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Rebuilding Scenarios for Striped Marlin in the Western and Central North Pacific Ocean

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Abstract

This working paper describes analyses and stochastic stock projections to develop a 2024 rebuilding plan for the striped marlin population in the Western and Central North Pacific Ocean (WCNPO). This management unit stock is currently estimated to be depleted and experiencing excess fishing mortality (F) relative to maximum sustainable yield-based reference points. The projection analyses described in this working paper are based on 2023 benchmark stock assessment of WCNPO striped marlin. The goal of the rebuilding plan is to increase the spawning biomass of the stock to 20% of the unfished level, or $20\%SB_{F=0}$ = 3,660 mt, within 10 years (2025–2034) with a probability of rebuilding success of least 60%.

Five types of rebuilding scenarios were evaluated: constant fishing mortality, constant catch, phased fishing mortality, phased catch, and catch-release of age-1 striped marlin with a constant catch. The constant F scenario determined the constant annual fishing mortality rate and associated fishing effort to be applied during 2025–2034 to rebuild the stock with at least 60% probability by 2034. Similarly, the constant catch (C) scenario determined the constant annual catch biomass to be applied during 2022–2034 to rebuild the stock with at least 60% probability by 2034. The phased rebuilding scenarios were designed to gradually reduce striped marlin harvest in order to rebuild the stock by 2034 and provide periods of stable annual catch quotas for reducing fishing mortality on striped marlin. One phased F scenario and three phased catch scenarios were analyzed. The time periods in the phased scenarios were chosen to reflect the planned stock assessment schedule for WCNPO striped marlin with updates occurring every four years. The catch-release scenarios were designed to illustrate the probable impacts of bycatch reduction combined with catch-release measures for juvenile fish.

Eight rebuilding scenarios were analyzed. The probabilities of rebuilding the stock were calculated under a 3-model ensemble for recruitment for each rebuilding scenario. The three recruitment models in the ensemble represented different hypotheses about future recruitment conditioned on the observed long-term declines in recruitment since the mid-1990s; these were the short-term, medium-term and long-term recruitment models. The short-term and medium-term models were based on the empirical distribution of recruitment over recent 5-year and 20-year periods. The long-term recruitment model was based on the fitted stock-recruitment relationship from the 1977-2020 stock assessment in 2023. Overall, the three recruitment models spanned a wide range of possible future recruitment scenarios.

Rebuilding analyses were conducted using an age-structured stochastic projection model (Brodziak et al. 1998, https://github.com/nmfs-fish-tools/AGEPRO and https://github.com/PIFSCstockassessments/AGEPRO). The results of the projection analyses showed that the constant F scenario to achieve the target was F=0.373. The constant annual catch scenario to achieve the rebuilding target was 2,175 mt. The phased F scenario to achieve the rebuilding target was a 2-period phased F = (0.55, 0.37) during (2025-2027, 2028-2034). Three phased catch scenarios

were analyzed. The first phased catch scenario was catch = (2,400, 2,150) mt during (2025-2027, 2028-2034); this scenario included a low catch reduction in the initial phase. The second phased catch scenario was catch = (2250, 2175) mt, which included a higher catch reduction in the initial phase. The third phased catch scenario had three periods with catch = (2400, 2225, 2100) mt during (2025-2027, 2028-2031, 2032-2034). The catch-release scenarios required assumptions about the post-release survival of age-1 juvenile striped marlin. The catch-release scenarios indicated that annual catch biomasses of 2180 mt and 2185 mt would be needed to rebuild the stock at low or high post-release survival rates, respectively. Overall, the rebuilding analyses indicated that the target spawning biomass could be achieved with 60% probability under each of the eight scenarios examined.

Sensitivity results were conducted to evaluate how applying the individual recruitment models to predict future recruitment dynamics would impact results under the constant F and constant catch scenarios. The sensitivity analyses showed that if the long-term recruitment model was used to predict future recruitment dynamics, then the rebuilding target could be achieved at a constant annual catch of 2500 mt, or about 3% above the recent average catch biomass of 2428 mt. In contrast, substantial catch reductions of about 42% would be required to rebuild the stock if the short-term recruitment model was used. Alternatively, achieving the target under the medium-term recruitment model would require a catch reduction of about 9%, similar to those needed using the 3-model ensemble for recruitment dynamics. Overall, the sensitivity analyses showed that selecting a single model to predict the future recruitment dynamics of WCNPO striped marlin would have a substantial impact on the harvest reductions needed to rebuild the stock.

Introduction

This working paper describes stock projections and analyses to develop harvest strategies to rebuild the Western and Central North Pacific Ocean (WCNPO) striped marlin stock. The projection analyses are based on the 2023 benchmark assessment of striped marlin in the WCNPO which provides the best scientific information available. (ISC BILLWG 2023).

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. Annual WCNPO striped marlin catches averaged 7,221 mt, or 60% above the maximum sustainable yield (MSY) catch of 4,513 mt during 1975–2000. Annual catches have decreased since 1993 and averaged 2,719 mt during 2011–2020, or 40% below MSY (Figure 1). Overall, international longline fishing fleets have harvested the vast majority of WCNPO striped marlin since 1994.

Stock Status

The 2023 benchmark stock assessment of WCNPO striped marlin provides the best scientific information available on stock status. The base case model indicated that under current conditions, the WCNPO MLS stock was very likely overfished (>99% probability) and was likely subject to overfishing (>66% probability) relative to the dynamic 20-year 20%$SSB_{F=0}$-based reference points (Tables 1 and 2). The 2023 status results were similar to results in the 2021 update, the 2019 benchmark and the 2015 stock assessments (ISC BILLWG 2015, ISC BILLWG 2019, ISC BILLWG 2023, Sculley 2021).

Spawning biomass decreased from 5,096 mt in 1977 to fluctuate around 3,300 mt between 1981 and 1992, or about 17% of the equilibrium unfished spawning biomass of 19,279 mt (Figure 2). Spawning biomass decreased to around 1,100 mt in the late-1990s and then fluctuated about an average of about 1,400 mt from 2001-2020. The lowest observed spawning biomass was 1,081 mt in 2011, or about 70% below the rebuilding target of SSB_{Target} = 3,660 mt based on the dynamic 20-year 20%$SSB_{(F=0)}$ reference point (Figure 2). Since then, spawning biomass increased to 1,696 mt in 2020, or about 54% below SSB_{Target} and the stock is currently depleted.

Fishing mortality (F) on the stock (average F on ages 3–12) fluctuated around F_{MSY} during the late-1970s and has declined in recent years (Figure 3). Fishing mortality averaged F = 0.68 during 2018–2020, or 28% above the $F_{20\%SSB(F=0)}$ overfishing level. Fishing mortality has exceeded the $F_{20\%SSB(F=0)}$ overfishing reference point in every year since 1978. Overall, the WCNPO striped marlin stock is overfished and experiencing overfishing relative to dynamic 20-year 20%$SSB_{(F=0)}$ and $F_{20\%SSB(F=0)}$ biological reference points (Figures 2 and 3), although no limit reference points have been formally established for the stock by the WCPFC.

Rebuilding Goals

Stock rebuilding goals for WCNPO striped marlin have been established by the WCPFC. In 2018, the Northern Committee (NC) of the WCPFC requested that the ISC Billfish Working Group conduct stock projection analyses to provide information for the development of a rebuilding plan for WCNPO striped marlin (NC14 2018). The Northern Committee made the following requests:

"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 2019 benchmark stock assessment provided the basis for stock projections (ISC Billfish WG 2019) which were 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%$SSB_{F=0}$). The ISC Billfish Working Group subsequently evaluated whether a dynamic unfished spawning biomass reference point was appropriate for WCNPO striped marlin and concluded that a dynamic unfished SSB reference point based on a 20-year period would be appropriate given the dynamic changes in stock productivity.

Based on the benchmark stock assessment and the stochastic stock projections reviewed at SC15 and NC15, a rebuilding plan for WCNPO striped marlin was adopted at WCPFC16. The plan set the rebuilding target for spawning biomass at 20%$SB_{F=0}$, a rebuilding period of 15 years (2020–2034), and a probability of rebuilding success of at least 60%.

The goals for the 2024 WCNPO striped marlin rebuilding scenario analyses were set to be consistent with the WCPFC16 rebuilding goals and are:

- The rebuilding target is SSB_{Target} = 3,660 mt of spawning biomass based on the 2023 estimate of the 20-year dynamic 20%$SB_{F=0}$ reference point (ISC BILLWG 2023).
- The rebuilding period is 2025–2034.
- Striped marlin conservation measures are implemented in 2025–2034.
- The required probability for achieving the rebuilding target is $P_{Rebuild} \geq 0.60$.

In this paper, we describe stochastic stock projections to calculate the fleet-wide reductions in catch biomass required to meet these goals and rebuild the WCNPO striped marlin stock. This includes descriptions of the initial conditions, recruitment dynamics, life history parameters, fishery dynamics, projection model, rebuilding scenarios, and results of alternative rebuilding scenarios. The WCNPO striped marlin projection analyses begin in 2021, the first year following the stock assessment time horizon of 1977–2020. Stochastic projections during 2021-2024 are based on the recent average fishing mortality during 2018-2020. Catch reductions and other conservation measures to rebuild the stock are modeled as being implemented in 2025 through 2034. A total of eight alternative rebuilding scenarios are developed and analyzed, including four scenarios based on stakeholder input. Sensitivity analyses show the effects of alternative recruitment modeling assumptions for constant F-based or catch-based rebuilding scenarios. We conclude with a discussion of key results and uncertainties.

Initial Conditions

The stock projections accounted for uncertainties in the initial conditions derived from the terminal year of the 2023 benchmark stock assessment. The two primary initial uncertainties were: (1) the estimates of the striped marlin population numbers at age at the start of 2021 and (2) the catch biomasses harvested in 2021–2024, the period after the terminal year of the assessment and prior to the start of the rebuilding projections in 2025.

Uncertainty in the estimate of the initial population size at age was an important feature to account for in the stock projections. Some statistical uncertainty will exist in terminal-year estimates of population size from an age-structured stock assessment because estimates of younger cohorts cannot be based on a full set of catch-at-age observations over their lifespans (Brodziak et al. 1998). For striped marlin, uncertainty in the population size in 2021 was characterized by calculating 100 bootstrap replicates of the population size at age using the bootstrapping option in the assessment model Stock Synthesis ([SS3], Methot and Wetzel 2013). This produced a sampling intensity of about 60 bootstraps per 1,000 mt of spawning biomass and generated a distribution of initial population sizes at age for the projections (Table 3, Figure 4). The bootstrapped mean and median total population sizes were similar at 445.2 and 444.1 thousand fish, respectively. On average, the majority of total population numbers were accounted for by ages 1 to 3 (97%). The range of bootstrapped total population sizes in 2021 was from 287.9 to 677.8 thousand fish.

Uncertainty in the distribution of catch biomasses during 2021–2024 was characterized using Monte Carlo simulation. All simulations were based on the 100 bootstrap replicates of initial population size. The estimates of catch biomasses prior to the implementation of rebuilding measures in 2025 were based on the 2018-2020 average fishing mortality from the 2023 stock assessment. This was the same assumption as was used in the 2021 rebuilding plan analyses (Brodziak 2021). The recent average fishing mortality was set to $F_{Initial}$=0.68 (the average annual F on age classes 3 to 12 during 2018–2020). The $F_{Initial}$ value in 2021 was 6% higher than $F_{Initial}$ = 0.64 in 2018 based on the 2019 assessment (ISC BILLWG 2019). The initial fishing mortality rate was applied to simulate population size-at-age trajectories during 2021–2024 and produced the projected distributions of population sizes and catches. The simulated annual catch biomasses in 2021-2024 averaged about 2,970, 3,420, 3,380 and 3,070 mt with CVs of 16%, 17%, 20%, and 22%, respectively, under each rebuilding scenario using the 3-model recruitment ensemble (see Recruitment Dynamics below). Overall, the initial conditions were set consistently across projection scenarios.

The treatment of the 2021-2024 catch biomasses for stock projections was based on applying the recent average fishing mortality to the stock in 2021-2024. This was the same approach that was used in the 2021 rebuilding analyses (Brodziak 2021) but differed from the 2019 approach (ISC BILLWG 2019). For the 2024 projections, the catches in 2021-2024 were based on the assumption that international longline fishing effort and the associated bycatch fishing mortality of WCNPO striped marlin would be relatively stable in this period Because the 2019 year class[1] was above recent average recruitments (e.g., Figures 5 and 6), it was important to account for expected increases in catches during 2021–2024 when this year class would be recruited to the fishery. In contrast, the initial catch biomasses used in the 2019 projections differed for the F-based and catch-based projection scenarios. For F-based rebuilding scenarios, initial catches were based on the recent average F, while for catch-based scenarios, initial catches were based on recent average catch. This produced minor differences in initial conditions across projection scenarios based on the 2019 assessment (ISC BILLWG 2019).

Recruitment Dynamics

Recruitment dynamics for the stochastic rebuilding projections included process uncertainty which was based on the empirical patterns observed in the 2023 stock assessment (Figure 5). The temporal patterns in recruitment for the 2023 assessment were similar to those observed in the 2019 benchmark and 2021 update assessments. In 2021, a 2-model ensemble with short-term (5-year) and long-term recruitment (43-year) hypotheses was used for modeling recruitment dynamics (Brodziak and Sculley 2020, Brodziak 2021). For the 2024 rebuilding analyses, we included a third medium-term (20-year) recruitment hypothesis to account for the relatively stable pattern of recruitment since 2000. The medium-term recruitment model was also included because it was consistent with the 20-year period used for calculating the dynamic 20%$SB_{F=0}$ reference point. Overall, the three working hypotheses for future recruitment dynamics reflected the temporal patterns observed

[1] "Year class" refers to the abundance of age-0 fish in contrast to "recruitment" which is the abundance of age-1 fish used in the projection model.

in the 2023, 2019 and 2021 stock assessments; these were the short-, medium-, and long-term recruitment model scenarios.

Short-Term Recruitment

The short-term hypothesis was that recruitment in the rebuilding period would be similar to the recent 5-year pattern of observed recruitment (Figures 6 and 7). This recruitment model was supported by the observation that recruitment estimates had remained relatively low in the past decade, and that this pattern was likely to persist in the future. The short-term model generated recruitment by randomly resampling the empirical cumulative distribution function (ECDF[2]) of age-1 recruitment observed during 2015–2019 (Figure 7). This 5-year period matched the mean generation time for WCNPO striped marlin (~ 5 years) and was consistent with the 2021 rebuilding analyses (Brodziak 2021). Point estimates of recruitment in 2020-2021 were held out in order to test the near-term predictive accuracy of the three alternative recruitment models. Under the short-term recruitment scenario, recruitment averaged 135.4 thousand age-1 fish with a CV of 43%.

Medium-Term Recruitment

The second hypothesis was that future recruitment would be similar to the 20-year recruitment pattern observed since 2000 (Figures 6 and 7). Under the medium-term recruitment scenario, future recruitment was generated by randomly resampling the empirical cumulative distribution function of age-1 recruitment during 2000-2019. This 20-year ECDF[2] model produced an annual average of 176.9 thousand age-1 fish (CV of 46%), with variability similar to the short-term model. The 20-year ECDF also matched the time window used to calculate the dynamic unfished spawning biomass reference points used for WCNPO striped marlin (ISC BILLWG 2022). Overall, the medium-term recruitment model was consistent with an expectation of higher recruitment relative to the low levels observed from 2015-2019.

Long-Term Recruitment

The third working hypothesis was that future recruitment would follow the fitted Beverton-Holt stock-recruitment curve[3] estimated in the 2023 assessment model. This was the long-term recruitment model. The long-term model generated recruitment by randomly sampling the fitted stock-recruitment curve with bias correction based on the value of spawning biomass and a lognormal error term (Figure 5). Under the long-term hypothesis, recruitment estimates averaged 302.6 thousand age-1 fish during 1978-2021 with a CV of 14%. Future recruitment generated under the long-term recruitment scenario would be expected to produce about 120% and 70% more recruits than under the short-term and medium-term scenarios, respectively, with about one-third less variability. Thus, the selection of a future recruitment

[2] This is recruitment model 14 in AGEPRO.
[3] This is recruitment model 5 in AGEPRO.

scenario was expected to have an important influence on stock projections for WCNPO striped marlin.

Recruitment Model Selection

Recruitment model selection is an important component of conducting stock projections. Previous stock projections for WCNPO striped marlin based on the 2019 benchmark assessment produced substantial differences between rebuilding trajectories based on short- (5-year ECDF, 2011-2015) and long-term (43-year ECDF, 1975-2015) recruitment models. These differences led the Northern Committee to ask which recruitment model was most likely (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.*".

In response, the ISC Billfish Working Group evaluated the empirical support for the short- and long-term recruitment scenarios (Brodziak and Sculley 2020). They found that the long-term decline in recruitment, combined with the better predictive accuracy of the short-term recruitment scenario and the observation that recruitments were positively auto-correlated, implied that the short-term recruitment model was the most likely scenario (ISC Billfish WG 2020).

The ISC Billfish WG also recognized that the long-term recruitment scenario may be appropriate if future environmental conditions changed. To account for this possibility in the 2019-2021 projection analyses, future recruitment dynamics were modeled as a 2-model mixture of the short-term and long-term recruitment models. The mixing probabilities, or model weights, were calculated based on the out-of-sample forecast accuracies for recruitment values in 2017–2018 using inverse-variance weights[4] (Brodziak and Sculley 2020). This led to calculated model weights of 0.92 and 0.08 for the short-term and long-term scenarios in 2019, respectively. When this analysis was revised using the updated 2021 assessment data, the mixing probabilities were recalculated to be 0.97 and 0.03 for the short- and long-term scenarios. As a result, the short-term model was much more probable than the long-term model.

We reexamined recruitment model selection for the 2024 rebuilding scenario analyses using the 2023 assessment data. The 2023 recruitment time series had a long-term declining trend (Figure 8) as was evident in the 2019 and 2021 assessments. We applied a change point analysis (Killick and Eckley 2014) to the recruitment and spawning biomass time series from the 2023 assessment. The change point analysis estimated whether there were years in the time series where either the mean or variance in the recruitment (indexed by the age-0 abundance estimates from SS3) or

[4] The inverse-variance model weights (w_i) were $w_i = \sigma_i^{-2} / \sum_k \sigma_k^{-2}$ where σ_i^2 is the error variance of the i^{th} model.

spawning biomass (thousand mt) series changed substantially. We used the pruned exact linear time method (Killick and Eckley 2012) to evaluate all potential change points during 1977-2020. Results indicated there was a change point in the recruitment time series in 1993, corresponding to a sharp decline in recruitment (Figure 9) . Results for the spawning biomass series showed a similar sharp drop in the spawning biomass time series in 1995 (Figure 10). An initial change point in 1978 was interpreted as an artifact of the numerical search for solutions near the time series boundary. The 1995 change point for spawning biomass was consistent with the 1993 change point in the recruitment time series. This was because the sharp decrease in recruits from 1993 would begin to contribute to spawning biomass as mature fish at about age-2. Overall, both recruitment and spawning biomass time series declined sharply in the mid-1990s and this pattern persisted to the end of the assessment time horizon.

We examined the set of all short-term 5-year and medium-term 20-year ECDFs of recruitment to identify temporal patterns. The 5-year moving average of recruitment decreased from a peak of 480 thousand recruits in 1987 to around 151 thousand in 2011 and then fluctuated around 150 thousand recruits during 2012 to 2021 (Figure 11). The coefficient of variation (CV) averaged 35% over 1982-2021 and the 5-year recruitment variability was highest during 2013-2018 with CVs ranging from 51% to 63%. Recruitment trends for the 5-year medians were similar to the moving averages (Figure 11) which suggested that these measures of central tendency were relatively consistent for the 5-year sequence of ECDFs. The sequence of 20-year ECDFs of recruitment showed a smoother decline in recruitment from the 1990s to the 2010s (Figure 12). The 20-year moving average of recruitment declined from about 393 thousand recruits in 1997 to 172 thousand recruits in 2021. The CVs of the 20-year averages ranged from 29%-38% during 1997-2004 and then increased to range from 42%-49% during 2005-2021. The trends in the 20-year mean and median recruitments were also consistent and showed similar declines in recruitment strength for the sequence of 20-year ECDFs (Figure 12). The long-term declines in mean and median recruitment showed that the choice of time period for setting the short-term and medium-term recruitment ECDFs would influence recruitment projections. Setting the ECDFs based on earlier periods would lead to higher projected future recruitments than setting the ECDFs based on more recent periods. This observation supported setting the ECDFs for short-term and medium-term recruitment to be as near to the terminal year of the assessment as possible, i.e., 2014-2018 and 1999-2018 respectively, while holding out the two most recent recruitments for testing out-of-sample prediction accuracy.

We evaluated the support for using the short-, medium-, and long-term models to simulate recruitment for rebuilding projections. The short-term and medium-term models were the 5-year and 20-year ECDFs for recruitment during 2014-2018 and 1999-2018. The long-term model was the fitted stock-recruitment curve with lognormal error from the 2023 assessment. Point predictions of recruitment were the expected values of each model and these predictions were compared to the estimated recruitment values during 1978-2021. The recruitment residuals showed different patterns for the medium-term, short-term, and long-term (Figure 13) models. The residuals for the long-term recruitment model were generally smaller than the ECDF models, as expected, but showed a stronger pattern of overestimating recruitments from 2005-2021. The short-term recruitment model underestimated recruitment prior to 2005 but produced relatively low residuals during 2005-2021. Residual patterns for the medium-term model were similar to the short-term model but had smaller residuals prior to 2005. Overall, the residual patterns indicated that the predictive accuracy of the three models differed throughout the assessment time horizon..

The squared residuals were used as a measure of each model's predictive accuracy for recruitment by year. The results showed that the long-term recruitment model generally produced the best predictive accuracy prior to 2005 (Figure 14). In comparison, the overall prediction errors during 2005 to 2021 were somewhat smaller and the short-term and medium-term models produced better predictions than the long-term model in most years. The squared residuals were used to calculate an inverse error-variance model weight by year. The results showed that the recruitment models produced different accuracies and model weights by year (Figures 15-17), as expected. The long-term recruitment model was generally assigned higher annual model weights prior to 2005. However, from 2005-2021, the short-term and medium-term models generally had higher models weights, although the long-term model had the highest weight for the larger age-1 recruitment values in 2006, 2011, 2014 and 2018 (Figures 15-17). Overall, the temporal patterns in model weights reflected the nonstationary nature of the recruitment time series.

We also calculated inverse error-variance model weights during different periods to characterize the temporal shifts in predictive accuracy (Table 4). The results showed that for the early periods of 1977-1992 and 1977-2000, the medium-term and short-term models produced similar accuracies with model weights of 0.15-0.17 and 0.11-0.12, respectively. In comparison, the long-term model was the best predictor for the early periods and was assigned model weights of 0.74 and 0.71 for 1977-1992 and 1977-2000. Over the full time series of 1977-2020, the long-term model produced the most accurate predictions, as expected, with a weight of 0.56. In comparison, the medium-term model had a weight of about 0.25 while the short-term model had the lowest weight of 0.19 for the whole time series. However, for the more recent periods of 1993-2020 and 2001-2020, the medium-term model had the best accuracies with model weights of 0.45 and 0.46 while the short-term model had the second highest weights of 0.31 and 0.37. In contrast, the long-term model had the lowest predictive accuracies of 0.23 and 0.17 for the later periods of 1993-2020 and 2001-2020. Overall, the model weights showed that the long-term model produced better predictive accuracy and was more probable than either the short-term or medium-term models during the early periods (Table 4) and for the entire time series. However, the medium-term model was the most probable model for the most recent periods, followed by the short-term model. Thus, the choice of period for evaluating the relative accuracy of the three models had a substantial influence on their support as predictors of future recruitment for stochastic projections.

We evaluated the relative weights of the short-, medium-, and long-term models for future stochastic projections. We used the same tactical model-averaging approach (Dorman et al. 2018) as was used to set recruitment model weights in the 2021 rebuilding analyses (Brodziak 2021). The inverse error-variance weights were calculated for the age-1 recruitment values in 2020 and 2021 (Table 5). The prediction error of the medium-term model was the lowest of the three recruitment models and its calculated model weight was 0.84. In comparison, the model weights for the short-term and long-term recruitment models were 0.12 and 0.04, respectively. These weights were used as the default setting for the stochastic projections of future recruitment for the 2024 rebuilding analyses.

Life History Parameters

Life history parameters for the rebuilding analyses were identical to those used in the 2023 benchmark stock assessment of WCNPO striped marlin (Table 6, WCNPO 2023 values). The 2023 mean weights at age used for the rebuilding analyses were slightly higher than the mean weights from the 2019 assessment (Figure 18) because the Brody growth coefficient was k=0.26 versus k=0.24 in the 2019 assessment (Table 6). The 2023 proportion of mature females at age used for the rebuilding analyses were higher than the proportions from the 2019 assessment (Figure 19) because the median female length at maturity was set at L_{50} = 152 cm EFL based on a reanalysis of maturity data collected in the Western and Central North Pacific (Humphreys and Brodziak 2024). For comparison, the median female length at maturity in the 2019 assessment was L_{50} = 161 cm EFL (Table 6).

We used the selectivity at age estimates from the 2023 and 2019 assessments to derive aggregate fishery selectivities at age for all fleets (Figure 20). This was done to calculate estimates of yield- and spawning biomass-per recruit as well as spawning potential ratio for the aggregate fishery. The 2023 fishery selectivities at age were calculated as the weighted average of the fishery selectivities at age for the 9 fleet groups with unique selectivity patterns in 2020 (see Fishery Dynamics section) with weights equal to the 2020 proportion of the total F by fleet. The 2019 fishery selectivities at age were taken from the 2021 rebuilding analyses which used a weighted average of two representative longline and drift gillnet fleets with domed- and flat-topped fishery selectivities (ISC BILLWG 2019). The aggregate fishery selectivities for ages 2-5 were higher from the 2023 compared to the 2019 assessment and associated rebuilding analyses (Figure 20). The differences in selectivity at age combined with differences in mean weights and maturity proportions at age produced higher estimates of yield per recruit as a function of fishing mortality in the 2023 versus the 2019 assessment and rebuilding analyses (Figure 21). The differences in life history parameters also led to moderate differences in the realized spawning biomass per recruit for the aggregate fishery (Figure 22), with higher values of SSB/R realized at low fishing mortality rates under the 2023 life history parameter values. The differences in life history parameters also produced minor differences in the mean generation times (Figure 23) with unfished values of 4.9 and 5.2 years for the 2023 and

2019 assessments and rebuilding analyses. The 2023 life history parameters also produced lower values of spawning potential ratios (Figure 24) as a function of fishing mortality than the 2019 life history parameters for the aggregate fishery. The life history parameters for the 2023 benchmark assessment produced faster growth, more rapid maturity and higher fishery selectivities at age than those used in the 2019 assessment. These differences, in turn, implied that yield per recruit was estimated to be higher in the 2023 assessment while spawning potential ratio at F was lower. However, there was no practical difference in mean generation times for the 2023 and 2019 life history parameters which indicated that population turnover rates were similar for both assessments.

Fishery Dynamics

The fleet dynamics used in the rebuilding analyses were the same as those used in the 2023 stock assessment. There were a total of 25 fishing fleets that reported WCNPO striped marlin catches (Table 7.1). This included 19 fishing fleets from Japan, 2 fleets from the USA, 3 fleets from Taiwan, and 1 aggregate fleet comprised of fishing fleets from countries that were WCPFC members. Of the 19 Japanese fleets, there were 14 longline fleets, 4 drift gillnet fleets and 1 aggregate fleet comprised of other fishing gears. Of the 2 USA fleets, there was 1 longline fleet from Hawaii and 1 aggregate fleet comprised of other gears, which included all reported USA recreational catches of striped marlin. Of the 3 Taiwanese fleets, there were 2 longline fleets and 1 aggregate fleet comprised of other gears. The single aggregate WCPFC fleet was comprised of country-specific fleets that used longline and other gears that were reported to incidentally harvest striped marlin as part of their tuna-targeting fishing operations. Thus, there was a complex stream of reported catch information for the WCNPO striped marlin stock used for the 2023 stock assessment and the rebuilding analyses.

The 2023 stock assessment used a fleets-as-areas approach to implicitly account for the spatial structure of the fishery for WCNPO striped marlin and the same approach was used for the fleet dynamics in the rebuilding analyses. The individual fleet catch and size data for the 25 fishing fleets were aggregated into 9 fleet groups with unique fishery length selectivities (Table 7.2) as in the 2023 stock assessment. These 9 fleet groups were used to set fishery selectivities at age for the rebuilding analyses. To set this information for the stock projections, we used a set of R language extraction scripts that gathered the exact fishery selectivity at age values as calculated by year within the base case stock synthesis model output for the 2023 stock assessment (M. Sculley, Pers. comm. 2024, available at https://github.com/PIFSCstockassessments/2024-WCNPO-MLS-Rebuilding). The 9 fleet groups with unique fishery selectivities used for the rebuilding analyses were (Tables 7 and 8 and Figure 25):

- Fleet F1: Japanese longline fleet group operating in Subarea 1 in Quarter 1
- Fleet F2: Japanese longline fleet group operating in Subarea 2 in Quarter 1
- Fleet F4: Japanese longline fleet group operating in Subarea 1 in Quarter 2
- Fleet F5: Japanese longline fleet group operating in Subarea 1 in Quarter 3

- Fleet F6: Japanese longline fleet group operating in Subarea 1 in Quarter 4
- Fleet F13: Japanese driftnet fleet group operating in Quarters 1 and 4, late
- Fleet F14: Japanese driftnet fleet group operating in Quarters 2 and 3, late
- Fleet F16: USA longline fleet group
- Fleet F18: Taiwanese distant-water longline fleet group

Each of the 9 fleet groups was comprised of individual fleets whose fishery selectivity was set to match that of the primary member of the fleet group (Tables 7 and 8, Figure 25). The number of individual fleets in the 9 fleets groups ranged from 1 (F13) to 5 (F4) fleets. Two of the fleet groups had time-varying fishery selectivity, fleet groups F1 and F16, although the magnitude of temporal change in their average annual selectivity patterns between 2016-2020 and 1994-2020 was minor (Figures 26 and 27). There were 6 fleet groups that were estimated to have dome-shaped fishery selectivity at age (Figures 25 and 26). These included the 5 Japanese longline fleet groups (F1, F2, F4, F5, F6) and the single USA longline fleet group (F16). There were 3 fleet groups with flat-topped fishery selectivity at age (Figures 25 and 27). These included 2 Japanese driftnet fleet groups (F13 and F14) and the 1 Taiwanese longline fleet group (F18). The fleet groups used for the 2023 stock assessment were used to set the fishery selectivities at age for the rebuilding analyses. In particular, we used the fishery selectivities by fleet group estimated for the year 2020 in the base case SS3 assessment model because these selectivities were used to estimate the biological reference points including the rebuilding target and the overfishing level.

It was important to maintain the 9 fleet-group structure for the rebuilding analyses because operational characteristics differed between the fleet groups. The proportion of fishing mortality by fleet group varied for fleet groups with dome-shaped (Table 9, Figure 28) and flat-topped (Table 9, Figure 29) fishery selectivities at age. There were also differences in the predicted mean catch weights at age for fleet groups with dome-shaped (Figure 30) and flat-topped (Figure 31) fishery selectivities at age. In particular, the catch weights at age calculated in the SS3 model were substantially larger for the flat-topped versus the dome-shaped fishery selectivity fleet groups (Figures 30 and 31). Differences among fleet groups were also apparent for the calculated catch biomasses by fleet group for dome- and flat-topped fleet groups (Figures 32 and 33). Here it is important to note that the catch biomass values for the Japanese longline fleet groups were calculated internally in the SS3 base case model as derived from the inputs of reported catch numbers and size compositions through time. The proportions of catch biomass by fleet group also differed by fleet group and fishery selectivity pattern (Figures 34 and 35). Despite these differences, it was apparent that two fleet groups, F4, the Japanese longline fleet group operating in Subarea 1 in Quarter 2 and F18, the Taiwanese distant-water longline fleet group, produced the majority of fishing mortality on WCNPO striped marlin in 2020 and that this pattern has persisted through time (Table 9). Overall, the 9 fleet groups have important differences in their fishery characteristics which are reflected in the rebuilding analyses.

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 previous sections. In each projection, 1000 simulations were run for each bootstrap replicate to characterize the effects of process errors in future recruitment, life history, and fishery parameters[5]. 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 used the assessment estimates of the multi-fleet, fishery selectivity at age to produce consistent results. 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 was 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

A total of 8 rebuilding scenarios were developed for the WCNPO striped marlin stock. Identifying feasible rebuilding strategy parameters under the 3-model ensemble for recruitment was the main goal of the stock projections. Each of the eight scenarios used the 3- model recruitment ensemble to predict future recruitment dynamics. The eight rebuilding scenarios were:

Scenario 1. A constant F rebuilding scenario

The constant F scenario was designed to determine the fishing mortality rate and associated fishing effort to be applied during 2022–2034 to rebuild the stock with at least 60% probability in 2034. This constant level of fishing mortality was iteratively calculated to meet the 60% rebuilding probability.

Scenario 2. A constant catch biomass rebuilding scenario

The constant catch scenario was designed to determine the constant catch biomass to be harvested during 2022–2034 to rebuild the stock with at least 60% probability in

[5] Process errors for weights at age, natural mortality rates at age and fishery selectivities at age were multiplicative lognormal errors with a mean of 1 and CV of 10%. Process errors for maturity at age were also lognormally distributed with a mean of 1 and a CV of 1%.

2034. This constant level of catch was iteratively calculated to meet the 60% rebuilding probability.

Scenario 3. A phased F rebuilding scenario

The phased fishing mortality rebuilding scenario was designed to gradually reduce catch quotas for the aggregate international fleet in order to rebuild the stock and to provide some temporal stability for bycatch for the aggregate longline fleet. The initial phased F strategy was set up for 2 periods, 2025-2027 and 2028-2034 with a lower F reduction in the first period to phase-in a higher F reduction in the second period. The length of the 3-year initial phase coincided with the next scheduled WCNPO striped marlin stock assessment.

Scenario 4. A phased catch rebuilding scenario with minimal initial reduction

The phased catch rebuilding scenario with minimal initial reduction consisted of setting catch amounts for two time periods: 2025-2027 and 2028-2034. The magnitudes of the catches were iteratively determined to rebuild the stock to the target spawning biomass with at least 60% probability in 2034 with a minimal reduction in the first phase followed by a major catch reduction in the second phase.

Scenario 5. A phased catch rebuilding scenario with moderate initial reduction

The phased catch rebuilding scenario with moderate initial reduction consisted of setting catch amounts for two periods: 2025-2027 and 2028-2034. The magnitudes of the catches were iteratively determined to rebuild the stock to the target spawning biomass with at least 60% probability in 2034 with a moderate reduction in the first phase followed by a larger catch reduction in the second phase.

Scenario 6. A 3-phase catch rebuilding scenario with minimal initial reduction

The 3-phase catch rebuilding scenario with minimal initial reduction consisted of setting catch amounts for three periods: 2025-2027, 2028-2031, and 2032-2034. The magnitudes of the catches were iteratively determined to rebuild the stock to the target spawning biomass with at least 60% probability in 2034 with a minimal reduction in the first phase followed by a larger catch reductions in the second and third phases. The length of phases 1 and 2 coincided with the next two scheduled WCNPO striped marlin stock assessments.

Scenario 7. A catch-release with low survival scenario

The catch-release rebuilding scenario with low survival included a catch and release measure for age-1 fish with a post-release survival rate of 20% and a constant catch biomass reduction. Post release survival was approximated as the product of a longline survival rate at capture of 50% (Brouwer et al. 2023) and a release survival of about 40% (Brouwer et al. 2023, Figure 21). This scenario was designed to determine the constant catch biomass along with low catch-release survival to rebuild the stock to the target spawning biomass with at least 60% probability in 2034.

Scenario 8. A catch-release with high survival scenario
The catch-release rebuilding scenario with high survival included a catch and release measure for age-1 fish with a post-release survival rate of 43% and a constant catch biomass reduction. Post release survival was approximated as the product of a longline survival rate at capture of 50% (Brouwer et al. 2023) and a release survival of about 86% (Musyl et el. 2015). This scenario was designed to determine the constant catch biomass along with high catch-release survival to rebuild the stock to the target spawning biomass with at least 60% probability in 2034.

Sensitivity Analyses

Sensitivity analyses were conducted to show how the application of individual recruitment models would impact rebuilding scenario results. Projections to calculate the constant F and constant catch biomass scenarios were conducted using either the short-term, medium-term, or long-term recruitment model to predict recruitment. A constant F = Fmsy projection was also run for each recruitment model for reference.

The sensitivity analyses were:

(1) A constant F rebuilding scenario based on either short-, medium-, or long-term recruitment

(2) A constant catch rebuilding scenario based on either short-, medium-, or long-term recruitment

The sensitivity analyses showed how harvest amounts to rebuild the stock would change under each of the individual working hypotheses about recruitment, i.e., the short-, medium-, and long-term recruitment scenarios.

Results

Projected distributions of initial catch biomasses were calculated for each of the rebuilding scenarios. The medians of the initial catch biomasses during 2021-2024 were roughly 2,900, 3,400, 3,300, and 3,000 mt under each scenario, except scenarios 7 and 8 where catch-release of age-1 fish reduced 2021 and 2022 median catches to about 2,700-2,800 mt and 3,300 mt.

Rebuilding Scenarios

The results of the eight rebuilding scenario analyses were (Table 9):

Scenario 1
The constant F scenario achieved the spawning biomass target at a fishing mortality of F = 0.373 during 2025-2034 with a rebuilding probability of P=0.60 in 2032. Scenario 1 required a fishing mortality reduction[6] of 45% in 2025.

Scenario 2
The constant catch scenario achieved the spawning biomass target at a catch of C = 2,175 mt during 2025-2034 with a rebuilding probability of P=0.61 in 2034. Scenario 2 required a catch reduction[2] of 10% in 2025.

Scenario 3
The phased F scenario achieved the spawning biomass target at F = (0.55, 0.37) during 2025-2027 and 2028-2034 with a rebuilding probability of P=0.61 in 2033. Scenario 3 required a total fishing mortality reduction of 46% with a 19% reduction in 2025 and a 26% reduction in 2028.

Scenario 4
The phased catch scenario with minimal initial reduction achieved the spawning biomass target at a catch of C = (2,400, 2,150) mt during 2025-2027 and 2028-2034 with a rebuilding probability of P=0.60 in 2034. Scenario 4 required a total catch reduction of 11% with a 1% reduction in 2025 and a 10% reduction in 2028.

Scenario 5
The phased catch scenario with moderate initial reduction achieved the spawning biomass target at a catch of C = (2,250, 2,175) mt during 2025-2027 and 2028-2034 with a rebuilding probability of P=0.60 in 2034. Scenario 5 required a total catch reduction of 10% with a 7% reduction in 2025 and a 3% reduction in 2028.

Scenario 6
The 3-phase catch scenario with minimal initial reduction achieved the spawning biomass target at a catch of C = (2,400, 2,225, 2,100) mt during 2025-2027, 2028-2031, and 2032-2034 with a rebuilding probability of P=0.60 in 2034. Scenario 6 required a total catch reduction of 15% with a 1% reduction in 2025, a 7% reduction in 2028, and a 6% reduction in 2032.

Scenario 7
The catch-release scenario with low survival achieved the spawning biomass target at a catch of C = 2,180 mt during 2025-2034 with a rebuilding probability of P=0.60 in 2034. Scenario 7 required catch-release of age-1 striped marlin and a catch reduction of 10% in 2025.

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[6] Harvest reductions for the rebuilding scenarios are expressed relative to either to the recent average fishing mortality or catch during 2018-2020 where $F_{2018\text{-}2020}$ = 0.68 or $C_{2018\text{-}2020}$ = 2,428 mt.

Scenario 8
The catch-release scenario with high survival achieved the spawning biomass target at a catch of C = 2,185 mt during 2025-2034 with a rebuilding probability of P=0.60 in 2034. Scenario 8 required catch-release of age-1 striped marlin and a catch reduction of 10% in 2025.

The projected median of total catch biomass during 2025-2034 under each of the eight scenarios is shown in Table 9. The projected reduction in median total catch relative to an expected catch equal to the 2018-2020 average catch harvested over 10 years under each of the eight scenarios is shown in Table 9.

The projected distributions of catch biomass results during 2025-2034 under each of the eight scenarios are shown in Tables 10.1-10.8 and Figures 36.1-36.8, respectively. Comparison of the catch biomass results under each of the rebuilding scenarios are shown in Table 10.9 and Figures 36.9-36.11.

The projected distributions of spawning biomass results during 2025-2034 under each of the eight scenarios are shown in Tables 11.1-11.8 and Figures 37.1-37.8, respectively. Comparison of the spawning biomass results under each of the rebuilding scenarios are shown in Table 11.9 and Figures 37.9-37.11.

The projected distributions of fishing mortality results during 2025-2034 under each of the eight scenarios are shown in Tables 12.1-12.8 and Figures 38.1-38.8, respectively. Comparison of the fishing mortality results under each of the rebuilding scenarios are shown in Table 12.9 and Figures 38.9-38.11.

The comparisons of annual probabilities of achieving the rebuilding target of 3,660 mt of spawning biomass with at least 60% probability during 2021-2034 under each of the eight scenarios are shown in Table 13 and Figures 39.1-39.3.

The comparisons of the annual probabilities of exceeding the potential overfishing reference point of $F_{20\%SSB(F=0)}$=0.53 during 2021–2034 under each of the eight scenarios relative to the even odds reference of not overfishing are shown in Table 14 and Figures 40.1-40.3.

Sensitivity Analyses

Medium-Term Recruitment Model
Under the medium-term recruitment model, the constant F scenario achieved the spawning biomass target at a fishing mortality of F = 0.38 during 2025-2034 with a rebuilding probability of P=0.60 in 2030. This scenario required a fishing mortality

reduction[7] of 44% in 2025.

The constant catch scenario under medium-term recruitment achieved the spawning biomass target at a catch of C = 2,200 mt during 2025-2034 with a rebuilding probability of P=0.60 in 2032. The constant catch scenario required a catch reduction of 9% in 2025.

The projected distributions of catch biomass results during 2025-2034 for the constant F and catch rebuilding scenarios are shown in Table 15 and Figure 41.1.

The projected distributions of spawning biomass results during 2025-2034 for the constant F and constant catch rebuilding scenarios are provided in Table 15 and Figure 42.1.

The projected distributions of fishing mortality results during 2025-2034 for the constant F and constant catch rebuilding scenarios are provided in Table 15.

Comparisons of the probabilities of achieving the rebuilding and probabilities of overfishing under the medium-term recruitment model for the constant F and constant catch scenarios are provided in Table 16 and Figures 43.1 and 44.1.

Short-Term Recruitment Model

Under the short-term recruitment model, the constant F scenario achieved the spawning biomass target at a fishing mortality of F = 0.26 during 2025-2034 with a rebuilding probability of P=0.61 in 2032. This scenario required a fishing mortality reduction of 62% in 2025.

The constant catch scenario under short-term recruitment achieved the spawning biomass target at a catch of C = 1,400 mt during 2025-2034 with a rebuilding probability of P=0.61 in 2034. The constant catch scenario required a catch reduction of 42% in 2025.

The projected distributions of catch biomass results during 2025-2034 for the constant F and constant catch rebuilding scenarios are provided in Table 17 and Figure 41.2.

The projected distributions of spawning biomass results during 2025-2034 for the constant F and constant catch rebuilding scenarios are provided in Table 17 and Figure 42.2.

The projected distributions of fishing mortality results during 2025-2034 for the

[7] Harvest reductions for the sensitivity analyses are expressed relative to either to the recent average fishing mortality or catch during 2018-2020 where $F_{2018\text{-}2020}$ = 0.68 or $C_{2018\text{-}2020}$ = 2,428 mt.

constant F and constant catch rebuilding scenarios are provided in Table 17.

Comparisons of the probabilities of achieving the rebuilding and probabilities of overfishing under the short-term recruitment model for the constant F and constant catch scenarios are provided in Table 18 and Figures 43.2 and 44.2.

Long-Term Recruitment Model

Under the long-term recruitment model, the constant F scenario achieved the spawning biomass target at a fishing mortality of F = 0.56 during 2025-2034 with a rebuilding probability of P=0.60 in 2031. This scenario required a fishing mortality reduction of 18% in 2025.

The constant catch scenario under short-term recruitment achieved the spawning biomass target at a catch of C = 2,500 mt during 2025-2034 with a rebuilding probability of P=0.63 in 2026. The constant catch scenario entailed a catch increase of 3% in 2025.

The projected distributions of catch biomass results during 2025-2034 for the constant F and constant catch rebuilding scenarios are provided in Table 19 and Figure 41.3.

The projected distributions of spawning biomass results during 2025-2034 for the constant F and constant catch rebuilding scenarios are provided in Table 19 and Figure 42.3.

The projected distributions of fishing mortality results during 2025-2034 for the constant F and constant catch rebuilding scenarios are provided in Table 19.

Comparisons of the probabilities of achieving the rebuilding and probabilities of overfishing under the long-term recruitment model for the constant F rebuild = 0.56, constant catch rebuild = 2,500 mt are provided in Table 20 and Figures 43.3 and 44.3.

Overall, the sensitivity analyses showed that the choice of a single model for predicting future recruitment would much different outcomes for constant F and catch rebuilding scenarios. Rebuilding scenarios under the medium-term model were similar to those under the 3-model recruitment ensemble with 2% and 1% increases in the constant F and catch scenarios relative to the ensemble, respectively. In contrast, rebuilding results under the short-term model were much lower than those under the 3-model ensemble with decreases of -31% and -36% in the constant F and catch scenarios. The long-term model produced constant F and catch scenarios that increased the constant F and catch scenarios by +50% and +15%, respectively. Thus, the rebuilding projections were sensitive to the recruitment model used to predict future recruitment.

Discussion

All eight of the rebuilding scenarios developed here are more likely than not to achieve the 2024 rebuilding goals for WCNPO striped marlin. There are also a wide variety of alternative scenarios that could be developed to achieve these goals under a phased rebuilding approach. In comparison, the constant F or catch scenarios are simpler but may be expected to produce less total striped marlin catch. This tradeoff may be an important consideration for rebuilding the stock. It is also important to note that constant F strategies based on maintaining the status quo fishing mortality or reducing fishing mortality to Fmsy are very unlikely to rebuild the stock by 2034.

Another important observation is that the initial striped marlin population size at the start of the projections in 2021 includes the 2019-2021 recruitments which were all above the average recruitment for the short-term recruitment model (Figure 6). This above-average recruitment pattern during 2019-2021 would be expected to provide an initial boost to rebuilding potential and projected catch biomasses. In fact, one sees that median catch biomasses in the initial projection period of 2021-2023 are all several hundred mt larger than the recent observed average of 2428 mt during 2018-2020 (Table 10.9). Similarly, the 2019-2021 recruitments increases the projected spawning biomasses more rapidly than would be expected under the recent short-term recruitment pattern. Thus, the stock projections reflect near-term changes in recruitment which have a positive effect on rebuilding potential.

The eight rebuilding scenarios would likely reduce fishing mortality to below the $F_{20\%SSB(F=0)}$ overfishing limit at different times during 2025–2034. Scenarios 1, 2, and 5 reduce F below $F_{20\%SSB(F=0)}$ with less than 50% probability in 2025. Scenarios 4, 6, 7, and 8 reduce F below $F_{20\%SSB(F=0)}$ with less than 50% probability in 2026, while scenario 3 reduces F below $F_{20\%SSB(F=0)}$ in 2028. Thus, almost all of the rebuilding scenarios would reduce fishing mortality below the overfishing reference in the first 2 years of the rebuilding period.

Further, while each of the rebuilding scenarios would require near-term reductions in catch biomass or fishing mortality, the reductions under the phased rebuilding scenarios are smaller than under the constant F or constant catch scenarios. This implies that the fishery impacts of achieving near-term conservation goals are likely to be lower under the phased rebuilding scenario. This may be a desirable feature because that it may be difficult to make substantial changes in fishing practices by the aggregate international fleet that harvests WCNPO striped marlin in the short-term due to management inertia and the general non-malleability of resource extraction capital. For example, the phased F rebuilding scenario 3 requires about a -19% reduction in the catch in 2025 relative to the 2018-2020 average F (Table 9). In comparison, the constant F scenario 1 requires a fishing mortality reduction of 45% that is over 2-fold larger. The phased rebuilding scenarios are likely to produce somewhat larger yields than the constant harvest scenarios over the rebuilding time horizon, with the exception of scenario 5 (Table 9). Overall, reducing the catch quotas under phased rebuilding scenarios 3, 4, or 6 would provide some short-term stability for the fleets that incidentally harvest this bycatch species.

The constant F and catch scenarios produce more rapid rebuilding of the WCNPO striped marlin stock than the phased rebuilding scenarios (Figures 37.9, 37.10 39.1 and 39.2), with the exception of scenario 5. This near-term response may be an important feature to consider relative to the long-term trends in catch, spawning biomass, and fishing mortality (Figures 1, 2, and 3).

Given that there are numerous international fleets that harvest WCNPO striped marlin as bycatch, predominantly with longline fishing gear, multiyear quotas which address issues of overage or underage of annual catch quotas by individual nations, may be a practical management option. In this context, it may be useful to consider carryover or multiyear quotas (i.e., Holland et al. 2020) for application in the WCPFC fishery management system. This approach may be useful for each of the eight rebuilding scenarios.

While uncertainty about fishery system dynamics has been included in each of the rebuilding scenarios for WCNPO striped marlin in a consistent manner, the fishery system may produce unexpected future outcomes due to unforeseen events. In practice, a flexible management approach may be needed to adjust to future shifts in life-history parameters, recruitment patterns, trophic interactions, or environmental factors that impact striped marlin rebuilding measures. To address uncertainties about expected future conditions, it would be useful to develop interim goals or "waypoints" to measure the progress achieved in a striped marlin rebuilding plan (i.e., Brodziak et al. 2008). The timing of such waypoints can be directly linked to the future assessment schedule for WCNPO striped marlin, which had a benchmark stock assessment in 2023. Overall, an adaptive management approach may be key for implementing a successful rebuilding plan under climate change.

