[18] McClatchie, S. et al. 2015. Food limitation of sea lion pups and the decline of forage off central and southern California. Available here .
[19] Fishing rates from Hill et al. 2017, *supra note* 1, at 13. E_{MSY} is calculated as, *EMSY* = -18.46452+3.25209(*T*) 0.19723(*T2*)+0.0041863(*T3*), using 3-year average CalCOFI SST values provided in Hill et al. 2017 at 73.
[20] 16 U.S.C. § 1802(34).

The CPS FMP states that, "[b]y definition, overfishing occurs in a fishery whenever fishing occurs over a period of one year or more at a ***rate*** that is high enough to jeopardize the capacity of the stock to produce MSY on a continuing basis..." [emphasis added]. [21] With this definition, the FMP also states, "In operational terms, overfishing occurs in the CPS fishery whenever catch exceeds OFL [the overfishing limit]."[22]

The U.S. fishery did not exceed annual overfishing limits established at the time. We now know, however, based on data in the 2017assessment as well as earlier NMFS Pacific sardine assessments that the rate of fishing continued to climb as the sardine population collapsed. The coastwide fishing rate exceeded the MSY fishing rate between 2010 and 2014, and the U.S. alone exceeded the MSY fishing rate in 2012 through 2014.

This retrospective understanding is not dissimilar to what occurred with rockfish during the 1980s and '90s. At the time, based on the available science, managers greatly overestimate sustainable rockfish fishing rates and overfishing occurred "due to a combination of inadequate data and fishery productivity that was far lower than anyone imagined."[23] With strong legal requirements and improved science, groundfish fishery management has since greatly advanced so that depleted rockfish populations are now either rebuilding or recovered.

We stress this understanding that sardine fishing rates far exceed MSY to highlight the role of fishing during the sardine collapse, demonstrate concerns with the current management framework, and to urge the Council and agency to reform sardine management to prevent similar situations in the future.

4. Management reform is needed

This sardine population collapse was predicted, and managers were warned of excessive exploitation rates. In 2012, scientists Zwolinski and Demer published a study predicting the collapse of the Pacific sardine stock, finding, "All indicators show that the northern sardine stock off the west coast of North America is declining steeply again and that imminent collapse is likely".[24] The authors warned "alarming is the repetition of the fishery's response to a declining sardine stock - progressively higher exploitation rates targeting the oldest, largest, and most fecund fish."[25]

[21] Pacific Fishery Management Council. 2016. Coastal Pelagic Species Fishery Management Plan as amended through Amendment 15, at page 36. www.pcouncil.org
[22] *Id.*
[23] Raslton, S. 2002. "The Groundfish Crises – What went wrong?" Ecosystem Observations for the Monterey Bay National Marine Sanctuary, NOAA NMS 2002.
[24] Zwolinski, J. 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 (PNAS) 109 (11). 4175-4180. Available here .
[25] *Id. at 1.*

The dearth of sardine and, simultaneously, anchovy has had significant impacts on dependent marine wildlife. These impacts are evidenced by the multi-year California sea lion unusual mortality event and likely much wider ecosystem impacts that may reverberate through the food web for years to come. One study of forage species in predator diets found that 32 species in the California Current ecosystem feed on Pacific sardine.[26]

Many scientific studies and reports recommend more precautionary harvest strategies for important forage fish like sardine. Based on these studies, Oceana has repeatedly requested the Council and NMFS revise the management system to leave more fish in the water to allow sardine to successfully reproduce, recover, and support ocean wildlife. Unless the current management framework is improved, the pattern of excessive fishing pressure on a declining stock, long periods with low sardine abundance, and rippling ecosystem impacts are likely to continue. Now is the time to develop an alternative, risk-based management framework and this can be done with little effect on long-term average catches.

Based on our analysis of the harvest control rule, previously presented to the Council, this means allowing increased fishing during periods of high abundance (increasing the maximum catch limit, 'maxcat' from 200,000 to 300,000 mt), limit the fishing 'fraction' to scale from 5% -15% (instead of the proposed 5%-20%), and increase cutoff (to 640,000 mt or ≥40% B_0).[27] As stated in a recent study on the collapse and recovery of Pacific forage fish populations, "A pulsed exploitation strategy where periods of high fishing mortality alternate with periods of much reduced or no fishing mortality might fit the natural fluctuations of these populations."[28]

An improved management framework also means adopting an alternative minimum stock size threshold (MSST) for Pacific sardine.[29] The NMFS MSST report for CPS finfish provided updated sardine MSST values ranging from 61,074 mt to 121,697 mt.[30] The Council should direct the SSC to determine which value represents the best available science and is most consistent with the national standard guidelines, and amend the CPS FMP accordingly. This is of immediate concern as the current stock size falls within this

[26] Szoboszlai, A.I., J.A. Thayer, S.A. Wood, W.J. Sydeman, and L.E. Koehn. 2015. Forage species in predator diets: Synthesis of data from the California Current. Ecological Informatics 29: 45-56.
[27] See, G. Shester, Oceana. (February 28, 2014) Letter to the Pacific Fishery Management Council, at http://www.pcouncil.org/wp-content/uploads/I1d_SUP_PC3_MAR2014BB.pdf
[28] McClatchie et al. 2017, *supra note* 15.
[29] 50 C.F.R. § 600.310(e)(2)(ii)(B). MSSTs must be expressed in terms of spawning biomass or other measure of reproductive potential and should equal whichever is *greater*: one-half the MSY stock size, or the minimum stock size at which rebuilding to the MSY level would be expected to occur within 10 years.
[30] NMFS 2016. Review and Re-evaluation of Minimum Stock Size Thresholds for Finfish in the Coastal Pelagic Species Fishery Management Plan for the U.S. West Coast. PFMC Agenda Item E.1.a. Supplemental NMFS Report. September 2016..

range and the MSST is the primary metric for determining whether the stock is overfished and a rebuilding plan is necessary.

An improved sardine management framework also means unilaterally or cooperatively addressing the international distribution of this sardine population to prevent coastwide overfishing.[31] Attached to this letter is a recent publication showing that the constant distribution factor (87%) in the sardine harvest control rule has not prevented coastwide target fishing levels from being exceeded, and the authors offer alternative methodologies for optimizing Pacific sardine catch. The study authors indicate that had their proposed methodologies been in place during the last decade, coastwide overfishing would have been prevented. In the absence of an international agreement, we request the Council select the methodology that best achieves target fishing levels and prevents coastwide overfishing.

Last, the Pacific sardine assessment describes two Pacific sardine populations off the U.S. West Coast, but the Council and NMFS are managing the sardine fishery based on the northern Pacific subpopulation alone. The NMFS assessment shows that U.S. fishermen have landed over 78,000 mt of the southern Pacific sardine population over the past decade. This southern sardine population is an important forage fish, it is in the U.S. fishery, and it should be addressed in the CPS FMP.

