REVISED PACIFIC SARDINE REBUILDING PLAN

INCLUDING REBUILDING PLAN SPECIFICATIONS, DRAFT ENVIRONMENTAL ASSESSMENT, AND MAGNUSON-STEVENS FISHERY CONSERVATION AND MANAGEMENT ACT ANALYSIS

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LIST OF ACRONYMS AND ABBREVIATIONS

ABC	acceptable biological catch
ACL	annual catch limit
ACT	annual catch target
AM	accountability measure
CalCOFI	California Cooperative Oceanic Fisheries Investigations
CPS	coastal pelagic species
CCE	California current ecosystem
CPFV	California Passenger Fishing Vessel
CPSAS	Coastal Pelagic Species Advisory Subpanel
CPSMT	Coastal Pelagic Species Management Team
DPS	distinct population segment
EA	Environmental Assessment
EEZ	exclusive economic zone (from 3-200 miles from shore)
ESA	Endangered Species Act
FMP	fishery management plan
FONSI	Finding of No Significant Impacts
HCR	harvest control rule
HG	harvest guideline
LE	limited entry
MBTA	Migratory Bird Treaty Act
MMPA	Marine Mammal Protection Act
MSA	Magnuson-Stevens Fishery Conservation and Management Act
MSST	minimum stock size threshold
MSY	maximum sustainable yield
NEPA	National Environmental Policy Act
NS1	National Standard 1
NSP	northern subpopulation
NMFS	National Marine Fisheries Service
OFL	overfishing limit
PacFIN	Pacific Fisheries Information Network
SSC	Scientific and Statistical Committee
SSP	southern subpopulation
SWFSC	Southwest Fisheries Science Center
U & A	Usual and Accustomed Area (Tribal)

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1 INTRODUCTION

NOAA's National Marine Fisheries Service (NMFS) declared the northern subpopulation (NSP) of Pacific sardine (Pacific sardine, *Sardinops sagax*) overfished in June 2019. This determination was based on the results of an April 2019 stock assessment (Hill et al., 2019), which indicated that the biomass of Pacific sardine had dropped below the overfished threshold of 50,000 metric tons (mt), as defined in the Coastal Pelagic Species (CPS) Fishery Management Plan (FMP). NMFS notified the Pacific Fishery Management Council (Council) about the overfished declaration on July 9, 2019. The Magnuson-Stevens Fishery Conservation and Management Act (MSA) requires that NMFS and the Council prepare and implement a rebuilding plan within 2 years of NMFS' overfished notification to the Council that specifies a rebuilding timeframe (T_{TARGET}) within 10 years, except where the biology of the stock or other environmental conditions dictate otherwise (see MSA Section 304(e)). The Council adopted a rebuilding plan (Amendment 18 to the CPS FMP) on September 16, 2020. The plan was approved by NMFS on June 14, 2021.

Amendment 18 was challenged in the U.S. District Court for the Northern District of California (Court). The Court issued a decision in the matter on April 22, 2024, holding that NMFS set a rebuilding target that does not violate the MSA, but that NMFS did violate the MSA by adopting a rebuilding plan that relies on conservation and management measures, rather than acceptable biological catch (ABC)/annual catch limits (ACLs) to rebuild the population and by failing to demonstrate that Amendment 18 will prevent overfishing. The Court also held that the associated Environmental Assessment (EA) violated the National Environmental Policy Act (NEPA) due to NMFS' reliance on flawed assumptions in comparing alternatives, and by failing to take a hard look at impacts to the endangered humpback whale and its critical habitat. On June 28, 2024, the Court issued an order on remedy, vacating the portions of Amendment 18 that it found invalid and remanding the remainder to NMFS without vacatur. The Court also vacated the EA in its entirety. The Court ordered NMFS to prepare a compliant rebuilding plan and EA by June 1, 2025. Because the Court only vacated portions of Amendment 18, the entire amendment and related analysis does not need to be abandoned. Rather, the revised Pacific sardine rebuilding plan and related EA can closely follow Amendment 18, making revisions as necessary to respond to the Court's order. In response to the Court order, this document analyzes proposed alternatives for the revised rebuilding plan that rely on ABC/ACLs to achieve the rebuilding target for Pacific sardine. In addition to considering alternatives for catch limits that will rebuild the Pacific sardine population within the statutory timeframe, the Council also considered whether T_{TARGET} had changed, given their final preferred rebuilding strategy.

As part of its finding that Amendment 18 will not prevent overfishing, the Court found that NMFS failed to demonstrate that it relied on the best scientific information available to set OFLs. Specifically, the Court found insufficient support for the use of the California Cooperative Oceanic Fisheries Investigations (CalCOFI) temperature index to calculate E_{MSY}. E_{MSY} is a parameter in the OFL and ABC harvest control rules, which were part of the FMP before Amendment 18 was adopted and are described in Section 4.6.4 of the FMP. The harvest control rules (HCRs) do not, however, mandate the use of a CalCOFI-based E_{MSY}, and Amendment 18 did not adopt its use. The methodology for determining E_{MSY} used in the HCRs to set harvest specifications is dependent upon the annual recommendation of the Council's Scientific and Statistical Committee (SSC). NMFS plans to review the CalCOFI temperature index before implementing harvest specifications for the 2025–2026 fishing year; however, that review is not a necessary part of the analysis for adopting a revised rebuilding plan and is therefore not discussed further in this EA.

This document is intended to meet the analytical needs and statutory requirements associated with NEPA and MSA. An EA/MSA analysis is a joint NEPA and MSA document providing assessments of the environmental impacts of a proposed action and its reasonable alternatives (the EA), and analysis of how the alternatives align with the 10 National Standards in the MSA (MSA analysis). An EA/MSA analysis is a standard document produced by the Council and the NMFS West Coast Region to provide the analytical background for decision-making.

1.1 PURPOSE AND NEED

The purpose of the proposed action is to develop a revised rebuilding plan for Pacific sardine. The rebuilding plan is needed to comply with MSA requirements to rebuild stocks that have been declared overfished.

1.2 HISTORY OF THIS ACTION

NMFS declared the NSP of the Pacific sardine overfished in June 2019. The Council considered a range of rebuilding alternatives at its June 2020 meeting and provided guidance to its Coastal Pelagic Species Management Team (CPSMT) on a final set of alternatives to be analyzed. The CPSMT then compiled a preliminary EA that was considered by the Council, which took final action at its September 2020 meeting. In June 2021, NMFS approved the plan (Amendment 18 to the CPS FMP; 86 FR 33142, June 24, 2021).

Amendment 18 set a rebuilding target for Pacific sardine at 150,000 mt age 1+ biomass (hereafter referred to as “stock biomass” or “biomass”). The rebuilding plan maintained “Status Quo” management processes including HCRs and other FMP provisions already in place for Pacific sardine. Per the requirements of the CPS FMP, the primary directed fishery for Pacific sardine was first closed in 2015 when the stock dropped below the 150,000-mt CUTOFF value, automatically triggering a preemptive closure of the fishery (see Section 4.6.1 of CPS FMP). In addition, per the requirements in the CPS FMP, incidental landing limits of Pacific sardine in other CPS fisheries were reduced from 40 percent by weight per landing to 20 percent (see Section 5.1.1 of CPS FMP) in 2019 when the stock’s biomass dropped below the 50,000-mt overfished threshold (also referred to as the minimum stock size threshold, MSST), further limiting the allowable harvest of Pacific sardine. Although this decrease in biomass below 50,000 mt triggered the requirement to declare the stock overfished, overfishing has never occurred for this stock, as Pacific sardine catch has been well below both the ABC and OFL since and before the closure of the primary directed fishery.

Amendment 18 was challenged in the U.S. District Court for the Northern District of California. The Court issued a decision in the matter on April 22, 2024, holding that NMFS set a rebuilding target (age 1+ biomass of 150,000 mt) that does not violate the MSA, but that NMFS did violate the MSA by adopting a rebuilding plan that relies on conservation and management measures, rather than ABCs/ACLs to rebuild the population and by failing to demonstrate that Amendment 18 will prevent overfishing. In order to comply with the Court’s June 28, 2024 order on remedy and implement a compliant rebuilding plan by June 1, 2025, the Council needed to take final action at the November 2024 meeting to make modifications to the rebuilding plan. The revised rebuilding plan builds off the Amendment 18 rebuilding plan and its supporting analysis. Due to the limited scope of the revisions and precedence of the Amendment 18 analysis, it was possible for the Council to take final action in this compressed timeline. The Council considered a range of proposed alternatives at their November 2024 meeting and selected a final preferred alternative and related T_{TARGET} on November 18, 2024.

1.3 ACTION AREA

The proposed action area is inclusive of and limited to the United States West Coast Exclusive Economic Zone (EEZ), from 3 to 200 nautical miles offshore of Washington, Oregon, and California. The range of Pacific sardines can extend beyond the U.S. West Coast EEZ; however, U.S. jurisdiction and management for CPS stocks does not extend beyond the EEZ.

1.4 CURRENT MANAGEMENT

1.4.1 REBUILDING PLAN SPECIFICATIONS (Implemented in Amendment 18)

NMFS' National Standard (NS) 1 guidelines provide direction on determining certain rebuilding reference points in order to specify T_{TARGET}, including a target rebuilt biomass level, T_{MIN} (the minimum time to rebuild the stock assuming zero fishing morality), and T_{MAX} (the maximum time allowable for rebuilding) (see 50 CFR 600.310(j)(3)). Amendment 18 to the CPS FMP established the rebuilding target at 150,000 mt age 1+ Pacific sardine biomass, which aligned with the CUTOFF threshold already defined in the CPS FMP. The Court determined that the rebuilding target adopted in Amendment 18 was based on the best available science. T_{MIN} and T_{MAX} were determined via the rebuilding analysis, documented in Hill et al. (2020); available in Appendices B and C.

These rebuilding reference points, which are unchanged by this proposed action, are as follows:

$$T_{MIN} = 12 \text{ years}$$

$$T_{MAX} = 24 \text{ years}$$

Rebuilt biomass = 150,000 mt age 1+ biomass

Additionally, rebuilding plans must contain a T_{TARGET}, which is defined in NS 1 guidelines as the specified time period for rebuilding a stock that is considered to be as short a time as possible, taking into account the factors described in 50 CFR 600.310(j)(3)(i). T_{TARGET} shall not exceed T_{MAX}. In 2020, the Council recommended status quo (Alternative 1) as its final preferred alternative and an associated T_{TARGET} of 14 years to rebuild to the target biomass level of 150,000 mt age 1+ Pacific sardine biomass. This T_{TARGET} was in the context of a T_{MIN} of 12 years and a T_{MAX} of 24 years and was determined to be the shortest time possible to rebuild the stock, taking into account the biology of the stock, the needs of fishing communities, and the interaction of the stock within the marine ecosystem. In consideration of this revised rebuilding plan, the Council considered any changes in the associated T_{TARGET}.

1.4.2 SARDINE MANAGEMENT

Management of Pacific sardine is described in Section 4.6.4 of the CPS FMP and at 50 CFR Part 660 Subpart I. According to the FMP, a rebuilding plan may be implicit in maintaining "status quo" management due to the closure of the fishery and additional restrictions on incidental harvest.

Harvest control rules (HCRs) in the CPS FMP are used to calculate the OFL and ABC for Pacific sardine annually based on stock assessments and estimates of age 1+ biomass. The ABC HCR accounts for scientific uncertainty in the estimate of OFL and any other scientific uncertainty, and thus represents a level of harvest that ensures overfishing will not occur.

The Pacific sardine HCRs include the following:

$$OFL = Biomass * E_{MSY} * Distribution$$

$$ABC = Biomass * BUFFER * E_{MSY} * Distribution$$

ACL = LESS THAN OR EQUAL to ABC

ACT = OPTIONAL; LESS THAN ACL

- BIOMASS is the age 1+ biomass of the Pacific sardine estimated in annual stock assessments.
- E_{MSY} is an estimate of the exploitation rate at maximum sustainable yield, and the value used for it is determined annually based on recommendations from the Council's SSC.
- DISTRIBUTION is defined as 0.87 and is intended on average to account for the portion of the NSP of Pacific sardine in U.S. waters, recognizing that Pacific sardine ranges beyond U.S. waters and is therefore subject to harvest by foreign fisheries.
- BUFFER is the percentage reduction of the OFL as determined by the SSC's evaluation of scientific uncertainty (sigma) and the Council's risk policy (P*).

The management measures described in the CPS FMP include the following:

- The primary directed fishery for Pacific sardine is closed when the age 1+ biomass is at or below 150,000 mt.
- When the primary directed fishery is closed, minor directed fishing for Pacific sardine may not exceed 1 mt per day per vessel or person, and is limited to 1 fishing trip per day by any vessel.
- Other CPS fisheries (e.g., Pacific mackerel) are restricted to an incidental allowance of 20 percent or less when the age 1+ biomass of Pacific sardine is at or below 50,000 mt (MSST). The incidental allowance is restricted to 45 percent or less when the age 1+ biomass is above MSST, but below 150,000 mt (CUTOFF).

In addition to the HCRs and management measures prescribed by the CPS FMP, through the annual harvest specifications process, the Council can recommend various additional management and accountability measures to limit Pacific sardine harvest, if warranted. For example, for the 2022–2023 fishing year, the Council recommended and NMFS implemented an annual catch target (ACT) of 3,800 mt where, if attained, all CPS fisheries would be restricted to a 1 mt per-trip limit of Pacific sardine. For the 2023–2024 fishing year, the Council recommended and NMFS implemented an accountability measure that would limit the live bait fishery to 1 mt of Pacific sardine per trip if landings in the live bait fishery attained 2,500 mt. Since Pacific sardine was declared overfished, the fisheries have not harvested Pacific sardine at levels that would have triggered these accountability measures (see Table 1), reflecting the relatively conservative nature of the fishery, but these measures act as safeguards should fishery dynamics shift towards increased harvest.

Table 1. Landings and reference points since the northern subpopulation of Pacific sardine was declared overfished. Data retrieved on November 7, 2024 from the PacFIN SAFE Portal.

Fishing Year	Landings (mt)	ABC (mt)	OFL (mt)	ACL (mt)	ACT (mt)
2019–2020	2,085	4,514	5,816	4,514	4,000
2020–2021	2,498	4,288	5,525	4,288	4,000
2021–2022*	1,772	3,329	5,525	3,329	3,000
2022–2023	1,619	4,274	5,506	4,274	3,800
2023–2024	1,774	3,953	5,506	3,600	3,600

* Year Amendment 18 rebuilding plan was first implemented

2 DESCRIPTION OF ALTERNATIVES

The scope of alternatives for potential consideration in the revision of the Pacific sardine rebuilding plan was narrow because the entirety of the Amendment 18 rebuilding plan was not vacated. The CPS FMP already dictates a management framework that is precautionary, including management actions that would typically be implemented under a rebuilding plan to minimize fishing mortality on an overfished stock, and is designed to ensure equitable opportunity across the fishing sectors (see Section 1.4).

Therefore, the six alternatives presented below are based on and include those existing elements of the CPS FMP that apply to the harvest of Pacific sardine, as well as the elements of the Amendment 18 rebuilding plan that were not invalidated by the court:

- The primary directed fishery for Pacific sardine is closed when the age 1+ biomass is less than 150,000 mt.
- The rebuilding target is 150,000 mt age 1+ biomass.
- The rebuilding reference points are T_{MAX} = 12 years and T_{MIN} = 24 years.
- The OFL and ABC harvest control rules calculate the OFL and ABC annually based on an estimate of that year's age 1+ biomass from stock assessments and recommendations on those values from the Council's SSC.
- Under any alternative, the ACL cannot exceed the ABC.

Alternatives 1–3 were first considered in the Amendment 18 rebuilding plan, and Alternatives 4–6 were developed based on analysis that occurred in support of the Amendment 18 rebuilding plan, but are responsive to the Court's orders. The primary change from Amendment 18 is the addition of reasonable alternatives that would implement specific ACLs to constrain harvest to the amounts analyzed in support of the Amendment 18 rebuilding plan.

Alternative 1 represents "No Action," maintaining status quo management and therefore the implicit rebuilding measures and catch restrictions that are already in effect per the CPS FMP. Alternatives 2–6 present ACLs that would require NMFS to adopt a revised rebuilding plan and are therefore action alternatives. Alternative 2 would set the U.S. Pacific sardine quota at zero, thereby prohibiting landings of Pacific sardine in all CPS and non-CPS fisheries. Alternative 3 would set an ACL at five percent of the biomass for that year. Alternative 4 would set a constant catch ACL of 2,200 mt. Alternative 5 would set a modified constant catch ACL slightly greater than the highest landings over the past 5 years. Alternative 6 would set ACLs based on stock status (at/below or above 50,000 mt; i.e., overfished or not overfished).

Under any of the ACLs presented under these alternatives (with the exception of Alternative 2, Zero U.S. Harvest), the Council could choose to recommend, through the annual harvest specifications process, that NMFS implement additional accountability measures such as a more precautionary ACT that, if attained, would result in reduced trip limits for the live bait and CPS and non-CPS incidental fisheries until the ACL is reached.

NMFS may only implement fishery management regulations in Federal waters (i.e., from 3 to 200 nautical miles offshore). The analysis of the alternatives below assumes the states would adopt complementary regulations for state waters, as has been common practice for CPS fisheries off West Coast states.

2.1 ALTERNATIVE 1 – NO ACTION

Alternative 1 (No Action) would maintain the conservation and management measures in the CPS FMP adopted under the Amendment 18 rebuilding plan, which are the "status quo" management processes, HCRs, and other provisions already in place for Pacific sardine (see Section 1.4). According to the FMP, a rebuilding plan may be implicit in maintaining "status quo" management due to the closure of the fishery and additional restrictions on incidental harvest. The FMP dictates the prohibition of the primary directed fishery for Pacific sardine when the biomass is at or below 150,000 mt, and the automatic reduction in incidental allowances in other CPS fisheries when the biomass is at or below 50,000 mt.

The Council's existing annual harvest specifications process would also be maintained, calculating the annual OFL and ABC based on an estimate of biomass from stock assessments and recommendations on those values from the Council's SSC. The ABC HCR accounts for scientific uncertainty in the estimate of OFL and any other scientific uncertainty, and thus represents a level of harvest that ensures overfishing will not occur. This alternative would not set a specific ACL to support rebuilding, but rather annually set an ACL at or below the ABC to account for any management uncertainty.

2.2 ALTERNATIVE 2 – ZERO (U.S.) HARVEST

Alternative 2 (Zero U.S. Harvest) would adopt a revised rebuilding plan using a U.S. zero-harvest approach. This alternative was considered in Amendment 18 for modeling and analysis purposes to aid in determining a T_{MIN} for a rebuilding timeline. Per NMFS' NS 1 guidelines, T_{MIN} is the expected time it would take to rebuild the stock in the absence of fishing (see 50 CFR 600.310(j)(3)). This alternative is primarily considered here for a comparison between T_{MIN} and the rebuilding timelines of the other reasonable alternatives.

A U.S. zero-harvest approach would entail a complete closure of the remaining fisheries that target Pacific sardine, including the live bait and minor directed fisheries, both of which are small sectors but dependent on some level of directed Pacific sardine harvest. Alternative 2 would also eliminate incidental landing allowances in other CPS and non-CPS fisheries, including Pacific mackerel, market squid, northern anchovy, and Pacific whiting.

Completely avoiding incidental catch of Pacific sardine is difficult in these fisheries; therefore, eliminating incidental landings in these fisheries would likely force their complete closure or result in a high level of discarding Pacific sardine bycatch at sea. NMFS only has authority to implement Alternative 2 in Federal waters (i.e., 3 to 200 nautical miles from shore). Fully implementing Alternative 2 would require additional state regulations to close fishing for Pacific sardine in state waters.

Specifying how this alternative could be implemented to reduce Pacific sardine catch to zero is also difficult (i.e., what specific regulatory restrictions could be adopted, such as closure of minor directed fisheries and elimination of incidental landing allowances in all fisheries). The ACL would be set to zero under this alternative, and would require the development of additional management measures. Thus, in practice, fully implementing this alternative would likely be difficult from a fishery management perspective. In addition, tribal treaty fisheries are established via Government-to-Government consultation and could potentially include Pacific sardine harvest.

2.3 ALTERNATIVE 3 – FIVE PERCENT FIXED U.S. HARVEST RATE

Alternative 3 would revise the rebuilding plan to set the ACL at 5 percent of estimated age 1+ biomass for that year, or the calculated ABC, whichever is less. This alternative was considered in Amendment 18 to represent a harvest level between Alternative 1 (No Action/Status Quo) and Alternative 2 (Zero U.S. Harvest) to explore the differences in rebuilding timelines of a reduced harvest level.

The ACL under this alternative represents a lower allowable harvest than landings every year since the implementation of Amendment 18 (see Table 2).

2.4 ALTERNATIVE 4 – CONSTANT CATCH

Under Alternative 4, the ACL would be set at 2,200 mt or the calculated ABC, whichever is less. This alternative was modeled in the Amendment 18 rebuilding analysis to represent the average catch of 2,200 mt (average of 2015–2020 catches) in an attempt to better understand the true rebuilding timeline under status quo management. Inherent to an average catch value, however, is that actual catch is more or less than the average on any given year. This alternative would restrict the fishery to a maximum catch of 2,200 mt.

2.5 ALTERNATIVE 5 – MODIFIED CONSTANT CATCH

Under Alternative 5, the ACL would be set at a value slightly higher than the highest landings reported in 2019–2024, or the calculated ABC, whichever is less.

Based on historical catch data (see Table 1), which defines the current level of industry operation, this alternative would allow the interannual flexibility and opportunity that Alternative 4 (a static ACL of 2,200 mt) might not.

A buffer was added to the highest annual catch since 2015 (landings in the 2020–2021 fishing year) to propose a modified ACL.[1] A modified constant catch harvest allows for a buffer above 2015–2020 average annual catch (i.e., 2,200 mt, Alternative 4), while limiting the ability of ACLs to increase with biomass as they would under a five percent harvest rate (Alternatives 3 and 6). This alternative would allow for rebuilding while providing for those years when, while the primary directed fishery remains closed, the live bait fishery and the other CPS fisheries that incidentally catch sardine need flexibility to adapt to changes in the environment, stock dynamics, incidental encounter rates, or market/economy. When the Council chose to recommend status quo for Amendment 18, the primary reasoning was to allow for the interannual variability in landings typically seen in the fisheries that incidentally catch sardine due to different mixing rates among years and seen in the live bait fishery due to changing market demand. Alternative 5 seeks to meet this goal by buffering the average catch and allowing those annual fluctuations in catch levels.

[1] The ACL for Alternative 5 was proposed in the Council's November 2024 Briefing Book as 3,200 mt based on a maximum landings value of 2,865 mt in 2020–2021 fishing year. This landings value was corrected to 2,498 mt in Agenda Item J.2, Supplemental Attachment 4, November 2024. The CPSMT proposed a modified alternative (5-1) that would set the ACL at 2,800 mt, based on the corrected data (see Agenda Item J.2 Supplemental Attachment 4). For the analysis in this document, the 3,200 mt value is presented as Alternative 5 in data tables as it was to the Council. The impacts to the target resource, ecosystem, and fishing industry under either modified constant catch value (i.e., 3,200 mt or 2,800 mt) are expected to be the same.

2.6 ALTERNATIVE 6 – MIXED RATE U.S. HARVEST (Final Preferred Alternative)

Under Alternative 6, the Final Preferred Alternative (FPA), an ACL would be set conditional upon certain tiered biomass levels, allowing the ACL to adjust based on the status of the stock. This is a modified version of Alternative 3 to address concerns that the static five percent harvest rate would result in negative economic consequences to the fleet at lower biomass levels.

UNDER 50,000 MT (Overfished Status)

If the age 1+ biomass is 50,000 mt (minimum stock size threshold) or less in a given fishing year, the ACL for that year would be set at 2,200 mt or the calculated ABC, whichever is less.

OVER 50,000 MT (Rebuilding Status)

If the age 1+ biomass is greater than 50,000 mt (minimum stock size threshold) but less than 150,000 mt (rebuilding target) in a given fishing year, the ACL would be set at five percent of the age 1+ biomass for that year or the calculated ABC, whichever is less.

Alternative 6, which combines Alternatives 3 and 4, was added to the range of alternatives to address the economic restrictions of Alternative 3 under low biomass levels and to provide more flexibility than the constant catch ACL of Alternative 4 may permit under higher biomass levels. As mentioned above, when the Council recommended Alternative 1, Status Quo, for Amendment 18, the primary reasoning was to allow for the interannual variability in the fisheries that incidentally catch sardine due to different mixing rates among years and a changing market demand in the live bait fishery. Therefore, Alternative 6 factors in some of the economic considerations the Council used in the rebuilding plan under Amendment 18. Like Alternative 3, Alternative 6 may provide additional flexibility to land more than 2,200 mt if incidental encounter rates increase as the stock biomass increases above 50,000 mt. Like Alternative 4, Alternative 6 would allow for up to a 2,200 mt constant catch ACL, representing 2015–2020 average annual landings, to avoid unnecessary restriction of economically important sectors and/or reduce the potential for discard at sea when the age 1+ biomass is below 50,000 mt.

Table 2. Annual Pacific sardine harvest specifications and landings from fishing years following closure of the primary directed fishery, and retrospective ACLs under each proposed alternative. Landings information is sourced from the Benchmark Stock Assessment for the 2014–2015 through the 2018–2019 fishing years and from the PacFIN data portal for the 2019–2020 through 2023–2024 fishing years. All weight values in mt.

Fishing Year	Biomass	OFL	ABC	Actual ACL	ACT	Landings	ACL under Alt 3	ACL under Alt 4	ACL under Alt 5	ACL under Alt 6 (*FPA*)
2014–2015	369,506	39,210	35,792	23,293 28,646*	23,293	23,293	18,475	2,200	23,293 28,646*	23,293 28,646*
2015–2016	96,688	13,227	12,074	7,000	4,000	1,919	4,834	2,200	3,200	4,834
2016–2017	106,137	23,085	19,236	8,000	5,000	1,885	5,307	2,200	3,200	5,307
2017–2018	86,586	16,957	15,479	8,000	-	1,775	4,329	2,200	3,200	4,329
2018–2019	52,065	11,324	9,436	7,000	-	2,278	2,603	2,200	3,200	2,603
2019–2020	27,547	5,816	4,514	4,514	4,000	2,085	1,377	2,200	3,200	2,200
2020–2021	28,276	5,525	4,288	4,288	4,000	2,498	1,413	2,200	3,200	2,200
2021–2022**	28,276	5,525	3,329	3,329	3,000	1,772	1,413	2,200	3,200	2,200
2022–2023**	27,369	5,506	4,274	4,274	3,800	1,619	1,368	2,200	3,200	2,200
2023–2024**	27,369	5,506	3,953	3,953	3,600	1,774	1,368	2,200	3,200	2,200
2024–2025**	58,614	8,312	6,005	6,005	5,500	-	2,930	2,200	3,200	2,931

* Closure of the directed fishery

** Implementation of Amendment 18 rebuilding plan

2.7 FINAL PREFERRED ALTERNATIVE

The Council recommended Alternative 6 – Mixed Rate U.S. Harvest – as their Final Preferred Alternative (FPA). Under the FPA, ACLs will be set as described in Section 2.6. As described under the industry recommendation in the CPS Advisory Subpanel (CPSAS) report (see Agenda Item J.2.a Supplemental CPSAS Report 1, November 2024) and the analysis presented in the November 2024 briefing book materials (Agenda Item J.2 Attachment 1, Supplemental Attachment 3, and Supplemental Attachment 4), Alternative 6 is expected to rebuild the stock in as short of time as possible, while addressing the needs of fishing communities. Alternative 6 is expected to provide stability for ongoing live bait, minor directed, and incidental fisheries at low stock biomass levels, while allowing flexibility for the ACL to increase if and when stock biomass increases. Given this FPA, the Council selected a resulting T_{TARGET} of 17 years to reach the target rebuilding biomass level of 150,000 metric tons (mt) age 1+ Pacific sardine biomass. This T_{TARGET} is in the context of a T_{MIN} of 12 years and a T_{MAX} of 24 years and was determined to be the shortest time possible to rebuild the stock, taking into account the biology of the stock, the needs of fishing communities, and the interaction of the stock within the marine ecosystem. As Alternative 6 represents a combination of Alternatives 3 and 4, which were modeled to rebuild within 16 and 17 years, respectively, it is also expected that Alternative 6 will rebuild within 17 years. While the Council could have shortened T_{TARGET} from the model outputs, as was done under Amendment 18, the Council determined that a T_{TARGET} of 17 years would adequately account for any uncertainty and represent a conservative estimate of the expected time to rebuild.

2.8 COMPARISON OF ALTERNATIVES

Table 3. Comparison of Range of Alternatives

	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5	Alternative 6 *(FPA)*
	No Action	Zero U.S. Harvest	Five Percent Fixed U.S. Harvest Rate	Constant Catch	Modified Constant Catch	Mixed Rate U.S. Harvest
Description	Amendment 18 rebuilding plan, management practices, HCRs, and other FMP provisions in place as of November 2024	Complete closure of fisheries targeting sardine and elimination of incidental landing in CPS and non-CPS fisheries	Set the ACL to the lesser of ABC or 5% of total age 1+ biomass for that year	Set the ACL to the lesser of ABC or 2,200 mt	Set the ACL to the lesser of ABC or 3,200 mt	Biomass < 50,000 mt: set the ACL to the lesser of ABC or 2,200 mt Biomass > 50,000 mt: set the ACL to the lesser of ABC or 5% of total age 1+ biomass for that year
ACL	Determined Annually	0	5% biomass (1+)	2,200 mt	3,200 mt	Biomass < 50,000 mt: 2,200 mt Biomass > 50,000 mt: 5% biomass (1+)
Chance of Rebuilding by T_{MAX}	< 50%	> 50%	> 50%	> 50%	> 50%	> 50%
Years to Rebuild	Not within modeled timeframe	12 years	< 16 years	< 17 years	< 17 years	< 17 years

3 AFFECTED ENVIRONMENT AND ANALYSIS OF ALTERNATIVES

This section first provides a description of the biological modeling conducted to examine potential rebuilding timelines and management strategies and explains how the model results were used as one aspect of analysis for each management alternative. Then, this section describes each component of the Affected Environment and analyzes how the rebuilding timeline of each management alternative may impact those components. Components of the Affected Environment include the target species (northern subpopulation of Pacific sardine), species in the ecosystem that prey on sardine, and fishing industry—any of which could potentially be affected by the time it takes for the sardine population to rebuild.