Last, it is important to note that the eight scenarios do not account for potential implementation uncertainty in the conservation measures (e.g., Link et al. 2012) designed to rebuild the WCNPO striped marlin stock. If effective implementation appears highly uncertain, then it may be appropriate to consider increasing the target probability for rebuilding success to be greater than 60%, or 3:2 odds of success. This would provide a precautionary buffer to account for uncertainty in the effectiveness of conservation measures to rebuild WCNPO striped marlin.

References

Brodziak J. 2021. Some Rebuilding Analyses for the Western and Central North Pacific Ocean Striped Marlin Stock. International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific/Billfish WG, ISC/21/BILLWG-01/04, 65 p. Available at: https://isc.fra.go.jp/pdf/BILL/ISC21_BILL_1/ISC_21_BILLWG-01_04v1.pdf

Brodziak J, Cadrin SX, Legault CM, Murawski SA. 2008. Goals and strategies for rebuilding New England groundfish stocks. Fish. Res. 94:355-366.

Brodziak J, Rago P, Conser R. 1998. A general approach for making short-term stochastic projections from an age-structured fisheries assessment model. In F. Funk, T. Quinn II, J. Heifetz, J. Ianelli, J. Powers, J. Schweigert, P. Sullivan, and C.-I. Zhang (Eds), Proceedings of the International Symposium on Fishery Stock Assessment Models for the 21st Century. Alaska Sea Grant College Program, Univ. of Alaska, Fairbanks. Available at:
https://www.researchgate.net/publication/267682539_A_General_Approach_for_Making_Short-Term_Stochastic_Projections_from_an_Age-Structured_Fisheries_Assessment_Model

Brodziak J, Sculley M. 2020. Which recruitment scenario is most likely for conducting future stock projections of Western and Central North Pacific Ocean striped marlin? PIFSC Working Paper, WP-20-002, https://doi.org/10.25923/7ak7-yz80, 9 p. Available at: http://isc.fra.go.jp/pdf/BILL/ISC20_BILL_1/ISC_20_BILLWG-01_07.pdf

Brouwer S, Farthing M, Hamer P. 2023. Billfish research plan, 2023-2027. Technical Report, Western Central Pacific Fisheries Commission. WCPFC-SC19-2023/SA-WP-16. Available at: https://meetings.wcpfc.int/index.php/node/19364

Holland D, Lambert D, Schnettler E, Methot R, Karp M, Brewster-Geisz K, Brodziak J, Crosson S, Farmer N, Frens K, Gasper J, Hastie J, Lynch P, Matson S, Thunberg E. 2020. National Standard 1 Technical Guidance for Designing, Evaluating, and Implementing Carry-over and Phase-in Provisions. NOAA Tech. Memo. NMFS-F/SPO-203, 41 p.

Humphreys RL Jr, Brodziak JKT. 2024. Reproductive dynamics of striped marlin (Kajikia audax) in the central North Pacific. Marine and Freshwater Research 75, MF23192. https://doi:10.1071/MF23192

International Scientific Committee for Tuna and Tuna-Like Species in the North Pacific [ISC Billfish WG]. 2015. Annex 11: Report of the Billfish Working Group Workshop, Stock assessment update for striped marlin (*Kajikia audax*) in the Western and Central North Pacific Ocean through 2013, 15-20 July 2015. Kona, HI, USA. ISC/15/Annex11. Available at:
http://isc.fra.go.jp/pdf/ISC15/Annex11_WCNPO_STM_ASSESSMENT_REPORT_2015.pdf

ISC Billfish WG. 2019. Annex 11: Stock Assessment Report for Striped Marlin (*Kajikia audax*) in the Western and Central North Pacific Ocean through 2018, 11-15 July 2019. Taipei, Taiwan. ISC/19/Annex11. Available at:
http://isc.fra.go.jp/pdf/ISC19/ISC19_ANNEX11_Stock_Assessment_Report_for_Striped_Marlin.pdf

ISC Billfish WG. 2020. Annex 7: Report of the Billfish Working Group Workshop, 30 January – 3 February 2020. National Taiwan University, Taipei, Taiwan. ISC/20/ANNEX/7, 28 p. Available at: http://isc.fra.go.jp/pdf/ISC20/ISC20_ANNEX07_SUMMARY_REPORT_BILLFISH_Working_Group_Workshop.pdf

ISC Billfish WG. 2023. Annex 9: Report of the Billfish Working Group Workshop, 12-18 July 2022. Kona, Hawaii, USA. ISC/22/Annex9, 24 p. Available at: https://isc.fra.go.jp/pdf/ISC22/ISC22_ANNEX09_Report_of_the_BILLWG_Workshop_Apr2022.pdf

ISC Billfish WG. 2023. Annex 14: Stock Assessment Report for Striped Marlin (*Kajikia audax*) in the Western and Central North Pacific Ocean through 2020, 12-17 July 2023. Kanazawa, Japan. ISC/23/Annex14, 113 p. Available at: https://isc.fra.go.jp/pdf/ISC23/ISC23_ANNEX14-Stock_Assessment_Report_for_WCNPO_Striped_Marlin-FINAL.pdf

Killick R, Fearnhead P, Eckley IA. 2012. Optimal detection of changepoints with a linear computational cost. Journal of the American Statistical Association, 107: 1590-1598.

Killick R, Eckley IA. 2014. changepoint: An R package for changepoint analysis. Journal of Statistical Software, 58:1-19.

Methot RD, Wetzel CR. 2013. Stock Synthesis: a biological and statistical framework for fish stock assessment and fishery management. Fish. Res., 142, 86–99.

Musyl MK, Moyes CD, Brill RW, Mourato BL, West A, McNaughton LM, Chiang W-C, Sun C-L. 2015. Postrelease mortality in istiophorid billfish. Canadian Journal of Fisheries and Aquatic Sciences. 72(4): 538-556. https://doi.org/10.1139/cjfas-2014-0323

Northern Committee Fourteenth Regular Session [NC14]. 2018. NC14 Summary Report, revision 1. Western and Central Pacific Fisheries Commission, Northern Committee Fourteenth Regular Session, Fukuoka, Japan 4 – 7 September 2018. Available at: https://www.wcpfc.int/meeting-folders/northern-committee

Northern Committee Fourteenth Regular Session [NC15]. 2019. NC15 Summary Report. Western and Central Pacific Fisheries Commission, Northern Committee Fifteenth Regular Session, Portland, Oregon 3 – 6 September 2019. Available at: https://www.wcpfc.int/meeting-folders/northern-committee

Sculley M. 2021. Update to the 2019 Western and Central North Pacific Ocean Striped Marlin stock assessment. PIFSC Working Paper, WP-21-01-02, 24 p.

Table 1. Reported catch (mt) used in the stock assessment along with annual estimates of population biomass (age-1 and older, mt), female spawning biomass (mt), relative female spawning biomass ($SSB/20\%SSB_{F=0}$), recruitment (thousands of age-0 fish), fishing mortality (average F, ages-3 – 12), relative fishing mortality ($F/F_{20\%SSB(F=0)}$), and spawning potential ratio of Western and Central North Pacific striped marlin.

Year	2014	2015	2016	2017	2018	2019	2020	Mean[1]	Min[1]	Max[1]
Reported Catch	2,745	3,272	2,456	2,256	2,177	2,695	2,412	5,383	2,177	10,912
Population Biomass	7,142	6,476	5,944	5,506	5,316	6,831	7,339	11,283	5,316	19,463
Spawning Biomass	1,142	1,293	1,305	1,238	1,223	1,158	1,696	2,266	1,081	5,118
Relative Spawning Biomass	0.31	0.35	0.35	0.33	0.33	0.31	0.46	0.61	0.29	1.38
Recruitment (age 0)	102,169	196,286	138,584	150,045	299,538	215,884	263,519	366,217	89,526	711,480
Fishing Mortality	0.77	0.91	0.70	0.74	0.69	0.77	0.58	0.89	0.53	1.42
Relative Fishing Mortality	1.46	1.70	1.31	1.39	1.30	1.45	1.09	1.67	1.00	2.67
Spawning Potential Ratio	0.14	0.11	0.16	0.16	0.16	0.14	0.20	0.13	0.06	0.23

[1] During 1977-2020

Table 2. Estimates of biological reference points along with estimates of fishing mortality (F), spawning biomass (SSB), 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 $SSB_{F=0}$ indicates the average 20-year dynamic B0 estimate, $20\%SSB_{F=0}$ is the associated reference point, and MSY indicates the maximum sustainable yield reference point and $F_{Initial}$ is the average fishing mortality during 2018-2020 and the expected fishing mortality used to initialize the stock projections in 2021-2024..

Reference Point	**Estimate**
$F_{20\%SSB(F=0)}$ (age 3-12)	0.53
F_{MSY} (age 3-12)	0.63
F_{2020} (age 3-12)	0.58
$F_{Initial} = F_{2018-2020}$	0.68
$SSB_{F=0}$	18,300 mt
$20\%SSB_{F=0}$	3,660 mt
SSB_{MSY}	2,920 mt
SSB_{2020}	1,696 mt
$SSB_{2018-2020}$	1,359 mt
$C_{20\%SSB(F=0)}$	4,468 mt
MSY	4,512 mt
$C_{2018-2020}$	2,428 mt
$SPR_{20\%SSB(F=0)}$	22%
SPR_{MSY}	18%
SPR_{2020}	20%
$SPR_{2018-2020}$	17%

Table 3. Summary of the WCNPO Striped Marlin bootstrapped numbers at age in 2021 from the 2023 assessment model used for stock projections, where numbers at age are expressed in units of thousands of fish, "MAD" is median absolute deviation, "CD" is the coefficient of MAD, or CD = MAD/Median and "0.0" indicates values less than 0.005.

	Age-1	Age-2	Age-3	Age-4	Age-5	Age-6	Age-7	Age-8
Mean	274.0	101.5	55.4	9.9	2.9	1.1	0.2	0.2
Stdev	75.1	19.3	10.6	2.7	1.3	0.8	0.3	0.4
CV	27%	19%	19%	27%	43%	71%	123%	213%
Median	261.1	100.4	54.9	9.5	2.7	1.0	0.2	0.1
MAD	51.3	12.4	6.1	1.3	0.5	0.3	0.1	0.1
CD	20%	12%	11%	13%	18%	27%	37%	47%
	Age-9	Age-10	Age-11	Age-12	Age-13	Age-14	Age-15+	Total
Mean	0.0	0.0	0.0	0.0	0.0	0.0	0.0	445.2
Stdev	0.0	0.0	0.0	0.0	0.0	0.0	0.0	85.3
CV	248%	370%	537%	564%	612%	646%	700%	19%
Median	0.0	0.0	0.0	0.0	0.0	0.0	0.0	444.1
MAD	0.0	0.0	0.0	0.0	0.0	0.0	0.0	61.3
CD	63%	63%	76%	85%	91%	95%	99%	14%

Table 4. Results of the inverse error-variance weight calculations for the medium-, short-, and long-term recruitment models within the 3-model recruitment ensemble for five periods, 1977-1992, 1977-2000, 1977-2020, 1993-2020, 2001-2020.

	Inverse Error-Variance Weights		
Period	Medium-term Recruitment	Short-term Recruitment	Long-term Recruitment
1977-1992	0.15	0.11	0.74
1977-2000	0.17	0.12	0.71
1977-2020	0.25	0.19	0.56
1993-2020	0.45	0.31	0.23
2001-2020	0.46	0.37	0.17

Table 5. Results of the inverse error-variance weights calculated for each single-model forecast of the 2020 and 2021 age-1 recruitment estimates.

Combined Forecast Weight for 2020 and 2021 Recruitment by Point Prediction	Unweighted Mean Squared Error (MSE)	Combined Inverse Variance with Equal Annual Weighting	Inverse Error-Variance Weights by Model with Equal Annual Weighting
Short-term ECDF R	2598.0	3.849123E-04	0.12
Medium-term ECDF R	367.6	2.720051E-03	0.84
Long-term SRR	8337.8	1.199358E-04	0.04
Total	11303.4	3.224899E-03	1

Table 6. Key life history parameters and model structures used in the 2019 and 2023 WCNPO striped marlin stock assessments.

Parameters	WCNPO 2019	WCNPO 2023
Natural mortality	0.54 (age 0) 0.47 (age 1) 0.43 (age 2) 0.40 (age 3) 0.38 (ages 4-15)	0.54 (age 0) 0.47 (age 1) 0.43 (age 2) 0.40 (age 3) 0.38 (ages 4-15)
Minimum reference age (A_{min})	0.3	0.5
Maximum reference age (A_{max})	15	15
Length at A_{min} (cm, EFL)	104	110.9
Length at A_{max} (cm, EFL)	214	215.5
Growth rate (k)	0.24	0.26
CV of Length at A_{min}	0.14	0.14
CV of Length at A_{max}	0.08	0.10
L_{inf} (cm, EFL)	217.3	217.8
t_0	-2.413	NA*
Weight-at-length	$W=4.68e\text{-}006 \times L^{3.16}$	$W=4.68e\text{-}006 \times L^{3.16}$
Size-at-50% Maturity	161	152.2
Age-at-50% Maturity	3.2	2.3
L_{50}/L_{inf}	74%	70%
Size-at-95% Maturity	196.9	166.6
Age-at-95% Maturity	7.4	3.2
L_{95}/L_{inf}	91%	90%
Slope of maturity ogive	-0.082	-0.204
Fecundity	Proportional to spawning biomass	Proportional to spawning biomass
Spawning season (quarter)	2	2
Spawner-recruit relationship	Beverton-Holt	Beverton-Holt
Spawner-recruit steepness (*h*)	0.87	0.87
Recruitment variability (σ_R)	0.6	0.6

Table 7.1. Fishing fleet catch and abundance indices used in the base case model for the 2023 stock assessment and the 2024 rebuilding analyses including fleet name and time-period where the representative fleet for each of the 9 fleet groups is shown in bold.

Catch Index	Abundance Index	Fleet Name	Time Period
F1	**S1**	**JPNLL_Q1A1_Late**	**1994-2020**
F2	**-**	**JPNLL_Q1A2**	**1975-2020**
F3	-	JPNLL_Q1A3	1975-2020
F4	**-**	**JPNLL_Q2A1**	**1975-2020**
F5	**S2**	**JPNLL_Q3A1_Late**	**1994-2020**
F6	**-**	**JPNLL_Q4A1**	**1975-2020**
F7	-	JPNLL_Q1A4	1975-2020
F8	-	JPNLL_Q2A2	1975-2020
F9	-	JPNLL_Q3A2	1975-2020
F10	-	JPNLL_Q4A2	1975-2020
F11	-	JPNLL_Q4A3	1975-2020
F12	-	JPNLL_Others	1975-2020
F13	**-**	**JPNDF_Q14_EarlyLate**	**1975-1976 and 1994-2020**
F14	**-**	**JPNDF_Q23_EarlyLate**	**1975-1976 and 1994-2020**
F15	-	JPN_Others	1975-2020
F16	**S3**	**US_LL**	**1987-2020**
F17	-	US_Others	1987-2020
F18	**S4**	**TWN_DWLL**	**1967-2020**
F19	-	TWN_STLL	1958-2020
F20	-	TWN_Others	1958-2020
F21	-	WCPFC_Others	1975-2020
F22	S5	JPNLL_Q1A1_Early	1975-1993
F23	S6	JPNLL_Q3A1_Early	1975-1993
F24	-	JPNDF_Q14_Mid	1977-1993
F25	-	JPNDF_Q23_Mid	1977-1993

Table 7.2. Fishery-specific selectivity assumptions for the 2023 WCNPO striped marlin stock assessment and the rebuilding analyses with mirrored fleets representing the 9 fleet groups shown in bold. The selectivity curves for fisheries lacking length composition data were assumed to be the same as (i.e., mirror gear) closely related fisheries or fisheries operating in the same area.

Fleet	Selectivity Function
F1	***Double-normal – Time Varying***
F2	***Double-normal***
F3	Mirror to F2
F4	***Double-normal***
F5	***Double-normal***
F6	***Double-normal***
F7	Mirror to F2
F8	Mirror to F4
F9	Mirror to F5
F10	Mirror to F6
F11	Mirror to F6
F12	Mirror to F4
F13	***Asymptotic lognormal***
F14	***Asymptotic lognormal***
F15	Mirror to F4
F16	***Double-normal – Time Varying***
F17	Mirror to F16
F18	***Asymptotic lognormal***
F19	Mirror to F18
F20	Mirror to F14
F21	Mirror to F12
F22	Mirror to F1
F23	Mirror to F5
F24	Mirror to F1
F25	Mirror to F5
S1	Mirror to F1
S2	Mirror to F5
S3	Mirror to F16
S4	Mirror to F18
S5	Mirror to F1
S6	Mirror to F5

Table 8. Average proportions of WCNPO striped marlin fishing mortalities (top) and catch biomasses (bottom) by fishing fleet group (Table 8) for 5 periods (1977-2020, 1994-2020, 2001-2020, 2016-2020, 2018-2020) and the terminal year of the 2023 stock assessment, 2020.

		Proportion of Fishing Mortality by Fleet Group								
	Period	F1	F2	F4	F5	F6	F13	F14	F16	F18
Mean	1977-2020	0.09	0.07	0.28	0.09	0.07	0.06	0.09	0.05	0.19
Mean	1994-2020	0.04	0.06	0.27	0.03	0.07	0.10	0.13	0.06	0.23
Mean	2001-2020	0.05	0.06	0.24	0.03	0.06	0.10	0.13	0.07	0.26
Mean	2016-2020	0.09	0.04	0.30	0.02	0.05	0.05	0.07	0.09	0.30
Mean	2018-2020	0.09	0.04	0.27	0.02	0.05	0.05	0.07	0.09	0.32
Year	2020	0.15	0.04	0.24	0.02	0.06	0.05	0.06	0.07	0.32

		Proportion of Catch Biomass by Fleet Group								
	Period	F1	F2	F4	F5	F6	F13	F14	F16	F18
Mean	1977-2020	0.08	0.09	0.31	0.13	0.08	0.05	0.10	0.09	0.08
Mean	1994-2020	0.04	0.08	0.30	0.05	0.09	0.08	0.15	0.13	0.09
Mean	2001-2020	0.04	0.08	0.28	0.04	0.07	0.08	0.15	0.14	0.11
Mean	2016-2020	0.08	0.05	0.35	0.03	0.06	0.04	0.08	0.17	0.13
Mean	2018-2020	0.09	0.06	0.32	0.03	0.07	0.04	0.08	0.17	0.14
Year	2020	0.14	0.06	0.30	0.03	0.09	0.04	0.07	0.13	0.14

Table 9. Eight rebuilding scenarios for WCNPO striped marlin including the harvest control measures of fishing mortality (F), catch (C), or catch release, the harvest change from 2018-2020 average values of fishing mortality (0.68) and catch (2428 mt), the projected median catch by scenario, the harvest values in 2025-2034 and the harvest reductions by period.

Harvest Scenarios to Rebuild WCNPO Striped Marlin

Rebuilding Scenario	Harvest Control	Description of Harvest Change from Recent Average Value in 2018-2020	Projected Median Total Catch (mt) in 2025-2034	Change in Total from Expected catch 2025-2034	Harvest in 2025-2027	Harvest in 2028-2031	Harvest in 2032-2034	Harvest Reduction in 2025	Harvest Reduction in 2028	Harvest Reduction in 2032	Total Reduction
Scenario 1	F = 0.373 in 2025-2034	Reduce F by 45% in 2025	22048	-9.2%	0.373	0.373	0.373	-45.1%			-45.1%
Scenario 2	Catch = 2175 mt in 2025-2034	Reduce C by 10% in 2025	21750	-10.4%	2175	2175	2175	-10.4%			-10.4%
Scenario 3	F = 0.55 in 2025-2027 and then F = 0.37 in 2028-2034	Reduce F by 19% in 2025 Reduce F by 46% in 2028	22872	-5.8%	0.55	0.37	0.37	-19.1%	-26.5%		-45.6%
Scenario 4	Catch=2400 mt in 2025-2027 & Catch=2150 mt in 2028-2034	Reduce C by 1% in 2025 Reduce C by 11% in 2028	22250	-8.4%	2400	2150	2150	-1.2%	-10.3%		-11.4%
Scenario 5	Catch=2250 mt in 2025-2027 & Catch=2175 mt in 2028-2034	Reduce C by 7% in 2025 Reduce C by 10% in 2028	21975	-9.5%	2250	2175	2175	-7.3%	-3.1%		-10.4%
Scenario 6	Catch=2400 mt in 2025-2027 & Catch=2200 mt in 2028-2031 & Catch=2100 mt in 2032-2034	Reduce C by 1% in 2025 Reduce C by 8% in 2028 Reduce C by 5% in 2031	22300	-8.2%	2400	2200	2100	-1.2%	-8.2%	-5.3%	-14.7%
Scenario 7	Catch = 2180 mt in 2025-2034	Reduce C by 10% in 2025 Catch release of age-1 fish	21800	-10.2%	2180	2180	2180	-10.2%			-10.2%
Scenario 8	Catch = 2185 mt in 2025-2034	Reduce C by 10% in 2025 Catch release of age-1 fish	21850	-10.0%	2185	2185	2185	-10.0%			-10.0%
	Recent average fishing mortality is F =	0.68									
	Recent average catch is C =	2428									
	Expected catch in 2025-2034 is E[C] =	24280									

Table 10.1. Median catch biomasses (mt) for rebuilding scenario 1 (constant F = 0.373) along with 5th, 10th, 25th, 75th, 90th, and 95th percentiles (P05, P10, P25, P75, P90, P95) of the annual catch biomass distributions under the 3-model recruitment ensemble.

Scenario 1. Constant F =0.373							
Catch Biomass (mt)							
Year	P05	P10	P25	Median	P75	P90	P95
2021	2353	2454	2664	2912	3235	3547	3792
2022	2581	2723	3000	3382	3748	4208	4483
2023	2389	2558	2891	3318	3793	4239	4521
2024	2062	2237	2586	3030	3507	3963	4244
2025	1156	1266	1479	1750	2042	2321	2499
2026	1323	1448	1692	2003	2339	2659	2866
2027	1437	1575	1834	2162	2518	2858	3072
2028	1509	1650	1915	2249	2609	2950	3170
2029	1547	1690	1956	2291	2654	3000	3220
2030	1563	1708	1974	2310	2675	3023	3247
2031	1573	1714	1981	2318	2682	3033	3258
2032	1575	1717	1987	2321	2686	3037	3267
2033	1575	1717	1986	2323	2688	3038	3269
2034	1576	1719	1988	2322	2689	3041	3269

Table 10.2. Median catch biomasses (mt) for rebuilding scenario 2 (constant catch = 2175 mt) along with 5th, 10th, 25th, 75th, 90th, and 95th percentiles (P05, P10, P25, P75, P90, P95) of the annual catch biomass distributions under the 3-model recruitment ensemble.

Scenario 2. Constant Catch =2175 mt							
Catch Biomass (mt)							
Year	P05	P10	P25	Median	P75	P90	P95
2021	2355	2456	2664	2911	3235	3548	3792
2022	2579	2724	2998	3383	3748	4211	4491
2023	2390	2560	2894	3319	3796	4246	4527
2024	2061	2235	2583	3033	3507	3962	4253
2025	2175	2175	2175	2175	2175	2175	2175
2026	2175	2175	2175	2175	2175	2175	2175
2027	2175	2175	2175	2175	2175	2175	2175
2028	2175	2175	2175	2175	2175	2175	2175
2029	2175	2175	2175	2175	2175	2175	2175
2030	2175	2175	2175	2175	2175	2175	2175
2031	2175	2175	2175	2175	2175	2175	2175
2032	2175	2175	2175	2175	2175	2175	2175
2033	2175	2175	2175	2175	2175	2175	2175
2034	2175	2175	2175	2175	2175	2175	2175

Table 10.3. Median catch biomasses (mt) for rebuilding scenario 3 (phased F = (0.55, 0.37)) along with 5th, 10th, 25th, 75th, 90th, and 95th percentiles (P05, P10, P25, P75, P90, P95) of the annual catch biomass distributions under the 3-model recruitment ensemble.

Scenario 3. Phased F = (0.55, 0.37) in (2025, 2028)							
Catch Biomass (mt)							
Year	P05	P10	P25	Median	P75	P90	P95
2021	2355	2456	2664	2911	3235	3548	3792
2022	2579	2724	2998	3383	3748	4211	4491
2023	2390	2560	2894	3319	3796	4246	4527
2024	2061	2235	2583	3033	3507	3962	4253
2025	1601	1750	2046	2425	2830	3215	3462
2026	1656	1819	2127	2526	2954	3367	3624
2027	1699	1862	2181	2589	3022	3435	3703
2028	1236	1357	1588	1880	2192	2492	2680
2029	1383	1512	1765	2081	2422	2752	2958
2030	1473	1611	1874	2200	2552	2897	3112
2031	1524	1663	1932	2261	2619	2968	3187
2032	1551	1692	1959	2291	2655	3001	3229
2033	1564	1704	1972	2305	2673	3023	3249
2034	1570	1711	1976	2314	2678	3028	3259

Table 10.4. Median catch biomasses (mt) for rebuilding scenario 4 (phased catch = (2400, 2150) mt) along with 5th, 10th, 25th, 75th, 90th, and 95th percentiles (P05, P10, P25, P75, P90, P95) of the annual catch biomass distributions under the 3-model recruitment ensemble.

Scenario 4. Phased Catch = (2400, 2150) mt in (2025, 2028)							
Catch Biomass (mt)							
Year	P05	P10	P25	Median	P75	P90	P95
2021	2352	2454	2663	2913	3234	3549	3795
2022	2574	2722	2999	3382	3749	4212	4494
2023	2390	2558	2890	3318	3795	4243	4533
2024	2057	2239	2582	3028	3511	3966	4251
2025	2400	2400	2400	2400	2400	2400	2400
2026	2400	2400	2400	2400	2400	2400	2400
2027	2400	2400	2400	2400	2400	2400	2400
2028	2150	2150	2150	2150	2150	2150	2150
2029	2150	2150	2150	2150	2150	2150	2150
2030	2150	2150	2150	2150	2150	2150	2150
2031	2150	2150	2150	2150	2150	2150	2150
2032	2150	2150	2150	2150	2150	2150	2150
2033	2150	2150	2150	2150	2150	2150	2150
2034	2150	2150	2150	2150	2150	2150	2150

Table 10.5. Median catch biomasses (mt) for rebuilding scenario 5 (phased catch = (2250, 2175) mt) along with 5th, 10th, 25th, 75th, 90th, and 95th percentiles (P05, P10, P25, P75, P90, P95) of the annual catch biomass distributions under the 3-model recruitment ensemble.

Scenario 5. Phased Catch = (2250, 2175) mt in (2025, 2028)							
Catch Biomass (mt)							
Year	P05	P10	P25	Median	P75	P90	P95
2021	2354	2454	2665	2914	3232	3546	3790
2022	2577	2723	2998	3383	3747	4206	4485
2023	2391	2560	2894	3322	3796	4248	4527
2024	2059	2238	2585	3036	3512	3967	4248
2025	2250	2250	2250	2250	2250	2250	2250
2026	2250	2250	2250	2250	2250	2250	2250
2027	2250	2250	2250	2250	2250	2250	2250
2028	2175	2175	2175	2175	2175	2175	2175
2029	2175	2175	2175	2175	2175	2175	2175
2030	2175	2175	2175	2175	2175	2175	2175
2031	2175	2175	2175	2175	2175	2175	2175
2032	2175	2175	2175	2175	2175	2175	2175
2033	2175	2175	2175	2175	2175	2175	2175
2034	2175	2175	2175	2175	2175	2175	2175

Table 10.6. Median catch biomasses (mt) for rebuilding scenario 6 (3-phased catch = (2400, 2225 2100) mt) along with 5th, 10th, 25th, 75th, 90th, and 95th percentiles (P05, P10, P25, P75, P90, P95) of the annual catch biomass distributions under the 3-model recruitment ensemble.

Scenario 6. Phased Catch = (2400, 2200, 2100) mt in (2025, 2028, 2032)							
Catch Biomass (mt)							
Year	P05	P10	P25	Median	P75	P90	P95
2021	2353	2454	2664	2913	3234	3545	3793
2022	2579	2725	3000	3384	3747	4213	4489
2023	2394	2560	2892	3324	3797	4242	4534
2024	2065	2242	2590	3033	3513	3965	4254
2025	2400	2400	2400	2400	2400	2400	2400
2026	2400	2400	2400	2400	2400	2400	2400
2027	2400	2400	2400	2400	2400	2400	2400
2028	2200	2200	2200	2200	2200	2200	2200
2029	2200	2200	2200	2200	2200	2200	2200
2030	2200	2200	2200	2200	2200	2200	2200
2031	2200	2200	2200	2200	2200	2200	2200
2032	2100	2100	2100	2100	2100	2100	2100
2033	2100	2100	2100	2100	2100	2100	2100
2034	2100	2100	2100	2100	2100	2100	2100

Table 10.7. Median catch biomasses (mt) for <u>rebuilding scenario 7</u> (catch-release with low survival and catch = 2180 mt) along with 5th, 10th, 25th, 75th, 90th, and 95th percentiles (P05, P10, P25, P75, P90, P95) of the annual catch biomass distributions under the 3-model recruitment ensemble.

Scenario 7. Catch-Release Age-1 Low Survival Catch = 2180 mt							
Catch Biomass (mt)							
Year	P05	P10	P25	Median	P75	P90	P95
2021	2291	2390	2582	2830	3149	3444	3686
2022	2550	2697	2965	3358	3718	4188	4467
2023	2367	2538	2878	3306	3787	4233	4516
2024	2040	2218	2571	3024	3499	3964	4247
2025	2180	2180	2180	2180	2180	2180	2180
2026	2180	2180	2180	2180	2180	2180	2180
2027	2180	2180	2180	2180	2180	2180	2180
2028	2180	2180	2180	2180	2180	2180	2180
2029	2180	2180	2180	2180	2180	2180	2180
2030	2180	2180	2180	2180	2180	2180	2180
2031	2180	2180	2180	2180	2180	2180	2180
2032	2180	2180	2180	2180	2180	2180	2180
2033	2180	2180	2180	2180	2180	2180	2180
2034	2180	2180	2180	2180	2180	2180	2180

Table 10.8. Median catch biomasses (mt) for rebuilding scenario 8 (catch-release with high survival and catch = 2185 mt) along with 5th, 10th, 25th, 75th, 90th, and 95th percentiles (P05, P10, P25, P75, P90, P95) of the annual catch biomass distributions under the 3-model recruitment ensemble.

Scenario 8. Catch-Release Age-1 High Survival Catch = 2185 mt							
Catch Biomass (mt)							
Year	P05	P10	P25	Median	P75	P90	P95
2021	2221	2317	2485	2733	3052	3332	3572
2022	2519	2667	2928	3329	3688	4167	4452
2023	2348	2515	2856	3292	3778	4237	4519
2024	2021	2194	2548	3012	3497	3961	4261
2025	2185	2185	2185	2185	2185	2185	2185
2026	2185	2185	2185	2185	2185	2185	2185
2027	2185	2185	2185	2185	2185	2185	2185
2028	2185	2185	2185	2185	2185	2185	2185
2029	2185	2185	2185	2185	2185	2185	2185
2030	2185	2185	2185	2185	2185	2185	2185
2031	2185	2185	2185	2185	2185	2185	2185
2032	2185	2185	2185	2185	2185	2185	2185
2033	2185	2185	2185	2185	2185	2185	2185
2034	2185	2185	2185	2185	2185	2185	2185

Table 10.9. Comparison of median catch biomasses (mt) under alternative WCNPO striped marlin rebuilding strategies along with the projected average catch, total catch, and percent of the maximum total catch during 2021–2034.

Catch Biomass (mt)										
Year	Scenario 1. Constant F Rebuild	Scenario 2. Contant Catch Rebuild	Scenario 3. Phased F Rebuild	Scenario 4. Phased Catch Rebuild with Minimal Initial Reduction	Scenario 5. Phased Catch Rebuild with Moderate Initial Reduction	Scenario 6. 3-Phase Catch Rebuild with Minimal Initial Reduction	Scenario 7. Catch-Release with Low Survival Rebuild	Scenario 8. Catch-Release with High Survival Rebuild	F Status Quo Scenario	Fmsy Scenario
2021	2912	2911	2911	2913	2914	2913	2830	2733	2912	2227
2022	3382	3383	3383	3382	3383	3384	3358	3329	3382	2575
2023	3318	3319	3319	3318	3322	3324	3306	3292	3320	2866
2024	3030	3033	3033	3028	3036	3033	3024	3012	3032	2519
2025	1750	2175	2425	2400	2250	2400	2180	2185	2864	2391
2026	2003	2175	2526	2400	2250	2400	2180	2185	2805	2396
2027	2162	2175	2589	2400	2250	2400	2180	2185	2782	2410
2028	2249	2175	1880	2150	2175	2200	2180	2185	2772	2417
2029	2291	2175	2081	2150	2175	2200	2180	2185	2771	2418
2030	2310	2175	2200	2150	2175	2200	2180	2185	2769	2419
2031	2318	2175	2261	2150	2175	2200	2180	2185	2765	2415
2032	2321	2175	2291	2150	2175	2100	2180	2185	2766	2415
2033	2323	2175	2305	2150	2175	2100	2180	2185	2767	2416
2034	2322	2175	2314	2150	2175	2100	2180	2185	2772	2416
Average 2025-2034	2205	2175	2287	2225	2198	2230	2180	2185	2783	2411
Total 2025-2034	22048	21750	22872	22250	21975	22300	21800	21850	27831	24112
Percent of Maximum Rebuilding Total	96%	95%	100%	97%	96%	98%	95%	96%	122%	105%

Table 11.1. Median spawning biomasses (mt) for rebuilding scenario 1 (constant F = 0.373) along with 5th, 10th, 25th, 40th, 75th, 90th, and 95th percentiles (P05, P10, P25, P40, P75, P90, P95) of the annual spawning biomass distributions under the 3-model recruitment ensemble.

Scenario 1. Constant F = 0.373								
Spawning Stock Biomass (mt)								
Year	P05	P10	P25	P40	Median	P75	P90	P95
2021	1727	1831	1998	2136	2229	2511	2809	3029
2022	1960	2086	2311	2481	2576	2853	3195	3403
2023	2072	2215	2494	2719	2869	3302	3755	4050
2024	1684	1827	2123	2359	2520	2979	3402	3663
2025	1740	1910	2253	2525	2712	3244	3741	4054
2026	2052	2258	2673	3013	3228	3862	4460	4836
2027	2279	2509	2961	3340	3564	4251	4895	5305
2028	2421	2659	3128	3519	3748	4438	5094	5516
2029	2499	2740	3219	3612	3845	4537	5189	5615
2030	2536	2784	3260	3637	3884	4586	5252	5676
2031	2557	2800	3274	3674	3903	4603	5273	5709
2032	2568	2811	3287	3668	3913	4610	5286	5715
2033	2569	2815	3288	3657	3919	4614	5287	5716
2034	2571	2815	3290	3660	3920	4620	5287	5727

Table 11.2. Median spawning biomasses (mt) for rebuilding scenario 2 (constant catch = 2175 mt) along with 5th, 10th, 25th, 40th, 75th, 90th, and 95th percentiles (P05, P10, P25, P40, P75, P90, P95) of the annual spawning biomass distributions under the 3-model recruitment ensemble.

Scenario 2. Constant Catch = 2175 mt								
Spawning Stock Biomass (mt)								
Year	P05	P10	P25	P40	Median	P75	P90	P95
2021	1727	1831	2000	2135	2227	2509	2809	3029
2022	1965	2086	2310	2479	2577	2855	3193	3397
2023	2073	2211	2492	2721	2868	3302	3764	4063
2024	1680	1828	2123	2361	2521	2981	3407	3665
2025	1401	1613	2020	2351	2565	3184	3769	4128
2026	1197	1496	2094	2577	2893	3812	4683	5229
2027	1127	1493	2230	2828	3216	4328	5413	6110
2028	1129	1542	2385	3058	3481	4712	5917	6723
2029	1171	1624	2530	3239	3694	5001	6303	7147
2030	1218	1700	2641	3389	3856	5207	6566	7445
2031	1276	1768	2730	3489	3976	5364	6770	7663
2032	1311	1818	2808	3579	4072	5496	6898	7834
2033	1333	1866	2863	3653	4158	5588	7030	7977
2034	1361	1896	2907	3704	4215	5670	7115	8058

Table 11.3. Median spawning biomasses (mt) for rebuilding scenario 3 (phased F = (0.55, 0.37)) along with 5th, 10th, 25th, 40th, 75th, 90th, and 95th percentiles (P05, P10, P25, P40, P75, P90, P95) of the annual spawning biomass distributions under the 3-model recruitment ensemble.

Scenario 3. Phased F = (0.55, 0.37) in (2025, 2028)								
Spawning Stock Biomass (mt)								
Year	P05	P10	P25	P40	Median	P75	P90	P95
2021	1727	1831	2000	2135	2227	2509	2809	3029
2022	1965	2086	2310	2479	2577	2855	3193	3397
2023	2073	2211	2492	2721	2868	3302	3764	4063
2024	1680	1828	2123	2361	2521	2981	3407	3665
2025	1590	1748	2060	2318	2487	2975	3434	3714
2026	1656	1827	2166	2441	2624	3156	3648	3953
2027	1709	1886	2236	2521	2712	3252	3759	4070
2028	1900	2097	2493	2803	3009	3602	4156	4503
2029	2183	2408	2848	3198	3426	4088	4711	5100
2030	2373	2606	3074	3448	3686	4372	5022	5440
2031	2481	2726	3195	3571	3819	4516	5181	5594
2032	2540	2784	3260	3635	3884	4585	5253	5681
2033	2562	2811	3291	3675	3918	4619	5301	5727
2034	2580	2827	3303	3686	3928	4645	5324	5755

Table 11.4. Median spawning biomasses (mt) for rebuilding scenario 4 (phased catch = (2400, 2150) mt) along with 5th, 10th, 25th, 40th, 75th, 90th, and 95th percentiles (P05, P10, P25, P40, P75, P90, P95) of the annual spawning biomass distributions under the 3-model recruitment ensemble.

Scenario 4. Phased Catch = (2400, 2150) mt in (2025, 2028)								
Spawning Stock Biomass (mt)								
Year	P05	P10	P25	P40	Median	P75	P90	P95
2021	1725	1830	1998	2135	2228	2511	2809	3029
2022	1959	2084	2311	2478	2577	2853	3194	3400
2023	2072	2213	2492	2720	2868	3299	3768	4070
2024	1679	1826	2122	2360	2519	2982	3406	3666
2025	1326	1538	1947	2269	2483	3109	3688	4051
2026	994	1299	1883	2362	2672	3579	4446	4996
2027	847	1191	1902	2480	2859	3947	5021	5712
2028	853	1241	2038	2678	3101	4319	5503	6293
2029	942	1373	2241	2939	3379	4684	5966	6804
2030	1038	1506	2419	3152	3622	4980	6336	7203
2031	1121	1615	2575	3336	3815	5211	6596	7512
2032	1204	1717	2688	3474	3966	5390	6809	7752
2033	1274	1795	2799	3588	4084	5532	6966	7917
2034	1329	1862	2879	3670	4181	5634	7078	8017

Table 11.5. Median spawning biomasses (mt) for rebuilding scenario 5 (phased catch = (2250, 2175) mt) along with 5th, 10th, 25th, 40th, 75th, 90th, and 95th percentiles (P05, P10, P25, P40, P75, P90, P95) of the annual spawning biomass distributions under the 3-model recruitment ensemble.

Scenario 5. Phased Catch = (2250, 2175) mt in (2025, 2028)								
Spawning Stock Biomass (mt)								
Year	P05	P10	P25	P40	Median	P75	P90	P95
2021	1729	1832	1999	2135	2228	2511	2807	3025
2022	1959	2087	2310	2477	2576	2855	3194	3402
2023	2065	2209	2494	2724	2871	3302	3764	4063
2024	1681	1828	2123	2364	2523	2981	3410	3673
2025	1375	1588	1998	2327	2544	3159	3741	4101
2026	1123	1423	2021	2507	2820	3735	4600	5146
2027	1024	1380	2114	2709	3099	4206	5266	5957
2028	1029	1435	2259	2925	3354	4570	5786	6575
2029	1084	1526	2408	3120	3574	4886	6183	7025
2030	1139	1614	2553	3282	3754	5113	6490	7373
2031	1200	1693	2671	3429	3904	5293	6687	7616
2032	1247	1760	2754	3529	4018	5435	6840	7775
2033	1293	1812	2829	3606	4106	5549	6982	7927
2034	1334	1864	2875	3671	4180	5630	7077	8035

Table 11.6. Median spawning biomasses (mt) for <u>rebuilding scenario 6</u> (3-phase catch = (2400, 2225, 2100) mt) along with 5th, 10th, 25th, 40th, 75th, 90th, and 95th percentiles (P05, P10, P25, P40, P75, P90, P95) of the annual spawning biomass distributions under the 3-model recruitment ensemble.

Scenario 6. Phased Catch = (2400, 2200, 2100) mt in (2025, 2028, 2032)								
Spawning Stock Biomass (mt)								
Year	P05	P10	P25	P40	Median	P75	P90	P95
2021	1725	1830	2000	2136	2229	2510	2811	3033
2022	1960	2085	2311	2478	2577	2854	3194	3405
2023	2073	2214	2495	2722	2868	3304	3768	4071
2024	1684	1832	2123	2363	2522	2985	3412	3673
2025	1327	1537	1948	2277	2492	3108	3698	4060
2026	1000	1294	1886	2368	2681	3588	4460	5006
2027	839	1189	1905	2493	2873	3962	5031	5716
2028	836	1224	2025	2674	3097	4314	5506	6286
2029	910	1339	2194	2889	3343	4641	5921	6759
2030	995	1439	2356	3078	3548	4896	6235	7092
2031	1054	1531	2477	3233	3717	5097	6464	7367
2032	1146	1643	2620	3388	3889	5288	6678	7601
2033	1251	1766	2767	3541	4036	5480	6891	7838
2034	1334	1870	2891	3676	4176	5614	7066	8015

Table 11.7. Median spawning biomasses (mt) for rebuilding scenario 7 (catch-release with low survival and catch = 2180 mt) along with 5th, 10th, 25th, 40th, 75th, 90th, and 95th percentiles (P05, P10, P25, P40, P75, P90, P95) of the annual spawning biomass distributions under the 3-model recruitment ensemble.

Scenario 7. Catch-Release Age-1 Low Survival Catch = 2180 mt								
Spawning Stock Biomass (mt)								
Year	P05	P10	P25	P40	Median	P75	P90	P95
2021	1723	1830	1999	2136	2227	2512	2811	3033
2022	1970	2093	2320	2489	2588	2869	3211	3418
2023	2093	2236	2522	2753	2903	3344	3806	4116
2024	1702	1852	2154	2399	2561	3023	3457	3724
2025	1418	1633	2049	2386	2604	3236	3827	4190
2026	1195	1499	2110	2604	2929	3864	4752	5297
2027	1120	1486	2239	2846	3237	4352	5452	6146
2028	1118	1538	2385	3052	3486	4732	5950	6736
2029	1151	1599	2508	3221	3685	5012	6324	7173
2030	1182	1669	2612	3358	3830	5222	6585	7488
2031	1232	1731	2695	3468	3953	5371	6779	7704
2032	1264	1774	2768	3547	4041	5479	6905	7852
2033	1289	1815	2825	3613	4118	5573	7011	7972
2034	1313	1853	2863	3676	4186	5641	7096	8082

Table 11.8. Median spawning biomasses (mt) for rebuilding scenario 8 (catch-release with high survival and catch = 2185 mt) along with 5th, 10th, 25th, 40th, 75th, 90th, and 95th percentiles (P05, P10, P25, P40, P75, P90, P95) of the annual spawning biomass distributions under the 3-model recruitment ensemble.

Scenario 8. Catch-Release Age-1 High Survival Catch = 2185 mt								
Spawning Stock Biomass (mt)								
Year	P05	P10	P25	P40	Median	P75	P90	P95
2021	1727	1832	2000	2135	2228	2510	2810	3029
2022	1984	2105	2333	2504	2603	2885	3227	3433
2023	2123	2266	2556	2791	2943	3391	3868	4178
2024	1731	1885	2189	2437	2602	3078	3519	3787
2025	1425	1648	2077	2423	2644	3290	3900	4271
2026	1197	1506	2130	2633	2964	3924	4828	5394
2027	1119	1496	2256	2872	3273	4410	5521	6238
2028	1115	1534	2401	3087	3517	4770	5996	6815
2029	1148	1611	2534	3253	3715	5037	6356	7212
2030	1190	1677	2636	3390	3864	5230	6600	7489
2031	1238	1739	2713	3482	3972	5374	6791	7690
2032	1269	1783	2784	3564	4059	5496	6905	7844
2033	1286	1826	2833	3629	4139	5578	7029	7980
2034	1309	1850	2871	3675	4190	5652	7108	8053

Table 11.9. Comparison of median spawning biomasses (mt) under alternative WCNPO striped marlin rebuilding strategies along with the projected average spawning biomass, total spawning biomass, and percent of the maximum total spawning biomass during 2021–2034.

Spawning Stock Biomass (mt)										
Year	Scenario 1. Constant F Rebuild	Scenario 2. Contant Catch Rebuild	Scenario 3. Phased F Rebuild	Scenario 4. Phased Catch Rebuild with Minimal Initial Reduction	Scenario 5. Phased Catch Rebuild with Moderate Initial Reduction	Scenario 6. 3-Phase Catch Rebuild with Minimal Initial Reduction	Scenario 7. Catch-Release with Low Survival Rebuild	Scenario 8. Catch-Release with High Survival Rebuild	F Status Quo Scenario	Fmsy Scenario
2021	2229	2227	2227	2228	2228	2229	2227	2228	2228	2913
2022	2576	2577	2577	2577	2576	2577	2588	2603	2576	3382
2023	2869	2868	2868	2868	2871	2868	2903	2943	2867	3319
2024	2520	2521	2521	2519	2523	2522	2561	2602	2518	3033
2025	2712	2565	2487	2483	2544	2492	2604	2644	2331	2700
2026	3228	2893	2624	2672	2820	2681	2929	2964	2266	2704
2027	3564	3216	2712	2859	3099	2873	3237	3273	2239	2716
2028	3748	3481	3009	3101	3354	3097	3486	3517	2232	2725
2029	3845	3694	3426	3379	3574	3343	3685	3715	2230	2724
2030	3884	3856	3686	3622	3754	3548	3830	3864	2228	2720
2031	3903	3976	3819	3815	3904	3717	3953	3972	2231	2719
2032	3913	4072	3884	3966	4018	3889	4041	4059	2225	2721
2033	3919	4158	3918	4084	4106	4036	4118	4139	2225	2720
2034	3920	4215	3928	4181	4180	4176	4186	4190	2229	2722
Average 2025-2034	3663	3612	3349	3416	3535	3385	3607	3633	2244	2717
Total 2025-2034	36635	36123	33492	34162	35352	33853	36069	36335	22436	27171
Percent of Maximum Rebuilding Total	100%	99%	91%	93%	96%	92%	98%	99%	61%	74%

Table 12. Comparison of fishing mortalities under alternative WCNPO striped marlin rebuilding strategies and constant status quo F and Fmsy strategies along with the projected average fishing mortality during 2025–2034.

Fishing Mortality										
Year	Scenario 1. Constant F Rebuild	Scenario 2. Contant Catch Rebuild	Scenario 3. Phased F Rebuild	Scenario 4. Phased Catch Rebuild with Minimal Initial Reduction	Scenario 5. Phased Catch Rebuild with Moderate Initial Reduction	Scenario 6. 3-Phase Catch Rebuild with Minimal Initial Reduction	Scenario 7. Catch-Release with Low Survival Rebuild	Scenario 8. Catch-Release with High Survival Rebuild	F Status Quo Scenario	Fmsy Scenario
2021	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
2022	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
2023	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
2024	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68	0.68
2025	0.37	0.48	0.55	0.55	0.50	0.50	0.48	0.49	0.68	0.63
2026	0.37	0.44	0.55	0.52	0.46	0.46	0.44	0.44	0.68	0.63
2027	0.37	0.40	0.55	0.49	0.43	0.43	0.41	0.41	0.68	0.63
2028	0.37	0.38	0.37	0.41	0.39	0.39	0.38	0.38	0.68	0.63
2029	0.37	0.36	0.37	0.38	0.37	0.37	0.36	0.37	0.68	0.63
2030	0.37	0.35	0.37	0.36	0.35	0.35	0.35	0.35	0.68	0.63
2031	0.37	0.34	0.37	0.34	0.34	0.34	0.34	0.35	0.68	0.63
2032	0.37	0.33	0.37	0.33	0.33	0.33	0.34	0.34	0.68	0.63
2033	0.37	0.32	0.37	0.32	0.33	0.33	0.33	0.33	0.68	0.63
2034	0.37	0.32	0.37	0.32	0.32	0.32	0.33	0.33	0.68	0.63
Average 2025-2034	0.37	0.37	0.42	0.40	0.38	0.38	0.38	0.38	0.68	0.63

Table 13. Comparison of the probabilities of achieving the rebuilding target under alternative WCNPO striped marlin rebuilding strategies and constant status quo F and Fmsy strategies along with the first year when the probability of rebuilding the stock was greater than or equal to 60% (green shade) during 2021-2034.

