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CONSERVATION AND MANAGEMENT MEASURE FOR NORTH PACIFIC STRIPED MARLIN CONSULTATIVE DRAFT PROPOSAL

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Submission by the United States of America

CONSERVATION AND MANAGEMENT MEASURE FOR NORTH PACIFIC STRIPED MARLIN

Consultative Draft Proposal by the United States of America to the Seventeenth Regular Session of the Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean

Explanatory note:

In 2010, the Western and Central Pacific Fisheries Commission (WCPFC or Commission), concerned about the status of North Pacific striped marlin, adopted a conservation and management measure (CMM) that established catch limits for members and cooperating nonmembers (hereafter referred to as CCMs) that had historically caught North Pacific striped marlin. These concerns for the stock were validated as the 2011 stock assessment indicated that relative to B_{MSY} and F_{MSY}, this stock was overfished and experiencing overfishing (the Commission has not adopted reference points to formally determine the stock's status). Unfortunately, the reductions adopted by the Commission in CMM 2010-01 were not large enough to eliminate overfishing or rebuild the stock as stock assessments conducted in 2015 and 2019 continued to find the stock to be overfished and experiencing overfishing. Several CCMs including the United States have expressed interest in revising the CMM to rebuild the stock and as a first step, in 2019, the WCPFC adopted an interim rebuilding plan where the interim rebuilding target for North Pacific striped marlin is 20%$SSB_{F=0}$, to be reached by 2034 with at least 60% probability. The rebuilding plan included the following rebuilding strategy:

"Beginning in 2020, and based on the best scientific information available, members will develop measures to rebuild the stock in accordance with the rebuilding objective, with the aim of adopting revised conservation and management measures for North Pacific striped marlin at WCPFC17. Members should consider reduced catch limits and retention, release, and gear requirements, among other potential tools"

The United States has developed a consultative draft revised CMM for North Pacific striped marlin that is designed to ensure that the interim rebuilding target is met according to the specifications of the interim rebuilding plan adopted in 2019 (Attachment 1). The proposed CMM would establish a total allowable catch (TAC) that would be reduced over four phases, 2021-2024, 2025-2028, 2029-2032, and 2033 and forward. This phased scenario was identified by the United States as a scenario that would meet the rebuilding target while allowing for greater harvest than the other two scenarios evaluated over the rebuilding period (see Attachment 2). The phase periods generally correspond with years when new stock assessments are expected for North Pacific striped marlin. Using data from the scientific services provider on striped marlin caught north of the equator from 2015-2019, the following flag CCMs were identified as catching greater than 10 mt/year of striped marlin north of the equator: American Samoa, China, Japan, Kiribati, Korea, Chinese Taipei, United States, and Vanuatu. The TAC is proposed to be allocated as follows:

1. The allocations for American Samoa, Kiribati and Vanuatu are calculated as their 2015-2019 annual average rounded upward to the nearest 5 mt. The allocations for these SIDS are constant through the four TAC phases.
2. The allocations for China, Japan, Korea, Chinese Taipei and the United States are calculated as the total allowable catch for the phase minus [X] mt (the total of the allocations for American Samoa, Kiribati, and Vanuatu plus the [X mt] buffer) multiplied by the percentage the 2015-2019 average annual catch for that CCM relative to the sum of the 2015-2019 average annual catch for China, Japan, Korea, Chinese Taipei and the United States.
3. CCMs that captured less than 10 mt/year of striped marlin north of the equator during 2015-2019 would have a limit of 10 mt annually. [X mt] of the TAC are unallocated as a buffer.

Significant reductions in the overall catch of North Pacific striped marlin are needed to ensure this stock is rebuilt according to the specifications of the rebuilding plan. The United States investigated the efficacy of requiring live release of all captured striped marlin, elimination of the shallowest hooks on deep sets and the use of circle hooks as potential mitigation methods and found that while none would meet the rebuilding target as stand-alone requirements, they could help to reduce catch in concert with other mitigation options. If striped marlin caught north of the equator are alive on haulback and the vessel does not intend to retain the fish, the proposed measure requires live release to the extent possible.

The United States understands that some members may be hesitant to discuss revision of the North Pacific striped marlin proposal at WCPFC17, and would like members to consider the attached consultative draft revised CMM as a basis for intersessional consultations, with the aim of adopting a revised CMM at WCPFC18. The United States has also noted some discrepancies between ISC stock assessment catch estimates of striped marlin in the Convention Area north of the equator and WCPFC catch estimates for that area, by CCM, and is working with the Scientific Services Provider to improve the WCPFC estimates and better understand reasons for the differences.

Proposal

WCPFC17 tasks the Scientific Services Provider to examine the differences between the ISC stock assessment catch estimates of striped marlin in the Convention Area north of the equator and the WCPFC catch estimates for that area, by CMM, and provide an assessment to SC17 of any shortcomings in, or notable uncertainties associated with, the WCPFC estimates, with the aim of allowing CCMs to improve their estimates, where appropriate. WCPFC17 also tasks SC17 to make recommendations towards improving CCM’s catch estimates and to develop best handling and safe release guidelines for North Pacific striped marlin, SC17 and TCC17 to provide advice on ISC analyses on scenarios that would achieve the rebuilding plan, and WCPFC18 to adopt a revised CMM that will achieve the rebuilding plan.

Attachment 1

CMM 2013-06 Criteria

a. Who is required to implement the proposal?

   All CCMs

b. Which CCMs would this proposal impact and in what way(s) and in what proportion?

   This proposal would impact CCMs that catch striped marlin north of the equator. All CCMs would be subject to catch limits to ensure that the prescribed catch limits are not exceeded. The following describes how the catch limits were derived:

   i. The allocations for American Samoa, Kiribati and Vanuatu were calculated as their 2015-2019 annual average rounded upward to the nearest 5 mt. The allocations for these SIDS are constant through the four TAC phases.
   ii. The allocations for China, Japan, Korea, Chinese Taipei and the United States are calculated as the total allowable catch for the phase minus [X] mt (the total of the allocations for American Samoa, Kiribati, and Vanuatu plus the [X mt] buffer) multiplied by the percentage the 2015-2019 average annual catch for that CCM relative to the sum of the 2015-2019 average annual catch for China, Japan, Korea, Chinese Taipei and the United States.
   iii. CCMs that captured less than 10 mt/year of striped marlin north of the equator during 2015-2019 would have a limit of 10 mt annually. [X mt] of the TAC are unallocated as a buffer.

   The phased catch reductions are imposed on non-SIDS CCMs that caught > 10 mt on average annually from 2015-2019. Phased catch reductions are not imposed on the allocations for Vietnam, American Samoa, Kiribati or Vanuatu.

c. Are there linkages with other proposals or instruments in other regional fisheries management organizations or international organizations that reduce the burden of implementation?

   No linkages have been identified.

d. Does the proposal affect development opportunities for SIDS?

   For SIDS CCMs that had > 10 mt of catch on average annually from 2015-2019, catch limits were set by rounding their average annual catch of North Pacific striped marlin from 2015-2019 up to the nearest 5 mt. This may constrain catches of North Pacific striped marlin for SIDS, but as North Pacific striped marlin are not targeted, it should minimally affect opportunities for development in targeting other species.

e. Does the proposal affect SIDS domestic access to resources and domestic aspirations?

   No

f. What resources, including financial and human capacity, are needed by SIDS to implement the proposal?

   All CCMs would need to monitor their catches of North Pacific striped marlin to ensure they do not exceed their limits.

g. What mitigation measures are included in the proposal?

The proposal includes catch limits. The measure also requires live release if striped marlin caught north of the equator are alive on haulback and the vessel does not intend to retain the fish. CCMs are encouraged to consider use of other mitigation measures including live release, maintaining hooks below a certain depth on deep sets, and circle hooks.

h. What assistance mechanisms and associated timeframe, including training and financial support, are included in the proposal to avoid a disproportionate burden on SIDS?

None

Western and Central Pacific Fisheries Commission

SEVENTEENTH REGULAR SESSION

~~Honolulu, Hawaii, USA~~

~~6-10 December 2010~~

CONSERVATION AND MANAGEMENT MEASURE FOR NORTH PACIFIC STRIPED MARLIN

Conservation and Management Measure 20X~~1~~0-0X~~1~~

The Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean:

Noting with concern that the latest stock assessment of North Pacific striped marlin, completed by the International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific Ocean (ISC) in 2019, indicated that current spawning stock biomass is very depleted ($SSB_{2018}/SSB_{F=0}$ = 0.05) and the average fishing mortality rate in 2015-2017 was greater than the fishing mortality rate associated with MSY (F/F_{MSY} = 1.07);

Also noting that the Commission adopted, in accordance to Article 10, an interim rebuilding plan with an interim rebuilding target for North Pacific striped marlin to be 20%$SSB_{F=0}$, to be reached by 2034, with at least 60% probability;

~~best available scientific advice from the International Scientific Committee for Tuna and Tuna-like Species in the North Pacific Ocean (ISC) on the status of North Pacific Striped Marlin shows that the stock is subject to fishing mortality above levels that are sustainable in the long term;~~

Further noting the advice from the ISC that recent recruitment levels are a reasonable predictor of future recruitment levels, and significant reductions in the fishing mortality rate are needed to meeting the objectives of the rebuilding plan;~~fishing mortality on the stock should be reduced from the 2003 levels;~~

~~*Also noting* that the Pacific Islands Forum Fisheries Agency (FFA) Members will be adopting a system of zone-based longline limits to replace the current system of flag-based arrangements within their Exclusive Economic Zones (EEZs);~~

~~*Acknowledging* the advice from the Scientific Committee that the information provided by the ISC does not support classification of North Pacific Striped Marlin as a "northern stock" under Annex 1 of the WCPFC Rules of Procedure;~~

Adopts, in accordance with Article 10 of the WCPF Convention:

1. This Measure shall apply in high seas and EEZs within the convention area north of the equator.

2. For the purposes of this measure, vessels operated under charter, lease or other similar mechanisms as an integral part of the domestic fleet of a coastal State, shall be considered to be vessels of the host State or Territory, provided they have been notified to the Commission as such under CMM 2019-08. Such charter, lease or other similar mechanism shall be conducted in a manner so as not to charter known IUU vessels.

~~3. Nothing in this measure shall prejudice the legitimate rights and obligations of Small Island Developing State Members and participating territories in the Convention Area seeking to develop their own domestic fisheries.~~

3. The total allowable annual catch of North Pacific Striped Marlin will be subject to ~~a~~ phased reductions as follows:

a [1,951 mt] for the years 2021-2024
b [1,751 mt] for the years 2025-2028
c [1,551 mt] for the years 2029-2032
~~a~~d [1,351 mt] for the year 2033 and onward ~~such that by 1 January 2013 the catch is [80%] of the levels caught in 2000 to 2003.~~

~~4.~~ Each flag/chartering CCM with vessels fishing in the convention area north of the equator shall be subject to the calendar-year annual retained ~~following~~ catch limits in Table 1 for North Pacific Striped Marlin. CCMs not listed in the table are limited to a calendar-year annual retained catch of 10 mt. Any overage of the catch limit shall be deducted from the catch limit for the following year. ~~for the years 2011 and beyond:~~

~~5. 2011 [10%] reduction of the highest catch between 2000 and 2003;~~

~~6. 2012 [15%] reduction of the highest catch between 2000 and 2003;~~

~~7.~~4. ~~2013 and beyond: [20%] reduction of the highest catch between 2000 and 2003;~~

~~8.~~5. Each flag/chartering CCM shall decide on the management measures required to ensure that its flagged/chartered vessels operate under the catch limits specified in paragraphs 3 and 4 ~~5~~, noting that previous examples of such measures have included effort reductions, gear modification and spatial management.

6. CCMs shall require the owners and operators of their fishing vessels to release striped marlin alive, to the extent possible, north of the equator if the striped marlin is alive when hauled back and the vessel does not intend to retain the fish. The Scientific Committee shall develop safe release and handling guidelines for striped marlin for consideration by the Commission in 2021.

~~By 30 April 2011, each flag/chartering CCM shall report to the Commission verifiable information regarding its catch of North Pacific Striped Marlin by its flagged/chartered vessels north of the equator.~~

~~10.~~7. Each year CCMs shall report in their Part 2 annual reports their implementation of this measure, including the measures applied to flagged/chartered vessels to reduce their catch and the total catch taken against the limits established under paragraphs 3~~5~~ and 4~~7~~.

8. This measure shall be reviewed and amended as needed to ensure the objectives of the rebuilding plan are met ~~in 2011 based on the revised stock assessment for north Pacific striped marlin~~.

9. Table 1, Annual catch limits for North Pacific striped marlin

CCM	2021-2024	2025-2028	2029-2032	2033 and onward
American Samoa	[X]	[X]	[X]	[X]
China	[X]	[X]	[X]	[X]
Japan	[X]	[X]	[X]	[X]
Kiribati	[X]	[X]	[X]	[X]
Korea	[X]	[X]	[X]	[X]
Chinese Taipei	[X]	[X]	[X]	[X]
United States	[X]	[X]	[X]	[X]
Vanuatu	[X]	[X]	[X]	[X]

Attachment 2

Some Rebuilding Analyses for the Western and Central North Pacific Ocean Striped Marlin Stock

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Abstract

In this working paper, we describe analyses and stochastic stock projections to develop a rebuilding plan for the Western and Central North Pacific Ocean (WCNPO) striped marlin stock. This stock is currently estimated to be depleted and experiencing excess fishing mortality relative to maximum sustainable yield-based reference points. The interim rebuilding plan has the goals of rebuilding the spawning biomass of the stock to 20% of the unfished level, or $20\%SB_{F=0}$ = 3,610 mt, with a rebuilding time frame set at 15 years (2020-2034) and with a probability of rebuilding success of least 60%. There are three management strategy scenarios developed for these rebuilding analyses: a phased scenario, a constant fishing mortality scenario, and a constant quota scenario. The phased rebuilding scenario was designed to gradually reduce harvest quotas for the aggregate international fleet in order to rebuild the stock and to provide some periods of temporal stability for bycatch for the aggregate longline fleet. The constant F scenario was designed to determine the constant fishing mortality rate and associated fishing effort to be applied during 2021-2034 to rebuild the stock with at least 60% probability in 2034. Similarly, the constant quota scenario was designed to determine the constant catch biomass quota to be applied during 2021-2034 to rebuild the stock with at least 60% probability in 2034. Given the projected catch quotas and spawning biomasses to meet the rebuilding goals, the probabilities of rebuilding the stock were calculated for each of the rebuilding scenarios. The results showed that, under the phased rebuilding scenario, the rebuilding probabilities increased from P=0.25 in 2021 to P=0.61 in 2034. In comparison, the rebuilding probabilities under the constant F scenario increased from about P=0.29 in 2021 to P=0.60 in 2027-2034. Similarly, under the constant quota scenario, the rebuilding probabilities increased from P=0.29 in 2021 to

P=0.60 in 2031-2034. Additionally, we discuss some of the key characteristics of the three alternative harvest scenarios to rebuild the WCNPO striped marlin stock.

Introduction

This working paper describes analyses and stock projections to develop a rebuilding plan for the Western and Central North Pacific Ocean (WCNPO) striped marlin stock. The WCNPO striped marlin (*Kajikia audax*) stock area consists of waters in the Western and Central Pacific Fisheries Commission (WCPFC) management area bounded on the south by the equator and in the east by 150°W. For background, annual WCNPO striped marlin catches averaged 7,451 mt during 1975-1999, or about 51% above MSY. Annual catch has had a decreasing trend since 1993 and has averaged 2,328 mt during 2008-2017, or about 53% below MSY. In recent years, the catch by Japanese fleets has decreased while catches by the U.S. and Chinese Taipei fleets have varied without trend (Figure 1). Overall, longline gear has accounted for the vast majority of Western and Central North Pacific striped marlin catches since 1994 (91%).

Stock Status

The WCNPO striped marlin stock was estimated to be depleted and experiencing overfishing relative to MSY-based reference points (Tables 1 and 2) in the 2019 benchmark stock assessment (ISC Billfish WG 2019). These results were similar to the stock status from the previous assessment conducted in 2015 (ISC Billfish WG 2015). Estimates of spawning biomass fluctuated around 2,800 mt between 1975 and 1992, or about 15% of the unfished spawning biomass of 18,051 mt (Figure 2). Spawning biomass decreased substantially from 1993 through the late 1990s and fluctuated without trend from then until the present. The lowest observed spawning stock biomass was 618 t in 2011, or about 76% below SB_{MSY}, the spawning stock biomass to produce MSY, and about 97% below the unfished spawning biomass (Figure 2). In 2017, spawning biomass had increased to 981 mt, or about 62% below SB_{MSY}. Fishing mortality on the stock (average F on ages 3-12) has fluctuated above F_{MSY} with a decreasing trend in recent years (Figure 3) and averaged roughly F = 0.64 during 2015-2017, or 7% above $F_{MSY.}$ In 2017, fishing mortality was F=0.80, or about 33% above F_{MSY} = 1.33. It is notable that fishing mortality has been above F_{MSY} in every year except 1984, 1992, and 2016. Overall, the WCNPO striped marlin stock is overfished and experiencing overfishing relative to MSY-based biological reference points (Figure 4), although we note that no target or limit reference points have been established for the stock under the auspices of the WCPFC.

Rebuilding Goals

In 2018, the WCPFC Northern Committee requested that stock projection analyses be conducted in order to provide information for the development of a rebuilding plan for WCNPO striped marlin (NC14 2018). In particular, the Northern Committee made the following requests to the ISC:

> "*70. NC14 agreed to request ISC to conduct projections examining rebuilding scenarios for North Pacific striped marlin that cover a range of rebuilding targets (20%SSBF=0, FMSY, and 0% to 50% reductions in increments of 10% from current catch limits), timelines (10, 15 and 20 years) and probabilities of each scenario to reach each target within different timelines. ISC should produce additional scenarios of catch*

reduction if the probability of reaching the rebuilding target in 10, 15, and 20 years is not at least 60%.

71. NC14 expressed concern over the status of NP striped marlin and urged the Commission to develop a rebuilding plan for the stock as a matter of priority. NC members are encouraged to submit a draft CMM, if possible."

The NC14 request for stock projections was fully addressed in the benchmark stock assessment of WCNPO striped marlin (ISC Billfish WG 2019). This assessment was reviewed at the NC15 meeting in 2019. The United States circulated a consultative draft rebuilding plan that proposed that the rebuilding target for spawning biomass be established as 20% of unfished spawning biomass (20%$SB_{F=0}$), which is equivalent to spawning biomass of 20%$SB_{F=0}$ = 3,610 mt (NC 15).