Hopefully the sardine population will rebound soon. In the meantime, we urge the Council to learn from past mistakes and consider independent and published science showing how to manage for sustainable forage fish fisheries that account for ecosystem needs.

Thank you for your consideration of these comments.

Sincerely,

Ben Enticknap
Pacific Campaign MGR & Sr. Scientist

Geoffrey Shester, Ph.D.
California Campaign Director & Sr. Scientist

[31] David A. Demer & Juan P. Zwolinski. 2017. A Method to Consistently Approach the Target Total Fishing Fraction of Pacific Sardine and Other Internationally Exploited Fish Stocks, North American Journal of Fisheries Management, 37:2, 284-293 **(Attached).**

North American Journal of Fisheries Management 37:284–293, 2017

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ARTICLE

A Method to Consistently Approach the Target Total Fishing Fraction of Pacific Sardine and Other Internationally Exploited Fish Stocks

David A. Demer*
National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Science Center, 8901 La Jolla Shores Drive, La Jolla, California 92037, USA

Juan P. Zwolinski
Institute of Marine Sciences, University of California, Santa Cruz (Southwest Fisheries Science Center affiliate), Earth and Marine Sciences Building, Room A317, Santa Cruz, California 95064, USA

Abstract
The "northern" stock of Pacific Sardine *Sardinops sagax* is fished by Mexico, the USA, and Canada. Without an international management agreement, the U.S. Pacific Fishery Management Council prorates its target total fishing fraction (*F*) in its harvest control rule (HCR) by 0.87. This is the proportion of the stock that it deemed in 1998 to be present, on average, during summer–fall 1964–1992 in the U.S. Exclusive Economic Zone. However, the portion of the stock in U.S. waters is variable, depending on the environment and stock biomass and demographics. Furthermore, irrespective of the stock distribution, the combined foreign and U.S. landings may exceed those determined by an *F* of 0.15, potentially reducing the stock biomass and yield. This occurred each year during 2001–2014, and the *F* (mean = 0.22; SD = 0.06) trended upward. To more consistently approximate the target *F*, a method was proposed to set harvest quotas with accounting for predicted foreign landings. We refined the method by adding a prediction error term and showed that the U.S. HCR, solved with predicted foreign landings and stock biomass from each annual assessment in 2001–2014, better stabilized *F* about the target *F* relative to the historical values (original method: mean = 0.16, SD = 0.02; new method: mean = 0.16, SD = 0.05). We also compared the historical *F* (mean = 0.18, SD = 0.07) and optimized *F* (original method: mean = 0.16, SD = 0.06; new method: mean = 0.17, SD = 0.08) calculated using updated biomass estimates from the 2013 assessment. Results showed that irrespective of the assessment and its assumptions, quotas that were optimized with respect to *F* better approached the target *F*-value. Although the new method reduces bias due to trend in the foreign landings, its performance may be less precise than the original method if—as recently occurred—the assessments are significantly revised and the stock migration is abruptly abbreviated.

In the California Current, there are two migrating stocks of Pacific Sardine *Sardinops sagax*, and landings at Ensenada, Mexico, and San Pedro, California (Figure 1) may include fish from one or both stocks (Smith 2005). The 2001–2013 U.S. assessments of the "northern" stock assumed that no landings at these ports or at ports farther north were from the "southern" stock. Subsequent assessments used concomitant measures of satellite-sensed sea surface temperature (SST) and the method we proposed (Demer and Zwolinski 2014b; see below) to differentiate landings from the two stocks (Hill et al. 2014).

The northern stock is fished by Mexico, the USA, and Canada. Without international management of the Pacific Sardine fishery, the total multinational harvest rate may be higher than the target, and biomass and fishery yields may be reduced due to too much

*Corresponding author: david.demer@noaa.gov
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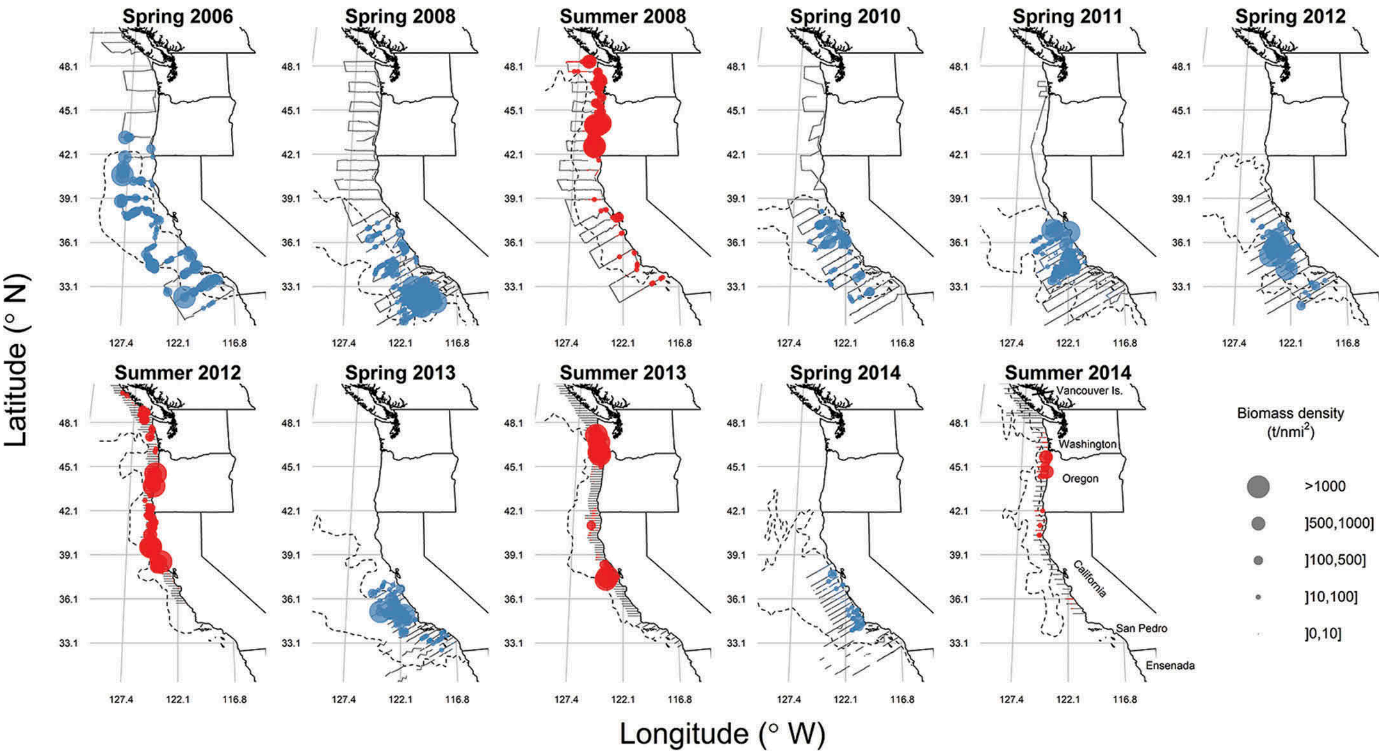