Probability of Achieving Rebuilding Target										
Year	Scenario 1. Constant F Rebuild	Scenario 2. Contant Catch Rebuild	Scenario 3. Phased F Rebuild	Scenario 4. Phased Catch Rebuild with Minimal Initial Reduction	Scenario 5. Phased Catch Rebuild with Moderate Initial Reduction	Scenario 6. 3-Phase Catch Rebuild with Minimal Initial Reduction	Scenario 7. Catch-Release with Low Survival Rebuild	Scenario 8. Catch-Release with High Survival Rebuild	F Status Quo Scenario	Fmsy Scenario
2021	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
2022	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
2023	0.12	0.12	0.12	0.12	0.13	0.13	0.14	0.15	0.12	0.12
2024	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.07	0.05	0.05
2025	0.12	0.12	0.06	0.11	0.12	0.11	0.13	0.15	0.03	0.04
2026	0.32	0.29	0.10	0.23	0.27	0.23	0.30	0.31	0.03	0.04
2027	0.46	0.39	0.12	0.31	0.36	0.31	0.40	0.41	0.02	0.05
2028	0.53	0.46	0.23	0.38	0.43	0.37	0.46	0.47	0.02	0.05
2029	0.58	0.51	0.40	0.44	0.48	0.43	0.51	0.51	0.02	0.05
2030	0.59	0.54	0.51	0.49	0.52	0.48	0.54	0.54	0.02	0.05
2031	0.599	0.57	0.56	0.53	0.55	0.51	0.56	0.56	0.02	0.05
2032	0.60	0.58	0.59	0.56	0.57	0.54	0.58	0.58	0.02	0.05
2033	0.60	0.598	0.61	0.59	0.59	0.58	0.59	0.59	0.02	0.05
2034	0.61	0.61	0.61	0.60	0.60	0.60	0.60	0.60	0.02	0.05

Green shading indicates the year when rebuilding achieved with at least 0.60 probability.

Table 14. Comparison of the probabilities of overfishing under alternative WCNPO striped marlin rebuilding strategies and constant status quo F and Fmsy strategies along with the first year when the probability of overfishing the stock was less than or equal to 50% (green shade) during 2021-2034.

Probability of Overfishing										
Year	Scenario 1. Constant F Rebuild	Scenario 2. Contant Catch Rebuild	Scenario 3. Phased F Rebuild	Scenario 4. Phased Catch Rebuild with Minimal Initial Reduction	Scenario 5. Phased Catch Rebuild with Moderate Initial Reduction	Scenario 6. 3-Phase Catch Rebuild with Minimal Initial Reduction	Scenario 7. Catch-Release with Low Survival Rebuild	Scenario 8. Catch-Release with High Survival Rebuild	F Status Quo Scenario	Fmsy Scenario
2021	1	1	1	1	1	1	1	1	1	1
2022	1	1	1	1	1	1	1	1	1	1
2023	1	1	1	1	1	1	1	1	1	1
2024	1	1	1	1	1	1	1	1	1	1
2025	0	0.38	1	0.54	0.43	0.54	0.38	0.39	1	1
2026	0	0.31	1	0.47	0.37	0.47	0.32	0.33	1	1
2027	0	0.27	1	0.43	0.32	0.43	0.28	0.28	1	1
2028	0	0.23	0	0.30	0.26	0.32	0.25	0.25	1	1
2029	0	0.21	0	0.26	0.23	0.28	0.22	0.23	1	1
2030	0	0.19	0	0.22	0.21	0.25	0.21	0.21	1	1
2031	0	0.18	0	0.20	0.19	0.23	0.19	0.20	1	1
2032	0	0.17	0	0.18	0.17	0.18	0.18	0.19	1	1
2033	0	0.16	0	0.16	0.17	0.16	0.17	0.18	1	1
2034	0	0.15	0	0.15	0.16	0.14	0.17	0.17	1	1

Green shading indicates the year when the probability of overfishing was less than 0.50.

Table 15. Medians of catch biomass, spawning biomass and fishing mortality distributions under the medium-term recruitment model for scenario 1 (constant F rebuild = 0.38), scenario 2 (constant catch rebuild = 2200 mt), and the F = Fmsy scenario along with the average catch, spawning biomass, and F, the total catch and spawning biomass, and the percent of the maximum total catch and spawning biomass during 2021–2034.

WCNPO Striped Marlin Rebuilding Scenarios Under Medium-term Recruitment

Catch Biomass (mt)				Spawning Stock Biomass (mt)				Fishing Mortality			
Year	Constant F	Constant Catch	Fmsy	Year	Constant F	Constant Catch	Fmsy	Year	Constant F	Constant Catch	Fmsy
2021	2913	2908	2908	2021	2227	2228	2228	2021	0.68	0.68	0.68
2022	3382	3383	3383	2022	2572	2576	2576	2022	0.68	0.68	0.68
2023	3333	3351	3351	2023	2873	2878	2878	2023	0.68	0.68	0.68
2024	3075	3092	3092	2024	2558	2575	2575	2024	0.68	0.68	0.68
2025	1816	2200	2763	2025	2772	2632	2450	2025	0.38	0.477	0.63
2026	2075	2200	2763	2026	3273	2989	2453	2026	0.38	0.432	0.63
2027	2231	2200	2777	2027	3618	3320	2467	2027	0.38	0.397	0.63
2028	2319	2200	2781	2028	3794	3583	2486	2028	0.38	0.371	0.63
2029	2359	2200	2783	2029	3861	3792	2474	2029	0.38	0.354	0.63
2030	2376	2200	2765	2030	3910	3969	2464	2030	0.38	0.342	0.63
2031	2386	2200	2775	2031	3929	4050	2464	2031	0.38	0.335	0.63
2032	2386	2200	2774	2032	3940	4139	2469	2032	0.38	0.327	0.63
2033	2394	2200	2774	2033	3944	4221	2470	2033	0.38	0.323	0.63
2034	2384	2200	2776	2034	3934	4275	2466	2034	0.38	0.317	0.63
Average 2025-2034	2273	2200	2773	Average 2025-2034	3697	3697	2466	Average 2025-2034	0.380	0.367	0.630
Total 2025-2034	22726	22000	27730	Total 2025-2034	36974	36970	24663				
Percent of Maximum	100%	97%	122%	Percent of Maximum	100%	100%	67%				

Table 16. Probabilities of achieving the rebuilding target and overfishing under the medium-term recruitment model for scenario 1 (constant F rebuild = 0.38), scenario 2 (constant catch rebuild = 2200 mt), and the F = Fmsy scenario during 2021–2034.

Rebuilding Scenarios Under Medium-term Recruitment								
Probability of Rebuilding					Probability of Overfishing			
Year	Constant F	Contant Catch	Fmsy		Year	Constant F	Contant Catch	Fmsy
2021	0.02	0.02	0.02		2021	1	1	1
2022	0.02	0.02	0.02		2022	1	1	1
2023	0.12	0.13	0.13		2023	1	1	1
2024	0.05	0.05	0.05		2024	1	1	1
2025	0.13	0.13	0.04		2025	0	0.36	1
2026	0.34	0.31	0.04		2026	0	0.30	1
2027	0.48	0.41	0.04		2027	0	0.26	1
2028	0.55	0.48	0.05		2028	0	0.22	1
2029	0.58	0.53	0.05		2029	0	0.20	1
2030	0.60	0.56	0.05		2030	0	0.18	1
2031	0.61	0.58	0.05		2031	0	0.17	1
2032	0.62	0.60	0.05		2032	0	0.16	1
2033	0.62	0.62	0.05		2033	0	0.15	1
2034	0.61	0.62	0.05		2034	0	0.15	1

Table 17. Medians of catch biomass, spawning biomass and fishing mortality distributions under the short-term recruitment model for scenario 1 (constant F rebuild = 0.38), scenario 2 (constant catch rebuild = 2200 mt), and the F = Fmsy scenario along with the average catch, spawning biomass, and F, the total catch and spawning biomass, and the percent of the maximum total catch and spawning biomass during 2021–2034.

WCNPO Striped Marlin Rebuilding Scenarios Under Short-term Recruitment

Catch Biomass (mt)				Spawning Stock Biomass (mt)				Fishing Mortality			
Year	Constant F	Constant Catch	Fmsy	Year	Constant F	Constant Catch	Fmsy	Year	Constant F	Constant Catch	Fmsy
2021	2913	2908	2908	2021	2227	2228	2228	2021	0.68	0.68	0.68
2022	3321	3319	3319	2022	2570	2574	2574	2022	0.68	0.68	0.68
2023	3013	3013	3013	2023	2751	2750	2750	2023	0.68	0.68	0.68
2024	2503	2514	2514	2024	2149	2161	2161	2024	0.68	0.68	0.68
2025	997	1400	2114	2025	2288	2151	1901	2025	0.26	0.377	0.63
2026	1194	1400	2063	2026	2855	2526	1845	2026	0.26	0.332	0.63
2027	1332	1400	2053	2027	3285	2892	1829	2027	0.26	0.296	0.63
2028	1414	1400	2051	2028	3543	3193	1831	2028	0.26	0.273	0.63
2029	1460	1400	2053	2029	3682	3416	1822	2029	0.26	0.256	0.63
2030	1488	1400	2045	2030	3768	3602	1818	2030	0.26	0.245	0.63
2031	1499	1400	2051	2031	3808	3737	1823	2031	0.26	0.237	0.63
2032	1501	1400	2045	2032	3834	3845	1824	2032	0.26	0.231	0.63
2033	1505	1400	2043	2033	3839	3929	1824	2033	0.26	0.228	0.63
2034	1503	1400	2046	2034	3840	3989	1823	2034	0.26	0.224	0.63
Average 2025-2034	1389	1400	2056	Average 2025-2034	3474	3328	1834	Average 2025-2034	0.260	0.270	0.630
Total 2025-2034	13892	14000	20563	Total 2025-2034	34743	33279	18339				
Percent of Maximum	99%	100%	147%	Percent of Maximum	100%	96%	53%				

Table 18. Probabilities of achieving the rebuilding target and overfishing under the short-term recruitment model for scenario 1 (constant F rebuild = 0.38), scenario 2 (constant catch rebuild = 2200 mt), and the F = Fmsy scenario during 2021–2034.

Probability of Rebuilding					Probability of Overfishing			
Year	Constant F	Contant Catch	Fmsy		Year	Constant F	Contant Catch	Fmsy
2021	0.02	0.02	0.02		2021	1	1	1
2022	0.02	0.02	0.02		2022	1	1	1
2023	0.09	0.09	0.09		2023	1	1	1
2024	0.00	0.00	0.00		2024	1	1	1
2025	0.00	0.01	0.00		2025	0	0.02	1
2026	0.10	0.08	0.00		2026	0	0.02	1
2027	0.28	0.20	0.00		2027	0	0.01	1
2028	0.43	0.32	0.00		2028	0	0.01	1
2029	0.51	0.41	0.00		2029	0	0.00	1
2030	0.57	0.48	0.00		2030	0	0.00	1
2031	0.59	0.53	0.00		2031	0	0.00	1
2032	0.61	0.57	0.00		2032	0	0.00	1
2033	0.61	0.60	0.00		2033	0	0.00	1
2034	0.62	0.61	0.00		2034	0	0.00	1

Table 19. Medians of catch biomass, spawning biomass and fishing mortality distributions under the long-term recruitment model for scenario 1 (constant F rebuild = 0.38), scenario 2 (constant catch rebuild = 2200 mt), and the F = Fmsy scenario along with the average catch, spawning biomass, and F, the total catch and spawning biomass, and the percent of the maximum total catch and spawning biomass during 2021–2034

WCNPO Striped Marlin Rebuilding Scenarios Under Long-term Recruitment

Catch Biomass (mt)				Spawning Stock Biomass (mt)				Fishing Mortality			
Year	Constant F	Constant Catch	Fmsy	Year	Constant F	Constant Catch	Fmsy	Year	Constant F	Constant Catch	Fmsy
2021	2912	2914	2914	2021	2229	2223	2223	2021	0.68	0.68	0.68
2022	3479	3465	3465	2022	2583	2579	2579	2022	0.68	0.68	0.68
2023	3700	3687	3687	2023	3031	3024	3024	2023	0.68	0.68	0.68
2024	3751	3766	3766	2024	2992	2984	2984	2024	0.68	0.68	0.68
2025	3295	2500	3624	2025	3249	3472	3125	2025	0.560	0.406	0.63
2026	3551	2500	3762	2026	3571	4417	3296	2026	0.560	0.335	0.63
2027	3709	2500	3839	2027	3774	5368	3399	2027	0.560	0.282	0.63
2028	3794	2500	3901	2028	3872	6243	3433	2028	0.560	0.245	0.63
2029	3834	2500	3906	2029	3928	7045	3466	2029	0.560	0.221	0.63
2030	3873	2500	3921	2030	3958	7732	3469	2030	0.560	0.202	0.63
2031	3914	2500	3919	2031	4010	8397	3455	2031	0.560	0.190	0.63
2032	3908	2500	3931	2032	4046	8880	3473	2032	0.560	0.180	0.63
2033	3914	2500	3978	2033	4040	9373	3502	2033	0.560	0.172	0.63
2034	3930	2500	3972	2034	4051	9803	3516	2034	0.560	0.166	0.63
Average 2025-2034	3772	2500	3875	Average 2025-2034	3850	7073	3413	Average 2025-2034	0.560	0.240	0.630
Total 2025-2034	37721	25000	38754	Total 2025-2034	38499	70729	34134				
Percent of Maximum	100%	66%	103%	Percent of Maximum	54%	100%	48%				

Table 20. Probabilities of achieving the rebuilding target and overfishing under the long-term recruitment model for scenario 1 (constant F rebuild = 0.38), scenario 2 (constant catch rebuild = 2200 mt), and the F = Fmsy scenario during 2021–2034.

Rebuilding Scenarios Under Long-term Recruitment								
Probability of Rebuilding					Probability of Overfishing			
Year	Constant F	Contant Catch	Fmsy		Year	Constant F	Contant Catch	Fmsy
2021	0.02	0.02	0.02		2021	1	1	1
2022	0.02	0.02	0.02		2022	1	1	1
2023	0.21	0.20	0.20		2023	1	1	1
2024	0.27	0.27	0.27		2024	1	1	1
2025	0.37	0.45	0.32		2025	1	0.24	1
2026	0.47	0.64	0.39		2026	1	0.17	1
2027	0.53	0.73	0.42		2027	1	0.13	1
2028	0.56	0.79	0.43		2028	1	0.10	1
2029	0.58	0.83	0.44		2029	1	0.08	1
2030	0.59	0.86	0.44		2030	1	0.07	1
2031	0.60	0.88	0.44		2031	1	0.06	1
2032	0.61	0.90	0.45		2032	1	0.05	1
2033	0.61	0.91	0.45		2033	1	0.04	1
2034	0.61	0.92	0.45		2034	1	0.03	1

Figure 1. Estimates of annual population biomass (age-1 and older, solid line) and unfished population biomass (dashed line) as well as annual reported catch biomass of WCNPO striped marlin during 1977–2020 for the 2023 benchmark stock assessment.

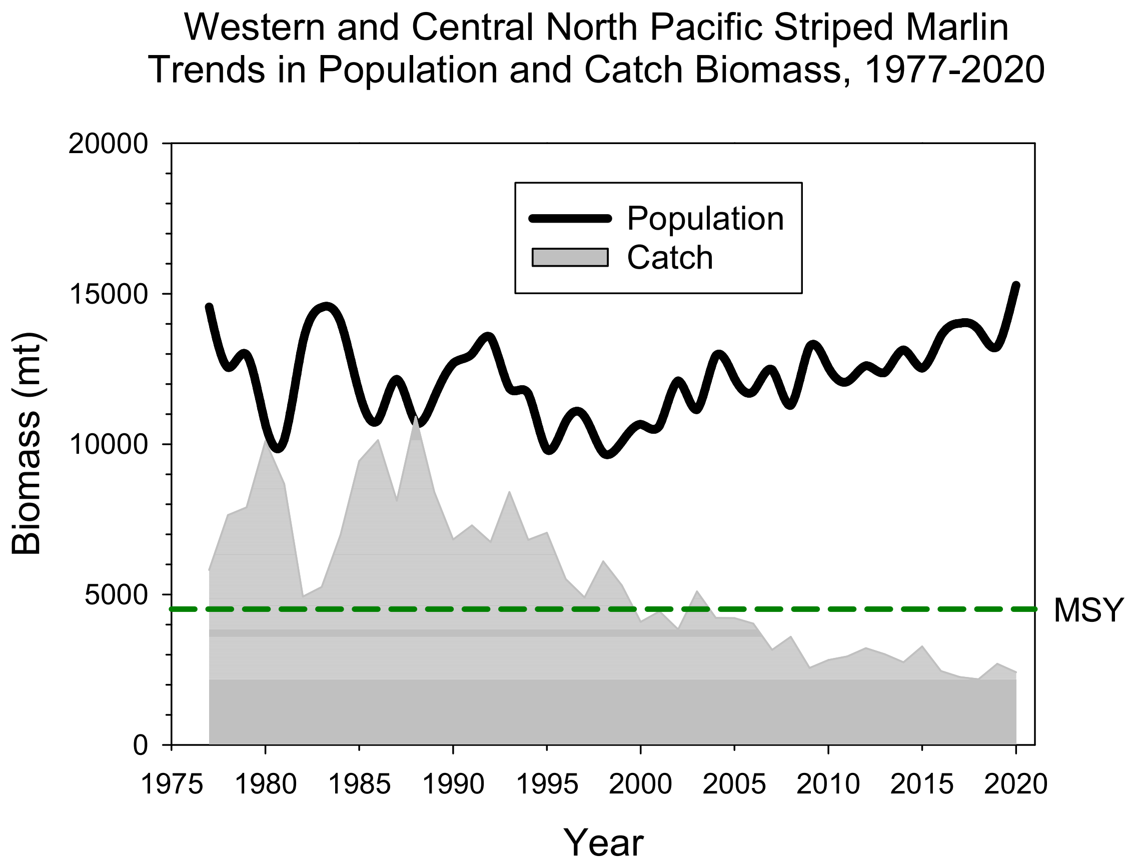


Figure 2. Time series of estimates of spawning biomass of WCNPO striped marlin (*Kajikia audax*) from the revised 2023 benchmark stock assessment (solid black circles) with 80% confidence intervals relative to B_{MSY} (dashed green line) and unfished spawning biomass (solid blue triangle with 80% confidence interval).

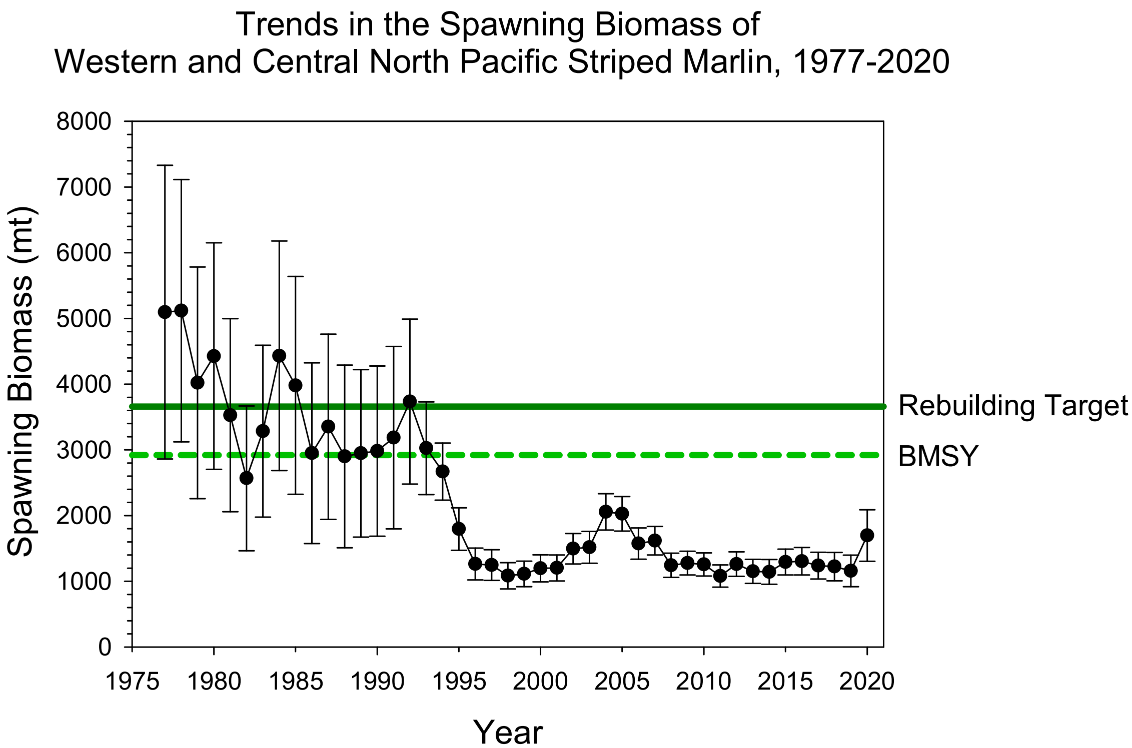


Figure 3. Time series of estimates of fishing mortality rates (average for age 3-12, yr^{-1}) for WCNPO striped marlin (*Kajikia audax*) from the 2023 benchmark stock assessment (solid black circles) with 80% confidence intervals relative to F_{MSY} (dashed red line).

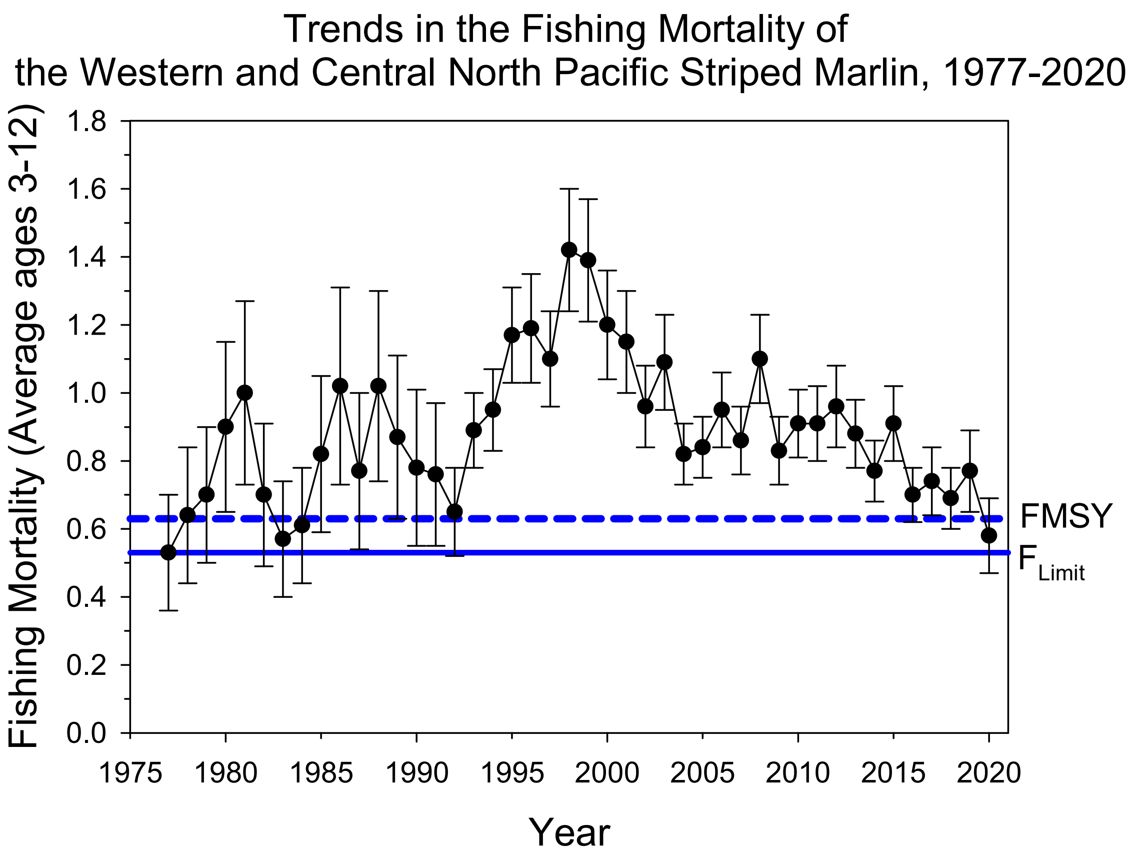
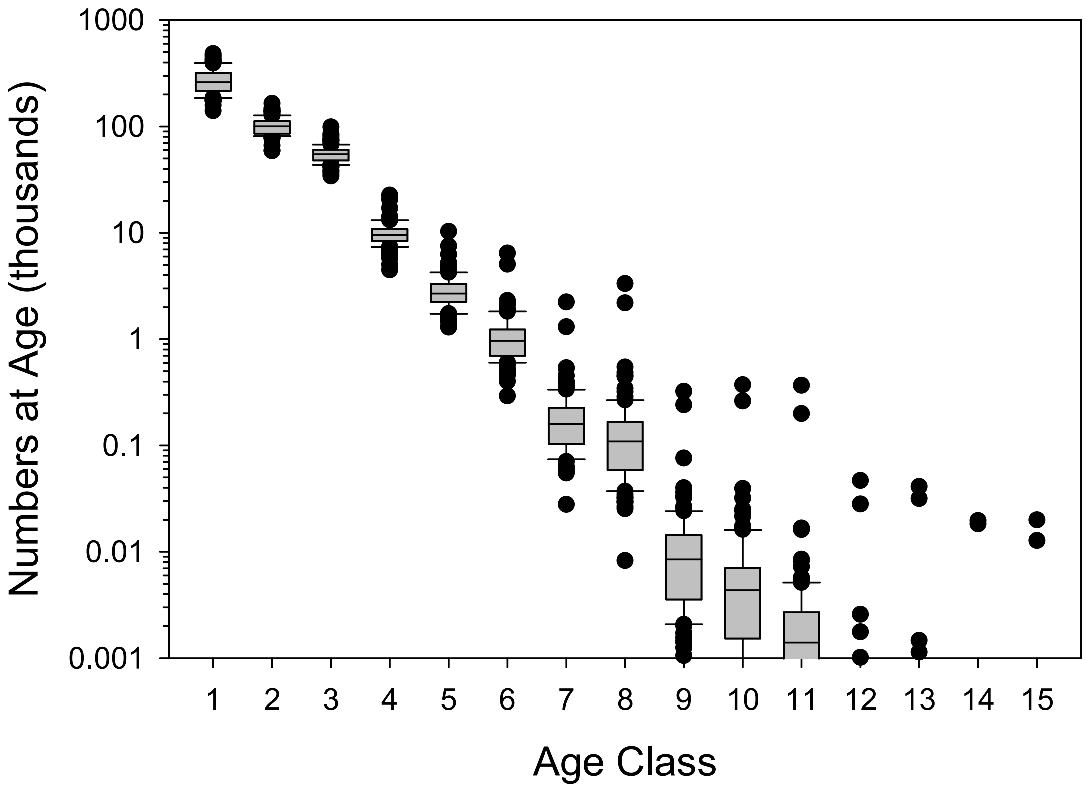


Figure 4. Boxplots of WCNPO striped marlin population numbers at age in 2021 on $\log_{10}$ scale (a) and a histogram (b) of total population sizes ($\underline{N}$) from the bootstrap resampling of the 2023 stock assessment model where age class 15 is the plus group and Med(.) denotes the median function.

(a)



(b)

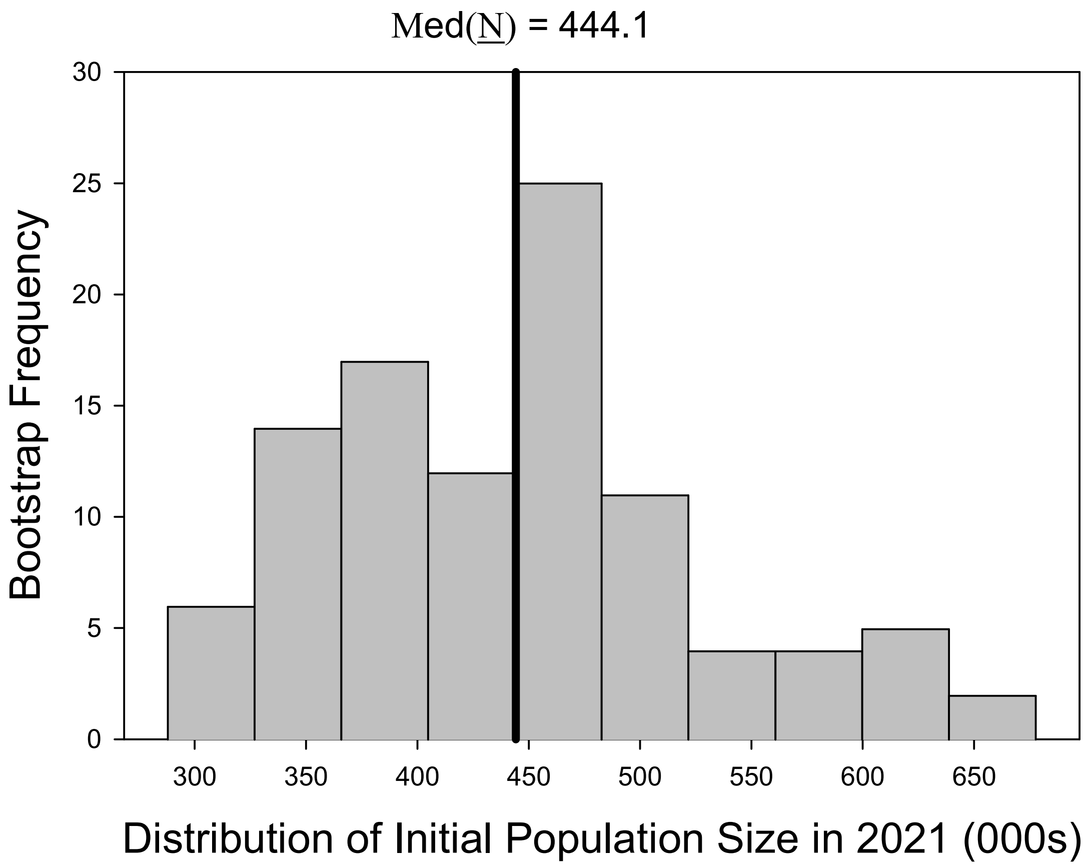

Med(N) = 444.1
Bootstrap Frequency
0
5
10
15
20
25
30
300
350
400
450
500
550
600
650
Distribution of Initial Population Size in 2021 (000s)

Figure 5. Stock-recruitment dynamics of WCNPO striped marlin as estimated in the 2023 benchmark stock assessment including the estimated stock recruitment curve (solid black line), recruitment during 1978–2014 (green triangles), recruitment during 2015–2019 (open circles), and recruitment during 2020–2021 (blue squares).

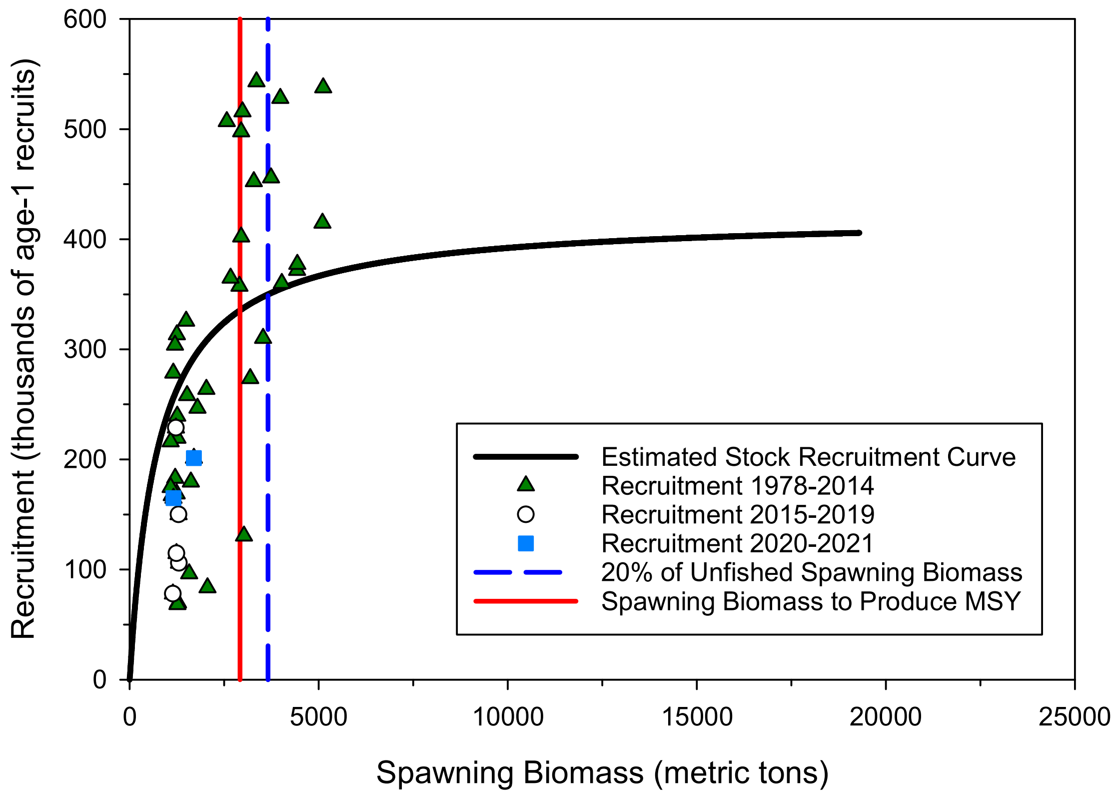


Figure 6. Time series of recruitment estimates (age-1 fish, solid black circles) for WCNPO striped marlin with 80% confidence intervals along with the expected magnitude of recruitment under the short-term (2015-2019 age-1 fish, solid blue line) and long-term (2000-2019 age-1 fish, dashed green line) scenarios from the 2023 benchmark stock assessment.

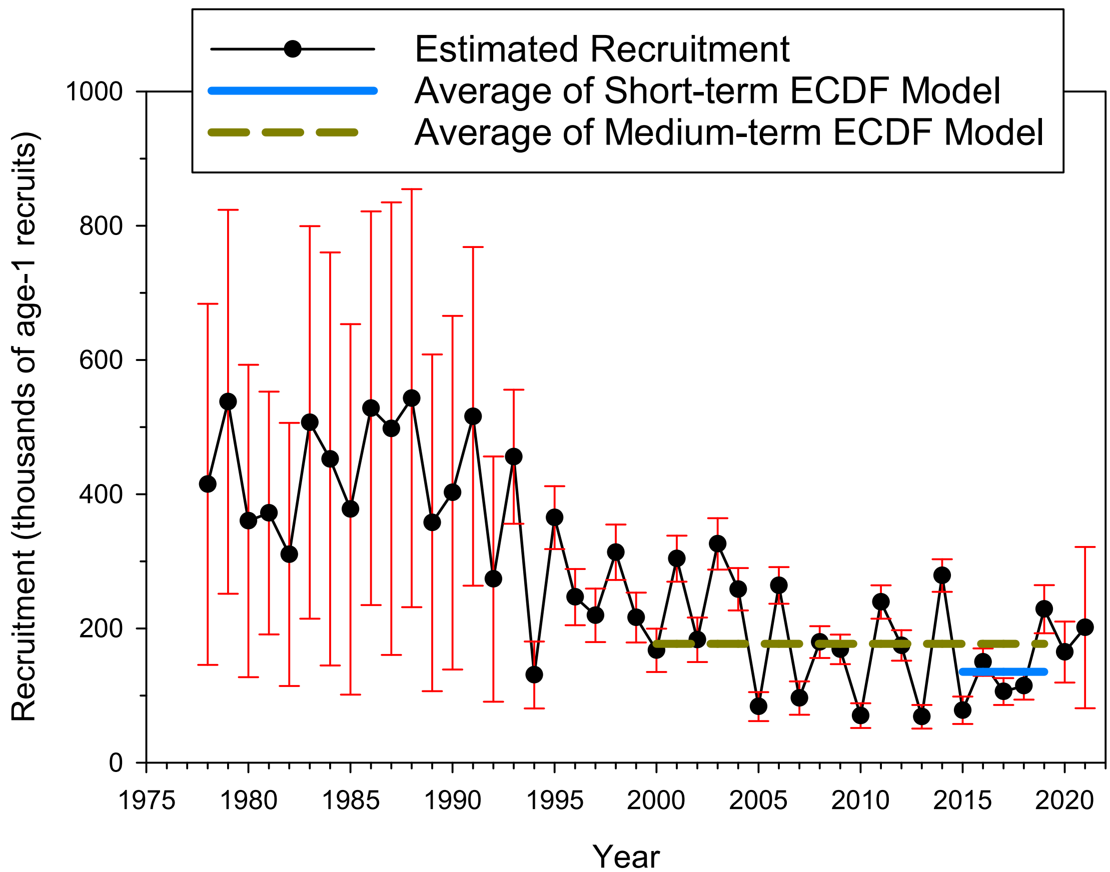


Figure 7. Empirical cumulative distribution functions of recruitment of WCNPO striped marlin under the short-term (dashed blue line) and long-term (solid green line) recruitment scenarios from the 2023 benchmark stock assessment.

Figure 8. Trends and variabilities of recruitment estimates (age-1 fish, solid black circles) for WCNPO striped marlin with 80% confidence intervals in relation to the estimated unfished recruitment from the stock-recruitment relationship estimated in the 2023 benchmark stock assessment.

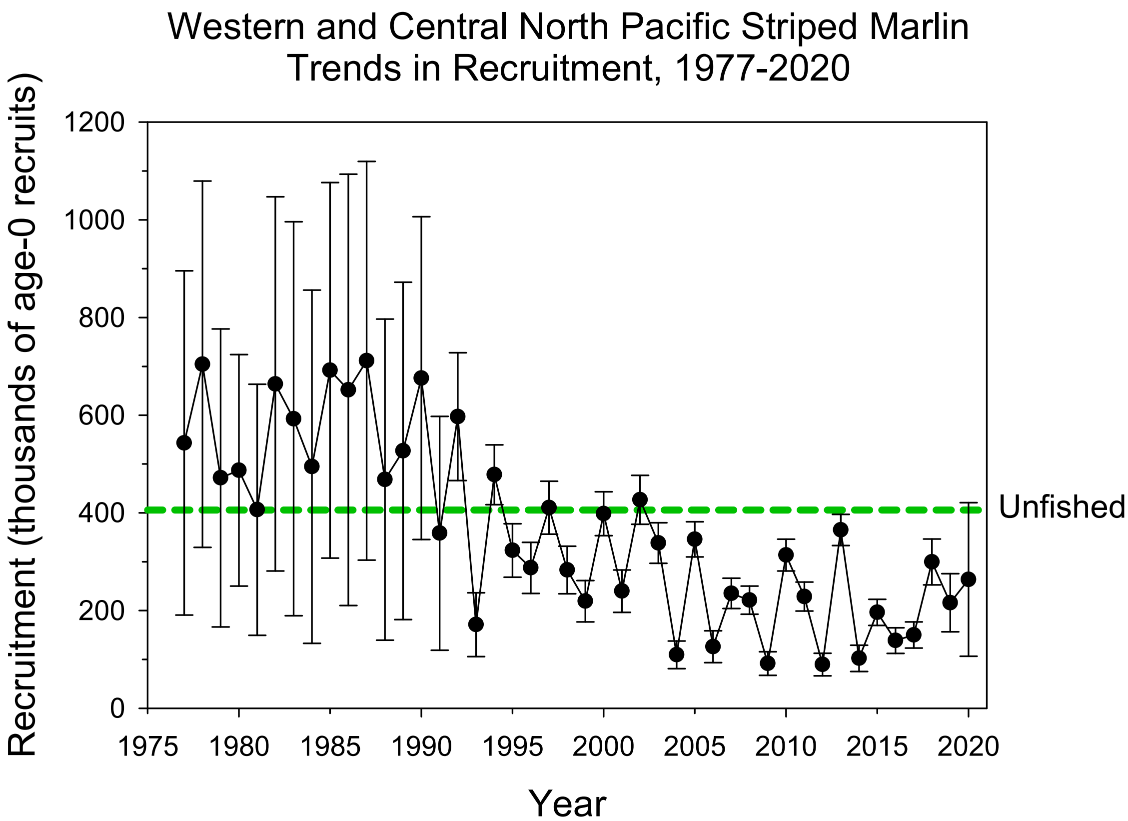


Figure 9. Results of change point analyses of recruitment estimates (age-1 fish, solid black circles) for WCNPO striped marlin with an estimated change in mean recruitment or variance in 1993.

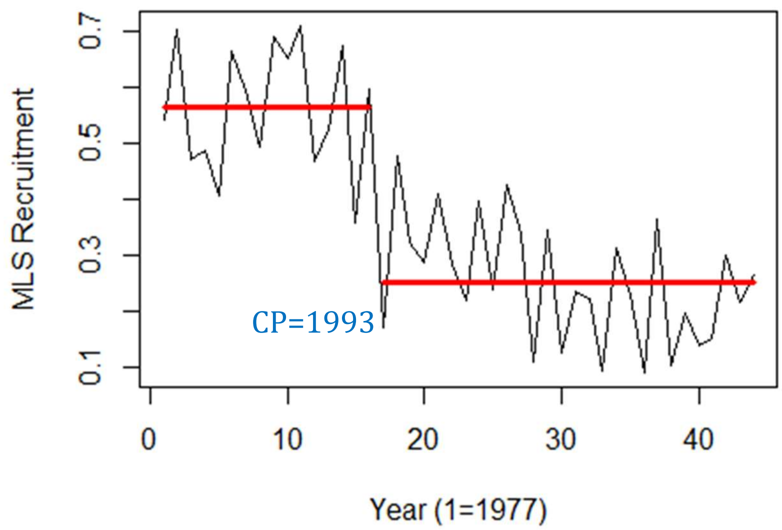


Figure 10. Results of change point analyses of spawning biomass estimates (thousand mt, solid black circles) for WCNPO striped marlin with an estimated change in mean spawning biomass or variance in 1995.

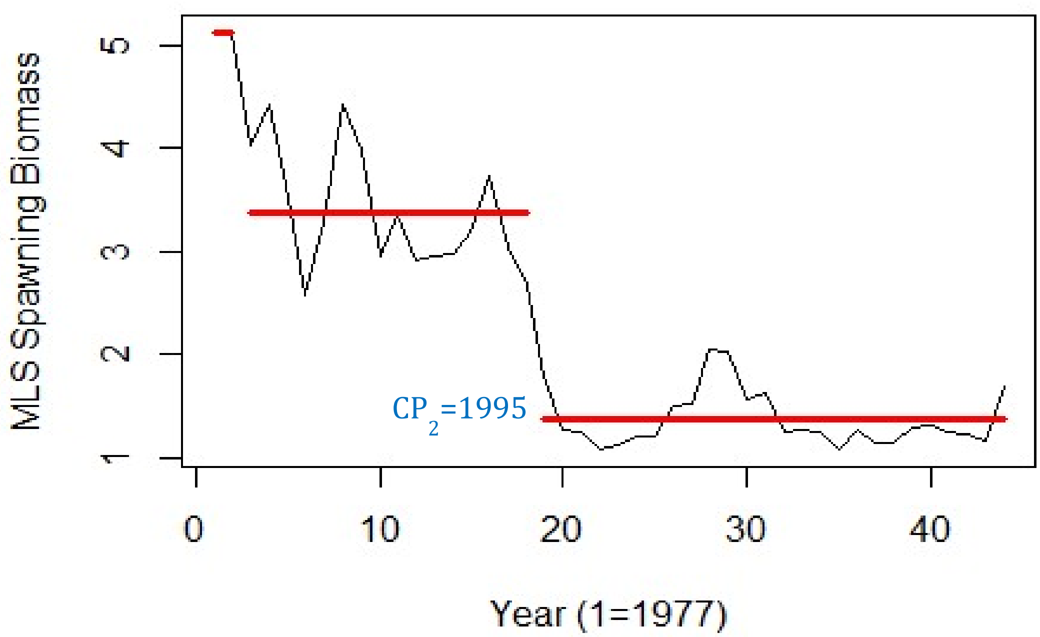


Figure 11. Sequence of mean and median values of 5-year empirical cumulative distribution functions of age-1 recruitment during 1982 to 2021 for WCNPO striped marlin along with the mean of the 5-year ECDF for 2019 used for the short-term recruitment scenario.

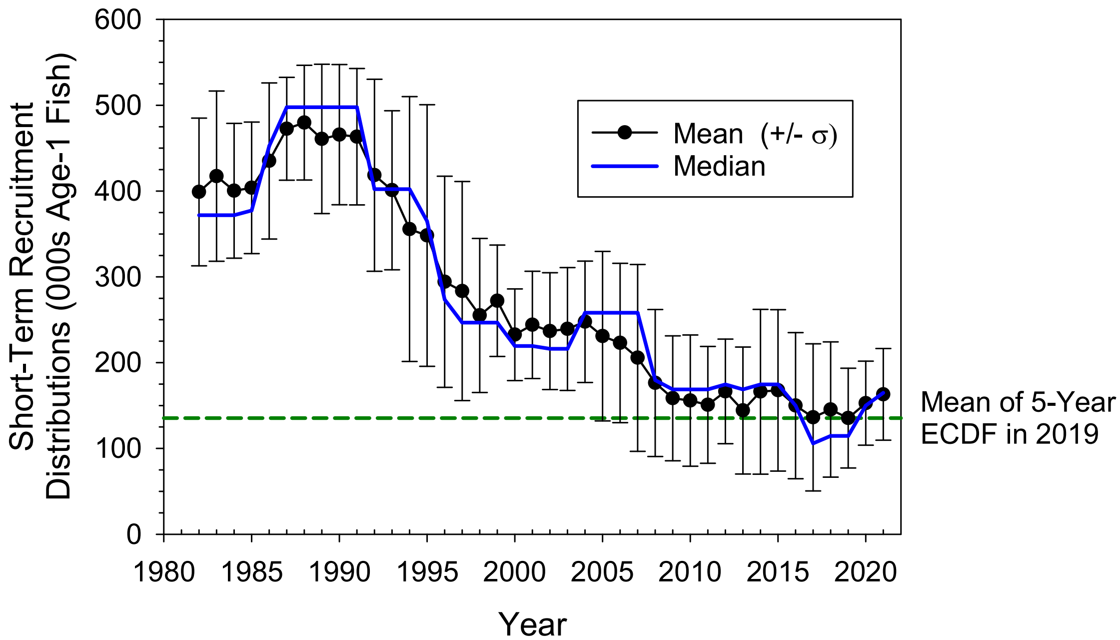


Figure 12. Sequence of mean and median values of 20-year empirical cumulative distribution functions of age-1 recruitment during 1997 to 2021 for WCNPO striped marlin along with the mean of the 20-year ECDF for 2019 used for the short-term recruitment scenario.

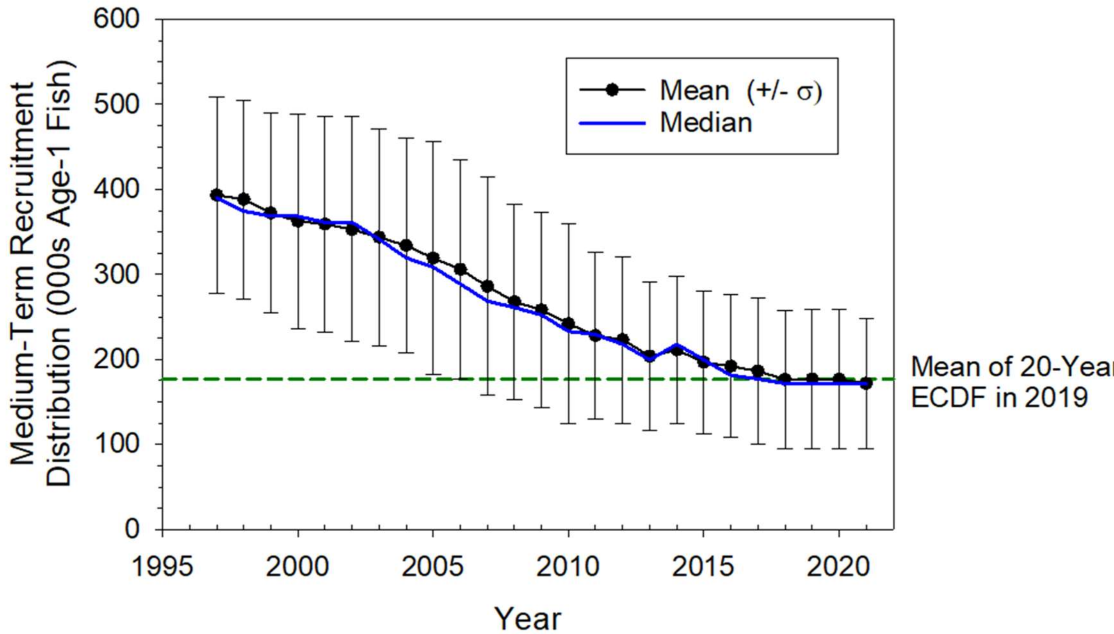
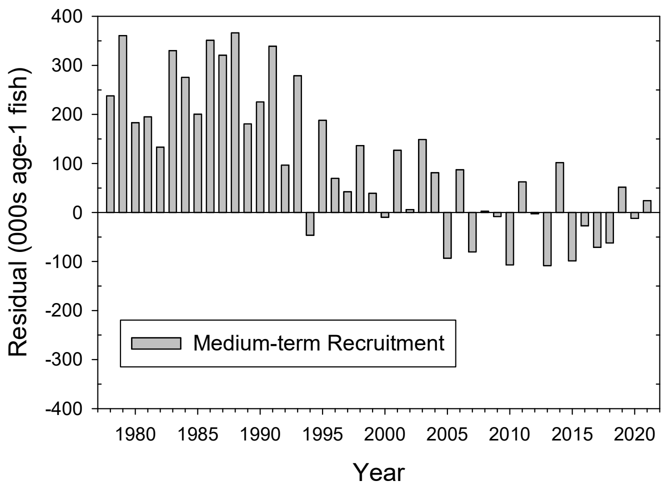


Figure 13. Recruitment residuals (age-1) for medium-term (top), short-term (middle) and long-term (bottom) recruitment model point predictions of estimated recruitment from the 2023 benchmark stock assessment during 1978-2021.