As there are no proposed changes to fishing gear types, fishing areas and seasons, or other key aspects of how the affected fisheries are or will be prosecuted, and because the primary directed fishery will remain closed during the entire rebuilding period, the scope of the affected environment analysis is narrow. The analysis below includes the impacts to Pacific sardine (target species), including their role in the ecosystem as prey for a variety of other fish, marine mammals, and seabirds, and to relevant CPS and non-CPS fishing industries. For example, no effects are presumed for non-target or prohibited species or for the habitat of Pacific sardine or other Council-managed fish stocks, as this action, as noted above, would not change the fact that the primary directed sardine fishery is closed and will remain closed for the duration of the rebuilding period. Additionally, although this action will set annual limits on the incidental catch and the allowed small and artisanal directed catch (outside of the primary sardine fishery), operational aspects of those fisheries will not change.

The analyses take into consideration more than just the results of the biological modeling work in the Hill et al. (2020) Pacific sardine rebuilding analysis and its addendum (see Appendices B and C); it was also necessary to rely on what is known about the basic biology and life history of Pacific sardine, including estimates of its large population fluctuations over thousands of years, and the history of the Pacific sardine fishery on the west coast of North America.

Impacts analyzed include effects on the environment that are direct, indirect, or cumulative. Direct effects are caused by the action itself and occur at the same time and place. Indirect effects are caused by the action and are later in time or farther removed in distance, but are still reasonably foreseeable. Cumulative effects are those impacts on the environment that result from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions, regardless of what agency (Federal or non-Federal) or person undertakes such other actions. Cumulative impacts can result from individually minor, but collectively significant actions taking place over a period of time.

3.1 MODELING DESCRIPTION AND USE IN ANALYSIS OF ALTERNATIVES

The “Rebuilder” modeling platform (hereafter referred to as the “Rebuilder tool” or “the model”) is an age-structured population dynamics simulator that projects a fish population forward in time, accounting for recruitment, growth, natural mortality, and fishing mortality. The Rebuilder tool was originally designed to analyze rebuilding groundfish stocks (Punt, 2012) but was revised to allow for rebuilding projections based on Pacific sardine HCRs (Punt et al., 2016). These revisions included simulating the Pacific sardine ABC HCR in conjunction with accounting for catch outside the United States (i.e., Mexican catch). The modeling was performed by a team from NMFS’ Southwest Fisheries Science Center (SWFSC), and details of the methods, model inputs, and results were presented in Hill et al. (2020), which is available in

APPENDIX B. The intent of this modeling was, in part, to help guide the analysis of management alternatives for rebuilding Pacific sardine; however, since Pacific sardine recruitment and productivity are largely driven by environmental conditions, which cannot be accurately predicted, it was expected that the modeling results would have limitations in informing realistic rebuilding timelines. These limitations of the Rebuilder tool have not changed since the implementation of Amendment 18. Additionally, because the analysis provided in Hill et al. (2020) covered a range of harvest scenarios, it was determined that it was not necessary to conduct new modeling in order to consider new alternatives within this range for a revised rebuilding plan.

For Alternatives 1–3, the Rebuilder tool was used to calculate: (1) the probabilities (at least 50 percent chance) of rebuilding the NSP of Pacific sardine stock to a modeled SB_{MSY} (spawning stock biomass at maximum sustainable yield (MSY)) and the target rebuilding biomass level (expressed in terms of age 1+ biomass), (2) median spawning stock values, and (3) median catch values. These values were calculated based on two different time periods that represent moderate and low Pacific sardine productivity and two different levels of potential harvest by Mexico (Tables 6–13 in APPENDIX B). The Rebuilder tool used data inputs from the 2020 benchmark stock assessment for the NSP of Pacific sardine that covers the time period 2005–2020 (Kuriyama et al., 2020). The two modeled time periods, 2005–2018 and 2010–2018, were chosen to represent different levels of potential future productivity (i.e., recruitment scenarios, also referred to as states of nature) for this stock. The two Mexican harvest scenarios included a fixed tonnage (6,044 mt) and a fixed rate (9.9 percent of Pacific sardine biomass).

The Rebuilder tool was also used to estimate virgin spawning biomass (SB_0, i.e., the average spawning biomass that the stock is capable of attaining in the absence of fishing) for the two different time periods, 2005–2018 and 2010–2018. The resulting average SB_0 estimates were 377,567 mt and 104,445 mt for 2005–2018 and 2010–2018, respectively (Table 4 of APPENDIX B

Although the modeling work explored different scenarios of productivity, ultimately it was determined in Amendment 18 that the modeling results that drew from recruitments for the period from 2005 to 2018 represented the best available science for developing the rebuilding plan. This period represents a broader range of recruitment observed for this stock than the modeled subset of years 2010 to 2018, which include only years with low Pacific sardine productivity. The modeling results for 2010–2018 also provide a relatively low spawning stock biomass target of only 38,122 mt (Table 4 of APPENDIX B); therefore, no further consideration was given to modeling results calculated for the low productivity 2010–2018 recruitment scenario. The decision was also made to utilize the modeling runs based on the fixed rate assumption for Mexico versus a fixed catch level on the presumption that it is reasonable to assume Mexican catch might go up and down based on stock size. Therefore, modeling results relevant to the Analysis of Alternatives below are the rebuilding probability, median catch, and median spawning stock values for the longer, moderate productivity time period (2005–2018) and fixed-rate Mexican catch scenario. These modeling results are presented in Tables 6, 8, 10, and 12 of APPENDIX B.

Although the modeling results from the 2005–2018 time period were deemed more appropriate for analyzing the management alternatives because the 2005–2018 time period captured a broader range of recruitment, this time period still did not represent all possible recruitment scenarios. The assessment authors state that “recruitment has declined since 2005–2006 with the exception of a brief period of modest recruitment success in 2009–2010. In particular, the 2011–2018 year classes have been among the weakest in recent history" (Kuriyama et al., 2024). This stock exhibited much greater productivity and recruitment in the years leading up to its most recent peak in abundance in 2006, and this occurred in the years after it came under Federal management in 2000. These years are not covered by modeling. Therefore, modeling only this time period was inadequate to capture the biological pattern of a stock that is known to go through boom-and-bust cycles driven by environmental conditions. The model also assumes the entire ABC is caught each year; however, that has not been the case in recent years when less than half of the ABC was taken in U.S. fisheries and much of that is thought to be from the southern subpopulation (SSP) and not from this stock. Given these uncertainties, the modeling results were used as only one analytical tool. However, despite its limitations, the modeling platform and its results do provide useful guidance and insights that are considered in the following analyses of alternatives. The model results were also used for determining T_{MIN}, T_{MAX}, and T_{TARGET} values as well as an appropriate proxy for the biomass level that represents a rebuilt stock. For a discussion of how the model results were used to determine the rebuilding reference points, see Section 1.4.1.

The Rebuilder outputs for probabilities of rebuilding to the target rebuilding age 1+ biomass level under Alternatives 1–4 are presented in Table 8 in APPENDIX C under "US rate=18," "US rate=0," "US rate=5," and "US=2,200 mt," respectively. Alternative 1 ("US rate=18") was prorated for BUFFER (0.7762) and U.S. Distribution (0.87), and was therefore modeled as 12.16 percent harvest rate. Fixed U.S. catch of 2,200 mt stood in as a proxy for average catch expected under the Amendment 18 "Status Quo" alternative, and represents Alternative 4 in this revised rebuilding plan. Alternatives 5–6 in this revised rebuilding plan were not explicitly analyzed by the Rebuilder tool. However, as explained below, given the similarity of these alternatives to Alternatives 1–3, the rebuilding timelines of Alternatives 5–6 can be interpolated from the modeling results. The rebuilding timelines discussed herein would begin in 2025, upon implementation of the final revised rebuilding plan.

3.2 TARGET SPECIES – PACIFIC SARDINE RESOURCE

3.2.1 AFFECTED ENVIRONMENT – PACIFIC SARDINE RESOURCE

Pacific sardine (*Sardinops sagax*) are small schooling fish that are found from the ocean surface down to 385 meters. Pacific sardine, along with other species such as northern anchovy, Pacific whiting, jack mackerel, and Pacific mackerel can achieve large populations in the California Current Ecosystem (CCE), as well as in other major eastern boundary currents. However, Pacific sardine, as well as other CPS populations, have undergone boom and bust cycles for roughly 2,000 years, even in the absence of commercial fishing (see Figure 1). Analyses of fish scale deposits in deep ocean sediments off southern California found layers of sardine and anchovy scales, with nine major sardine recoveries and subsequent declines over a 1,700-year period. These boom/bust cycles are heavily influenced by the interannual and intraannual climate cycles, such as the Pacific Decadal Oscillation (PDO), shaping the CCE.

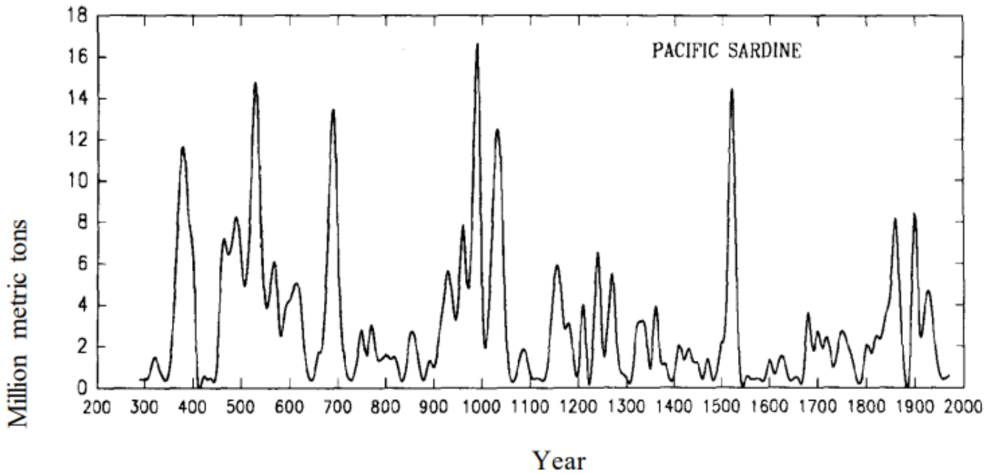

Figure 1. 1,700-year hindcast series of Pacific sardine biomasses off California and Baja California (figure reproduced from Baumgartner, Soutar, & Ferreira-Bartrina, (1992) and modified to exclude Northern anchovy).

Pacific sardine is assumed to comprise three subpopulations (see review by Smith & Moser, 2003). The northern subpopulation (NSP), which ranges from southeast Alaska to the northern portion of the Baja Peninsula, is most important to U.S. commercial fisheries and is the stock managed by the CPS FMP. The southern subpopulation (SSP) ranges from the southern Baja Peninsula to southern California, and the third subpopulation is in the Gulf of California. Off the U.S. West Coast, sardines are known to migrate northward in spring and summer and southward in fall and winter. This is true for both the NSP and the SSP. Although these two subpopulations overlap, they are considered to be distinct subpopulations (Feliz-Uraga et al., 2004; Felix-Uraga et al., 2005; Demer & Zwolinski, 2014; Zwolinski & Demer, 2023). The Pacific sardine NSP ranges from the waters off northern Baja California, Mexico to southeast Alaska and commercial fishing occurs on this transboundary stock by fleets from Mexico, the U.S., and Canada during times of high abundance. It was previously assumed that the stock's range is reduced when population levels are low, with the bulk of the biomass and harvest typically centered off southern/central California and northern Baja. However, an updated habitat model produced by Zwolinski & Demer (2023) indicates that over the last 10 years of reduced biomass, the NSP has occurred mainly off central/northern California and that harvest by Mexico has been dominated by SSP.

Factors Contributing to Overfished Status

The recent population decline of Pacific sardine appears to be due to poor recruitment. Specifically, the spawning stock biomass and recruitment have largely declined since 2005–2006, reaching low levels in recent years (2014–present) (Kuriyama et al., 2024). The 2024 assessment provided an age 1+ biomass projection of 58,614 mt on July 1, 2024, reflecting a similar trend of decline since 2005–2006. The assessment also calculated the annual U.S. exploitation rate for the NSP to be 1 percent or less every calendar year since the closure of the primary directed fishery.

Fluctuations and declines in population are by no means unprecedented. As described above, the Pacific sardine has undergone large population fluctuations for centuries, even in the absence of industrial fishing (see Figure 1). Although there is general scientific consensus that environmental conditions are a critical factor driving the population size of this stock, as well as how quickly it recovers from low levels, the specific environmental conditions and variables that are most important and the degree to which fishing may affect population fluctuations has long been investigated and is still debated (Clark & Marr, 1955; Baumgartner et al., 1992; Mantua et al., 1997; Minobe, 1997; Schwartzlose et al., 1999; McFarlane et al., 2002; Smith & Moser, 2003; Rykaczewski & Checkley, 2008; Field et al., 2009; MacCall, 2009; Demer & Zwolinski, 2014; Lindgren, et al., 2013). Further, recent climate change-related events, such as marine heat waves in the eastern Pacific Ocean along the U.S. West Coast have altered the structure of the greater pelagic ecosystem (Peterson et al., 2017). No one environmental condition is the sole driver of population abundance. Additionally, recent research (Koenigstein et al., 2022) has hypothesized that the lack of recovery of the sardine population since 2014, a period that has included warm ocean conditions, may be explained by reduced food availability for the early life stages of sardine. Therefore, while environmental conditions are critical drivers of Pacific sardine populations, the complexity of the CCE and the difficulty in understanding the exact mechanisms driving life history dynamics has created difficulties predicting stock biomass and recruitment success.

There is less evidence that harvest has been a factor leading to the overfished status of Pacific sardine. The U.S. harvest of this stock is highly regulated based on the CPS FMP; the HCRs and management measures contained therein are considered to be quite conservative as well as responsive to declines in the biomass. For example, an approximately 33 percent decline in biomass from 2012 to 2013 resulted in an approximately 60 percent decrease in allowable harvest from 2012 to 2013 and a subsequent 44 percent decline in biomass from 2013 to 2014 resulted in a 66 percent decrease in allowable harvest from 2013 to 2014. These reductions were primarily a result of the CUTOFF parameter in the HCR for Pacific sardine (150,000 mt age 1+ biomass), which was designed to keep more fish in the ocean for reproductive purposes as the stock biomass declines and reduces allowable harvest in the directed fishery as biomass gets closer to 150,000 mt.

The primary directed fishery was closed during the 2015–2016 fishing year; 4 years prior to the stock being declared overfished in 2019. Since the closure, the limited landings allowed incidental to other fisheries as well as de minimis targeted catch have remained relatively constant, averaging about 2,200 mt/year from 2015 to 2020 and about 2,000 mt/year since, through 2023, well below any year's ACL (see Table 2). This is due primarily to closure of the primary directed fishery, but also other explicit regulatory measures in the CPS FMP, such as limits on minor directed fishing and the amount of Pacific sardine that can be caught incidental to other fisheries (see Section 1.4.2).

Additionally, all Pacific sardine catch landed into U.S. West Coast ports is counted against the ACL, even though some portion is retroactively attributed to the SSP of Pacific sardine in stock assessments. For example, of the 1,619 mt of U.S. total landings of Pacific sardine in the 2022–2023 fishing year, the 2024 stock assessment retroactively assigned only 517 mt to the NSP (see Table 1.5 in Kuriyama et al., 2024). Compared to stock assessments prior to 2024, a smaller proportion of total U.S. catch was attributed to NSP due to updates to a habitat model (Zwolinki & Demer, 2023) following the 2020 benchmark assessment. Based on this refined data, the average U.S. harvest of NSP Pacific sardine has been less than one percent of the stock biomass in the years since the closure of the primary directed fishery.

As stated above, harvest of Pacific sardine also occurs off northern and central Baja by Mexican fisheries with catch landed into Ensenada, Mexico. This catch from Mexican waters can also include fish from the NSP. The catch of NSP from this fishery also appears to be comparatively low in recent years. Using the apportioned landings information in the 2020 stock assessment, from 2015 to 2019, the Ensenada fishery was assumed to have caught approximately 5,000 mt/year of NSP sardine on average. The 2024 stock assessment, which incorporated the updated habitat model, estimated that zero NSP have been caught by Mexico since 2012 (see Table 9.2 in Kuriyama et al., 2024).

Stock assessment results suggest that even in the absence of any fishing, the NSP sardine stock would have been expected to decline significantly (Figure 2). These results suggest that environmental conditions and ecosystem constraints contributing to low recruitment, rather than fishing, are the most important factors contributing to the overfished status of this stock, even if the specific mechanisms and environmental conditions that affect recruitment remain poorly understood.

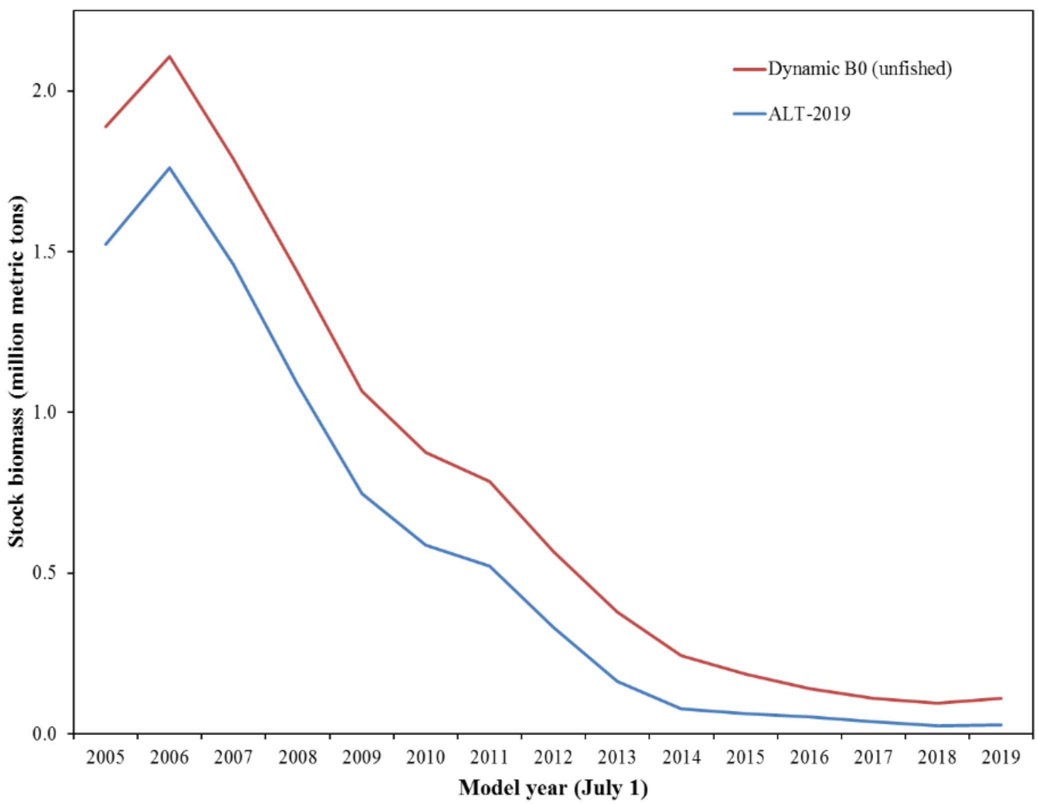

Figure 2. Estimated stock biomass (age 1+ fish, mt) time series and dynamic B_0 (unfished population) from model ALT-2019 (Figure 29c in Hill et al., 2019).

3.2.2 ANALYSIS OF IMPACTS – PACIFIC SARDINE RESOURCE

The following analysis examines the potential effects of each management alternative on the ability of Pacific sardine to rebuild in the near and long term. This analysis relies on modeling work which, despite inherent assumptions, provides critical insight into rebuilding timelines under each alternative harvest scenario.

Under each of the alternatives, the model assumes that U.S. fisheries would harvest the full ABC/ACL. Due to the prohibition on primary directed fishing, restrictions on incidental, live bait, and minor directed harvest, and to some degree market dynamics, actual landings of Pacific sardine in these minor fisheries have averaged 2,200 mt or less even prior to the stock's decline below 150,000 mt. The model also assumes that all Pacific sardine landings will be from the NSP of Pacific sardine (the subpopulation managed under the CPS FMP). However, the SSP of Pacific sardine ranges from the southern tip of Baja, Mexico to the Southern California Bight off the U.S. West Coast and overlaps with the NSP in U.S. waters during the summer. While average catch of Pacific sardine from 2015 to 2023 was close to 2,000 mt, the 2024 stock assessment attributed an average of only 423 mt NSP to the U.S. harvest of Pacific sardine during those years. It is therefore likely that the actual removal of NSP under any of these harvest scenarios is much lower than the modeled removal, potentially resulting in shorter rebuilding timelines.

As noted previously, there is scientific consensus that environmental conditions will be the primary determinant in both the amount of time it takes and to what extent the Pacific sardine biomass rebounds from its current low levels. Even if further refinements could be made to the model, it is virtually impossible to predict when environmental conditions might produce favorable recruitment and therefore allow the stock to increase in size.

Alternative 1 (No Action) was modeled as a U.S. harvest rate of 12.16 percent. When the full ABC/ACL is taken, the model results showed that the stock would not rebuild to the rebuilding age 1+ biomass target of 150,000 mt within the modeled 30 years (see Table 8 in APPENDIX B). Despite evidence that actual landings would never reach the ABC due to the directed fishery closure and management and accountability measures that restrict harvest, and that only a small portion of the landings are NSP, because the model does not project further than 30 years, it cannot be used to estimate an actual time to rebuild under this alternative.

Under Alternative 2 (Zero U.S. Harvest), the modeled time to rebuild Pacific sardine with a greater than 50 percent probability to the rebuilding age 1+ biomass target of 150,000 mt is 12 years (APPENDIX C). This is the fastest rebuilding timeline of any of the alternatives; however, historical studies have shown that the stock can stay low due to environmental conditions even in the absence of fishing. The modeling results do not capture the full range of productivity of which this stock is capable, nor can the modeling work predict future productivity. Therefore, even though there would be no U.S. landings associated with this alternative, these uncertainties cast doubt on if or how much faster the stock would rebuild under this alternative.

Under Alternative 3 (Five Percent Fixed U.S. Harvest Rate), the modeled time to rebuild Pacific sardine with a greater than 50 percent probability to the selected rebuilding biomass target of 150,000 mt age 1+ biomass is 16 years (APPENDIX C). Assuming that the full 5 percent is harvested each year, when the biomass is 50,000 mt or greater, annual harvest would be 2,500 mt or more (see Table 5 in APPENDIX A). However, U.S. landings have not exceeded 2,500 mt since the closure of the directed fishery. As with other alternatives that increase ACLs with increased biomass, this harvest level will likely not be attained if historical catch data are representative of the future. It is also likely that the actual harvest rate under Alternative 3 would be less than the modeled harvest rate when considering that only a portion of U.S. landings are attributed to the NSP of Pacific sardine. Therefore, the rebuilding timeline under Alternative 3 is expected to be longer than the 12 years for Alternative 2, but potentially shorter than the 16 years initially modeled.

Under Alternative 4 (Constant Catch), the modeled time to rebuild Pacific sardine with a greater than 50 percent probability to reach the rebuilding biomass target of 150,000 mt age 1+ biomass is 17 years (APPENDIX C). This specific harvest scenario was modeled in Amendment 18 as a more representative amount of real-world conditions under the status quo alternative (i.e., average catch from 2015 to 2020, which was 2,200 mt, even at varying biomass and allowable catch levels). When status quo was adopted under Amendment 18 (assuming the 2,200 constant catch scenario), instead of adopting a T_{TARGET} of 17 years, as modeled, a T_{TARGET} of 14 years was chosen based on the assumption that a portion of the modeled landings would be from the SSP. This T_{TARGET} of 14 years was considered reasonable and adequate time to evaluate rebuilding.

Under Alternative 5 (Modified Constant Catch), it is expected that the time to rebuild Pacific sardine with a greater than 50 percent probability to reach the rebuilding biomass target of 150,000 mt age 1+ biomass is within 17 years. Alternative 5 sets a modified constant catch ACL that was not explicitly modeled; however, it is reasonable to interpolate that the rebuilding time would be similar to the modeled constant catch of 2,200 mt. Further, based on the 2024 stock assessment's retroactive apportionment of the landings to SSP, even if a 3,200 mt ACL is fully attained (the larger of the two values considered under this alternative), NSP landings will likely remain below the modeled 2,200 mt ACL, and it can reasonably be assumed that with modified constant catch, the stock would rebuild in less than 17 years.

Under Alternative 6 (Mixed Rate U.S. Harvest), the FPA, it is expected that the time to rebuild Pacific sardine with a greater than 50 percent probability to reach the selected target of 150,000 mt age 1+ biomass is within 17 years. This rebuilding timeline is interpolated from the modeling of catch scenarios under Alternatives 3 (Five Percent Fixed U.S. Harvest Rate) and 4 (Constant Catch) (see APPENDIX B). Alternative 3 resulted in a 50 percent probability of reaching the biomass target within 16 years. However, under Alternative 6, a constant catch value of 2,200 mt would be more than projected harvest under Alternative 3 when the biomass is less than 44,000 mt, and less than Alternative 3 when the biomass is between 44,000 mt and 50,000 mt (see Table 5 in APPENDIX A). The constant catch value of 2,200 mt was analyzed to rebuild in 17 years.

As with other alternatives that increase ACLs with age 1+ biomass, harvest levels greater than 2,500 mt will likely not be attained if historical catch data are representative of the future. While Alternative 6 would permit higher removals in lower biomass years (noting exception between 44,000 to 50,000 mt) compared to Alternative 3, it is likely that the total removals of NSP would be less than 2,200 mt, given that a portion of that removals would be of the SSP. As noted above, the 2024 stock assessment attributed only a portion of U.S. catch to NSP. On average, about 23 percent of catch that counted towards the ACL was attributed to the NSP, with the remaining 77 percent from the SSP (Kuriyama et al., 2024). It is therefore reasonable to assume that if the full 2,200 mt ACL is removed annually when the stock's biomass is 50,000 mt or less, only about 506 mt of these landings would be NSP (on average). Therefore, when the biomass is between 11,000 and 50,000 mt, landings would be less than what was modeled under Alternative 3 (see Table 5 in APPENDIX A). As Alternative 3 was projected to rebuild within 16 years, it can reasonably be assumed that, given removals of NSP under Alternative 6 will be less than the ACL modeled under Alternative 3, the stock is likely to rebuild within 16 years under Alternative 6. At very low stock biomass levels, if the calculated ABC is less than the ACL prescribed under Alternative 6, then the ACL would be reduced to equal the ABC and further restrict Pacific sardine harvest, as it would with all of the alternatives except Alternative 2.

Lastly, as shown in Figure 3, below, Alternatives 3 (green) and 4 (yellow), which are combined to generate Alternative 6, follow very similar rebuilding trajectories. Therefore, while a rebuilding model was not explicitly run for Alternative 6, it can be reasonably assumed that the rebuilding timeline will be less than 17 years.

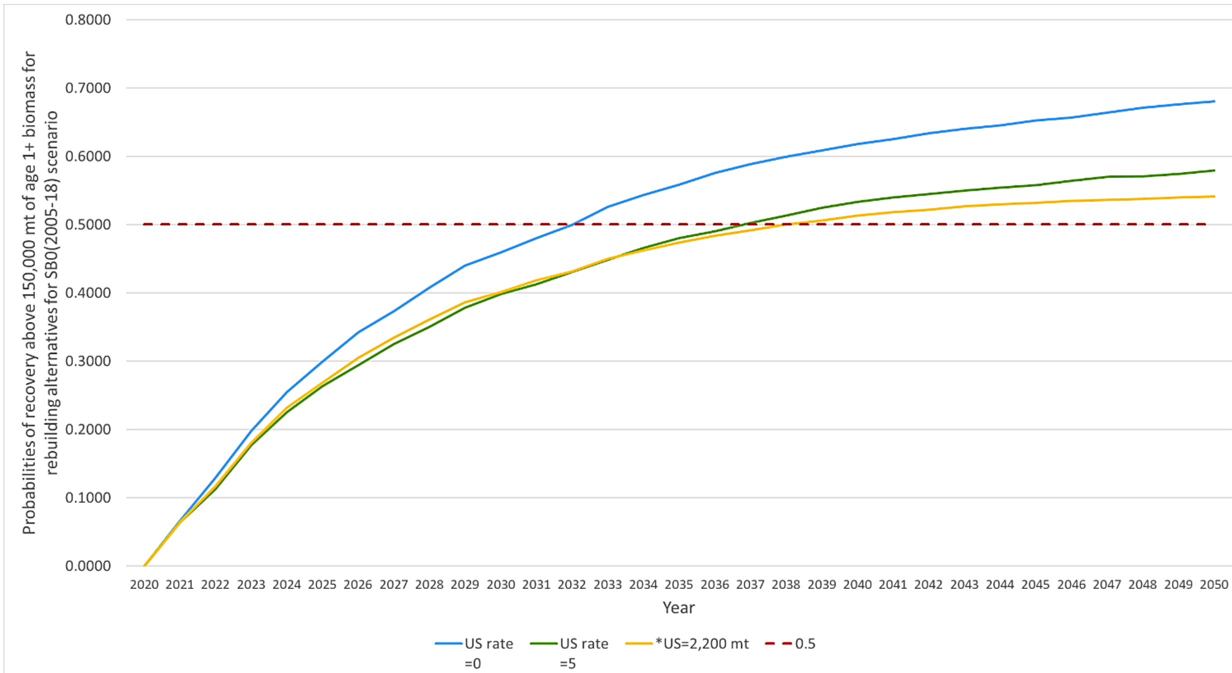

Figure 3. Probabilities of recovery above 150,000 mt of age 1+ biomass for rebuilding alternatives. Red dashed line indicates rebuilding threshold of 50 percent probability of recovery. Model outputs used to produce graph available in Appendix A.

Table 4. Recent ACL and landings values compared with ACL values for Alternatives 3–6. Shaded cells show where actual landings would have exceeded the ACL under that alternative. All ACL and landings values in mt. Landings information is sourced from the Benchmark Stock Assessment for the 2014–2015 through 2018–2019 fishing years and from the PacFIN data portal for the 2019–2020 through 2023–2024 fishing years.