FIGURE 1. Pacific Sardine biomass densities averaged over 2-km intervals, as estimated from acoustic trawl transects (black lines) conducted during spring 2006, 2008, and 2010–2014 and during summer 2008 and 2012–2014 (Demer et al. 2012, 2013; Zwolinski et al. 2012, 2014). Confined by their dynamic potential habitat (dashed lines), the Pacific Sardine were located offshore of central and southern California during spring (blue shading) and close to the coast in the northeast Pacific in summer (red shading). The Pacific Sardine did not span their entire potential habitat, but they did fill more of their potential habitat when their population was larger (Demer and Zwolinski 2014b).

fishing (PFMC 1998). Therefore, the harvest level for the U.S. Pacific Sardine fishery is set by prorating the total target harvest level according to the portion of the stock that is resident in U.S. waters (PFMC 1998). However, if the portion of the stock in U.S. waters cannot be estimated or is highly variable, then other approaches may be used (PFMC 1998). We (Demer and Zwolinski 2014b) proposed explicit accounting for predicted foreign landings to set harvest quotas that consistently approximate the target total fishing fraction (*F*). Basically, the landings at Ensenada, Mexico, and Vancouver Island, Canada, are used to estimate their values in the following year, as is done in the annual assessments. Using stock-differentiated and undifferentiated landings, we (Demer and Zwolinski 2014b) showed that application of this method better stabilizes the actual *F* about the target *F*, permits more U.S. Pacific Sardine fishing during most periods when the stock is large and predominantly residing in the U.S. Exclusive Economic Zone (EEZ), and curtails U.S. Pacific Sardine fishing during periods when a large proportion of the stock is present and fished in the EEZ of Mexico, Canada, or both. The method is applicable and effective regardless of the assessment data used and regardless of whether the landings are stock differentiated (Demer and Zwolinski 2014b). Furthermore, because the optimization is with respect to the target *F*, the efficacy of the method for any stock with international harvest depends only on the accuracy of the forecasted total landings and stock biomass.

Distribution of the Northern Stock

The northern stock of Pacific Sardine migrates seasonally along the west coasts of Mexico, the USA, and Canada (Clark and Janssen 1945; Félix-Uraga et al. 2004; Smith 2005), and the extent of the migration depends on the stock size and demographic structure (Zwolinski and Demer 2012). Typically, the northern stock spawns offshore of southern and central California during spring and forages in nearshore areas between central California and Vancouver Island during summer (Figure 1; Demer et al. 2012; Zwolinski and Demer 2014), all the while constrained by the dynamic boundaries of its potential oceanographic habitat, defined mainly by SST and chlorophyll-*a* concentration (Zwolinski et al. 2011, 2014; Demer and Zwolinski 2014a). However, from 1936 to 1992, after the stock biomass had fallen below approximately 740,000 metric tons (mt; Zwolinski and Demer 2012), Pacific Sardine did not migrate into the Canadian EEZ (PFMC 2011). From 1993 to 2011, after the spawning stock biomass (SSB) in the 2010 assessment (Hill et al. 2010) increased to more than roughly 750,000 mt, Pacific Sardine resumed their migration to Canada (Zwolinski and Demer 2012). From 2012 to

2014, with the SSB again below approximately the same value (Hill et al. 2014), Pacific Sardine did not migrate to Canada (Zwolinski et al. 2014). Although the precise reason for geographic variation in stock migration is presently unknown, there is evidence that a linkage to SSB exists. Petitgas et al. (2010) and MacCall (2012) hypothesized that the population must include a dominant number of experienced migrators to influence new recruits and teach them when, where, and why to migrate. Perhaps a small SSB with low bioenergetic requirements may find sufficient food during the summer feeding period to support growth and maturation without an extensive migration. Below an SSB of about 740,000 mt, Pacific Sardine recruitment decreases quasi-linearly, but for larger values of SSB, Pacific Sardine condition factor and recruitment might be linked to the summer feeding environment in the northeast Pacific (Zwolinski and Demer 2014). Irrespective of the precise functional relationship, the distribution of Pacific Sardine varies seasonally and annually (e.g., Demer et al. 2012; Zwolinski and Demer 2014; Zwolinski et al. 2014) depending on oceanographic conditions (e.g., Demer et al. 2012; Zwolinski et al. 2014; Demer and Zwolinski 2014a), stock size (e.g., Demer et al. 2012), and stock demographics (Clark and Janssen 1945; Lo et al. 2011).

U.S. Harvest Control Rule

When available and when fishing is permitted, the northern stock of Pacific Sardine is exploited by Mexico, the USA, and Canada. Since 2001, the U.S. Pacific Fishery Management Council (PFMC) has managed the northern stock of Pacific Sardine and set its annual U.S. harvest quota (H; mt) by using a harvest control rule (HCR), formulated as the harvest guideline,

$$H = (B - C)FD, \tag{1}$$

where B is the assessment-estimated biomass of age-1 and older (age-1+) Pacific Sardine; C is the cutoff (consistently 150,000 mt), or the lowest level of estimated B at which harvest is allowed; F (consistently 0.15) is the target fraction of $B - C$ to be harvested by the fisheries; and D is the proportion of the biomass deemed to be present in U.S. waters (PFMC 2011). The PFMC set D at 0.87, designating 87% of the stock as present in the U.S. EEZ (PFMC 1998). However, because D does not account for combined landings at Ensenada, Mexico (L_{Mexico}), multiple ports in the USA (L_{USA}), and Vancouver Island, Canada (L_{Canada}), the HCR has not maintained an F ($[L_{Mexico} + L_{USA} + L_{Canada}]/[B - C]$) below the target F-value (Hill et al. 2014, 2015). This situation could reduce the stock's biomass and yield (PFMC 1998).

Optimizing the Quota with Respect to the Fishing Fraction

We (Demer and Zwolinski 2014b) proposed that the target F (PFMC 1998) could be more consistently achieved by evaluating H in each management year y, with accounting for Pacific Sardine mortality due to foreign fishing ($L_{foreign} = L_{Mexico} + L_{Canada}$) predicted (as in each annual assessment) by the value reported for the previous year ($y - 1$),

$$H_y = \left(B_y - C\right)F - L_{foreign,y-1}. \tag{2}$$

Alternatively (and with functional equivalence), D in equation (1) could be annually optimized with respect to the target F,

$$D_y = 1 - \frac{L_{foreign,y-1}}{\left(B_y - C\right)F}. \tag{3}$$

Either strategy—equation (2) or equation (3)—could serve to stabilize the actual F about the target value, permit more U.S. Pacific Sardine fishing when the stock is large and predominantly fished in the U.S. EEZ, and curtail U.S. Pacific Sardine fishing when a large proportion of the stock is fished in the EEZ of Mexico, Canada, or both (Demer and Zwolinski 2014b).