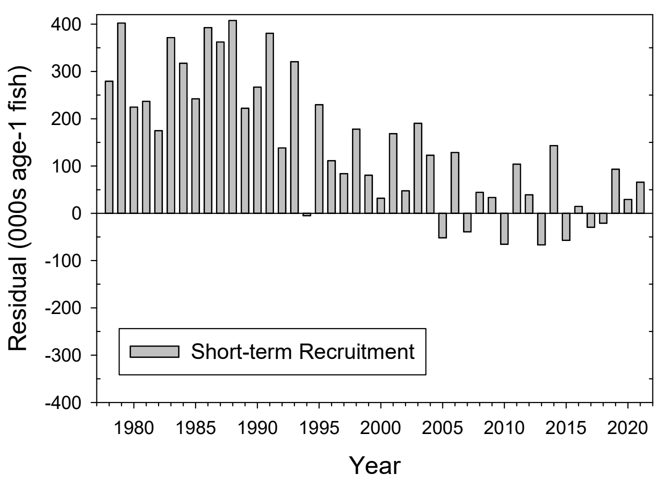


Figure 13. Continued.

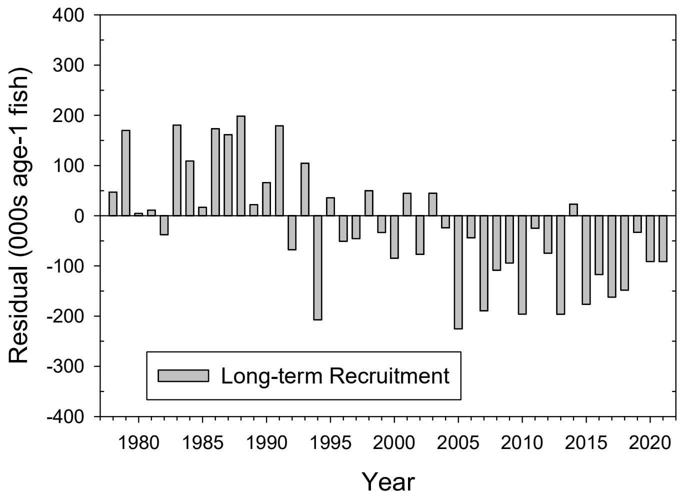


Figure 14. Squared age-1 recruitment prediction errors for medium-term (top), short-term (middle) and long-term (bottom) recruitment model point predictions of estimated recruitment from the 2023 benchmark stock assessment during 1978-2021.

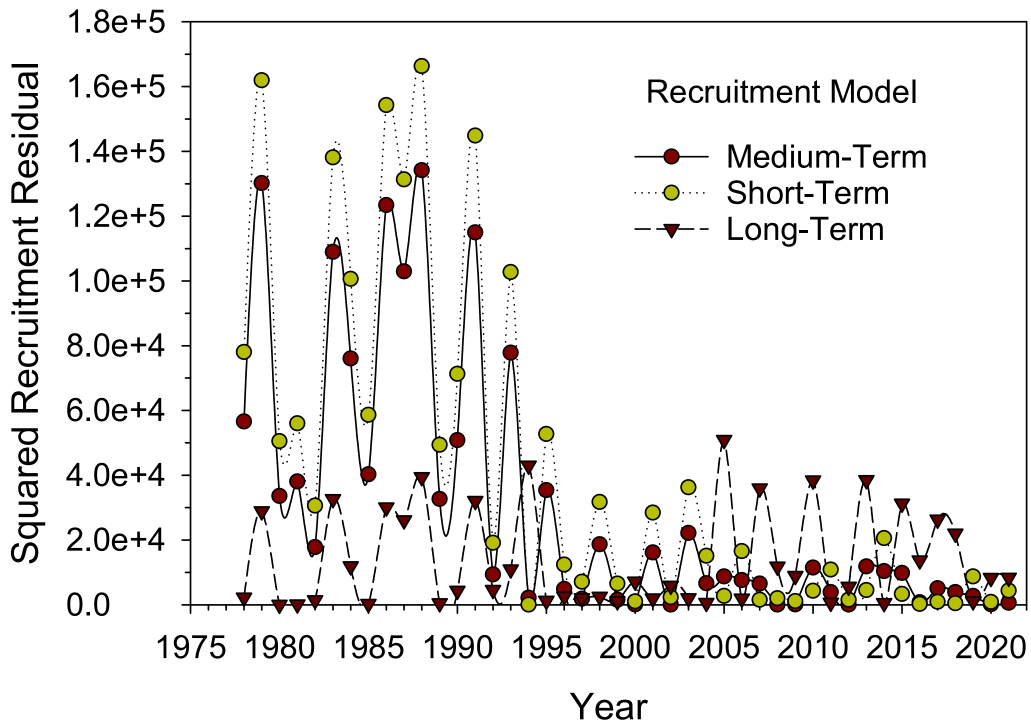


Figure 15. Inverse error-variance weights for medium-term, short-term and long-term recruitment model point predictions of estimated recruitment from the 2023 benchmark stock assessment during 1978-2021.

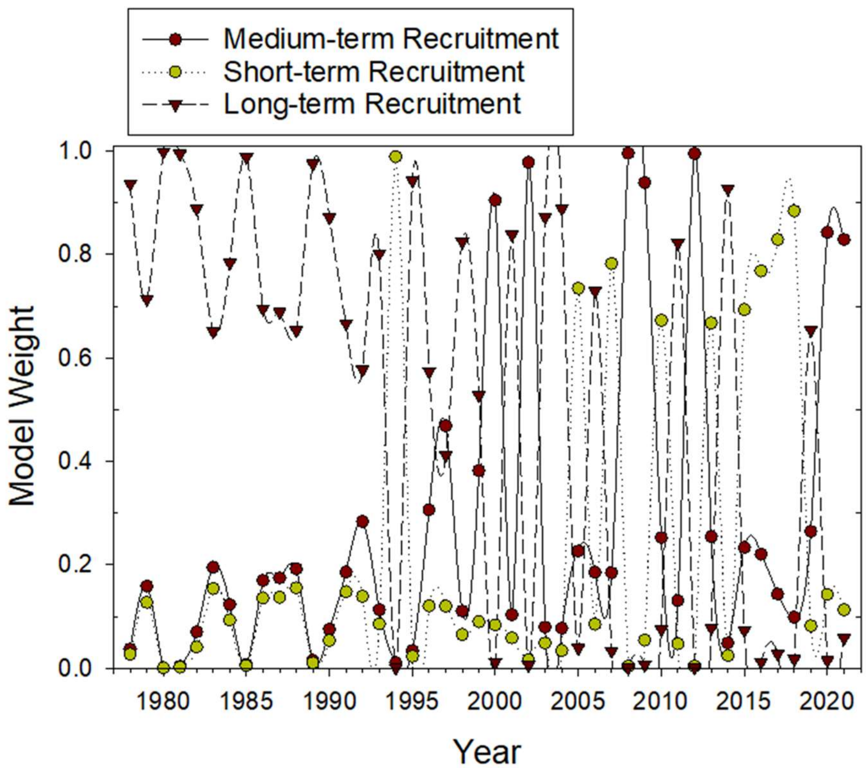


Figure 16. Inverse error-variance weights for medium-term, short-term and long-term recruitment model point predictions of estimated recruitment from the 2023 benchmark stock assessment during 1978-2021.

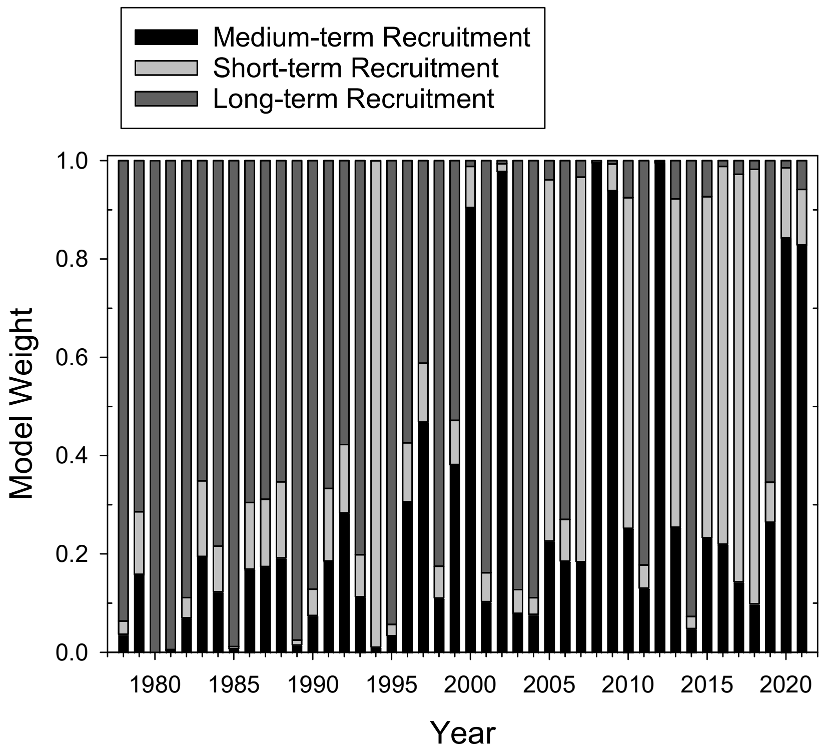


Figure 17. Inverse error-variance weights for medium-term, short-term and long-term recruitment model point predictions of estimated recruitment from the 2023 benchmark stock assessment during 1978-2021.

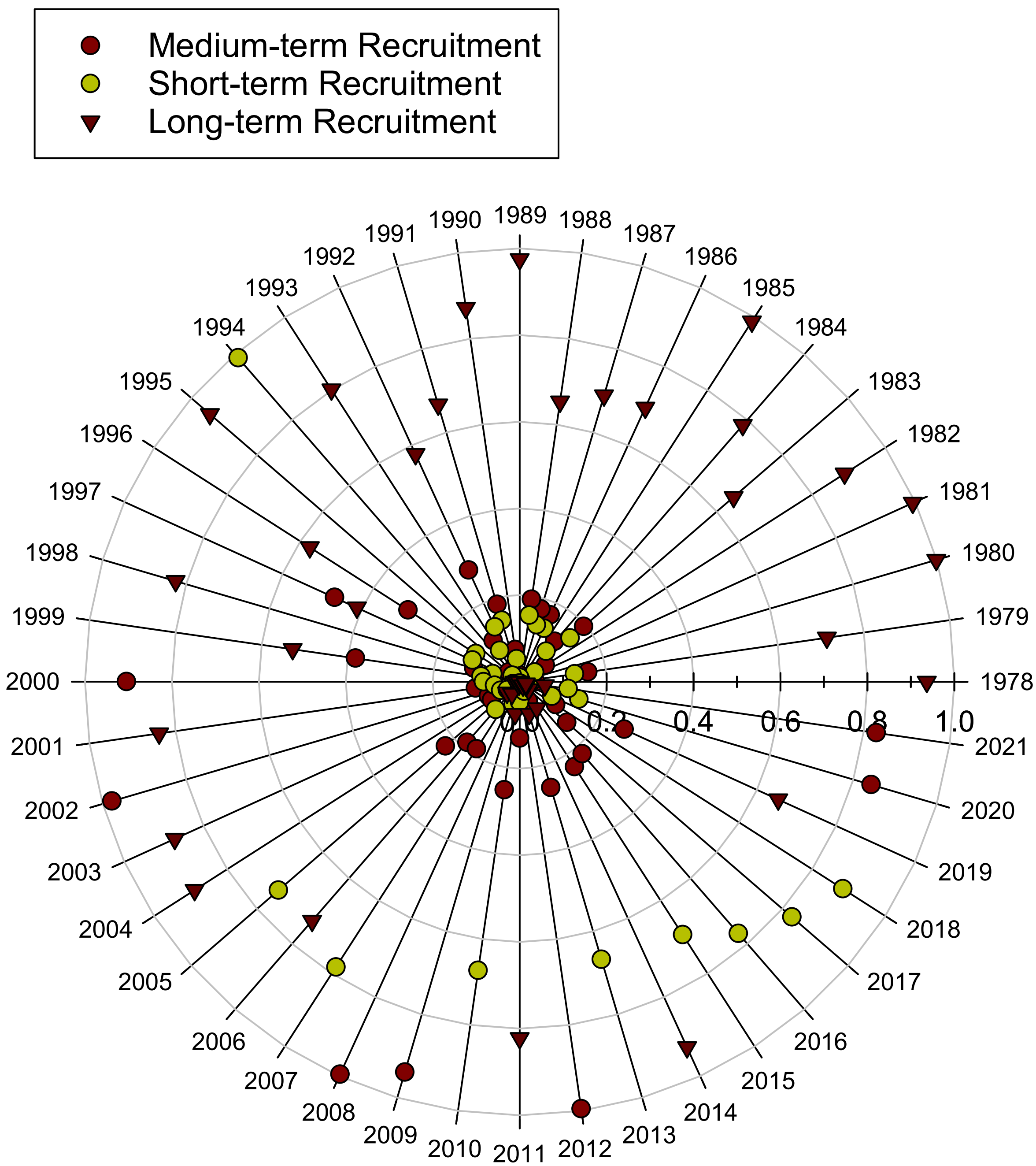


Figure 18. Comparison of aggregated mean weights at age across fleets based on the 2019 and 2023 WCNPO striped marlin stock assessments.

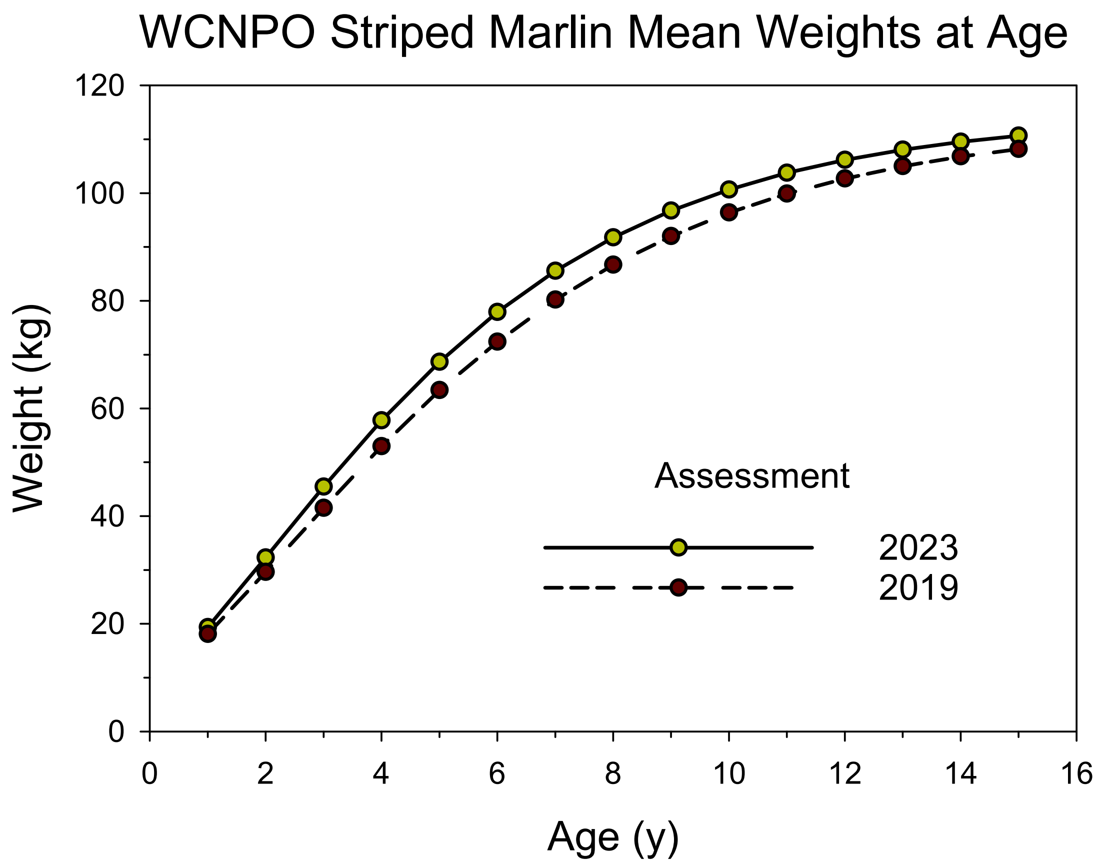


Figure 19. Comparison of female maturity at age ogives based on the 2019 and 2023 WCNPO striped marlin stock assessments.

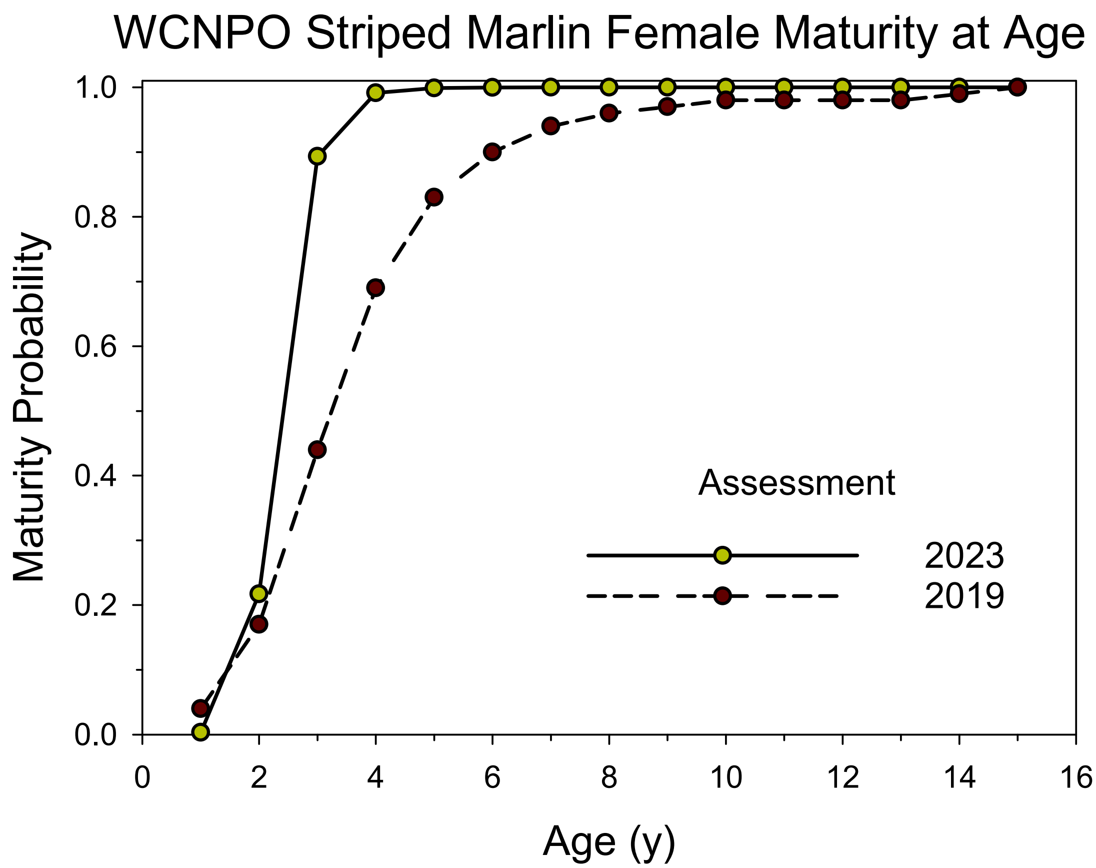


Figure 20. Comparison of aggregated fishery selectivities at age across fleets based on the 2019 and 2023 WCNPO striped marlin stock assessments.

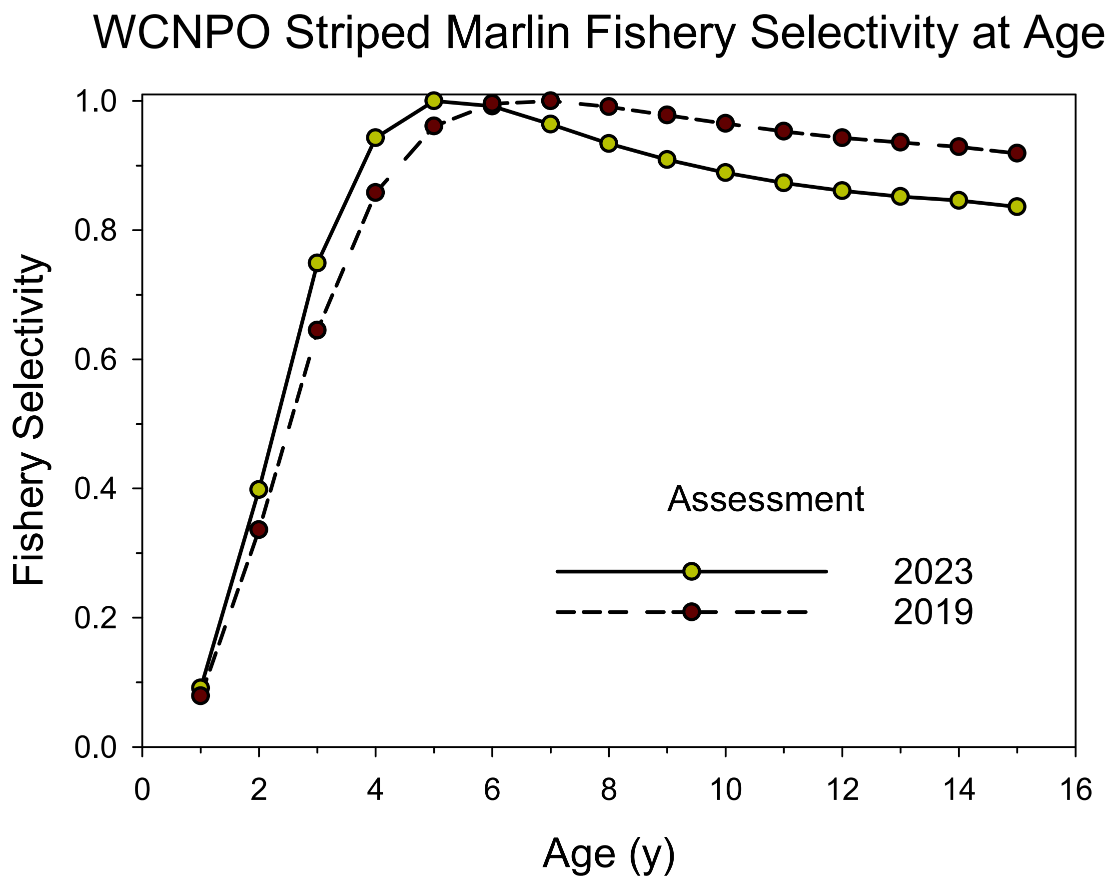


Figure 21. Comparison of aggregated fishery yield per recruit as a function of fishing mortality based on the 2019 and 2023 WCNPO striped marlin stock assessments.

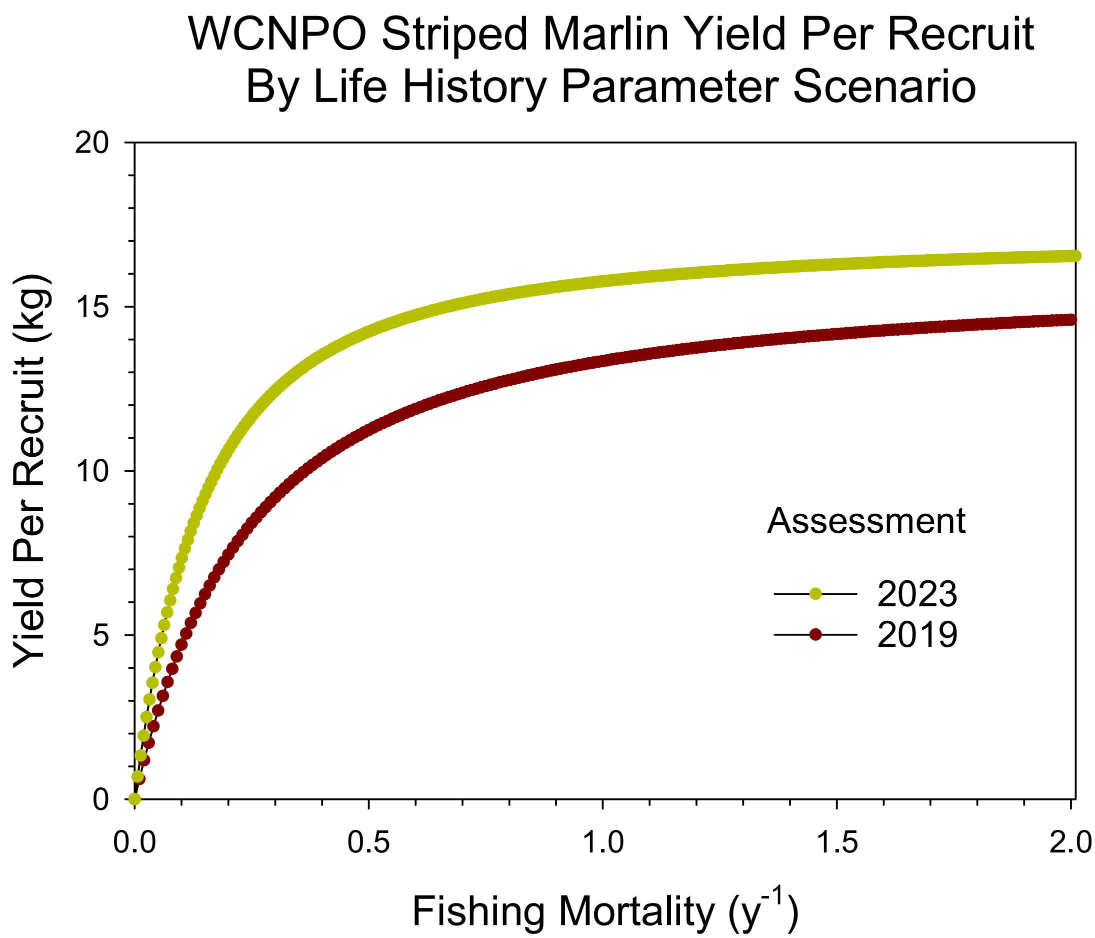


Figure 22. Comparison of aggregated fishery spawning biomass per recruit as a function of fishing mortality based on the 2019 and 2023 WCNPO striped marlin stock assessments.

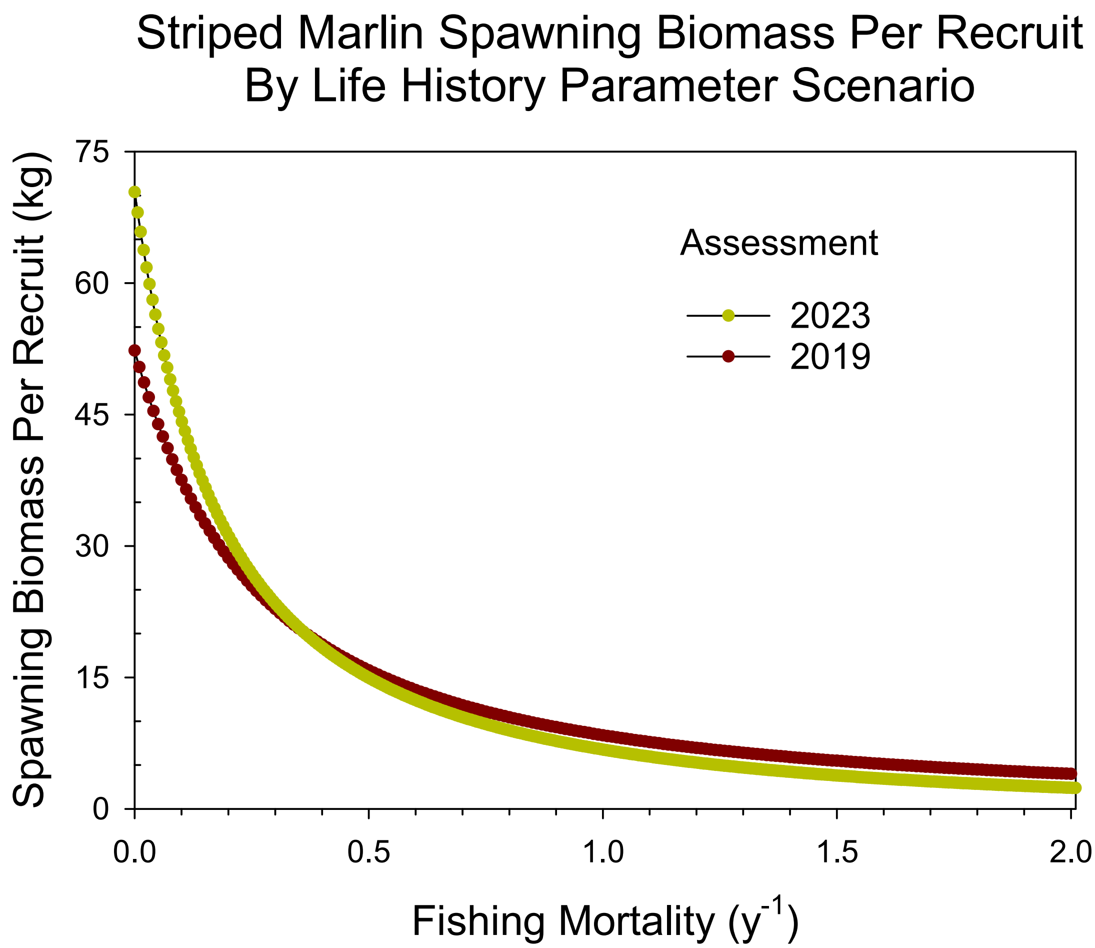


Figure 23. Comparison of estimates of mean generation time for WCNPO striped marlin based on the 2019 and 2023 stock assessments.

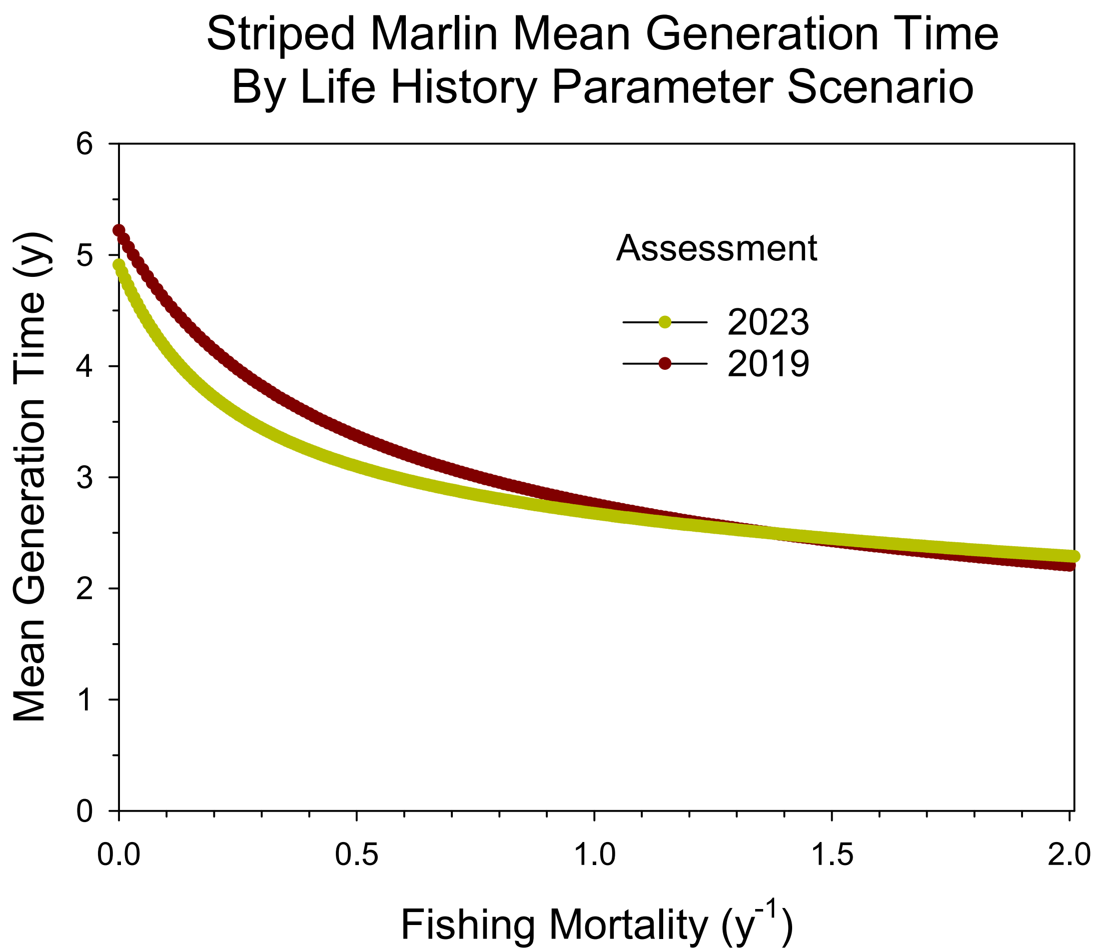


Figure 24. Comparison of aggregated fishery spawning potential ratio as a function of fishing mortality based on the 2019 and 2023 WCNPO striped marlin stock assessments.

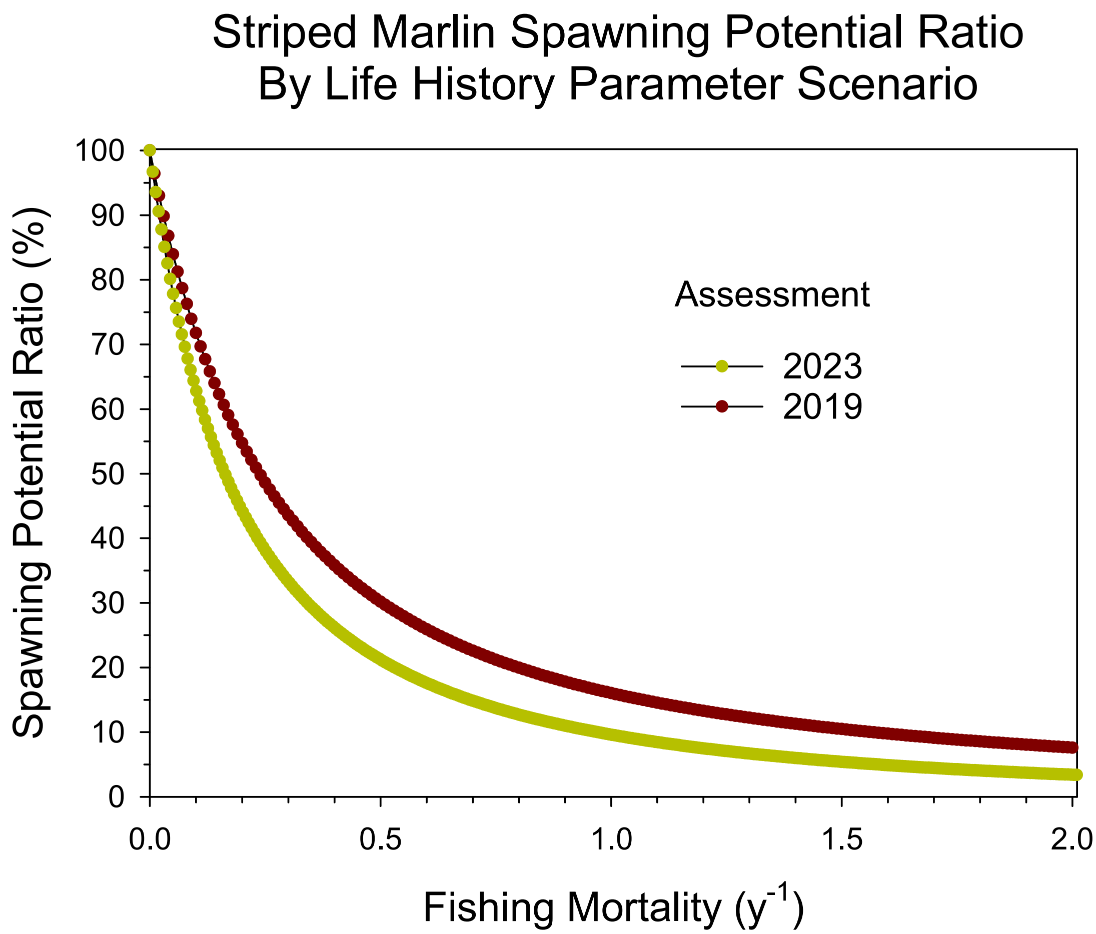


Figure 25. Diagram of the shared fishery selectivities for the 9 fleet groups where the representative fleet is circled in black. Fleet groups with flat-topped fishery selectivity are shaded green and fleet groups with time-varying fishery selectivity are shaded in orange.

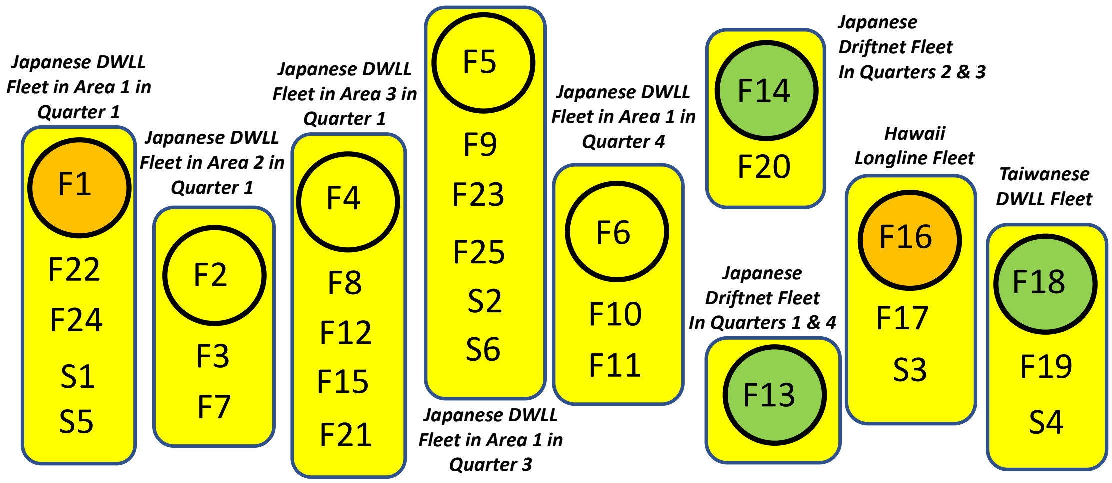
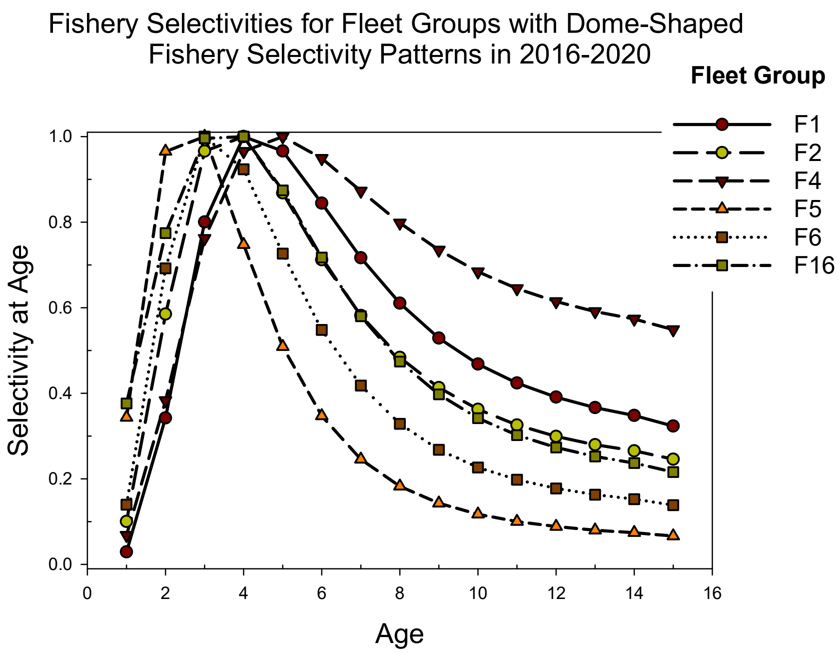


Figure 26. Average fishery selectivities at age during 2016-2020 (top) and 1994-2020 (bottom) from the 2023 stock assessment for fleet groups with domed selectivity patterns.



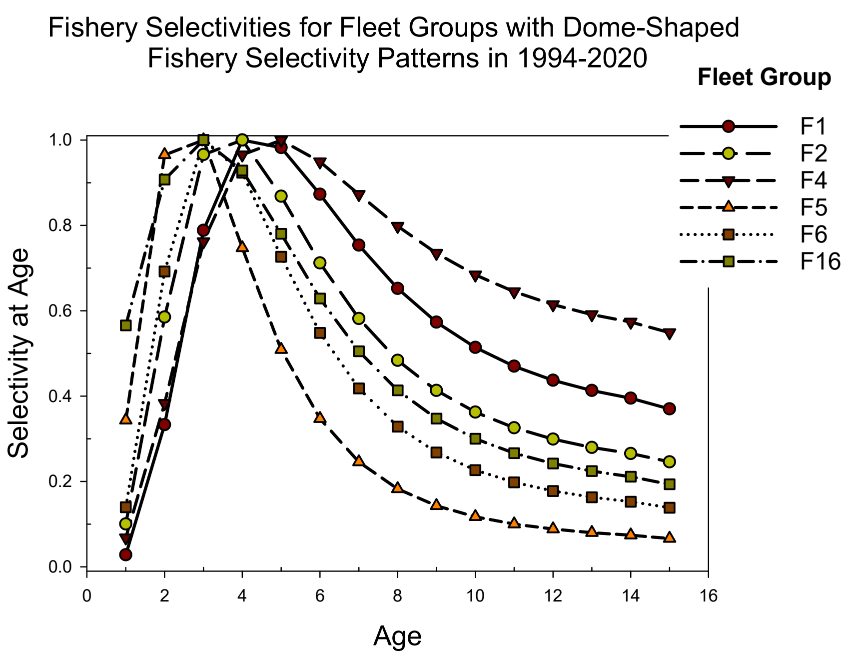
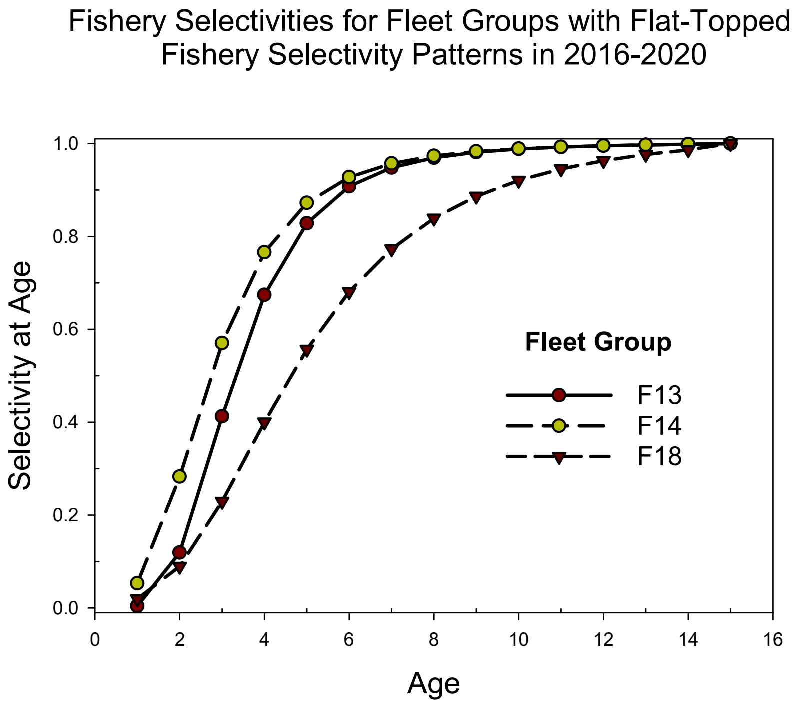


Figure 27. Average fishery selectivities at age during 2016-2020 (top) and 1994-2020 (bottom) from the 2023 stock assessment for fleet groups with flat-topped selectivity patterns.



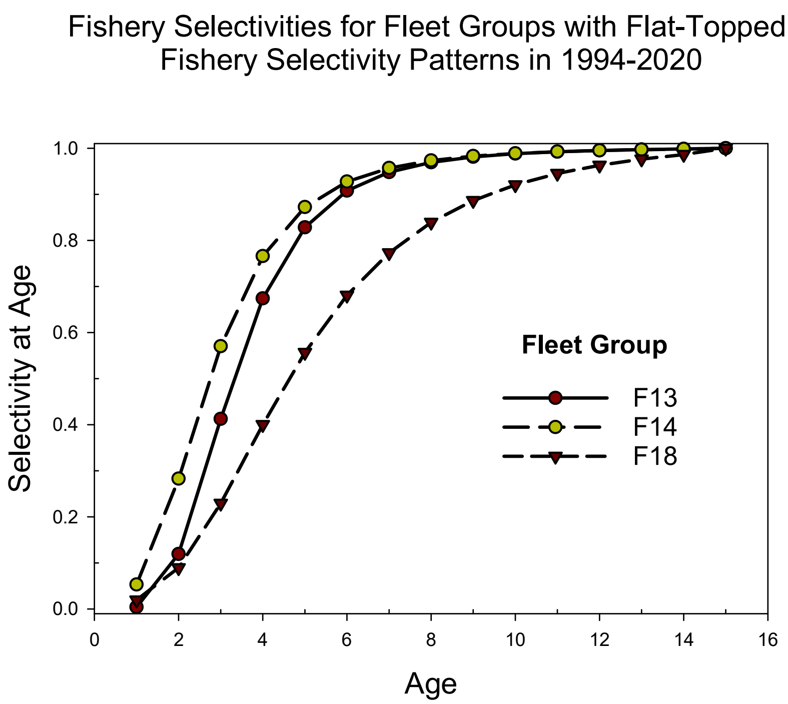


Figure 28. Annual proportions of total fishing mortality for fleet groups with domed selectivities at age during 1977-2020.

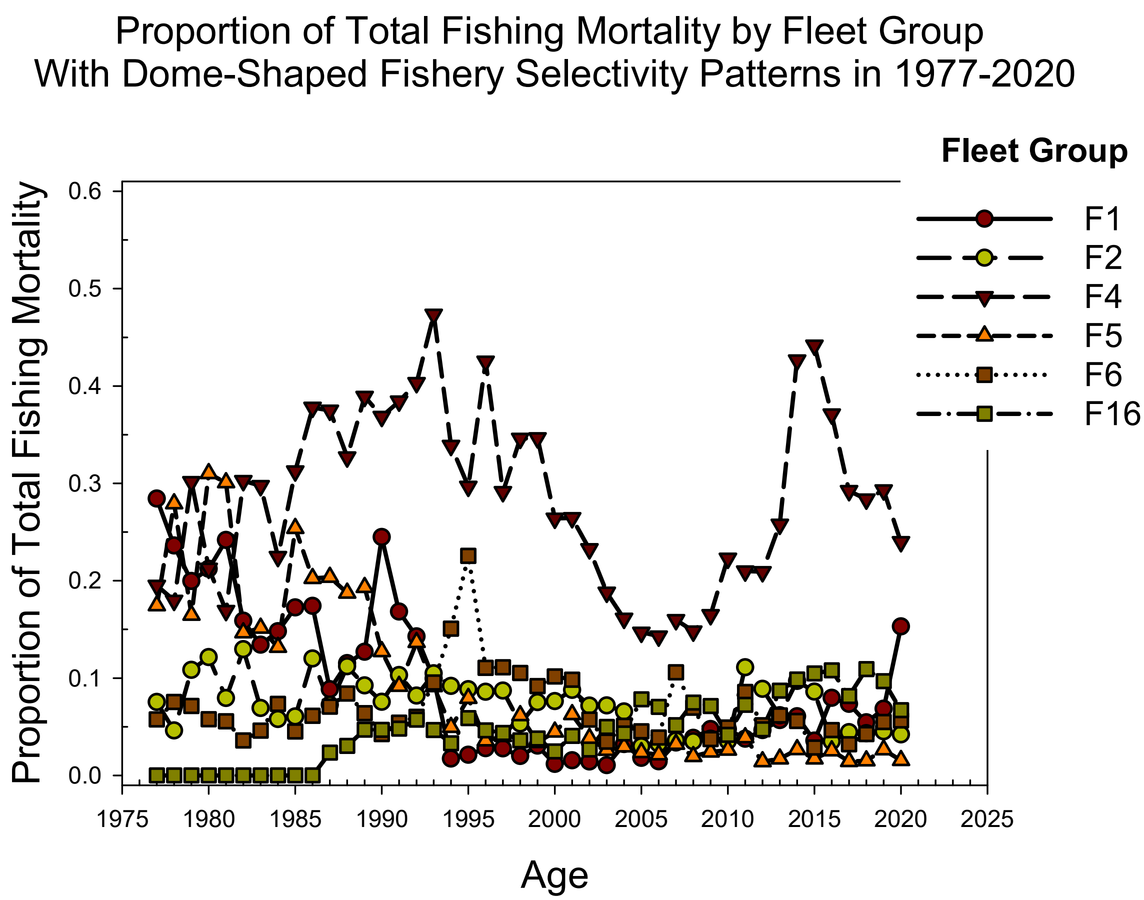


Figure 29. Annual proportions of total fishing mortality for fleet groups with flat-topped selectivities at age during 1977-2020.

