Rebuilding Plan Scenarios for the Western and Central North Pacific Ocean Striped Marlin Stock in 2024

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This working paper was submitted to the ISC Billfish Working Group Workshop, held in March 2024 in Taipei, Taiwan.

Abstract

In this working paper, we describe some analyses and stochastic stock projections to develop an interim rebuilding plan for the Western and Central North Pacific Ocean (WCNPO) striped marlin stock. This stock is currently estimated to be depleted and experiencing excess fishing mortality relative to maximum sustainable yield-based reference points. The projection analyses described in this working paper are based on 2023 benchmark stock assessment of WCNPO striped marlin. The rebuilding plan has the goals of rebuilding the spawning biomass of the stock to 20% of the unfished level, or 20%$SB_{F=0}$ = 3,660 mt, within a rebuilding time horizon of 10 years (2025–2034) and with a probability of rebuilding success of least 60%. There are four management strategy scenarios developed for these rebuilding analyses: <u>constant fishing mortality</u>, <u>constant quota, phased fishing mortality</u> and <u>phased catch quota.</u> The constant F scenario was designed to determine the constant 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 quota scenario was designed to determine the constant catch biomass quota 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 harvest quotas for the international longline and other fleets in order to rebuild the stock by 2034 and provide some periods of stable annual catch quotas for reducing fishing mortality on striped marlin. Given the projected catch quotas and spawning biomasses to meet the rebuilding goals, the probabilities of rebuilding the stock were calculated for each of the rebuilding scenarios under a 3-model ensemble for recruitment. The three alternative recruitment models represented different temporal hypotheses about future recruitment given the observed long-term declines in recruitment since the mid-1990s; these were the short-term, medium-term and long-term recruitment models. The results of the rebuilding analyses showed that the constant F to achieve the target was F=0.373. The constant annual catch quota to achieve the rebuilding target was 2,175 mt. The phased F and phased catch quota scenarios to achieve the rebuilding target were phased F = (0.55, 0.37) and phased catch quota = (2,400, 2,150) mt during 2025-2027 and 2028-2034. Sensitivity results show the rebuilding target could be achieved with moderate harvest reductions under the long-term recruitment model. In contrast, substantial harvest reductions would be required to rebuild the stock under the short-term recruitment model while achieving the target would require intermediate harvest reductions under the medium-term recruitment model. Overall, these rebuilding analyses indicate that the target spawning biomass could be achieved with 60% probability under each of the management strategies examined.

Introduction

This working paper describes analyses and stock projections for alternative harvest strategies to rebuild the Western and Central North Pacific Ocean (WCNPO) striped marlin stock based on the best scientific information available. In this context, the projection analyses described in this working paper are based on the 2023 benchmark stock assessment of WCNPO striped marlin (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. For background, annual WCNPO striped marlin catches averaged 7,221 mt, or about 60% above the maximum sustainable yield (MSY) catch of 4,513 mt during 1975–2000. Annual catch has had a decreasing trend since 1993 and has averaged 2,719 mt during 2011–2020, or about 40% below MSY (Figure 1). Overall, international longline fishing fleets have accounted for the vast majority of Western and Central North Pacific striped marlin catches since 1994.

Stock Status

The benchmark 2023 stock assessment of WCNPO striped marlin indicated the stock is currently estimated to be depleted and experiencing overfishing relative to MSY-based reference points (Table 1 and Table 2). The current stock status results from the 2023 benchmark assessment were similar to the 2021 update, the 2019 benchmark and the 2015 assessments (ISC BILLWG 2015 & 2019, Sculley 2021, ISC BILLWG 2023). Estimates of spawning biomass decreased from 5,096 mt in 1977 to fluctuate around 3,320 mt between 1981 and 1992, or about 17% of the estimated equilibrium unfished spawning biomass of 19,279 mt (Figure 2). Spawning biomass decreased substantially from 1993 to around 1,100 mt in the late-1990s and then fluctuated around an average of 1,391 mt from 2001-2020. The lowest observed spawning stock biomass was 1,081 mt in 2011, or about 63% below SB_{MSY}, the spawning stock biomass to produce MSY and about 70% below the rebuilding target estimated at dynamic 20-year $20\%SSB_{(F=0)}$ = SSB_{Target} = 3,660 mt in the 2023 assessment (Figure 2). In 2020, spawning biomass had increased to 1,696 mt, or about 54% below SSB_{Target}. Fishing mortality on the stock (average F on ages 3–12) has fluctuated at or above F_{MSY} since the late-1970s but has declined in recent years (Figure 3) and averaged roughly F = 0.68 during 2018–2020, or 28% above the $F_{20\%SSB(F=0)}$ overfishing reference point. It is notable that fishing mortality has been estimated above 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 we note that no target or limit reference points have been established for the stock under the auspices of the WCPFC.