Fishing Year	Biomass (mt)	Alt 1 (ACL implemented under Am18 Status Quo)	Alt 3 ACL	Alt 4 ACL	Alt 5 ACL	Alt 6 (FPA) ACL	Actual Landings
2015–2016	96,688	8,000	4,834	2,200	3,200	4,834	1,919
2016–2017	106,137	8,000	5,307	2,200	3,200	5,307	1,885
2017–2018	86,568	8,000	4,328	2,200	3,200	4,328	1,775
2018–2019	52,065	7,000	2,603	2,200	3,200	2,603	2,278
2019–2020	27,547	4,514	1,377	2,200	3,200	2,200	2,085
2020–2021	28,276	4,288	1,414	2,200	3,200	2,200	2,498
2021–2022	28,276	3,329	1,414	2,200	3,200	2,200	1,772
2022–2023	27,369	4,274	1,368	2,200	3,200	2,200	1,619
2023–2024	27,369	3,953	1,368	2,200	3,200	2,200	1,774
2024–2025	58,614	3,953	2,931	2,200	3,200	2,931	-

In conclusion, no management alternative is expected to significantly impact the ability of the Pacific sardine resource to rebuild in the near or long term, as fishing mortality is not the primary driver of stock biomass. As described in Section 3.2.1, the environment will likely be the primary determinant for the stock increasing. The incidental and minor directed fisheries are already heavily restricted under current management, as the primary directed fishery is currently closed and will remain so under all alternatives, and it is unclear if the reductions in annual catch under Alternatives 3, 4, 5, or 6 would allow the stock to realistically rebuild any faster than other alternatives.

3.3 SARDINE IN THE ECOSYSTEM

3.3.1 AFFECTED ENVIRONMENT – SARDINE IN THE ECOSYSTEM

Pacific sardine and other CPS populations are important to the trophic dynamics of the CCE. For example, anchovy and Pacific sardine are key consumers of large quantities of primary production (phytoplankton) in the ecosystem, and all five species of CPS are significant consumers of zooplankton, including early life stages of fish. At both juvenile and adult life stages, CPS are also important as forage for seabirds, pinnipeds, cetaceans, and other fish. For the purpose of this analysis, the affected environment relevant to implementing a rebuilding plan for the NSP of Pacific sardine consists of their predators in the CCE.

Pacific sardine are prey for several commercially important marine fishes, such as Pacific salmonids, including endangered Chinook stocks, albacore tuna, and Pacific whiting, as well as Pacific spiny dogfish and several shark species (Szoboszlai et al., 2015; PFMC 1998). Trophic interactions between CPS and higher-trophic-level fish are complex, and the extent to which predator populations are affected by CPS abundance and distribution is difficult to measure. The value of CPS as forage to adult predators versus the negative effects of predation from CPS (on larvae and juveniles of predator fish species) and competition (removal of phytoplankton, zooplankton, and other fish) is unknown.

A number of seabirds are known to forage on Pacific sardine, including grebes and loons, petrels and albatrosses, pelicans and cormorants, gulls, terns, auks, and some raptors, which are all non-Endangered Species Act (ESA) listed (PFMC 1998). The marbled murrelet is one example of an ESA-listed bird that is also known to consume Pacific sardine. Marbled murrelets are known to consume many different prey species including CPS and, like many predators, are capable of prey switching, with uncertainty as to the relative importance of Pacific sardine in its diet (Burkett 1995; Becker & Bessinger, 2006; McShane et al., 2004; Szoboszlai et al., 2015). Anecdotal evidence documents how marbled murrelets' prey flexibility and opportunistic feeding strategies were essential to allowing the species to persist through other Pacific sardine population crashes (Burkett, 1995).

Pacific sardine are also forage for a variety of marine mammals, such as common dolphins, sea lions, harbor seals, and humpback whales (PFMC 1998). Importantly, sardine are prey for two distinct population segments (DPSs) of ESA-listed humpback whales that feed in this action area—the Mexico DPS (ESA threatened) and Central America DPS (ESA endangered)—and were included in a list of small pelagic schooling fishes in the prey essential features used to designate these populations' critical habitat (see 86 FR 21082, April 21, 2021). Humpback whales, like other marine mammals in the CCE that prey on Pacific sardine, are generalist predators, and sardine are just one species within a complex of the primary prey that humpbacks consume: euphausiids and small pelagic schooling fishes such as northern anchovy, Pacific herring capelin, juvenile walleye pollock, Pacific sardine, and Pacific sand lance (see 86 FR 21082, April 21, 2021). Like the aforementioned predators of CPS, substantial data support that humpback whales are known to switch between target prey species depending on what is most abundant. Notably, the primary direct threats to these populations, as described in a recent Recovery Outline, are entanglement in fishing gear (not of the kind used in the sardine fisheries) and vessel strike (NMFS 2022).

3.3.2 ANALYSIS OF IMPACTS - SARDINE IN THE ECOSYSTEM

The following analyses address the potential impacts of the action alternatives on the ecosystem components identified above—the various predators of sardines, in the context of the CCE. Differences between the action alternatives, with respect to ecosystem impacts, amount to variations in the projected time the population will take to rebuild to the target of 150,000 mt age 1+ biomass between the alternative rebuilding strategies. Considering the closure of the directed commercial fishery and the CPS FMP's conservative management and accountability measures that already restrict the incidental and minor directed harvest of Pacific sardine (see Section 1.4), no rebuilding plan alternative is expected to significantly impact prey availability for marine predators, including protected species, as they likely would not notice small differences in potential sardine removals and rebuilding timelines.

Pacific sardine, as well as other CPS populations, have undergone boom and bust cycles for roughly 2,000 years. Abundance fluctuations are common in species that generally have higher reproductive rates, are shorter-lived, attain sexual maturity at younger ages, and have faster individual growth rates than species such as rockfish and many flatfish. Predators of CPS off the U.S. West Coast have therefore evolved in an ecosystem in which relative abundances of prey species frequently fluctuate. Consequently, most predators are generalists who are not dependent on the availability of a single species but rather on many species, any one (or more) of which is likely to be abundant in a given year. Many of them also have other life history traits, such as long lifespans or adaptive reproductive strategies, that help mitigate against years of low prey availability. Trophic models have been used to examine the impacts of forage fish populations within these complex dynamics, and efforts are ongoing to refine our understanding of trophic linkages (Ruzicka et al., 2012; Koehn et al., 2016). Trophic modeling efforts have sometimes ignored important factors that need to be considered before drawing conclusions about any direct effects of the overall abundance of a particular forage fish population on its predators' populations (Hilborn et al., 2017).

Koehn et al. (2016) found that due to the broad distribution of predator diets, dynamic models would generally not predict widespread ecological effects from depleting individual forage fish species; rather, certain species aggregates—key forage assemblages, such as Pacific sardine and anchovy together—are the minimum unit on which food web models can predict impacts. Therefore, to analyze the impact of Pacific sardine abundance fluctuations, this section also considers the fluctuations of other CPS populations that make up this prey base. For example, while the biomass of Pacific sardine is currently low, the central subpopulation of northern anchovy biomass is high (approximately 800,000 mt in 2019 and 2,879,010 mt in June 2022), (see Stierhoff et al., 2020; Kuriyama et al., 2022). While this scenario may not always be the case, it is an example of the variability of the forage in the system and why predators have adapted to consume multiple prey species (McClatchie et al., 2017).

Moreover, other elements of the CPS forage base remain protected under provisions of the CPS

FMP. For instance, fishing for krill, one of the most important prey species in the ecosystem, is prohibited by the CPS FMP; Amendment 12 (74 FR 33372, July 13, 2009) specifically took action to protect krill species from harvest in order to safeguard prey for marine predators. These are just some examples of other species that provide prey-switching opportunities and, therefore, varied forage availability in the ecosystem, making it unlikely that there would be a measurable difference in foraging benefits among the expected rebuilding timelines for Pacific sardine.

Because predators of Pacific sardine are generalists capable of prey-switching, Pacific sardine (and, within that, the NSP) are one constituent of this forage base, and because environmental conditions are the primary drivers of the population (see Section 3.2) and fishery harvest is already strictly limited (see Section 1.4), no significant impacts are expected on the affected environment from any of the alternatives presented in this rebuilding plan; however, each of the rebuilding timelines are considered here in this context.

Under Alternative 1 (No Action), the model results showed that when the full ABC/ACL is taken, the stock would not rebuild to the rebuilding age 1+ biomass target of 150,000 mt within 30 years (Table 8 in APPENDIX C). Although these results suggest the slowest probable rebuilding timeline, due to the reasons described above, this management option would not result in significant removals of Pacific sardine that would impact the affected environment. However, as the model did not project beyond 30 years, it is uncertain if and when a 12.16 percent harvest rate would allow the species to rebuild to high enough abundance to regain its role among other environmentally-driven populations as an important forage base in the small pelagic finfish assemblage.

Under Alternative 2 (Zero U.S. Harvest), the modeled time to rebuild Pacific sardine with a greater than 50 percent probability to the rebuilding age 1+ biomass target of 150,000 mt is within 12 years (APPENDIX C). This is, inherently, the fastest rebuilding timeline of any of the alternatives and was used to establish T_{MIN}. However, historical studies have shown that the stock biomass can stay low even with no fishing, and marine predators of CPS have evolved in an ecosystem in which relative abundances of prey species frequently fluctuate. Therefore, prohibiting the minimal harvest proposed by the other rebuilding alternatives presents little to no significant benefit to the affected environment.

While these conclusions apply to all marine predators of the affected environment, this section further discusses potential impacts to the endangered humpback whale and its critical habitat.

The total biomass of Pacific sardine available in the CCE, even while low during the course of rebuilding, is unlikely a limiting factor for humpback whale populations, generally. Many studies have attempted to examine the relative importance of prey types to humpback foraging. For example, humpbacks feeding off the West Coast have been estimated to consume as many as 157,735 tons (143,095 mt) of total prey annually, 83 percent of which is estimated to come from the CCE, and only 15 percent of which is estimated to be composed of small pelagic fish, like sardines (Barlow et al., 2008). This estimate results in a total consumption of 17,815 mt of small pelagic fish annually. Recognizing that the humpback whale stock examined here has grown approximately 60 percent since the time of that study (Curtis et al., 2022), that estimate may be as much as 28,505 mt of small pelagic fish eaten in the CCE. Only a very small portion of that CPS-wide figure is composed of, specifically, the NSP of Pacific sardine. Further, humpback populations feeding off the West Coast have continued to increase, even during a recent period of decreasing sardine biomass, with the best approximations on the Central America and

Southern Mexico DPSs reporting positive annual growth rates for both populations (Curtis et al., 2022, Calambokidis & Barlow, 2020). Additionally, data from a study by Rice (1963) showed that during the mid-century crash of sardine, humpbacks made a distinct shift in the schooling fish they targeted (cited in NMFS 2020).

Finally, as previously mentioned, the primary direct threats to the Central America and Southern Mexico DPSs, as described in their recent Recovery Outline, are entanglement in (non-CPS) fishing gear and vessel strikes (NMFS 2022). None of the alternatives proposed in the humpback recovery outline identify competition from commercial fishing as an area that warrants action. And, critically, while sardine were included in the list of small pelagic schooling fishes used as prey features to delineate the geographic areas constituting these populations' critical habitat (86 FR 21082, April 21, 2021), the purpose of this rebuilding plan is, ultimately, to ensure that harvest is restricted to a level that would allow the biomass of Pacific sardine to increase in the ecosystem, supporting the overall health of the species and their habitats.

None of the proposed management alternatives, including the FPA, are expected to significantly impact the affected environment (marine predators). Pacific sardine are one component of their forage base, these predators are generalists capable of prey-switching, and the environment will be the primary driver for increases in sardine abundance. Slight differences in the proposed ACLs and the rebuilding timelines across this range of alternatives would cause relatively negligible impacts to the sardine resource or ecosystem, and evidence shows that even highly-studied species such as humpback whales have continued to increase in population size during periods of reduced sardine abundance. Therefore, no management alternative is expected to significantly impact prey availability for marine predators, including protected species, but will instead potentially provide beneficial impacts by implementing a plan to help rebuild the sardine population.

3.4 FISHING INDUSTRY

3.4.1 AFFECTED ENVIRONMENT – FISHING INDUSTRY

California's Pacific sardine fishery began in the 1860s as a supplier of fresh whole fish. The fishery shifted to canning from 1889 to the 1920s in response to a growing demand for food during World War I. Peaking in 1936–1937, Pacific sardine landings in the three west coast states plus British Columbia reached a record 717,896 mt. In the 1930s and 1940s, Pacific sardine supported the largest commercial fishery in the western hemisphere, with sardines accounting for nearly 25 percent of all the fish landed in the United States by weight. The fishery declined and collapsed in the late 1940s due to extremely high catches and changes in environmental conditions and remained at low levels for nearly 40 years. The fishery declined southward, with landings ceasing in Canadian waters during the 1947–1948 season, in Oregon and Washington in the 1948–1949 season, and in the San Francisco Bay in the 1951–1952 season. The CalCOFI, a consortium of state and Federal scientists, emerged to investigate the causes of the Pacific sardine decline. Analyses of fish scale deposits in deep ocean sediments off southern California found layers of sardine and anchovy scales, with nine major sardine recoveries and subsequent declines over a 1,700-year period (Figure 1; Baumgartner et al., 1992).

The decline of the sardine fishery became a classic example of a "boom and bust" cycle, a characteristic of clupeid stocks (i.e., certain small pelagic fish like sardines). In 1967, the California Department of Fish and Game implemented a moratorium in state waters that lasted nearly 20 years. Sardines began to return to abundance in the late 1970s, when the Pacific Decadal Oscillation shifted to a warm cycle again, but this time fishery managers adopted a highly precautionary management framework. California's Pacific sardine fishery reopened in 1986 with a 1,000 short ton quota, authorized by the California state legislature when the biomass exceeded 20,000 mt. The sardine resource grew exponentially in the 1980s and early 1990s, with recruitment estimated at 30 percent or greater each year. By 1999, the biomass was estimated to be around 1 million mt (Conser et al., 2001). The Pacific sardine biomass appeared to level off during 1999–2002. In 2005, Oregon landings surpassed California for the first time since the fishery reopened. California caught nearly 81,000 mt of the 152,564 mt harvest guideline (HG) in 2007—the highest landings since the 1960s. Around this time, recruitment began to decline. The directed fishery for sardine has been closed since the 2015–2016 fishing year, when the projected biomass fell below the CUTOFF value of 150,000 mt. Biomass has remained below this value since, precluding the re-opening of the directed fishery. The 2024 base model age 1+ biomass was projected to be 58,614 mt in July 2024 (Kuriyama et al., 2024). However, minor directed fisheries and the live bait fishery have been allowed some harvest of Pacific sardine. Incidental catch in CPS and non-CPS (i.e., Pacific whiting) has also been allowed.

For the purpose of this analysis, the effects analyzed on the affected fishing industry include the near- and long-term economic impacts associated with loss of fishing opportunity under each management alternative.

3.4.1.1 PRIMARY DIRECTED COMMERCIAL FISHERY

The Pacific sardine primary directed fishery has historically been the largest component of CPS fisheries and represents the historical fishery dating back to the 1920s in California and the contemporary expansion from the late 1990s of the fishery into the Pacific Northwest. In addition to Pacific sardine, the CPS complex includes market squid, Pacific mackerel, jack mackerel, and northern anchovy fisheries; in total, the CPS complex accounted for an average of over $117 million of ex-vessel revenue (in inflation-adjusted 2023 dollars) from 2010 to 2014. The primary directed fishery is the main fishery that operates in Federal waters. Fishing opportunity in the primary directed fishery is determined by the output of the harvest guideline HCR, which has imposed a closure of the sardine fishery since the NSP Pacific sardine biomass fell below the CUTOFF of 150,000 mt in the 2015–2016 fishing year. Prior to its closure, the ex-vessel value of this fishery averaged over $18.35 million annually (in 2023 dollars) from 2009 through 2014 (PFMC 2019b, adjusted for inflation). Because the primary directed fishery has been closed since the 2015–2016 fishing year and will remain closed until the sardine biomass exceeds the target rebuilding level of 150,000 mt age 1+ biomass, the rebuilding plan will impact the timeline of re-opening of the fishery, but the fishery will not be affected in the interim. With the primary directed fishery closed, the CPS stock complex has landed a total of $49 million of ex-vessel value (in 2023 dollars) from 2015 through 2023 (PFMC 2024a).

3.4.1.2 LIVE BAIT FISHERY

Live bait fisheries typically use various types of round haul gear such as purse seines to capture relatively small-sized CPS schools and deliver the catch alive to receiver vessels (or "live bait barges") that have holding tanks or dockside net pens. Private and charter recreational vessels and commercial vessels then purchase live bait by the scoop from these receiver vessels or pens, as they depart for fishing trips. Although the live bait fishery harvests a small amount of Pacific sardine compared to the harvest of a directed commercial fishery, it is dependent on the ability to directly target pure schools of Pacific sardine to meet the needs of recreational fisheries. The live bait fishery is authorized in the EEZ but is primarily conducted in state waters, and, in addition to the ACL, is subject to annual accountability measures under the CPS FMP (see Section 1.4).

CALIFORNIA

The Southern California recreational fishery is part of an extremely valuable statewide fishery generating over $510 million in value added impact to California in 2022 (NMFS 2024). Live bait is primarily used by recreational anglers on commercial passenger fishing vessels (CPFVs) and private boats. There are 321 CPFVs that operate throughout California. From this total, 206 vessels (68 percent) operate in southern California (South of Point Conception) and 102 vessels (34 percent) operate in northern California (North of Point Conception). In San Diego County alone, 117 vessels operate out of three ports and account for the majority of sportfishing activity that occurs in California.

The California sportfishing industry relies on Pacific sardine for live bait. Between 2015 and 2020, live bait catches averaged 1,408 mt of Pacific sardine per year, making up 85 percent of total live bait catch in California (see Table 4-13 in PFMC 2022c Appendix). The ratio of anchovy to sardine in the southern California live bait harvests does shift significantly as the populations of these two fish expand and contract over periods of years or decades. However, the vast majority of catch comprises sardine; from 2015 to 2023, the proportion of sardine in reported live bait catch averaged 86.56 percent, ranging from 73 percent to 93 percent (PFMC 2024a). Pacific sardine are preferred for long-range trips to Mexico, as they are heartier and more likely to survive and be active than other bait species for the duration of extended trips, which can be several days or longer. Anglers often check fishing reports and will plan trips based on catch by species, which can be strongly affected by available bait species. Therefore, the appeal of sportfishing trips can be adversely affected by an inconsistent supply of varied bait species. A reliable and varied supply of live bait (including Pacific sardine) is an essential component of this fishery. Public comments on the Pacific Sardine Assessment, Harvest Specifications, and Management Measures agenda item at the 2021–2024 April Council meetings detail the importance of this fishery. In particular, stakeholders from multiple industries (recreational, live bait, and non-governmental organizations) have commented on the essential role the live bait fishery plays in supporting the California recreational sector of millions of fishers and how crucial it is for CPS management to support the continued existence of the live bait sector.

OREGON

In Oregon, fishing for CPS to use as live bait is minimal, with small amounts, including Pacific sardine, from the minor directed fisheries sometimes sold as live bait.

WASHINGTON

In Washington, the sole opportunity to target Pacific sardine is in the Federal primary directed sardine fishery which has been closed by moratorium since 2015. Therefore, although baitfishing for other species is allowed, directed baitfishing for Pacific sardine is currently prohibited. Total incidental landings of Pacific sardine by baitfish licenses are less than 0.5 mt per year.

3.4.1.3 MINOR DIRECTED FISHERY

Amendment 16 of the CPS FMP, implemented in 2018, allows minor directed commercial fishing on CPS finfish to continue when the primary commercial fishery is otherwise closed. The amendment included a maximum of 1 mt per vessel per day, with a one-trip-per-day limit (see section 1.4). This sector accounts for a very small portion of the overall catch of any particular CPS stock and has a negligible impact. However, it is an important source of income for some small ports and producers, especially when the directed fishery is closed. Under the trip limits implemented by Amendment 16, the majority of historical small-scale sardine fishing activities are allowed. When Amendment 16 was implemented, the number of participants coastwide with targeted sardine landings of less than one metric ton per day ranged from 5 to 12 per year for years 2005–2015. In the same years, 95 percent of the landings by beach seine operations and 100 percent of hook-and-line operations were less than 1.0 mt per day. Only 77 mt of sardine were landed in California and Oregon in 2022–2023 (PFMC 2024a). Washington's state regulatory framework essentially precludes minor directed fishing when the age 1+ biomass estimate is below 150,000 mt. Although the minor directed fishery harvests a small amount of Pacific sardine, it is dependent on the ability to directly target pure schools of Pacific sardine to accommodate its markets (i.e., dead bait and restaurant sales). In addition, small-scale fishermen that participate in the minor directed fishery typically do not participate in any other fishery and are therefore heavily reliant on this fishing opportunity from a socioeconomic aspect.

3.4.1.4 INCIDENTAL HARVEST

CPS FISHERIES

The CPS FMP allows up to 45 percent incidental landings of Pacific sardine when the stock is below the CUTOFF biomass of 150,000 mt and above the minimum stock size threshold (MSST) of 50,000 mt age 1+ biomass, and no more than 20 percent when it is below MSST (see Section 1.4). Incidental harvest of Pacific sardine in CPS fisheries targeting northern anchovy, Pacific mackerel, and market squid was restricted to 40 percent per landing for the 2015–2016 to 2018–2019 fishing years and then 20 percent per landing starting from 2019–2020 to 2022–2023. As of 2024, the projected age 1+ biomass was 58,614 mt (Kuriyama et al., 2024). Given the CPS FMP allows the incidental landing limit to range up to 45 percent when the stock is above the MSST, the incidental allowance was increased to 30 percent for the 2024–2025 fishing year. If the stock's estimated age 1+ biomass increases, per landing restrictions could increase in future harvest specifications. When possible, fishermen avoid mixed schools because processors often prefer to have landings without high levels of incidental species in order to reduce the time to sort fish. In recent years, California CPS fishermen have indicated increased difficulty catching other CPS because they have encountered schools mixed with Pacific sardine frequently, and they must release the school if it comprises more than the incidental landings percent allowance of Pacific sardine.

From the closure of primary directed Pacific sardine fishing in the 2015–2016 fishing year through the 2018–2019 fishing year, an average of 300 mt of incidental sardine was landed annually in California (PFMC 2022b). These mixed landings averaged over $1.8 million in value (PFMC 2022b). From the 2019–2020 fishing year through the 2022–2023 fishing year, an average of 179 mt incidental sardine was landed annually (PFMC 2024b). Incidental fishery mixed landings averaged $4.3 million in value from 2019 to 2022 in California (PFMC 2022b). In their April 2024 reports, the CPSMT and CPSAS conferred that an increase in the incidental landing limit, now that the stock is above the minimum stock size threshold of 50,000 mt, would provide more flexibility for other CPS fisheries that incidentally catch sardine (PFMC 2024b).

NON-CPS FISHERIES

Incidental harvest of Pacific sardine also occurs in other fisheries such as the Pacific whiting (hake) trawl fishery where fishermen do not have the ability to avoid capturing Pacific sardine and operate under a maximized retention model. Annual management measures for Pacific sardine include an incidental catch allowance of sardine for non-CPS directed fisheries, expressed as a limit in metric tons per landing. The limit has been up to 2 mt. The Pacific whiting fishery accounts for most non-CPS directed fishery incidental catch.

The Pacific whiting trawl fishery is composed of at-sea and shoreside fisheries. The at-sea sector is subdivided between mothership processing vessels accepting fish from catcher boats and catcher-processor vessels. The Pacific whiting fishery begins in May; shoreside sector landings peak in August while the at-sea sectors show higher landings in May, a steep drop in the summer, and a resurgence in the fall.

The shoreside fishery delivers to processing plants on land; with Westport and Ilwaco, Washington and Astoria, Oregon being the principal ports for shoreside landings. These vessels catch almost exclusively Pacific whiting. Since 2015, when Pacific sardine biomass fell below CUTOFF or 150,000 mt, incidental landings in the Pacific whiting fishery have varied widely—ranging from less than 1 mt to nearly 30 mt in the 2021–2022 sardine fishing year. Between the at-sea and shoreside sectors, there is interannual variability on which sector has more incidental catch of sardine—likely due to the differences in operation between the at-sea and shoreside fisheries as well as location of Pacific whiting schools and Pacific sardine. Excluding the 2020–2021 fishing year (30 mt), the whiting sectors caught 6.8 mt of Pacific sardine on average during the 2015–2016 to 2022–2023 fishing years. In 2022, commercial landings of Pacific whiting across sectors totaled 577 million pounds and were valued at $64 million (NOAA Fisheries commercial fishing landings database).

3.4.1.5 TRIBAL FISHERY

The CPS FMP recognizes the rights of treaty Indian tribes to harvest Pacific sardine and provides a framework for the development of a tribal fishery. Pacific Ocean waters and estuaries north of Point Chehalis, Washington, include the usual and accustomed (U & A) fishing areas of four treaty Indian tribes (as defined at 50 CFR 660.4) that may initiate their right to harvest Pacific sardine in any fishing year by submitting a written request to the NMFS Regional Administrator at least 120 days prior to the start of the fishing year.

Treaties between the United States and Pacific Northwest Indian Tribes reserve the rights of the Tribes to take fish at U & A fishing grounds. Amendment 9 to the CPS FMP (66 FR 44986, August 27, 2001) outlined the process for the Council and NMFS to consider and implement tribal allocation requests for CPS, and codified these procedures in Federal regulations at 50 CFR 660.518.

Tribal treaty fisheries are established via Government-to-Government consultation and could potentially include Pacific sardine harvest. The Quinault Indian Nation has exercised their rights to harvest Pacific sardine in their U & A Fishing Area off the coast of Washington State, pursuant to the 1856 Treaty of Olympia (Treaty with the Quinault). The Quinault U & A is defined at 50 CFR 660.4(a)(4) and represents an area directly off Westport/Grays Harbor, Washington and waters to the north of this area.

3.4.2 ANALYSIS OF IMPACTS - FISHING INDUSTRY

Since the closure of the primary directed fishery in 2015, Pacific sardine has only been harvested in the smaller-scale sectors of the CPS fishery (i.e., the live bait, minor directed, and tribal fisheries), and as incidental catch in other CPS (e.g., Pacific mackerel) and non-CPS (e.g., Pacific whiting) fisheries. With these fisheries in mind, this analysis considers the potential socioeconomic effects of each of the six proposed alternatives, both from an evaluation of past fishery performance and based on the Rebuilder tool modeling results, respectively.

The CPS fishing industry has already been significantly restricted since the closure of the primary directed fishery and the reduction in incidental landing limits; therefore, the below analysis considers the current state of the fishery as the baseline comparison for any additional restrictions that may be imposed by each management alternative. ACLs set since the closure of the primary directed fishery in 2015 (see Table 2) have more than adequately accommodated the minor amount of catch needed to maintain these sectors. The small amount of harvest that remains is mostly in the live bait fishery. Between 2005 and 2015, prior to the closure of the primary directed fishery, reported live bait catches averaged 2,600 mt Pacific sardine, ranging from 1,562 mt in 2014 to 3,601 mt in 2006 (see Table 4-12 in the May 2017 CPS SAFE Tables (PFMC 2017)). Since the closure of the primary directed fishery in 2015, live bait catches of Pacific sardine have been slightly lower, averaging 1,326 mt in the years 2015–2023 and ranging from 1,075 mt in 2019 to 1,996 mt in 2015 (see Table 2-3 in the 2024 CPS SAFE Appendix A (PFMC 2024a). Due to the supply role that live bait landings play in the recreational fishing sector, an expansion in demand outside the historical range is unlikely and would require an increase in demand from the recreational fishing industry. Additionally, the incidental Pacific sardine percentages and tonnage amounts that have been implemented since the closure of the primary directed fishery have generally allowed fishermen in other CPS and non-CPS fisheries that catch Pacific sardine incidentally to land their targeted catch when sardine cooccur in the schools. However, members of the CPS industry have expressed continued frustration that they must be more selective in targeting other CPS schools when the proportion of Pacific sardine mixed with the load does not meet the incidental percentage limit. If these other CPS fisheries were to be further limited, many fishermen have said it would not be economically viable for them to continue, as they would have to spend more time and resources searching for schools with few Pacific sardine.

Under Alternative 1 (No Action), the smaller-scale directed fishing sectors would expect a consistent and familiar management strategy. However, this alternative does not set catch limits that would rebuild the Pacific sardine population within the statutory timeframe. Based on the modeling results assuming a sardine removal rate of 12.16 percent, catch would not be limited below 2,500 mt for approximately 20 years (see Table 12 in APPENDIX B). However, considering the closure of the primary directed fishery and historical landings data under varying biomasses and allowable catches, the level of harvest modeled for this alternative is not realistic or even attainable for the minor fisheries that harvest Pacific sardine.

Under Alternative 2 (Zero U.S. Harvest), the smaller fishery sectors and their communities are expected to be severely and adversely impacted in the near term and would continue to be impacted until the stock reached its target rebuilding level of 150,000 mt age 1+ biomass. Additionally, these near-term impacts would come without an expectation of when they could be potentially mitigated by a shorter rebuilding timeframe. A zero harvest U.S. fishing approach (assuming that it would be adopted by the states) would completely eliminate Pacific sardine harvest in the live bait and minor directed fisheries, and curtail other fisheries that catch Pacific sardine incidentally, including other CPS fisheries and the Pacific whiting fishery. This could have far-reaching negative socioeconomic effects on the various user groups and communities that rely on these fisheries, including non-sardine CPS, groundfish, and live bait fisheries. From a fishery management perspective, it would be difficult to implement a true zero catch alternative, and it would likely have substantial adverse economic effects. In addition, NMFS regulates only the portion of the fishery that occurs in the EEZ and therefore could not fully implement this alternative. However, this alternative is further explored below for its potential impacts to the fishing industry.