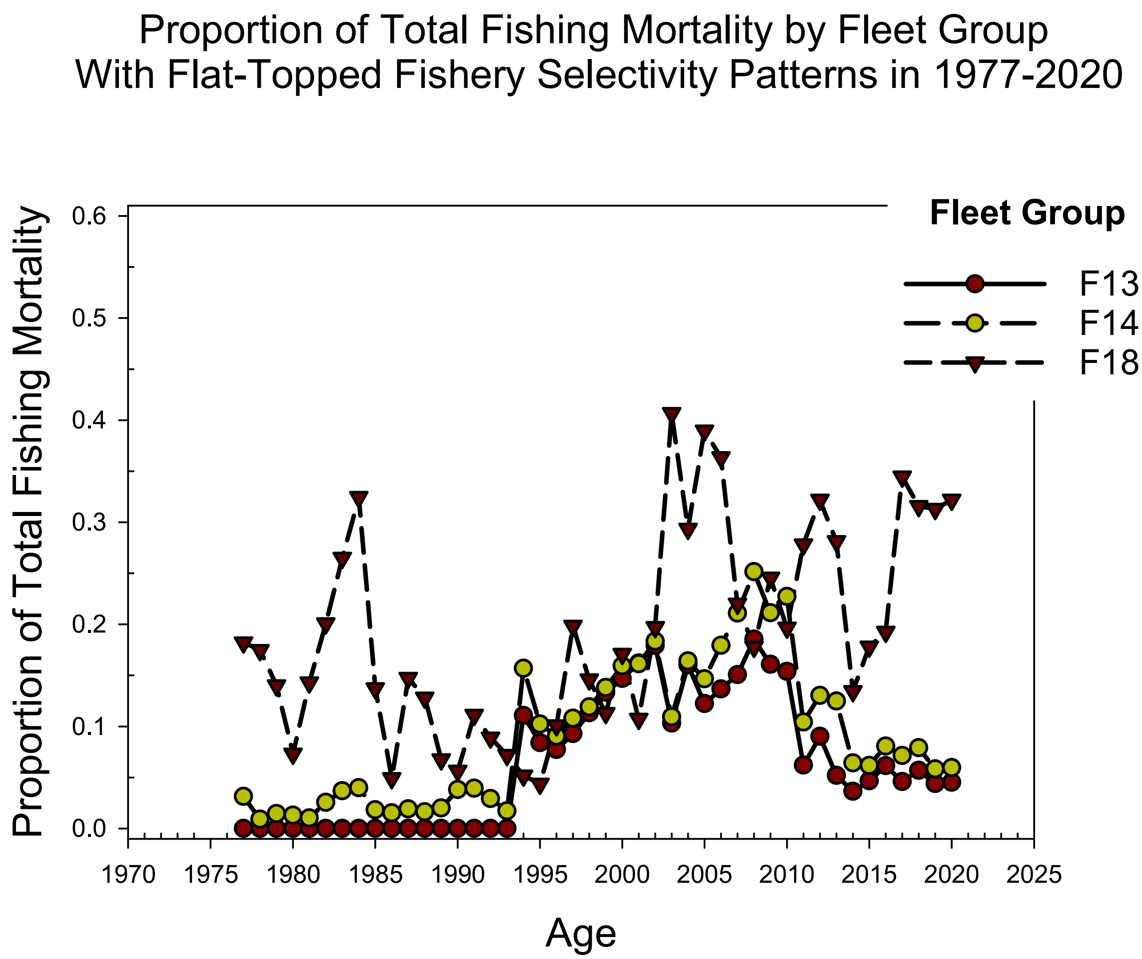
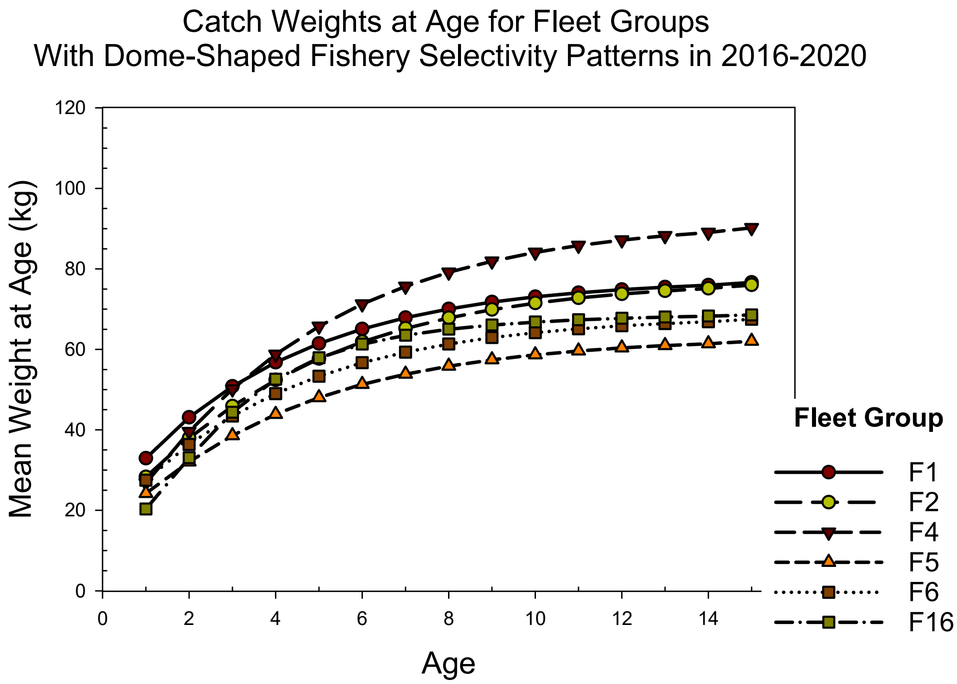


Figure 30. Mean fishery catch weights at age during 2016-2020 (top) and 1994-2020 (bottom) from the 2023 stock assessment for fleet groups with domed selectivity patterns.



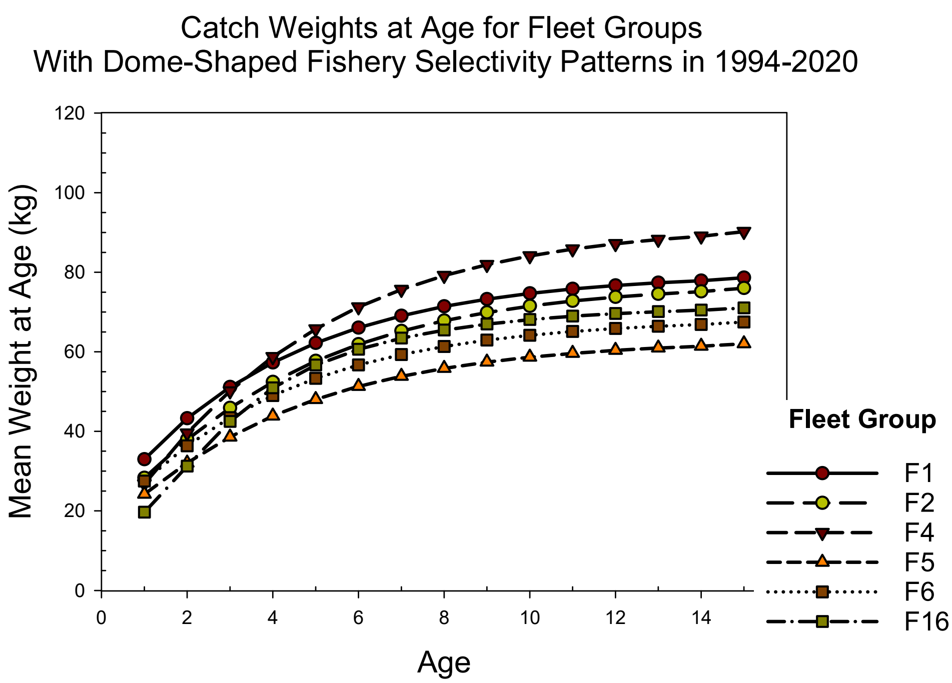
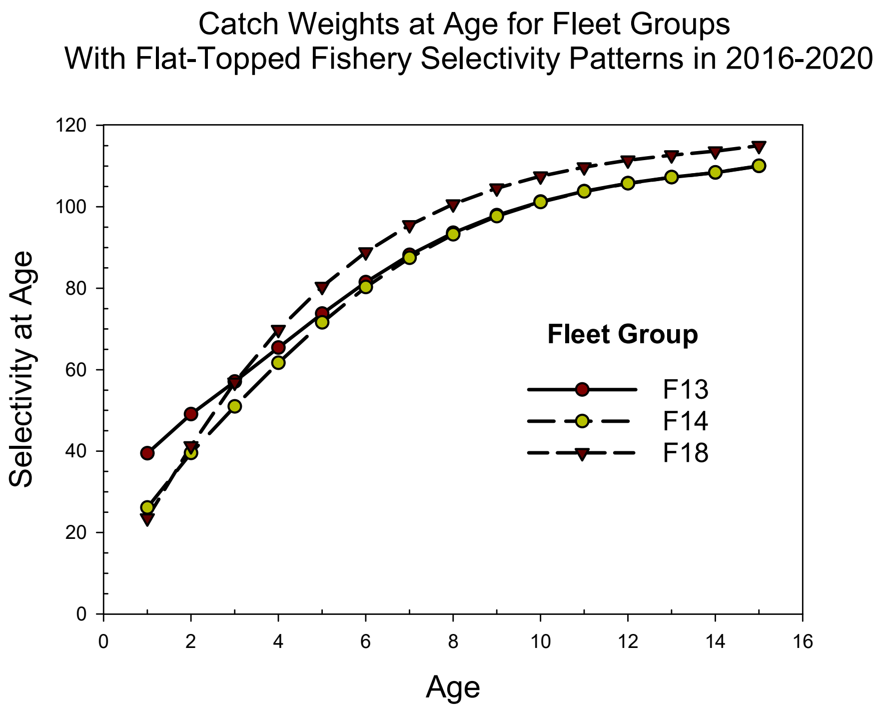


Figure 31. Mean fishery catch weights at age during 2016-2020 (top) and 1994-2020 (bottom) from the 2023 stock assessment for fleet groups with flat-topped selectivity patterns.



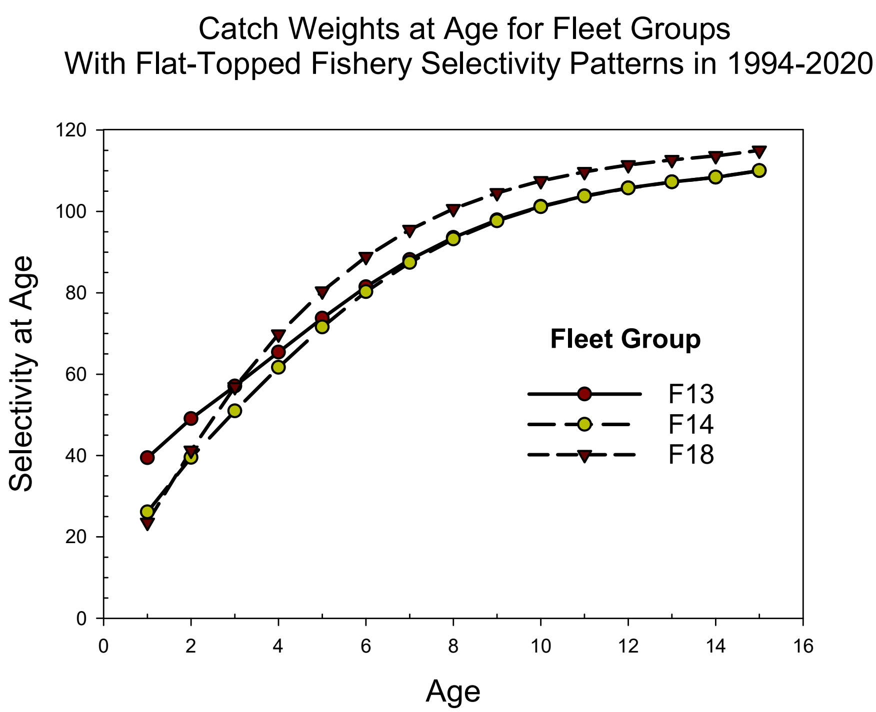


Figure 32. Annual catch biomasses of WCNPO striped marlin for fleet groups with domed selectivities at age during 1977-2020.

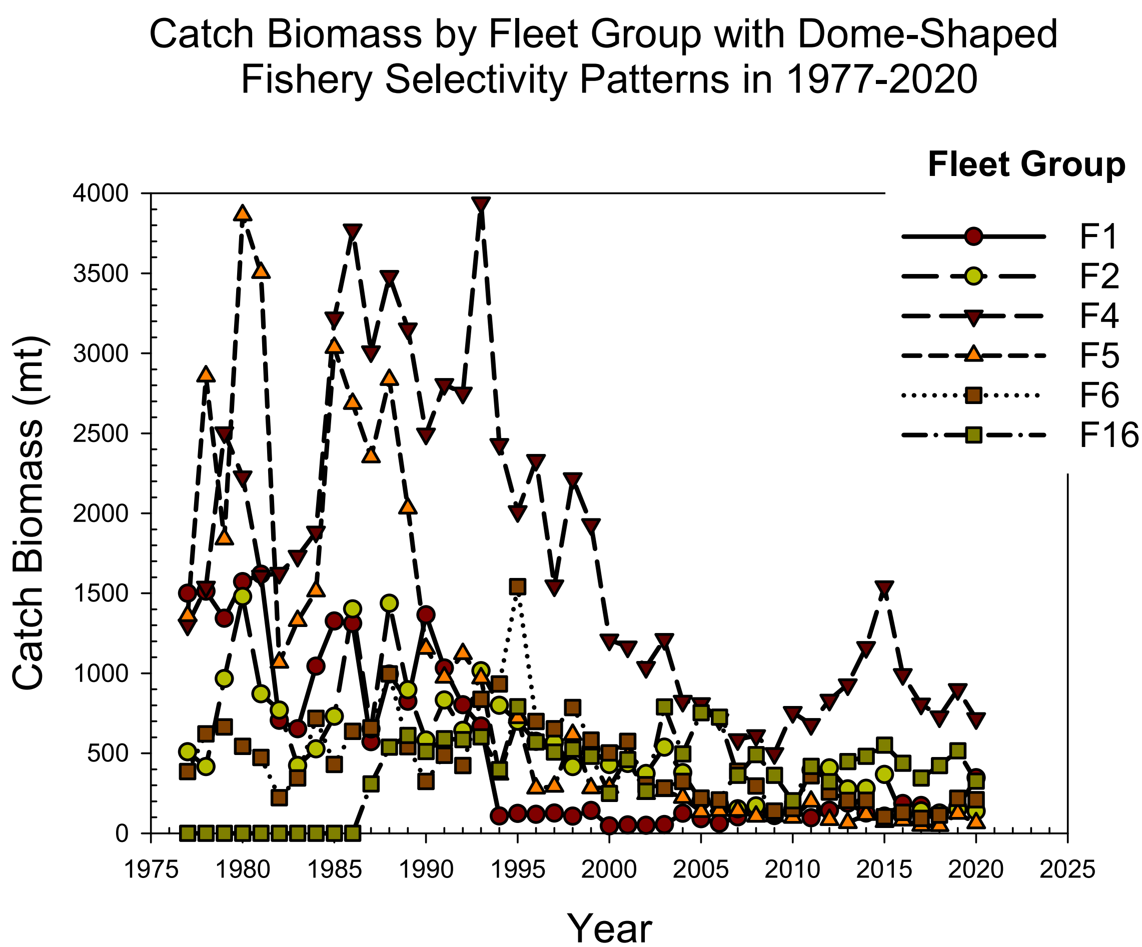


Figure 33. Annual catch biomasses of WCNPO striped marlin for fleet groups with flat-topped selectivities at age during 1977-2020.

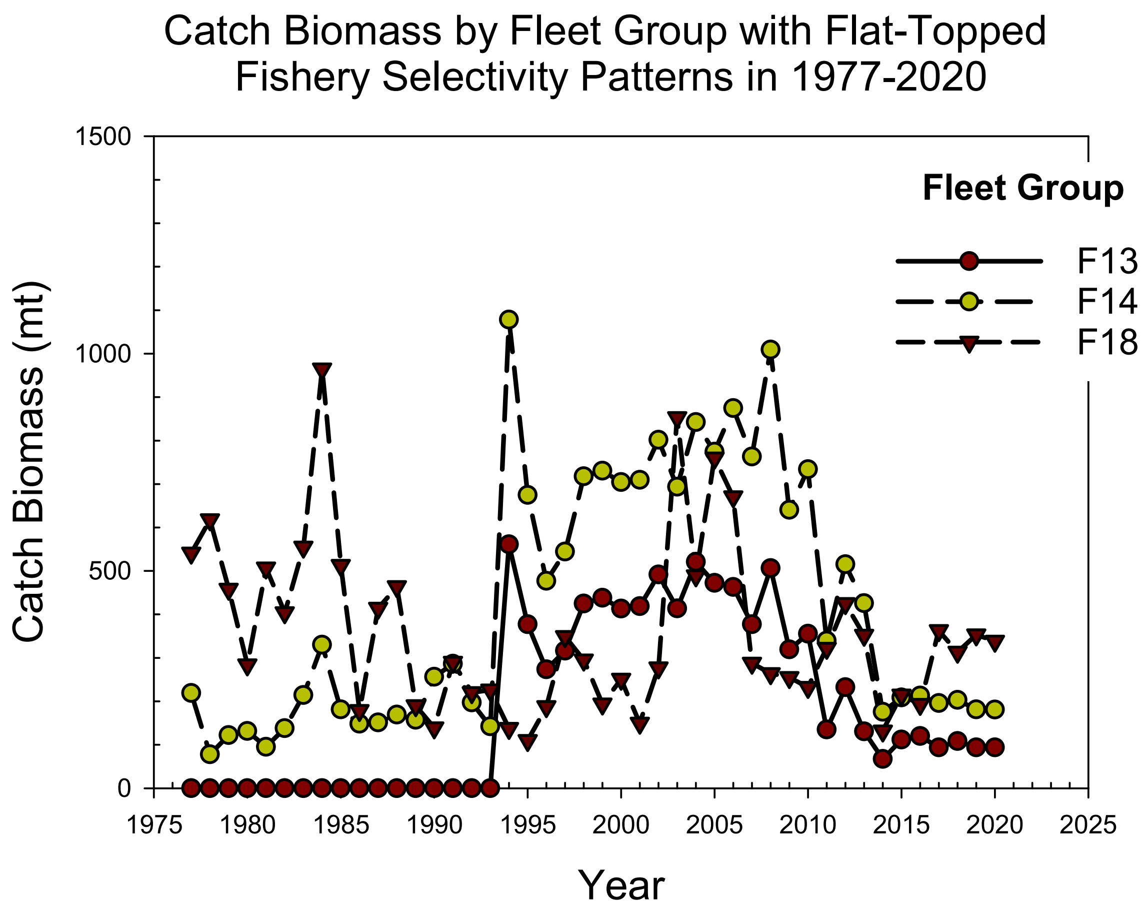


Figure 34. Annual proportions of total catch biomass for fleet groups with domed selectivities at age during 1977-2020.

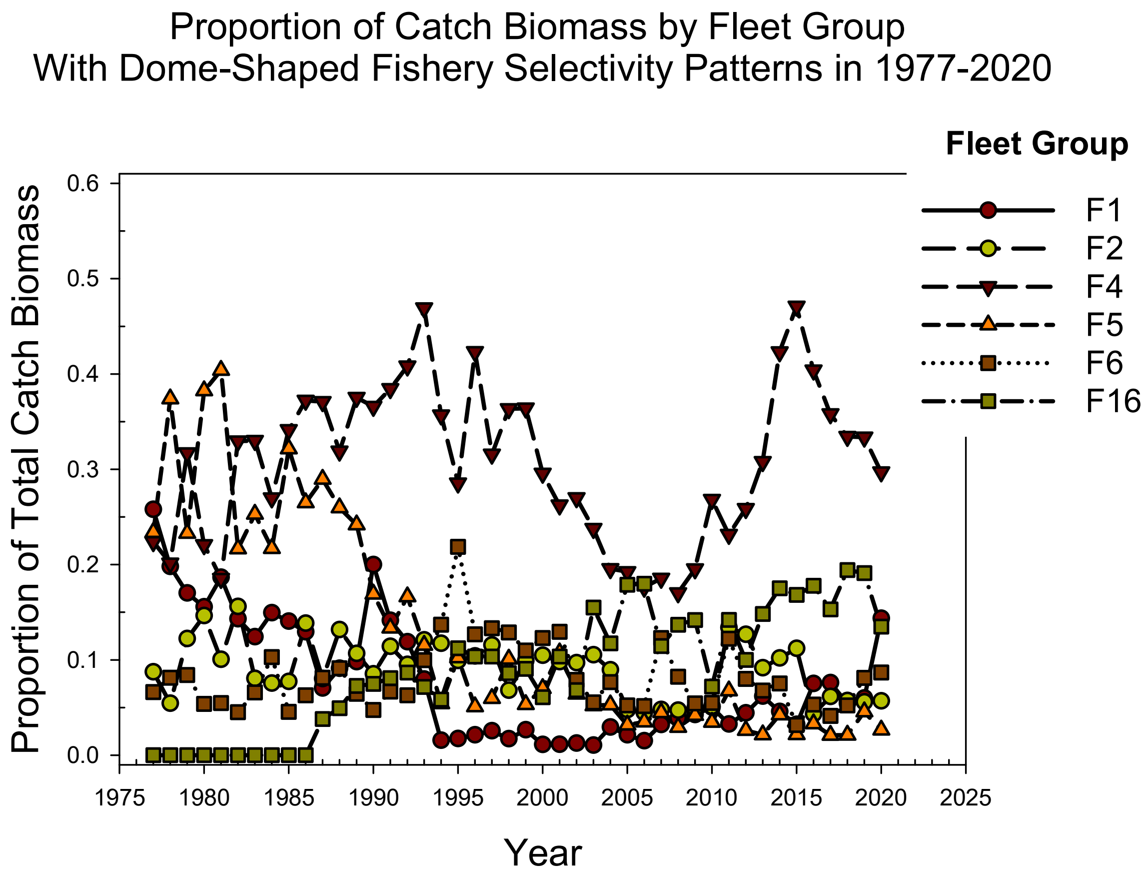


Figure 35. Annual proportions of total fishing mortality for fleet groups with flat-topped selectivities at age during 1977-2020.

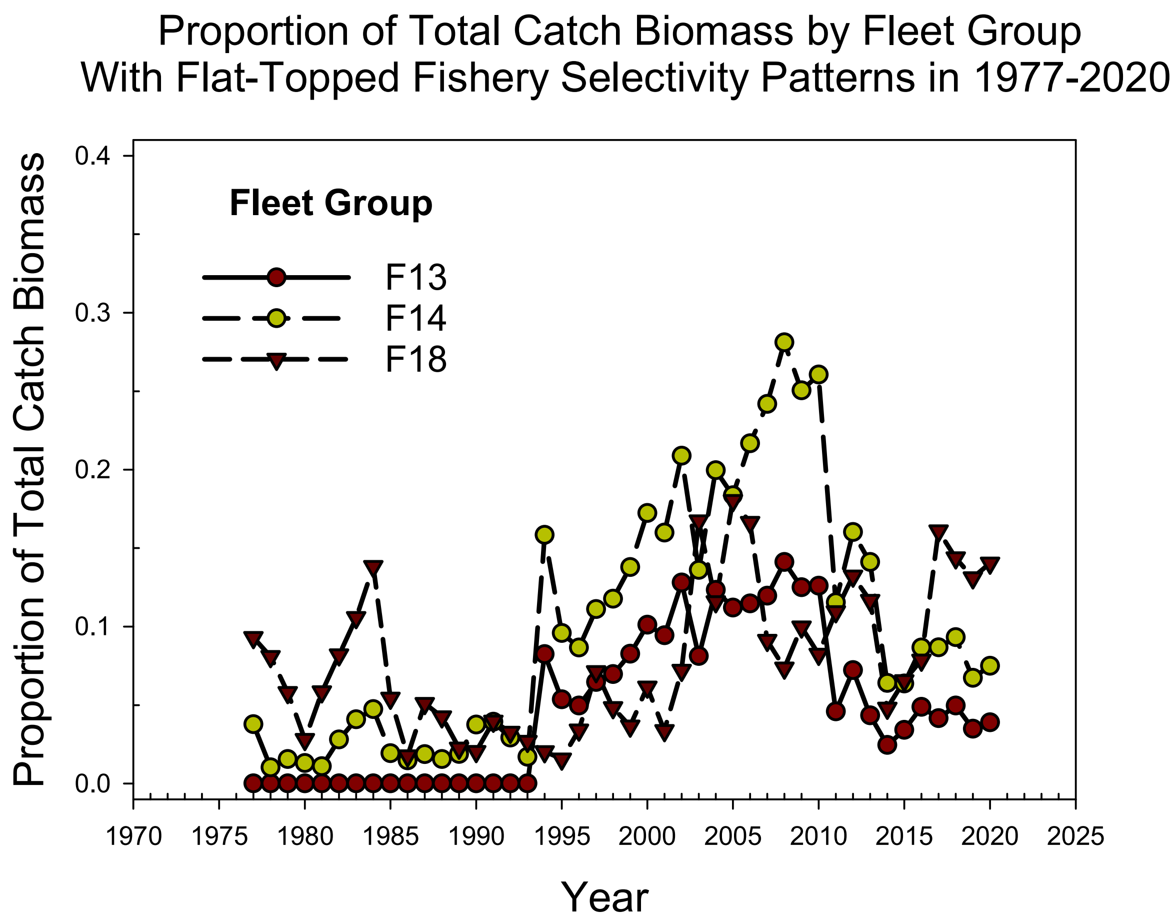


Figure 36.1. The time series of median catch biomasses to rebuild the stock under Scenario 1 (constant F = 0.373) with the 10th (P10) and 90th (P90) percentiles of the annual catch biomass distributions relative to the recent average yield during 2018–2020 of 2,428 mt along with individual trajectories (grey lines).

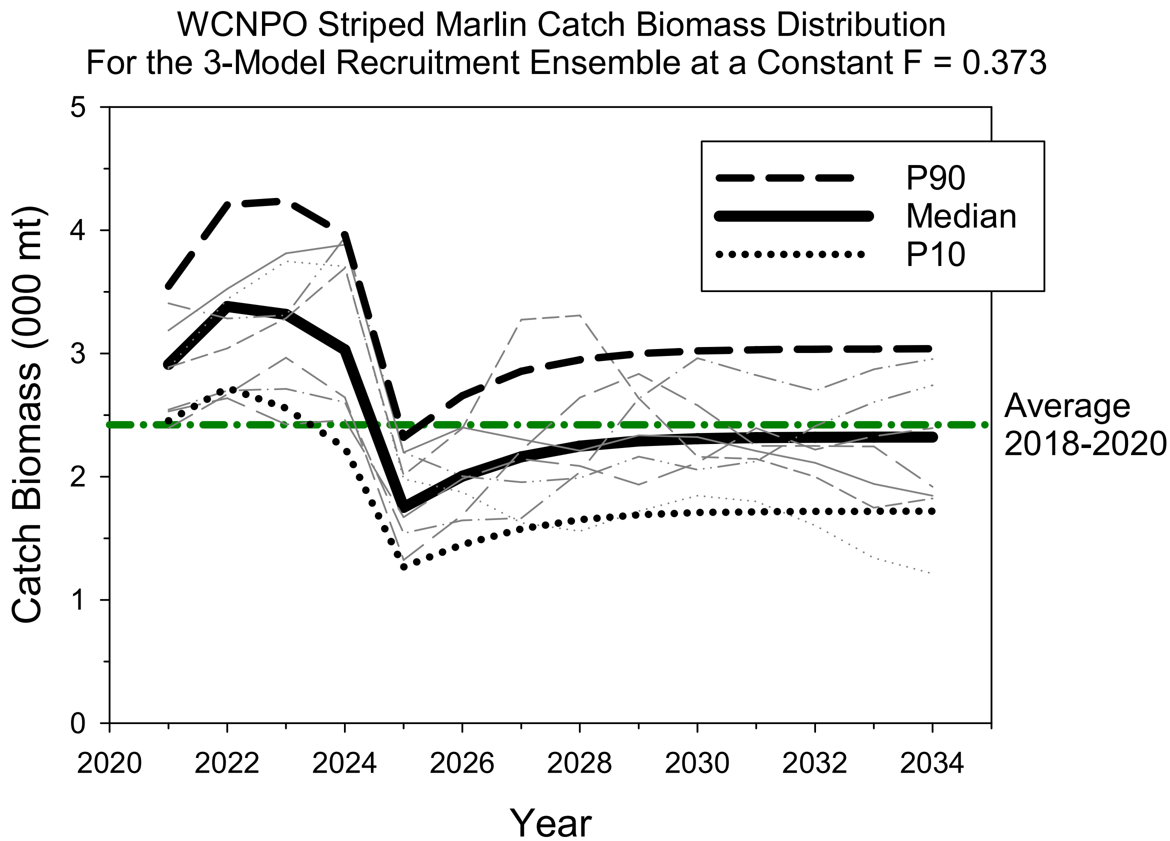


Figure 36.2. The time series of median catch biomasses to rebuild the stock under Scenario 2 (constant catch = 2175 mt) with the 10th (P10) and 90th (P90) percentiles of the annual catch biomass distributions relative to the recent average yield during 2018–2020 of 2,428 mt along with individual trajectories (grey lines).

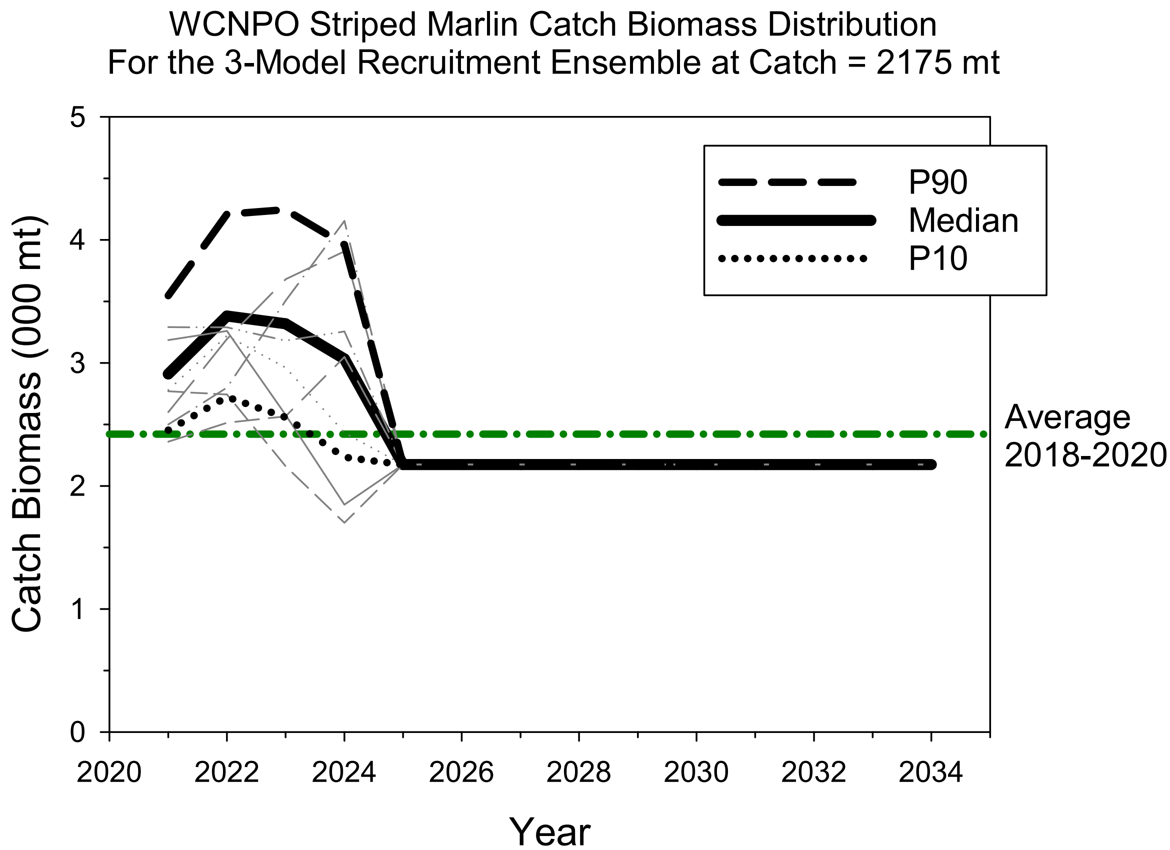


Figure 36.3. The time series of median catch biomasses to rebuild the stock under Scenario 3 (phased F = (0.55, 0.37) with the 10th (P10) and 90th (P90) percentiles of the annual catch biomass distributions relative to the recent average yield during 2018–2020 of 2,428 mt along with individual trajectories (grey lines).

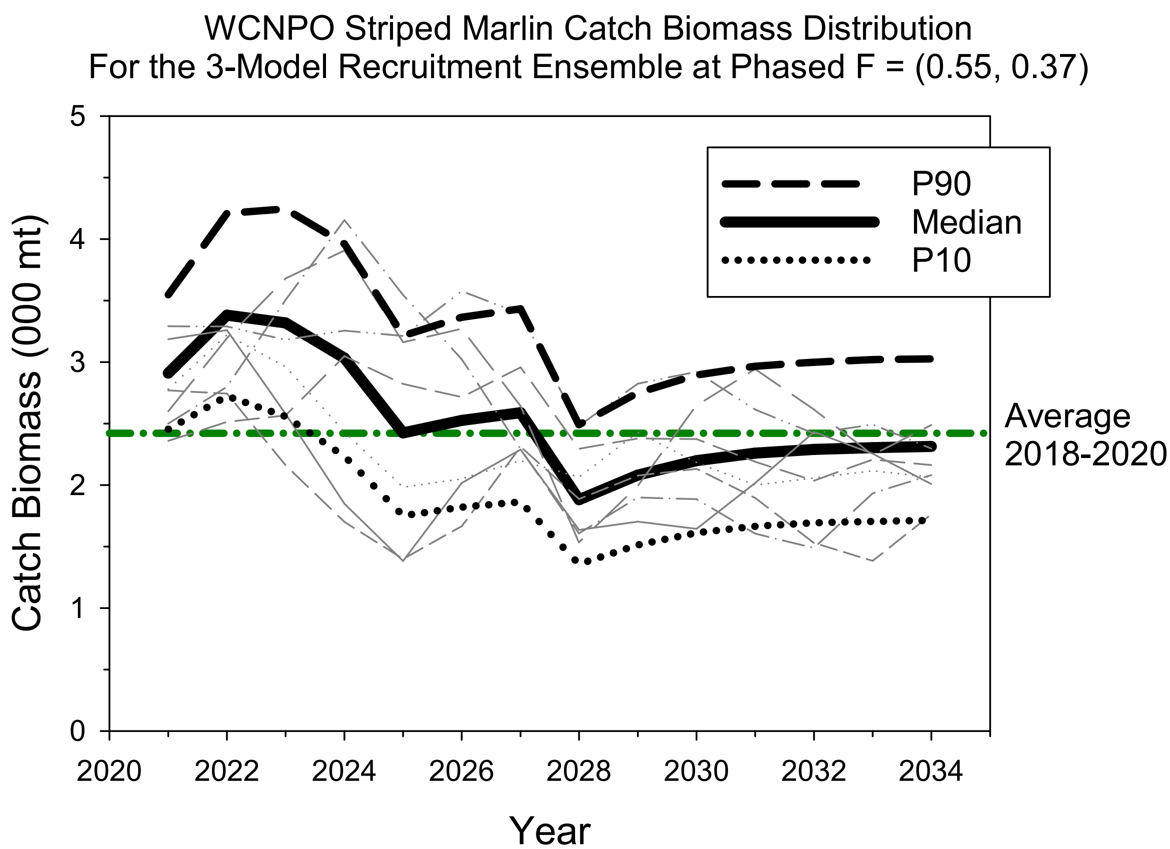


Figure 36.4. The time series of median catch biomasses to rebuild the stock under Scenario 4 (phased catch = (2400, 2150) mt) with the 10th (P10) and 90th (P90) percentiles of the annual catch biomass distributions relative to the recent average yield during 2018–2020 of 2,428 mt along with individual trajectories (grey lines).

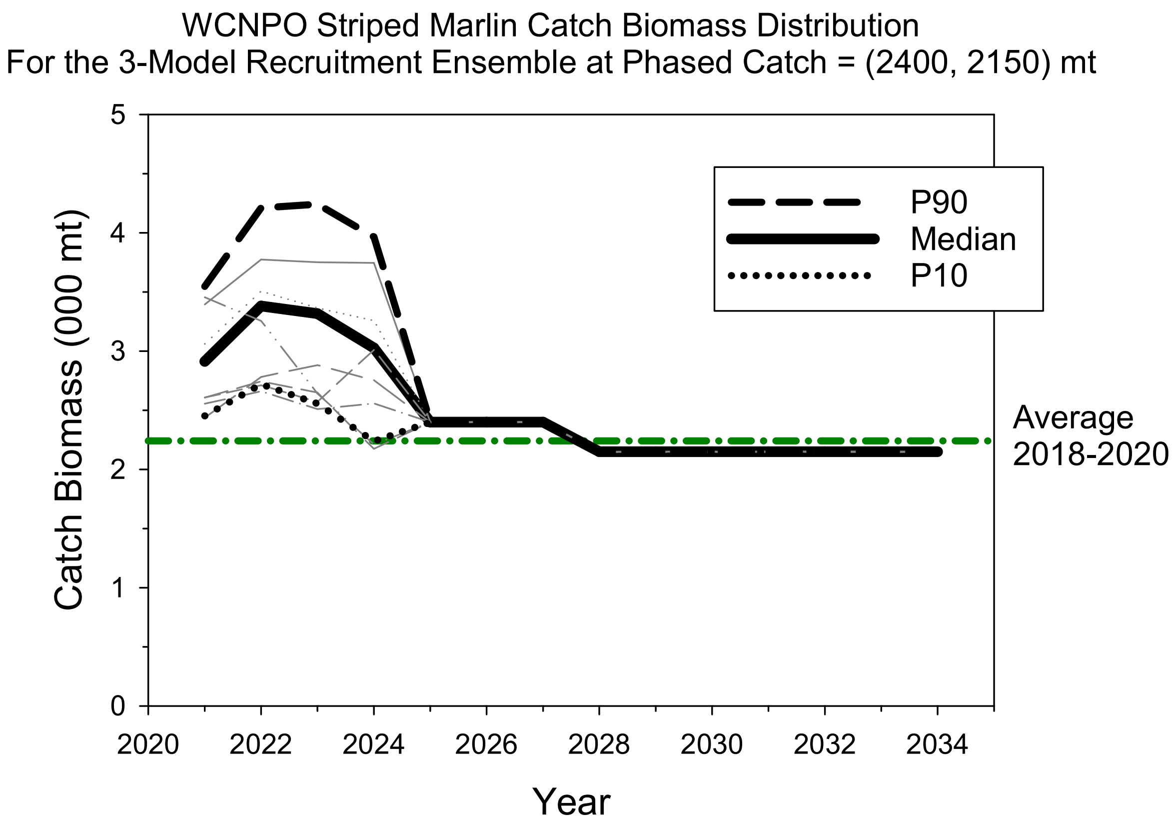


Figure 36.5. The time series of median catch biomasses to rebuild the stock under Scenario 5 (phased catch = (2250, 2175) mt) with the 10th (P10) and 90th (P90) percentiles of the annual catch biomass distributions relative to the recent average yield during 2018–2020 of 2,428 mt along with individual trajectories (grey lines).

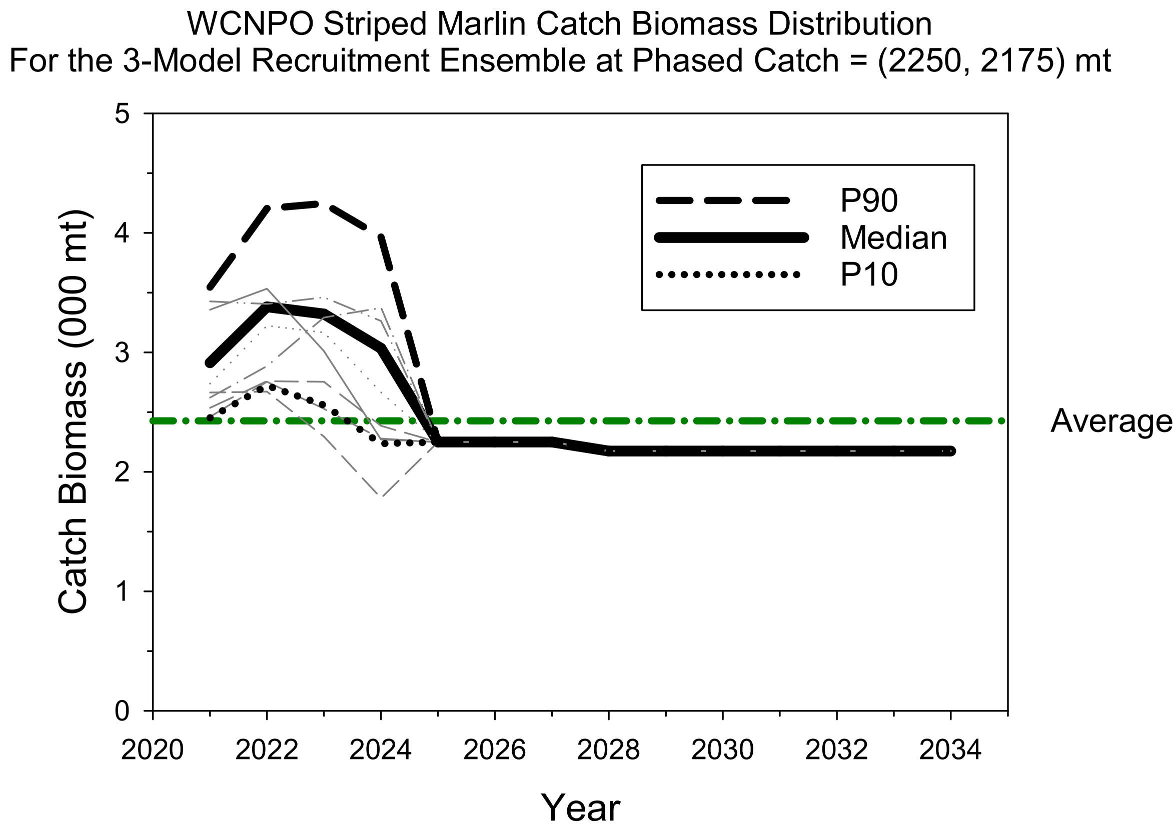


Figure 36.6. The time series of median catch biomasses to rebuild the stock under Scenario 6 (3-phase catch = (2400, 2200, 2100) mt) with the 10th (P10) and 90th (P90) percentiles of the annual catch biomass distributions relative to the recent average yield during 2018–2020 of 2,428 mt along with individual trajectories (grey lines).

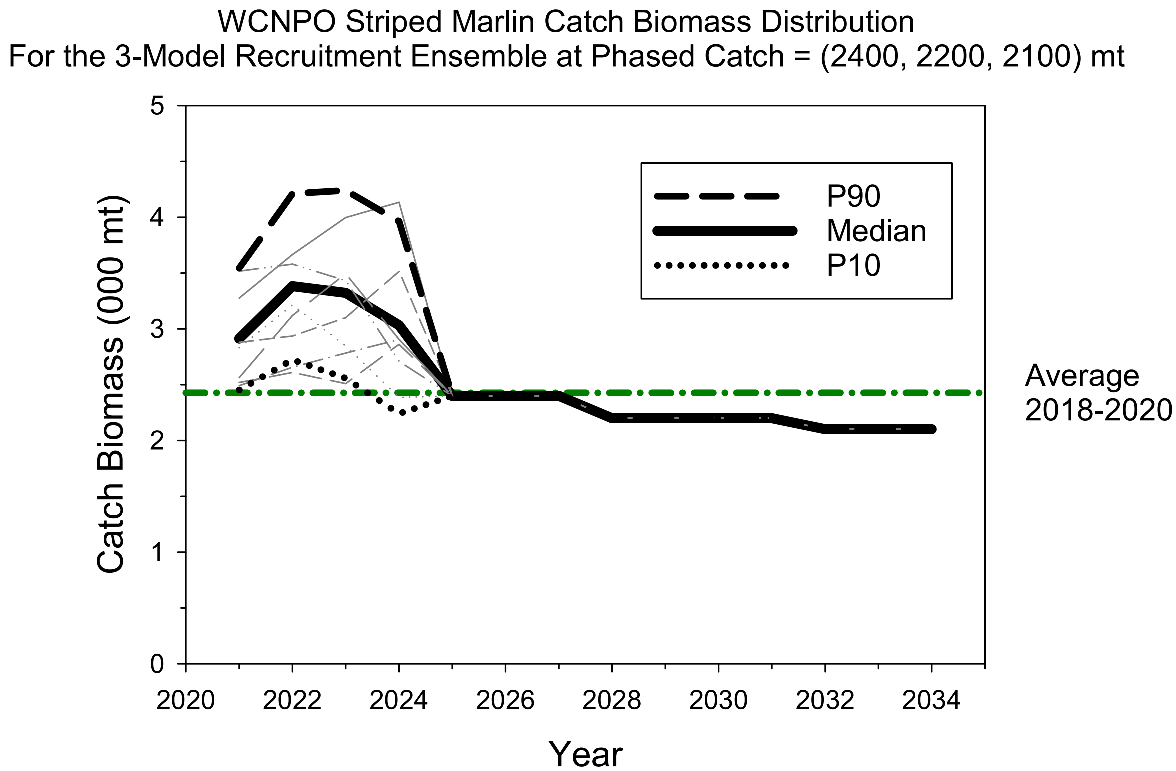


Figure 36.7. The time series of median catch biomasses to rebuild the stock under Scenario 7 (catch-release with low survival and catch = 2180 mt) with the 10th (P10) and 90th (P90) percentiles of the annual catch biomass distributions relative to the recent average yield during 2018–2020 of 2,428 mt along with individual trajectories (grey lines) along with individual trajectories (grey lines).

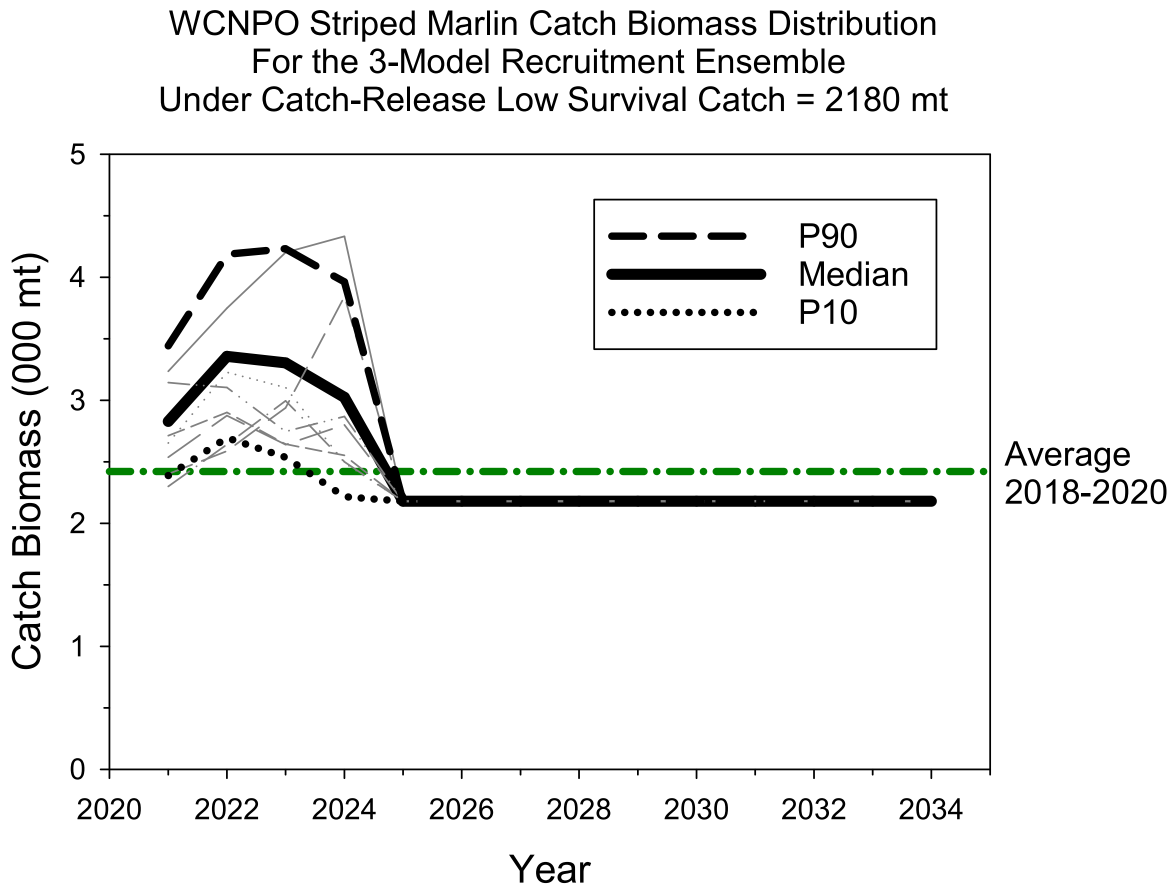


Figure 36.8. The time series of median catch biomasses to rebuild the stock under Scenario 8 (catch-release with high survival and catch = 2185 mt) with the 10th (P10) and 90th (P90) percentiles of the annual catch biomass distributions relative to the recent average yield during 2018–2020 of 2,428 mt along with individual trajectories (grey lines) along with individual trajectories (grey lines).