The method is not only applicable to the management of Pacific Sardine but also to other coastal pelagic species (CPS) that potentially could be managed using the same HCR formula (e.g., Northern Anchovy *Engraulis mordax*, Pacific Chub Mackerel *Scomber japonicus*, and Jack Mackerel *Trachurus symmetricus* off the U.S. West Coast). According to PFMC (2011), "The general harvest control rule for CPS (depending on parameter values) is compatible with the MSA [Magnuson–Stevens Fishery Conservation and Management Act] and useful for CPS that are important as forage." Additionally, the method may be applicable to the management of other transboundary stocks: "The general formula for MSY [maximum sustainable yield] control rules in CPS includes policies used to manage most of the world's fisheries" (PFMC 1998).

Here, we first evaluate whether the proportion of the northern Pacific Sardine stock that is present in the U.S. EEZ has been constant throughout the management period, as is assumed in the U.S. HCR. To do this, we consider information about the Pacific Sardine's spatial distribution that is potentially contained in the results of periodic acoustic trawl surveys (e.g., Demer et al. 2012; Zwolinski et al. 2012, 2014), a model of Pacific Sardine potential habitat (Zwolinski et al. 2011; Demer and Zwolinski 2014a), and Pacific Sardine landings data. We then refine equations (2) and (3) and evaluate their efficacy to better stabilize the F about the target F by using (1) information that was available when the annual fishing quotas were set (i.e., the 2000–2013 assessments); and (2) information taken entirely from the 2013 assessment (Hill 2013).

METHODS

The spatial distribution of Pacific Sardine was sampled by acoustic trawl surveys conducted off southern and central

California during spring 2006, 2008, and 2010–2014 and off the west coasts of the USA and Canada during summer 2008 and 2012–2014 (Demer et al. 2012, 2013; Zwolinski et al. 2012, 2014). These results are plotted (Figure 1) with the survey period's mean boundaries of optimal and good potential habitat (defined by the probability of Pacific Sardine presence; Zwolinski et al. 2011), illustrating the seasonal and interannual dynamics of Pacific Sardine density and potential habitat relative to Mexico, the USA, and Canada at the times of these surveys. Pacific Sardine potential habitat is defined by a model of the probabilistic association of certain satellite-sensed oceanographic conditions and Pacific Sardine presence (see http://swfscdata.nmfs.noaa.gov/AST/sardineHabitat/habitat.asp).

For 2001 to 2014, annually optimized values of H_y and D_y were calculated using equations (2) and (3), which we proposed (Demer and Zwolinski 2014b), and those refined here with an additional term to compensate for error in the foreign landings predicted in each annual assessment,

$$H_y = \left(B_y - C\right)F - L_{foreign,y-1} + \left(L_{foreign\,,y-2} - L_{foreign,y-1}\right)$$

or

$$H_y = \left(B_y - C\right)F - 2L_{foreign\,,y-1} + L_{foreign,y-2}, \tag{4}$$

and

$$D_y = 1 - \frac{L_{foreign\,,y-1} - \left(L_{foreign,y-2} - L_{foreign,y-1}\right)}{\left(B_y - C\right)F}$$

or

$$D_y = 1 - \frac{2L_{foreign,y-1} - L_{foreign,y-2}}{\left(B_y - C\right)F}, \tag{5}$$

where the subscript $y-2$ indicates values from 2 years prior to the management year (Tables 1, 2). In other words, the difference between the predicted and actual prior-year foreign landings is added to the U.S. harvest quota in the subsequent year (see equation 4) to mitigate the effects of any trend in $L_{foreign}$. Because D_y in equation (5) must be between 0 and 1, if $L_{foreign,y-1} - (L_{foreign,y-2} - L_{foreign,y-1})$ exceeds $(B_y - C)F$, then the former is set equal to the latter (i.e., $D = 0$); and if the error term $(L_{foreign,y-2} - L_{foreign,y-1})$ exceeds the predicted foreign landings ($L_{foreign,y-1}$), then the former is set equal to the latter (i.e., $D = 1$).

Although the harvest quota may be optimized with respect to many biological, ecological, sociological, and economic factors, we optimized it with respect to the target *F*. In this case, the relevant variables (regardless of the species, stock, ecosystem, or ocean) are the total landings and the estimated stock biomass. We (Demer and Zwolinski 2014b) explored a variety of methods to predict foreign landings of the northern Pacific Sardine stock and concluded that the foreign landings from the previous year were the best predictor for the foreign landings during the subsequent year. There is independent precedence in each of the annual U.S. Pacific Sardine assessments for this approach to predicting foreign landings.

To demonstrate the efficacies of the original method and the refined method for annually optimizing H_y either directly or indirectly (i.e., via optimized D_y), data were calculated using equations (2)–(5), which were parameterized with foreign landings and B_y values from each assessment used to calculate the H_y value during each year from 2001 to 2014 (Table 1). Assuming that assessment time series are retrospectively refined relative to those in each of the earlier assessments, the historical and optimized *F*-values were retrospectively evaluated by using foreign landings and B_y values from the 2013 Pacific Sardine stock assessment (Hill 2013; Table 2). Subsequent assessments used our proposed method (Demer and Zwolinski 2014a) to ascribe landings to the assessed northern Pacific Sardine subpopulation versus the unassessed southern subpopulation (Hill et al. 2014, 2015).

We (Demer and Zwolinski 2014b) used data from the 2012 assessment (Hill et al. 2012) and demonstrated how different attributions of landings from the two stocks affected the estimated annual *F*-values for the northern stock during the period 1993–2011. In 2014, the PFMC began using temperature-differentiated landings to estimate Pacific Sardine biomass in the assessment, but landings are not differentiated for assessing the quota. Therefore, prior to 2014, the PFMC calculated *F* by using all landings at ports from Ensenada, Mexico, to Vancouver Island and a biomass estimated from those stock-undifferentiated landings. Since 2014, the PFMC has calculated *F* by using stock-undifferentiated landings and a biomass estimated for the northern stock based on temperature-differentiated landings.

In August 2015, we presented our method for optimizing quotas with respect to the target *F* by using data from the 2015 assessment of the northern stock (Demer and Zwolinski 2015) and temperature-differentiated landings for the northern stock. The workshop report (NMFS and PFMC 2015) claimed that the 2015 assessment provided "perfect knowledge" and was therefore not representative of the information that was available to managers when quotas were set. Therefore, in this paper, we use biomass and landings data from the latest assessment that was available to managers during each year in which they set the Pacific Sardine harvest quota. This tests the method's efficacy for approaching the target *F* by using the best available science at the time of management's decision.