Rebuilding Goals

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

> "*70. NC14 agreed to request ISC to conduct projections examining rebuilding scenarios for North Pacific striped marlin that cover a range of rebuilding targets (20%SSBF=0, FMSY, and 0% to 50% reductions in increments of 10% from current catch limits), timelines (10, 15 and 20 years) and probabilities of each scenario to reach each target within different timelines. ISC should produce additional scenarios of catch reduction if the probability of reaching the rebuilding target in 10, 15, and 20 years is not at least 60%.*
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> *71. NC14 expressed concern over the status of NP striped marlin and urged the Commission to develop a rebuilding plan for the stock as a matter of priority. NC members are encouraged to submit a draft CMM, if possible."*

The NC14 request for stock projections was fully addressed in the benchmark stock assessment of WCNPO striped marlin (ISC Billfish WG 2019). This assessment was reviewed at the NC15 meeting in 2019. The United States circulated a consultative draft rebuilding plan that proposed that the rebuilding target for spawning biomass be established as 20% of unfished spawning biomass (20%$SSB_{F=0}$). The ISC Billfish Working Group subsequently worked to evaluate whether a dynamic unfished spawning biomass reference point was needed 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 observed stock productivity.

Based on the benchmark stock assessment and the stock projections reviewed at SC15 and NC15, WCPFC16 adopted a rebuilding plan for WCNPO striped marlin where the rebuilding target was 20%$SB_{F=0}$, and the rebuilding time frame was set at 15 years (2020–2034) with a required probability of rebuilding success of least 60%. The goals for the 2024 WCNPO striped marlin rebuilding plan were set to be consistent with the WCPFC16 rebuilding goals and are:

- Rebuilding target SSB_{Target} is 20-year dynamic 20%$SB_{F=0}$ = 3,660 mt of spawning biomass (ISC BILLWG 2023).
- Rebuilding time frame is 2025–2034.
- Striped marlin conservation measures are implemented in 2025–2034.
- The minimum probability $P_{Rebuild}$ 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 period of 1977–2020, and the catch reductions or other conservation measures to rebuild the stock are modeled to be implemented in 2025 through 2034. Last, we also evaluate the robustness of rebuilding scenario results to alternative projection assumptions and model configurations and summarize these results.

Initial Conditions

The stock projections were designed to account for uncertainties in the initial conditions derived from the terminal year of the 2023 benchmark stock assessment. The two primary uncertainties were: (1) the estimates of the initial striped marlin population numbers at age in 2021 and (2) the initial catch biomasses harvested in 2021–2024 prior to the modeled implementation of rebuilding measures

Uncertainty in the estimate of the initial WCNPO striped marlin population size at age was an important feature to account for. Some statistical uncertainty always exists in the terminal-year estimates of population size from an age-structured stock assessment (Brodziak et al. 1998) because estimates of younger cohorts cannot be based on a full set of catch-at-age observations over their lifespans. In particular, uncertainty in the initial population size in 2021, the first year of the projections, was characterized by calculating 100 bootstrap replicates of the population size at age. This was accomplished using the bootstrapping option for the modeling platform Stock Synthesis ([SS3], Methot and Wetzel 2013). This corresponded to a sampling intensity of about 60 bootstraps per 1,000 mt of spawning biomass and produced a distribution of initial population sizes at age that were used for projections under each rebuilding scenario (Table 3, Figure 4). Mean and median total population sizes were 445.2 and 444.1 thousand fish. On average, the vast majority of bootstrapped population numbers were accounted for by age classes 1 to 3 (97%). Overall, the total bootstrapped population sizes in 2021 ranged from 287.9 to 677.8 thousand fish.

Uncertainty in the distribution of annual catch biomasses during 2021–2024 was characterized using Monte Carlo simulation based on the bootstrap replicates of initial population size. In this case, it was assumed that best estimates of WCNPO striped marlin harvesting intensity prior to the implementation of rebuilding measures in 2025 could be based on the recent average fishing mortality from the 2023 stock assessment, the same assumption as was used in the 2021 rebuilding plan analyses (Brodziak 2021). In particular, the recent average fishing mortality was set to be the average annual F on age classes 3 to 12 during 2018–2020 from the 2023 stock assessment, which was $F_{Initial}$=0.68. This was a decrease in $F_{Initial}$ of about 1% from the 2019 assessment (ISC BILLWG 2019). The fishing mortality rate of $F_{Initial}$=0.68 was applied to simulate population sizes at age during 2021–2024 and produce the distributions of population sizes and catches. Based on the 3-model recruitment ensemble, the resulting annual catch biomasses in 2021-2024 averaged approximately 2,970, 3,420, 3,380 and 3,070 mt with CVs of 16%, 17%, 20%, and 22%, respectively, for each rebuilding scenario. Thus, the harvest patterns used to set the initial conditions for the projections were consistent across rebuilding scenarios.