Pacific sardine is one of the primary species harvested for live bait in the Southern California recreational fishery, which is part of an extremely valuable statewide recreational fishery generating over $510 million in value added impact to California in 2022 (National Marine Fisheries Service 2022). Under Alternative 2, the live bait fishery would no longer be able to provide Pacific sardine as live bait to recreational fisheries. Between 2015 and 2023, reported sardine live bait catches averaged 1,326 mt per year, or 87 percent of total live bait catch (see Table 2-3 in PFMC 2024a Appendix A). Most recently in 2023, reported live bait catches have remained similar, totaling 1,136 mt in 2023 and accounting for 88 percent of total live bait catches (PFMC 2024a). While the live bait fishery also targets anchovy, current preference for sardine in the live bait fishery would make sole reliance on anchovy highly disruptive to the sector. The live bait fishery contributes to several live bait user groups that would be severely affected economically, including vessels that harvest live bait, CPFVs and private vessels that purchase live bait for recreational fishing trips, CPFV and private boat based recreational anglers, bait and tackle shops, and tourism-related businesses that benefit from the California sportfishing industry (e.g., hotels and restaurants).

The minor directed fishery consists of a small number of niche-level harvesters that do not participate in other fisheries. They are allowed to harvest no more than 1 mt of Pacific sardine per trip. Under Alternative 2, these fishermen would be unable to provide their product; therefore, this alternative would likely have negative impacts on this sector. At the time of the 2015 primary directed fishery closure, this small sector of the fishery was adversely impacted because it was not exempt from the closure. In 2017, Amendment 16 to the CPS FMP was implemented specifically to alleviate this economic harm. Since the implementation of Amendment 16 in 2018 through 2023, an annual average of 52 mt of sardine has been harvested in the minor directed fishery coastwide. Implementation of Alternative 2 would reverse the economic relief given by Amendment 16 to fishers in the minor directed sector.

Other CPS fisheries and non-CPS fisheries incidentally harvested an average of 296 mt and 6 mt, respectively, of Pacific sardine from 2015 to 2020 (see PFMC 2022d, Table 3), and an average of 152 mt and 12 mt, respectively, from 2020 to 2023 (PFMC 2024b). Other CPS fisheries that commonly catch sardine incidentally include market squid, northern anchovy, and Pacific mackerel. The Pacific whiting fishery, valued at $64 million (NMFS 2024), accounts for a significant portion of incidental harvest in non-CPS fisheries; however, its harvest of Pacific sardine is relatively minor (see section 3.4.1). If incidental catch of Pacific sardine were prohibited, these fisheries, as they currently operate, would either be severely constrained or prohibited.

The modeling results in Table 12 of Hill et al. (2020) provide median catch values under Alternative 2; however, these values represent potential median catch by Mexico, as Alternative

2 assumes zero U.S. harvest. Therefore, the modeling results were not used to further analyze potential impacts on the U.S. fishing industry under Alternative 2.

Under Alternative 3 (Fixed Five Percent U.S. Harvest Rate), which was presented in Amendment 18 as a policy and modeling intermediary between Alternatives 1 and 2, the smaller-scale fishery sectors would experience some negative economic impacts when the sardine biomass is below 50,000 mt, compared to other alternatives. For example, had Alternative 3 been in place for the 2020–2021 fishing year, an ACL of 1,414 mt would have been implemented compared to the ACL of 4,288 mt implemented for that year (see Table 2). The 2020–2021 fishing year saw 2,498 mt in total landings (PFMC 2022c). Therefore, under the harvest policy of Alternative 3, in 2020 only 1,414 mt (and likely a lower ACT and more conservative accountability measures to provide a buffer) would need to have been allocated across both the CPS fisheries that target Pacific sardine (i.e., live bait and minor directed) and those that rely on the ability to incidentally land sardine in order to pursue other important CPS and non-CPS fisheries. Most likely, NMFS would have been forced to set an incredibly small sector-specific catch limit for the live bait fishery, which harvested an average of 1,404 mt per year from 2015 to 2020 and averaged about 1,161 mt from 2020 to 2023 (PFMC 2022c, PFMC 2024a). Cutting the live bait fishery's already small harvest in half or more would have adverse impacts to not only the live bait industry, but would also disrupt various recreational fisheries, most notably in Southern California. Negative impacts to these fishing communities would likely have negative impacts to the associated community infrastructure (i.e., tackle shops, restaurants, hotels, fuel docks, marinas).

Based on the modeling results, Alternative 3 would not restrict catch in the smaller-scale sectors in the near or long term because the projected median catch values in Table 12 of Hill et al. (2020) never decrease below recent average landings (2,200 mt, 2015–2020); however, the model assumes a very specific biomass trajectory that may or may not be realistic, depending on environmental conditions. If the spawning stock values presented in Table 10 of Hill et al. (2020) for Alternative 3 are true, then the fixed five percent ACL would restrict catch to much lower levels than reflected in the median catch values in Table 12 of Hill et al. (2020). Rebuilder tool results then indicate that based on these median values, the only alternative to rebuild the stock in the presence of fishing was Alternative 3. Given that fishing is not the likely cause of the stock decline, it is uncertain that the reduction in sardine landings for Alternative 3 compared to Alternatives 4, 5, and 6 would cause the stock to rebuild any faster.

Under Alternative 4 (2,200 mt Constant Catch), there is potential for some negative economic impacts to small-scale sectors, particularly in terms of accommodating variation in annual harvest. Annual landings of Pacific sardine averaged 1,956 mt from 2015 to 2023, ranging from a low of 1,619 mt in the 2022–2023 fishing season to a high of 2,498 mt in the 2020–2021 fishing season. Therefore, a 2,200 mt constant catch ACL under Alternative 4 can reasonably accommodate the majority of landings. While Alternative 4 utilizes the 2015–2020 average catch expected under status quo to set a reasonable constant catch guideline for ensuring long term persistence of small-scale sectors, Alternative 4 lacks the flexibility to reduce economic restriction in years of high variability.

Under Alternative 5 (Modified Constant Catch), the ACL would be set at a value slightly higher than the highest landings reported in 2019–2024. Though not modeled in the Amendment 18 rebuilding analysis, based on the modeling results for Alternative 4 (2,200 mt constant catch), this alternative is not expected to significantly restrict the small-scale sectors, compared to Alternative 3 (5 percent fixed U.S. harvest rate). Alternative 5 (under either of the two modified constant catch values considered (i.e., 3,200 mt or 2,800 mt)) would likely accommodate the current level of landings for active sectors, given that actual landings since 2015 have remained below 2,500 mt (Table 4). Under Alternative 5, landings may remain at current levels, protecting short-term economic viability of affected sectors. Further, because this alternative would set an ACL slightly above the maximum annual landings level since the 2015 closure of the primary directed fishery, it would allow greater flexibility than Alternative 4 for affected sectors, while setting a responsible maximum to ensure long term viability of the stock and the fisheries.

Given that actual landings have not exceeded 2,500 mt since the closure of the primary directed fishery in 2015 (see Table 1), a modified constant catch ACL slightly above that value is not expected to limit or negatively impact the live bait fishery, minor directed fishery, or those fisheries that incidentally encounter sardine while prosecuting other fisheries.

Under Alternative 6 (Mixed Rate U.S. Harvest), the FPA, there would be potential to provide the affected small-scale sectors with some flexibility and opportunity to persist in the short and long term. While Alternative 6 was not modeled in the original rebuilding analysis, based on modeling results for Alternatives 3 and 4 (which Alternative 6 is a combination of), it is not expected to significantly restrict small-scale sectors. Compared to Alternative 3, small-scale sectors could expect the same 5 percent fixed harvest rate above 50,000 mt, while avoiding potential negative economic impacts below 50,000 mt. As seen in Table 4, actual landings exceeded the proposed ACL under Alternative 3 in the 5 fishing years where age 1+ biomass was below 50,000 mt. In comparison, it was only in the 2020–2021 fishing year that actual landings exceeded the proposed ACL under Alternative 6. Setting a 5 percent fixed harvest rate above a stock biomass of 50,000 mt would allow affected sectors to maintain flexibility and long-term viability as the stock rebuilds. As with Alternative 3, this would avoid a situation where the stock expands and landings may vary to be greater than 2,200 mt due to increased interactions and market demand, but the live bait and minor fisheries are restricted below 2,200 mt, stunting these sectors and increasing discards of mixed hauls. If the age 1+ biomass drops below 50,000 mt again, these affected sectors can expect a constant ACL of 2,200 mt, which supports recent actual landings. Actual landings from 2020 to 2023 averaged 1,916 mt/year. Based on this average, the proposed mixed 5 percent harvest rate and 2,200 mt constant catch ACL would not severely limit the ability for small-scale harvesters and non-CPS fisheries that incidentally catch sardine to continue to operate. The only recent year where total landings exceeded the ACL that would have been in place under Alternative 6 was in the 2020–2021 fishing year (see Table 4). In comparison, actual landings would have exceeded ACLs under Alternative 3 in the last five completed fishing years, 2019–2020 through 2023–2024 (see Table 4).

Alternatives 3–6 may provide some future economic and operational advantage to industry and the communities that they support if the stock reaches the target rebuilding biomass level faster. Alternative 2 was modeled to rebuild the stock quickest but would essentially eliminate all active fishing sectors during the rebuilding process. Setting a predetermined percentage or a lower constant catch under Alternatives 3 and 4 allows for the persistence of small-scale sectors but may reduce the interannual economic flexibility. A constant catch ACL reflecting a historical average may restrict access to Pacific sardine in such a way that could result in both inefficient fishery operations and prevention of other fisheries from achieving their optimal yield due to Pacific sardine bycatch restrictions. Specifically, further restrictions on incidental fisheries would increase discards of target species as well as incidentally-caught Pacific sardine. Alternatives 5 and 6 seek to potentially mitigate these shortcomings of Alternatives 3 and 4 by providing some flexibility to account for interannual variabilities. Alternative 4–6 may also provide more long-term economic stability if the stock does temporarily decline as they would maintain a set level of opportunity, preventing the long-term consequences of short-term restriction on the remaining fishing sectors.

3.4.3 VESSEL SAFETY

None of the alternatives are expected to impact vessel safety.

3.5 CLIMATE CHANGE

Climate change is exerting interconnected effects on Pacific sardines and the ecosystems upon which they depend. Disruptions in ocean currents due to climate change can alter the distribution of nutrients and prey for Pacific sardine. Sea surface temperatures have been reported to affect the abundance/productivity of sardine, anchovy and other CPS (Chavez et al., 2003; Jacobson et al., 2001, 2005). Until the start of a strong upwelling season, the sea surface temperature in 2024 was relatively warm in most of the California Current. The El Niño/Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) cause fluctuations at annual and longer time scales, altering primary and secondary production in the California Current and influencing CPS abundances. Strong upwelling kept a heatwave in the NE Pacific from intruding into coastal waters during the summer of 2024 (PFMC 2024a). Climate change may result in the exposure of Pacific sardine to nearshore oxygen declines that are projected in the California Current (Smith et al., 2022). Some studies have projected that landings of the northern subpopulation of Pacific sardine will shift northward in response to climate change (Smith et al., 2021), as factors such as increased temperature and upwelling would likely shift both sardine and anchovy further north (Checkley et al., 2017).

The alternatives presented here are not expected to affect climate change. The purpose of the rebuilding plan is to allow harvest to continue at levels that rebuild the Pacific sardine stock in the shortest time possible while sustaining operations of the incidental, live bait, and minor directed Pacific sardine fisheries. This action will therefore not affect fishing fleet dynamics (i.e., fuel usage and emissions from the number of vessels, number of trips, amount of time spent fishing) in ways that could affect climate change.

3.6 CUMULATIVE EFFECTS IN THE AFFECTED ENVIRONMENT

The proposed action is not the only action affecting the biological and socioeconomic environment as described in this EA. There are other past, present, and reasonably foreseeable future actions that, in addition to the impacts of the action, require consideration. Sections 3.2.1, 3.3.1, and 3.4.1 on the Affected Environment describe the baseline condition of each resource (the target species, ecosystem, and fishing industry). Section 3.5 also describes the climate impacts on and from this action. The following section builds on this information to provide a cumulative effects analysis for each of these resources. Cumulative effects include past, present, and reasonably foreseeable future actions within as well as outside the scope of this action. The purpose of presenting the effects is to determine the cumulative effects resulting from the incremental impact of this action, when added to other past, present, and reasonably foreseeable future actions. With the exception of Alternative 1 (No Action), all of the action alternatives that allow fishing (Alternatives 3–6) are expected to rebuild to the selected target of 150,000 mt age 1+ biomass in very similar timeframes (between 16 and 17 years). Additionally, the potential total fishing removals of sardine under the various alternative ACLs are relatively similar in the context of impacts in the duration of this action. Therefore, for the purposes of this section, potential cumulative effects are expected to be similar across the alternatives.

3.6.1 TARGET SPECIES (PACIFIC SARDINE RESOURCE) and SARDINE IN THE ECOSYSTEM

The proposed action is not likely to result in adverse significant cumulative impacts to the Pacific sardine resource or to its role in the ecosystem as potential forage when added to other past, present, and reasonably foreseeable future actions. Sardine productivity and population size, over short (annual) and long (multidecadal) time scales, is primarily driven by ocean conditions and environmental factors. All of the alternatives considered in this section are expected to allow, and explicitly not hinder, the population of Pacific sardine to increase when environmental conditions become favorable for their productivity and growth, and therefore will not add an incremental impact to environmental forces. Outside of this environmental forcing, the primary past, present, and reasonably foreseeable future actions that may impact sardines are primarily those associated with the directed commercial harvest of Pacific sardine. The primary directed fishery for Pacific sardine was precautionarily closed during the 2015–2016 fishing year and will remain closed for the duration of this action. Once the Pacific sardine resource is considered rebuilt, and therefore no longer subject to this action, management of the species will revert to the management structure and harvest policy in the CPS FMP, which provides benefits to society while maintaining a renewable resource. This strategy takes into account the environmentally driven nature of the population as well as its role in the ecosystem. Outside of the primary directed fishery, Pacific sardine can be caught as part of the live bait fisheries, minor directed fishery, and incidentally to certain other Federal fisheries; however, landings by those fisheries are explicitly accounted for under this action with those landings being monitored against, and limited by, the ACLs implemented by this action. There are no foreseeable large changes in these other fisheries that would change their impact to Pacific sardine, however, even if there were, because any landings are accounted for against the ACL, the impact of those changes would not change. There are no state or Federal fisheries for which a significant amount of Pacific sardine is caught as bycatch and not accounted for, and research catch of this species is de minimus (less than 1 mt).

3.6.3 FISHING INDUSTRY

The proposed action is not likely to result in adverse significant cumulative impacts to the fishing industry. In the context of this action, the primary past, present, and reasonably foreseeable future actions that affect the fishing industry are those associated with the directed commercial harvest of Pacific sardine. The purpose of this action is to implement a plan that rebuilds the sardine population in the shortest possible time so that the primary directed commercial fishery can reopen, while allowing the minor directed, incidental, and live bait fisheries to continue operations in a manner that sustains harvest levels reported over the past decade and minimizes economic impact. Due to the overfished status of the Pacific sardine, the primary directed commercial fishery for Pacific sardine has been closed since the 2015–2016 fishing year and will continue to be closed until the stock is considered rebuilt. Once the Pacific sardine resource is considered rebuilt, and therefore no longer subject to this action, the fishery will reopen under the management structure and harvest policy in the CPS FMP, which provides benefits to society while maintaining a renewable resource.

An economic analysis is provided in Section 3.4, which includes discussion of non-CPS fisheries and sectors that interact with or rely on the sardine fishery. Additional cumulative impacts on fisheries from any of these action alternatives are difficult to determine because of the wide variety of environmental conditions, market dynamics, and past, present, and reasonably foreseeable future actions that might influence the other fisheries in which they participate. Of the impacts that are available for consideration, no change is expected from the FPA that would contribute to cumulative impacts on these fisheries.

4 MAGNUSON-STEVENS ACT ANALYSIS

Below are the 10 National Standards as contained in the Magnuson-Stevens Fishery Conservation and Management Act (Magnuson-Stevens Act), and a brief discussion of how each alternative, including the Final Preferred Alternative (FPA), is consistent with the National Standards, where applicable. In recommending the preferred alternative, the Pacific Fishery Management Council (Council) considered the alternatives and the analysis of impacts in the above Environmental Assessment, which demonstrate consistency with the national standards.

4.1 NATIONAL STANDARD 1—Optimum Yield

Conservation and management measures shall prevent overfishing while achieving, on a continuing basis, the optimum yield (OY) from each fishery for the United States fishing industry.

Each alternative in the range of alternatives, except Alternative 2 (Zero U.S. Harvest), selects the existing harvest control rules (HCRs) for the overfishing limit (OFL) and acceptable biological catch (ABC) and management measures for the northern subpopulation of Pacific sardine (Pacific sardine) as part of the rebuilding plan. The HCRs have been determined to prevent overfishing by the Council's Scientific and Statistical Committee (SSC), and the fishery is managed so that catch does not approach the OFL (see Section 1.4.2). Additionally, the existing HCRs and management measures were developed to conserve the Pacific sardine stock during expected periods of low abundance, while also allowing access to limited amounts of Pacific sardine and other profitable fish stocks that interact with Pacific sardine. Amendment 18 selected status quo management as the rebuilding plan (here, Alternative 1 (No Action)), which does not specifically set an ACL at expected harvest levels, and instead relies on existing management and accountability measures to restrict overall harvest; however, the U.S. District Court for the Northern District of California determined that the rebuilding plan must rely on ABC/annual catch limits (ACLs) to rebuild the fishery, even if other measures are also employed. All alternatives in this analysis assume full ACL removals. The Rebuilder analysis modeled that Alternative 1 as a U.S. harvest rate of 12.16 percent would not rebuild the stock to the target age 1+ biomass of 150,000 mt within 30 years. The remainder of the alternatives would prevent overfishing and rebuild within the statutory timeframe based upon the Rebuilder analysis. Alternative 6, the Final Preferred Alternative, sets the OFL and ABC according to the HCRs, and sets ACLs to support rebuilding of the Pacific sardine stock and prevent overfishing.

OY is defined "as the amount of fish that will provide the greatest overall benefit to the Nation, particularly with respect to food production and recreational opportunities and taking into account the protection of marine ecosystems" (50 CFR 600.310(3)(i)(A)). The HCRs for Pacific sardine take into account the protection of the marine ecosystem. However, compared to Alternatives 1, 5, and 6, Alternatives 2, 3, and 4 would result in reduced net benefit to the Nation as they would restrict potential recreational fishing opportunities through possible limitations to the live bait fishery and restrict supply of seafood to the Nation through limitations on incidental landing limits for other coastal pelagic species (CPS) and non-CPS stocks. The Final Preferred Alternative will allow for current average harvest levels with room for flexibility as opportunities for recreational fishing, incidental encounters, or markets dictate.

For overfished stocks, the Magnuson-Stevens Act's National Standard 1 guidelines (see 50 CFR 600.310(j)(3)) provide direction on determining certain rebuilding reference points in order to specify T_{TARGET}, including a target rebuilt biomass level, T_{MIN} (i.e., the minimum time to rebuild the stock assuming zero fishing morality), and T_{MAX} (i.e., the maximum allowable time to rebuild the stock). Amendment 18 established the rebuilding target (i.e., rebuilt biomass), T_{MIN}, and T_{MAX}, which were upheld by the U.S. District Court. Under the Final Preferred Alternative, those reference points remain unchanged and the T_{TARGET} is 17 years, setting the rebuilding reference points as follows (see also Section 1.4):

$$T_{MIN} = 12 \text{ years}$$

$$T_{MAX} = 24 \text{ years}$$

$$T_{TARGET} = 17 \text{ years}$$

Rebuilt biomass = 150,000 mt age 1+ biomass

The T_{TARGET} is the rebuilding timeline expected under the FPA, in the context of T_{MIN} and T_{MAX}, and was determined to be the shortest time possible to rebuild the stock, taking into account the biology of the stock, the needs of fishing communities, and the interaction of the stock within the marine ecosystem. A discussion of rebuilding timelines under management alternatives in the context of these reference points is included in years under Section 3.2.2.

4.2 NATIONAL STANDARD 2—Scientific Information

Conservation and management measures shall be based upon the best scientific information available.

The best scientific information available (BSIA) was used in the development of the range of alternatives and the selection of the Final Preferred Alternative. The Council's recommendation of the FPA is based upon a holistic analysis of the Rebuilder modeling results, the basic biology and life history of Pacific sardine, and the history of the Pacific sardine fishery on the U.S. West Coast. Each of the alternatives in the range of alternatives, including the FPA but excluding Alternative 2 (Zero U.S. harvest), retains the annual harvest specifications process for Pacific sardine, in line with the requirements in the Fishery Management Plan (FMP) for when the biomass is below certain thresholds (i.e., 50,000 mt and 150,000 mt). The annual Pacific sardine harvest specifications process establishes overfishing limits, acceptable biological catch levels, annual catch limits (including those under the FPS, which are adjusted based on the status of the stock), and other management measures based on annual determinations of BSIA. For example, stock assessments used to inform annual harvest specifications and management measures are reviewed by the Council's Scientific and Statistical Committee (SSC) and, as part of a separate BSIA process for benchmark assessments, a panel of independent experts known as a stock assessment review panel. These reviews then become a part of the annual BSIA determination process the SSC uses when recommending overfishing limits and acceptable biological catch levels that account for scientific uncertainty in those overfishing limits.

The U.S. District Court for the Northern District of California found insufficient support for the use of the CalCOFI index in calculating E_{MSY} for setting annual harvest specifications (see Section 1.4.2). NMFS is currently reviewing the correlation of the CalCOFI index with Pacific sardine productivity as a part of the 2025–2026 Pacific harvest specifications process.

4.3 NATIONAL STANDARD 3—Management Units

To the extent practicable, an individual stock of fish shall be managed as a unit throughout its range, and interrelated stocks of fish shall be managed as a unit or in close coordination.

This action is related to an existing management unit stock in the CPS FMP, the northern subpopulation of Pacific sardine, and, under any of the alternatives, is not changing how that stock is managed according to its range or relationship to other stocks. The northern subpopulation of Pacific sardine is managed as a unit throughout its range within U.S. waters by the National Marine Fisheries Service in cooperation with the Pacific Fishery Management Council, and the west coast states of California, Oregon, and Washington.

4.4 NATIONAL STANDARD 4—Allocations

Conservation and management measures shall not discriminate between residents of different states. If it becomes necessary to allocate or assign fishing privileges among various United States fishermen, such allocation shall be: (A) fair and equitable to all such fishermen, (B) reasonably calculated to promote conservation, and (C) carried out in such a manner that no particular individual, corporation, or other entity acquires an excessive share of such privileges.

During the annual Pacific sardine specifications process that employs the HCRs and other provisions in the CPS FMP, the Council determines and recommends to NMFS allocations to user groups for opportunity, such as the allowance for live bait fisheries, minor directed fisheries, and incidental fisheries. Allocations to these sectors would continue under any of the alternatives (excluding Alternative 2, in which no harvest would be permitted). None of the alternatives in the described range, including the FPA, would discriminate between residents of different states. The management framework in the CPS FMP dictates measures that restrict harvest among the fishing sectors throughout the fishing year (see Section 1.4.2), which effectively protect fisheries in northern states from inequitable access to allowable harvest during months when weather conditions and stock migrations may otherwise preclude fishing activity. All of the alternatives except Alternative 2 would maintain that management framework as part of the rebuilding plan.

4.5 NATIONAL STANDARD 5—Efficiency

Conservation and management measures shall, where practicable, consider efficiency in the utilization of fishery resources, except that no such measure shall have economic allocation as its sole purpose.

This action would allow for efficient utilization of the Pacific sardine resource while still allowing the stock to rebuild. The CPS finfish fishery operates under a limited entry (LE) program described in the CPS FMP and in regulation. The goals of the LE program are to promote efficiency and profitability in the fishery, achieve OY, accommodate existing fishery segments, and use resources spent on management of CPS efficiently. While the primary directed commercial fishery for Pacific sardine is closed, the affected LE fisheries include the CPS finfish vessels that catch sardine incidentally to other targeted CPS (e.g., market squid), and the groundfish trawl vessels that catch sardine incidentally to other target species (e.g., whiting). Alternative 1 (No Action) selects the existing HCRs and management measures for Pacific sardine in the CPS FMP for when the stock is at low biomass levels; thus, Alternative 1 would allow the Council to manage the remaining sectors of the Pacific sardine fishery with minimal administration or enforcement change and no additional costs; however, the U.S. District Court found that adopting status quo management as the rebuilding plan violates the MSA because it does not set an ABC/ACL that would rebuild the sardine population by the target date. Alternative 2 (Zero U.S. Harvest) would unnecessarily disallow any utilization of fishery resources, and Alternatives 3 and 4 could result in inefficient fishery operations for Pacific sardine, including increased at-sea discards if interactions increase but catch limits do not. Other fisheries that incidentally catch Pacific sardine may be prevented from achieving the OY for their target stock when incidental catch of Pacific sardine is further restricted by low ACLs. Alternatives 5 and 6 (the FPA) would allow for flexibility to efficiently manage the remaining sectors of the Pacific sardine fishery as harvest levels and stock biomass fluctuate annually.

4.6 NATIONAL STANDARD 6—Variations and Contingencies

Conservation and management measures shall take into account and allow for variations among, and contingencies in, fisheries, fishery resources, and catches.

Although Alternative 1 adopts a specific management framework for setting harvest levels each year, it also allows the Council to adapt these annual harvest specifications and management measures, if necessary, based on the best scientific information available on the resource and the associated fisheries. Alternatives 2 through 6 (including the FPA) would pre-determine future ACLs and thereby limit the Council's ability to react to any variations among, and contingencies in fisheries and fishery resources. However, because Pacific sardine management and science is reviewed annually, and the FPA would not change that, under the FPA, there is still inherently an ability of the management to account for certain variations and contingencies.

4.7 NATIONAL STANDARD 7—Costs and Benefits

Conservation and management measures shall, where practicable, minimize costs and avoid unnecessary duplication.

Alternative 1 uses the existing management measures for Pacific sardine as the rebuilding plan. This strategy avoids duplication efforts in minimizing fishing mortality on Pacific sardine, as the CPS FMP already provides mechanisms to reduce harvest concurrently with a decrease in biomass. Compared to Alternative 1, Alternatives 2–6 (including the FPA) impose additional management measures to the existing management framework by establishing pre-determined ACLs. Alternative 6 (the FPA) would not result in additional costs or unnecessary duplication for the affected entities, including the fishing industry, which is discussed in further detail in Section 3.4. Established annual research efforts and analysis will continue to inform progress towards rebuilding under the FPA.

4.8 NATIONAL STANDARD 8—Communities

Conservation and management measures shall, consistent with the conservation requirements of this Act (including the prevention of overfishing and rebuilding of overfished stocks), take into account the importance of fishery resources to fishing communities by utilizing economic and social data that meet the requirements of National Standard 2, in order to (A) provide for the sustained participation of such communities, and (B) to the extent practicable, minimize adverse economic impacts on such communities.

The CPS fishing industry has already been suffering adverse socioeconomic impacts since the closure of the primary directed fishery in 2015 and the subsequent reductions in incidental allowances. Both of these measures were mandated by the CPS FMP in response to decreasing Pacific sardine biomass. Using the fishery's current state as a baseline comparison for selecting a rebuilding plan, Alternatives 1, 5, and 6 (the FPA) will likely adequately provide for sustained participation for the smaller sectors of the fishery, thus minimizing additional and unnecessary adverse economic impacts. The Final Preferred Alternative was recommended by the industry members of the Coastal Pelagic Species Advisory Subpanel (Agenda Item J.2.a Supplemental CPSAS Report 1, November 2024), who stated the FPA would provide for sustained participation of ongoing sectors. Alternatives 2, 3, and 4 would impose additional and unnecessary socioeconomic impacts.

4.9 NATIONAL STANDARD 9—Bycatch

Conservation and management measures shall, to the extent practicable, (A) minimize bycatch, and (B) to the extent bycatch cannot be avoided, minimize the mortality of such bycatch.

Catch limits considered in the range of alternatives have the potential to impact bycatch in the Pacific sardine fishery. Pacific sardine is an incidentally-harvested species in CPS (e.g., market squid, mackerel) and non-CPS (e.g., Pacific whiting) fisheries. The CPS FMP restricts incidental landings of Pacific sardine to 45 percent of the overall landing, by weight, when the stock is below the CUTOFF biomass of 150,000 mt and above the minimum stock size threshold (MSST) of 50,000 mt age 1+ biomass, and no more than 20 percent when it is below MSST (see Section 1.4). When CPS fishermen encounter schools of target species appearing to be mixed with more Pacific sardine than the incidental percent landings allowance, they must release the entire haul. When possible, they avoid mixed schools altogether. Processors often prefer to have landings without high levels of incidental species in order to reduce the time to sort fish. Non-CPS fisheries do not always have the ability to avoid capturing Pacific sardine, and operationally could not reduce mortality of resulting discards. See section 3.4.1.4 for valuation of these fisheries and mixed landings.

Alternative 2 was modeled as zero U.S. harvest that would eliminate incidental retention, increasing incidental fishery operational costs associated with avoiding or releasing mixed schools of CPS and releasing dead discards of Pacific sardine while processing non-CPS catch at sea. The limited catch under Alternatives 3 and 4 would allow for the persistence of small-scale sectors but may result in tightened restrictions on incidental catch, increasing discards inseason as landings approach the ACL. Alternatives 5 and 6 (the FPA) provide some flexibility in catch limits to account for interannual variabilities and mitigate the risk of increased discards in the incidental fisheries.

4.10 NATIONAL STANDARD 10—Safety of Life at Sea

Conservation and management measures shall, to the extent practicable, promote the safety of human life at sea.

Alternatives considered in the range of alternatives, including the FPA, do not impact safety at sea in the Pacific sardine fishery.

4.11 Section 303(a)(9) Fishery Impact Statement

Section 303(a)(9) of the Magnuson-Stevens Act requires that a fishery impact statement be prepared for each FMP amendment. A fishery impact statement is required to assess, specify, and analyze the likely effects, if any, including the cumulative conservation, economic, and social impacts, of the conservation and management measures on, and possible mitigation measures for (a) participants in the fisheries and fishing communities affected by the plan amendment; (b) participants in the fisheries conducted in adjacent areas under the authority of another Council; and (c) the safety of human life at sea, including whether and to what extent such measures may affect the safety of participants in the fishery.