RESULTS

During the 2006–2014 surveys, the large majority of the putative northern Pacific Sardine stock was located off the U.S. West Coast, and the proportions of Pacific Sardine biomass and potential habitat there were neither constant nor

TABLE 1. Age-1 and older Pacific Sardine biomass (B) values used in equation (1) to set the U.S. harvest quota (H) during each year of the federal management period; the forecasts of Pacific Sardine landings at Ensenada, Mexico (L_{Mexico}), and Vancouver Island, Canada (L_{Canada}); the expected total fishing fraction ($F_{exp} = [L_{Mexico} + H + L_{Canada}]/[B - C]$) derived from the harvest guideline (HG) formula (equation 1; PFMC 2011); the optimized U.S. harvest quota calculated using equation (2) ($H_{Eq.[2]}$) and equation (4) ($H_{Eq.[4]}$); the optimized total fishing fractions ($F_{Eq.[2]} = [L_{Mexico} + H_{Eq.[2]} + L_{Canada}]/[B - C]$ and $F_{Eq.[4]} = [L_{Mexico} + H_{Eq.[4]} + L_{Canada}]/[B - C]$); and the optimized distribution parameters calculated by using equation (3) ($D_{Eq.[3]}$) and equation (5) ($D_{Eq.[5]}$). Gray shading indicates when F_{exp} exceeds the target F of 0.15 (see Figure 2).

Management year	B (mt)	H (mt)	L_{Mexico} (mt)	L_{Canada} (mt)	F_{exp}	$H_{Eq.[2]}$ (mt)	$F_{Eq.[2]}$	$D_{Eq.[3]}$	$H_{Eq.[4]}$ (mt)	$F_{Eq.[4]}$	$D_{Eq.[5]}$	Reference
2000			58,569	0								
2001	1,182,465	134,737	53,579	0	0.18	101,291	0.15	0.65	106,281	0.15	0.69	Conser et al. 2000
2002	1,057,599	118,442	34,973	0	0.17	101,167	0.15	0.74	119,773	0.17	0.88	Conser et al. 2001
2003	999,871	110,908	27,422	0	0.16	100,059	0.15	0.78	107,610	0.16	0.84	Conser et al. 2002
2004	1,090,587	122,747	43,693	0	0.18	97,395	0.15	0.69	81,124	0.13	0.57	Conser et al. 2003
2005	1,194,000	136,242	30,537	954	0.16	125,109	0.15	0.80	137,311	0.16	0.88	Conser et al. 2004
2006	1,061,391	118,937	41,897	4,259	0.18	90,553	0.15	0.66	75,888	0.13	0.56	Hill et al. 2006a
2007	1,319,072	152,564	56,684	3,232	0.18	115,445	0.15	0.66	101,685	0.14	0.58	Hill et al. 2006b
2008	832,706	89,093	57,438	1,575	0.22	43,393	0.15	0.42	44,296	0.15	0.43	Hill et al. 2007
2009	662,886	66,932	35,654	1,520	0.20	39,759	0.15	0.52	61,598	0.19	0.80	Hill et al. 2008
2010	702,024	72,039	54,213	10,425	0.25	18,166	0.15	0.22	0	0.12	0.00	Hill et al. 2009
2011	537,173	50,526	56,357	15,334	0.32	0	0.19	0.00	0	0.19	0.00	Hill et al. 2010
2012	988,385	109,409	56,821	21,801	0.22	47,136	0.15	0.37	40,205	0.14	0.32	Hill et al. 2011
2013	659,539	66,495	70,336	19,316	0.31	0	0.18	0.00	0	0.18	0.00	Hill et al. 2012
2014	378,120	29,770	49,355	0	0.35	0	0.22	0.00	25,160	0.33	0.74	Hill 2013
Mean	904,701	98,489	48,502	5,228	0.22	62,819	0.16	0.47	64,352	0.16	0.52	
SD	268,368	35,022	11,823	7,378	0.06	44,673	0.02	0.29	45,434	0.05	0.31	

equivalent (Figure 1). During spring, some of the stock may have been present off Mexico (Zwolinski et al. 2011), but based on the consistent agreement between spring and summer survey estimates (Zwolinski et al. 2014), this probably constituted a negligible portion of the stock (Demer et al. 2012). During spring, there was neither potential habitat nor Pacific Sardine landings off Canada (Table 1; Figure 1; Zwolinski et al. 2011; Demer and Zwolinski 2014a). Conversely, during summer (Figure 1), when Pacific Sardine migrated north (Demer et al. 2012), there was no potential habitat or landings from the stock off Ensenada, Mexico (Zwolinski et al. 2011; Demer and Zwolinski 2014a). Although there was potential habitat off Canada during each summer (Figure 1), no Pacific Sardine had been landed there since 2012 (Tables 1, 2; Zwolinski et al. 2014).

In the 2001–2014 historical analysis, the annual F uniformly exceeded the target F and trended upward (Table 1; Figure 2). With accounting for foreign landings, the mean expected total fishing fraction (F_{exp}) was 0.22 (SD = 0.06; Table 1). The term "expected" indicates values that were or could have been anticipated given the data available from each annual assessment. The foreign landings alone, normalized by $B - C$, exceeded the target F of 0.15 in 2011, 2013, and 2014 (Figure 2). For comparison, the method we proposed (Demer and Zwolinski 2014b; equation 2) and the method refined with a landings estimation error term (equation 4) better stabilized the F about the target F (mean $F_{Eq.[2]} = 0.16$, SD = 0.02; mean $F_{Eq.[4]} = 0.16$, SD = 0.05, respectively; Figure 2). Paired t-tests were used to evaluate differences in the results. The mean $F_{Eq.(2)}$ and mean $F_{Eq.(4)}$ were less than the mean F_{exp} (P = 0.0001 and P = 0.0007, respectively), but mean $F_{Eq.(2)}$ and $F_{Eq.(4)}$ were not statistically different from each other (P = 0.453). The F_{exp} trended upward between 2006 and 2014 (Figure 2), whereas both $F_{Eq.(2)}$ and $F_{Eq.(4)}$ trended up less and only during the final 2 years of the study period.

Identical results were obtained by annually optimizing D in the HCR using equation (3) or its refined form, equation (5) (Table 1; Figure 2). The mean optimized D-values during this period were $D_{Eq.(3)} = 0.47$ (SD = 0.29) and $D_{Eq.(5)} = 0.52$ (SD = 0.31), respectively (Table 1), approximately 46% and 40% less than the D-value of 0.87, on average.