Based on the benchmark stock assessment and the stock projections reviewed at SC15 and NC15, WCPFC16 adopted a rebuilding plan for WCNPO striped marlin where the rebuilding target was 20%$SB_{F=0}$ = 3,610 mt, and the rebuilding time frame was set at 15 years (2020-2034) with a probability of rebuilding success of least 60%. Overall, the goals for the WCNPO striped marlin rebuilding plan are:

- Rebuilding target is SB_{Target}=3,610 mt of spawning biomass
- Rebuilding time frame is 2020-2034
- Conservation measures are implemented in 2021-2034
- Target probability for rebuilding success is $P_{Success}$=0.60

In what follows, we describe the stochastic stock projections to calculate the fleet-wide reductions in catch biomass required to rebuild the WCNPO striped marlin stock to meet these goals. This includes descriptions of the initial conditions, recruitment dynamics, projection model, rebuilding scenarios, and results. In particular, the projection analyses begin in 2018, the first year following the stock assessment time period of 1975-2017, and the catch reductions to rebuild the stock are assumed to be first implemented in 2021. Last, we also calculated the projection results to rebuild the WCNPO striped marlin stock to the rebuilding target with a target probability for rebuilding success of $P_{Success}$=0.67 for comparison and briefly report these results.

Initial Conditions

The stock projections were designed to account for uncertainty in the initial striped marlin population size at age in 2018 and the catch biomasses harvested in 2018-2020. Uncertainty in the initial population size was an important feature to account for, noting that there is always some uncertainty in the terminal estimates of stock size based on an age-structured stock assessment (Brodziak et al. 1998). In particular, uncertainty in the initial population size in 2018, the first year of the projections, was characterized by calculating 100 bootstrap replicates of the population size at age using the bootstrapping option for the modeling platform Stock Synthesis (SS) version 3.30.08 (Methot and Wetzel 2013). This produced a distribution of initial population sizes at age that were used in each of the projection analyses (Figure 5).

Uncertainty in the distribution of annual catch biomasses during 2018-2020 was characterized using Monte Carlo simulation based on the 100 bootstrap replicates of the initial population size for each projection. In this case, it was assumed that the best estimates of catches prior to the implementation of rebuilding measures in 2021 were based on the recent average fishing mortality from the benchmark stock assessment. In particular, the recent average fishing mortality from the 2019 stock assessment was the average annual F on age classes 3 to 12 during 2015-2017, which was $F_{Initial}$=0.64 (ISC Billfish WG 2019). This initial F of $F_{Initial}$=0.64 was applied to the simulated population sizes at age during 2018-2020 to produce the expected catches. The resulting median catch biomasses in 2018, 2019, and 2020 were approximately 2,200, 2,800, and 2,900 mt for each projection analysis. This treatment of the initial catch biomasses for stock projections differed from that used in 2019 assessment in two ways. First, the additional initial year of 2020 was included to account for the change in time period from the 2019 assessment. Second, it was assumed that the initial catches were best determined by assuming that a constant fishing mortality rate was applied to the stock during 2018-2020. Here the assumption of a constant F during 2018-2020 was more consistent with the fact that the striped marlin catches are primarily the result of bycatch in the international longline fisheries in the North Pacific and not the result of targeted fishing effort. In this case, one would expect that the expected bycatch of striped marlin would reflect the pattern of relatively constant fishing effort in the aggregate longline fleet. Given that the size of the 2017 year class[1] appears to be above average relative to recent recruitment strengths, it was also important to account for expected increases in catches during 2018-2020 as this year class recruited to the fishery. In comparison, the treatment of initial catch biomasses in the 2019 assessment projections differed by harvest and recruitment scenario (ISC Billfish WG 2019). For fishing mortality-based harvest scenarios, the 2019 assessment projections used the average recent fishing mortality rate of $F_{Initial}$=0.64 to generate the expected catches in 2018-2019. In this case, the median catch biomasses in 2018-2019 under the short-term recruitment scenario were 2,200 and 2,800 mt,

[1] Here we use "year class" to refer to the abundance of age-0 or young-of-the-year fish in contrast to "recruitment" which refers to the abundance of age-1 fish used in the projection model.

respectively, while the median catch biomasses under the long-term recruitment scenario were 2,200 and 2,900 mt, respectively. For the quota-based harvesting scenarios, the 2019 projections used the recent average catch biomass during 2015-2017 to set the catch biomasses in 2018-2019. Here the average annual catch biomass was set to be $C_{Initial}$=2,151 mt during 2018-2019 under both the short-term and long-term recruitment scenarios (ISC Billfish WG 2019).

Recruitment Dynamics

Recruitment dynamics for the stochastic rebuilding projections explicitly included uncertainty about future recruitment strength (Brodziak et al. 1998) based on the empirical patterns observed in the 2019 stock assessment (Figure 6). Recruitment for the stochastic projections was based on two alternative hypotheses about future recruitment. The first hypothesis was that future recruitment would be similar to recent short-term recruitment (Figure 7). This hypothesis was based on the observation that recruitment estimates had remained relatively low in recent years, and one may not expect this to change in the future. In particular, the short-term recruitment scenario was based on resampling the empirical cumulative distribution function of recruitment observed during 2012-2016 (Figure 8). Under the short-term recruitment scenario, the average recruitment was 134,020 age-1 fish with a CV of 58%. The second hypothesis was that future recruitment would be similar to the long-term recruitment pattern (Figure 7). This hypothesis was based on the observation that the average of the bootstrap distribution of recruitment in 2018 (294,574 age-1 fish with a CV of 44%) was more than two-fold higher than the recent 5-year average, suggesting that achieving higher recruitment was a possibility. In particular, the long-term recruitment scenario was based on resampling the empirical cumulative distribution function of age-1 recruitment values that were observed during

1976-2016 (Figure 8). Under the long-term recruitment scenario, the average recruitment was 360,989 age-1 fish with a CV of 54%. Thus, the long-term recruitment scenario would be expected to produce over twice as many recruits as the short-term scenario on average, although both scenarios had similar levels of observed recruitment variability.

In 2019, after the ISC Billfish working group presented the WCNPO striped marlin stock assessment to the WCPFC Scientific and Northern Committees for review, the Northern Committee then requested the ISC Billfish working group to provide additional information on which recruitment scenario was more likely given the observed assessment data. This request was made because there were substantial differences in the probable rebuilding trajectories under the short- and long-term recruitment scenarios. In particular, the Northern Committee requested that (NC15 2019)

> "*48. Recognizing the need for additional scientific advice to refine a rebuilding strategy, NC15 requested that the ISC Billfish Working Group provide advice on which future recruitment scenario is the most likely one over the near term.* ".

This request was made after the IWSC Billfish Working Group had completed the 2019 benchmark stock assessment.

Subsequently, Brodziak and Sculley (2020) provided additional analyses to address the request of the Northern Committee of the WCPFC to provide advice on which recruitment scenario was most likely for the 2019 WCNPO striped marlin stock assessment projections. First, they applied linear regression analyses to evaluate the time trend of the recruitment estimates from the stock assessment. The regression results showed a significant long-term decline in age-0 recruits, which indicated that using a long-term recruitment trend for the future projections, was not consistent with the observed recent recruitment values. Second, they evaluated out-of-sample forecasts of the relative prediction errors for the observed 2017 and 2018 recruitments under the short-term and long-term recruitment scenarios using cross validation (e.g., Wood 2006). This analysis indicated that the weighted error variance for recruitment predictions under the short-term scenario was roughly one-tenth of the error variance under the long-term recruitment scenario.This, in turn, indicated that the short-term scenario provided 10-fold better predictive accuracy than the long-term scenario for near term recruitment. Third, they analyzed the autocorrelation function for the time series of standardized recruitment residuals during 1976-2018 and found that significant positive autocorrelations existed at time lags of 1, 5, and 6 years. This analysis provided empirical support for the existence of some autocorrelation in the striped marlin recruitment time series after correcting for maternal effects in the estimated stock-recruitment curve. Here it was noted that the observed autocorrelations likely represent the combined effects of environmental drivers on recruitment strength and provide empirical support for the short-term recruitment scenario as the most likely recruitment scenario. Overall, the long-term decline in recruitment, combined with the better predictive accuracy of the short-term recruitment scenario and the observation that recruitment was positively auto-correlated, led to the conclusion that the short-term recruitment scenario was the most likely recruitment scenario for conducting future stock projections for WCNPO striped marlin (ISC Billfish WG 2020). Given this conclusion, it was also noted that there was some chance that the long-term recruitment scenario could be the best approximation of future recruitment dynamics relative to the short-term scenario. To account for this possibility, future recruitment dynamics were modeled as a mixture distribution of the short-term and long-term recruitment scenarios. The mixing probabilities were based on the out-of-sample forecast accuracies for recruitment values in 2017-2018 described in Brodziak and Sculley (2020), which led to annual mixing probabilities of 0.92 and 0.08 for the short-term and long-term scenarios, respectively. As a result, it was about 11-fold more likely that future recruitment dynamics would follow the short-term scenario versus the long-term scenario in each projection analysis.

Projection Model

Rebuilding projections for WCNPO striped marlin were conducted using an age-structured projection model (Brodziak et al. 1998). This stochastic projection model can account for future variability in recruitment, initial population size, and process error in life history and fishery selectivity parameters (AGEPRO software available at: https://nmfs-fish-tools.github.io/AGEPRO/). In the application to rebuilding projections for WCNPO striped marlin, variability in initial conditions and recruitment were modeled as described in the sections above. In each projection, 1000 total simulations were run for each bootstrap replicate to characterize the effects of process errors in future recruitment, life history and fishery parameters. This gave 100,000 total simulated trajectories to evaluate the central tendency and variability of population and fishery quantities of interest, such as spawning biomass and catch biomass, in each projection. The stochastic projections employed model estimates of the multi-fleet, multi-season, size- and age-selectivity, and structural complexity in the assessment model to produce consistent results. Life history parameters for the projections were based on the exact same values as were used in the 2019 assessment (ISC Billfish WG 2019). This included natural mortality at age, maturity at age, and mean spawning weights at age. Mean fishery catch weights at age were calculated as a weighted average of the catch weights at age for the representative dome-shaped (95%) and flat-topped (5%) selectivity fleets. In each stochastic projection, life history parameters at age were randomly sampled with a multiplicative lognormal process error with a mean of unity and a CV of 10% to represent uncertainty about future values, with the exception of maturity at age, which was sampled with a CV of 1%. Similarly, fishery selectivity at age parameters were sampled with a multiplicative lognormal process error with a mean of unity and a CV of 10% to represent uncertainty about future selectivity.

Rebuilding Scenarios

Three alternative harvest scenarios to rebuild the stock and satisfy the rebuilding goals were conducted. These were:

- a phased rebuilding scenario
- a constant F rebuilding scenario, or constant fishing mortality rate scenario
- a constant quota rebuilding scenario, or constant catch biomass scenario

The phased rebuilding scenario was designed to gradually reduce harvest quotas for the aggregate international fleet in order to rebuild the stock and to provide some periods of temporal stability for bycatch for the aggregate longline fleet. The phased rebuilding scenario consisted of setting fixed catch biomass quotas during 4 time periods: 2021-2024, 2025-2028, 2029-2032, and 2033-2034. The magnitudes of the quotas were iteratively determined to rebuild the stock to the target spawning biomass with at least 60% probability in 2034 using roughly equal catch reductions in each phase. The constant F scenario was designed to determine the constant fishing mortality rate and associated fishing effort to be applied during 2021-2034 to rebuild the stock with at least 60% probability in 2034. This constant level of fishing mortality was iteratively calculated to meet the rebuilding goals. Similarly, the constant quota scenario was designed to determine the constant catch biomass quota to be applied during 2021-2034 to rebuild the stock with at least 60% probability in 2034. This constant level of catch quota was iteratively calculated to meet the rebuilding goals.

Results

The probable distributions of future catch biomasses were calculated for each of the rebuilding scenarios. The central tendency of annual catch biomass was roughly 2,200, 2,785, and 2,860 mt during 2018-2020 for each scenario. Under the phased scenario, the median catch biomasses to rebuild the stock decreased from 1,951 mt to 1,351 mt in four phases during 2021-2034 (Table 3 and Figure 9). In contrast, the median catch biomasses under the constant F scenario increased from 1,382 in 2021 to 1,590 mt in 2027 and then remained constant during 2028-2034 (Table 4 and Figure 10). Under the constant quota scenario, the catch biomass quota to rebuild the stock was about 1,550 mt during 2021-2034 (Table 5 and Figure 11). The percent reductions in catch biomass in 2021 under the phased, constant F, and constant quota scenarios were -9%, -36%, and -28%, respectively (Table 6a and Figure 12). Comparing the sum of the median catch biomasses through 2021-2034 indicated that the phased rebuilding scenario produced the highest total catch of about 31,554 mt (Table 6a and Figure 12) while the constant F and constant quota rebuilding scenarios produced similar total catches of about 29,618 and 28.287 mt, respectively, or about 8% less catch than the phased scenario. Last, when the target probability of rebuilding success was increased to 67%, the results for projected catch biomasses were similar but showed a lower overall magnitude of annual catch biomass under each of the rebuilding scenarios (Table 6b).

Similarly, we calculated the probable distributions of future spawning biomasses for each of the rebuilding scenarios. The central tendency of annual spawning biomass during 2018-2020 was roughly 1,915, 2,530, and 3,025 mt for each scenario. Under the phased scenario, the median spawning biomasses to rebuild the stock increased from 2,993 mt to 4,061 mt during 2021-2034 (Table 7 and Figure 13). Under the constant F scenario, the median spawning biomasses increased from 3,174 mt in 2021 to about 3,840 mt in 2028 and then increased slightly during 2029-2034 (Table 8 and Figure 14). In comparison, the median spawning biomasses under the constant quota scenario increased from 3,121 mt in 2021to about 4,000 mt in 2030 and then increased slightly during 2031-2034 (Table 9 and Figure 15). The percent changes in catch biomass from 2020 to 2021 under the phased, constant F, and constant quota scenarios were -1%, +5%, and +3%, respectively (Table 10 and Figure 16). Comparing the average of the median spawning biomasses through 2021-2034 indicated that the constant quota and constant F rebuilding scenarios produced similar averages of about 3,773 and 3,726 mt, respectively (Table 10 and Figure 16) while the phased rebuilding scenarios produced a lower average of about 3,320 mt of spawning biomass, or about 12% below the constant quota scenario. Last, when the target probability of rebuilding success was increased to 67%, the results for projected spawning biomasses were similar but showed a higher overall magnitude of spawning biomass under each rebuilding scenario (Table 10b).

The probable distributions of future fishing mortality were also calculated for each rebuilding scenario. In the absence of any new stock assessment information, it was assumed that the annual fishing mortality rate during 2018-2020 was equal to F_{Recent}=0.64 as estimated in the most recent stock assessment for each scenario. Under the phased scenario, the median fishing mortality to rebuild the stock decreased from F=0.46 in 2021 to F=0.25 in 2034, for a decline of about -47% (Table 11 and Figure 17). Under the constant F scenario, the median fishing mortality remained constant at F=0.31 during 2021-2034 by design (Table 12 and Figure 18). In comparison, the median fishing mortality under the constant quota scenario decreased from F=0.35 in 2021 to F=0.30 in 2026 and then decreased slightly to F=0.29 in 2034 for an overall decline of about -17% (Table 3 and Figure 19). The percent decreases in fishing mortality from 2020 to 2021 under the phased, constant F, and constant quota scenarios were -28%, -52%, and -45%, respectively (Table 14a and Figure 20). Comparing the average of the median fishing mortality rates through 2021-2034 indicated that the constant quota and constant F rebuilding scenarios produced similar averages of F=0.31 (Table 14a and Figure 20). In contrast, the phased rebuilding scenarios produced a higher average fishing mortality of about F=0.37, or about 12% above the constant F and quota scenarios and about -21% below the overfishing reference point. Last, the results for projected fishing mortality rates were similar when the target probability of rebuilding success was increased to 67%, but the results showed a lower overall magnitude of fishing mortality was required to rebuild the stock under each scenario (Table 14b).

Given the projected catch quotas and spawning biomasses to meet the rebuilding goals, the probabilities of rebuilding the stock were calculated for each of the rebuilding scenarios. The results showed that, under the phased rebuilding scenario, the rebuilding probabilities increased from P=0.25 in 2021 to P=0.61 in 2034 (Table 15 and Figure 21). In comparison, the rebuilding probabilities under the constant F scenario increased from about P=0.29 in 2021 to P=0.60 in 2027-2034 (Table 15 and Figure 22). Similarly, under the constant quota scenario, the rebuilding probabilities increased from P=0.29 in 2021 to P=0.60 in 2031-2034 (Table 15 and Figure 23). Comparing the rebuilding probabilities through 2021-2034 across scenarios showed that the first year in which the rebuilding goal was achieved was 2034, 2027, and 2031 for the phased, constant F, and constant quota scenarios, respectively (Table 15a). Overall, the time series of rebuilding probabilities were similar for the constant F and constant quota scenarios which both exhibited a concave increase through time (Table 15a and Figure 24), while the time series of rebuilding probabilities for the phased scenario showed a more or less steady increase during 2021-2034. Last, when the target probability of rebuilding success was increased to 67%, the results showed a higher overall annual probability of rebuilding the stock under each scenario (Table 15b).

Similarly, we calculated the annual probabilities that the stock was experiencing overfishing under each of the rebuilding scenarios. Under the phased rebuilding scenario, the overfishing probabilities slightly increased from P=0.46 in 2021 to P=0.49 in 2022-2023 and then steadily decreased to P=0.06 in 2034 (Table 16 and Figure 25). In contrast, the overfishing probabilities under the constant F scenario were P=0 during 2021-2034 by design (Table 16 and Figure 26). In comparison, the overfishing probabilities under the constant quota scenario slowly decreased from about P=0.13 in 2021 to P=0.11 in 2034 (Table 16 and Figure 27). Comparing the overfishing probabilities through 2021-2034 showed that the first year in which overfishing was not occurring with less than or equal to 50% probability was 2021 (Table 16 and Figure 28). Overall, the time series of overfishing probabilities were highest for the phased scenario and lowest for the constant F scenario (Table 16 and Figure 28), while the time series of overfishing probabilities under the constant quota scenario were low (≤15%) and relatively constant during 2021-2034. Last, when the target probability of rebuilding success was increased to 67%, the results showed a lower overall annual probability of overfishing the stock under each scenario (Table 16b), with the exception of the constant F scenario, which remained the same.

Discussion

In what follows, we discuss some of the key characteristics of the three alternative harvest scenarios to rebuild the WCNPO striped marlin stock.

First, it is important to keep in my mind that the estimated size of the 2017 year class is relatively large compared to the short-term recruitment pattern but is also more uncertain (Figure 7). If it is true that the 2017 year class is near the long-term average recruitment strength (Figure 7), then one can expect that stock rebuilding may occur more rapidly than may be expected based on the short-term trends in recruitment of WCNPO striped marlin.

Second, it is important to note that each of the rebuilding scenarios reduces fishing mortality to be below the putative overfishing reference point during 2021-2034. This implies that each of the rebuilding scenarios meets the requirements of the USA Magnuson Stevens Act to reduce fishing mortality to be below the overfishing limit reference point, or F_{MSY} proxy, as soon as practicable.