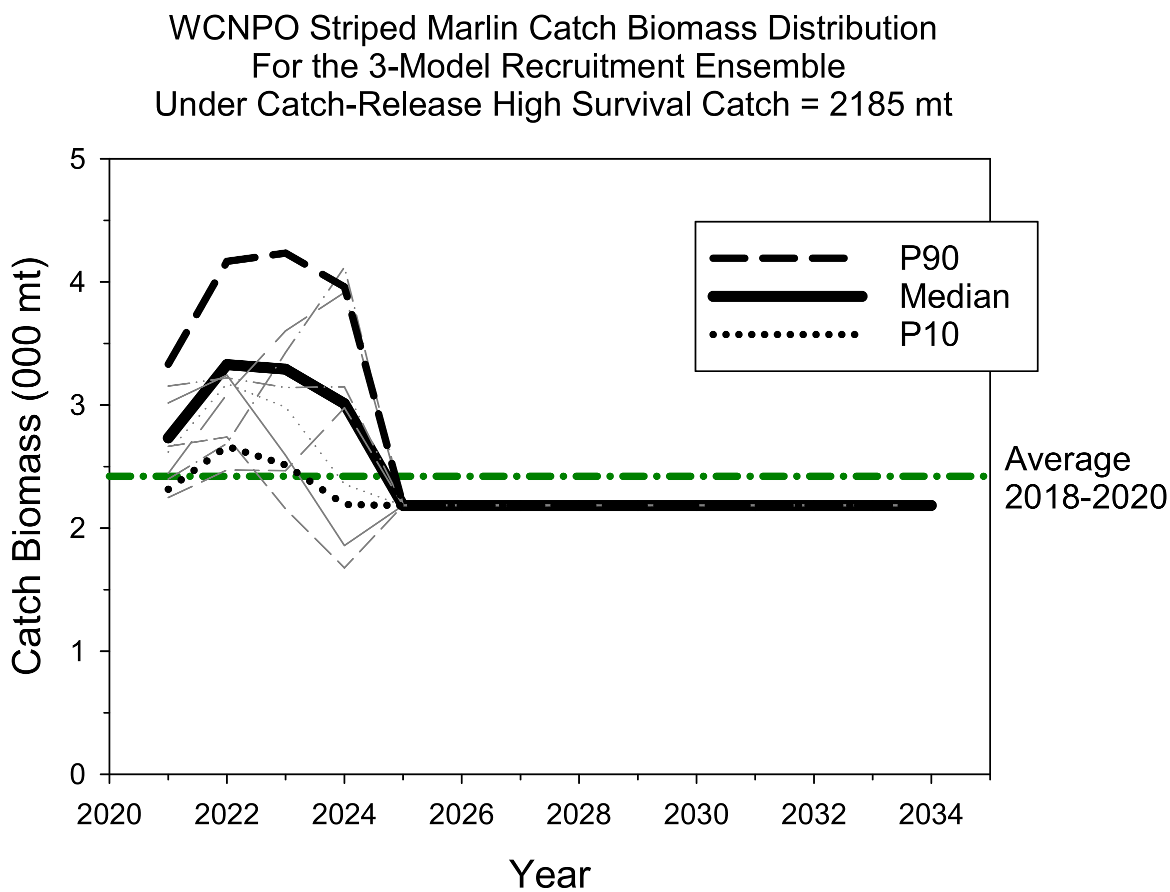


Figure 36.9. Comparison of median catch biomasses to rebuild the stock under fishing mortality-based rebuilding scenarios along with biomasses under constant status quo F and Fmsy scenarios.

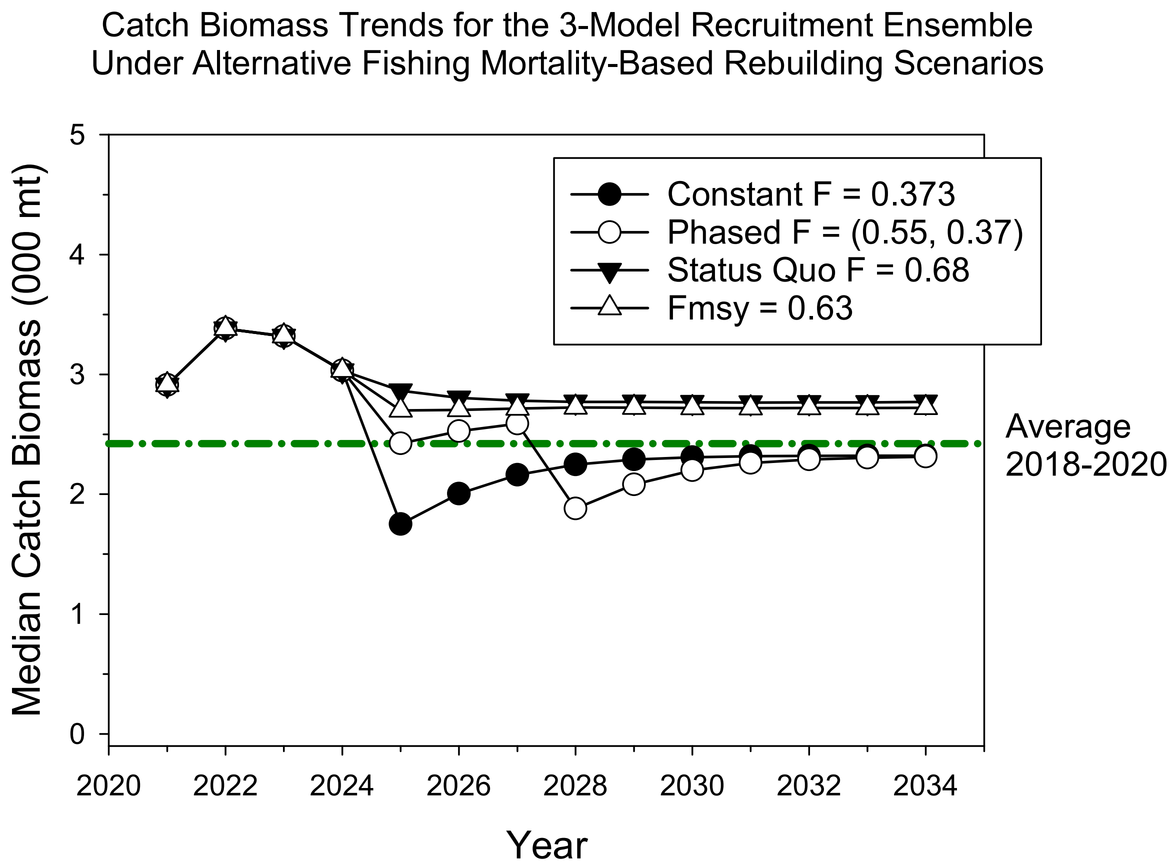


Figure 36.10. Comparison of median catch biomasses to rebuild the stock under catch biomass-based rebuilding scenarios.

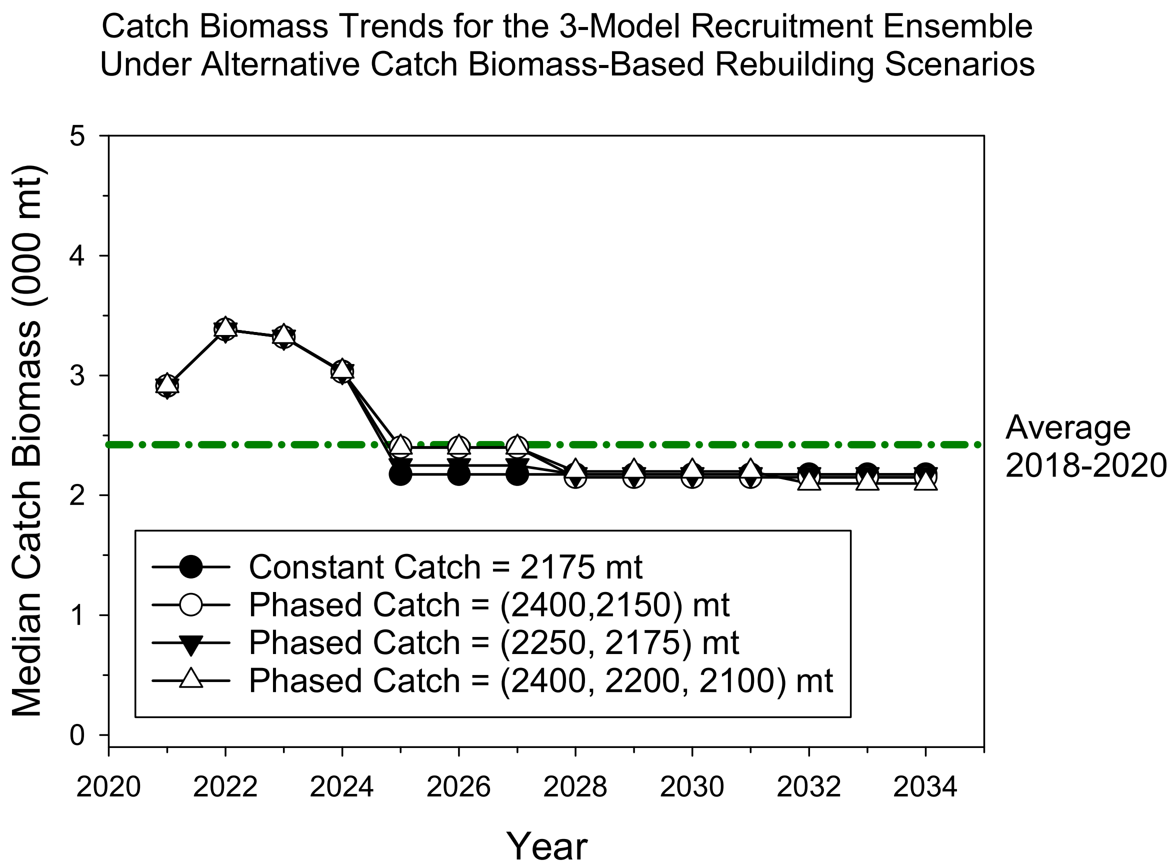


Figure 36.11. Comparison of median catch biomasses to rebuild the stock under catch catch release-based rebuilding scenarios.

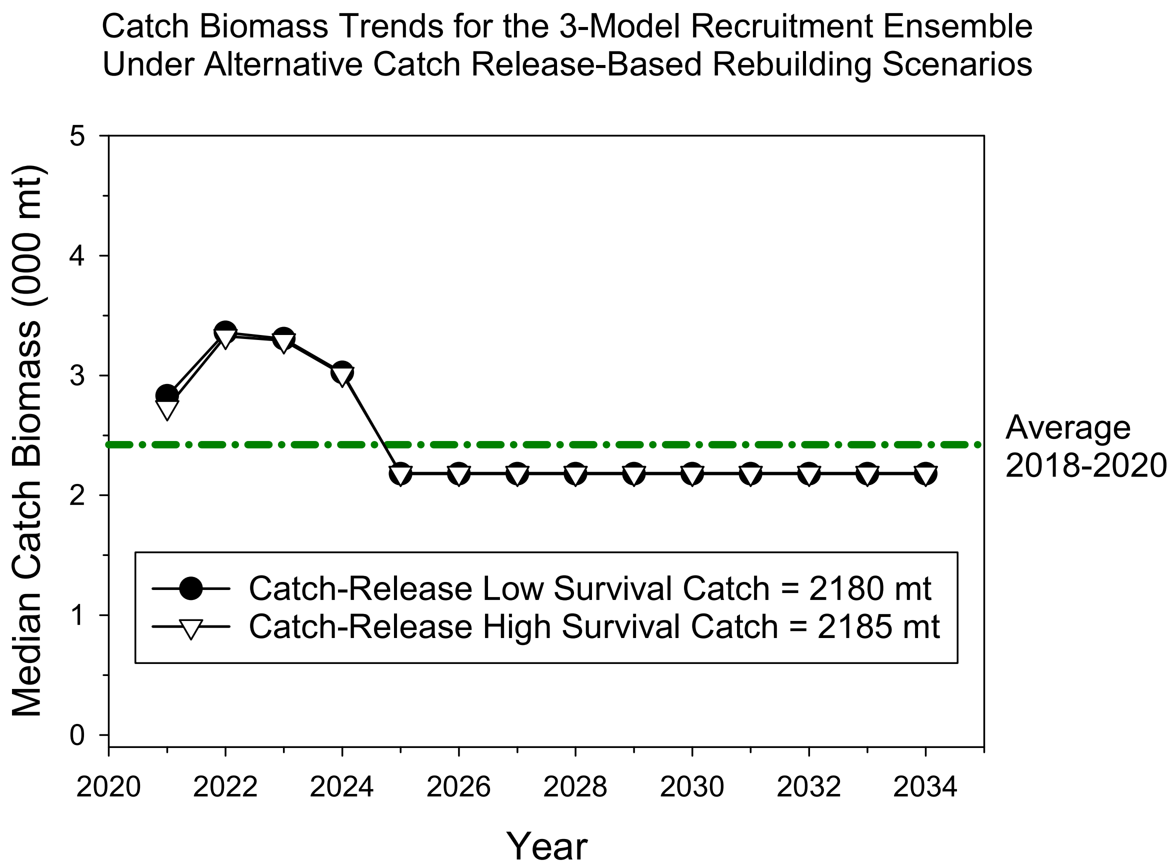


Figure 37.1. The time series of median spawning biomasses to rebuild the stock under Scenario 1 (constant F = 0.373) with the 10th (P10), 40th (SSB Rebuild, blue line), and 90th (P90) percentiles of the annual spawning biomass distributions relative to the rebuilding target of 3,660 mt along with individual trajectories (grey lines).

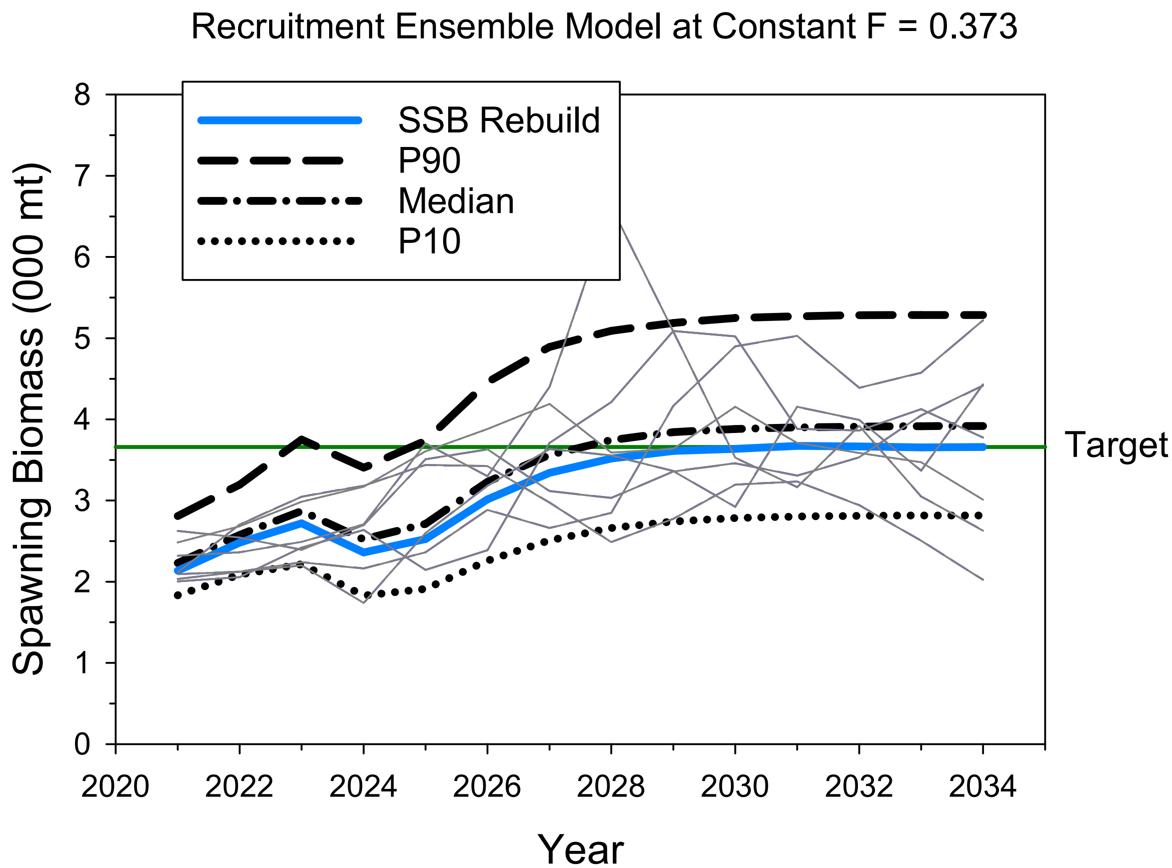


Figure 37.2. The time series of median spawning biomasses to rebuild the stock under <u>Scenario 2</u> (constant catch = 2175 mt) with the 10th (P10), 40th (SSB Rebuild, blue line), and 90th (P90) percentiles of the annual spawning biomass distributions relative to the rebuilding target of 3,660 mt along with individual trajectories (grey lines).

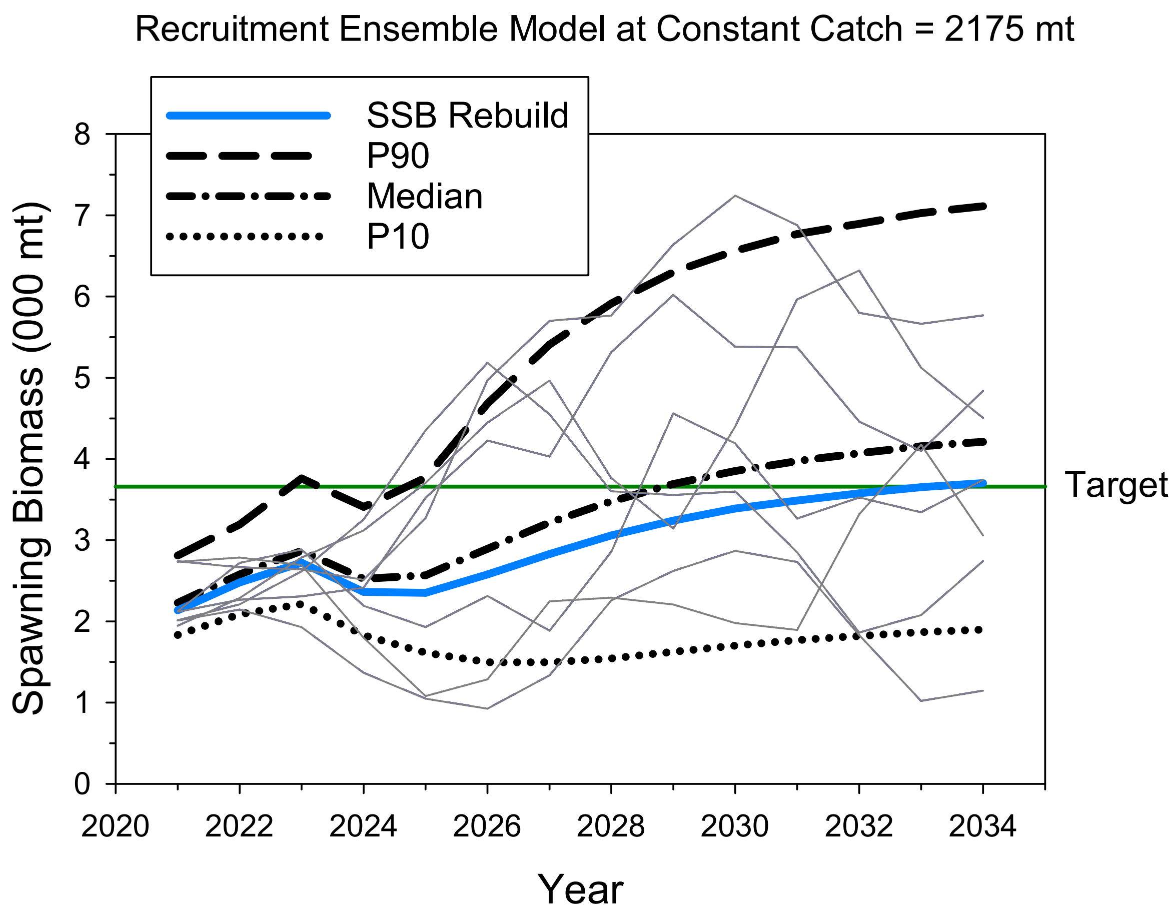


Figure 37.3. The time series of median spawning biomasses to rebuild the stock under Scenario 3 (phased F = (0.55, 0.37)) with the 10th (P10), 40th (SSB Rebuild, blue line), and 90th (P90) percentiles of the annual spawning biomass distributions relative to the rebuilding target of 3,660 mt along with individual trajectories (grey lines).

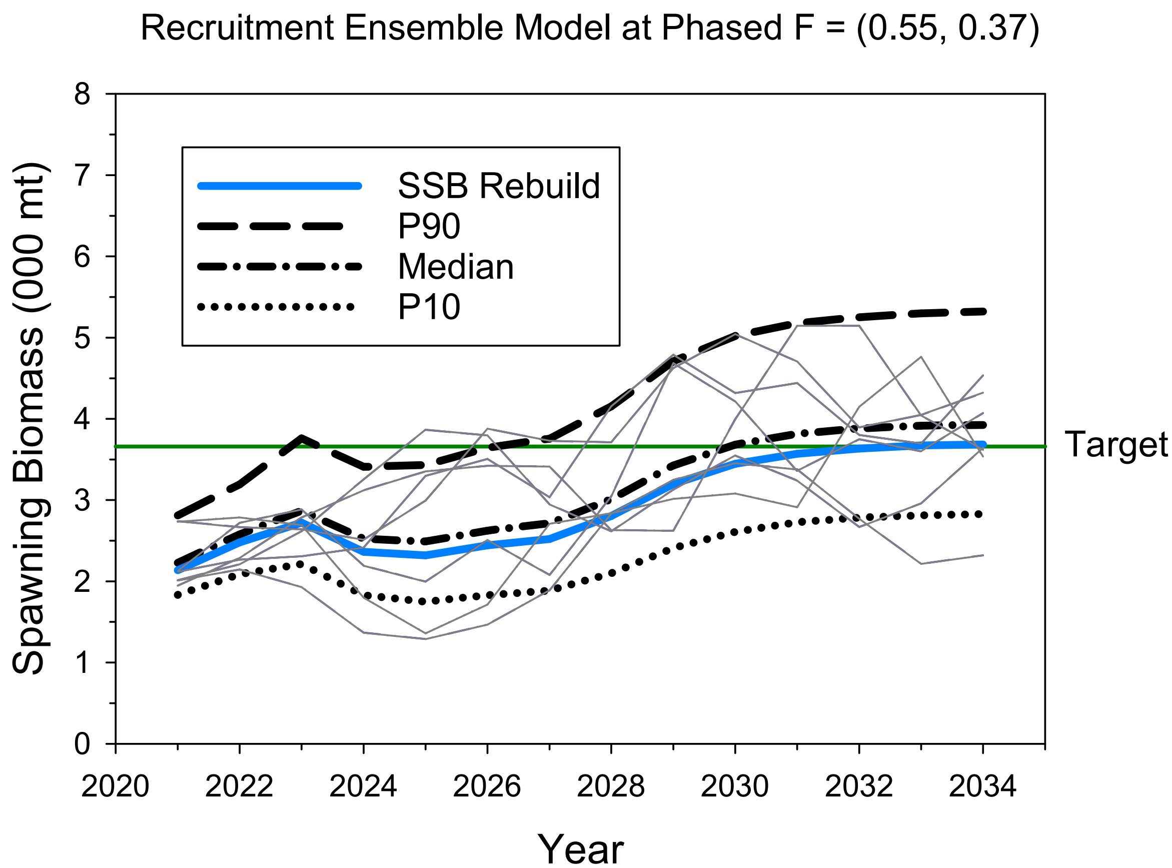


Figure 37.4. The time series of median spawning biomasses to rebuild the stock under Scenario 4 (phased catch = (2400, 2150) mt) with the 10th (P10), 40th (SSB Rebuild, blue line), and 90th (P90) percentiles of the annual spawning biomass distributions relative to the rebuilding target of 3,660 mt along with individual trajectories (grey lines).

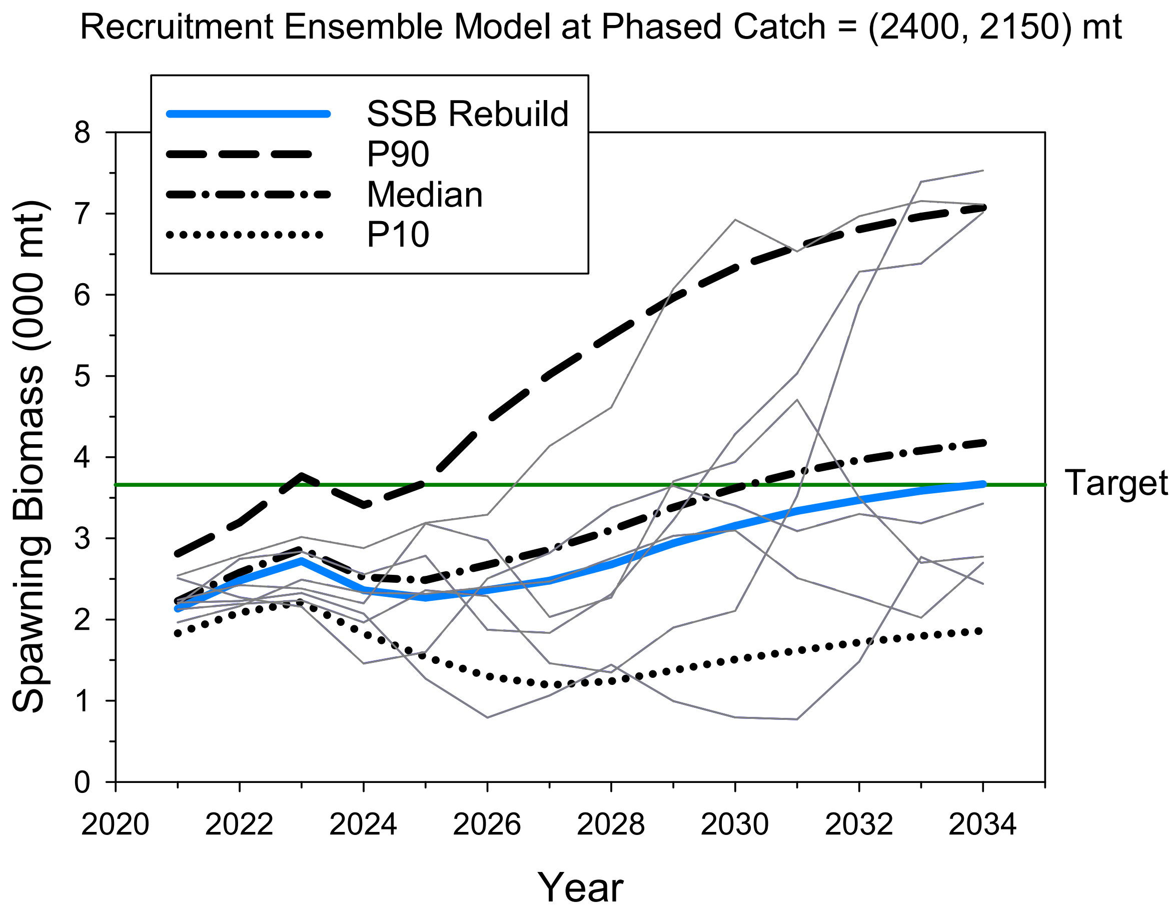


Figure 37.5. The time series of median spawning biomasses to rebuild the stock under Scenario 5 (phased catch = (2250, 2175) mt) with the 10th (P10), 40th (SSB Rebuild, blue line), and 90th (P90) percentiles of the annual spawning biomass distributions relative to the rebuilding target of 3,660 mt along with individual trajectories (grey lines).

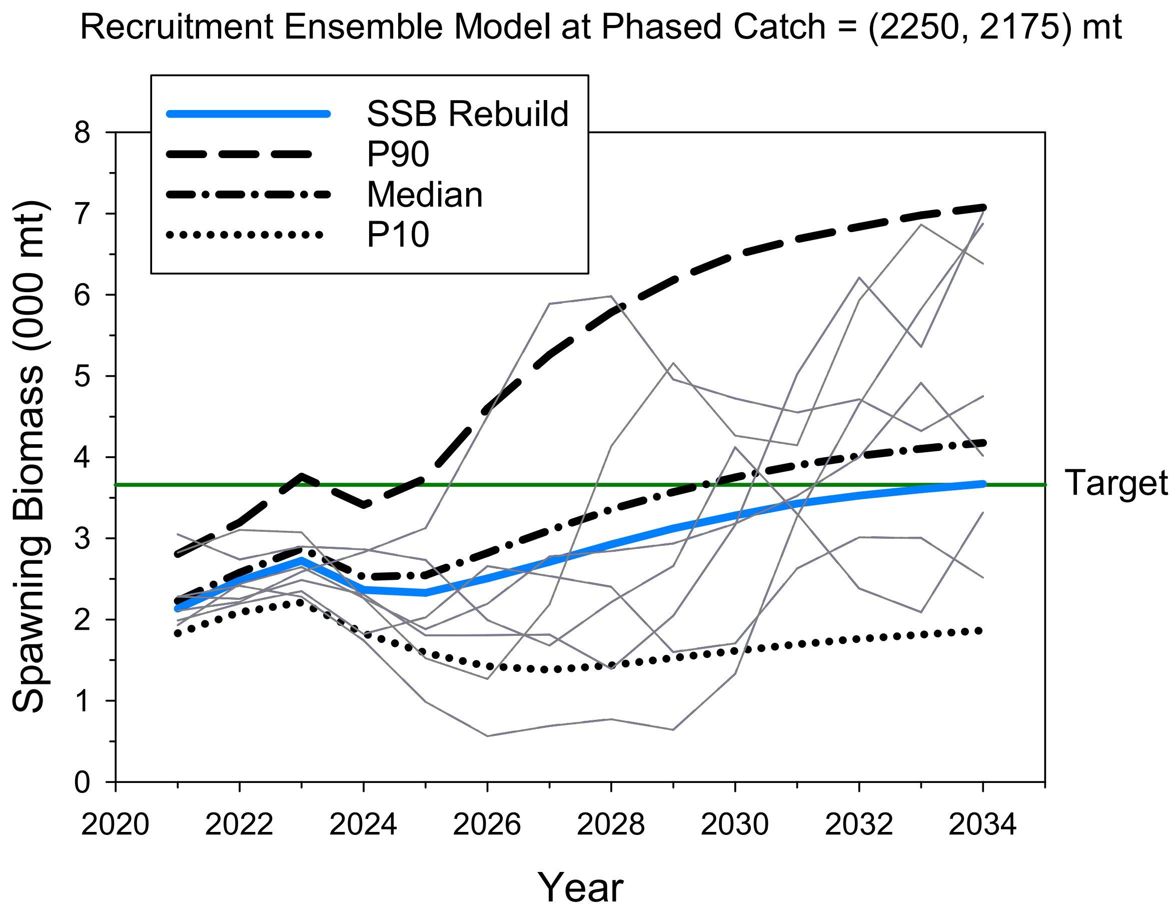


Figure 37.6. The time series of median spawning biomasses to rebuild the stock under Scenario 6 (3-phase catch = (2400, 2200, 2100) mt) with the 10th (P10), 40th (SSB Rebuild, blue line), and 90th (P90) percentiles of the annual spawning biomass distributions relative to the rebuilding target of 3,660 mt along with individual trajectories (grey lines).

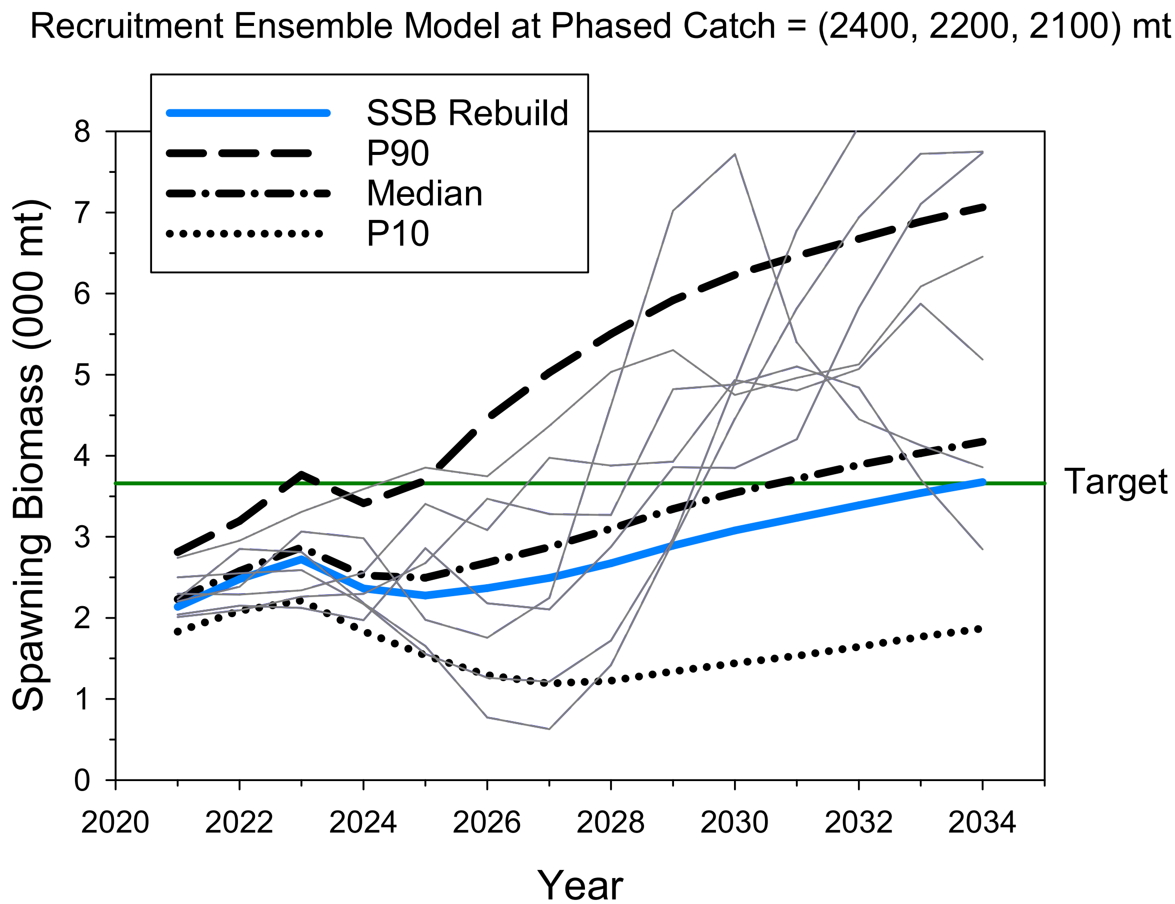


Figure 37.7. The time series of median spawning biomasses to rebuild the stock under Scenario 7 (catch-release with low survival and catch = 2180 mt) with the 10th (P10), 40th (SSB Rebuild, blue line), and 90th (P90) percentiles of the annual spawning biomass distributions relative to the rebuilding target of 3,660 mt along with individual trajectories (grey lines).

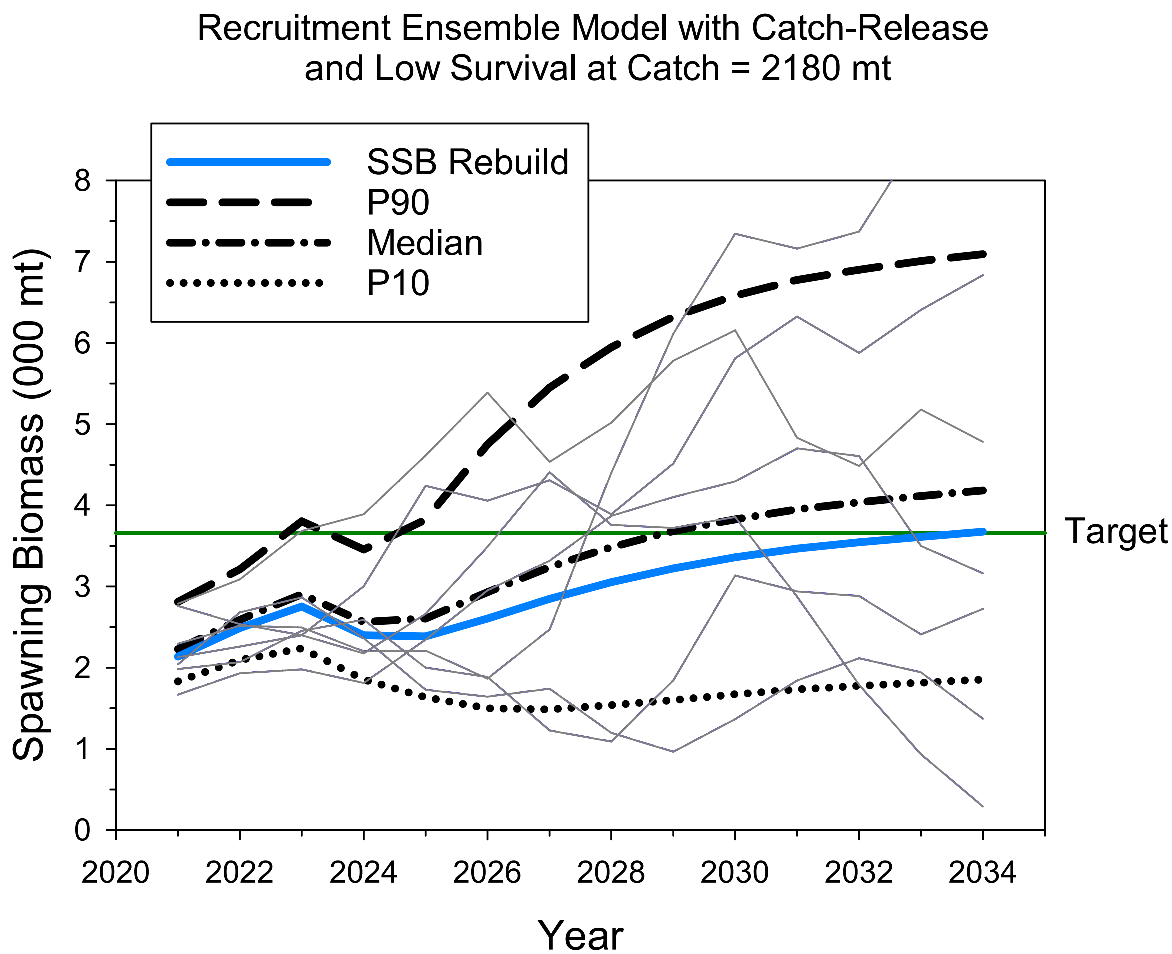


Figure 37.8. The time series of median spawning biomasses to rebuild the stock under Scenario 8 (catch-release with high survival and catch = 2185 mt) with the 10th (P10), 40th (SSB Rebuild, blue line), and 90th (P90) percentiles of the annual spawning biomass distributions relative to the rebuilding target of 3,660 mt along with individual trajectories (grey lines).

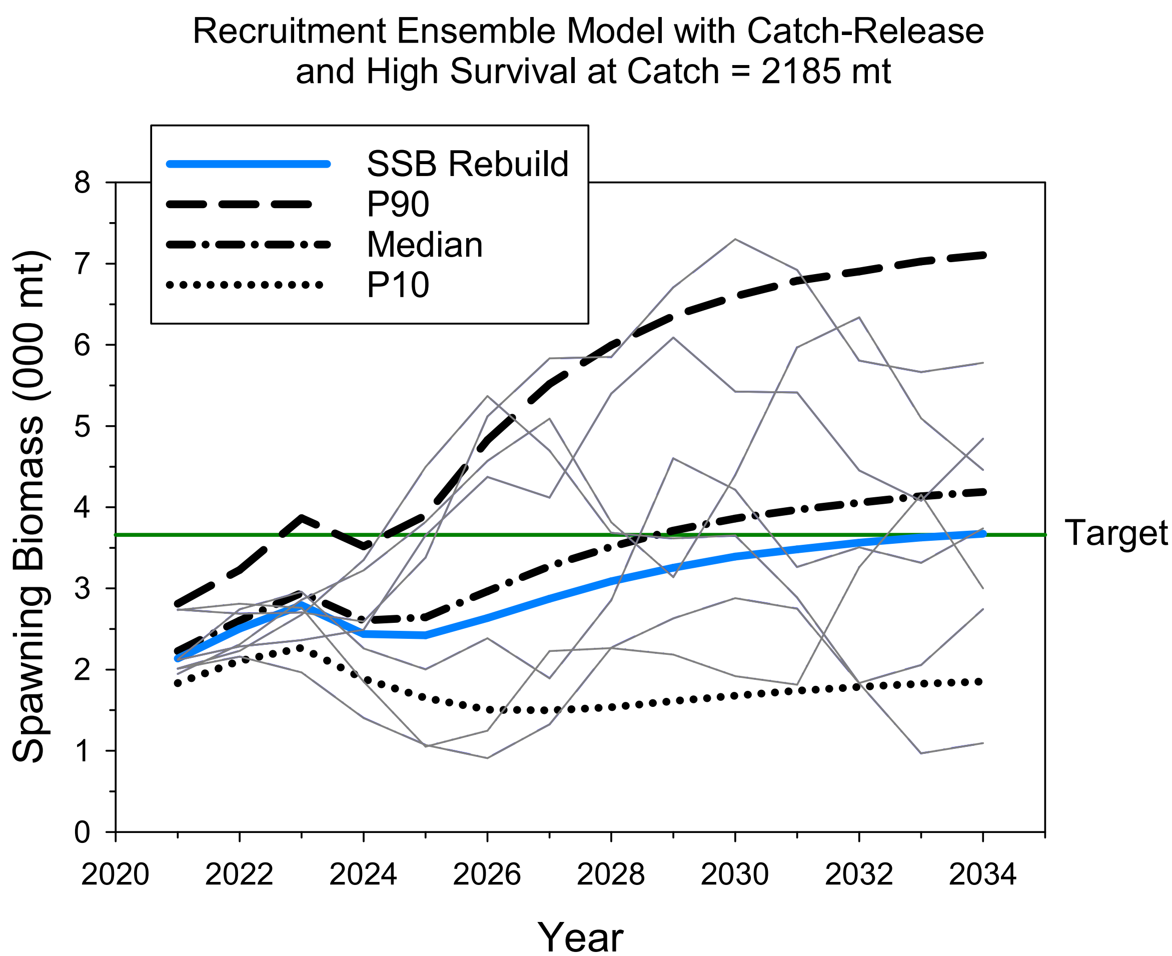


Figure 37.9. Comparison of median spawning biomasses under fishing mortality-based rebuilding scenarios along with biomasses under constant status quo F and Fmsy scenarios.

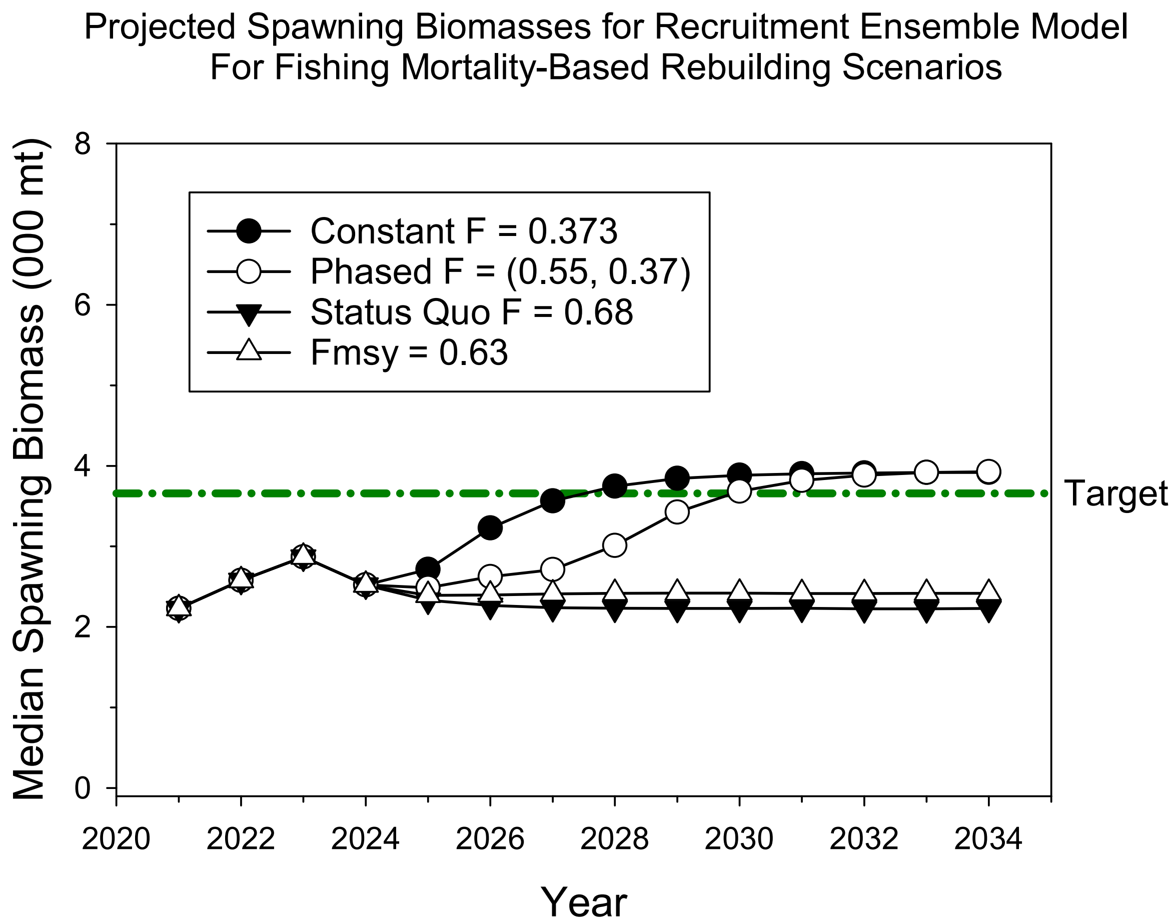


Figure 37.10. Comparison of median spawning biomasses under catch biomass-based rebuilding scenarios.

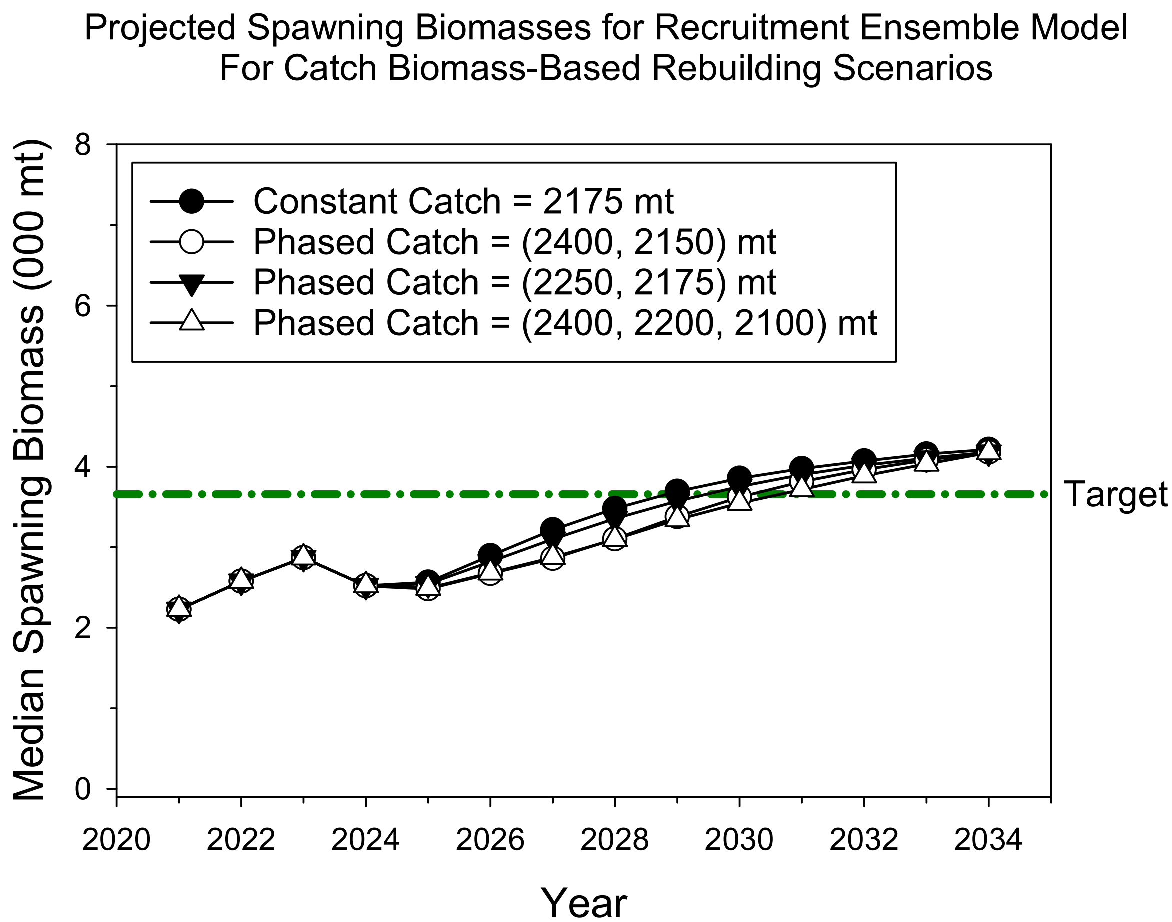


Figure 37.11. Comparison of median spawning biomasses under catch release-based rebuilding scenarios.