In the 2001–2014 retrospective analysis, the U.S. fishery accounted for, on average, 56% of the Pacific Sardine landings (Table 2). The term "retrospective" indicates the values that were derived using the last assessment in the study period—presumably the best available information for a hindsight evaluation. The total annual catch of Pacific Sardine, normalized by $B - C$, exceeded the target F during 2002–2005 and 2012–2014 (Table 2; Figure 3); the retrospective total fishing fraction (F_{retro}) increased to 0.40 in 2014 (Table 2), and the mean F_{retro} of 0.19 (SD = 0.07) exceeded the target F of 0.15 (Table 2). Uncertainty in the assessed B_y values (compare those in Table 1 versus Table 2; and Figure 2 versus Figure 3) caused the U.S. landings alone to exceed the target F in 2004 (Table 2; Figure 3). For comparison, the method we proposed (Demer and Zwolinski 2014b), when implemented using equation (2) and the

TABLE 2. Age-1 and older Pacific Sardine biomass (B) estimated in the 2013 assessment (Hill 2013); Pacific Sardine biomass landed at Ensenada, Mexico (L_{Mexico}), the USA (L_{USA}), and Vancouver Island, Canada (L_{Canada}), and their respective proportions (P) of the total annual landings ($L_{total} = L_{Mexico} + L_{USA} + L_{Canada}$); the expected total fishing fractions ($F_{exp} = [L_{Mexico} + H + L_{Canada}]/[B - C]$; where H is the U.S. harvest quota from Table 1); the total fishing fractions if the optimized harvest values $H_{\text{Eq.}(2)}$ and $H_{\text{Eq.}(4)}$ in Table 1 had been achieved ($F_{\text{Eq.}[2]} = [L_{Mexico} + H_{\text{Eq.}[2]} + L_{Canada}]/[B - C]$and $F_{\text{Eq.}[4]} = [L_{Mexico} + H_{\text{Eq.}[4]} + L_{Canada}]/[B - C]$, respectively); the retrospective total fishing fraction ($F_{retro} = L_{total}/[B - C]$); and the retrospective optimized distribution parameter ($D_{retro} = 1 - [L_{Mexico} + L_{Canada}]/[B - C]F$). Gray shading indicates when F_{retro} exceeds the target F of 0.15 (see Figure 3).

Management year	B (mt)	L_{Mexico} (mt)	P_{Mexico}	L_{USA} (mt)	P_{USA}	L_{Canada} (mt)	P_{Canada}	L_{total} (mt)	F_{exp}	$F_{\text{Eq.}[2]}$	$F_{\text{Eq.}[4]}$	F_{retro}	D_{retro}
2001	1,246,290	46,071	0.37	78,520	0.62	1,265	0.01	125,856	0.17	0.14	0.14	0.11	0.71
2002	1,032,760	46,846	0.31	101,367	0.68	740	0.00	148,953	0.19	0.17	0.19	0.17	0.64
2003	868,532	41,341	0.35	74,600	0.64	977	0.01	116,918	0.21	0.20	0.21	0.16	0.61
2004	646,971	41,897	0.30	92,613	0.67	4,438	0.03	138,948	0.34	0.29	0.26	0.28	0.38
2005	989,222	55,323	0.37	90,130	0.61	3,231	0.02	148,684	0.23	0.22	0.23	0.18	0.53
2006	1,118,270	57,237	0.38	90,778	0.61	1,575	0.01	149,590	0.18	0.15	0.14	0.15	0.60
2007	1,371,320	36,846	0.22	127,696	0.77	1,522	0.01	166,064	0.16	0.13	0.11	0.14	0.79
2008	1,356,870	66,866	0.41	87,175	0.53	10,425	0.06	164,466	0.14	0.10	0.10	0.14	0.57
2009	1,279,250	55,911	0.40	67,083	0.48	15,334	0.11	138,328	0.12	0.10	0.12	0.12	0.58
2010	1,093,190	56,821	0.39	66,892	0.46	22,223	0.15	145,936	0.16	0.10	0.08	0.15	0.44
2011	1,051,900	70,337	0.51	46,743	0.34	20,719	0.15	137,799	0.16	0.10	0.10	0.15	0.33
2012	866,584	49,810	0.29	101,104	0.59	19,172	0.11	170,086	0.25	0.16	0.15	0.24	0.36
2013	635,551	49,355	0.44	62,940	0.56	0	0.00	112,295	0.24	0.10	0.10	0.23	0.32
2014	378,120	66,744	0.74	23,697	0.26	0	0.00	90,442	0.42	0.29	0.40	0.40	0.00
Mean	995,345	52,958	0.39	79,381	0.56	7,259	0.05	139,597	0.21	0.16	0.17	0.19	0.49
SD	281,501	9,848	0.12	24,695	0.13	8,172	0.06	21,429	0.08	0.06	0.08	0.07	0.19

information available when the PFMC set each H_y, stabilized the F (mean $F_{\text{Eq.}[2]} = 0.16$, SD = 0.06) closer to the target F. The method refined with a predicted foreign landings error term, implemented using equation (4) and the information available when the PFMC set each H_y, also achieved an F (mean $F_{\text{Eq.}[4]} = 0.17$, SD = 0.08) that was closer to the target F (Table 2; Figure 3). Mean $F_{\text{Eq.}(2)}$ and mean $F_{\text{Eq.}(4)}$ were less than mean F_{exp} (P = 0.0002 and 0.0008, respectively) and mean F_{retro} (P = 0.0432 and 0.0815, respectively). Mean $F_{\text{Eq.}(2)}$ and mean $F_{\text{Eq.}(4)}$ were not statistically different from each other (P = 0.5338). Mean F_{retro} was less than F_{exp} (P = 0.0008). The F_{retro} trended upward between 2006 and 2014 (Figure 3), whereas both $F_{\text{Eq.}(2)}$ and $F_{\text{Eq.}(4)}$ trended up to a lesser extent and only in the final 2 years of the study period. The average retrospective distribution parameter (D_{retro}) was 0.49 (SD = 0.19; Table 2), or approximately 44% below the D of 0.87.

Mean $F_{\text{Eq.}(2)}$ and mean $F_{\text{Eq.}(4)}$ from the retrospective analysis (Table 2) were less than mean F_{exp} from the historic analysis (Table 1; P = 0.0189 and 0.0339, respectively). Mean F_{exp} and mean F_{retro} from the retrospective analysis (Table 2) did not significantly differ from the mean F_{exp} from the historic analysis (Table 1; P = 0.7298 and 0.1025, respectively).