Third, while each of the rebuilding scenarios requires near-term reductions in catch biomass and fishing mortality, the near-term reductions under the phased rebuilding scenario are much smaller than under the constant F or constant quota scenarios (Figures 12 and 20). This implies that the impacts of achieving near-term conservation goals are likely to be lower under the phased rebuilding scenario. This may be a desirable outcome given that it may be difficult to make substantial changes in fishing practices by the aggregate international fleet that harvests WCNPO in the short-term due to management inertia and the general non-malleability of resource extraction capital. In this context, the phased rebuilding scenario requires a -9% reduction in catch from 2020 to 2021 compared to the constant F and constant quota scenarios that require catch reductions that are 4-fold and 3-fold larger. It is also useful to note that the potential size of the 2017 year class leads to differences between the relative reductions in catch and fishing mortality needed at the start of the rebuilding period. Reducing the catch quotas for WCNPO striped marlin under a phased rebuilding scenario will likely promote greater stability in the fishing operations that incidentally harvest this bycatch species.

Fourth, it is important to note that the phased rebuilding approach is likely to produce the largest yields from the WCNPO striped marlin stock. The increase in yield under the phased versus the constant F or quota scenarios is about 8% in terms of biomass over the rebuilding time period. This increase in benefits would likely be larger if translated into a discounted revenue stream, although that is beyond the scope of these analyses.

Fifth, the constant F and quota scenarios produce more rapid rebuilding of the WCNPO striped marlin stock than the phased rebuilding scenario. In particular, it appears that the stock could be rebuilt sooner than 2034, perhaps by the mid- to late-2020s under the constant F or constant quota scenarios (Figures 16 and 24). This may be an important feature to consider in relation to the long-term trends in catch, spawning biomass, and fishing mortality for this stock (Figures 1 to 3).

Sixth, given that there are several international fleets that harvest WCNPO striped marlin as bycatch, primarily by longline fleets, it may be useful to consider the option of multiyear quotas to address issues of overage or underage of annual catch quotas by individual nations. In this context, it may be useful to include carryover or multiyear quotas provisions (i.e., Holland et al. 2020) in a 2021-2034 rebuilding plan that may be developed for application in the WCPFC fishery management system. This approach may be useful in any of the rebuilding scenarios described here.

Seventh, while uncertainty about fishery system dynamics have been included in each of the rebuilding scenarios for WCNPO striped marlin in a comparable manner, the fishery system may produce unexpected results due to unforeseen changes. In this context, adapting to changes in life history parameters, recruitment patterns, trophic interactions or environmental factors may be important for implementing a successful rebuilding plan. Here it would be useful to develop an interim rebuilding goal or a "waypoint" to measure the progress achieved in a striped marlin rebuilding plan (i.e., Brodziak et al. 2008). The timing of the assessment of the achievement of the interim rebuilding goal could be directly linked to the future assessment schedule for WCNPO striped marlin, which includes a plan to conduct a benchmark stock assessment in 2024 (ISC Billfish WG 2020) and likely every five years after that.

Last, it is important to note that the rebuilding scenarios developed herein do not explicitly account for implementation uncertainty in the conservation measures (e.g., Link et al. 2012) designed to rebuild the WCNPO striped marlin stock. In this context, it may be appropriate to consider increasing the target probability for rebuilding success to be greater than 60% (e.g., 67%) to provide a precautionary buffer that accounts for uncertainty in the effectiveness of the conservation measures.

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Table 1. Summaries of the reported catch (mt) used in the 2019 stock assessment along with annual estimates of population biomass (age-1 and older, mt), spawning biomass (mt), relative spawning biomass (SB/SB_{MSY}), recruitment (thousands of age-0 fish), fishing mortality (average F, ages-3 to 12), relative fishing mortality (F/F_{MSY}), and spawning potential ratio of Western and Central North Pacific Ocean striped marlin.

Year	2011	2012	2013	2014	2015	2016	2017	Mean[1]	Min[1]	Max[1]
Reported Catch	2,690	2,757	2,534	1,879	2,072	1,892	2,487	5,643	1,879	10,862
Population Biomass	5,874	6,057	4,937	6,241	5,745	5,832	6,196	12,153	4,509	22,303
Spawning Biomass	618	809	743	864	1,073	1,185	981	1,765	618	3,999
Relative Spawning Biomass[2]	0.24	0.31	0.29	0.33	0.41	0.46	0.38	0.68	0.24	1.54
Recruitment (age 0)	196,590	87,956	330,550	77,274	185,438	195,069	354,391	396,218	77,274	1,049,460
Fishing Mortality	1.11	1.06	0.86	0.63	0.62	0.51	0.80	1.06	0.51	1.71
Relative Fishing Mortality[2]	1.85	1.76	1.42	1.05	1.03	0.85	1.33	1.76	0.85	2.85
Spawning Potential Ratio	9%	11%	11%	16%	17%	20%	14%	12%	20%	6%

[1] During 1975-2017

[2] Relative to MSY-based reference points

Table 2. Estimates of biological reference points along with estimates of fishing mortality (F), spawning biomass (SB), recent average yield (C), and spawning potential ratio (SPR) of Western and Central North Pacific striped marlin, derived from the base case model assessment model, where "MSY" indicates reference points based on maximum sustainable yield.

Reference Point	**Estimate**
F_{MSY} (age 3-12)	0.60
F_{2017} (age 3-12)	0.80
$F_{20\%SB(F=0)}$	0.47
SB_{MSY}	2,604 mt
SB_{2017}	981 mt
$SB_{20\%(F=0)}$	3,610 mt
MSY	4,946 mt
$C_{2015-2017}$	2,151 mt
SPR_{MSY}	18%
SPR_{2017}	14%
$SPR_{20\%SB(F=0)}$	23%

Table 3. The median projected catch biomass time series (thousand mt) under the phased rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the catch biomass distributions.

	Catch Biomass (Thousand metric tons) Phased Rebuild		
Year	P10	Median	P90
2018	1597	2202	2870
2019	2053	2785	3649
2020	2118	2860	3828
2021	1951	1951	1951
2022	1951	1951	1951
2023	1951	1951	1951
2024	1951	1951	1951
2025	1751	1751	1751
2026	1751	1751	1751
2027	1751	1751	1751
2028	1751	1751	1751
2029	1551	1551	1551
2030	1551	1551	1551
2031	1551	1551	1551
2032	1551	1551	1551
2033	1351	1351	1351
2034	1351	1351	1351
Total	29477	31554	34055

Table 4. The median projected catch biomass time series (thousand mt) under the constant F rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the catch biomass distributions.

	Catch Biomass (Thousand metric tons) Constant F Rebuild		
Year	P10	Median	P90
2018	1597	2203	2870
2019	2051	2785	3650
2020	2121	2858	3828
2021	1031	1382	1886
2022	1088	1462	2033
2023	1124	1517	2111
2024	1150	1549	2147
2025	1168	1569	2170
2026	1176	1578	2182
2027	1181	1588	2188
2028	1184	1589	2193
2029	1184	1591	2195
2030	1187	1591	2195
2031	1188	1589	2200
2032	1187	1589	2198
2033	1186	1589	2196
2034	1186	1589	2195
Total	21987	29618	40436

Table 5. The median projected catch biomass time series (thousand mt) under the constant quota rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the catch biomass distributions.

	Catch Biomass (Thousand metric tons) Constant Quota Rebuild		
Year	P10	Median	P90
2018	1595	2202	2875
2019	2050	2786	3656
2020	2122	2859	3829
2021	1550	1550	1550
2022	1550	1550	1550
2023	1550	1550	1550
2024	1550	1550	1550
2025	1550	1550	1550
2026	1550	1550	1550
2027	1550	1550	1550
2028	1550	1550	1550
2029	1550	1550	1550
2030	1550	1550	1550
2031	1550	1550	1550
2032	1550	1550	1550
2033	1550	1550	1550
2034	1550	1550	1550
Total	26208	28287	30800

Table 6a. Comparison of the central tendencies of the projected catch biomass time series (median catch, thousand mt) under the phased, constant F, and constant quota rebuilding scenarios along with the average of the median catch, total of the median catch and percent of the maximum total catch.

Catch Biomass Quota (mt)			
YEAR	Phased Rebuild Catch Quota	Constant F Rebuild Catch Quota	Constant Quota Rebuild Catch Quota
2018	2202	2203	2202
2019	2785	2785	2786
2020	2860	2858	2859
2021	1951	1382	1550
2022	1951	1462	1550
2023	1951	1517	1550
2024	1951	1549	1550
2025	1751	1569	1550
2026	1751	1578	1550
2027	1751	1588	1550
2028	1751	1589	1550
2029	1551	1591	1550
2030	1551	1591	1550
2031	1551	1589	1550
2032	1551	1589	1550
2033	1351	1589	1550
2034	1351	1589	1550
AVERAGE 2021-2034	1693	1555	1550
TOTAL 2021-2034	23709	21772	21700
PERCENT OF MAXIMUM	100%	92%	92%

Table 6b. Comparison of the central tendencies of the projected catch biomass time series (median catch, thousand mt) based on a 67% target probability of rebuilding success under the phased, constant F, and constant quota rebuilding scenarios along with the average of the median catch, total of the median catch and percent of the maximum total catch.

Catch Biomass Quota (mt)			
YEAR	Phased Rebuild Catch Quota	Constant F Rebuild Catch Quota	Constant Quota Rebuild Catch Quota
2018	2202	2203	2202
2019	2785	2785	2786
2020	2860	2858	2859
2021	1914	1296	1460
2022	1914	1385	1460
2023	1914	1447	1460
2024	1914	1484	1460
2025	1678	1507	1460
2026	1678	1518	1460
2027	1678	1528	1460
2028	1678	1530	1460
2029	1441	1533	1460
2030	1441	1534	1460
2031	1441	1532	1460
2032	1441	1532	1460
2033	1204	1531	1460
2034	1204	1532	1460
AVERAGE 2021-2034	1610	1492	1460
TOTAL 2021-2034	22538	20887	20440
PERCENT OF MAXIMUM	100%	93%	91%

Table 7. The median projected spawning biomass time series (thousand mt) under the phased rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the spawning biomass distributions.

Spawning Stock Biomass (mt)			
	Phased Rebuild		
Year	P10	Median	P90
2018	1372	1916	2568
2019	1855	2529	3262
2020	2222	3023	4046
2021	2070	2993	4269
2022	1790	2952	4691
2023	1585	2925	5034
2024	1456	2914	5217
2025	1441	2976	5391
2026	1486	3082	5570
2027	1536	3170	5716
2028	1570	3243	5836
2029	1670	3361	5981
2030	1792	3514	6153
2031	1901	3649	6284
2032	1984	3753	6409
2033	2109	3892	6566
2034	2269	4061	6762

Table 8. The median projected spawning biomass time series (thousand mt) under the constant F rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the spawning biomass distributions.

Spawning Stock Biomass (mt)			
	Constant F Rebuild		
Year	P10	Median	P90
2018	1370	1915	2571
2019	1852	2530	3262
2020	2220	3027	4049
2021	2340	3174	4325
2022	2525	3424	4760
2023	2645	3597	5043
2024	2722	3702	5179
2025	2776	3764	5248
2026	2805	3799	5291
2027	2821	3826	5309
2028	2836	3838	5327
2029	2835	3843	5337
2030	2835	3845	5340
2031	2845	3845	5355
2032	2842	3840	5359
2033	2842	3836	5344
2034	2842	3837	5340

Table 9. The median projected spawning biomass time series (thousand mt) under the constant quota rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the spawning biomass distributions.

Spawning Stock Biomass (mt)			
	Constant Quota Rebuild		
Year	P10	Median	P90
2018	1371	1914	2572
2019	1854	2528	3265
2020	2220	3026	4048
2021	2197	3121	4403
2022	2126	3304	5072
2023	2078	3466	5611
2024	2079	3599	5959
2025	2094	3715	6204
2026	2120	3803	6364
2027	2145	3871	6475
2028	2165	3922	6548
2029	2185	3953	6596
2030	2199	3981	6639
2031	2215	4003	6665
2032	2231	4020	6687
2033	2239	4029	6689
2034	2247	4033	6679

Table 10a. Comparison of the central tendencies of the projected spawning biomass time series (median spawning biomass, thousand mt) under the phased, constant F, and constant quota rebuilding scenarios along with the average, total, and percent of the maximum, of the median spawning biomass.

Spawning Biomass (mt)			
YEAR	Phased Rebuild Median Spawning Biomass	Constant F Rebuild Median Spawning Biomass	Constant Quota Rebuild Median Spawning Biomass
2018	1916	1915	1914
2019	2529	2530	2528
2020	3023	3027	3026
2021	2993	3174	3121
2022	2952	3424	3304
2023	2925	3597	3466
2024	2914	3702	3599
2025	2976	3764	3715
2026	3082	3799	3803
2027	3170	3826	3871
2028	3243	3838	3922
2029	3361	3843	3953
2030	3514	3845	3981
2031	3649	3845	4003
2032	3753	3840	4020
2033	3892	3836	4029
2034	4061	3837	4033
AVERAGE 2021-2034	3320	3726	3773
TOTAL 2021-2034	46484	52169	52819
PERCENT OF MAXIMUM	88%	99%	100%

Table 10b. Comparison of the central tendencies of the projected spawning biomass time series (median spawning biomass, thousand mt) based on a 67% target probability of rebuilding success under the phased, constant F, and constant quota rebuilding scenarios along with the average, total, and percent of the maximum, of the median spawning biomass.

Spawning Biomass (mt)			
YEAR	Phased Rebuild Median Spawning Biomass	Constant F Rebuild Median Spawning Biomass	Constant Quota Rebuild Median Spawning Biomass
2018	1916	1915	1914
2019	2529	2530	2528
2020	3023	3027	3026
2021	3004	3200	3148
2022	2984	3496	3381
2023	2973	3705	3588
2024	2974	3835	3756
2025	3058	3913	3900
2026	3193	3957	4008
2027	3304	3991	4090
2028	3395	4006	4154
2029	3540	4011	4195
2030	3725	4015	4226
2031	3888	4017	4254
2032	4014	4012	4275
2033	4182	4008	4286
2034	4386	4008	4292
AVERAGE 2021-2034	3473	3869	3968
TOTAL 2021-2034	48617	54172	55554
PERCENT OF MAXIMUM	88%	98%	100%

Table 11. The median projected annual fishing mortality time series under the phased rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the fishing mortality distributions.

	Fishing Mortality ($Year^{-1}$) Phased Rebuild		
Year	P10	Median	P90
2018	0.64	0.64	0.64
2019	0.64	0.64	0.64
2020	0.64	0.64	0.64
2021	0.32	0.46	0.65
2022	0.30	0.46	0.72
2023	0.29	0.47	0.78
2024	0.28	0.47	0.83
2025	0.25	0.41	0.75
2026	0.24	0.40	0.73
2027	0.24	0.39	0.71
2028	0.23	0.39	0.70
2029	0.20	0.33	0.59
2030	0.20	0.32	0.56
2031	0.19	0.31	0.54
2032	0.19	0.31	0.52
2033	0.16	0.26	0.43
2034	0.16	0.25	0.41

Table 12. The median projected annual fishing mortality time series under the constant F rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the fishing mortality distributions.

	Fishing Mortality ($Year^{-1}$) Constant F Rebuild		
Year	P10	Median	P90
2018	0.64	0.64	0.64
2019	0.64	0.64	0.64
2020	0.64	0.64	0.64
2021	0.31	0.31	0.31
2022	0.31	0.31	0.31
2023	0.31	0.31	0.31
2024	0.31	0.31	0.31
2025	0.31	0.31	0.31
2026	0.31	0.31	0.31
2027	0.31	0.31	0.31
2028	0.31	0.31	0.31
2029	0.31	0.31	0.31
2030	0.31	0.31	0.31
2031	0.31	0.31	0.31
2032	0.31	0.31	0.31
2033	0.31	0.31	0.31
2034	0.31	0.31	0.31

Table 13. The median projected annual fishing mortality time series under the constant quota rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the fishing mortality distributions.

	Fishing Mortality (Year^{-1})		
	Constant Quota Rebuild		
Year	P10	Median	P90
2018	0.64	0.64	0.64
2019	0.64	0.64	0.64
2020	0.64	0.64	0.64
2021	0.25	0.35	0.49
2022	0.22	0.34	0.51
2023	0.21	0.33	0.51
2024	0.20	0.32	0.51
2025	0.19	0.31	0.50
2026	0.19	0.30	0.50
2027	0.19	0.30	0.50
2028	0.19	0.30	0.49
2029	0.19	0.29	0.49
2030	0.19	0.29	0.49
2031	0.18	0.29	0.48
2032	0.18	0.29	0.48
2033	0.18	0.29	0.48
2034	0.18	0.29	0.48

Table 14a. Comparison of the central tendencies of the projected fishing mortality time series (median fishing mortality, yr^{-1}) under the phased, constant F, and constant quota rebuilding scenarios along with the average of the median fishing mortality during 2021-2034.

Fishing Mortality			
YEAR	Phased Rebuild Median F	Constant F Rebuild Median F	Constant Quota Rebuild Median F
2018	0.64	0.64	0.64
2019	0.64	0.64	0.64
2020	0.64	0.64	0.64
2021	0.46	0.31	0.35
2022	0.46	0.31	0.34
2023	0.47	0.31	0.33
2024	0.47	0.31	0.32
2025	0.41	0.31	0.31
2026	0.40	0.31	0.30
2027	0.39	0.31	0.30
2028	0.39	0.31	0.30
2029	0.33	0.31	0.29
2030	0.32	0.31	0.29
2031	0.31	0.31	0.29
2032	0.31	0.31	0.29
2033	0.26	0.31	0.29
2034	0.25	0.31	0.29
AVERAGE 2021-2034	0.37	0.31	0.31

Table 14b. Comparison of the central tendencies of the projected fishing mortality time series (median fishing mortality, yr^{-1}) based on a 67% target probability of rebuilding success under the phased, constant F, and constant quota rebuilding scenarios along with the average of the median fishing mortality during 2021-2034.

Fishing Mortality			
YEAR	Phased Rebuild Median F	Constant F Rebuild Median F	Constant Quota Rebuild Median F
2018	0.64	0.64	0.64
2019	0.64	0.64	0.64
2020	0.64	0.64	0.64
2021	0.45	0.29	0.33
2022	0.45	0.29	0.31
2023	0.45	0.29	0.30
2024	0.45	0.29	0.29
2025	0.39	0.29	0.28
2026	0.37	0.29	0.27
2027	0.36	0.29	0.27
2028	0.36	0.29	0.27
2029	0.30	0.29	0.26
2030	0.29	0.29	0.26
2031	0.28	0.29	0.26
2032	0.27	0.29	0.26
2033	0.22	0.29	0.26
2034	0.21	0.29	0.26
AVERAGE 2021-2034	0.35	0.29	0.28

Table 15a. Comparison of the annual probabilities of rebuilding the stock during 2021-2034 under the phased, constant F, and constant quota rebuilding scenarios along with the first year when the probability of rebuilding the stock was greater than or equal to 60%.