The EA prepared for this plan amendment constitutes the fishery impact statement. The likely effects of the proposed action are analyzed and described throughout the EA. The effects of the proposed action on safety of human life at sea are discussed above under National Standard 10. Based on the information reported in this section, there is no need to update the Fishery Impact Statement included in the FMP.

The proposed action affects the Pacific Coast sardine fishery in the EEZ off the U.S. West Coast, which is under the jurisdiction of the Pacific Fishery Management Council. Impacts on participants in fisheries conducted in adjacent areas under the jurisdiction of other Councils are not anticipated as a result of this action.

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6 APPENDIX A

Table 5. Comparison of ACLs and NSP removals under Alternatives 3 and 6. Note that the stock biomass age 1+ biomass has never dropped below 27,000 mt. Alternatives 3 and 6 produce the same ACL above a stock age 1+ biomass of 50,000 mt.

Biomass Level (mt)	ACL under Alt 3 (5%) (mt)	ACL Under Alt 6 (mt)	NSP removal under Alt 6, Accounting SSP (mt)
9,000	450	2,200	506
10,000	500	2,200	506
11,000	550	2,200	506
12,000	600	2,200	506
13,000	650	2,200	506
14,000	700	2,200	506
15,000	750	2,200	506
16,000	800	2,200	506
17,000	850	2,200	506
18,000	900	2,200	506
19,000	950	2,200	506
20,000	1,000	2,200	506
21,000	1,050	2,200	506
22,000	1,100	2,200	506
23,000	1,150	2,200	506
24,000	1,200	2,200	506
25,000	1,250	2,200	506
26,000	1,300	2,200	506
27,000	1,350	2,200	506
28,000	1,400	2,200	506
29,000	1,450	2,200	506
30,000	1,500	2,200	506
31,000	1,550	2,200	506
32,000	1,600	2,200	506
33,000	1,650	2,200	506
34,000	1,700	2,200	506
35,000	1,750	2,200	506
36,000	1,800	2,200	506
37,000	1,850	2,200	506

Biomass Level (mt)	ACL under Alt 3 (5%) (mt)	ACL Under Alt 6 (mt)	NSP removal under Alt 6, Accounting SSP (mt)
38,000	1,900	2,200	506
39,000	1,950	2,200	506
40,000	2,000	2,200	506
41,000	2,050	2,200	506
42,000	2,100	2,200	506
43,000	2,150	2,200	506
44,000	2,200	2,200	506
45,000	2,250	2,200	506
46,000	2,300	2,200	506
47,000	2,350	2,200	506
48,000	2,400	2,200	506
49,000	2,450	2,200	506
50,000	2,500	2,200	506
51,000	2,550	2,550	586.5
52,000	2,600	2,600	598
53,000	2,650	2,650	609.5
54,000	2,700	2,700	621
55,000	2,750	2,750	632.5
56,000	2,800	2,800	644
57,000	2,850	2,850	655.5
58,000	2,900	2,900	667
59,000	2,950	2,950	678.5
60,000	3,000	3,000	690
61,000	3,050	3,050	701.5
62,000	3,100	3,100	713
63,000	3,150	3,150	724.5
64,000	3,200	3,200	736
65,000	3,250	3,250	747.5

7 APPENDIX B

PACIFIC SARDINE REBUILDING ANALYSIS BASED ON THE 2020 STOCK ASSESSMENT

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Introduction

The Pacific sardine (*Sardinops sagax caerulea*) northern subpopulation (NSP) has been managed under the PFMC's CPS-FMP since 2000. Stock assessments have been conducted to support annual management specifications since 1995. The stock underwent a rapid increase throughout the 1980s and 1990s, peaking in 2000 and again in 2005, and declining from 2006 to present low levels. The stock was declared overfished in June 2019. The following analysis, the first of its kind for Pacific sardine, evaluates harvest alternatives for the full rebuilding plan.

Overview of the 2020 benchmark stock assessment

The 2020 benchmark assessment (Kuriyama et al. 2020) was developed using Stock Synthesis (SS version 3.30.14) and included fishery and survey data collected from mid-2005 through 2019. The model was based on a July-June biological year (aka 'model year'), with two semester-based seasons per year (S1=Jul- Dec and S2=Jan-Jun). Catches and biological samples for the fisheries off ENS, SCA, and CCA were pooled into a single MexCAL fleet, for which selectivity was modeled separately in each season (S1 and S2). Catches and biological samples from OR, WA, and BC were modeled by season as a single Pacific Northwest (PNW) fleet. A single AT survey index of abundance from ongoing SWFSC surveys (2006-2019) was included in the model.

The 2020 base assessment model incorporated the following specifications:

- Sexes were combined; ages 0-8+.
- Two fisheries (MexCal and PacNW fleets), with an annual selectivity pattern for the PNW fleet and seasonal selectivity patterns (S1 and S2) for the MexCal fleet.
- MexCal fleets: domed age-based selectivity (time-varying and non-parametric [option 17 in Stock Synthesis]).
- PNW fleet: asymptotic age-based selectivity (time-varying for the inflection point).
- AT survey age compositions with effective sample sizes set to 1 per cluster (externally).
- Age compositions for the spring AT survey omitted.
- Fishery age compositions with effective sample sizes calculated by dividing the number of fish sampled by 25 (externally) and lambda weighting=1 (internally);
- Initial equilibrium ("SR regime" parameter) estimated with the 'lambda' for this parameter set to zero (no penalty contributing to total likelihood estimate).
- Natural mortality (M) estimated with a prior.
- Recruitment deviations estimated from 2005-2018.
- Virgin recruitment estimated, and total recruitment variability (σR) fixed at 1.2.
- Beverton-Holt stock-recruitment relationship with steepness fixed at h=0.3.
- Initial fishing mortality (F) estimated for the MexCal S1 fleet and assumed to be 0 for the other fleets.
- F for the 2020-1 to 2020-2 model years set to those for the 2018 (S2) and 2019 (S1) model years.
- AT survey biomass 2006-2019, partitioned into two (spring and summer) surveys, with catchability (Q) set to 1 for 2005-2014 and 0.733 for 2015-2019.
- AT survey selectivity is assumed to be uniform (fully selected) above age 1 and estimated annually for age-0.

Spawning biomass, recruitment, and stock biomass (ages 1+) time series from the 2020 benchmark stock assessment are shown in Figures 1-3, respectively.

Recent management performance
The Pacific sardine NSP underwent a decline beginning in 2006. The directed commercial fishery was closed in July 2015 when age 1+ biomass dropped below 150,000 mt 'Cutoff' threshold in the harvest guideline control rule. The stock dropped below the 50,000 mt minimum stock size threshold (MSST) in 2019 and was declared overfished in June 2019. OFLs, ABCs, ACTs, and realized landings (total and NSP) since the 2015-16 management year are provided in Table 1. Ensenada landings of NSP sardine, also included in this analysis, are provided in Table 1.

Rebuilding calculations

1. Rebuilding software: Pacific sardine rebuilding analyses were conducted using Rebuilder package version 3.12g (June 2020). Rebuilder is an age-structured population dynamics simulator that projects the population forward in time, accounting for recruitment, growth, natural mortality, and fishing mortality. It calculates the probabilities of rebuilding the stock to SB_{MSY} (rebuilt) for a given range of recruitment and fishing scenarios. Rebuilder was written by Dr. Andre Punt for conducting groundfish rebuilding analyses (Punt 2012) and recently revised to allow for projections based on Pacific sardine harvest control rules. Sardine rebuilding analyses were conducted from March through July 2020, and the SSC provided recommendations for revisions to the analysis at their June 2020 meeting. Subsequently, the SSC's CPS Subcommittee held a meeting July 15-16 to review preliminary rebuilding model results. Both the SSC and CPS Subcommittee recommendations have been incorporated in the following analyses. The Rebuild.dat file is provided in Appendix A, and the multiple parameter line file (Rebuild_samp.sso), used to set starting values and target depletion levels over a range of steepness values, is provided in Appendix B.

2. Definition of SB_0: SB_0 was estimated with Rebuilder by averaging recruitments over two ranges of model years to characterize outcomes based two states of nature. The first, '$SB_{0(2005\text{-}18)}$', was based on all estimated recruitments from the assessment model (2005-18), and the second scenario, '$SB_{0(2010\text{-}18)}$' based on a subset of years with low recruitments (2010-18). Resulting distributions of SB_0 for the two productivity scenarios are shown in Figure 4. Average SB_0 was 377,567 mt for the $SB_{0(2005\text{-}18)}$ model and 104,445 mt for the $SB_{0(2010\text{-}18)}$ model.

3. Biological data: Biological data by age were taken from Kuriyama et al. (2020). Data included natural mortality rate, weight-at-age, maturity-at-age, fecundity-at-age, selectivity-at-age, population numbers-at-age for 2019 (year declared overfished), and population numbers-at-age for the 2020. Vectors of biology-at-age are provided in Table 2. Mean generation time in this rebuilding analysis was estimated to be 3 years. In order to transition the modeled time step from seasonal (SS) to annual (Rebuilder), it was necessary to change fecundity at age zero from 0.0046 to 0.0000 (Table 2). Net spawning output-at-age is highest at age-2 (Figure 5). Natural mortality rate was ~0.584 for all ages, but this value varied slightly over the full range of profiled steepness. Steepness was profiled in SS, providing different initial numbers-at-age for 2020 based on each steepness level (see Section 5.c below).

4. Fishing mortality and selectivity: A single fleet (fishery) was modeled using selectivity and weight-at-age from the MexCal Season 2 (S2; Table 2). MexCal-S2 (Jan-Jun) best typifies the selectivity pattern for the overall MexCal fleet, and most of the northern sub-population (NSP) sardine catch is taken by this fishery at that time of year. The PNW fleet was not modeled given the low probability that sardine will be taken for live bait or incidentally in the foreseeable future.

   The MexCal fleet includes catches for both US and Mexico (Ensenada) fisheries. Mexican sardine catch was treated in two ways for these analyses: 1) as a fixed amount of catch (mt) added to the US control rule, or 2) as a fixed rate added to the US fishing rate, i.e., proportionate to the age 1+ biomass.

   For the constant Mexico catch scenarios, total catch was modeled using the ABC control rule for Pacific sardine, with addition of a constant tonnage to account for Mexico removals. We based Mexico's constant catch (6,044 mt) on the average of NSP landed in Ensenada between 2015-16 and 2018-19 (Table 1). Total catch was defined:

   Catch = ($\text{Biomass}_{\text{age1+}}$ * US Exploitation Rate * Buffer * US Distribution) + Mexico catch

   where Buffer=0.7762 (Tier 2, Pstar 0.4), US Distribution=0.87, and Mexico catch=6,044 mt per year for all fixed Mexico catch strategies.

   For the constant Mexico harvest rate scenarios, a single constant exploitation rate of 9.9% was applied as opposed to assuming a constant catch of 6,044mt. The value was calculated from stock assessment models with steepness values ranging from 0.3 to 0.8 (with intervals of 0.05). Specifically, the stock assessment model was run with a single fixed steepness value, and the season 1, age 1+ biomass values were averaged from the 2015-15 to 2018-19 management years. The assumed average NSP catch of 6,044 mt was divided by the average biomass value to calculate average exploitation rates at each steepness value. The steepness-specific exploitation rates were then averaged, weighted by relative probabilities (Table 3a) to calculate a single exploitation rate of 9.9%. Relative exploitation rates for the US and Mexico fisheries for the three harvest alternatives are shown in Table 3b.

5. Inclusion of uncertainty: Uncertainty in the rebuilding analysis was accounted for in several ways:
   a. The spawner-recruit relationship used a high σR value (1.2; from Kuriyama et al. 2020), allowing for large fluctuations in recruitment in all rebuilding projections.
   b. Uncertainty was explored by rebuilding under two different productivity states of nature (see '2. Definition of SB_0' above). Projections between the two productivity scenarios differ with respect to the level of the rebuilding target (SB_{MSY}), and the magnitude of potential recruitments generated when rebuilding to that level. In addition, each state of nature draws from a distribution of SB_0 as opposed to a single value.

c. Uncertainty in Mexico's annual NSP sardine catch was partially addressed by applying a constant harvest rate versus a constant tonnage per year (see Section 4 above). Note this does not address larger questions regarding actual stock source of Ensenada landings from year to year or general hypotheses regarding subpopulation structure of the transboundary stocks.
d. Finally, uncertainty in spawner-recruit calculations was accounted for by profiling on the Beverton-Holt steepness parameter (h). This was accomplished by first profiling h in the Stock Synthesis model to provide new starting values for the multiple parameter file (Appendix B). Steepness was profiled from 0.3 to 0.8 in 0.05 intervals. Attempts to model steepness at values lower than 0.28 resulted in runtime errors in Rebuilder, so the profile was constrained to steepness values of 0.3 and higher. For sardine, changing steepness affected the initial numbers-at age in 2020 and, to a trivial extent, natural mortality (Appendix B). Steepness was poorly estimated in Stock Synthesis, with negative log-likelihoods ranging from 91.6851 at h=0.3 to 94.2932 at h=0.8 (Figure 6). To calculate relative probabilities for constructing the multiple parameter line file (Rebuild_samp.sso; see Appendix B), the difference between the lowest and highest likelihood was calculated and the differences were normalized. Relative probabilities associated with each normalized likelihood value were calculated and multiplied by 100. Steepness of 0.3 had the highest relative probability (19/100) whereas parameters associated with steepness of 0.8 had the lowest relative probability (0/100) (Table 4, Figure 6).

6. <u>Definition of rebuilt:</u> Rebuilding is determined to be met when the spawning stock has a greater than 0.5 probability of rebuilding to SB_{MSY} under a given harvest scenario. Rebuilder makes this determination when the stock has reached the target depletion level (0.X*SB_0). For most groundfish stocks, target depletion is 0.4*SB_0 based on a meta-analysis of groundfish productivity. No such meta-analysis exists for Pacific sardine, so it was necessary to use Rebuilder to determine an appropriate target depletion level. This was accomplished by running the model as follows:
   a. Sardine control rule was reset to: E=0.XX, Buffer=1, Distribution=1, and Mexico catch=0.
   b. σR was set to 0.
   c. Target depletion was set to 1.0.
   d. The simulation was run, and the population rebuilt to SB_0 for F=0. SB_{MSY} was the equilibrium biomass while fishing at E_{MSY} with the above sardine control rule settings.
   e. Target depletion was then equal to SB_{MSY}/SB_0.

   Since Rebuilder samples across a range of steepness levels, and steepness and E_{MSY} are linked, it was necessary to iteratively search for an $\mathrm{E_{MSY}}$ corresponding to each steepness. Once E_{MSY} was found, simulations were rerun, as above, and steepness-specific target depletions were determined. The above analyses were conducted for both the high and low productivity models, and results are presented in Table 4. Estimates of E_{MSY} and target depletion were nearly identical for both scenarios. E_{MSY} ranged from 0.075 at steepness=0.3, and 0.64 at steepness=0.8. Target depletion ranges from 0.42983 for steepness=0.3 to 0.2057 for steepness=0.8. As expected, median catch and SB_{MSY} were markedly different for the two states of nature (Table 4). While it is possible to model multiple target depletion levels in Rebuilder, the SSC's CPS Subcommittee recommended running all simulations with a single target depletion value. A single target depletion value was calculated as the average, weighted by relative probabilities (Table 4), at each steepness value. Weighted averages from the two scenarios were then averaged resulting in a single target depletion value of **0.365**. Based on this single target depletion level and average SB_0 estimates for the two states of nature, the average target SB rebuilding levels are:

- $SB_{0(2005\text{-}18)}$: 377,567 * 0.365 = **137,812 mt**
- $SB_{0(2010\text{-}18)}$: 104,445 * 0.365 = **38,122 mt**

7. Alternate rebuilding strategies:

Three alternative harvest strategies were analyzed for the rebuilding plan:
Alt 1: 'Status quo' US management.
Alt 2: Zero US harvest.
Alt 3: US five percent fixed harvest rate.

For the constant Mexico catch runs, harvest strategies were:
Alt 1: US E=0.18 (prorated by Buffer and US Distribution) + Mexico catch=6,044 mt
Alt 2: US E=0.00 + Mexico catch 6,044 mt
Alt 3: US E=0.05 (not prorated) + Mexico catch=6,044 mt

For the constant Mexico harvest rate runs, strategies were:
Alt 1: Total E=0.2202 (where US E=0.1216 and Mexico E=0.0986)
Alt 2: Total E=0.0986 (where US E=0.0000 and Mexico E=0.0986)
Alt 3: Total E=0.1486 (where US E=0.0500 and Mexico E=0.0986)

The above strategies were evaluated for both productivity states of nature.

Note that the current harvest control rules (HCRs: i.e. OFL, ABC, HG) for Pacific sardine modulate exploitation rate based on CalCOFI sea surface temperature. The Rebuilder package is unable to incorporate environmental effects, nor do reliable environmental forecasts exist for the coming decades. So, for purposes of this rebuilding analysis, the static stochastic E_{MSY}= 0.18 yr^{-1} from the recent management strategy evaluation (Hurtado and Punt 2013) was be used to project the population forward under the 'Status Quo' harvest strategy.

Results

Interpretation of the results should consider the different target biomass levels for both states of nature (see SB_0 distributions in Figure 4). The difference between these two states of nature arises from the number and magnitude of annual recruitments considered for each state of nature. Average SB_0 levels were 377,567 mt for $SB_{0(2005\text{-}18)}$ and 104,445 for $SB_{0(2010\text{-}18)}$ (Tables 4 and 5). Average target SB_{MSY} levels were 137,812 mt for $SB_{0(2005\text{-}18)}$ and 38,122 mt for $SB_{0(2010\text{-}18)}$ (Tables 4 and 5). It is important to note that individual rebuilding simulations (2,000 per run) were based on draws from the broad respective distributions of SB_0 (Figure 4), and probabilities of rebuilding were based on a corresponding range of $SB_{0.365}$ target biomass values. For the

$SB_{0(2005\text{-}18)}$ state of nature, SB_0 values ranged from 77,476 to 1,606,085 mt (Figure 4) and corresponding $SB_{0.365}$ values ranged from 28,279 to 586,221 mt. For the $SB_{0(2010\text{-}18)}$ state of nature, SB_0 values ranged from 34,849 to 455,497 mt (Figure 4) and corresponding $SB_{0.365}$ values ranged from 12,723 to 166,256 mt.

Rebuilding probabilities were examined with two metrics: 1) with respect to rebuilding to target SB_{MSY}, and 2) rebuilding to the 150,000 mt of age 1+ biomass ('Cutoff' level in the sardine harvest guideline control rule). With Total F=0, the spawning stock rebuilds above target depletion by 2029 for $SB_{0(2005\text{-}18)}$ and 2022 for $SB_{0(2010\text{-}18)}$ (Tables 6 and 7, resp.). For $SB_{0(2005\text{-}18)}$ and fixed Mexican catch (6,044 mt), the spawning stock rebuilds by 2041 with US exploitation rate=0 (US 0%) and does not rebuild with higher exploitation rates (Table 6). For $SB_{0(2005\text{-}18)}$, with fixed Mexican exploitation rate=9.9%, the spawning stock rebuilds by 2036 with US 0% and 2047 with US 5% (Table 6; Figure 7a). For $SB_{0(2010\text{-}18)}$, with fixed Mexican catch, the spawning stock rebuilds by 2023 with US 0%, or 2024 with US 5% (Table 7; Figure 7a). For $SB_{0(2010\text{-}18)}$, with fixed Mexican exploitation rate=9.9%, the stock rebuilds by 2022 with US 0%, 2023 US 5%, and 2024 US 18% (Table 7; Figure 7a). Based on these results, T_{MIN} for $SB_{0(2005\text{-}18)}$ is 2029, and T_{MAX} (2031) would be 10 years from the onset of the rebuilding plan, anticipated to be implemented by 2021 (Table 5). For the $SB_{0(2010\text{-}18)}$ state of nature, T_{MIN} is 2022 and T_{MAX} would also be 2031 (Table 5). Probabilities of rebuilding to $SB_{0.365}$ by T_{MAX} are provided for the three harvest alternatives and two states of nature in Table 5. Under the $SB_{0(2005\text{-}18)}$ scenario, none of the three harvest alternatives rebuild by T_{MAX}, whereas all three of the harvest alternatives rebuild the stock by T_{MAX} under the $SB_{0(2010\text{-}18)}$ scenario (Table 5).

With respect to 'Cutoff', the age 1+ stock rebuilds above 150,000 mt with Total F=0 by 2027 for $SB_{0(2005\text{-}18)}$ and 2037 for $SB_{0(2010\text{-}18)}$ (Tables 8 and 9, Figure 7b). For $SB_{0(2005\text{-}18)}$ and fixed Mexican catch, the stock only rebuilds above 150,000 mt by 2036 when US E=0% (Table 8; Figure 7b). For $SB_{0(2005\text{-}18)}$ and fixed Mexican exploitation, the age 1+ stock rebuilds by 2033 (US E=0%) and 2037 (US E=5%; Table 8). For $SB_{0(2010\text{-}18)}$, the stock did not rebuild above 150,000 mt under any harvest scenarios (Table 9; Figure 7b). Note, for the $SB_{0(2005\text{-}18)}$ models, the age 1+ stock rebuilds above 150,000 mt sooner than rebuilding to target SB levels.

Median spawning stock biomass (SB) was greater than 50,000 mt by 2023 with Total F=0 and 2026 with fixed rate and US 0% with the $SB_{0(2005\text{-}18)}$ scenario (Table 10; Figure 8). With Total F=0, the median spawning stock biomass exceeded 150,000 mt by 2033 (Table 10). In no other harvest scenarios did the median SSB exceed 50,000 nor 150,000 mt. In the $SB_{0(2010\text{-}18)}$ scenario, median SB exceeded 50,000 mt by 2027 (Table 11) and did not exceed 50,000 mt in any other harvest scenario (Table 11). Detailed figures including values of 5th, 25th, 50th, 75th, and 90th percentiles are included for $SB_{0(2005\text{-}18)}$ (Figure 9) and $SB_{0(2010\text{-}18)}$ (Figure 10).

The definition of rebuilding does not require the population to sustain a biomass greater than reference biomass values once that level has been attained. As a result, scenarios with fixed catch and fixed exploitation rate show SB declining through time despite probabilities of recovery remaining above 0.5 (see gray shaded values in Tables 10 and 11). In these cases, the population exceeded a particular biomass level at some point and was recorded as rebuilt.

Scenarios with fixed Mexican catches severely depleted the population, whereas scenarios with a fixed Mexican harvest rate sustained some level of catch. Median total catch values ranged from 0 to ~8,000 tons for $SB_{0(2005\text{-}18)}$ (Table 12, Figure 11) and 0 to 6,044 mt for $SB_{0(2010\text{-}18)}$ (Table 13; Figure 11). Detailed figures including 5th, 25th, 50th, 75th, and 90th percentiles are shown for $SB_{0(2005\text{-}18)}$ (Figure 12) and $SB_{0(2010\text{-}18)}$ (Figure 13). Note that the catch values in Tables 12 and 13 represent the total catch (Mexico and US combined), and do not represent US portions of that catch. US portions of the total catch can be calculated by subtracting 6,044 mt from the fixed Mexico catch columns. For the fixed Mexico rate columns, the reader should multiply the total catch by the US portions in the last column of Table 3b.

Finally, it is important to reiterate the high degree of variability in the sardine rebuilding projections and the extent to which rebuilding depends upon productivity assumptions for the two scenarios. For example, Figure 14 illustrates *SB* projections in the complete absence of fishing (US and Mexico E=0) for the two productivity scenarios. Both the large σR (1.2) and profiled range of steepness contributed to this uncertainty. The absolute magnitude of rebuilding is highly dependent upon the choice of recruitments selected to base SB_0. In the $SB_{0(2005\text{-}18)}$ scenario, more than 50% of the projections exceed the 150,000 mt threshold, whereas in the $SB_{0(2010\text{-}18)}$ scenario approximately 10% of the projections exceed that threshold (Figure 14).

Discussion

These rebuilding results are difficult to interpret as the target biomass levels and times to achieve rebuilding are strongly dependent on assumptions of the state of nature. Rebuilding above 150,000 mt with greater than 50% probability was achieved by 2037 with US (5%) and Mexico (9.9%) harvest for $SB_{0(2005\text{-}18)}$, whereas rebuilding to this level occurred by 2037 only with Total F=0 for $SB_{0(2010\text{-}18)}$.

This rebuilding analysis is limited to the available data from the current stock assessment and does not include early historic high recruitment estimates from the 1980s and 1990s or early 20th century. The analysis represents a relatively narrow time frame (15 years) relative to the number of projection years, and likely represents a limited snapshot of the long-term population fluctuations. Pacific sardine are members of the coastal pelagic species (CPS) assemblage of the northeastern Pacific Ocean, which represents an important forage base in the California Current. Pacific sardine biology is characteristic of CPS in general, including relatively small body size, short-lived, mature early, tendency to form large schools, seasonally migratory, and most importantly, highly variable recruitment success and related population abundance based primarily on oceanographic factors (environmental drivers). Further, although there is general consensus in the marine ecology community that oceanographic dynamics are likely the key drivers of year-to-year variation in recruitment and stock abundance exhibited by small pelagic fish populations (e.g., Glantz 1992; McGinn 2002; Checkley et al. 2009; NMFS 2019), detailed understanding of the relationship between specific environmental drivers and a stock's productivity is generally lacking or at the very least, refuted when evaluated over longer time periods (Bakun 1985; Walters and Collie 1988; Myers 1998; Francis 2006; Keyl and Wolff 2008; Haltuch and Punt 2011; Koslow et al. 2013; Subbey et al. 2014; Zwolinski and Demer 2019). Pacific sardine are illustrative of the challenges associated with using oceanographic data to forecast future abundance for management purposes, given repeated research resulting in inconsistent findings of meaningful statistical correlation between the stock's recruitment success and various sea-surface temperature-related indices evaluated over time (Jacobson and MacCall 1995; McClatchie et al. 2010; Lindegren and Checkley 2013; Zwolinski and Demer 2014).

The required analysis by the Pacific Fishery Management Council for rebuilding a formally declared overfished stock is based on a population dynamics model that ultimately provides projected estimates of catch/fishing mortality and associated time periods that would be needed to allow the overfished stock to realize a specified level of abundance or 'rebuilt' (Punt 2012, PFMC 2019). An important parametrization in the rebuilding program concerns the generation of future recruitment, which represents the most critical estimates from the analysis, and the basis for determining abundance (rebuilding levels) from varying trajectories of projected fishing intensities/time periods. The inherent recruitment uncertainty exhibited by CPS likely due to environmental forcing mechanisms necessarily confounds straightforward interpretation of rebuilding programs in general for these highly variable stocks. That is, rebuilding programs for longer-lived species that are generally subject to much less variation in recruitment from year-to-year driven largely by underlying biological mechanisms (e.g., parental stock size or spawning stock biomass), such as groundfish stocks that inhabit the continental shelf/slope off the U.S. Pacific coast (e.g., Dick and MacCall 2014, Gertseva and Cope 2018), are more likely to provide meaningful results regarding levels of fishing pressure and amounts of time needed to effectively rebuild an overfished stock to desired sustainable abundance levels. Additionally, the profile on steepness may or may not be realistic for the stock over the past 15 years. Steepness would be expected to shift toward higher levels in a rebounding stock and was poorly estimated in the 2020 benchmark assessment. The median value for our steepness profile was 0.4, while meta-analysis of life history parameters predicts Clupeiformes have steepness around 0.72 (Thorson 2019).

In the above context, it is important to note that although reasonable/documented estimates of historical recruitment patterns (rebuilding scenarios) from the most recent Pacific sardine stock assessment were used here, this species' biology and substantial recruitment variation in any given year based primarily on unaccounted for environmental factors translates to increased uncertainty surrounding the generated results from the overall rebuilding analysis. Thus, the results presented here are likely to be more accurate in capturing short-term projected stock and fishery dynamics as opposed to the longer term since there is an absence of critical environmental data generally believed to be the underlying/overriding factors that influence this species' population dynamics.

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Table 1. Management quantities and landings (metric tons) since the 2015-16 management year (July-June).

	U.S. Management					
Mgmt Year	OFL	$ABC_{0.4}$	ACT	U.S. Total Landings (mt)	U.S. NSP Landings (mt)	Ensenada NSP Landings (mt)
2015-16	13,227	12,074	4,000	1,919	260	0
2016-17	23,085	19,236	5,000	1,885	601	6,936
2017-18	16,957	15,479	5,000	1,775	372	6,032
2018-19	11,324	9,436	2,500	2,282	655	11,210
2019-20	5,816	4,514	4,000	incomplete	incomplete	nd
2020-21	5,525	4,288	4,000	---	---	---
		Average for 2015-19:		1,965	472	6,044

Table 2. Rebuilding input parameters by age. Note that initial numbers-at-age and natural mortality will vary with steepness for the multiple parameter projections. In order to transition the modeled time step from seasonal (SS) to annual (Rebuilder), it was necessary to change fecundity at age zero from 0.0046 to 0.0000.

Age	Fecundity	*M*	Init N	Init N Tmin	Weight	Selectivity
0	0.0000	0.585	438996.00	580925.00	0.034	0.49003
1	0.0354	0.585	194984.00	222512.00	0.059	1.00000
2	0.0773	0.585	44087.50	46832.80	0.083	0.25724
3	0.1100	0.585	19995.00	12386.50	0.160	0.03762
4	0.1339	0.585	6617.46	47853.50	0.170	0.05343
5	0.1515	0.585	25027.30	11486.90	0.172	0.04378
6	0.1644	0.585	5931.46	5723.79	0.183	0.01445
7	0.1739	0.585	3052.62	4551.15	0.186	0.01366
8	0.1808	0.585	2481.45	1750.78	0.191	0.00306
9	0.1858	0.585	970.42	8726.19	0.195	0.00306
10	0.1939	0.585	6040.54	2171.82	0.200	0.00306

Table 3a. Respective harvest rates for U.S. and Mexico for the constant harvest rate simulations.

Steepness	Relative Probability	Assumed MX Catch (mt)	S1 Age 1+ Biomass (mt)	S1 MX Exploitation Rate
0.30	0.19	6,044	61,240	0.0987
0.35	0.17	6,044	61,219	0.0987
0.40	0.15	6,044	61,214	0.0987
0.45	0.13	6,044	61,229	0.0987
0.50	0.11	6,044	61,260	0.0987
0.55	0.09	6,044	61,307	**0.0986**
0.60	0.07	6,044	61,367	0.0985
0.65	0.05	6,044	61,436	0.0984
0.70	0.03	6,044	61,513	0.0983
0.75	0.01	6,044	61,596	0.0981
0.80	0.00	6,044	61,683	0.0980

Table 3b. Respective exploitation rates (*E*) for U.S. and Mexico for the constant harvest rate simulations.