DISCUSSION

The proportion of the northern Pacific Sardine stock present in the U.S. EEZ is not constant, and the landings by Mexico, the USA, and Canada are not proportional to the potential habitat or biomass of Pacific Sardine in their respective EEZs (Tables 1, 2; Figure 1). The proportion of the northern stock in U.S. waters may be estimated for survey periods if the sampling is sufficiently synoptic, but fishing effort occurs during other periods when the distribution of Pacific Sardine has changed. More importantly, fishing effort and landings by any country are generally not proportional to the Pacific Sardine in that country's EEZ. Therefore, the use of a constant D-value in the HCR will not protect the stock against multinational exploitation (PFMC 1998; Demer and Zwolinski 2014b).

We have shown that the F for Pacific Sardine in 2001–2014 consistently exceeded the U.S. target value and trended up as the stock declined (i.e., 2006–2014). However, using the HCR formulated as the overfishing limit (PFMC 2011), the $F = (L_{Mexico} + H + L_{Canada})/B$ (data from Table 1) only exceeded the F for MSY (F_{MSY} = 0.18; Hill et al. 2011) during 2010–2014. In some years, the foreign landings alone, normalized by $B - C$, exceeded the target F (Tables 1, 2; Figures 2, 3). Additionally, due to uncertainties in the stock assessments, the F and even just the U.S. landings (normalized by $B - C$) exceeded the target F (Table 2; Figure 3). To ensure that the F better approximates the target F, the harvest quota H_y or distribution D_y could be optimized for each year y, with explicit accounting for predicted $L_{foreign,y-1}$, by use of equations (2) and (3) (Demer and Zwolinski 2014b); or refined with a prediction error term using equations (4) and (5). Both approaches will better achieve the target F, and either approach can be applied irrespective of the assumptions made in the assessments and irrespective of the HCR

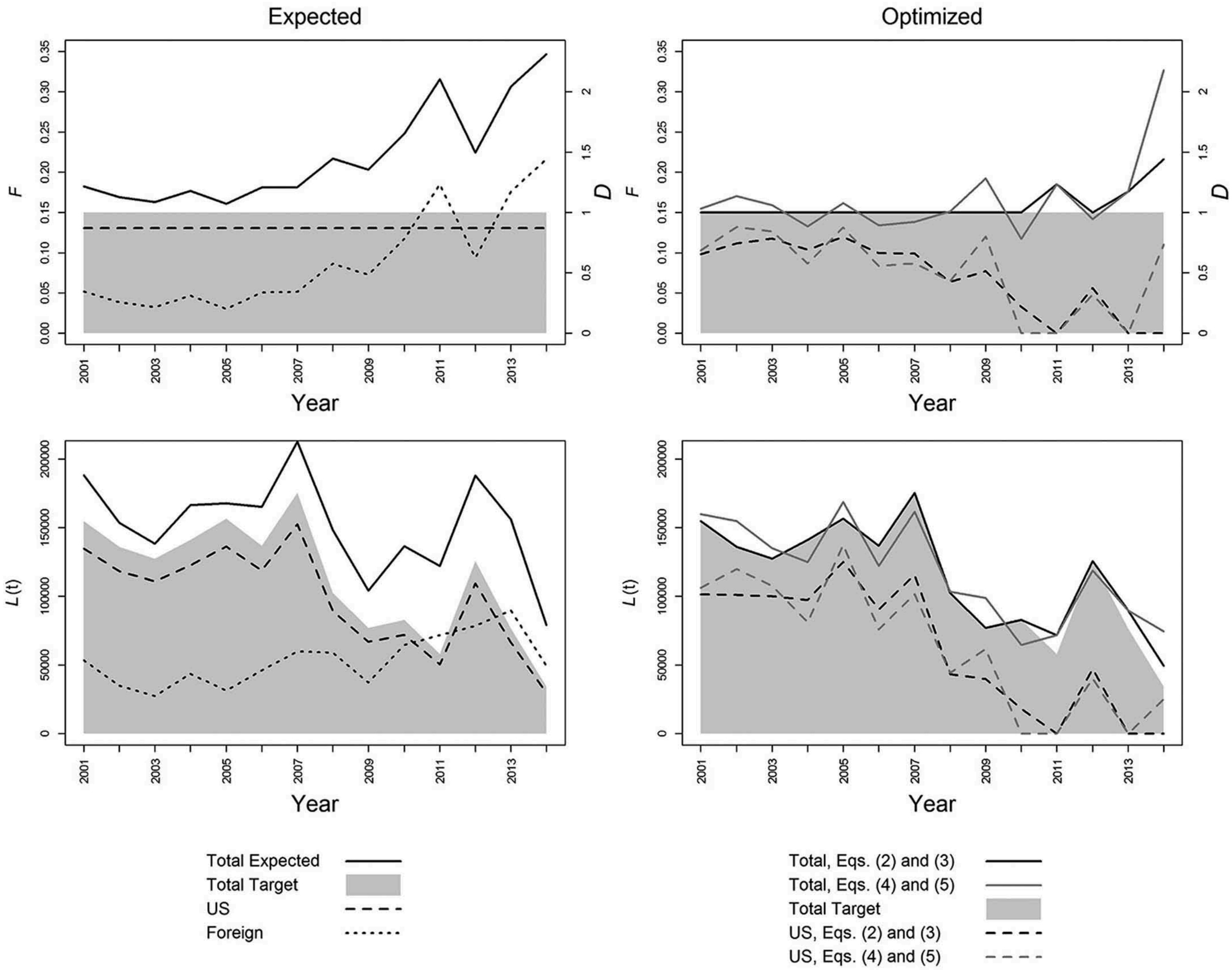

FIGURE 2. Expected fishing fractions for Mexico and Canada ($F_{foreign} = L_{foreign}/[B - C]$; dotted line) and for the USA ($F_{USA} = F \times 0.87$; dashed line) and the expected total fishing fraction ($F_{exp} = \left[H + L_{foreign}\right]/[B - C]$; black line), where B is the assessment-estimated Pacific Sardine biomass that was used to calculate the annual harvest quota (Table 1), H is the U.S. harvest quota, C is the cutoff (C = 150,000 mt), and F is the target total fishing fraction (F = 0.15; top of gray area) of the biomass above the cutoff. Optimized F-values (dashed line) based on the predicted $F_{foreign}$ were used to ensure that F (black and gray lines, respectively) better approximated the target F. Optimized F was calculated as F_{USA} by using equation (2) (black line) and equation (4) (gray line) or equivalently as distribution parameter D by using equation (3) and equation (5), respectively. The lower plots show the same information as the upper plots but are expressed in terms of landings L.

formulation. The refined method may serve to mitigate the effects of error in the predicted foreign landings, but the long-term mean F may exhibit greater variability relative to the original method.