Probability of Rebuilding			
YEAR	Phased Rebuild Probability of Achieving Rebuilding Target	Constant F Rebuild Probability of Achieving Rebuilding Target	Constant Quota Rebuild Probability of Achieving Rebuilding Target
2018	0.00	0.00	0.00
2019	0.04	0.04	0.04
2020	0.22	0.23	0.23
2021	0.25	0.29	0.29
2022	0.29	0.41	0.39
2023	0.31	0.49	0.45
2024	0.32	0.54	0.50
2025	0.34	0.57	0.53
2026	0.37	0.59	0.55
2027	0.39	0.60	0.57
2028	0.41	0.60	0.58
2029	0.44	0.60	0.59
2030	0.48	0.60	0.59
2031	0.51	0.60	0.60
2032	0.53	0.60	0.60
2033	0.57	0.60	0.60
2034	0.61	0.60	0.61
FIRST YEAR WHEN REBUILDING PROBABILITY >= 60%	2034	2027	2031

Table 15b. Comparison of the annual probabilities of rebuilding the stock during 2021-2034 based on a 67% target probability of rebuilding success under the phased, constant F, and constant quota rebuilding scenarios along with the first year when the probability of rebuilding the stock was greater than or equal to 67% (cells with thick borders).

Probability of Rebuilding			
YEAR	Phased Rebuild Probability of Achieving Rebuilding Target	Constant F Rebuild Probability of Achieving Rebuilding Target	Constant Quota Rebuild Probability of Achieving Rebuilding Target
2018	0.00	0.00	0.00
2019	0.04	0.04	0.04
2020	0.22	0.23	0.23
2021	0.25	0.31	0.30
2022	0.29	0.45	0.42
2023	0.32	0.54	0.49
2024	0.33	0.60	0.54
2025	0.36	0.63	0.58
2026	0.39	0.65	0.60
2027	0.42	0.66	0.62
2028	0.45	0.67	0.64
2029	0.48	0.67	0.65
2030	0.53	0.68	0.65
2031	0.57	0.67	0.66
2032	0.60	0.67	0.66
2033	0.64	0.67	0.67
2034	0.69	0.67	0.67

Table 16a. Comparison of the annual probabilities of the stock experiencing overfishing during 2021-2034 under the phased, constant F, and constant quota rebuilding scenarios along with the first year when the probability of overfishing the stock was less than or equal to 50%.

Probability of Overfishing			
YEAR	Phased Rebuild Probability of Overfishing	Constant F Rebuild Probability of Overfishing	Constant Quota Rebuild Probability of Overfishing
2018	1	1	1
2019	1	1	1
2020	1	1	1
2021	0.46	0	0.13
2022	0.48	0	0.14
2023	0.49	0	0.15
2024	0.49	0	0.14
2025	0.38	0	0.13
2026	0.36	0	0.13
2027	0.34	0	0.12
2028	0.32	0	0.12
2029	0.21	0	0.12
2030	0.18	0	0.11
2031	0.16	0	0.11
2032	0.15	0	0.11
2033	0.07	0	0.11
2034	0.06	0	0.11
FIRST YEAR WHEN OVERFISHING PROBABILITY =< 50%	2021	2021	2021

Table 16b. Comparison of the annual probabilities of the stock experiencing overfishing during 2021-2034 based on a 67% target probability of rebuilding success under the phased, constant F, and constant quota rebuilding scenarios along with the first year when the probability of overfishing the stock was less than or equal to 50% (cells with thick borders).

Probability of Overfishing			
YEAR	Phased Rebuild Probability of Overfishing	Constant F Rebuild Probability of Overfishing	Constant Quota Rebuild Probability of Overfishing
2018	1	1	1
2019	1	1	1
2020	1	1	1
2021	0.43	0	0.09
2022	0.45	0	0.09
2023	0.46	0	0.09
2024	0.46	0	0.09
2025	0.32	0	0.08
2026	0.29	0	0.08
2027	0.27	0	0.07
2028	0.26	0	0.07
2029	0.14	0	0.07
2030	0.11	0	0.06
2031	0.10	0	0.06
2032	0.08	0	0.06
2033	0.03	0	0.06
2034	0.02	0	0.06

Figure 1. Annual catch biomasses of WCNPO striped marlin by country for Japan, Chinese Taipei, the USA and other WCPFC countries during 1975-2017.

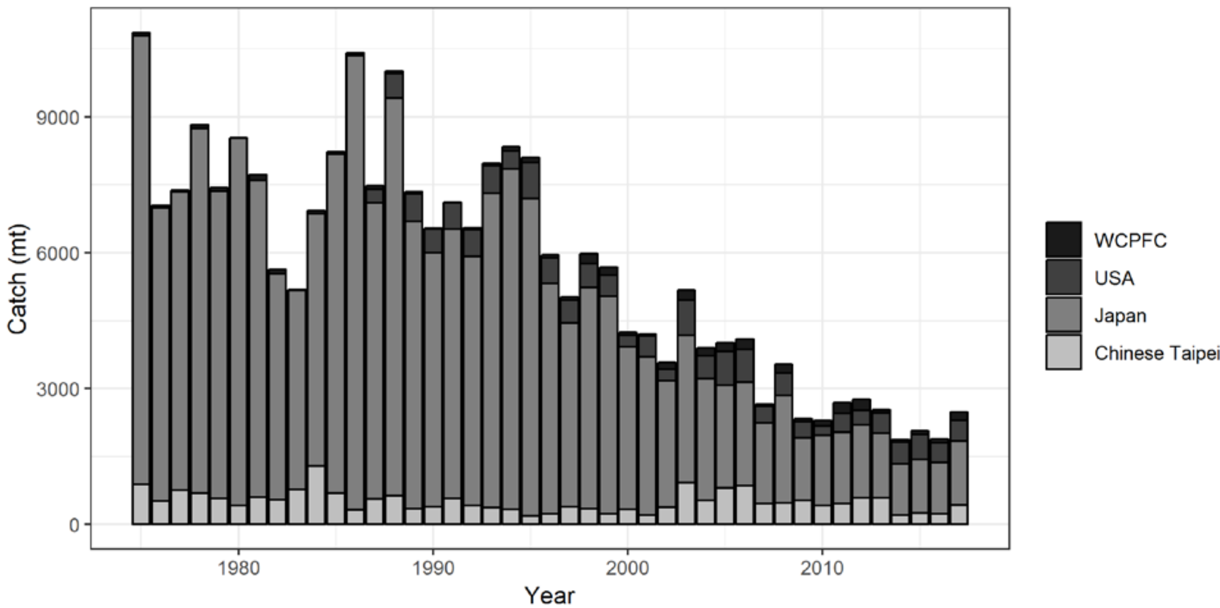

Figure 2. Time series of estimates of spawning biomass of Western and Central North Pacific striped marlin (*Kajikia audax*) from the 2019 stock assessment (solid black circles) with 80% confidence intervals relative to SB_{MSY} (dashed green line) and unfished spawning biomass (solid blue triangle with 80% confidence interval).

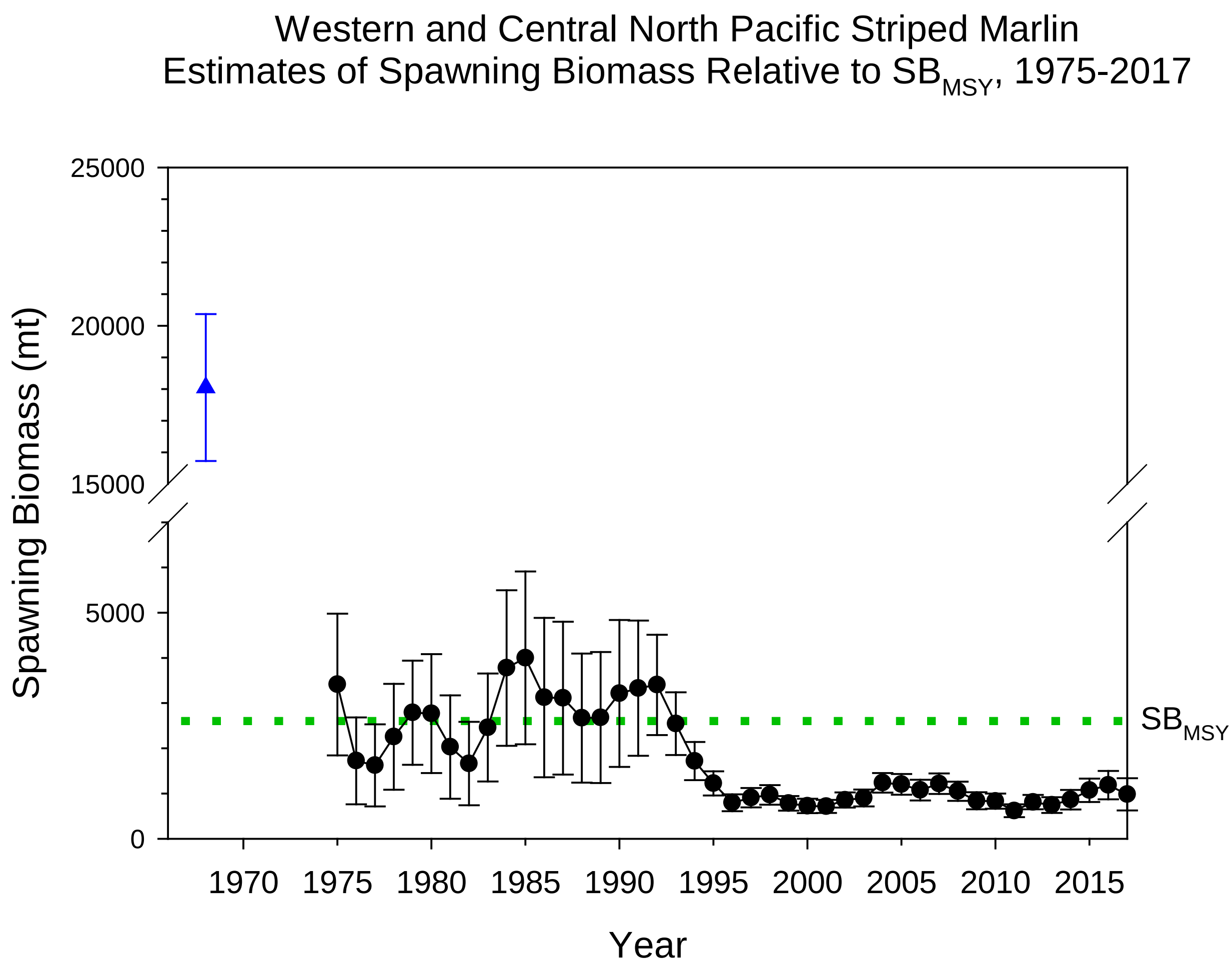

Figure 3. Time series of estimates of fishing mortality rates (average for age 3-12, year^{-1}) for Western and Central North Pacific striped marlin (*Kajikia audax*) from the 2019 stock assessment (solid black circles) with 80% confidence intervals relative to F_{MSY} (dashed red line).

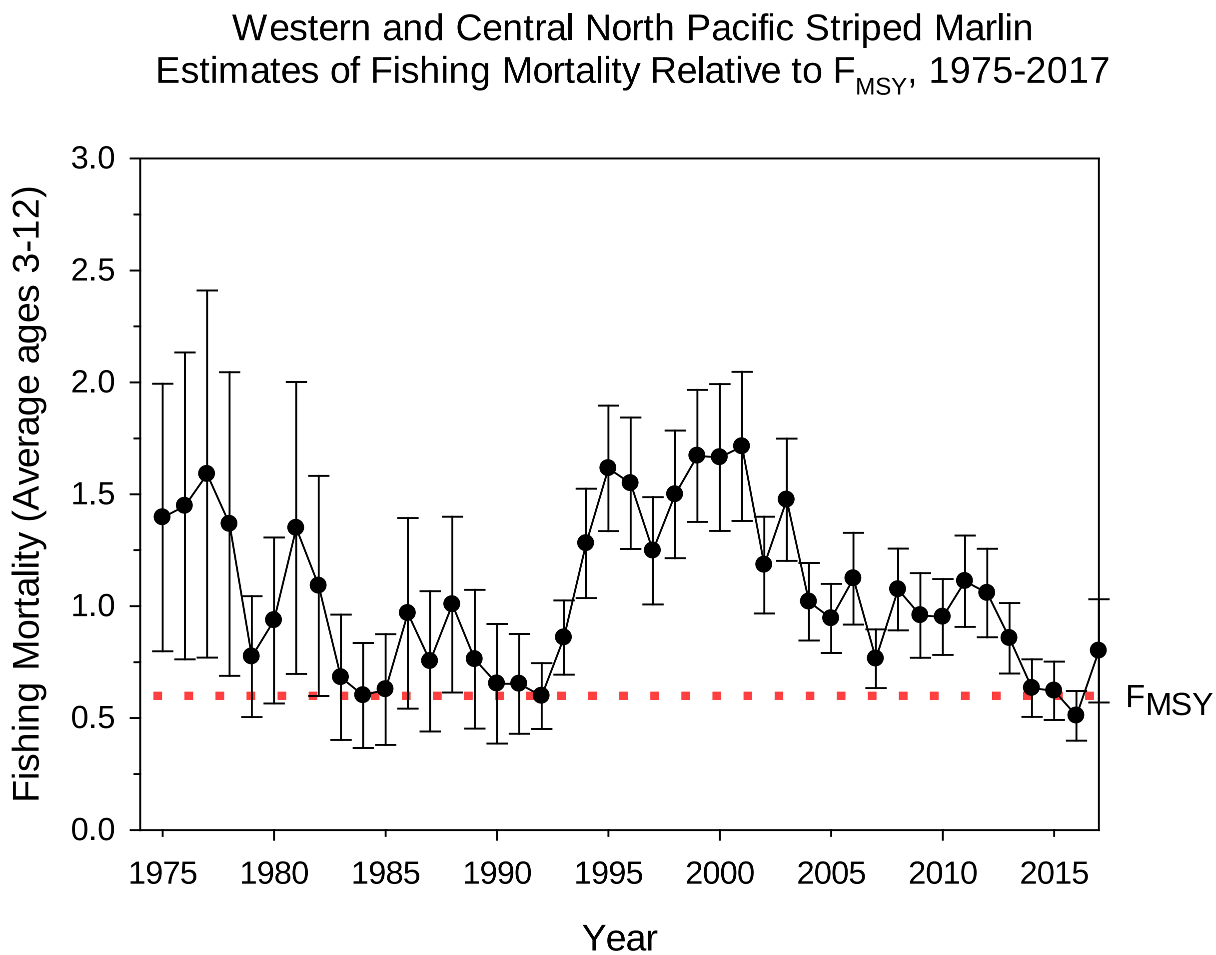

Figure 4. Kobe plot of the time series of estimates of relative fishing mortality (average for age 3-12, $year^{-1}$) and relative spawning stock biomass (SSB) of Western and Central North Pacific striped marlin (*Kajikia audax*) with respect to MSY-based reference points during 1975-2017. The white square denotes the first (1975) year of the assessment, the white circle denotes 2004, and the white triangle denotes the last (2017) year of the assessment.

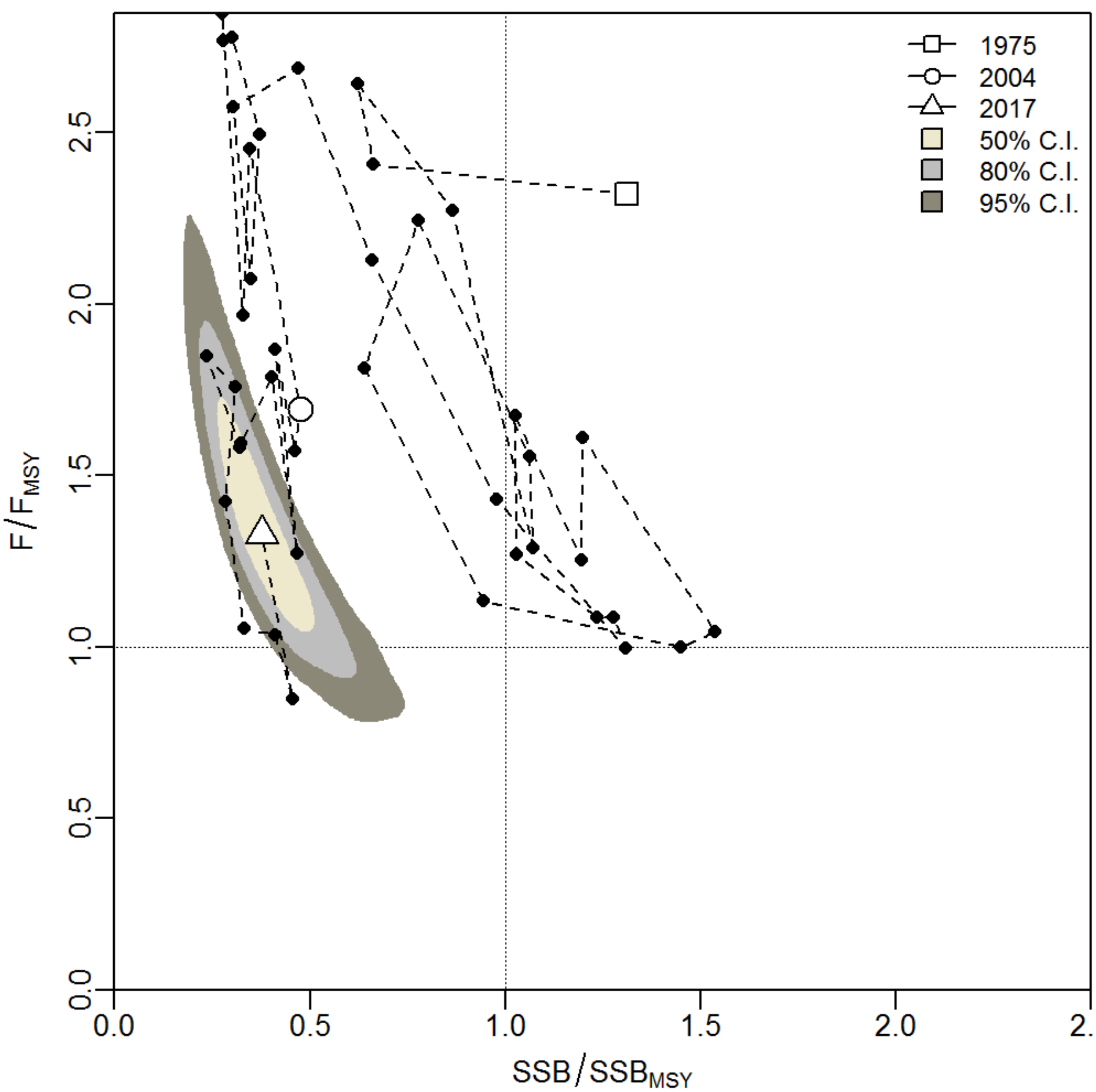

Figure 5. Boxplots by age group of the bootstrap replicates of population numbers at age used in each of the projection analyses.