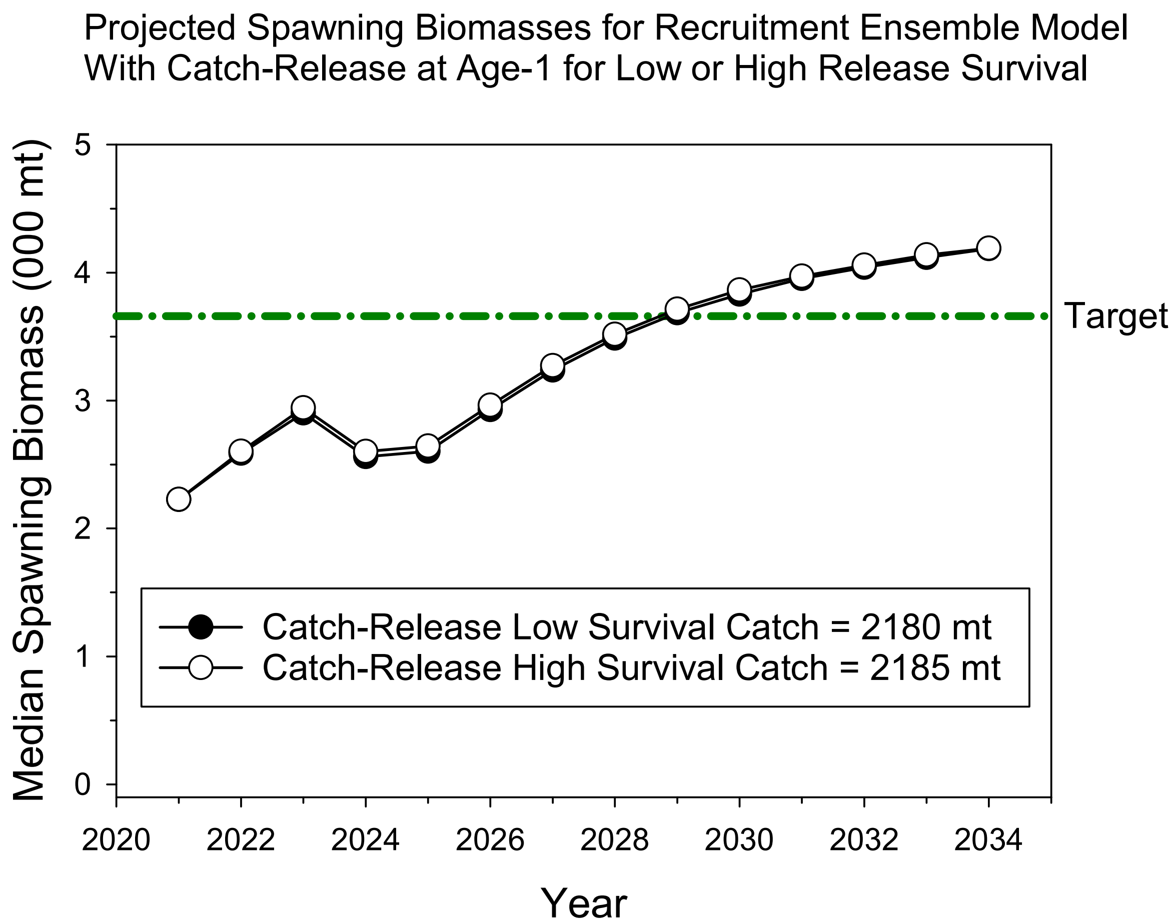


Figure 38.1. The time series of median fishing mortalities to rebuild the stock under Scenario 1 (constant F = 0.373) along with the 10th (P10) and 90th (P90) percentiles of the annual fishing mortality distributions relative to the potential overfishing reference point of $F_{20\%SSB(F=0)}$=0.53.

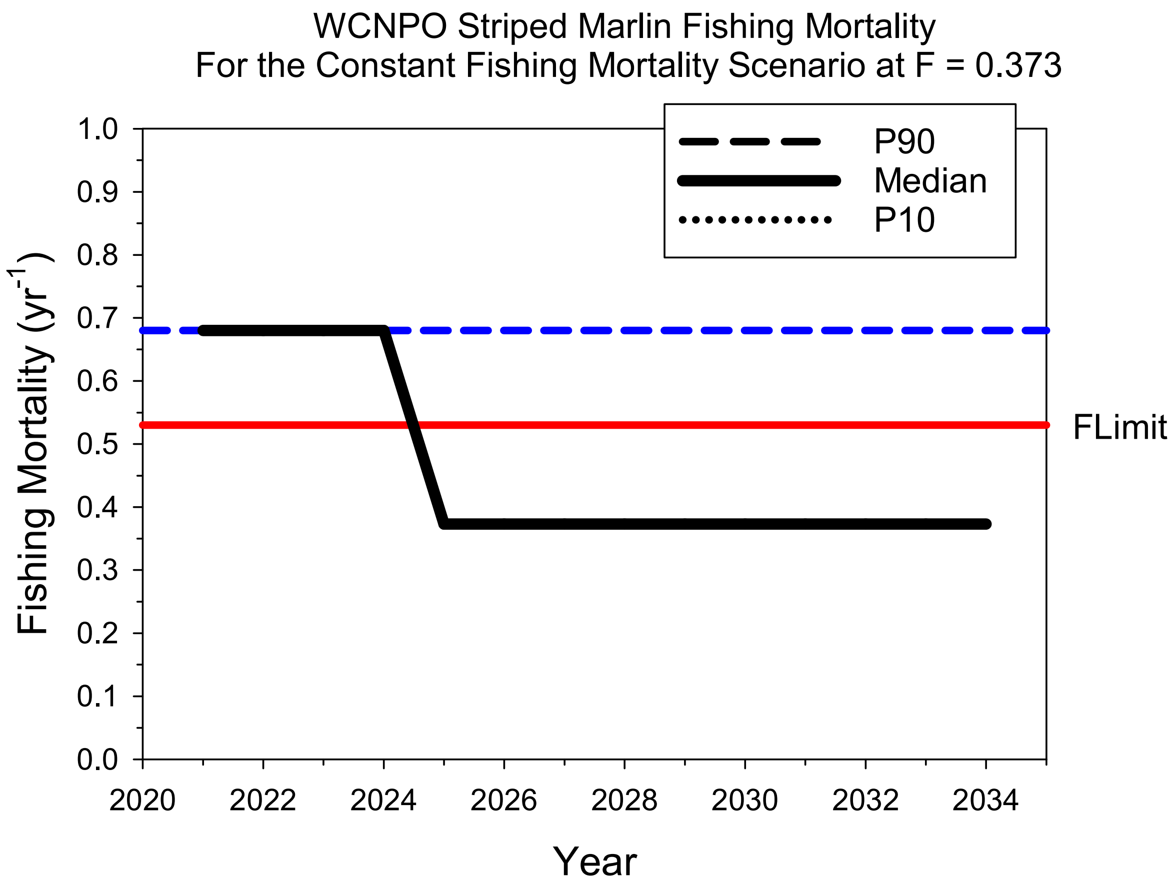


Figure 38.2. The time series of median fishing mortalities to rebuild the stock under Scenario 2 (constant catch = 2175 mt) with the 10th (P10) and 90th (P90) percentiles of the annual fishing mortality distributions relative to the potential overfishing reference point of2$F_{20\%SSB(F=0)}$=0.53 along with individual trajectories (grey lines).

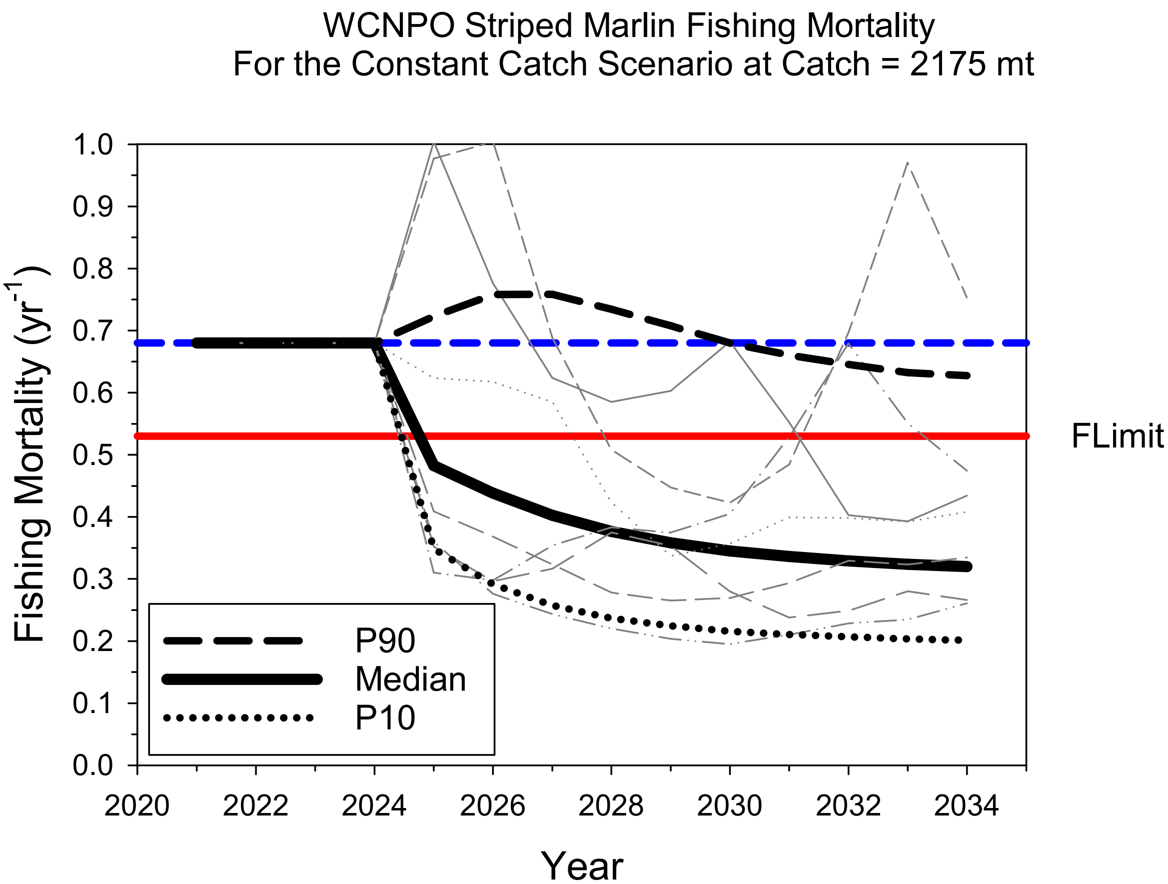


Figure 38.3. The time series of median fishing mortalities to rebuild the stock under Scenario 3 (phased F = (0.55, 0.37)) along with the 10th (P10) and 90th (P90) percentiles of the annual fishing mortality distributions relative to the potential overfishing reference point of $F_{20\%SSB(F=0)}$=0.53.

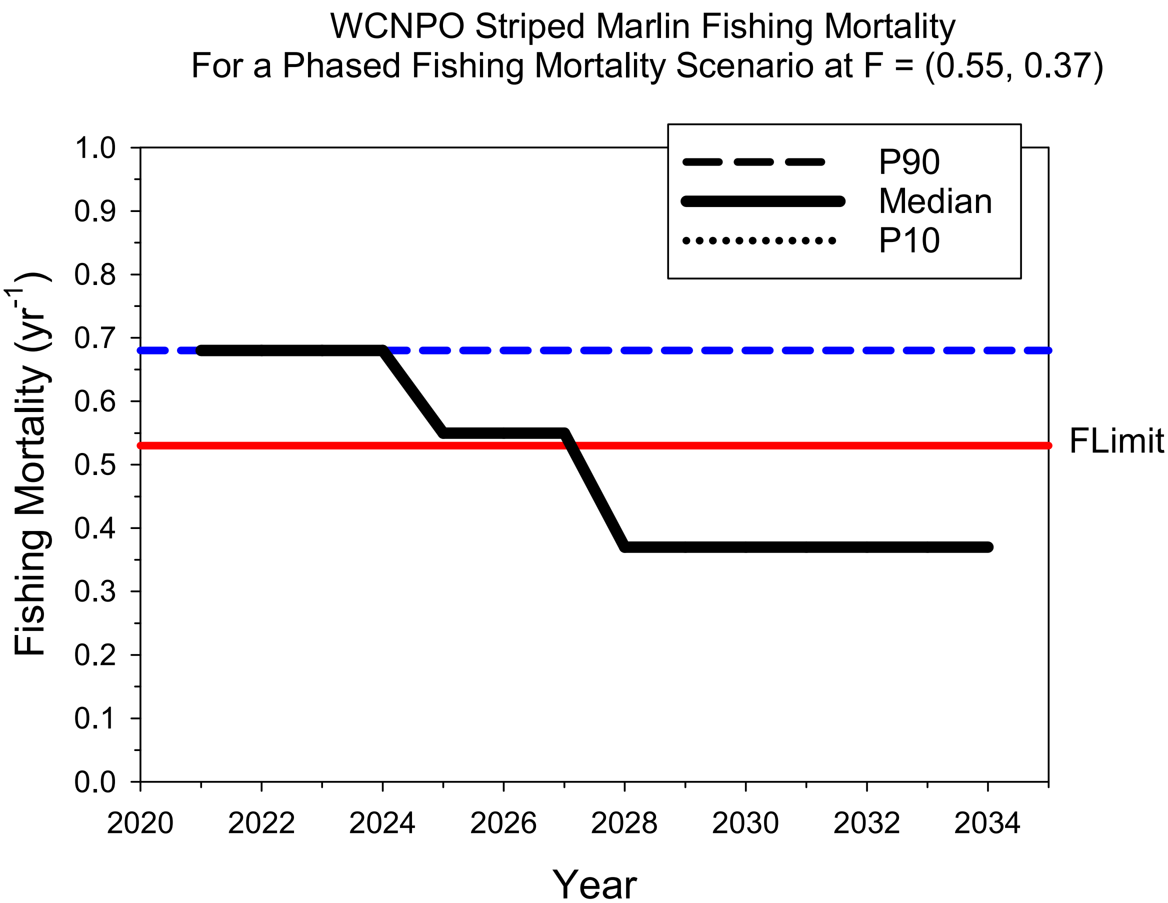


Figure 38.4. The time series of median fishing mortalities to rebuild the stock under Scenario 4 (phased catch = (2400, 2150) mt) with the 10th (P10) and 90th (P90) percentiles of the annual fishing mortality distributions relative to the potential overfishing reference point of $2F_{20\%SSB(F=0)}=0.53$ along with individual trajectories (grey lines).

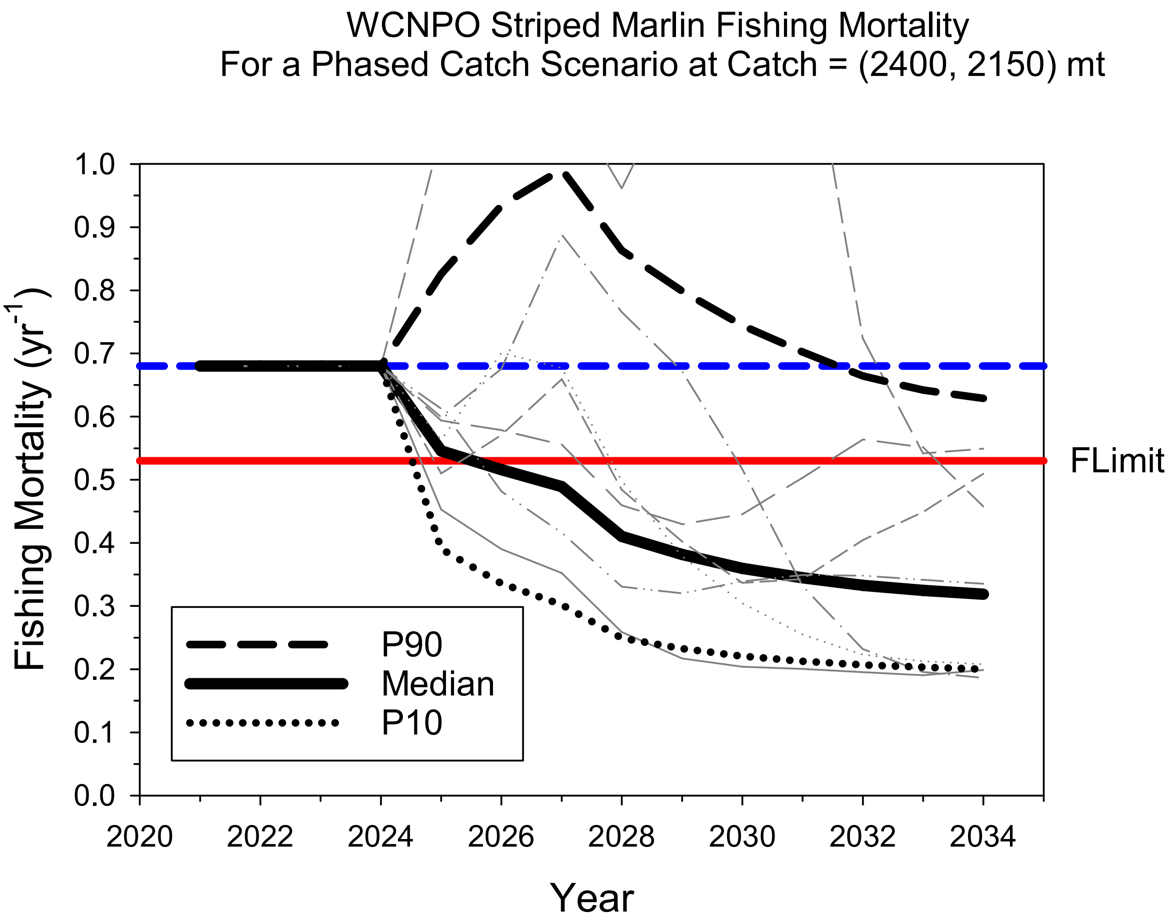


Figure 38.5. The time series of median fishing mortalities to rebuild the stock under Scenario 5 (phased catch = (2250, 2175) mt) with the 10th (P10) and 90th (P90) percentiles of the annual fishing mortality distributions relative to the potential overfishing reference point of $2F_{20\%SSB(F=0)}$=0.53 along with individual trajectories (grey lines).

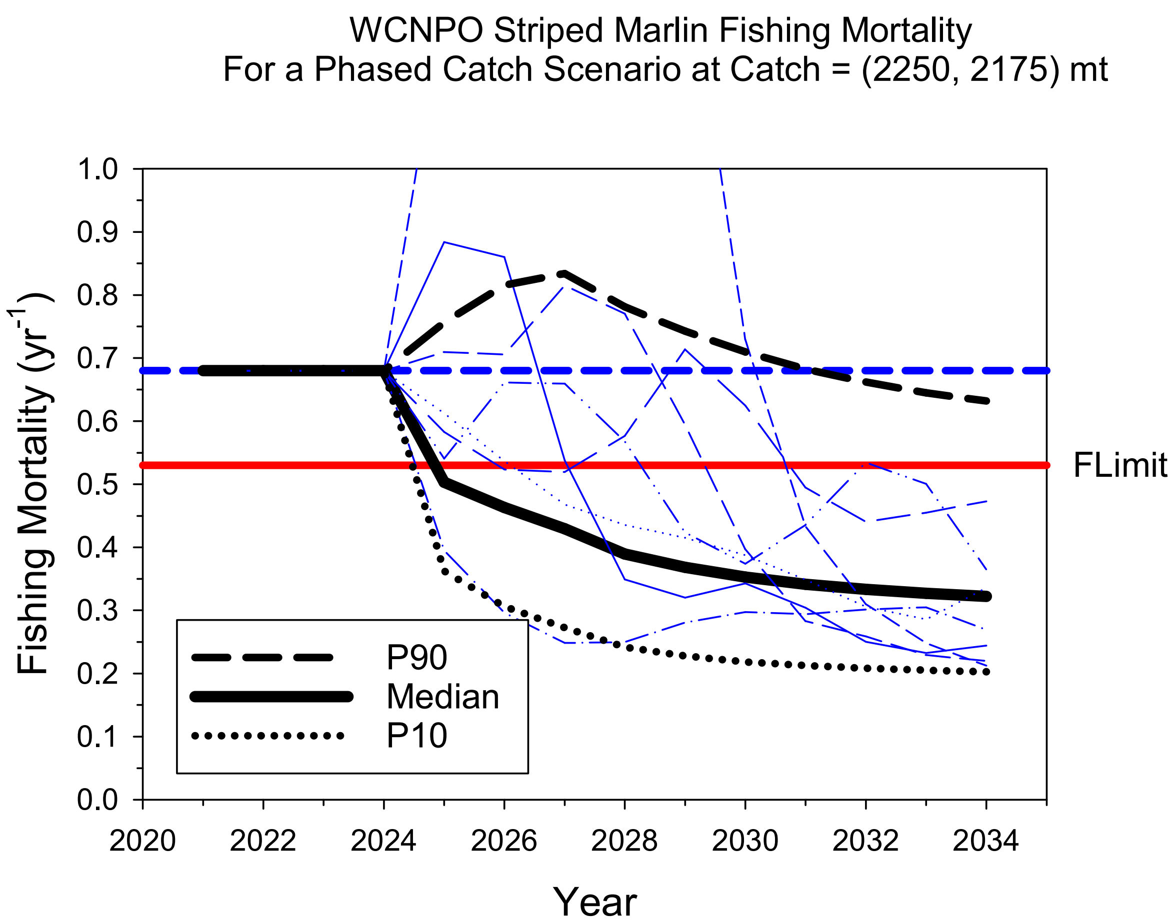


Figure 38.6. The time series of median fishing mortalities to rebuild the stock under Scenario 6 (3-phase catch = (2400, 2200, 2100) mt) with the 10th (P10) and 90th (P90) percentiles of the annual fishing mortality distributions relative to the potential overfishing reference point of $2F_{20\%SSB(F=0)}$=0.53 along with individual trajectories (grey lines).

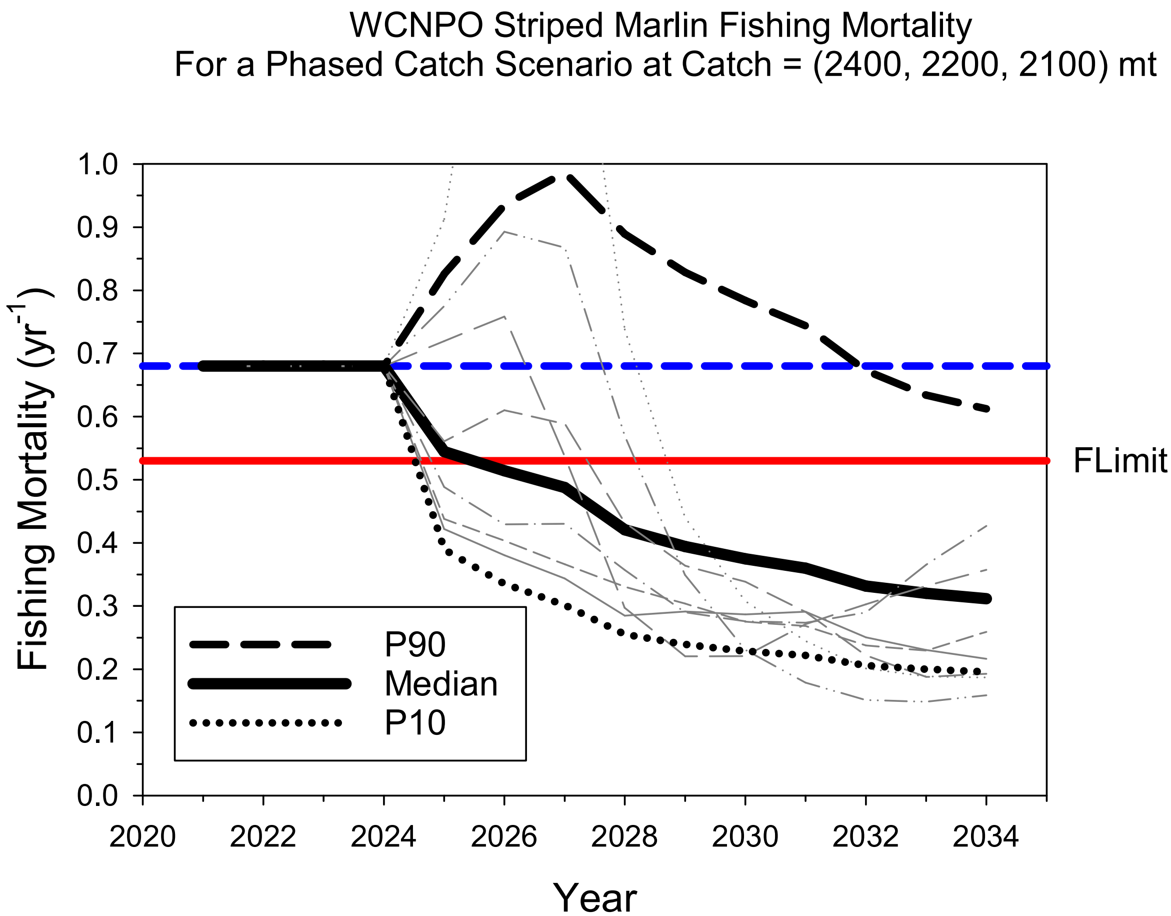


Figure 38.7. The time series of median fishing mortalities to rebuild the stock under Scenario 7 (catch-release with low survival and catch = 2180 mt) with the 10th (P10) and 90th (P90) percentiles of the annual fishing mortality distributions relative to the potential overfishing reference point of $2F_{20\%SSB(F=0)}$=0.53 along with individual trajectories (grey lines).

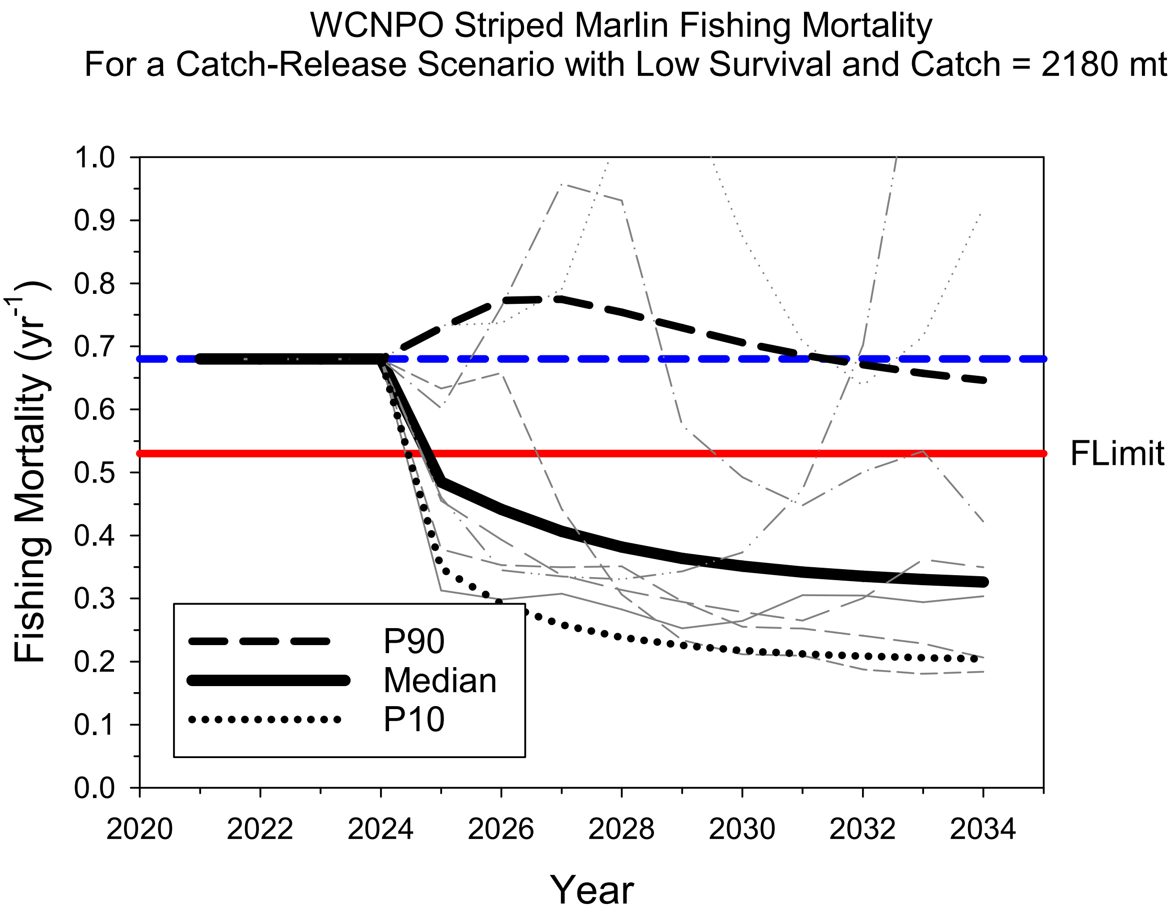


Figure 38.8. The time series of median fishing mortalities to rebuild the stock under Scenario 8 (catch-release with high survival and catch = 2185 mt) with the 10th (P10) and 90th (P90) percentiles of the annual fishing mortality distributions relative to the potential overfishing reference point of$2F_{20\%SSB(F=0)}$=0.53 along with individual trajectories (grey lines).

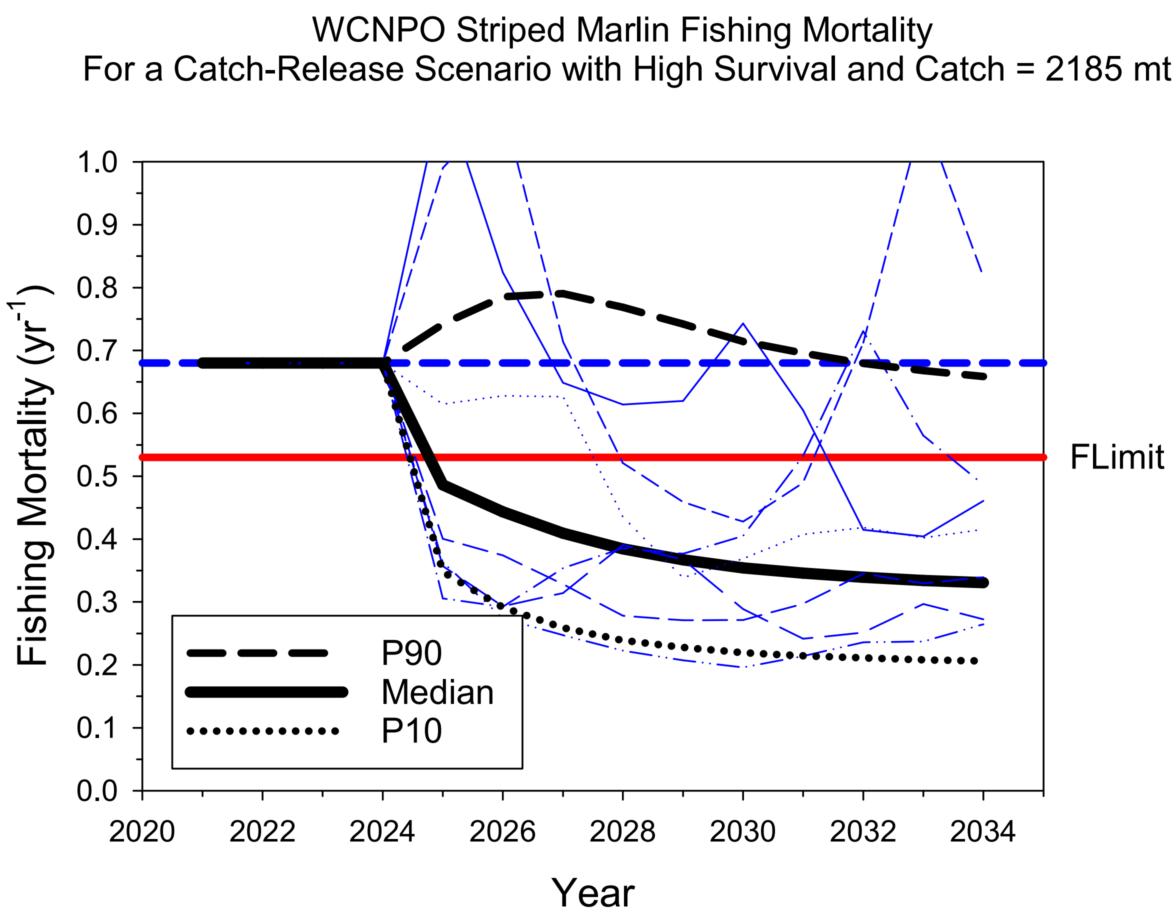


Figure 38.9. Comparison of median fishing mortalities to rebuild the stock under fishing mortality-based rebuilding scenarios along with fishing mortalities under constant status quo F and Fmsy scenarios.

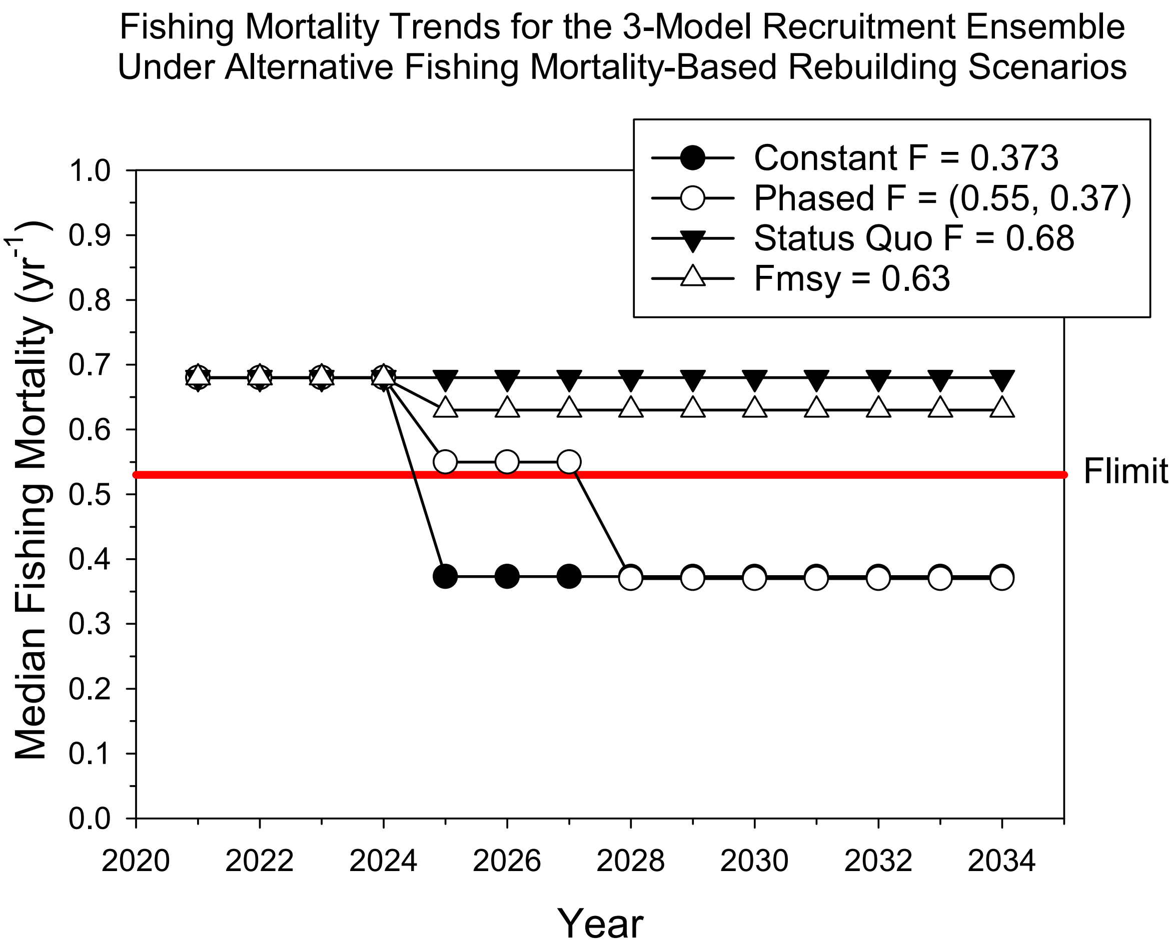


Figure 38.10. Comparison of median fishing mortalities to rebuild the stock under catch biomass-based rebuilding scenarios.

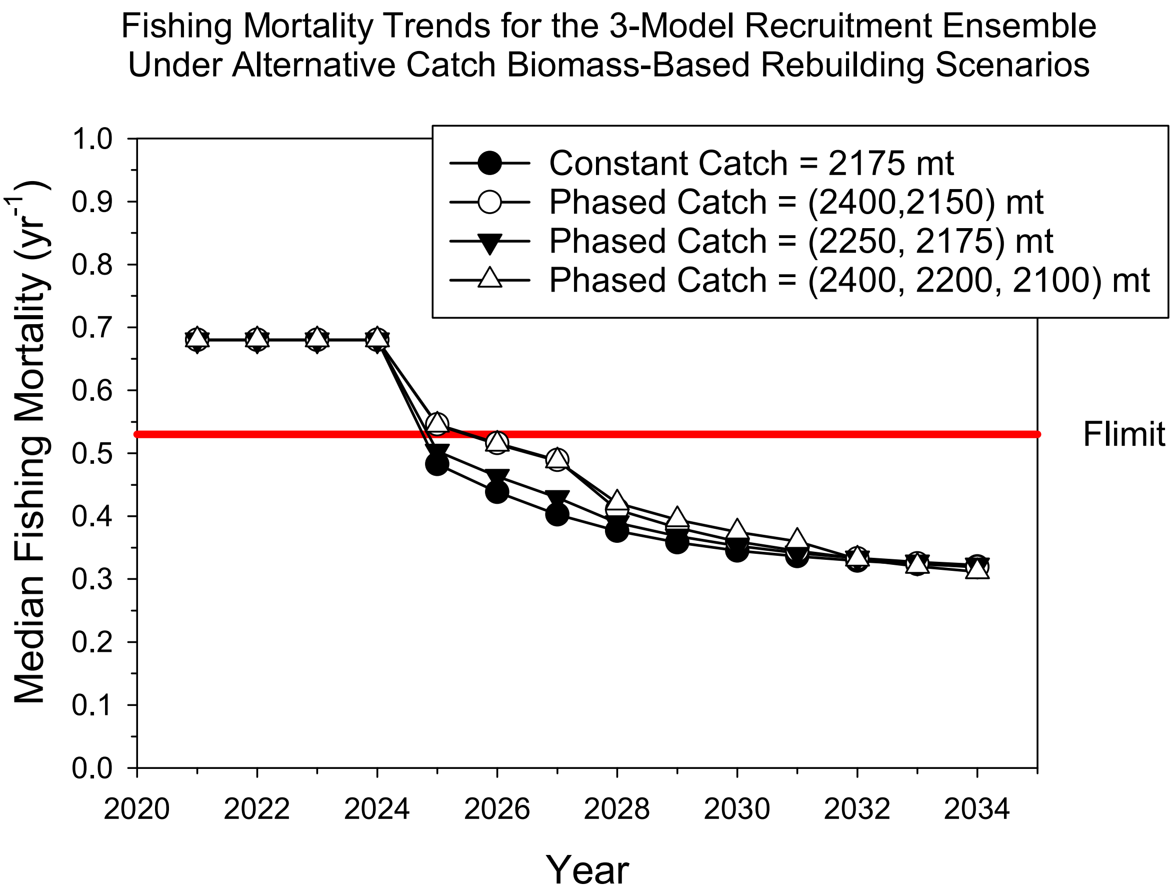


Figure 38.11. Comparison of median fishing mortalities to rebuild the stock under catch release-based rebuilding scenarios.

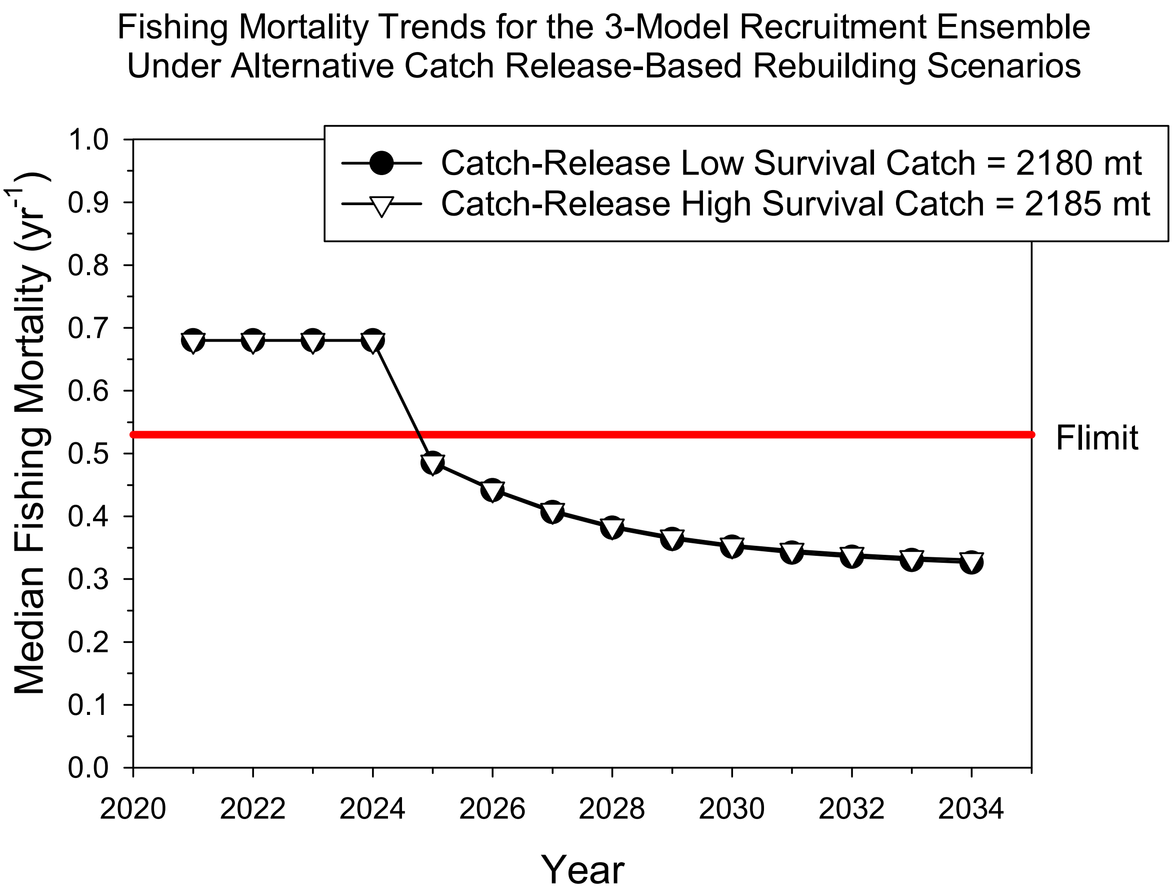


Figure 39.1. Comparison of annual probabilities of achieving the rebuilding target of 3,660 mt of spawning biomass with at least 60% probability during 2021–2034 under the fishing mortality-based rebuilding scenarios.

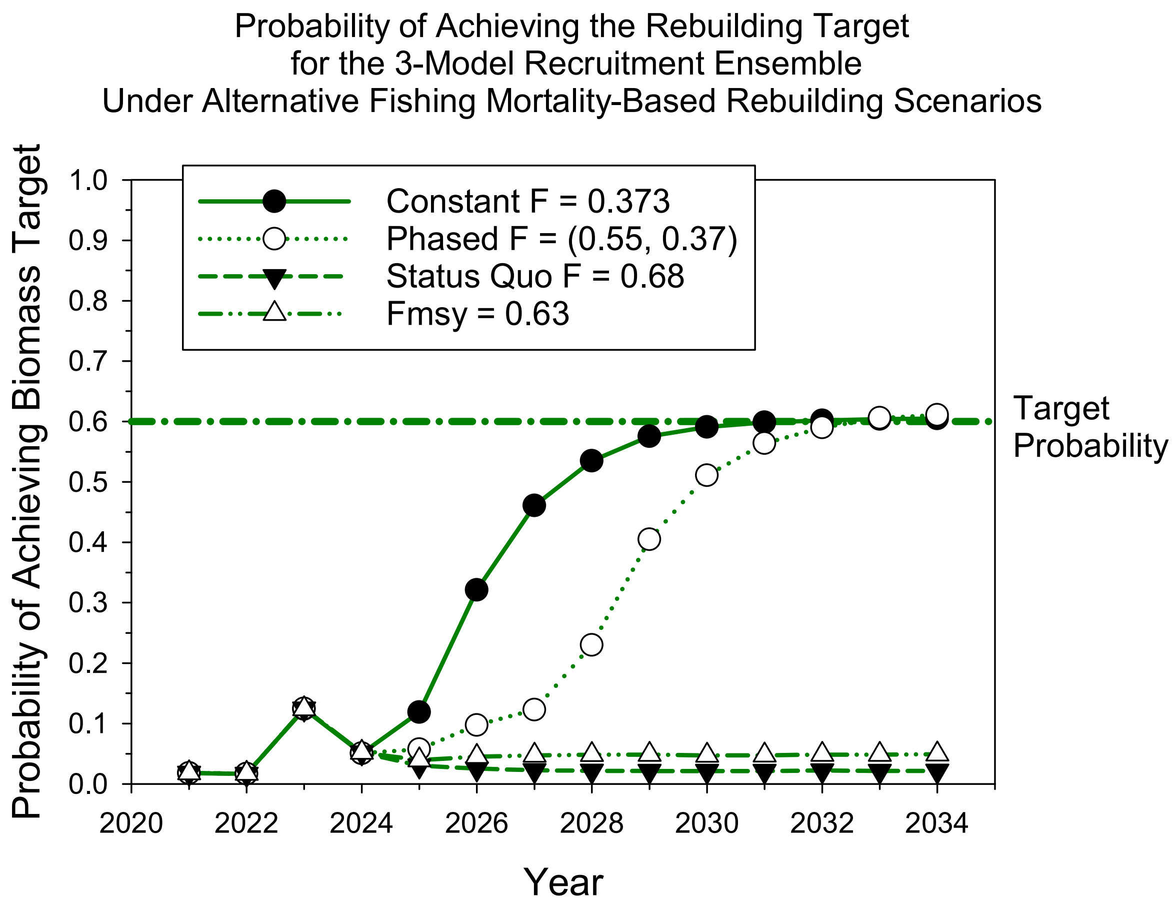


Figure 39.2. Comparison of annual probabilities of achieving the rebuilding target of 3,660 mt of spawning biomass with at least 60% probability during 2021–2034 under the catch biomass-based rebuilding scenarios.

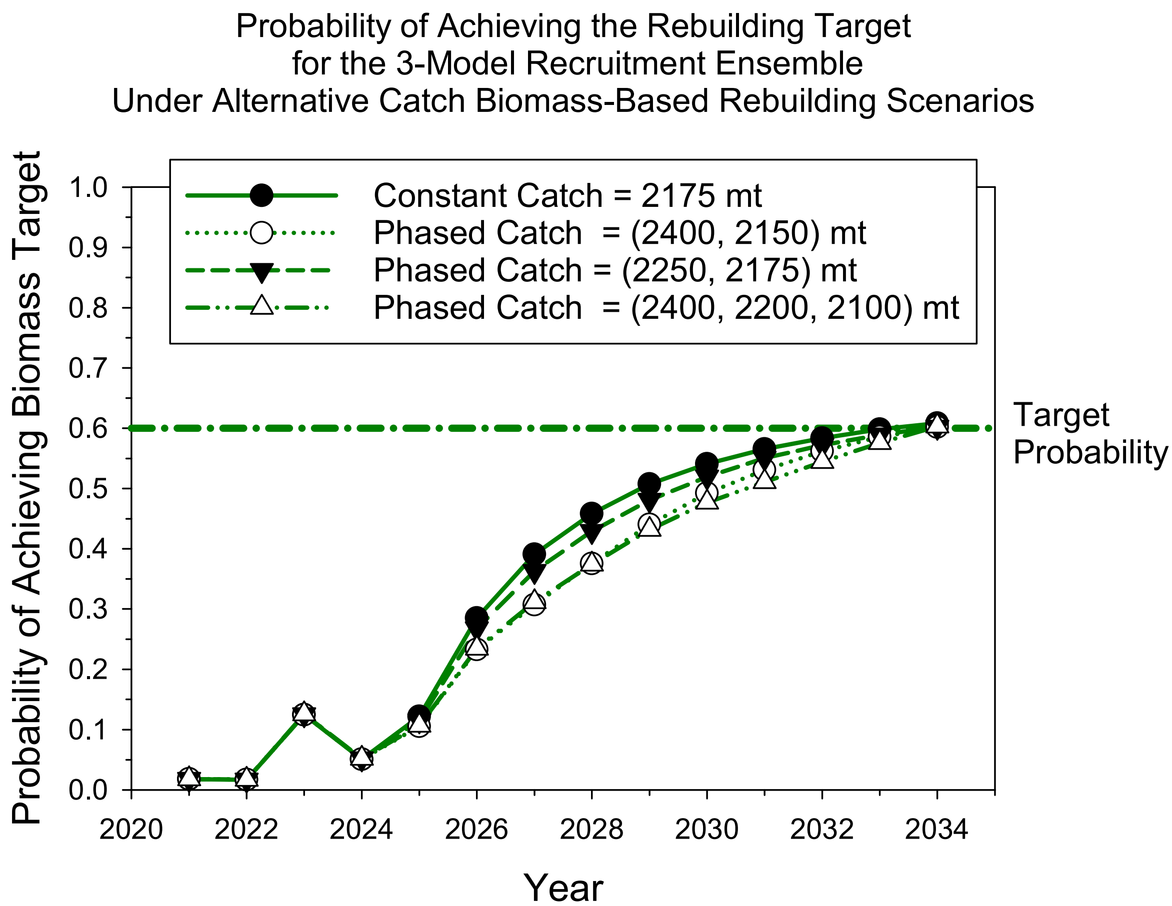


Figure 39.3. Comparison of annual probabilities of achieving the rebuilding target of 3,660 mt of spawning biomass with at least 60% probability during 2021–2034 under the catch release-based rebuilding scenarios.