Harvest Alternative	MX *E*	US *E*	Total *E*	US Portion
Alt 1 (US *E*=18%)	0.0986	0.1216	0.2202	0.5520
Alt 2 (US *E*=0)	0.0986	0.0000	0.0986	0.0000
Alt 3 (US *E*=5%)	0.0986	0.0500	0.1486	0.3364

Table 4. MSY references points and relative probabilities over the profiled range of steepness for two productivity states of nature. SB_0 values and the single weighted target depletion level are provided at the bottom of each table.

SB **0(2005-18)**					
Steepness	E_{MSY}	Median Catch (mt)	SB_{MSY} (mt)	Target Depletion	Relative Probability
0.30	0.075	16,112	162,286	0.42983	19%
0.35	0.110	22,791	155,613	0.41213	17%
0.40	0.150	28,880	143,687	0.38057	15%
0.45	0.190	34,538	134,826	0.35710	13%
0.50	0.230	39,897	127,896	0.33870	11%
0.55	0.280	45,058	117,800	0.31200	9%
0.60	0.330	50,109	110,394	0.29240	7%
0.65	0.390	55,125	101,953	0.27000	5%
0.70	0.455	60,198	94,656	0.25070	3%
0.75	0.535	65,423	86,664	0.22950	1%
0.80	0.640	70,942	77,650	0.20570	0%
		SB_0=	**377,567**	**0.36500**	**<-Wtd Value**
		SB_{MSY}=	**137,812**		

SB **0(2010-18)**					
Steepness	E_{MSY}	Median Catch (mt)	SB_{MSY} (mt)	Target Depletion	Relative Probability
0.30	0.075	4,465	44,975	0.43062	19%
0.35	0.110	6,307	43,066	0.41233	17%
0.40	0.150	7,990	39,751	0.38059	15%
0.45	0.190	9,554	37,296	0.35710	13%
0.50	0.230	11,037	35,379	0.33870	11%
0.55	0.280	12,464	32,587	0.31200	9%
0.60	0.330	13,861	30,538	0.29240	7%
0.65	0.385	15,249	28,588	0.27370	5%
0.70	0.455	16,652	26,184	0.25070	3%
0.75	0.535	18,098	23,974	0.22950	1%
0.80	0.640	19,624	21,480	0.20570	0%
		SB_0=	**104,445**	**0.36500**	**<-Wtd Value**
		SB_{MSY}=	**38,122**		

Table 5. Pacific sardine rebuilding reference points for the $SB_{0(2005\text{-}18)}$ and $SB_{0(2010\text{-}18)}$ states of nature and fixed Mexico fishing rate models. Probabilities of rebuilding to T_{MAX} are shown for the three harvest alternatives being considered in the rebuilding plan.

Parameter	$SB_{0(2005\text{-}18)}$	$SB_{0(2010\text{-}18)}$
Year declared overfished	2019	2019
Current year	2020	2020
Year 1 rebuilding plan (anticipated)	2021	2021
T_{MIN}	2029	2022
T_{MAX}	2031	2031
Alt 1 probability of rebuilding by T_{MAX}	25.8%	56.7%
Alt 2 probability of rebuilding by T_{MAX}	40.6%	69.3%
Alt 3 probability of rebuilding by T_{MAX}	33.3%	62.8%
Mean generation time	3	3
Average SB_0	377,567	104,445
Average rebuilding target ($SB_{36.5\%}$)	137,812	38,122

Table 6. Probabilities of recovery for rebuilding alternatives for $SB_{0(2005\text{-}18)}$ scenario. Mexico catch was fixed at 6,044 mt or at an exploitation rate of 9.9. Probabilities of recovery with no Mexico or US harvest is also shown. Grey shading indicates probabilities greater than 0.5.

	Fixed Mex. Catch (6,044mt)			**Fixed Mex. Rate (9.9)**			**Total F=0**
Year	**US rate=0**	**US rate=5**	**US rate=18**	**US rate=0**	**US rate=5**	**US rate=18**	
2019	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2020	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2021	0.0315	0.0300	0.0295	0.0310	0.0305	0.0295	0.0335
2022	0.0850	0.0710	0.0600	0.0760	0.0665	0.0565	0.1000
2023	0.1440	0.1200	0.0970	0.1290	0.1095	0.0915	0.1810
2024	0.1970	0.1670	0.1330	0.1805	0.1550	0.1240	0.2530
2025	0.2380	0.2040	0.1630	0.2240	0.1950	0.1510	0.3155
2026	0.2795	0.2350	0.1805	0.2620	0.2240	0.1705	0.3825
2027	0.3090	0.2575	0.2015	0.2955	0.2485	0.1920	0.4330
2028	0.3380	0.2805	0.2180	0.3280	0.2750	0.2110	0.4810
2029	0.3670	0.3045	0.2300	0.3620	0.3020	0.2315	0.5210
2030	0.3865	0.3195	0.2390	0.3870	0.3200	0.2435	0.5620
2031	0.4050	0.3315	0.2500	0.4060	0.3330	0.2580	0.6005
2032	0.4235	0.3450	0.2610	0.4285	0.3515	0.2715	0.6310
2033	0.4405	0.3610	0.2710	0.4560	0.3750	0.2850	0.6560
2034	0.4525	0.3705	0.2770	0.4765	0.3900	0.2965	0.6750
2035	0.4630	0.3780	0.2835	0.4935	0.4080	0.3065	0.7005
2036	0.4725	0.3830	0.2910	0.5090	0.4205	0.3180	0.7160
2037	0.4800	0.3895	0.2940	0.5260	0.4320	0.3275	0.7300
2038	0.4860	0.3970	0.2970	0.5370	0.4450	0.3360	0.7500
2039	0.4905	0.4050	0.3000	0.5505	0.4550	0.3425	0.7640
2040	0.4965	0.4075	0.3040	0.5620	0.4625	0.3465	0.7725
2041	0.5015	0.4095	0.3070	0.5690	0.4670	0.3530	0.7825
2042	0.5045	0.4135	0.3085	0.5800	0.4730	0.3575	0.7965
2043	0.5065	0.4150	0.3095	0.5880	0.4825	0.3650	0.8085
2044	0.5090	0.4185	0.3125	0.5940	0.4870	0.3690	0.8220
2045	0.5105	0.4195	0.3155	0.6010	0.4920	0.3765	0.8355
2046	0.5110	0.4210	0.3180	0.6075	0.4965	0.3815	0.8455
2047	0.5150	0.4240	0.3200	0.6155	0.5015	0.3860	0.8525
2048	0.5160	0.4245	0.3205	0.6225	0.5080	0.3930	0.8610
2049	0.5175	0.4245	0.3210	0.6265	0.5120	0.3960	0.8670
2050	0.5195	0.4250	0.3225	0.6315	0.5140	0.3995	0.8720

Table 7. Probabilities of recovery for rebuilding alternatives for $SB_{0(2010\text{-}18)}$ scenario. Mexico catch was fixed at 6,044 mt or at an exploitation rate of 9.9. Probabilities of recovery with no Mexico or US harvest is also shown. Grey shading indicates probabilities greater than 0.5. Rebuilding occurs earlier than in scenario $SB_{0(2005\text{-}18)}$ because the biomass target is lower for $SB_{0(2010\text{-}18)}$. See Figure 4 for the difference in SB0 target values between scenarios.

	Fixed Mex. Catch (6,044 mt)			**Fixed Mex. Rate (9.9)**			**Total F=0**
Year	**US rate=0**	**US rate=5**	**US rate=18**	**US rate=0**	**US rate=5**	**US rate=18**	
2019	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400	0.0400
2020	0.3600	0.3600	0.3600	0.3600	0.3600	0.3600	0.3600
2021	0.4445	0.4340	0.4225	0.4580	0.4465	0.4295	0.4905
2022	0.4885	0.4680	0.4500	0.5150	0.4960	0.4645	0.5730
2023	0.5195	0.4940	0.4635	0.5595	0.5300	0.4915	0.6485
2024	0.5375	0.5110	0.4755	0.5940	0.5570	0.5115	0.6960
2025	0.5495	0.5215	0.4790	0.6185	0.5715	0.5250	0.7250
2026	0.5555	0.5255	0.4830	0.6360	0.5885	0.5325	0.7560
2027	0.5610	0.5285	0.4830	0.6530	0.5980	0.5410	0.7780
2028	0.5650	0.5295	0.4845	0.6645	0.6085	0.5500	0.7955
2029	0.5665	0.5315	0.4855	0.6755	0.6150	0.5575	0.8085
2030	0.5685	0.5325	0.4855	0.6855	0.6230	0.5620	0.8210
2031	0.5685	0.5330	0.4855	0.6925	0.6280	0.5665	0.8315
2032	0.5700	0.5335	0.4855	0.7005	0.6330	0.5695	0.8440
2033	0.5705	0.5335	0.4855	0.7060	0.6385	0.5725	0.8610
2034	0.5710	0.5335	0.4855	0.7125	0.6460	0.5775	0.8690
2035	0.5710	0.5335	0.4860	0.7215	0.6505	0.5785	0.8785
2036	0.5710	0.5335	0.4860	0.7320	0.6585	0.5840	0.8855
2037	0.5710	0.5335	0.4860	0.7355	0.6640	0.5865	0.8965
2038	0.5710	0.5335	0.4860	0.7395	0.6665	0.5875	0.9035
2039	0.5710	0.5335	0.4860	0.7460	0.6705	0.5885	0.9100
2040	0.5710	0.5335	0.4860	0.7505	0.6745	0.5895	0.9150
2041	0.5720	0.5335	0.4860	0.7540	0.6765	0.5900	0.9195
2042	0.5720	0.5335	0.4860	0.7590	0.6795	0.5910	0.9235
2043	0.5720	0.5335	0.4860	0.7630	0.6800	0.5910	0.9275
2044	0.5720	0.5335	0.4860	0.7670	0.6820	0.5915	0.9325
2045	0.5720	0.5335	0.4860	0.7695	0.6825	0.5930	0.9335
2046	0.5720	0.5335	0.4860	0.7715	0.6865	0.5935	0.9370
2047	0.5720	0.5335	0.4860	0.7780	0.6865	0.5935	0.9390
2048	0.5720	0.5335	0.4860	0.7815	0.6885	0.5940	0.9420
2049	0.5720	0.5335	0.4860	0.7845	0.6900	0.5945	0.9460
2050	0.5720	0.5335	0.4860	0.7855	0.6910	0.5955	0.9490

Table 8. Probabilities of recovery above 150,000 mt of age 1+ biomass for rebuilding alternatives for $SB_{0(2005\text{-}18)}$ scenario. Mexico catch was fixed at 6,044 mt or at an exploitation rate of 9.9. Probabilities of recovery with no Mexico or US harvest is also shown. Grey shading indicates probabilities greater than 0.5.

	Fixed Mex. Catch (6,044mt)			**Fixed Mex. Rate (9.9)**			**Total F=0**
Year	**US rate=0**	**US rate=5**	**US rate=18**	**US rate=0**	**US rate=5**	**US rate=18**	
2020	0	0	0	0	0	0	0
2021	0.0655	0.0635	0.0615	0.066	0.0635	0.0615	0.071
2022	0.1275	0.115	0.104	0.129	0.1125	0.1035	0.1525
2023	0.196	0.1785	0.152	0.198	0.1775	0.153	0.244
2024	0.253	0.2245	0.19	0.255	0.2255	0.1925	0.326
2025	0.2985	0.257	0.22	0.299	0.2635	0.2215	0.3995
2026	0.3335	0.2895	0.2395	0.342	0.294	0.2455	0.459
2027	0.3645	0.316	0.2585	0.3735	0.325	0.264	0.5105
2028	0.3925	0.3365	0.2725	0.4075	0.35	0.2845	0.5505
2029	0.417	0.3555	0.2865	0.44	0.3785	0.307	0.591
2030	0.432	0.368	0.2945	0.4595	0.398	0.3225	0.6275
2031	0.449	0.377	0.3005	0.48	0.4125	0.3315	0.6555
2032	0.466	0.388	0.3105	0.4995	0.4305	0.3455	0.6775
2033	0.4815	0.4005	0.3175	0.526	0.4485	0.3585	0.7015
2034	0.4865	0.4095	0.3235	0.5435	0.4655	0.371	0.7225
2035	0.4955	0.4145	0.3275	0.5585	0.48	0.3795	0.744
2036	0.504	0.4195	0.332	0.5755	0.49	0.39	0.757
2037	0.5085	0.426	0.334	0.5885	0.5025	0.3985	0.772
2038	0.515	0.4325	0.3355	0.5995	0.5135	0.4065	0.789
2039	0.5175	0.436	0.3385	0.6085	0.525	0.414	0.8
2040	0.521	0.438	0.3395	0.618	0.533	0.419	0.809
2041	0.524	0.4385	0.342	0.625	0.54	0.423	0.8185
2042	0.527	0.4425	0.343	0.634	0.545	0.4275	0.833
2043	0.5285	0.4435	0.344	0.64	0.55	0.4345	0.8425
2044	0.5285	0.4435	0.345	0.6455	0.554	0.437	0.8545
2045	0.5315	0.4445	0.3465	0.6525	0.5575	0.442	0.8645
2046	0.532	0.446	0.3475	0.657	0.5645	0.4435	0.8725
2047	0.534	0.4465	0.348	0.664	0.57	0.4465	0.8775
2048	0.5345	0.447	0.3485	0.671	0.5705	0.452	0.885
2049	0.535	0.447	0.3485	0.676	0.5745	0.455	0.89
2050	0.5355	0.4475	0.35	0.6805	0.579	0.4585	0.896

Table 9. Probabilities of recovery above 150,000 mt of age 1+ biomass for rebuilding alternatives for $SB_{0(2010\text{-}18)}$ scenario. Mexico catch was fixed at 6,044 mt or at an exploitation rate of 9.9. Probabilities of recovery with no Mexico or US harvest is also shown. Grey shading indicates probabilities greater than 0.5.

	Fixed Mex. Catch (6,044mt)			Fixed Mex. Rate (9.9)			Total F=0
Year	US rate=0	US rate=5	US rate=18	US rate=0	US rate=5	US rate=18	
2019	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2020	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2021	0.0250	0.0240	0.0220	0.0260	0.0235	0.0220	0.0280
2022	0.0410	0.0380	0.0345	0.0435	0.0380	0.0345	0.0535
2023	0.0650	0.0575	0.0505	0.0665	0.0585	0.0520	0.0935
2024	0.0895	0.0730	0.0620	0.0890	0.0740	0.0650	0.1380
2025	0.1045	0.0850	0.0700	0.1035	0.0880	0.0735	0.1715
2026	0.1225	0.0975	0.0785	0.1260	0.1030	0.0840	0.2100
2027	0.1420	0.1105	0.0880	0.1480	0.1195	0.0945	0.2410
2028	0.1550	0.1225	0.0945	0.1630	0.1330	0.1035	0.2755
2029	0.1680	0.1305	0.0980	0.1805	0.1465	0.1125	0.3105
2030	0.1765	0.1335	0.1020	0.1935	0.1535	0.1180	0.3360
2031	0.1850	0.1405	0.1055	0.2075	0.1650	0.1260	0.3580
2032	0.1940	0.1470	0.1095	0.2215	0.1765	0.1360	0.3850
2033	0.1995	0.1520	0.1110	0.2340	0.1865	0.1420	0.4170
2034	0.2095	0.1590	0.1150	0.2510	0.1975	0.1490	0.4385
2035	0.2130	0.1620	0.1155	0.2615	0.2035	0.1540	0.4635
2036	0.2205	0.1645	0.1175	0.2765	0.2135	0.1585	0.4915
2037	0.2265	0.1685	0.1185	0.2890	0.2235	0.1615	0.5065
2038	0.2305	0.1735	0.1195	0.3020	0.2370	0.1705	0.5270
2039	0.2325	0.1755	0.1215	0.3125	0.2420	0.1735	0.5470
2040	0.2345	0.1765	0.1225	0.3170	0.2470	0.1760	0.5600
2041	0.2385	0.1785	0.1230	0.3250	0.2520	0.1795	0.5685
2042	0.2425	0.1805	0.1250	0.3340	0.2610	0.1850	0.5860
2043	0.2470	0.1805	0.1255	0.3405	0.2655	0.1875	0.6030
2044	0.2485	0.1815	0.1255	0.3465	0.2700	0.1895	0.6180
2045	0.2505	0.1830	0.1260	0.3545	0.2775	0.1930	0.6335
2046	0.2520	0.1840	0.1275	0.3615	0.2830	0.1970	0.6470
2047	0.2530	0.1845	0.1280	0.3655	0.2865	0.1995	0.6640
2048	0.2550	0.1845	0.1280	0.3735	0.2925	0.2015	0.6800
2049	0.2565	0.1845	0.1285	0.3800	0.2985	0.2065	0.6910
2050	0.2585	0.1850	0.1285	0.3930	0.3060	0.2110	0.6985

Table 10. Median spawning stock biomass (mt) for rebuilding alternatives for $SB_{0(2005\text{-}18)}$ scenario. Mexico catch was fixed at 6,044 mt or at an exploitation rate of 9.9. Probabilities of recovery with no Mexico or US harvest is also shown. Gray shading indicates years in which the probability of recovery was greater than 0.5 (based on probabilities in Table 4).

	Fixed Mex. Catch (6,044mt)			Fixed Mex. Rate (9.9)			Total F=0
Year	**US rate=0**	**US rate=5**	**US rate=18**	**US rate=0**	**US rate=5**	**US rate=18**	
2019	25,879	25,879	25,879	25,879	25,879	25,879	25,879
2020	29,598	29,598	29,598	29,598	29,598	29,598	29,598
2021	33,372	31,509	28,881	35,055	33,122	30,418	38,877
2022	35,113	30,509	25,152	37,730	33,867	28,298	47,007
2023	37,177	30,269	21,784	41,633	34,991	27,326	56,350
2024	37,684	28,087	17,628	45,365	36,564	26,198	67,391
2025	39,095	26,290	13,643	47,036	35,943	23,932	76,492
2026	41,052	24,557	9,360	49,628	36,332	22,197	88,273
2027	42,838	23,165	6,360	51,792	36,591	21,372	97,579
2028	43,371	20,122	4,155	53,898	36,529	20,042	109,517
2029	46,100	18,720	2,399	56,132	36,043	18,180	119,732
2030	46,096	16,216	1,514	58,819	37,270	17,803	130,959
2031	47,985	12,522	883	60,556	36,980	17,127	140,751
2032	47,713	8,705	543	61,399	37,587	16,379	147,730
2033	48,194	5,263	287	62,813	36,351	15,597	154,344
2034	49,143	3,011	163	61,038	35,600	14,210	159,140
2035	47,250	1,808	98	63,922	35,757	13,524	163,850
2036	46,615	1,003	55	64,624	35,722	13,416	171,223
2037	45,184	593	32	65,286	35,588	13,088	179,906
2038	39,576	326	17	66,074	35,186	12,463	183,075
2039	36,632	186	9	67,704	35,571	11,879	187,576
2040	36,561	108	5	66,133	34,895	10,997	188,222
2041	38,561	62	3	65,706	33,671	9,757	187,551
2042	35,637	36	2	66,693	31,988	9,205	190,559
2043	33,449	19	1	65,268	31,210	8,744	190,788
2044	28,748	12	1	64,371	30,536	8,208	190,213
2045	29,926	6	0	64,005	29,386	7,962	192,664
2046	24,725	3	0	62,368	29,093	7,275	200,334
2047	21,019	2	0	62,426	27,685	6,660	201,381
2048	17,921	1	0	63,063	28,550	6,294	200,019
2049	15,550	1	0	62,605	28,549	5,898	201,301
2050	12,453	0	0	65,031	28,349	5,413	198,358

Table 11. Median spawning stock biomass (mt) for rebuilding alternatives for $SB_{0(2010\text{-}18)}$ scenario. Mexico catch was fixed at 6,044 mt or at an exploitation rate of 9.9. Probabilities of recovery with no Mexico or US harvest is also shown. Gray shading indicates years in which the probability of recovery was greater than 0.5 (based on probabilities in Table 5).

	Fixed Mex. Catch (6,044mt)			Fixed Mex. Rate (9.9)			Total F=0
Year	**US rate=0**	**US rate=5**	**US rate=18**	**US rate=0**	**US rate=5**	**US rate=18**	
2019	25,879	25,879	25,879	25,879	25,879	25,879	25,879
2020	29,598	29,598	29,598	29,598	29,598	29,598	29,598
2021	31,594	29,557	26,726	33,042	30,989	28,217	37,110
2022	28,916	25,000	20,100	31,639	27,859	23,149	39,706
2023	26,213	20,751	14,646	30,875	25,748	19,617	42,936
2024	22,597	16,095	9,694	29,709	23,764	16,952	44,856
2025	19,497	12,298	6,122	28,740	22,077	14,833	46,577
2026	16,558	8,445	3,771	27,835	20,590	13,182	48,217
2027	12,795	5,381	2,252	27,256	19,312	11,679	50,173
2028	9,940	3,367	1,340	26,169	18,112	10,639	51,160
2029	7,254	2,033	807	25,764	17,558	9,569	51,889
2030	4,575	1,218	465	25,467	16,768	8,953	53,379
2031	2,873	708	265	25,370	16,631	8,425	54,524
2032	1,621	445	157	24,880	15,894	7,801	55,188
2033	986	243	90	24,474	15,440	7,205	55,887
2034	556	144	50	23,665	14,347	6,364	56,050
2035	330	84	29	23,416	13,991	6,078	57,317
2036	182	47	16	23,298	13,551	5,619	58,743
2037	106	27	9	23,618	13,460	5,343	58,343
2038	62	16	6	23,822	13,352	4,970	58,573
2039	35	9	3	23,187	12,944	4,658	59,633
2040	20	5	2	22,418	12,380	4,515	59,371
2041	12	3	1	21,933	12,006	4,053	58,814
2042	6	2	1	21,896	11,721	3,646	58,824
2043	3	1	0	21,343	11,180	3,435	58,247
2044	2	1	0	21,321	10,858	3,215	59,268
2045	1	0	0	20,813	10,415	3,137	58,704
2046	1	0	0	20,479	10,065	2,780	60,412
2047	0	0	0	20,160	9,668	2,553	59,710
2048	0	0	0	20,426	9,955	2,496	59,834
2049	0	0	0	20,378	9,630	2,341	58,446
2050	0	0	0	20,008	9,445	2,109	58,442

Table 12. Median catch (mt) for rebuilding alternatives for $SB_{0(2005\text{-}18)}$ scenario. Mexico catch was fixed at 6,044 mt or at an exploitation rate of 9.9. Gray shading indicates years in which the probability of recovery was greater than 0.5 (based on probabilities in Table 4 for $SB_{0(2005\text{-}18)}$ scenario). Catch values represent the total catch (Mexico and US combined), and do not represent only US catches.

	Fixed Mex. Catch (6,044mt)			Fixed Mex. Rate (9.9)		
Year	**US rate=0**	**US rate=5**	**US rate=18**	**US rate=0**	**US rate=5**	**US rate=18**
2019	7,500	7,500	7,500	7,500	7,500	7,500
2020	6,044	7,963	10,709	3,785	5,704	8,452
2021	6,044	8,132	10,702	4,549	6,499	8,846
2022	6,044	8,117	10,105	5,026	6,738	8,296
2023	6,044	8,003	9,357	5,418	6,884	7,849
2024	6,044	7,835	8,626	5,805	6,983	7,320
2025	6,044	7,749	7,715	6,002	6,894	6,703
2026	6,044	7,609	6,914	6,251	6,840	6,167
2027	6,044	7,476	4,944	6,502	6,944	6,047
2028	6,044	7,319	3,037	6,793	6,847	5,600
2029	6,044	7,177	1,801	6,992	6,896	5,166
2030	6,044	6,954	1,191	7,426	7,084	4,978
2031	6,044	6,621	659	7,543	6,905	4,717
2032	6,044	5,755	375	7,772	6,995	4,651
2033	6,044	3,429	189	7,944	6,932	4,269
2034	6,044	2,038	119	7,671	6,661	3,912
2035	6,044	1,037	67	7,893	6,848	3,865
2036	6,044	629	40	8,137	6,597	3,801
2037	6,044	429	21	8,318	6,832	3,541
2038	6,044	191	13	8,166	6,559	3,453
2039	6,044	94	6	8,412	6,588	3,203
2040	6,044	69	3	8,306	6,570	3,124
2041	6,044	38	2	8,068	6,162	2,694
2042	6,044	21	1	8,165	6,077	2,545
2043	6,044	14	1	8,027	5,850	2,305
2044	6,044	7	0	7,914	5,839	2,331
2045	6,044	4	0	7,956	5,433	2,214
2046	6,044	3	0	7,798	5,431	1,974
2047	6,044	1	0	7,870	5,175	1,853
2048	6,044	1	0	7,831	5,392	1,721
2049	6,044	0	0	7,769	5,407	1,593
2050	6,044	0	0	8,025	5,287	1,520

Table 13. Median catch (mt) for rebuilding alternatives for $SB_{0(2010\text{-}18)}$ scenario. Mexico catch was fixed at 6,044 mt or at an exploitation rate of 9.9. Gray shading indicates years in which the probability of recovery was greater than 0.5 (based on probabilities in Table 5 for $SB_{0(2010\text{-}18)}$ scenario). Catch values represent the total catch (Mexico and US combined), and do not represent only US catches.

	Fixed Mex. Catch (6,044mt)			Fixed Mex. Rate (9.9)		
Year	**US rate=0**	**US rate=5**	**US rate=18**	**US rate=0**	**US rate=5**	**US rate=18**
2019	7,500	7,500	7,500	7,500	7,500	7,500
2020	6,044	7,963	10,709	3,785	5,704	8,452
2021	6,044	7,955	10,274	4,199	5,969	8,141
2022	6,044	7,707	9,124	4,179	5,546	6,810
2023	6,044	7,355	7,887	3,935	4,938	5,532
2024	6,044	6,983	6,514	3,672	4,394	4,538
2025	6,044	6,620	4,480	3,476	4,016	3,964
2026	6,044	6,122	2,677	3,478	3,862	3,579
2027	6,044	4,023	1,651	3,368	3,595	3,206
2028	6,044	2,498	1,008	3,223	3,393	2,844
2029	5,169	1,552	607	3,184	3,305	2,610
2030	3,422	982	349	3,143	3,156	2,480
2031	2,060	576	200	3,142	3,092	2,295
2032	1,196	336	123	3,111	2,974	2,150
2033	653	182	68	3,036	2,874	1,985
2034	462	117	42	2,876	2,664	1,724
2035	256	65	23	2,936	2,596	1,724
2036	137	35	13	2,916	2,563	1,559
2037	89	20	7	2,935	2,600	1,491
2038	43	11	4	2,864	2,459	1,352
2039	24	6	2	2,860	2,455	1,301
2040	14	3	1	2,764	2,349	1,221
2041	8	2	1	2,746	2,203	1,104
2042	5	1	0	2,744	2,185	1,003
2043	3	1	0	2,629	2,074	953
2044	1	0	0	2,569	2,030	895
2045	1	0	0	2,550	1,949	844
2046	1	0	0	2,535	1,905	740
2047	0	0	0	2,499	1,808	690
2048	0	0	0	2,509	1,803	680
2049	0	0	0	2,475	1,807	628
2050	0	0	0	2,516	1,775	577

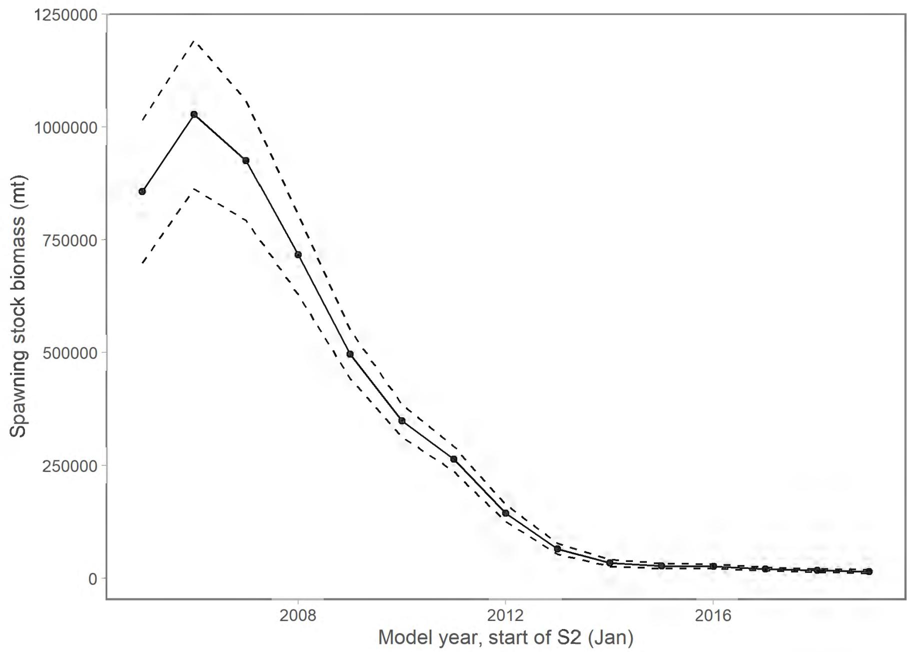

Figure 1: Spawning stock biomass time series (95% CI dashed lines) from the 2020 benchmark assessment (Kuriyama et al. 2020).