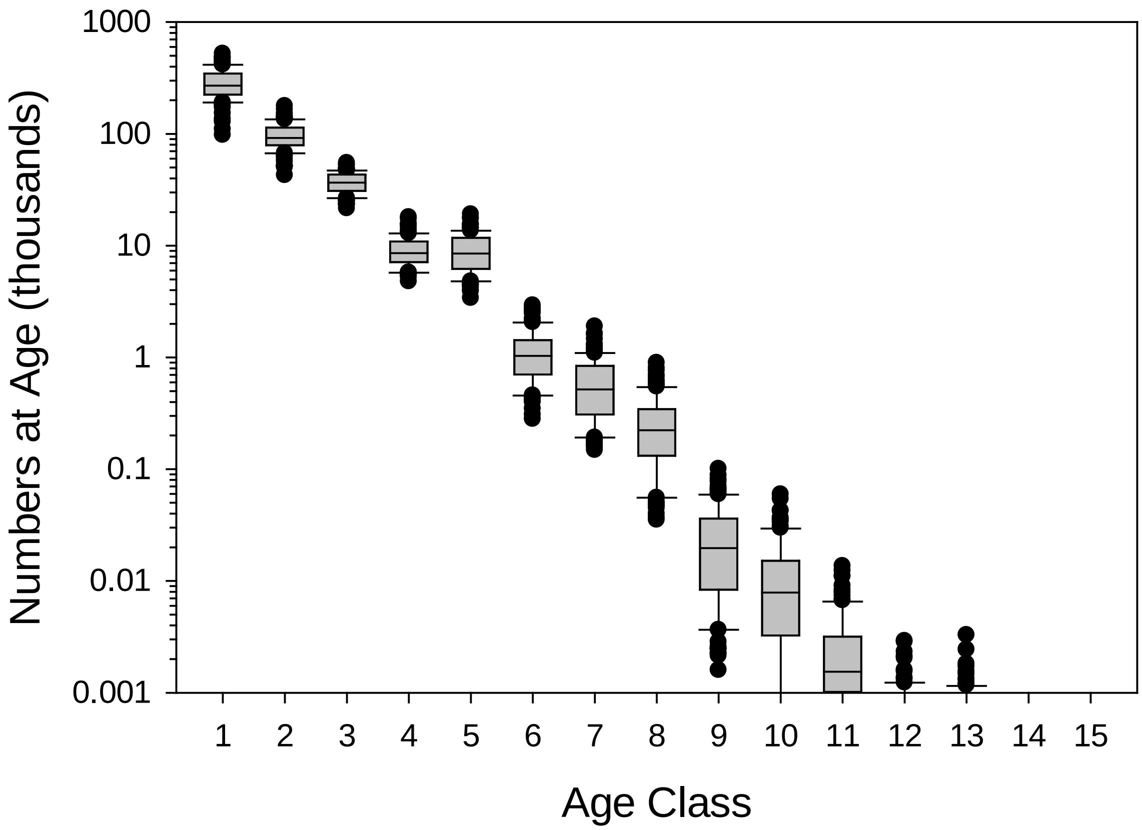

Figure 6. Stock-recruitment dynamics of WCNPO striped marlin as estimated in the 2019 benchmark stock assessment.

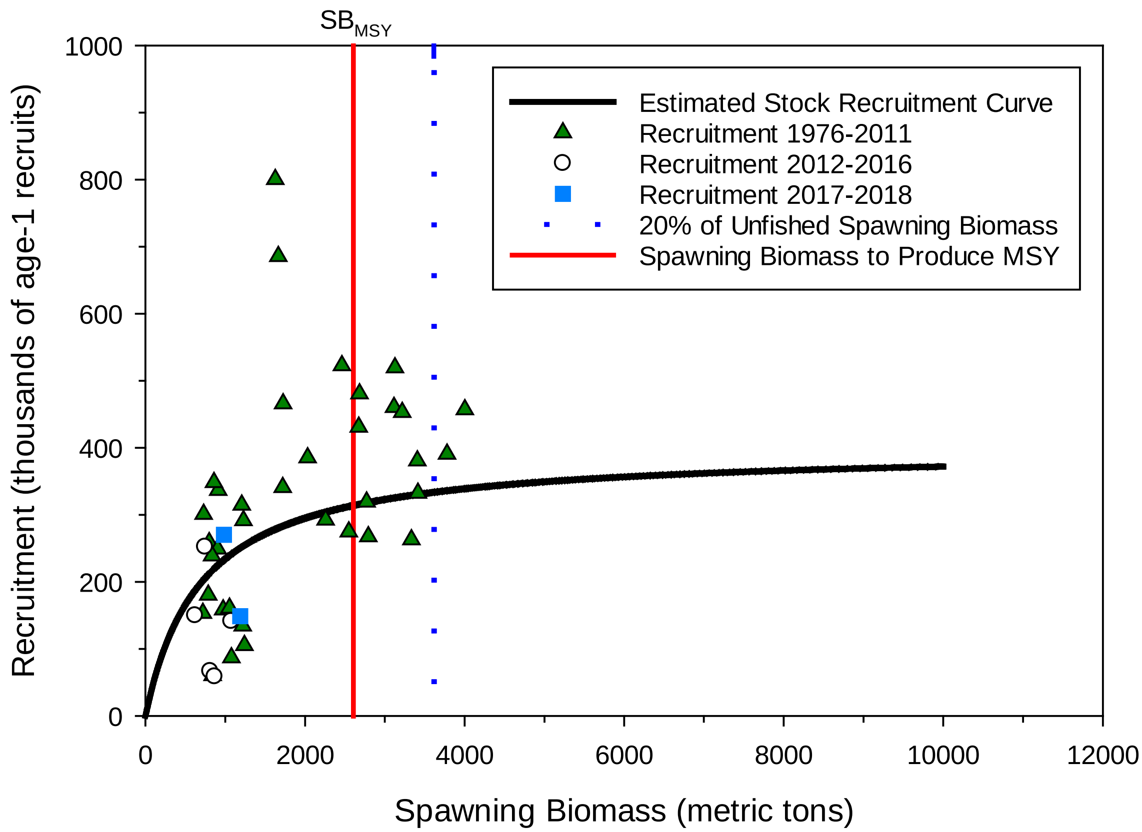

Figure 7. Time series of recruitment estimates (age-1 fish, solid black circles) for WCNPO striped marlin with 80% confidence intervals along with the expected magnitude of recruitment under the short-term (solid red line) and long-term (dashed green line) scenarios.

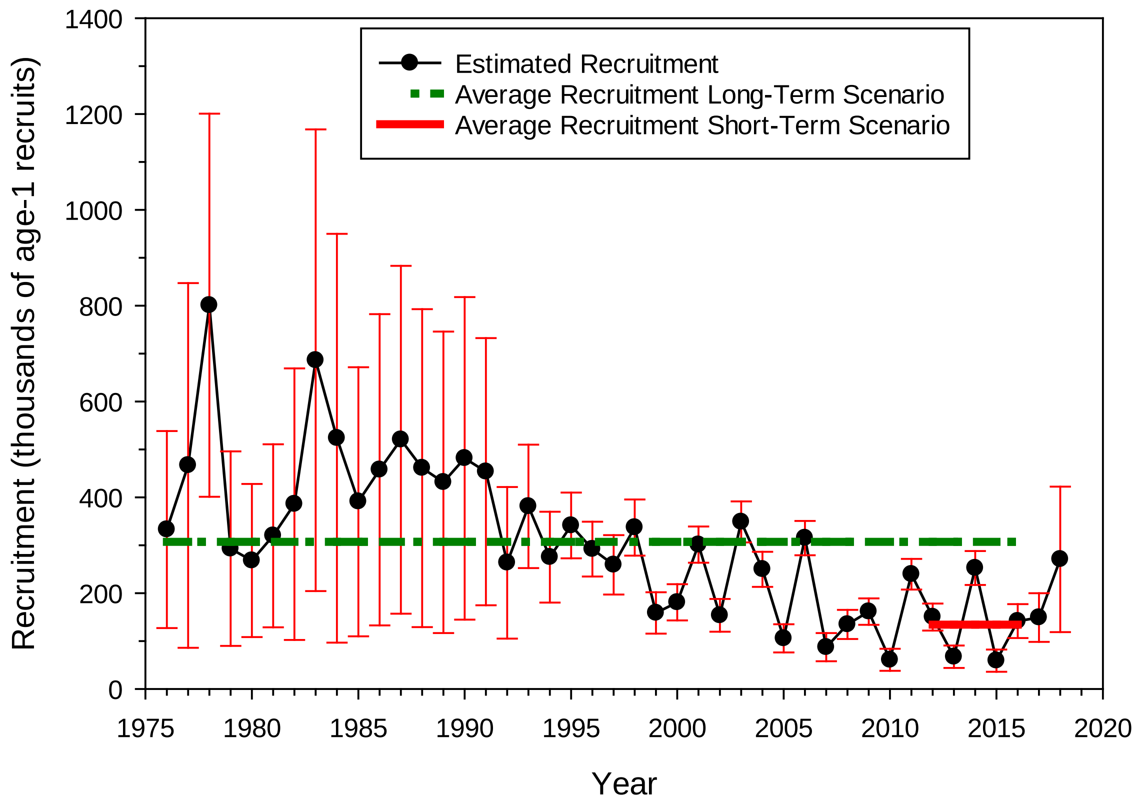

Figure 8. Empirical cumulative distribution functions of recruitment of WCNPO striped marlin under the short-term (dashed blue line) and long-term (solid green line) recruitment scenarios.

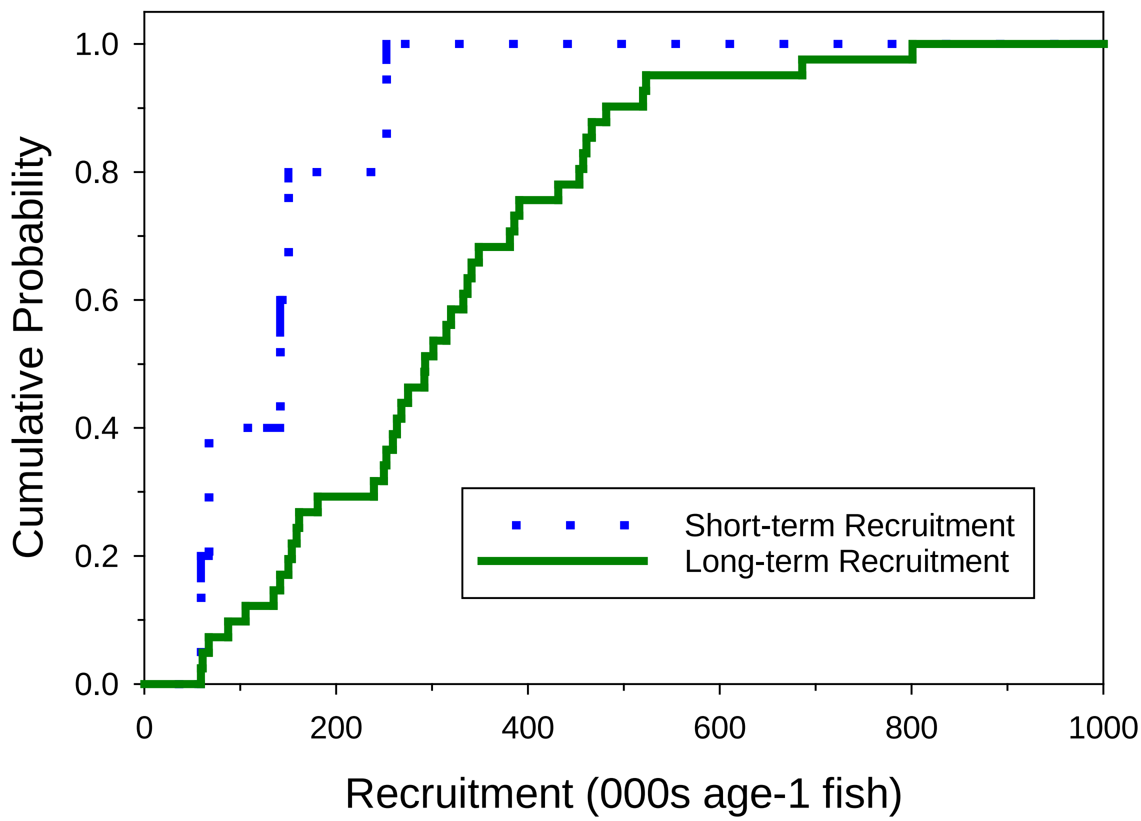

Figure 9. The time series of median catch biomass quotas to rebuild the stock under the phased rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the annual catch biomass distributions relative to the recent average yield during 2015-2017 of 2,151 mt. A sample of 10 simulated catch trajectories are shown for comparison (light blue lines).

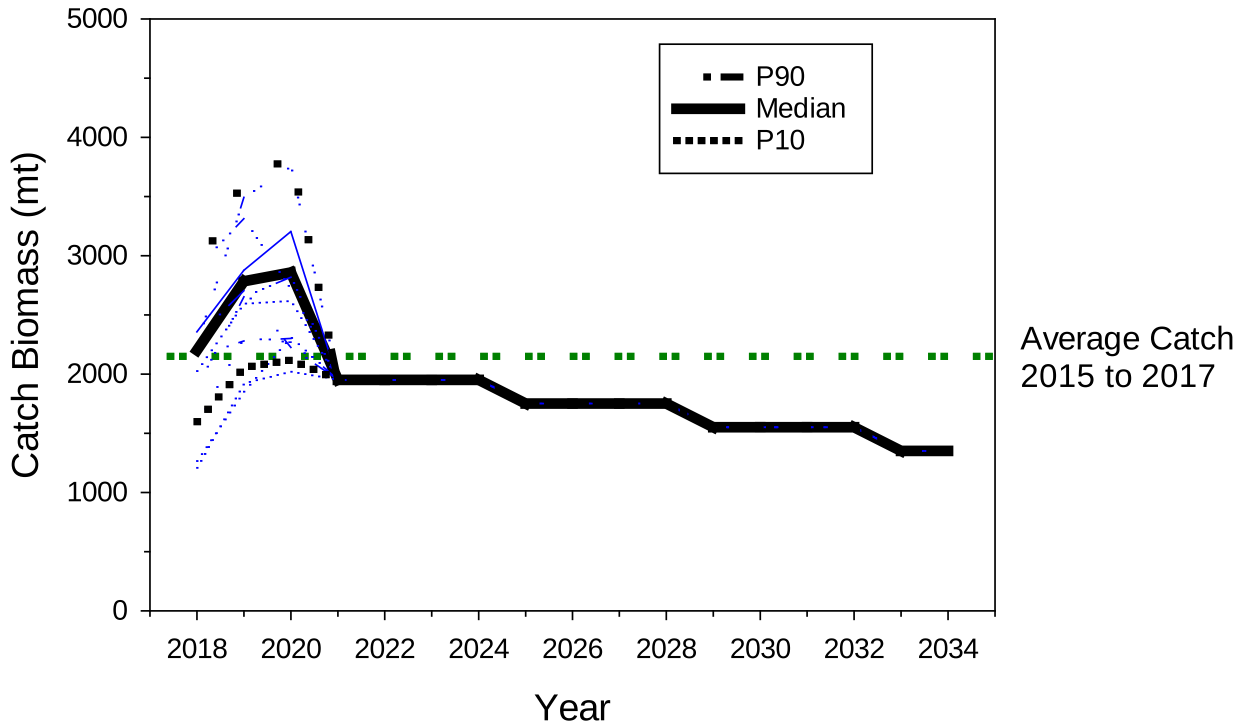

Figure 10. The time series of median catch biomass quotas to rebuild the stock under the constant F rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the annual catch biomass distributions relative to the recent average yield during 2015-2017 of 2,151 mt. A sample of 10 simulated catch trajectories are shown for comparison (light blue lines).

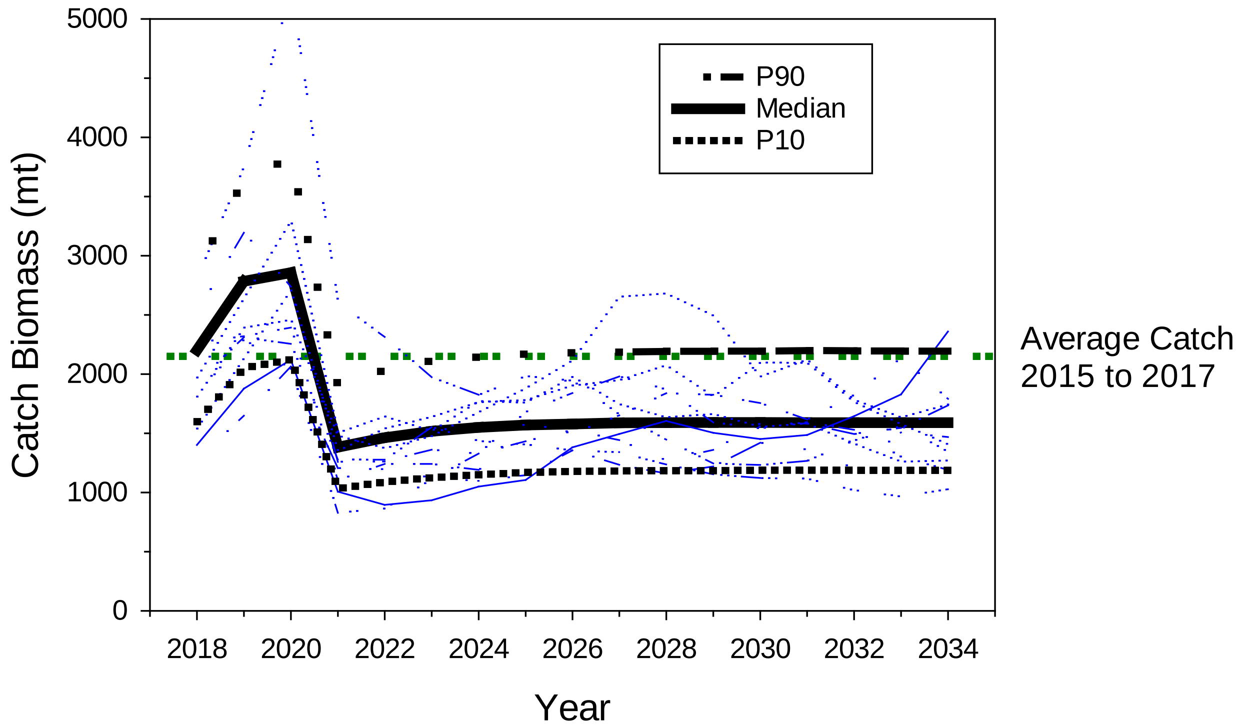

Figure 11. The time series of median catch biomass quotas to rebuild the stock under the constant quota rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the annual catch biomass distributions relative to the recent average yield during 2015-2017 of 2,151 mt. A sample of 10 simulated catch trajectories are shown for comparison (light blue lines).