Both $F_{\text{Eq.}(2)}$ and $F_{\text{Eq.}(4)}$ trended upward in the latter 2 years of the study period, although much less so than F_{exp} (Figure 2) or F_{retro} (Figure 3). These trends in $F_{\text{Eq.}(2)}$ and $F_{\text{Eq.}(4)}$ were due to revisions in the assessment-estimated stock biomass, coupled with increased fishing before an abrupt contraction of the Pacific Sardine stock migration. To partially mitigate such potential concurrences, an additional term could be added to the HCR to account for prediction error in the annually assessed B-values, similar to the term that accounted for error in predicted foreign landings. With further studies of the apparent relationships between Pacific Sardine migration, SSB, and oceanographic conditions, the dynamic stock distribution may become more predictable.

Here, we have demonstrated that the present method of using a constant D in the HCR has not effectively maintained a target F, and we have proposed two variants of a method that

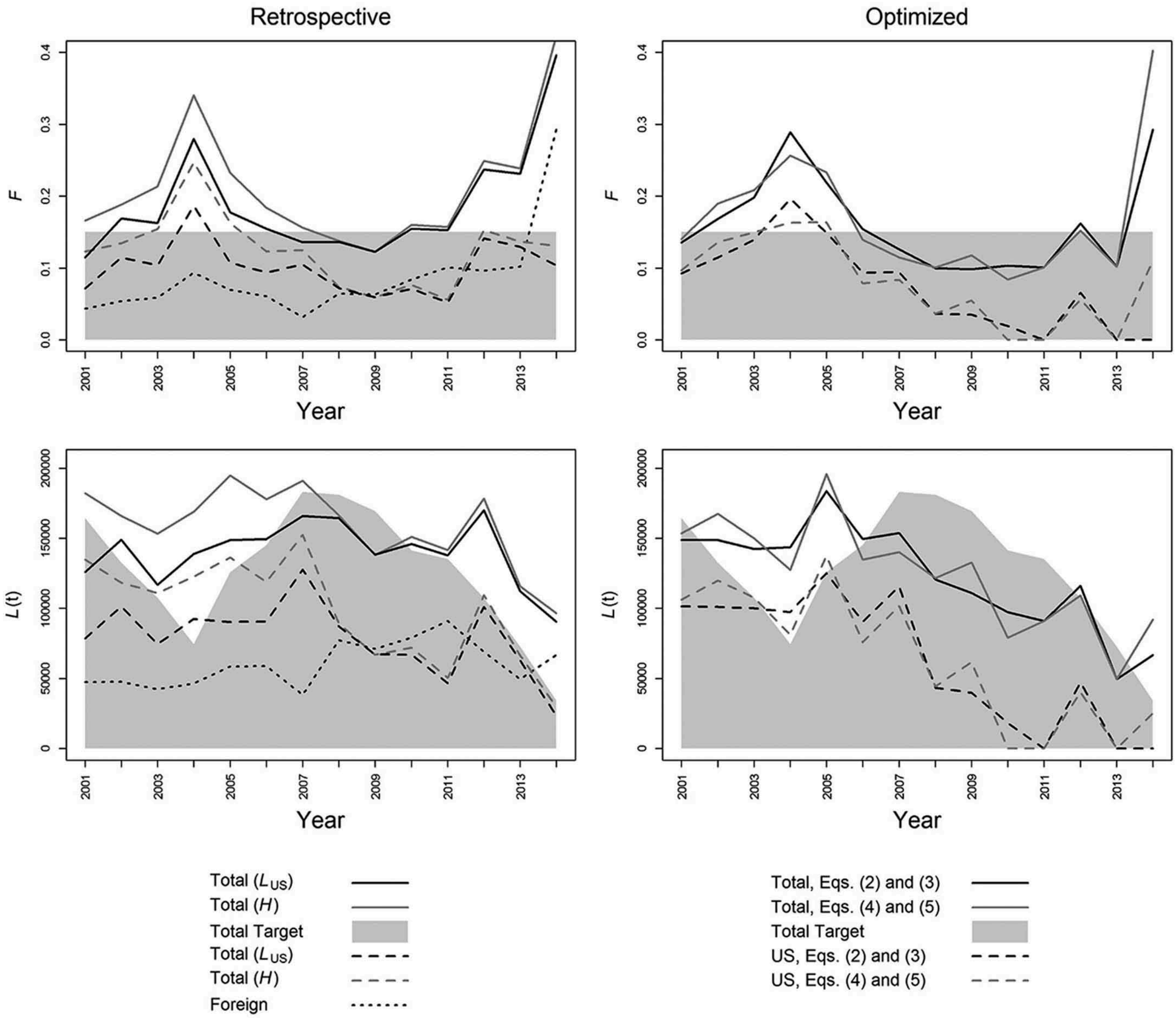

FIGURE 3. Retrospective fishing fractions for Mexico and Canada ($F_{foreign} = L_{foreign}/[B - C]$; black dotted line) and for the USA ($F_{USA} = L_{USA}/[B - C]$, black dashed line; and $F_{USA} = H/[B - C]$, gray dashed line) and the retrospective total fishing fraction ($F_{retro} = [L_{USA} + L_{foreign}]/[B - C]$, black line; and $F_{retro} = [H + L_{foreign}]/[B - C]$, gray line), where B is the Pacific Sardine biomass estimated in the 2013 assessment (Hill 2013; Table 2), H is the U.S. harvest quota from Table 1, C is the cutoff value (C = 150,000 mt), and F is the target total fishing fraction (F = 0.15; top of gray area) of the biomass above the cutoff. Optimized F-values (dashed lines) were based on the foreign landings data (Table 2) and optimized H-values (Table 1) from the 2013 assessment (Hill 2013) and were calculated as F_{USA} via equation (2) (black) or equation (4) (gray), providing a retrospective evaluation of the optimized total fishing fractions (black and gray lines, respectively). The lower plots show the same information as the upper plots but are expressed in terms of landings (L).

could serve to more consistently approach the target F. To our knowledge, the proposed method has not been applied to the management of Pacific Sardine or other CPS. However, logically it should be applicable to the management of any transboundary species, with respect to a target total harvest rate, if the stock is harvested by independent entities and their takes are known or predictable. We recognize that landings are influenced by the fish stock, the environment, markets, geopolitics, and other human factors and that setting harvest quotas while accounting for foreign landings may result in undesirably lower and unstable quotas (PFMC 1998) or else requires, for example, explicit modulation of the target F, use of an alternate HCR formulation (PFMC 2011), or an international management agreement. Without an international management agreement, application of our new method to the harvest guideline with the present F (0.15) would have permitted more U.S. fishing for Pacific Sardine during 2002 and 2005, when the northern stock was large and predominantly located within the U.S. EEZ, but would have curtailed U.S. fishing in all other years of the study. However, the proposed method could be used with the overfishing limit and F_{MSY}, for example, and common goals (e.g., stabilizing socio-economic returns, sustaining exploitation rates, and preserving biodiversity) could motivate an international management approach to cooperatively optimize quotas with respect to a desirable total harvest rate.

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