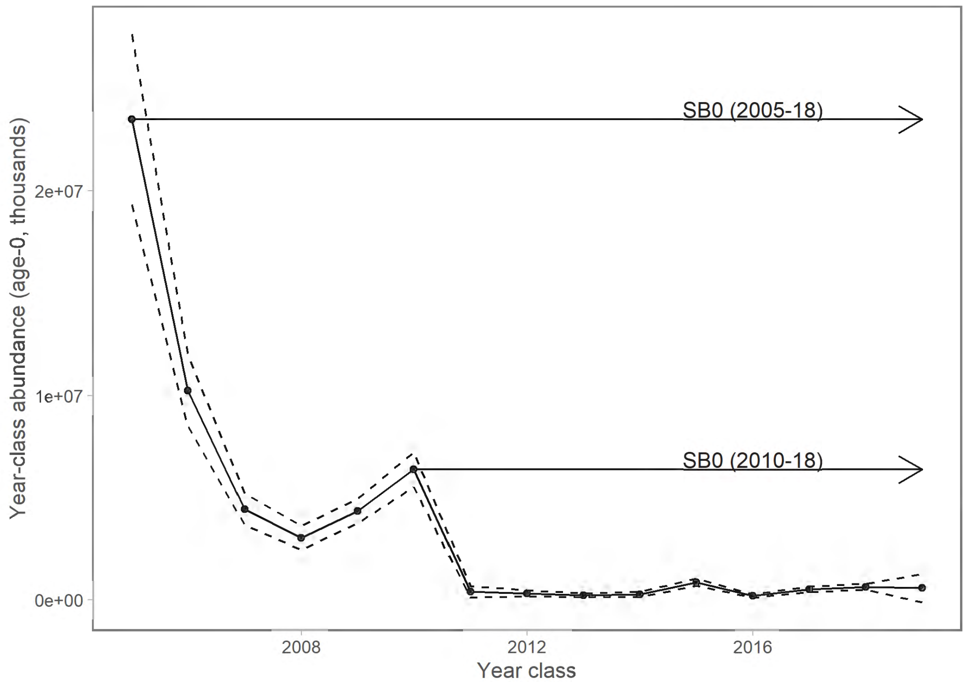

Figure 2. Estimated Pacific sardine recruitment time series from the 2020 Pacific sardine benchmark assessment (Kuriyama et al. 2020). Arrows indicate the two states of nature considered in the rebuilding analysis: SB0 sampled from 2005-18 (top arrow) and SB0 sampled from 2010-2018 (bottom arrow).

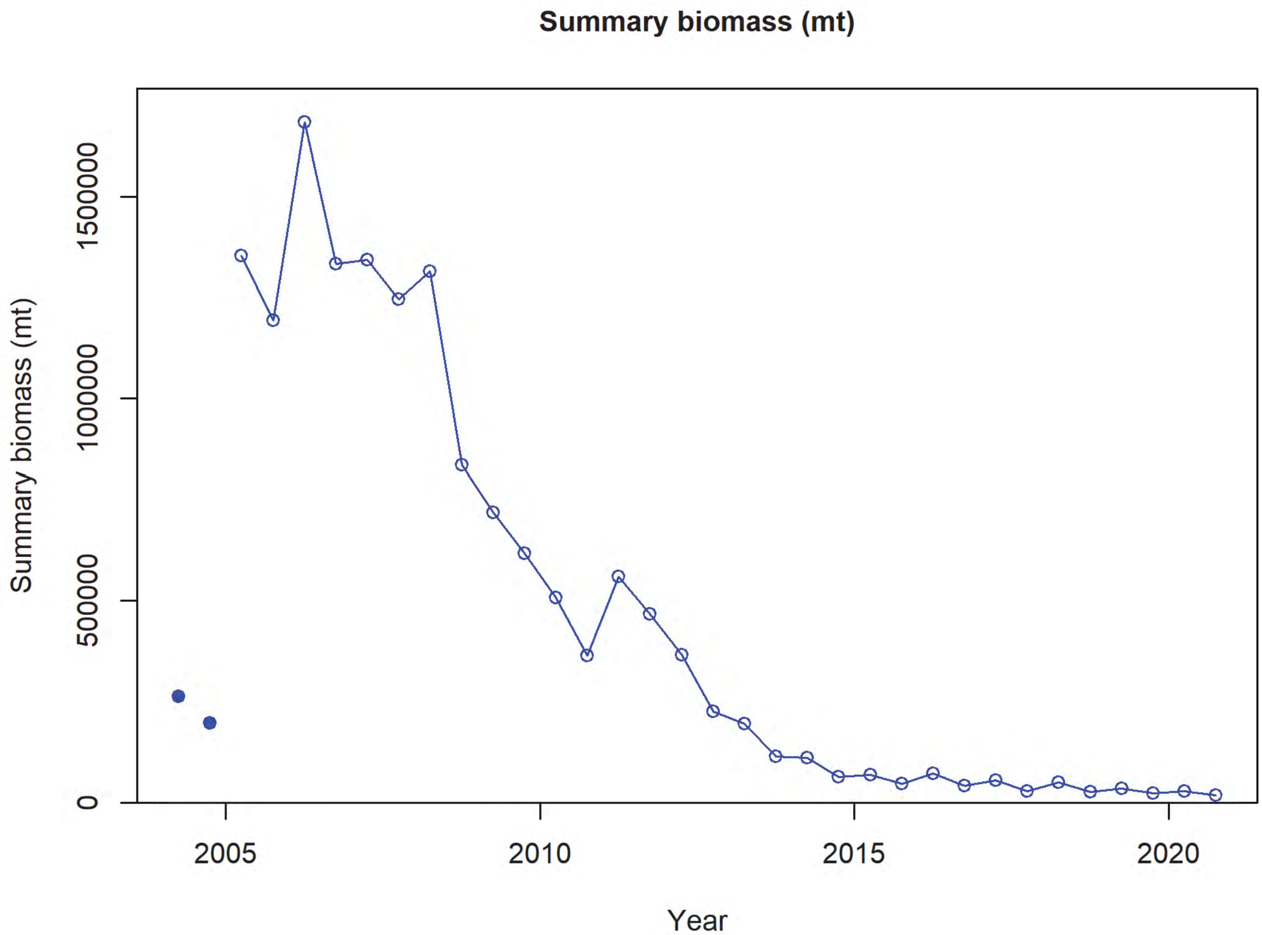

Figure 3. Estimated stock biomass (age 1+ fish; mt) time series from the 2020 benchmark assessment model (Kuriyama et al. 2020).

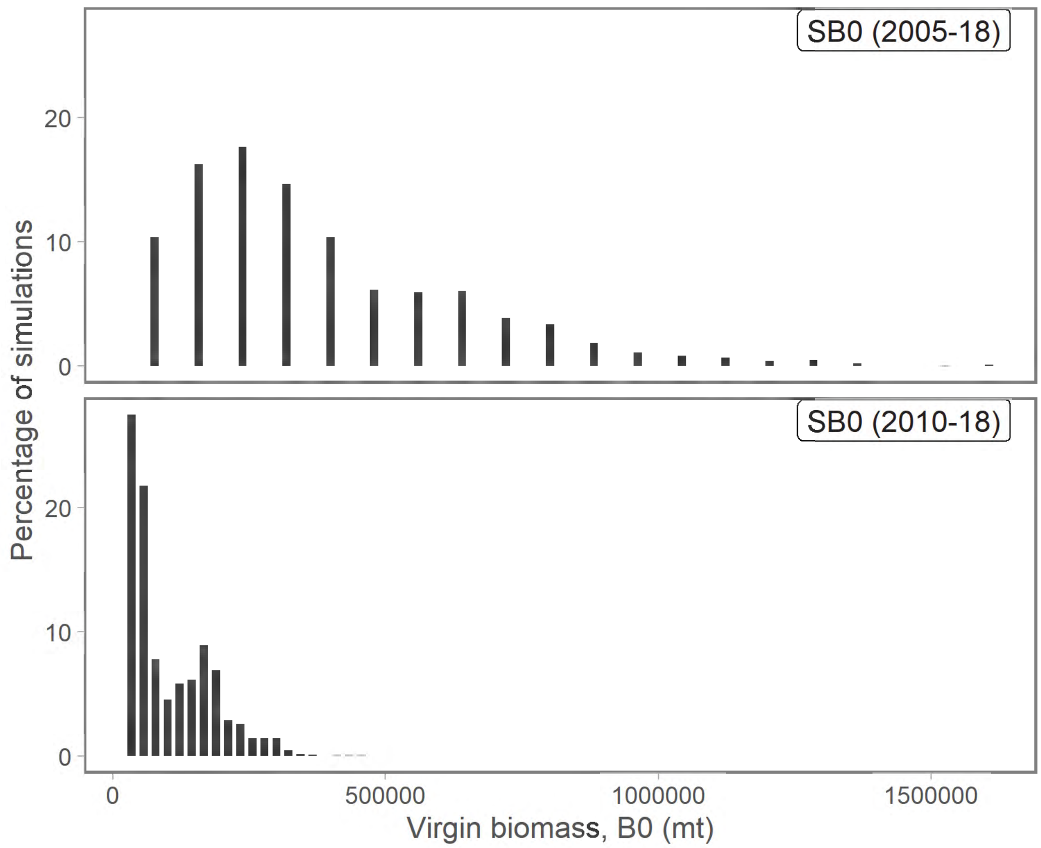

Figure 4. Virgin spawning biomass (SB_0) for the two states of nature.

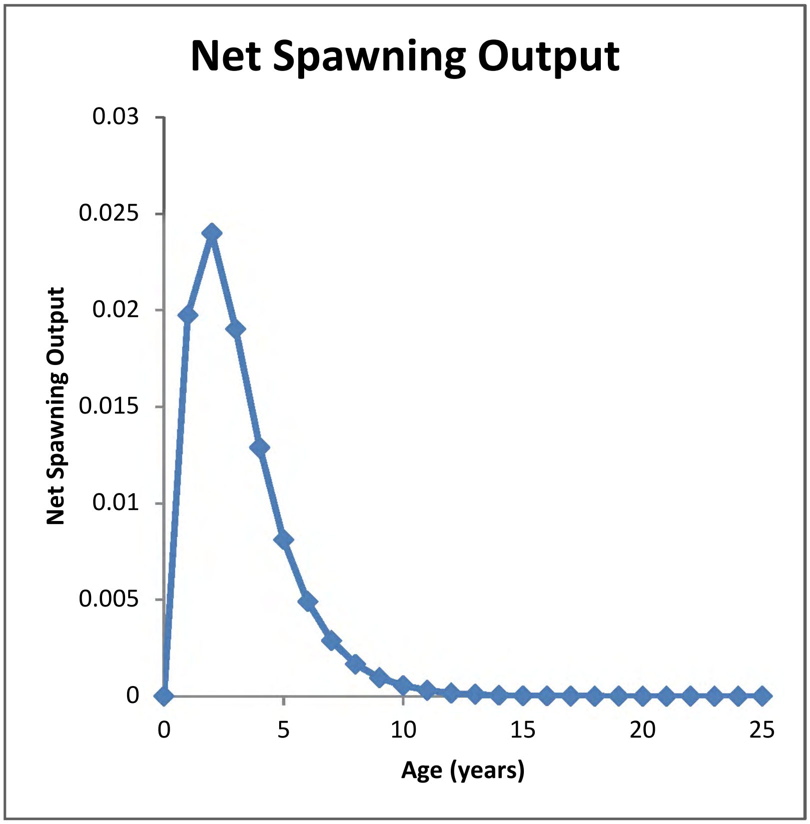

Figure 5. Pacific sardine net spawning output by age.

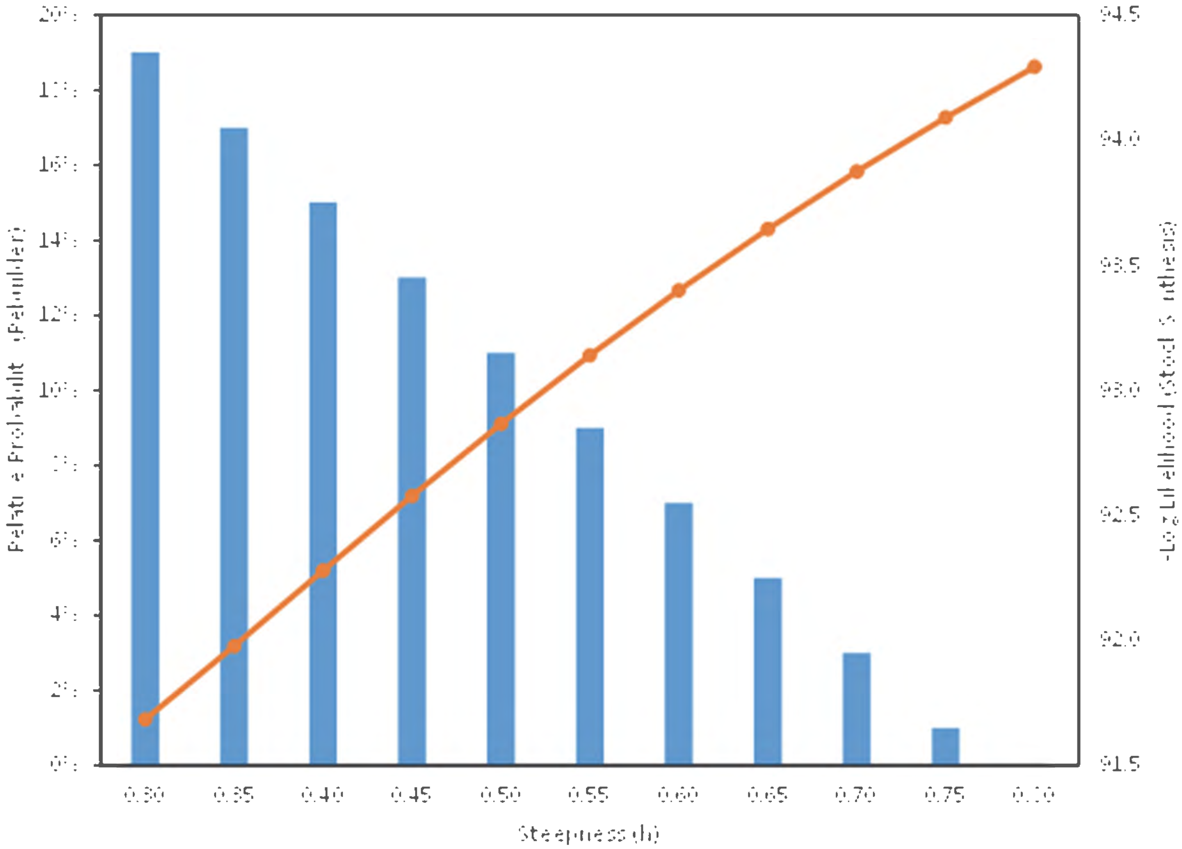

Figure 6. Relative probabilities (blue bars) for steepness levels profiled in rebuilding projections. Relative probabilities were based on negative log likelihood estimates from Stock Synthesis steepness profiles (orange line).

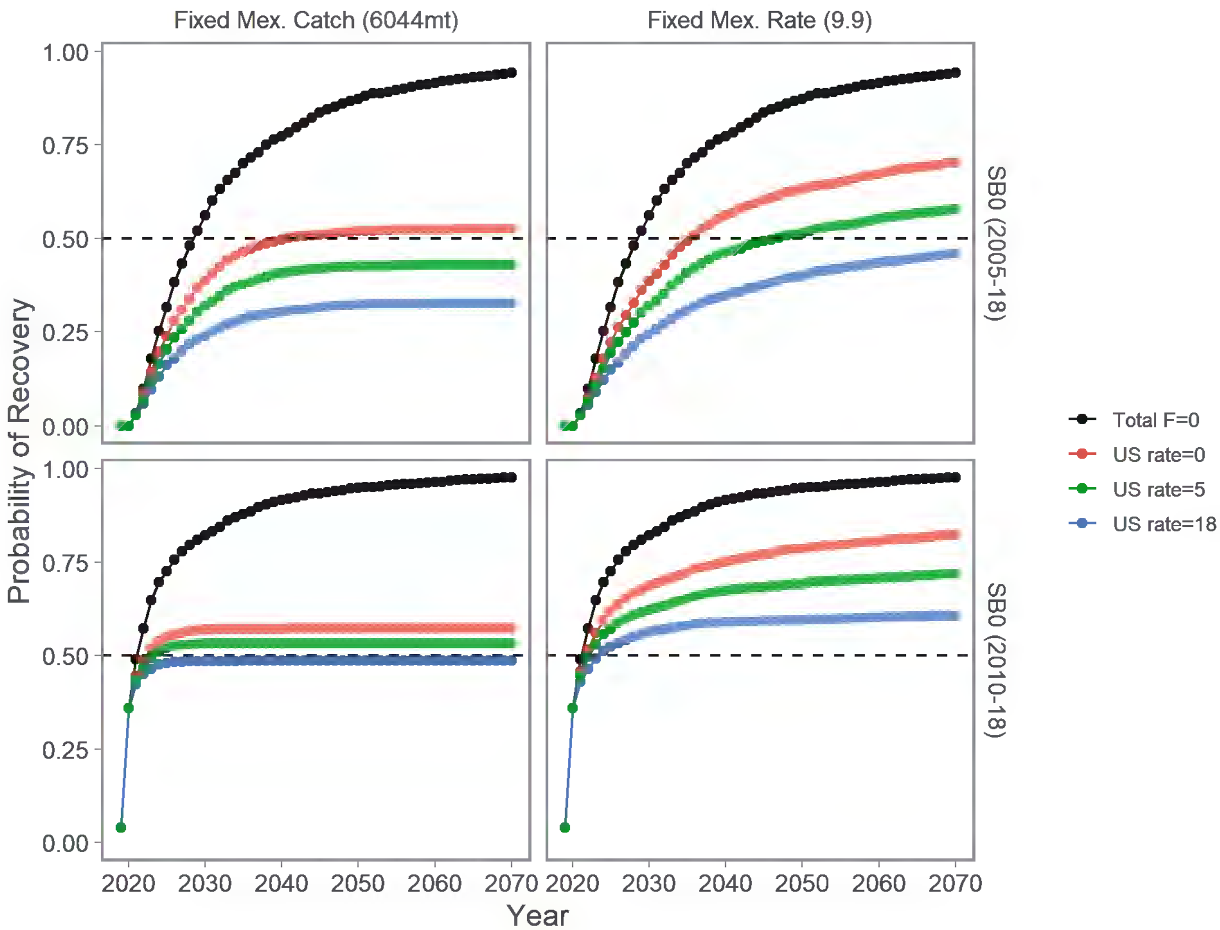

Figure 7a. Probabilities of recovery for Pacific sardine rebuilding alternatives. Panels are arranged by state of nature [$SB_{0(2005\text{-}18)}$ – top row; $SB_{0(2010\text{-}18)}$ – bottom row]. Mexico catch was fixed at 6,044 mt (left column) or assumed to have a fixed harvest rate of 9.9 (right column). The Total F=0 (black) had no harvest from Mexico nor the US. US harvest rates were 0 (red), 5 (green), and 18 (blue). The probability of recovery threshold was 0.5 (dashed black line). Note, the probability of recovery is higher with the $SB_{0(2010\text{-}18)}$ scenario because the target depletion level (as a fraction of B0; see Figure 4) is lower than that from the $SB_{0(2005\text{-}18)}$ scenario.

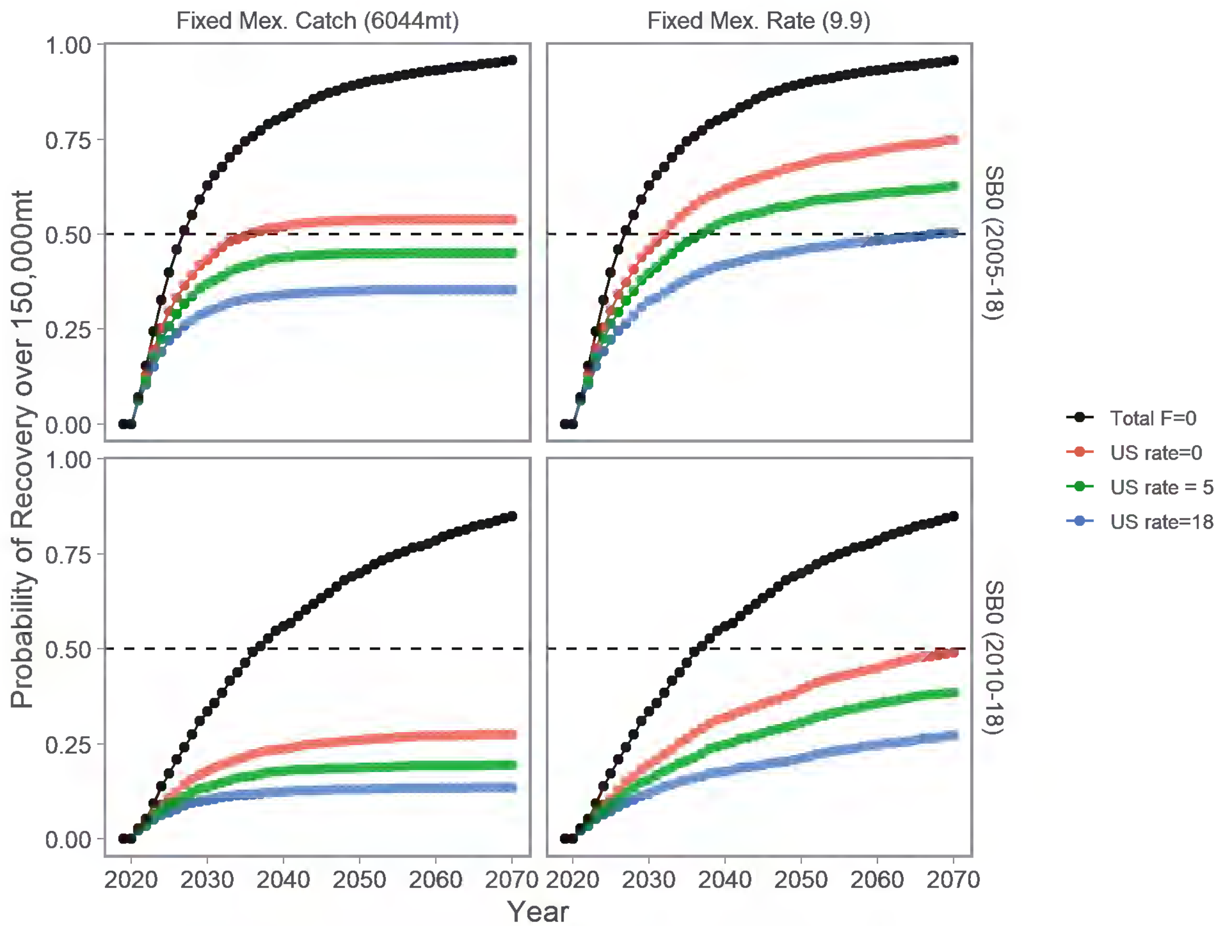

Figure 7b. Probabilities of recovery to the 150,000 mt Cutoff threshold for Pacific sardine rebuilding alternatives. Panels are arranged by state of nature [$SB_{0(2005\text{-}18)}$ – top row; $SB_{0(2010\text{-}18)}$ – bottom row]. Mexico catch was fixed at 6,044 mt (left column) or assumed to have a fixed harvest rate of 9.9 (right column). The Total F=0 (black) had no harvest from Mexico nor the US. US harvest rates were 0 (red), 5 (green), and 18 (blue). The probability of recovery threshold was 0.5 (dashed black line). Note, the probability of recovery is higher with the $SB_{0(2010\text{-}18)}$ scenario because the target depletion level (as a fraction of B0; see Figure 4) is lower than that from the $SB_{0(2005\text{-}18)}$ scenario.

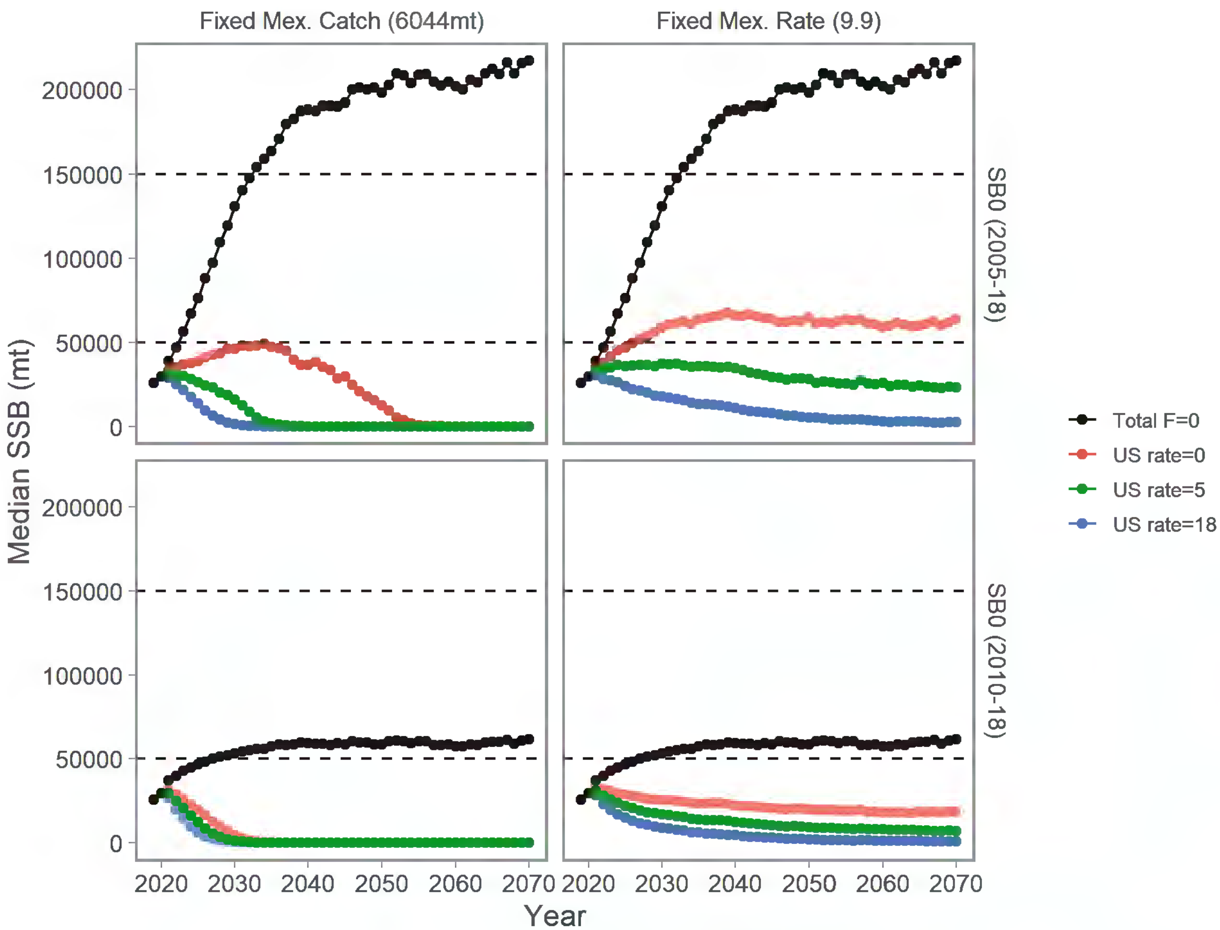

Figure 8. Median spawning stock biomass (mt) for Pacific sardine rebuilding alternatives. Panels are arranged by state of nature [$SB_{0(2005\text{-}18)}$ – top row; $SB_{0(2010\text{-}18)}$ – bottom row]. Mexico catch was fixed at 6,044 mt (left column) or assumed to have a fixed harvest rate of 9.9 (right column). The Total F=0 (black) had no harvest from Mexico nor the US. US harvest rates were 0 (red), 5 (green), and 18 (blue). The management thresholds of 50,000 mt and 150,000 mt are shown in black horizontal dashed lines. For the $SB_{0(2010\text{-}18)}$ scenario, even with Total F=0, the median SSB values do not get higher than 150,000 mt.

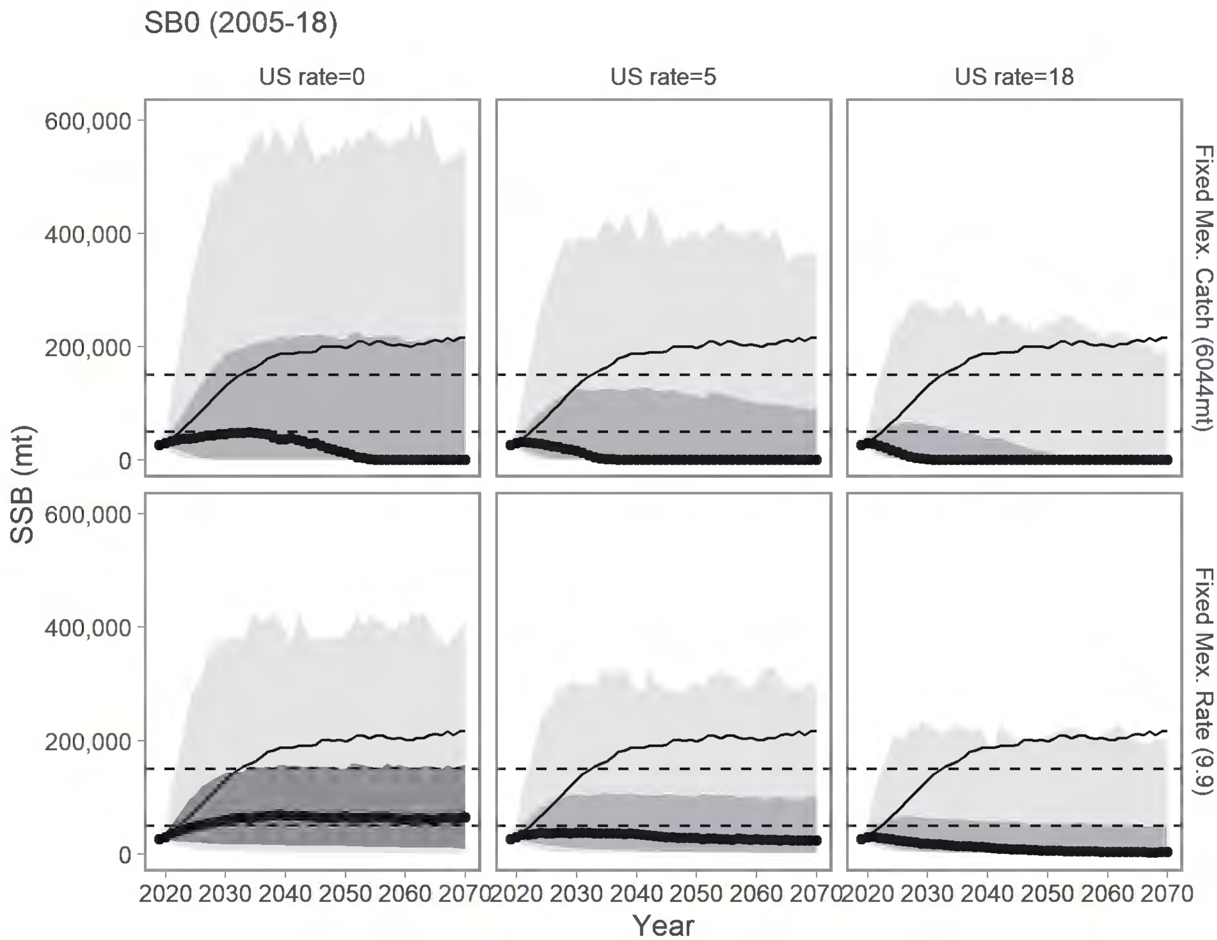

Figure 9. Projected spawning stock biomass (mt) for $SB_{0(2005\text{-}18)}$ scenario. Mexico catch was either fixed at 6,044 mt (top row) or fixed at a harvest rate of 9.9% (bottom row). US harvest rate was 0, 5, or 18% (left to right columns). Values displayed are median SSB values (black points), 25-75 percentiles (dark gray shading), and 5-95 percentiles (light gray shading). Median SSB values with total F=0 (black line), i.e. no harvest from US or Mexico, and Management thresholds at 50,000 and 150,000 mt (horizontal dashed lines) are shown in the figure.