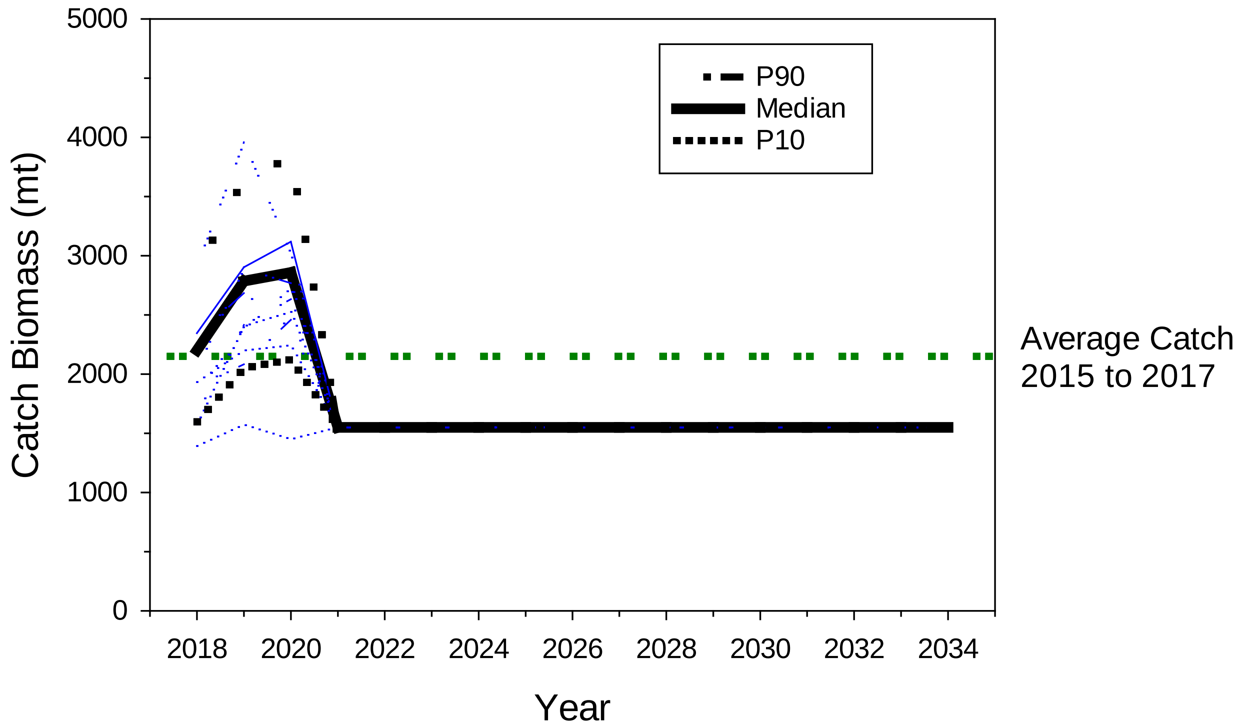

Figure 12. Comparison of the time series of median catch biomass quotas to rebuild the stock under the phased, constant F, and constant quota rebuilding scenarios relative to the recent average yield during 2015-2017 of 2,151 mt.

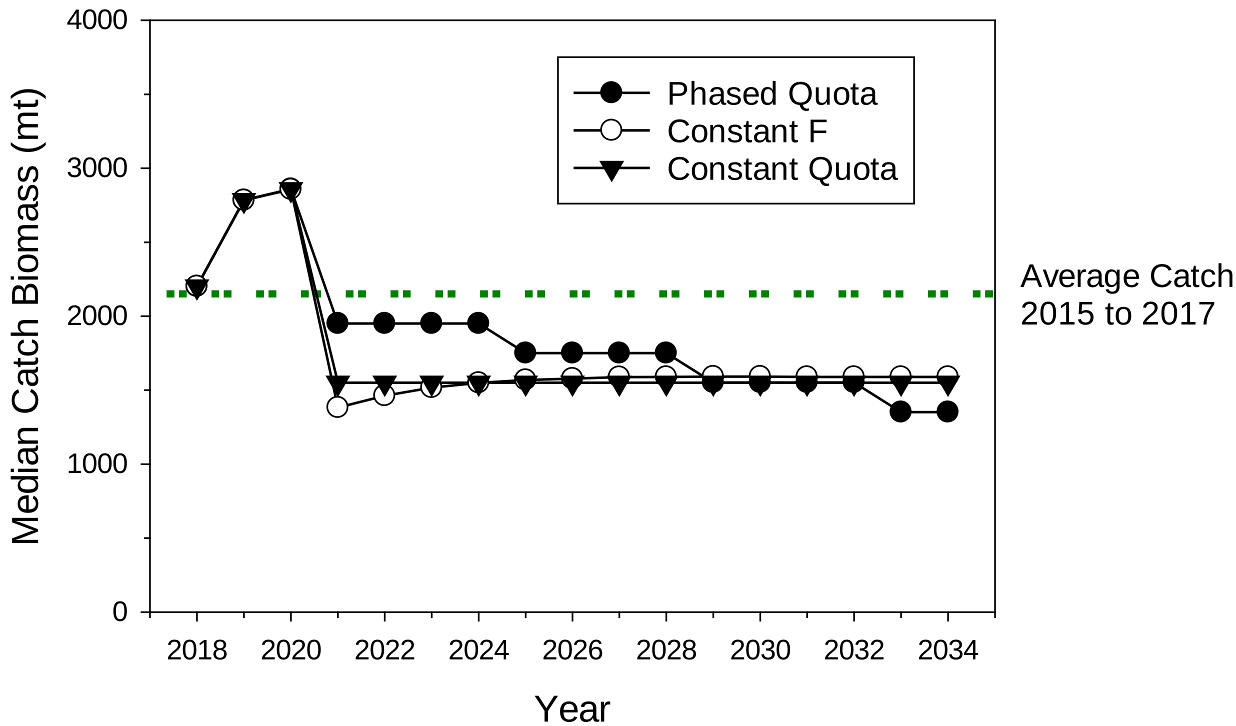

Figure 13. The time series of median spawning biomasses to rebuild the stock under the phased rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the annual spawning biomass distributions relative to the rebuilding target of 3,610 mt. A sample of 10 simulated spawning biomass trajectories are shown for comparison (light blue lines).

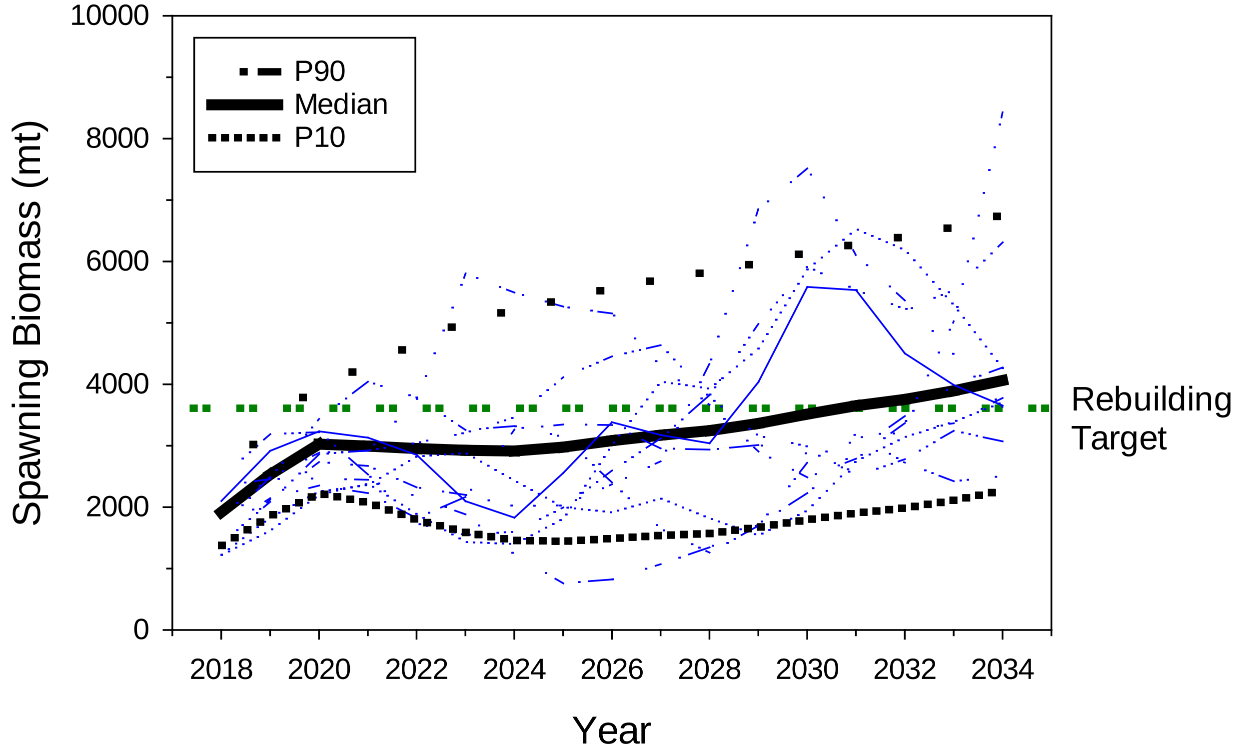

Figure 14. The time series of median spawning biomasses to rebuild the stock under the constant F rebuilding scenario along with the 10^{th} (P10) and 90^{th} (P90) percentiles of the annual spawning biomass distributions relative to the rebuilding target of 3,610 mt. A sample of 10 simulated spawning biomass trajectories are shown for comparison (light blue lines).

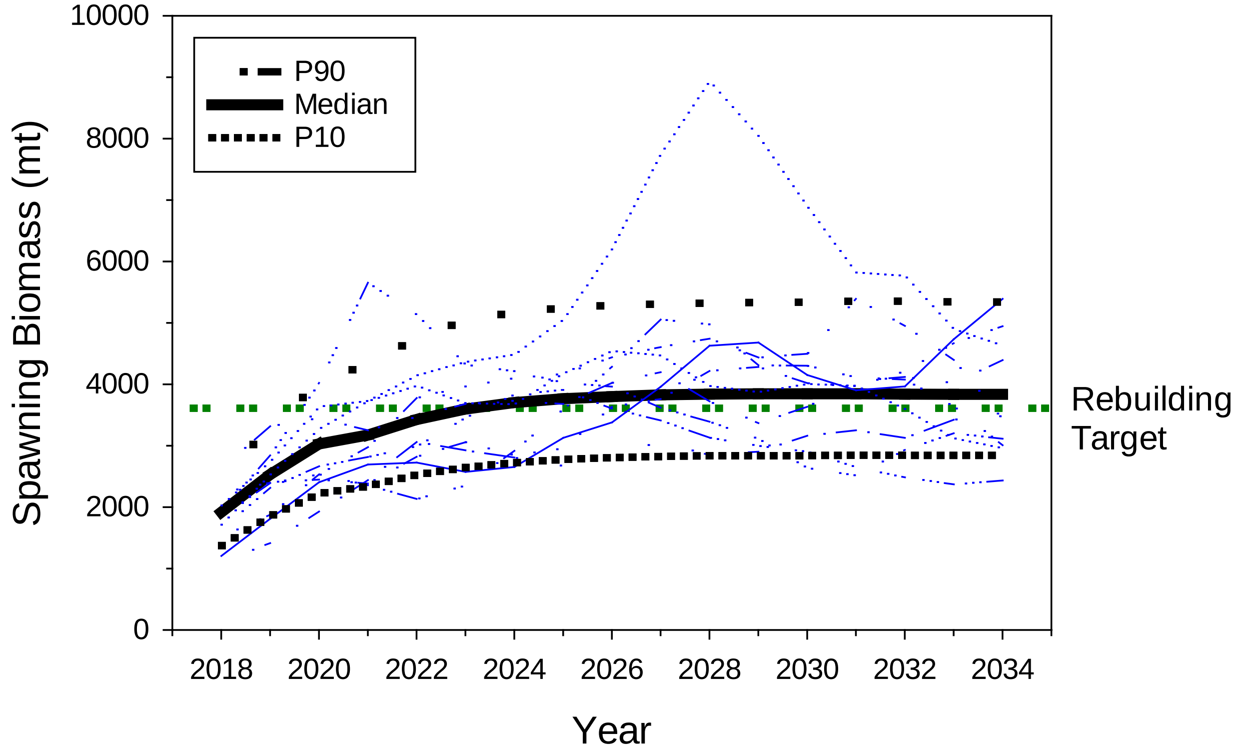

Figure 15. The time series of median spawning biomasses to rebuild the stock under the constant quota rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the annual spawning biomass distributions relative to the rebuilding target of 3,610 mt. A sample of 10 simulated spawning biomass trajectories are shown for comparison (light blue lines).

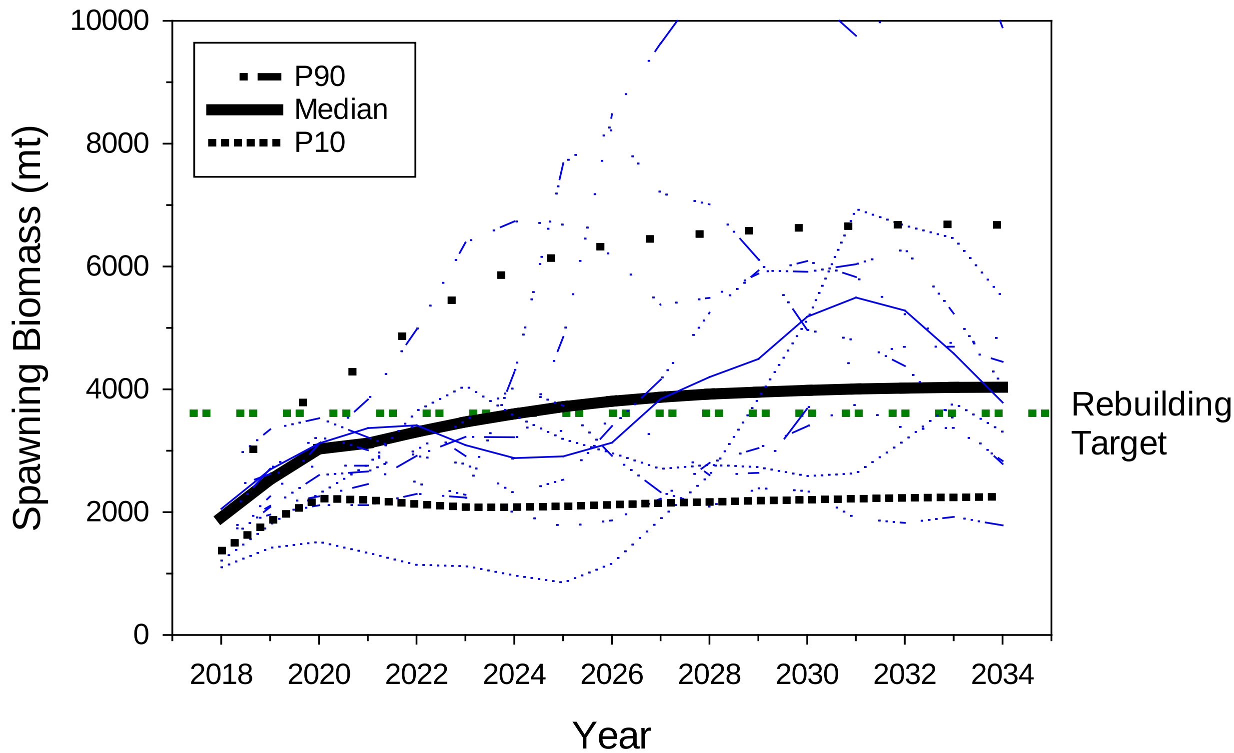

Figure 16. Comparison of the time series of median spawning biomasses to rebuild the stock under the phased, constant F, and constant quota rebuilding scenarios relative to the rebuilding target of 3,610 mt.

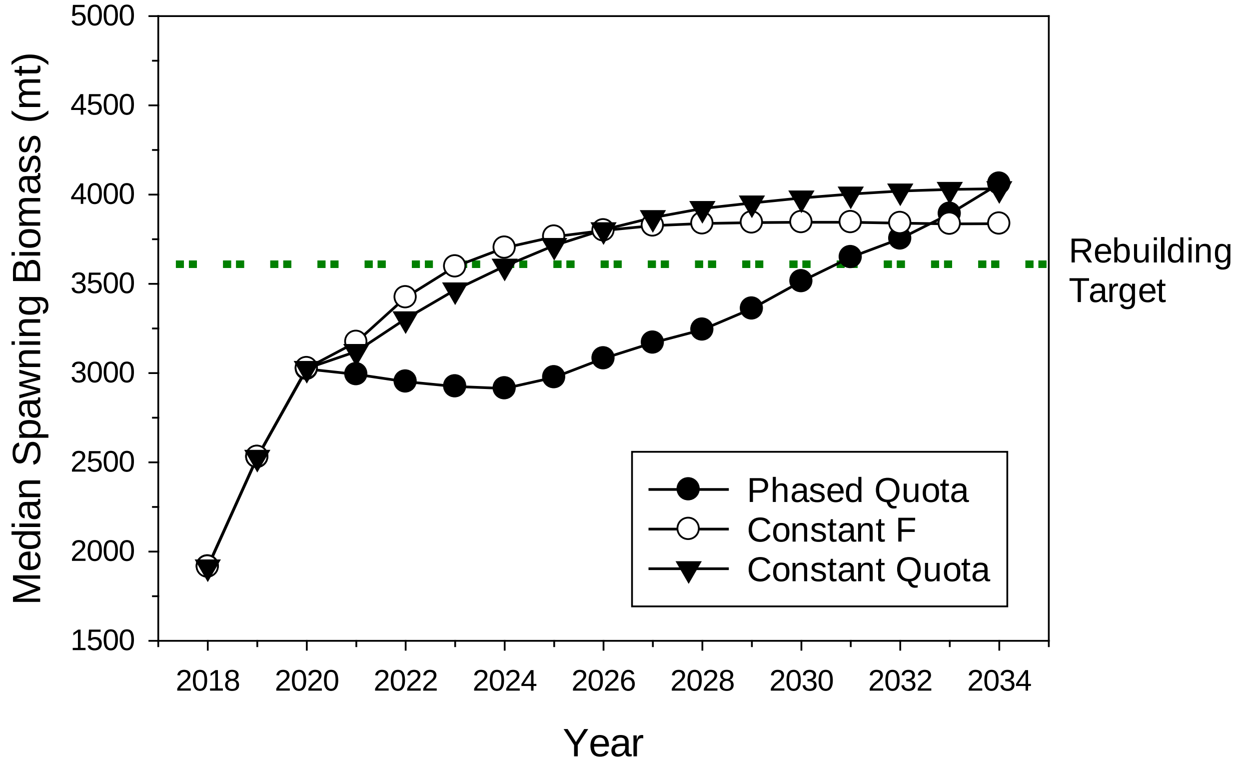

Figure 17. The time series of median fishing mortalities to rebuild the stock under the phased rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the annual fishing mortality distributions relative to the overfishing reference point of $F_{20\%SSB(F=0)}$=0.47. A sample of 10 simulated fishing mortality trajectories are shown for comparison (light blue lines).