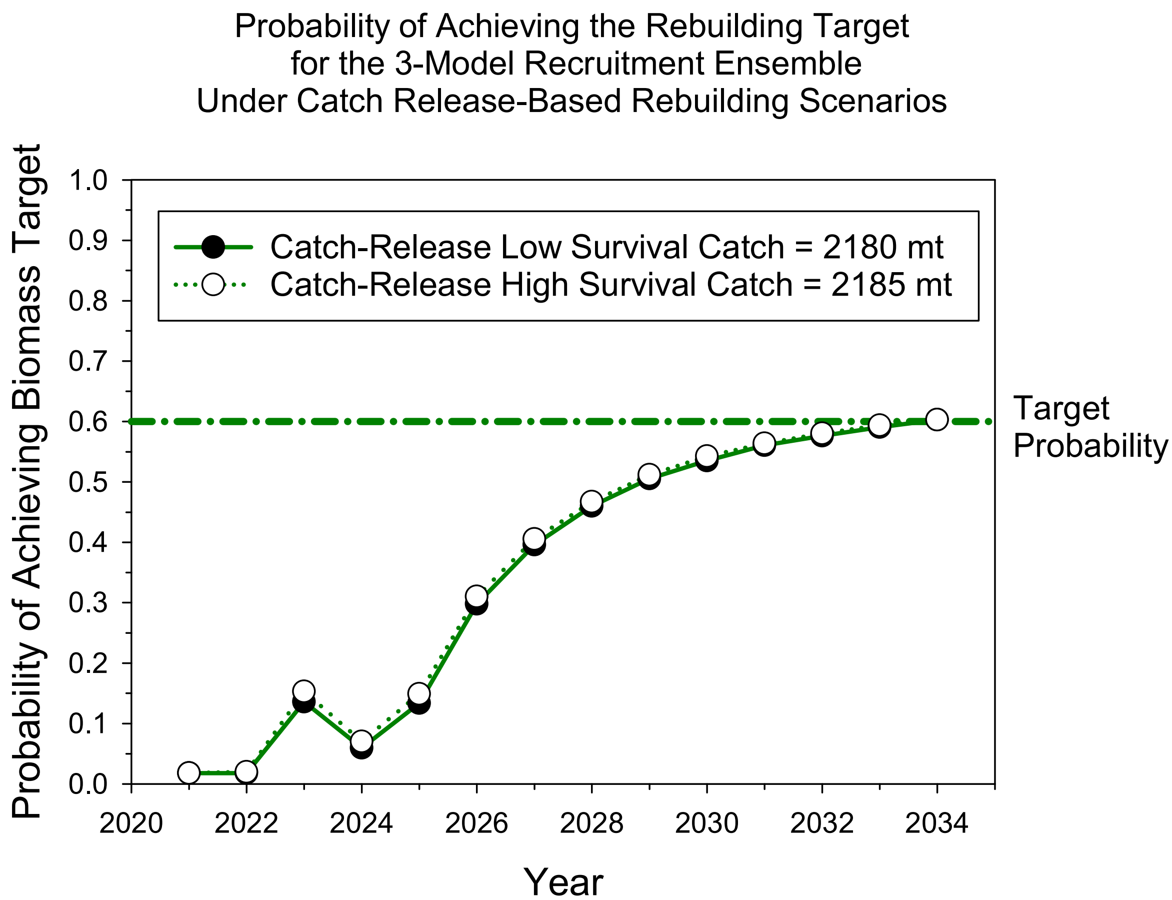


Figure 40.1. Comparison of the annual probabilities of exceeding the potential overfishing reference point of $F_{20\%SSB(F=0)}$=0.53 during 2021–2034 under the fishing mortality-based rebuilding scenarios relative to the even odds reference of not overfishing (red dash-dot line).

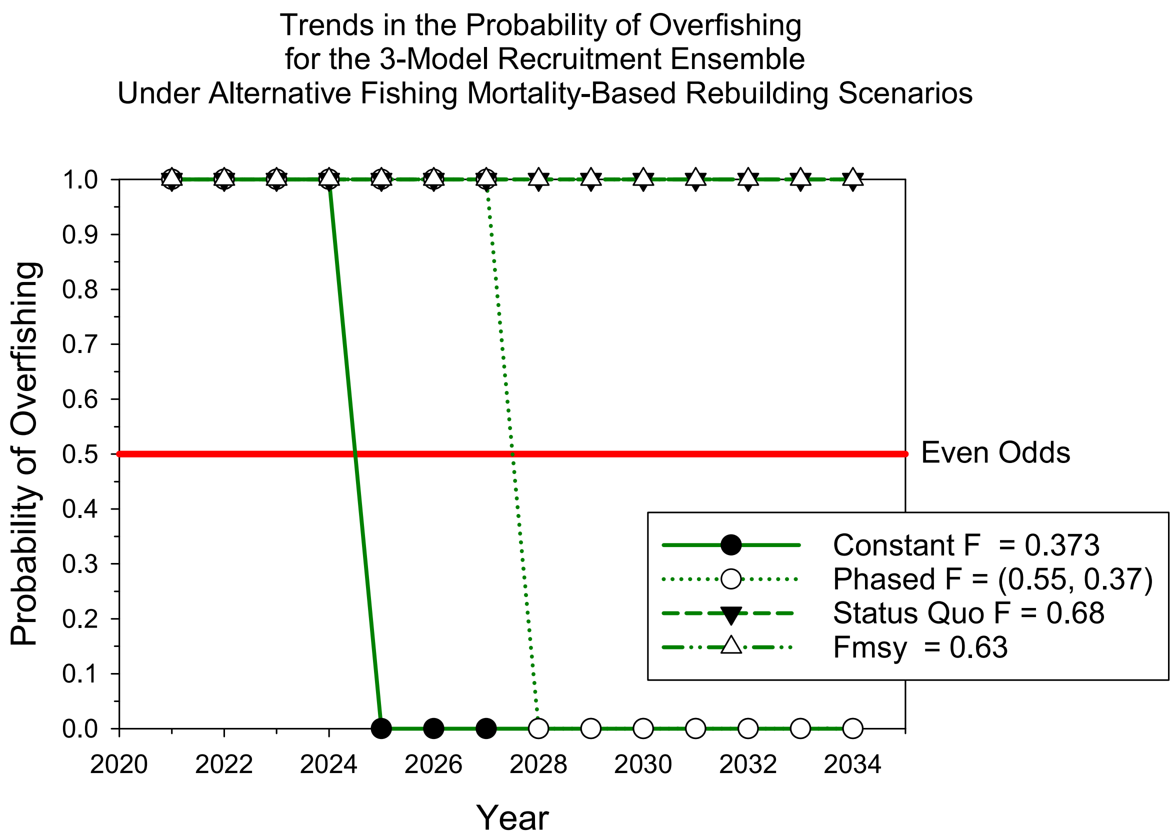


Figure 40.2. Comparison of the annual probabilities of exceeding the potential overfishing reference point of $F_{20\%SSB(F=0)}$=0.53 during 2021–2034 under the catch biomass-based rebuilding scenarios relative to the even odds reference of not overfishing (red dash-dot line).

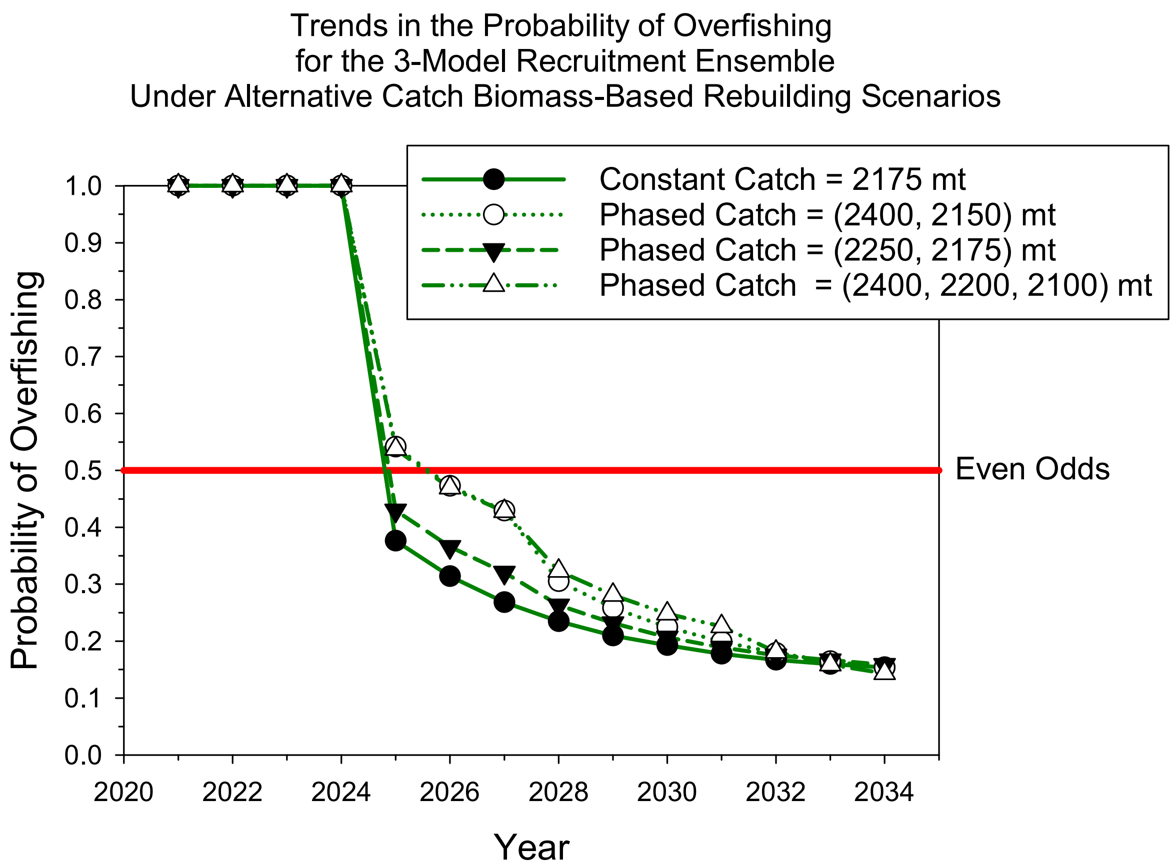


Figure 40.3. Comparison of the annual probabilities of exceeding the potential overfishing reference point of $F_{20\%SSB(F=0)}$=0.53 during 2021–2034 under the catch release-based rebuilding scenarios relative to the even odds reference of not overfishing (red dash-dot line).

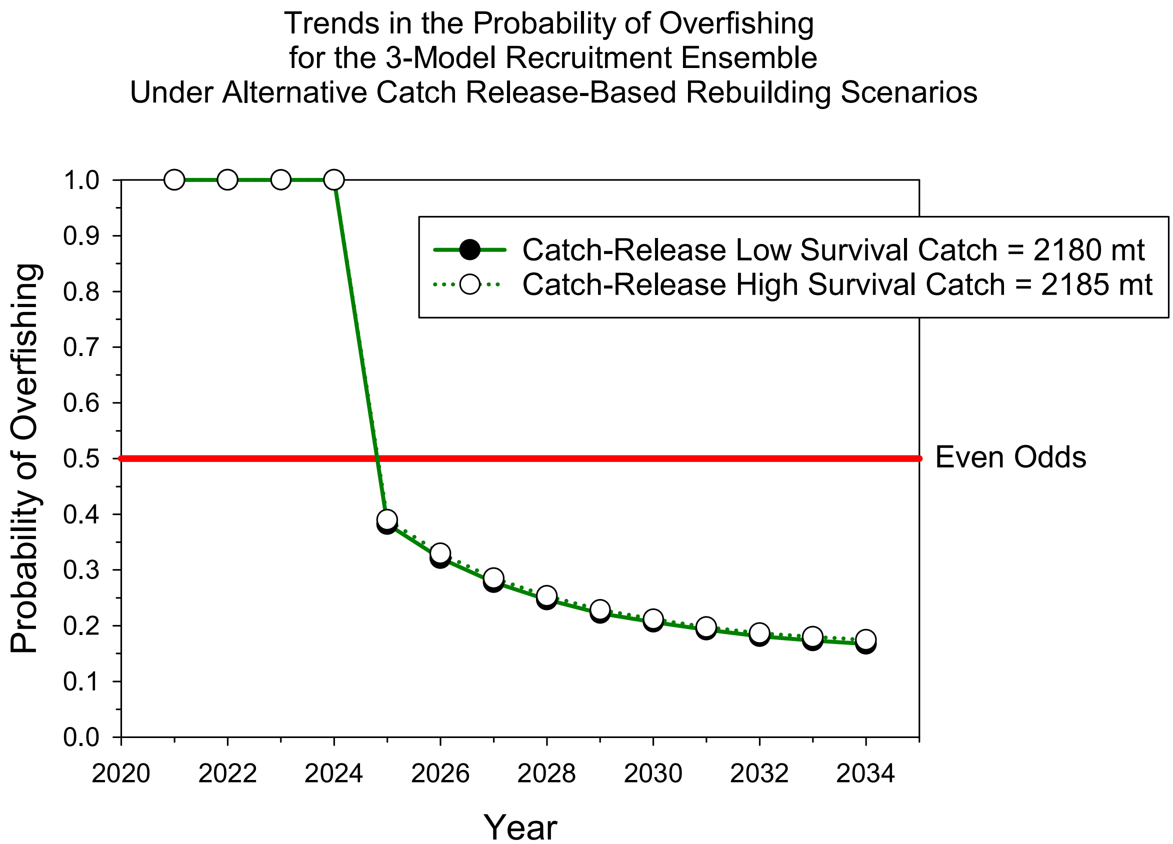


Figure 41.1. Comparison of the time series of median catch biomasses to rebuild the stock under the constant F and constant catch rebuilding and F_{msy} scenarios for the <u>medium-term recruitment</u> model relative to the recent average yield during 2018–2020 of 2,428 mt.

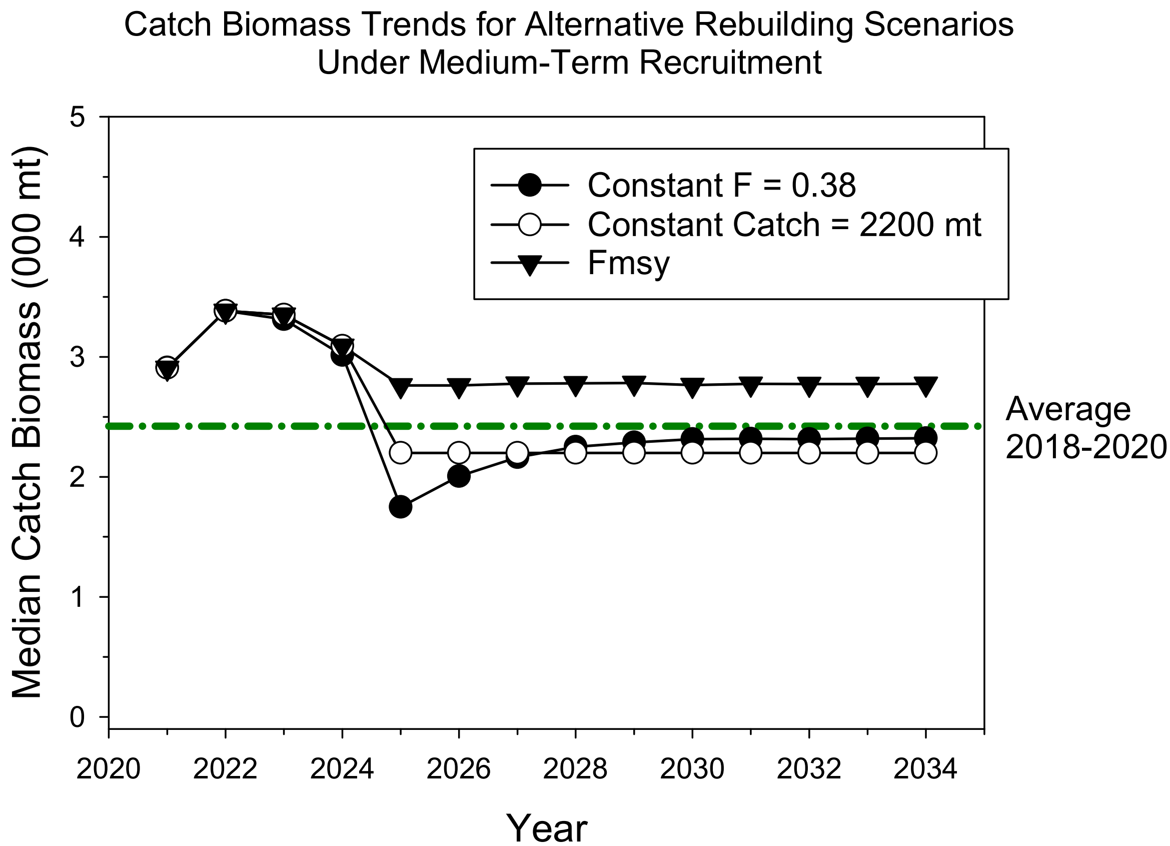


Figure 41.2. Comparison of the time series of median catch biomasses to rebuild the stock under the constant F and constant catch rebuilding and F_{msy} scenarios for the short-term recruitment model relative to the recent average yield during 2018–2020 of 2,428 mt.

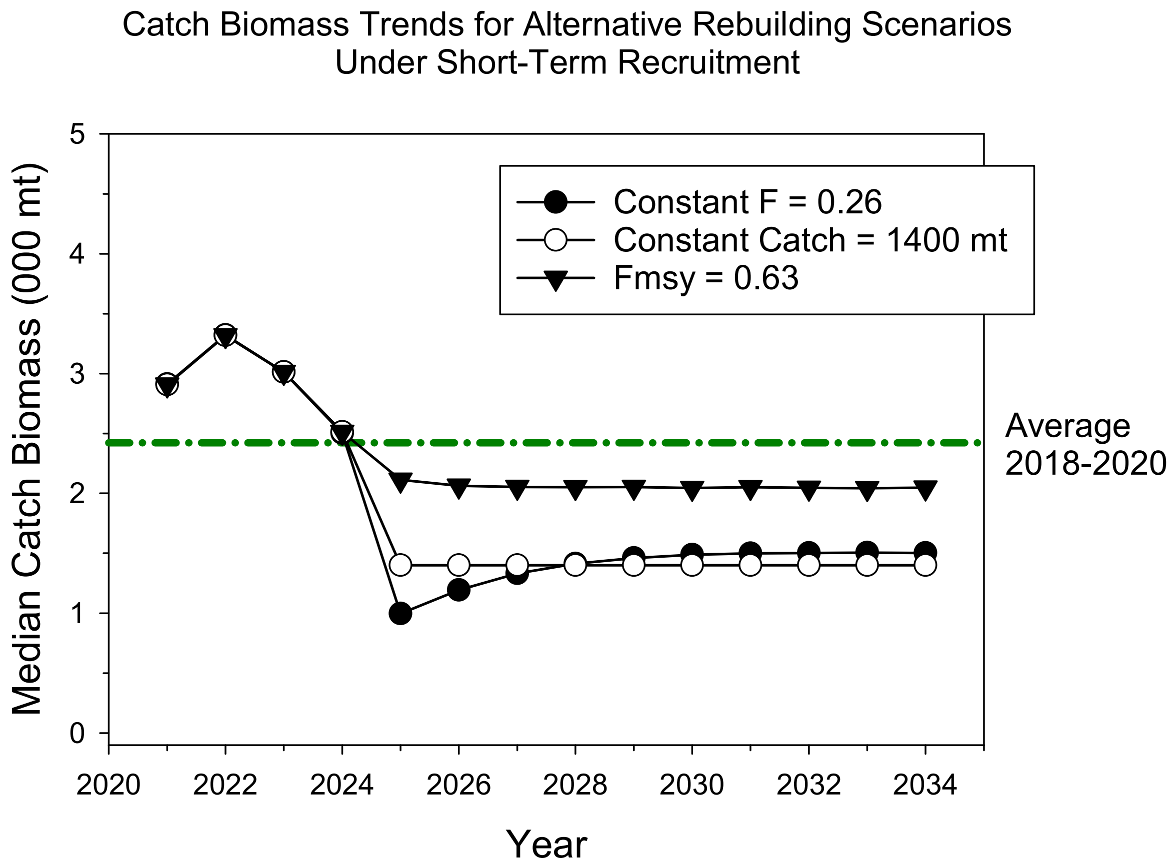


Figure 41.3. Comparison of the time series of median catch biomasses to rebuild the stock under the constant F and constant catch rebuilding and F_{msy} scenarios for the long-term recruitment model relative to the recent average yield during 2018–2020 of 2,428 mt.

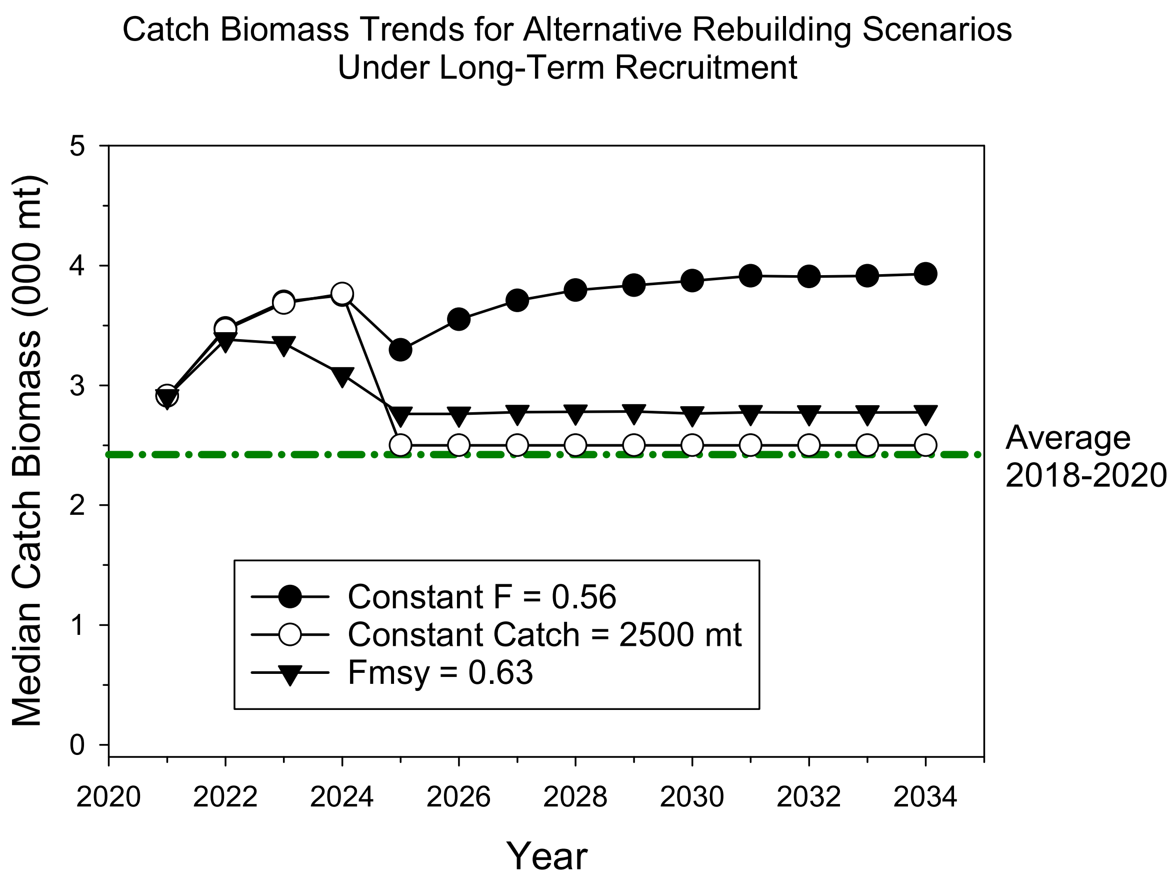


Figure 42.1. Comparison of the time series of median spawning biomasses to rebuild the stock under the constant F and constant catch rebuilding and F_{msy} scenarios for the medium-term recruitment model relative to the recent average spawning biomass during 2018–2020 of 1,359 mt.

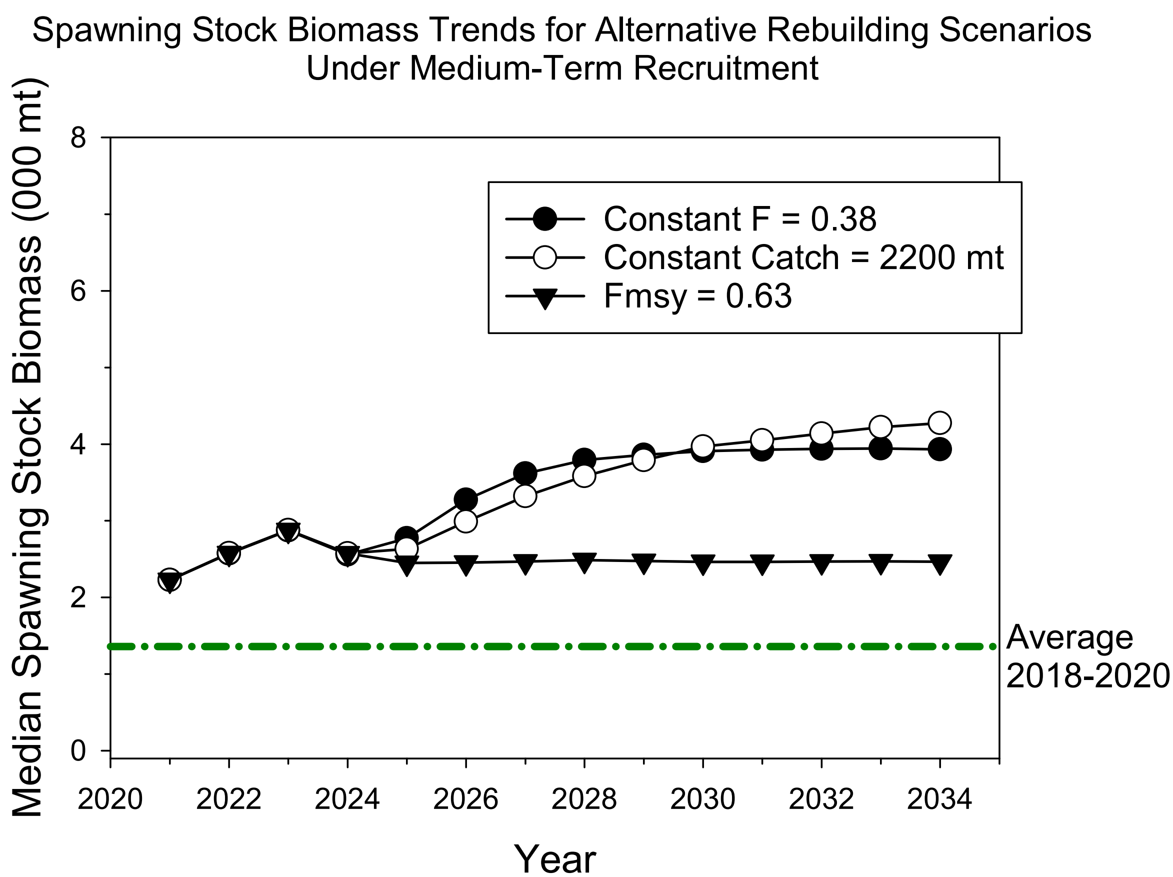


Figure 42.2. Comparison of the time series of median spawning biomasses to rebuild the stock under the constant F and constant catch rebuilding and F_{msy} scenarios for the short-term recruitment model relative to the recent average spawning biomass during 2018–2020 of 1,359 mt.

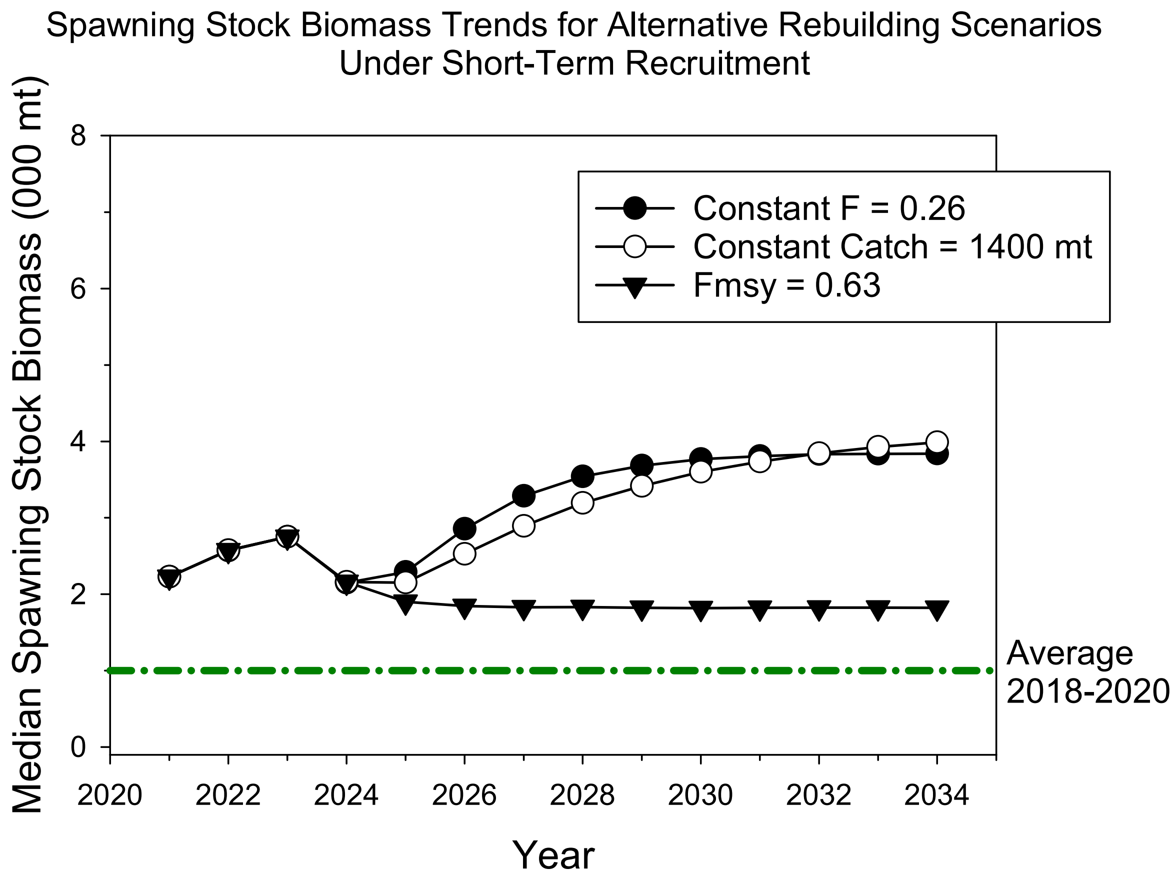


Figure 42.3. Comparison of the time series of median spawning biomasses to rebuild the stock under the constant F and constant catch rebuilding and F_{msy} scenarios for the long-term recruitment model relative to the recent average spawning biomass during 2018–2020 of 1,359 mt.

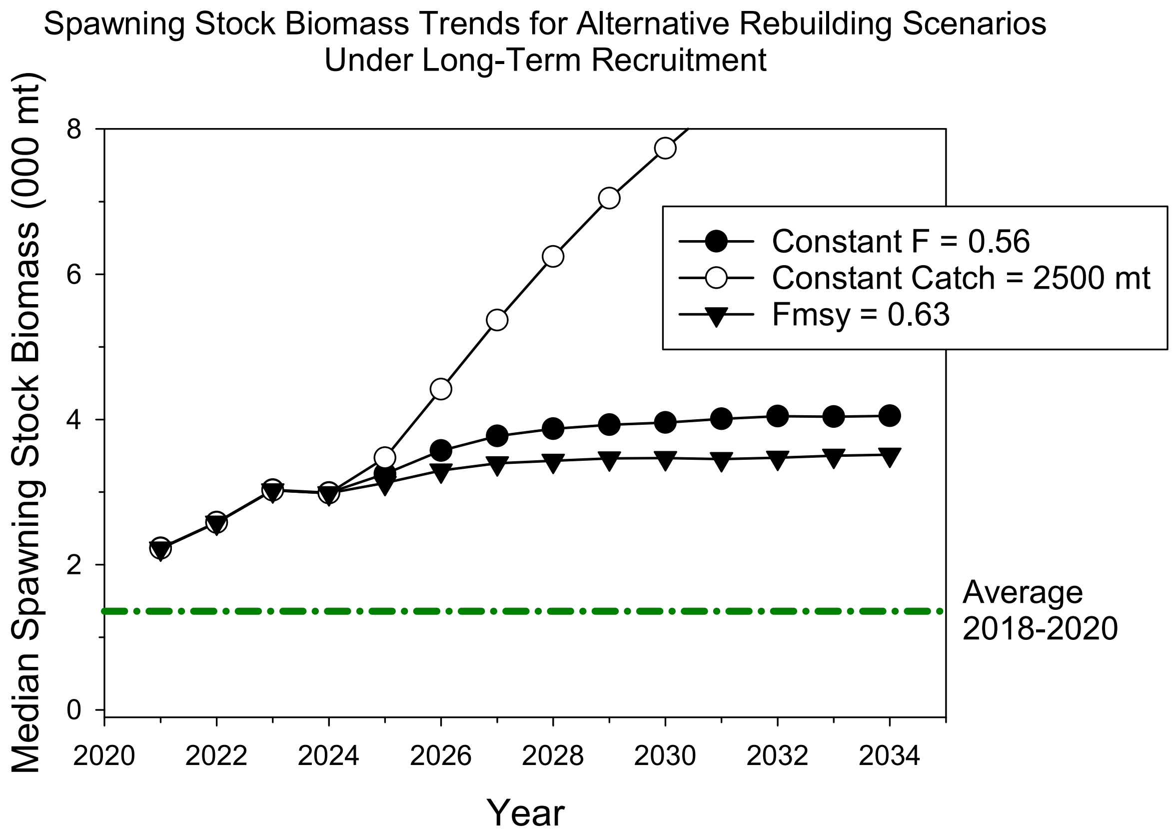


Figure 43.1. Comparison of annual probabilities of achieving the rebuilding target of 3,660 mt of spawning biomass with at least 60% probability for the <u>medium-term recruitment</u> model during 2021–2034 under the constant F and constant catch rebuilding scenarios.

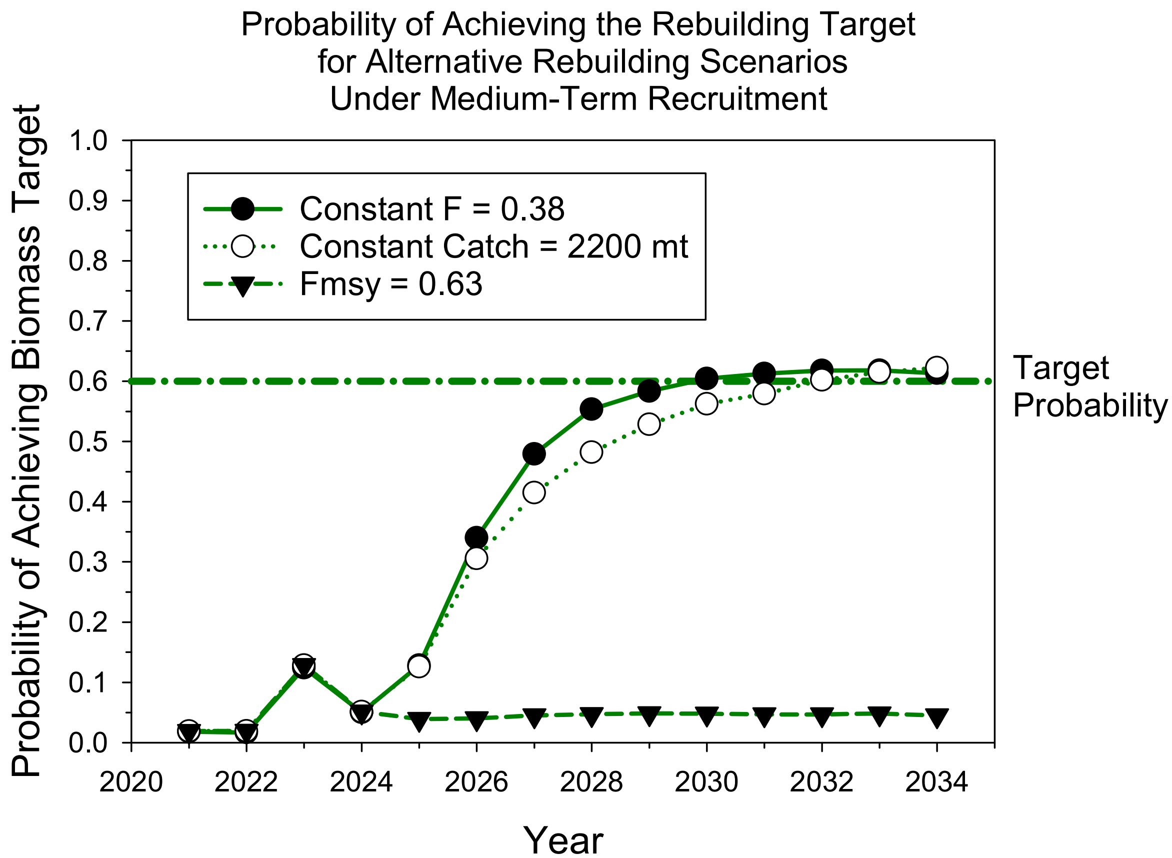


Figure 43.2. Comparison of annual probabilities of achieving the rebuilding target of 3,660 mt of spawning biomass with at least 60% probability for the short-term recruitment model during 2021–2034 under the constant F and constant catch rebuilding scenarios.

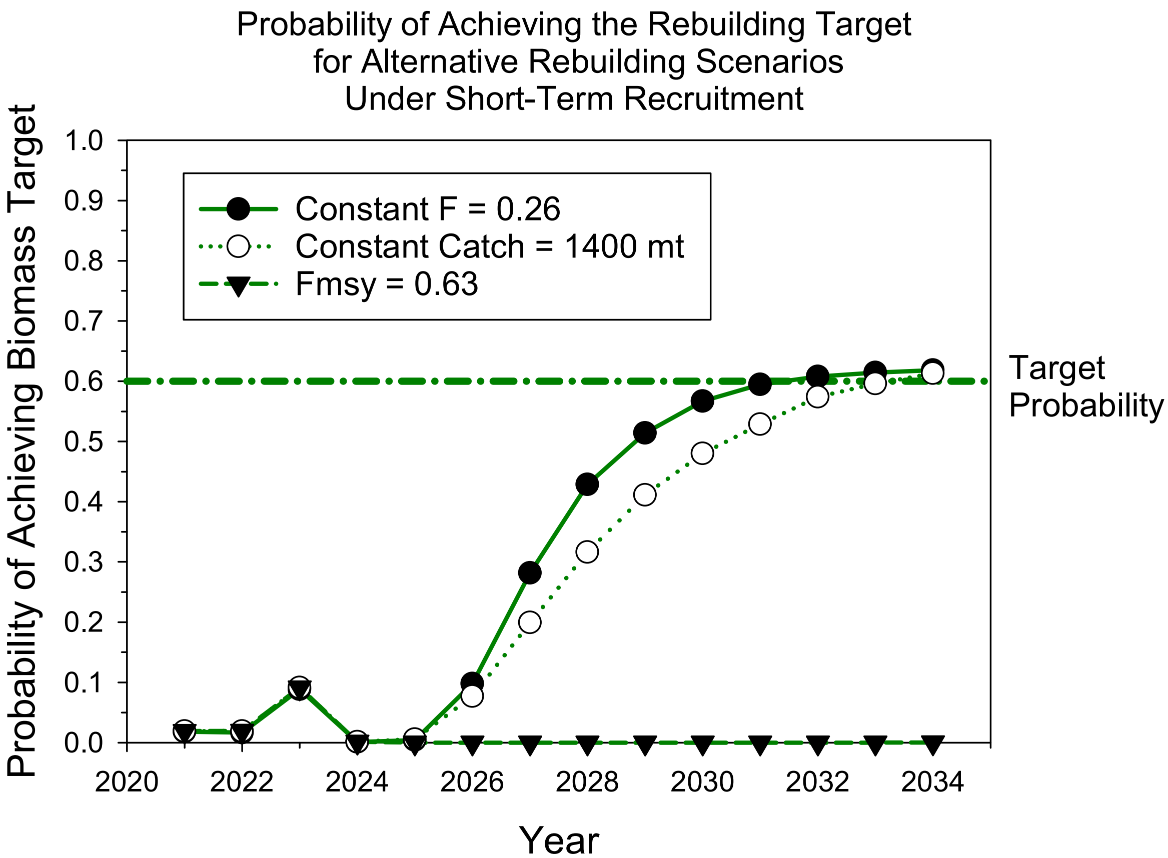


Figure 43.3. Comparison of annual probabilities of achieving the rebuilding target of 3,660 mt of spawning biomass with at least 60% probability for the long-term recruitment model during 2021–2034 under the constant F and constant catch rebuilding scenarios.

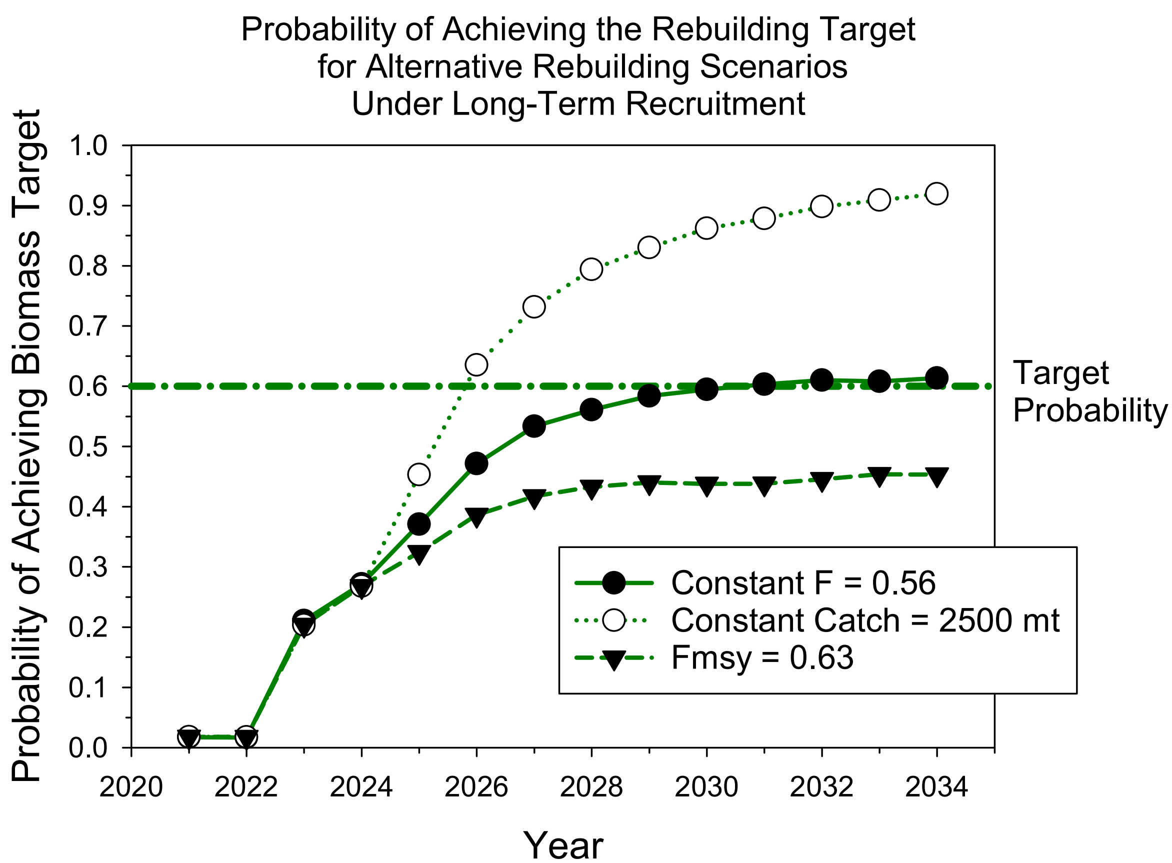


Figure 44.1. Comparison of the annual probabilities of exceeding the potential overfishing reference point of $F_{20\%SSB(F=0)}$=0.53 during 2021–2034 for the medium-term recruitment model during 2021–2034 under the constant F and constant catch rebuilding and F_{msy} scenarios.

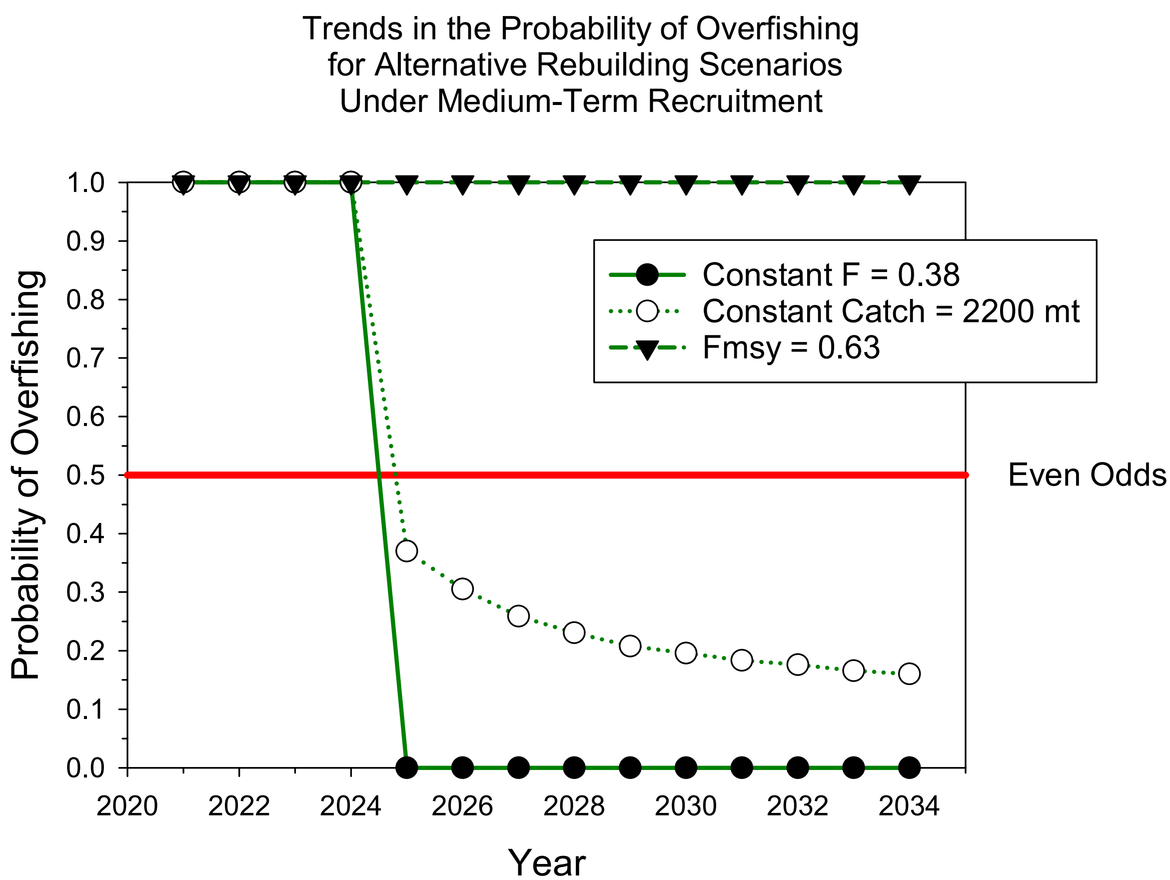


Figure 44.2. Comparison of the annual probabilities of exceeding the potential overfishing reference point of $F_{20\%SSB(F=0)}$=0.53 during 2021–2034 for the short-term recruitment model during 2021–2034 under the constant F and constant catch rebuilding and F_{msy} scenarios.

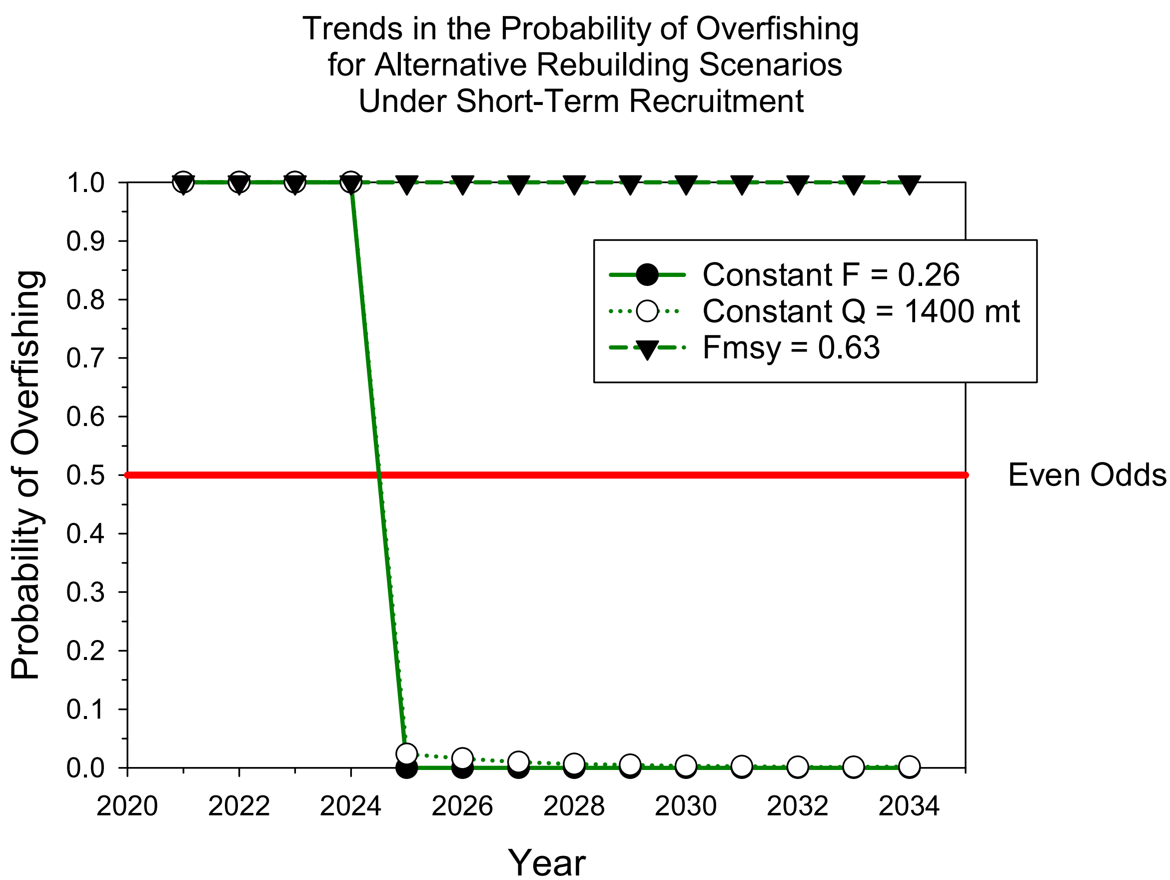


Figure 44.3. Comparison of the annual probabilities of exceeding the potential overfishing reference point of $F_{20\%SSB(F=0)}$=0.53 during 2021–2034 for the long-term recruitment model during 2021–2034 under the constant F and constant catch rebuilding and F_{msy} scenarios.