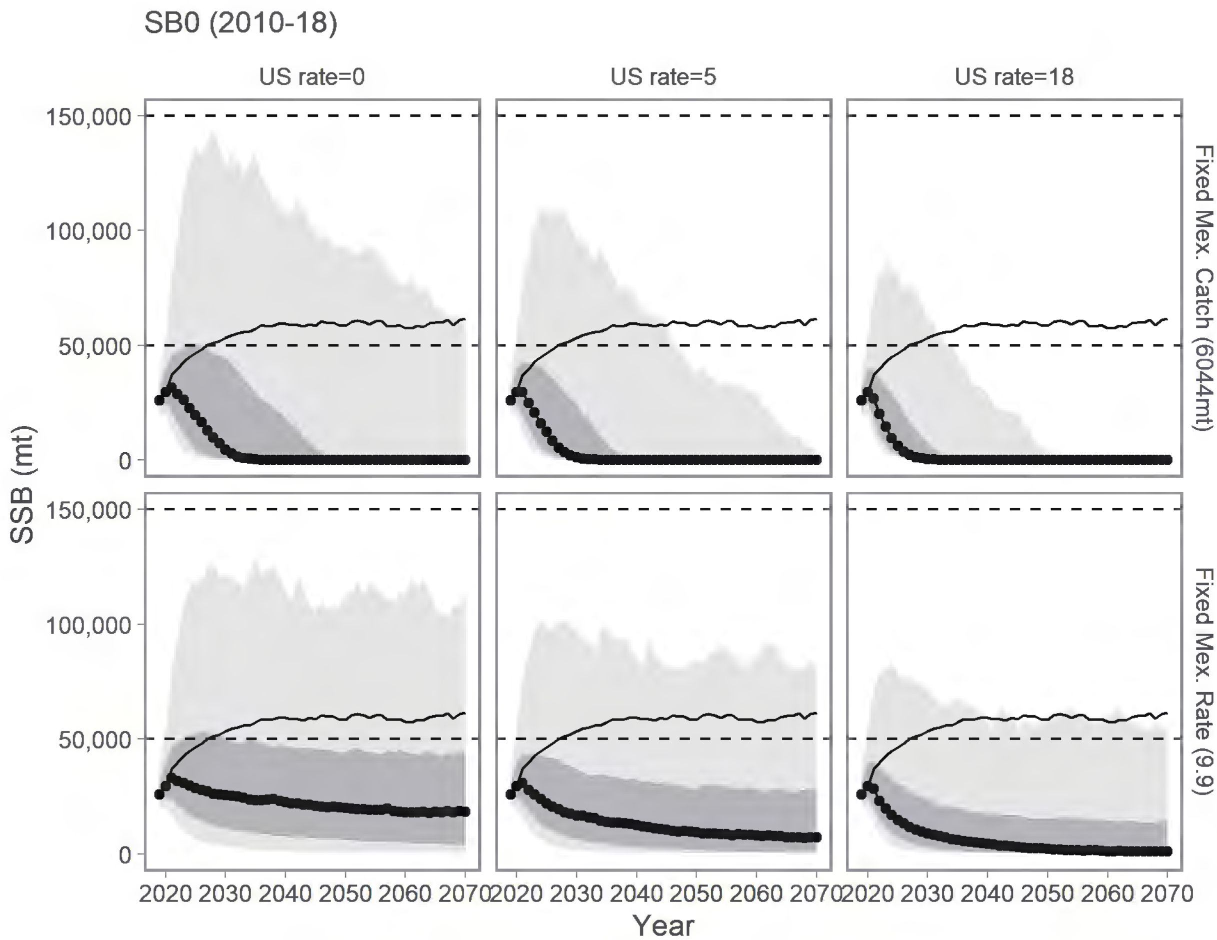

Figure 10. Projected spawning stock biomass (mt) for $SB_{0(2010\text{-}18)}$ scenario. Mexico catch was either fixed at 6,044 mt (top row) or fixed at a harvest rate of 9.9% (bottom row). US harvest rate was 0, 5, or 18% (left to right columns). Values displayed are median SSB values (black points), 25-75 percentiles (dark gray shading), and 5-95 percentiles (light gray shading). Median SSB values with total F=0 (black line), i.e. no harvest from US or Mexico, and Management thresholds at 50,000 and 150,000 mt (horizontal dashed lines) are shown in the figure.

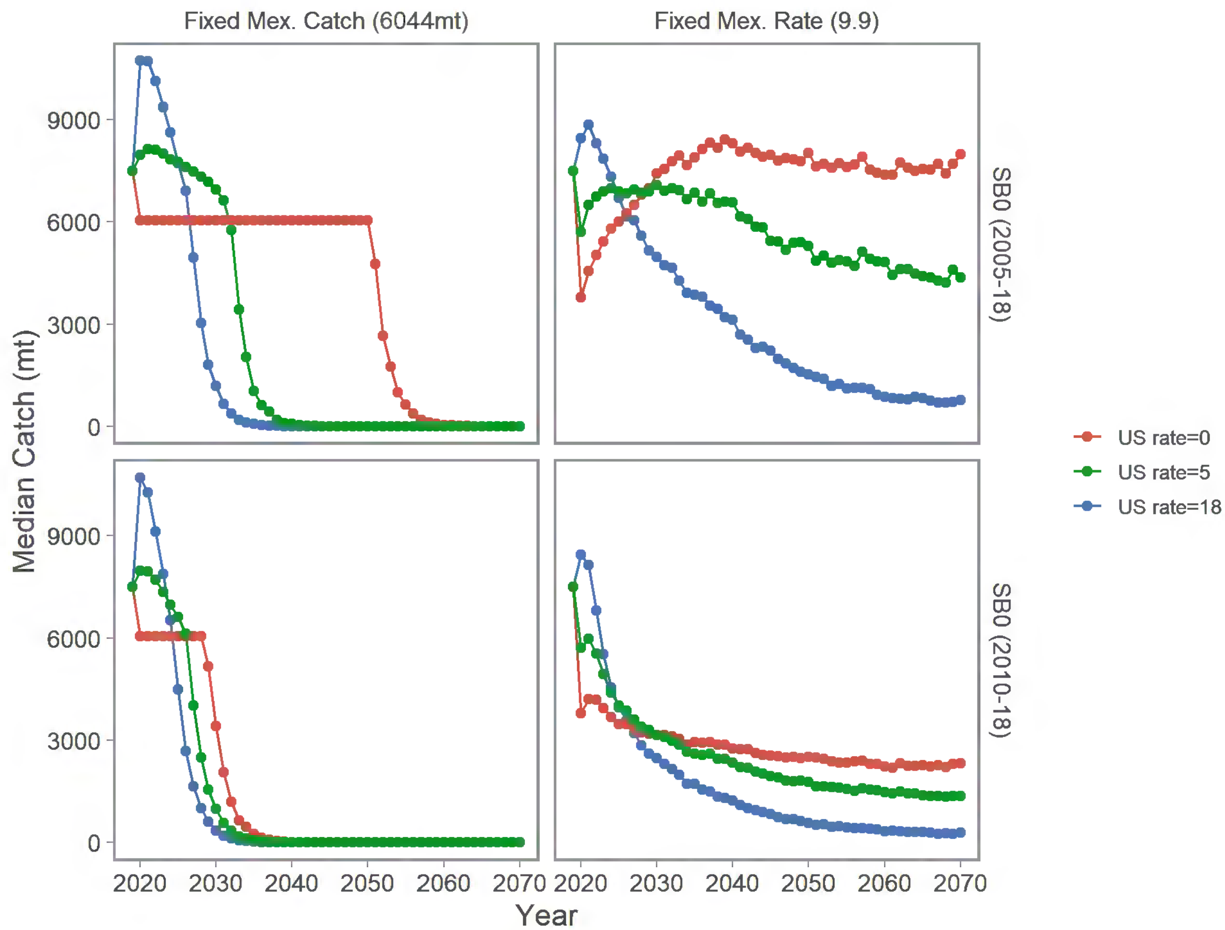

Figure 11. Median projected catch (mt) for Pacific sardine rebuilding alternatives. Panels are arranged by state of nature: $SB_{0(2005\text{-}18)}$ – top row; $SB_{0(2010\text{-}18)}$ – bottom row. Mexico catch was fixed at 6,044 mt (left column) or assumed to have a fixed harvest rate of 9.9 (right column). US harvest rates were 0 (red), 5 (green), and 18 (blue).

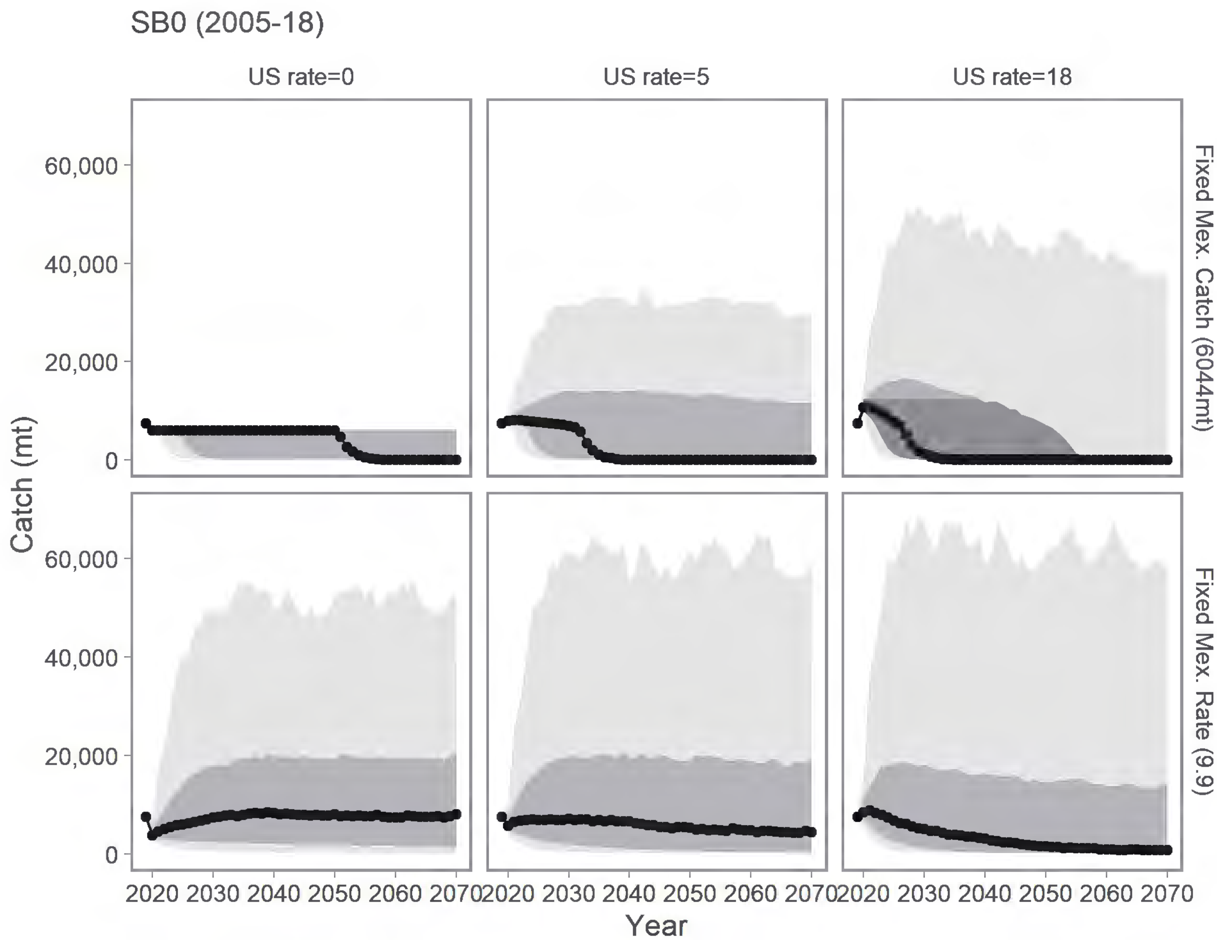

Figure 12. Projected catch (mt) for $SB_{0(2005\text{-}18)}$ scenario. Mexico catch was either fixed at 6,044 mt (top row) or fixed at a harvest rate of 9.9% (bottom row). US harvest rate was 0, 5, or 18% (left to right columns). Values displayed are median catch values (black points), 25-75 percentiles (dark gray shading), and 5-95 percentiles (light gray shading).

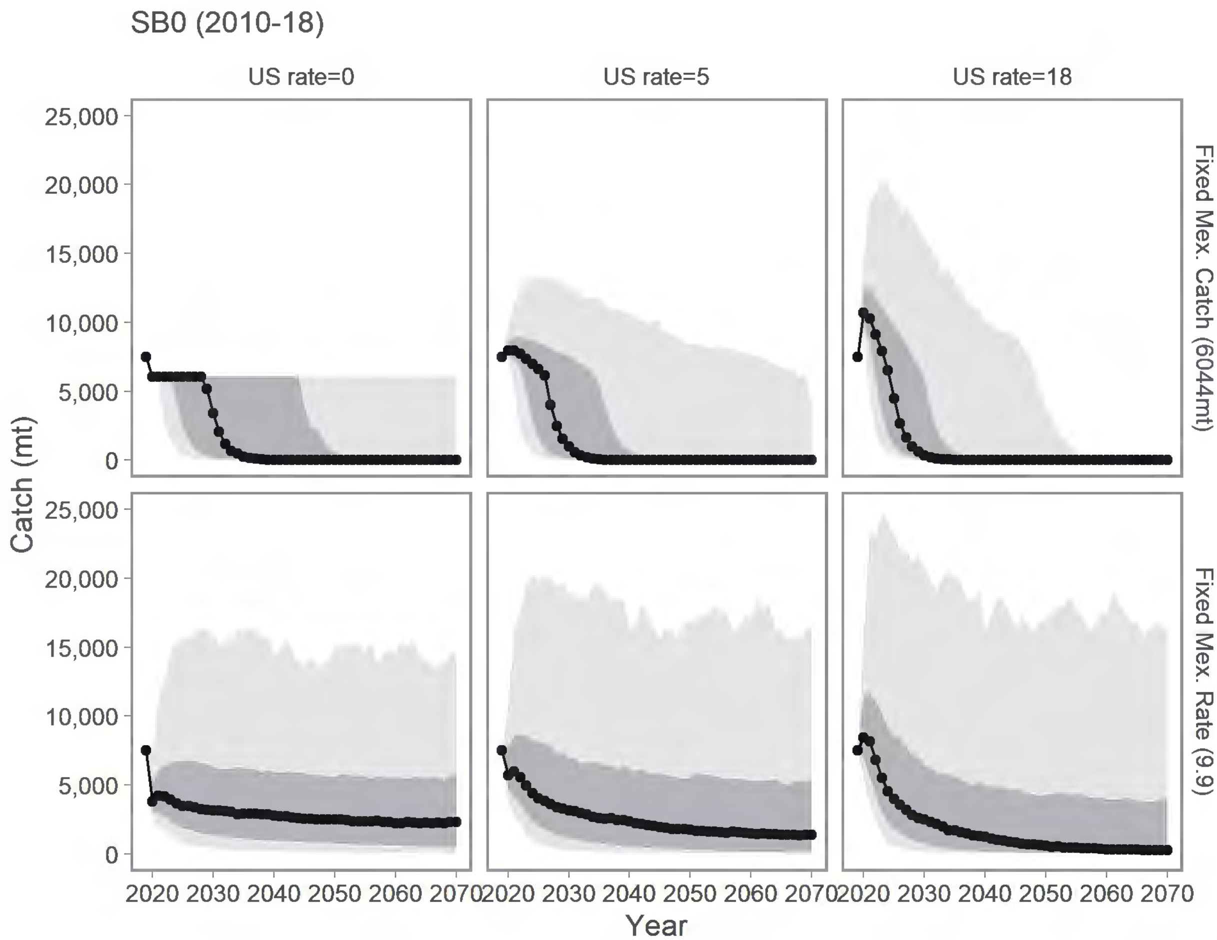

Figure 13. Projected catch (mt) for $SB_{0(2010\text{-}18)}$ scenario. Mexico catch was either fixed at 6,044 mt (top row) or fixed at a harvest rate of 9.9% (bottom row). US harvest rate was 0, 5, or 18% (left to right columns). Values displayed are median catch values (black points), 25-75 percentiles (dark gray shading), and 5-95 percentiles (light gray shading).

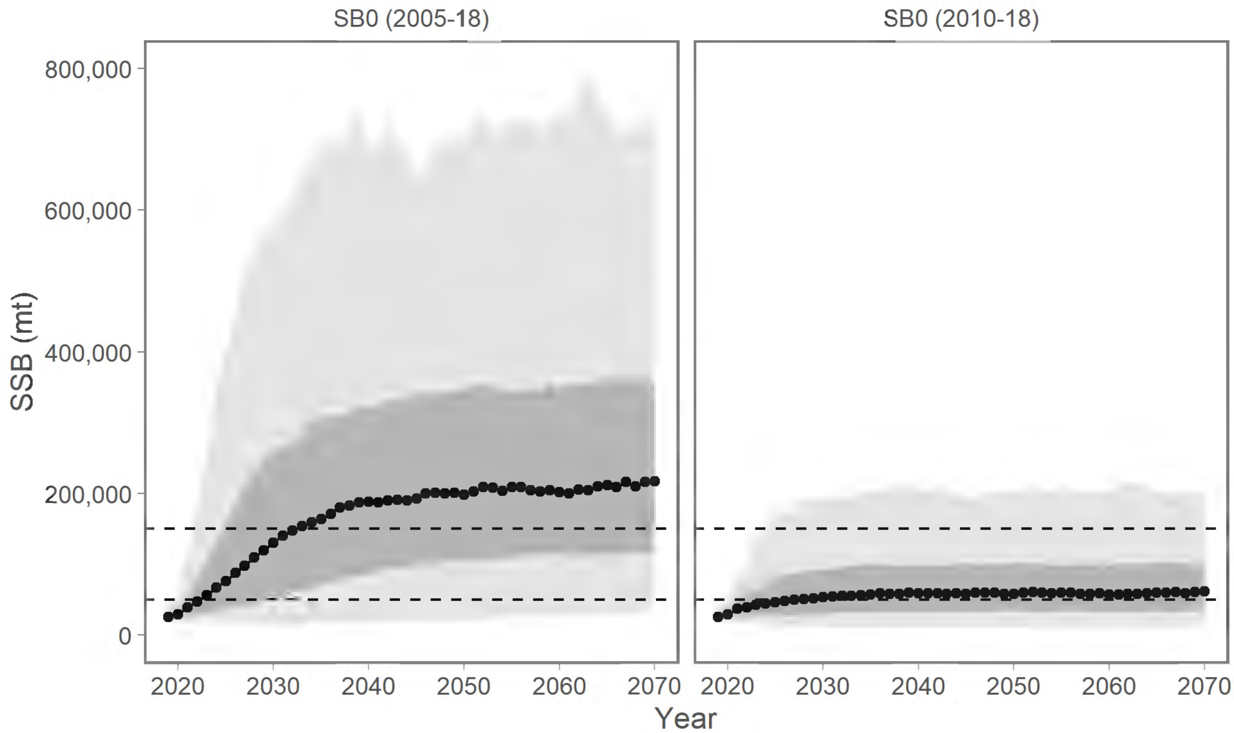

Figure 14. Projected spawning stock biomass (mt) for the $SB_{0(2005\text{-}18)}$ and $SB_{0(2010\text{-}18)}$ scenarios in the complete absence of fishing (Total *E*=0 for the US and Mexico). Values displayed are median SSB values (black points), 25-75 percentiles (dark gray shading), and 5-95 percentiles (light gray shading). Management thresholds at 50,000 and 150,000 mt are shown as horizontal dashed lines.

Appendix A. Rebuild.dat file for sardine rebuilding projections. The only difference between the high productivity and low productivity Rebuild.dat was the range of years selected for averaging recruitment for calculating SB0 (see input (22)).

```
# (1)Title
Sardine_2020_Rebuilding
# (2)Number of sexes
1
# (3)Age range to consider
0 10
# (4)Number of fleets
1
# (5)First year of projection (Yinit)
2019
# (6)First year the OY could have been zero
2020
# (7)Number of simulations
2000
# (8)Maximum number of years
500
# (9)Conduct projections with multiple starting values (0=No;else yes)
1
# (10)Number of parameter vectors
100
# (11)Is the maximum age a plus-group (1=Yes;2=No)
1
# (12)Generate future recruitments using historical recruitments (1)
historical recruits/spawner (2)  or a stock-recruitment (3)
3
# (13)Constant fishing mortality (1) or constant Catch (2)
1
# (14)Fishing mortality based on SPR (1) or F (2)
1
# (15)Pre-specify the year of recovery (or -1) to ignore
-1
# (16)Fecundity-at-age
# 0 1 2 3 4 5 6 7 8 9 10
0.0000 0.0354 0.0773 0.11 0.1339 0.1515 0.1644 0.1739 0.1808 0.1858 0.1939
# (17)Age specific information (females then males) weight / selectivity
#
0.0344 0.0591 0.0833 0.1601 0.17 0.1721 0.183 0.186 0.1913 0.1947 0.1995
0.490027 1 0.257237 0.0376225 0.0534343 0.0437764 0.0144477 0.0136617
0.00306224 0.00306224 0.00306224
# (18)M and current age-structure
#
0.585221 0.585221 0.585221 0.585221 0.585221 0.585221 0.585221 0.585221
0.585221 0.585221 0.585221
438996 194984 44087.5 19995 6617.46 25027.3 5931.46 3052.62 2481.45 970.423
6040.54
# (19)Age-structure at the start of year Yinit^0
580925 222512 46832.8 12386.5 47853.5 11486.9 5723.79 4551.15 1750.78 8726.19
2171.82
# (20)Year Ynit^0
2019
#  recruitment and biomass
# (21)Number of historical assessment years
```

```
16
# (22)Historical data
# year, recruitment, spawner, in B0, in R project, in R/S project
2004 2005 2006 2007 2008 2009 2010 2011 2012 2013 2014 2015 2016 2017 2018
2019
1864030 23481700 10243900 4440300 3036910 4349860 6382960 400378 320608
230611 267296 874285 198698 533748 644242 580925
186412 1341469 1590355 1476111 1102498 758713 543791 424294 282412 141519
65602 41595 45097 36936 32953 27771
0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0
0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0
0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0
# (23)Number of years with pre-specified catches
1
# (24)catches for years with pre-specified catches
2019 7500
# (25)Number of future recruitments to override
1
# (26)Process for overiding (-1 for average otherwise index in data list)
2019 1 2019
# (27)Which probability to produce detailed results for (1=0.5; 2=0.6;
6=sardineHCR)
6
# (28)Steepness sigma-R, and auto-correlation
0.3 1.2 0
# (29)Target SPR rate (FMSY Proxy)
0.75
# (30)Discount rate (for cumulative catch)
0.1
# (31)Truncate the series when 0.4B0 is reached (1=Yes)
0
# (32)Set F to FMSY once 0.4B0 is reached (1=Yes)
0
# (33)Maximum possible F for projection (-1 to set to FMSY)
3
# (34)Defintion of recovery (1=now only;2=now or before)
2
# (35)Projection type (1, 2, 3, 4, 5, 11 or 12)
1
# (36)Definition of the ""40-10"" rule
10   40
# (37)Sigma Assessment Error
0.607
# (38)Pstar
0.40
# (39)Constrain catches by the ABC (1=Yes;2=No)
2
# (40)Implementation error (0=No;1=Lognormal;2=Uniform)
0
# (41)Parameters of Implementation Error
1 0.3
# (42)Calculate coefficients of variation (1=Yes)
0
# (43)Number of replicates to use
10
# (44)Random number seed
-99004
```

```
# (45)File with multiple parameter vectors
rebuild_samphi.sso
# (46)User-specific projection (1=Yes); Output replaced (1->9)
0   5
# (47)Catches and Fs (Year; 1/2 (F or C); value); Final row is -1
2020 2 7500
-1    -1    -1
# (48)Fixed catch project (1=Yes); Output replaced (1->9); Approach (-1=Read
in else 1-9)
2 8 9 -1 -1
# (48a) Special catch options (1-Yes) [CUT_OFF, Emsy, distribution, MAXCAT,
Add, replace_code]
1 0.2202 1 1 0 6
# (48b) B1Target
150000
# (49)Split of Fs
2019 1
-1    1
# (50)Five pre-specified inputs
0.5 0.6 0.7 0.8 0.9 # 200 300 400 500 600 2048 2036 2030.0 2026.7 2036
# (51)Years for which a probability of recovery is needed
2027 2028 2029 2030 2031 2032 2033 2034
# (52)Time varying weight-at-age (1=Yes;0=No)
0
# (53)File with time series of weight-at-age data
HakWght.Csv
# (54)Use bisection (0) or linear interpolation (1)
0
# (55)Target Depletion
0.365
```

8 APPENDIX C

ADDENDUM TO SARDINE REBUIDLING DOCUMENT

Table 8. Probabilities of recovery above 150,000 mt of age 1+ biomass for rebuilding alternatives for $SB_{0(2005\text{-}18)}$ scenario. Mexico catch was fixed at 6,044 mt or at an exploitation rate of 9.9. Probabilities of recovery with no Mexico or US harvest is also shown. Grey shading indicates probabilities greater than 0.5.

	Fixed Mex. Catch (6,044mt)			**Fixed Mex. Rate (9.9)**				**Total F=0**
Year	**US rate=0**	**US rate=5**	**US rate=18**	**US rate=0**	**US rate=5**	**[2]US rate=18**	***US= 2,200 mt**	
2020	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2021	0.0655	0.0635	0.0615	0.0660	0.0635	0.0615	0.0635	0.0710
2022	0.1275	0.1150	0.1040	0.1290	0.1125	0.1035	0.1165	0.1525
2023	0.1960	0.1785	0.1520	0.1980	0.1775	0.1530	0.1810	0.2440
2024	0.2530	0.2245	0.1900	0.2550	0.2255	0.1925	0.2320	0.3260
2025	0.2985	0.2570	0.2200	0.2990	0.2635	0.2215	0.2685	0.3995
2026	0.3335	0.2895	0.2395	0.3420	0.2940	0.2455	0.3050	0.4590
2027	0.3645	0.3160	0.2585	0.3735	0.3250	0.2640	0.3345	0.5105
2028	0.3925	0.3365	0.2725	0.4075	0.3500	0.2845	0.3610	0.5505
2029	0.4170	0.3555	0.2865	0.4400	0.3785	0.3070	0.3860	0.5910
2030	0.4320	0.3680	0.2945	0.4595	0.3980	0.3225	0.4015	0.6275
2031	0.4490	0.3770	0.3005	0.4800	0.4125	0.3315	0.4185	0.6555
2032	0.4660	0.3880	0.3105	0.4995	0.4305	0.3455	0.4315	0.6775
2033	0.4815	0.4005	0.3175	0.5260	0.4485	0.3585	0.4500	0.7015
2034	0.4865	0.4095	0.3235	0.5435	0.4655	0.3710	0.4620	0.7225
2035	0.4955	0.4145	0.3275	0.5585	0.4800	0.3795	0.4735	0.7440
2036	0.5040	0.4195	0.3320	0.5755	0.4900	0.3900	0.4840	0.7570
2037	0.5085	0.4260	0.3340	0.5885	0.5025	0.3985	0.4920	0.7720
2038	0.5150	0.4325	0.3355	0.5995	0.5135	0.4065	0.5005	0.7890
2039	0.5175	0.4360	0.3385	0.6085	0.5250	0.4140	0.5060	0.8000
2040	0.5210	0.4380	0.3395	0.6180	0.5330	0.4190	0.5135	0.8090
2041	0.5240	0.4385	0.3420	0.6250	0.5400	0.4230	0.5185	0.8185
2042	0.5270	0.4425	0.3430	0.6340	0.5450	0.4275	0.5215	0.8330
2043	0.5285	0.4435	0.3440	0.6400	0.5500	0.4345	0.5270	0.8425
2044	0.5285	0.4435	0.3450	0.6455	0.5540	0.4370	0.5300	0.8545
2045	0.5315	0.4445	0.3465	0.6525	0.5575	0.4420	0.5315	0.8645
2046	0.5320	0.4460	0.3475	0.6570	0.5645	0.4435	0.5350	0.8725
2047	0.5340	0.4465	0.3480	0.6640	0.5700	0.4465	0.5365	0.8775
2048	0.5345	0.4470	0.3485	0.6710	0.5705	0.4520	0.5375	0.8850
2049	0.5350	0.4470	0.3485	0.6760	0.5745	0.4550	0.5395	0.8900
2050	0.5355	0.4475	0.3500	0.6805	0.5790	0.4585	0.5410	0.8960

**Probability of recovery results from a model run of 2,200 mt constant U.S. catch. This additional model run was requested by the CPSMT at the September 2020 Council meeting as an alternative way to model Alternative 1 Status Quo Management.*

[2] "US rate=18" was prorated by Buffer (0.7762) and U.S. Distribution (0.87); US E=0.1216 (12.16% harvest rate)