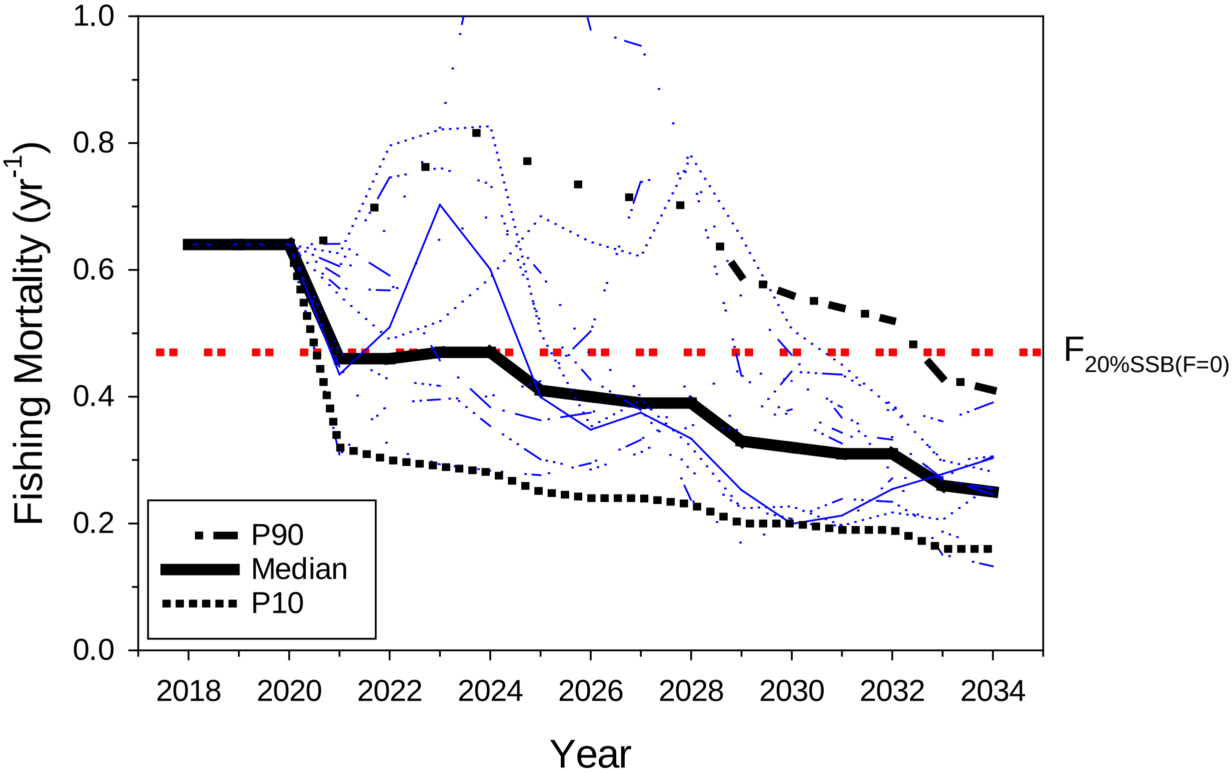

Figure 18. The time series of median fishing mortalities to rebuild the stock under the constant F rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the annual fishing mortality distributions relative to the overfishing reference point of $F_{20\%SSB(F=0)}$=0.47. A sample of 10 simulated fishing mortality trajectories are shown for comparison (light blue lines).

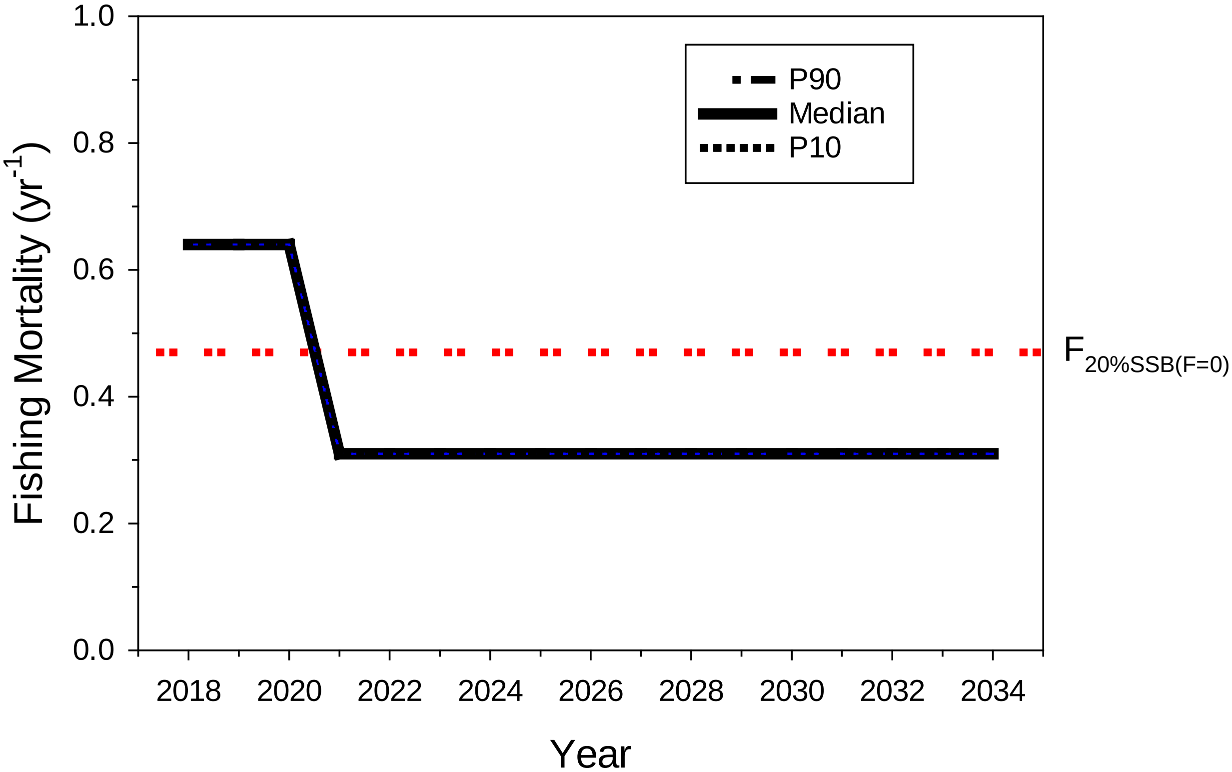

Figure 19. The time series of median fishing mortalities to rebuild the stock under the constant quota rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the annual fishing mortality distributions relative to the overfishing reference point of $F_{20\%SSB(F=0)}$=0.47. A sample of 10 simulated fishing mortality trajectories are shown for comparison (light blue lines).

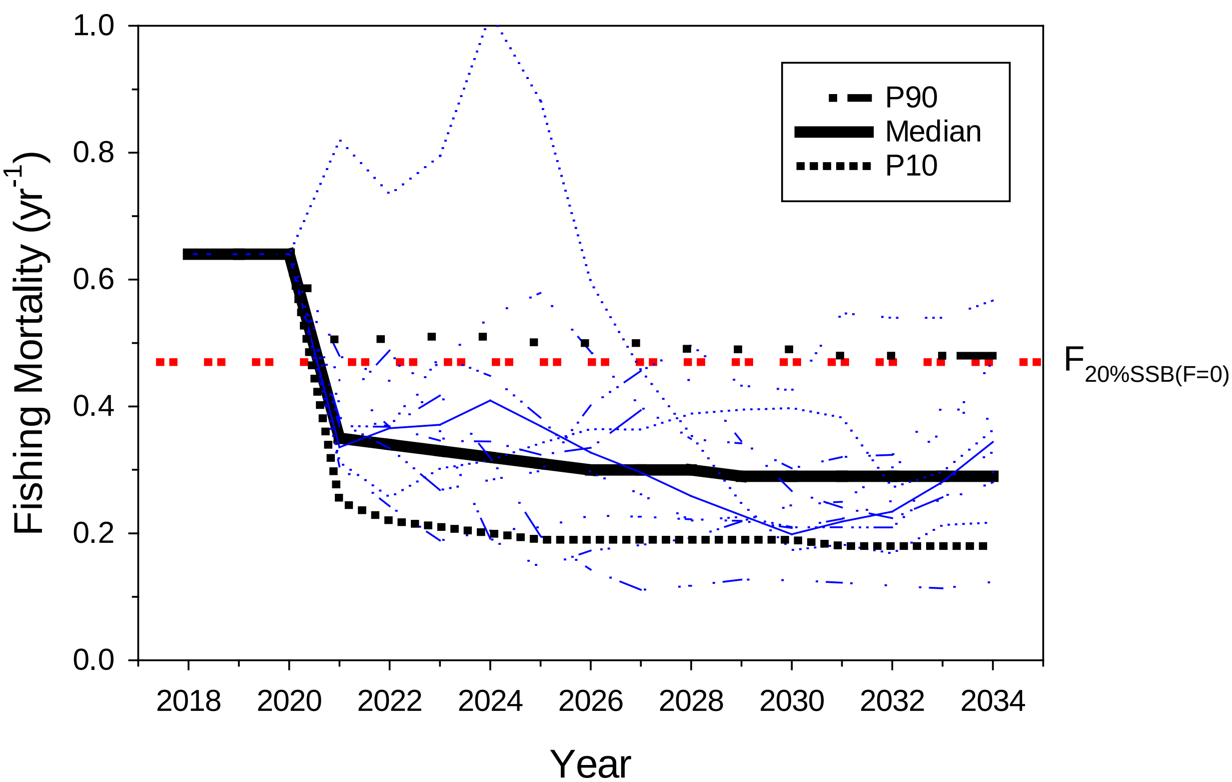

Figure 20. Comparison of the time series of median fishing mortalities to rebuild the stock under the phased, constant F, and constant quota rebuilding scenarios relative to the overfishing reference point of $F_{20\%SSB(F=0)}$=0.47.

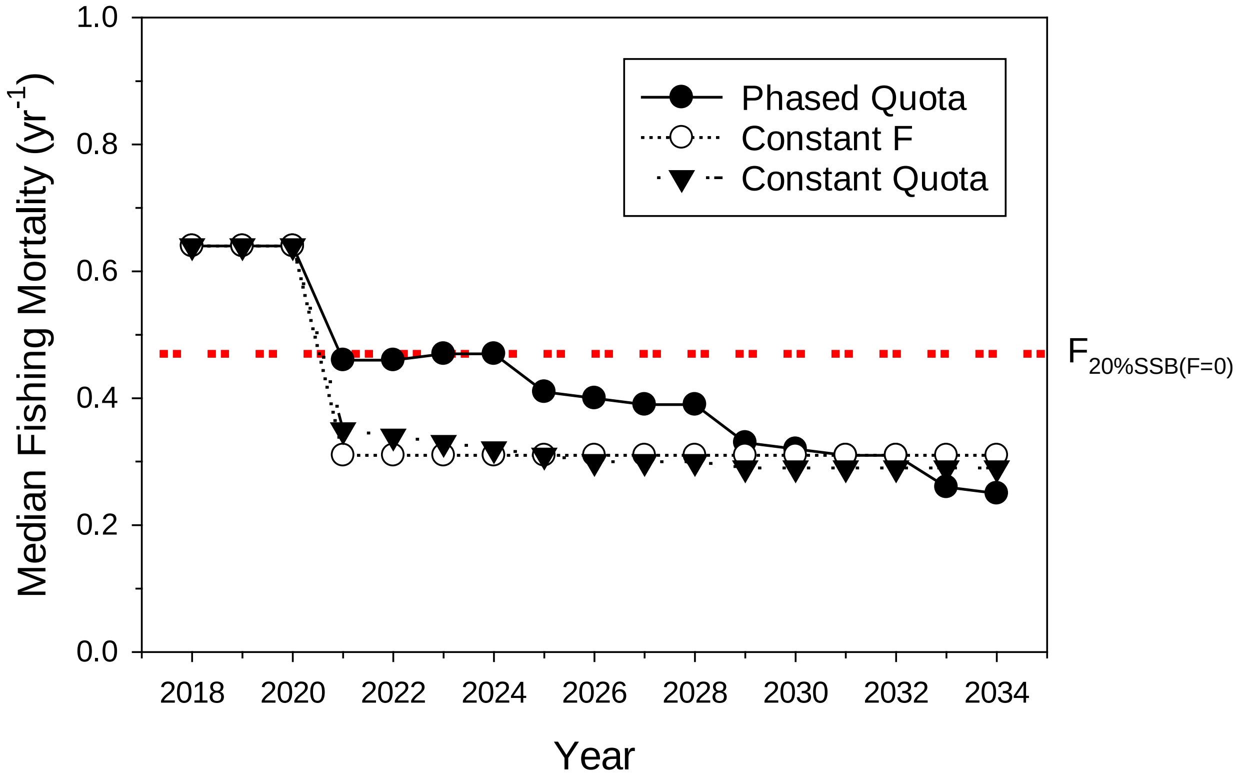

Figure 21. Annual probabilities of achieving the rebuilding target of 3,610 mt of spawning biomass with at least 60% probability during 2021-2034 under the phased rebuilding scenario.

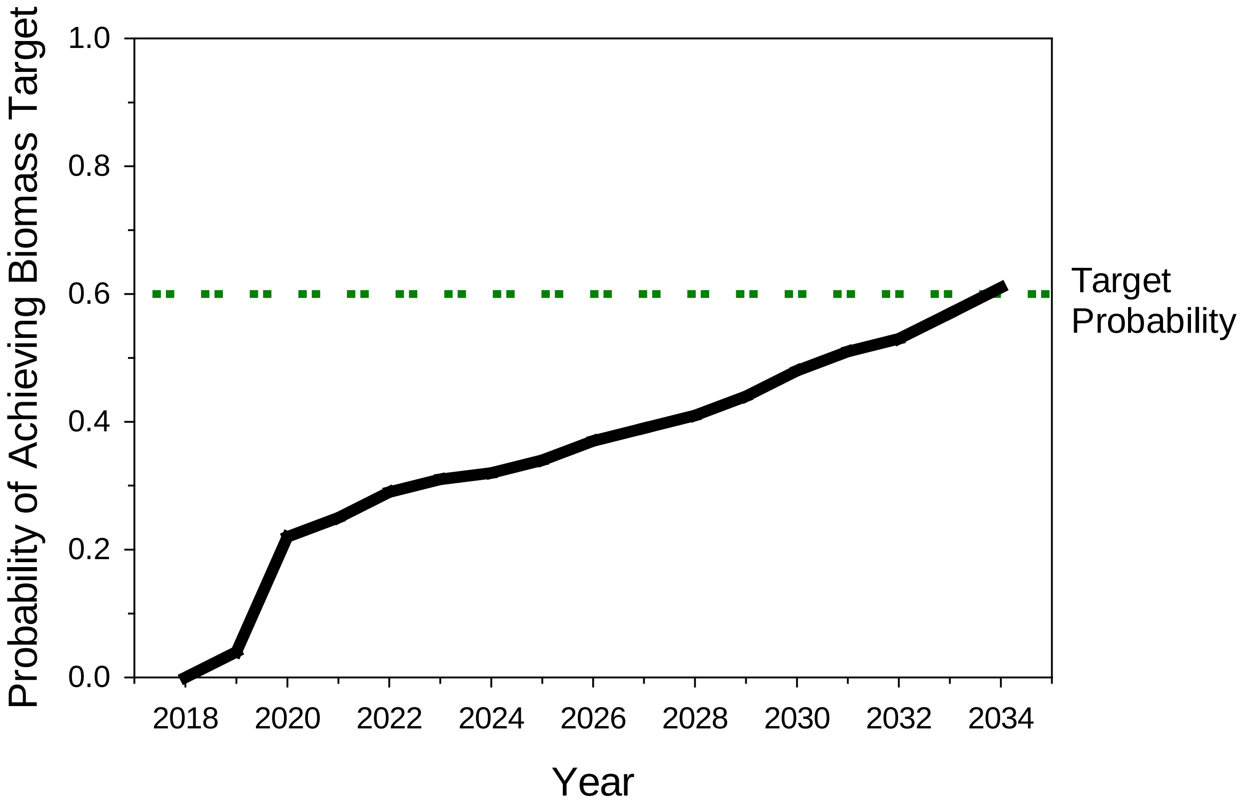

Figure 22. Annual probabilities of achieving the rebuilding target of 3,610 mt of spawning biomass with at least 60% probability during 2021-2034 under the constant F rebuilding scenario.

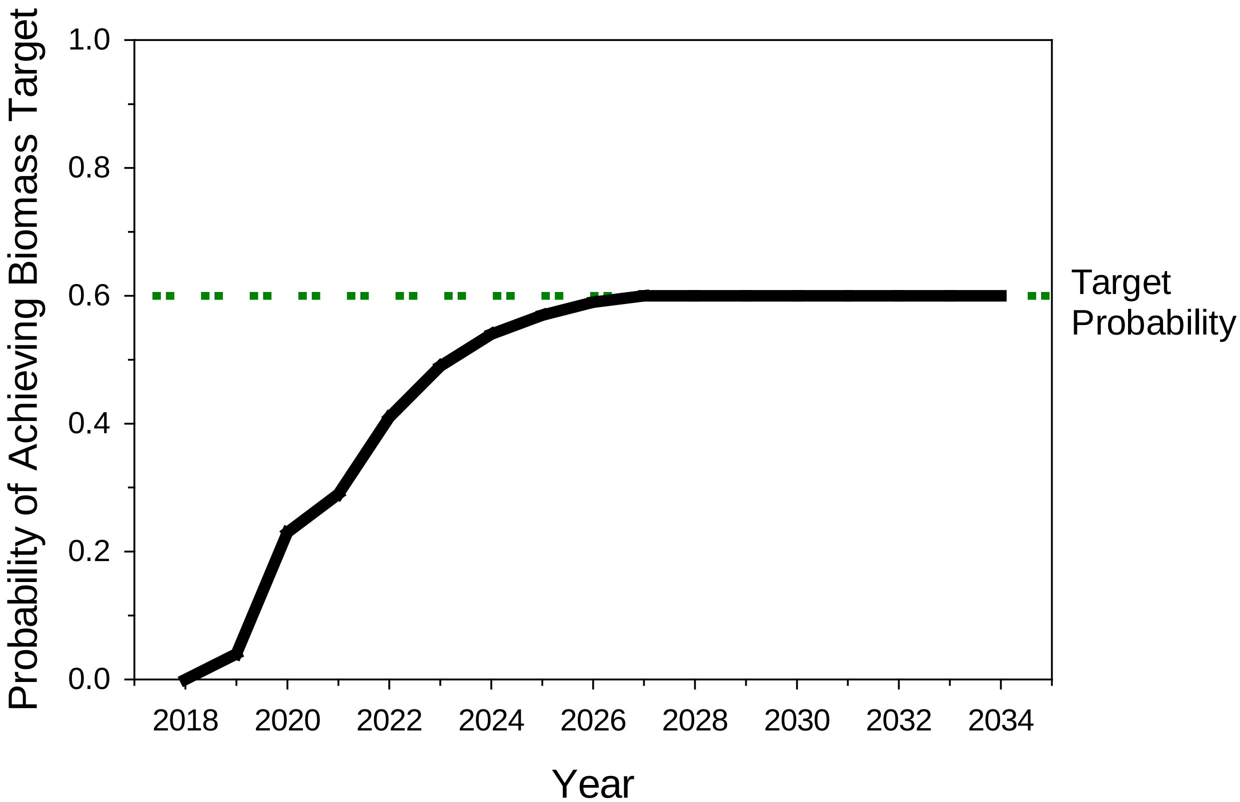

Figure 23. Annual probabilities of achieving the rebuilding target of 3,610 mt of spawning biomass with at least 60% probability during 2021-2034 under the constant quota rebuilding scenario.

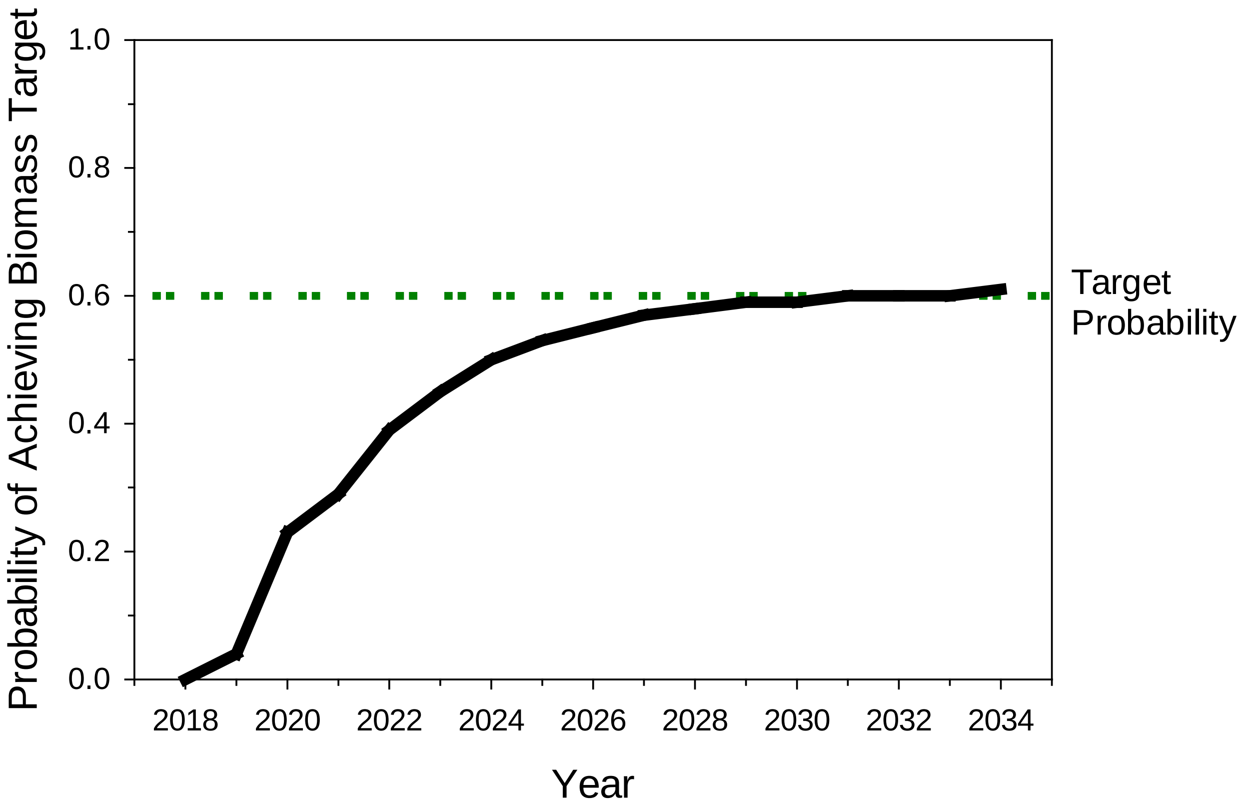

Figure 24. Comparison of annual probabilities of achieving the rebuilding target of 3,610 mt of spawning biomass with at least 60% probability during 2021-2034 under the phased, constant F, and constant quota rebuilding scenarios.

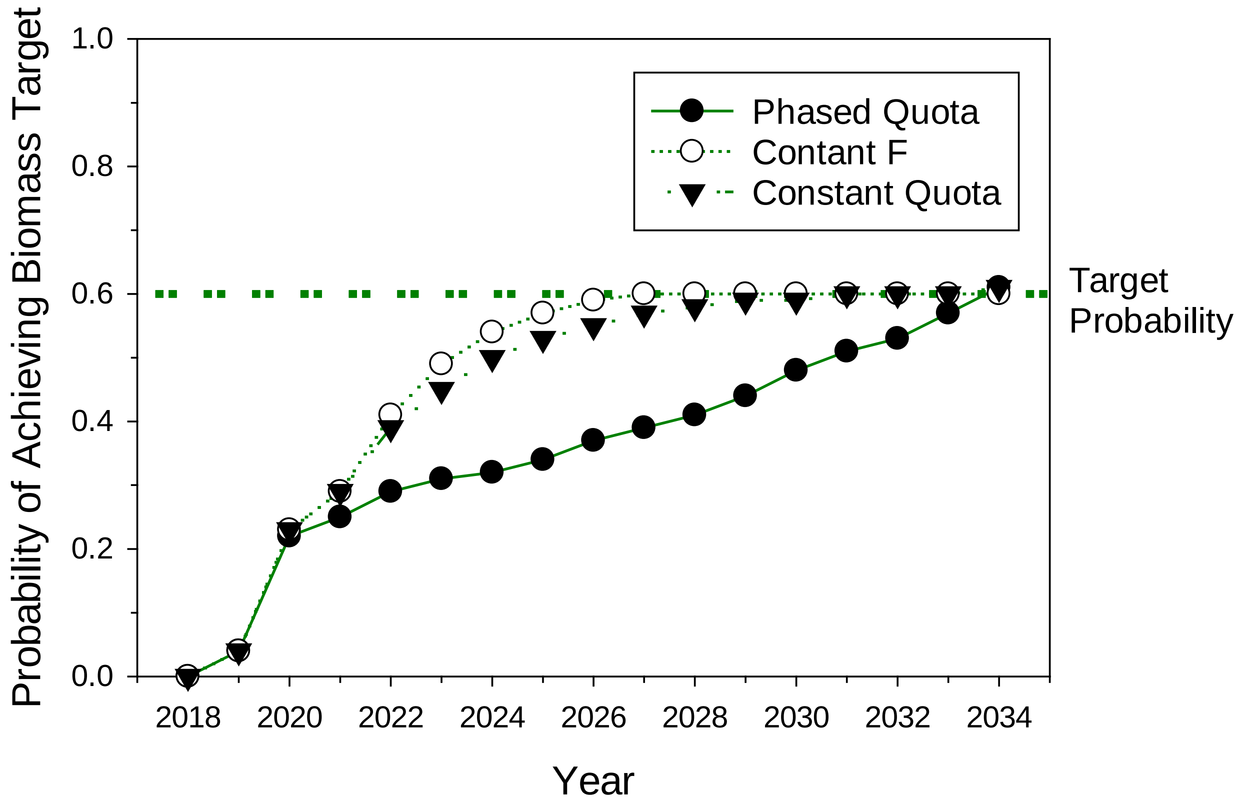

Figure 25. Annual probabilities of exceeding the overfishing reference point of $F_{20\%SSB\ (F=0)}=0.47$ during 2021-2034 under the phased rebuilding scenario relative to the even odds reference of not overfishing (red dash-dot line).

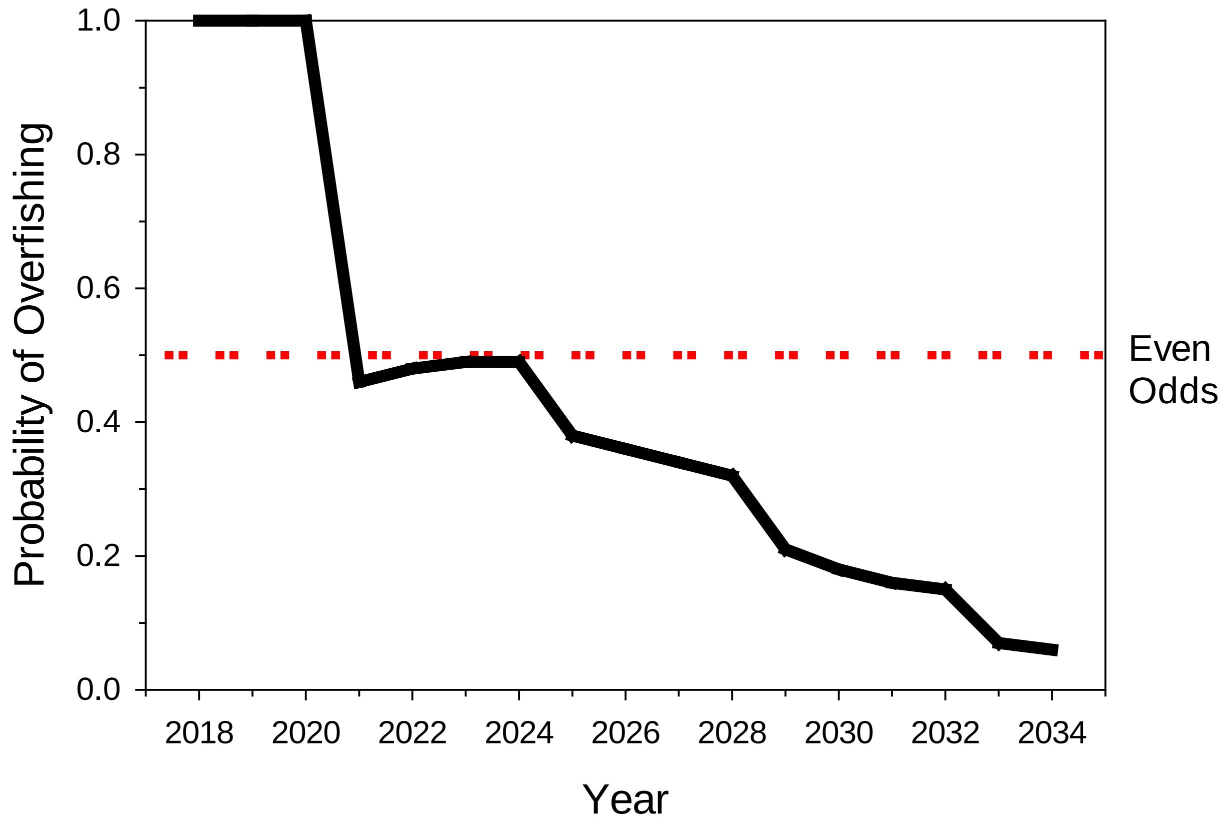

Figure 26. Annual probabilities of exceeding the overfishing reference point of $F_{20\%SSB(F=0)}$=0.47 during 2021-2034 under the constant F rebuilding scenario relative to the even odds reference of not overfishing (red dash-dot line).

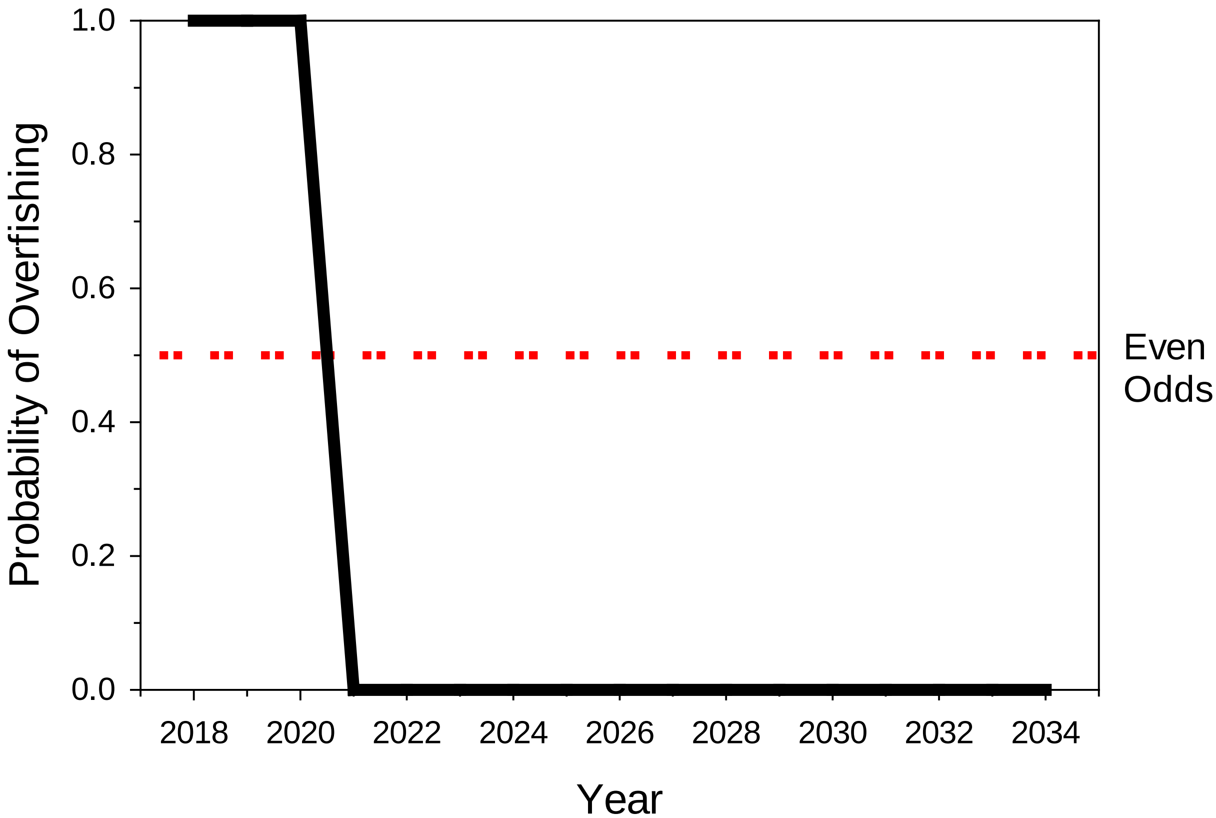

Figure 27. Annual probabilities of exceeding the overfishing reference point of $F_{20\%SSB(F=0)}$=0.47 during 2021-2034 under the constant quota rebuilding scenario relative to the even odds reference of not overfishing (red dash-dot line).

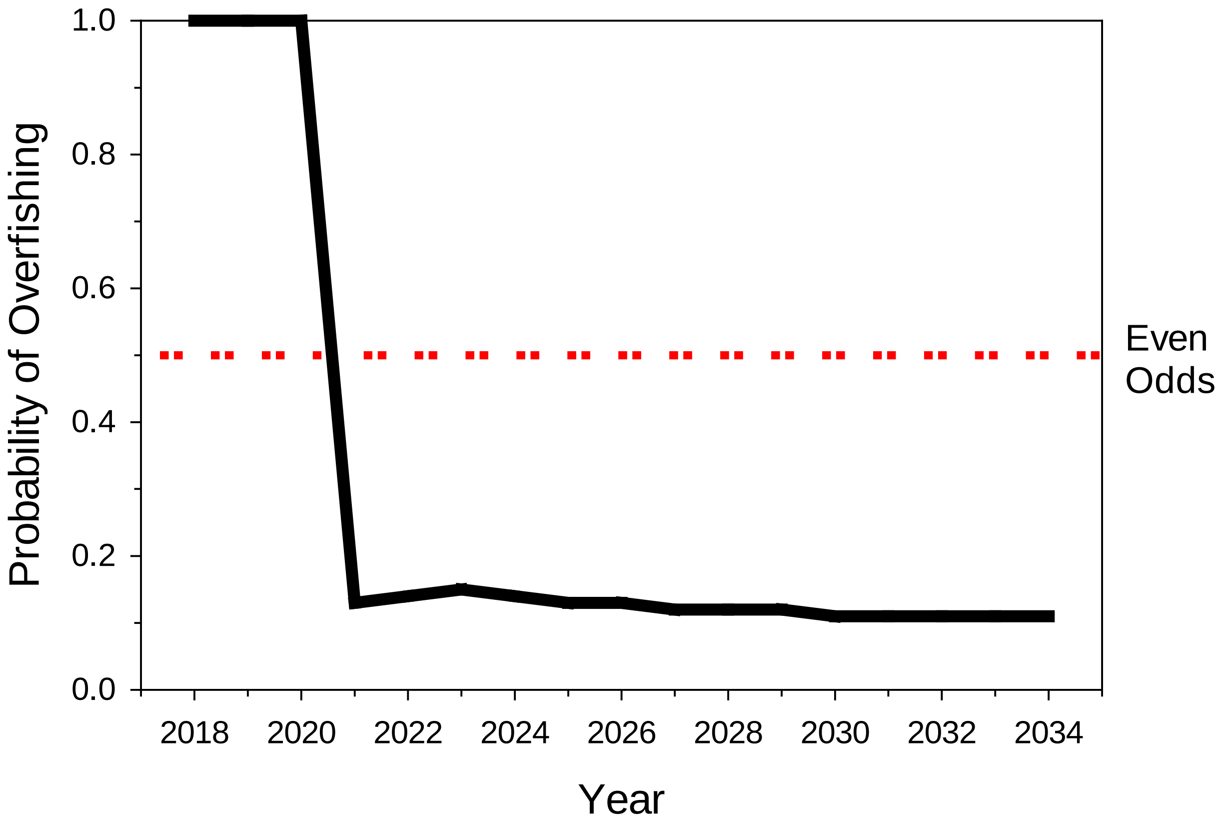

Figure 28. Comparison of the annual probabilities of exceeding the overfishing reference point of $F_{20\%SSB(F=0)}$=0.47 during 2021-2034 under the phased, constant F, and constant quota rebuilding scenarios relative to the even odds reference of not overfishing (red dash-dot line).