This consistent treatment of the initial catch biomasses for stock projections across scenarios was similar to that used in the 2021 rebuilding analyses (Brodziak 2021) but differed from that used in the 2019 assessment report (ISC BILLWG 2019). In particular, the initial expected 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 during 2021–2024. The application of a constant harvest rate of $F_{Initial}$=0.68 during 2021–2024 was consistent with the fact that striped marlin is primarily a bycatch species and one would expect the bycatch of striped marlin to reflect the short-term pattern of relatively stable fishing effort in the aggregate international longline fleet. Given that the size of the 2017-year class[1] was well above average relative to recent recruitment strengths, it was also 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 assessment projections were based on average fishing mortality for F-based rebuilding scenarios and on average catch biomass for quota-based scenarios which produced differences in average initial conditions by scenario (ISC BILLWG 2019).

Recruitment Dynamics

Recruitment dynamics for the stochastic rebuilding projections included uncertainty about future recruitment strength based on the empirical patterns observed in the 2023 stock assessment (Figure 5). Recruitment dynamics in the 2023 assessment were similar to the patterns observed in the 2019 benchmark and 2021 update assessments. IN 2021, a 2-model ensemble was used for modeling recruitment dynamics based on the 2019 and 2021 assessments for stock rebuilding analyses (Brodziak and Sculley 2020, Brodziak 2021). For the 2024 rebuilding analyses, we included a third recruitment hypothesis based on the medium-term recruitment patterns to generate future recruitment for the stochastic rebuilding analyses. This was done to address concerns that there was some stability in the WCNPO striped marlin recruitment pattern since 2000 and also to include a recruitment model that was consistent with the 20-year period used for calculating the dynamic unfished spawning biomass reference point.

The three working hypotheses for recruitment dynamics reflected the nonstationary recruitment patterns observed in the 2023 and also the 2019 and 2021 stock assessments. These were the short-, medium-, and long-term recruitment model scenarios.

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

Short-Term Recruitment: The first hypothesis was that recruitment in the next decade would be similar to recent 5-year pattern of observed recruitment (Figures 6 and 7). This short-term recruitment scenario was built on the observation that recruitment estimates had remained relatively low in the past decade, and that this pattern was unlikely to change in the future. The short-term recruitment scenario was based on randomly resampling the empirical cumulative distribution function (ECDF) of age-1 recruitment observed during 2015–2019 (Figure 7). The period of 5 years was chosen for consistency with the treatment of recruitment in the 2021 rebuilding analyses (Brodziak 2021) and also to match the period of one mean generation time (~ 5 years) for WCNPO striped marlin. The recruitment estimates from 2020-2021 were not included to test the near-term predictive accuracy of the alternative recruitment models. Under the short-term recruitment scenario, the 5-year average recruitment was 135.4 thousand age-1 fish per year with a CV of 43%.

Medium-Term Recruitment: The second hypothesis was that future recruitment would be similar to the stable recruitment pattern used to calculate the 20-year dynamic unfished spawning biomass reference point (Figures 6 and 7). Under the medium-term recruitment scenario, future recruitment would be based on randomly resampling the empirical cumulative distribution function of age-1 recruitment during 2000-2019. The 20-year ECDF model produced an annual average of 176.9 thousand age-1 fish with a CV of 46%, with a higher average but variability similar to the short-term model. The 20-year ECDF matched the time window used to calculate the dynamic unfished spawning stock biomass reference points used for WCNPO striped marlin (ISC BILLWG 2022). The medium-term recruitment model was also consistent with the recommendation for including an additional recruitment hypothesis from the WPRFMC's Scientific and Statistical Committee in 2021. Overall, the medium-term recruitment scenario suggested that achieving higher recruitment than the low levels observed in late 2010s was a possibility.

Long-Term Recruitment: The third working hypothesis was that future recruitment would be similar to that produced by the fitted Beverton-Holt stock-recruitment curve estimated in the 2023 assessment model. This was the long-term recruitment scenario and was based on randomly resampling the stock-recruitment curve as a function of current spawning biomass with the lognormal error term (Figure 5). Under the long-term, or stock-recruitment curve scenario, the average of the expected recruitment during 1978-2021 was 302.6 thousand age-1 fish with a CV of 14%. Thus, under the long-term recruitment scenario, future recruitment 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 of the expected variability. Thus, the selection of recruitment scenarios was expected to have an important influence on stock projections for WCNPO striped marlin as was the case for the 2020-2021 stock rebuilding analyses.

For background, previous stock projections based on the 2019 benchmark assessment produced substantial differences in probable rebuilding trajectories under short- (5-year ECDF, 2011-2015) and long-term (43-year ECDF, 1975-2015) recruitment scenarios. As a result, the Northern Committee requested that (NC15 2019):

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

Subsequently, Brodziak and Sculley (2020) produced additional analyses to address which recruitment scenario was most likely for the 2019 WCNPO striped marlin stock assessment projections. They found that the empirical 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 short-term recruitment was the most likely scenario for conducting future stock projections for WCNPO striped marlin (ISC Billfish WG 2020).

The BILLWG also recognized that there was some chance that the long-term recruitment scenario might provide a better approximation of future recruitment dynamics compared to the short-term scenario. To account for this possibility, future recruitment dynamics were modeled as a mixture distribution of the short-term and long-term recruitment scenarios. The mixing probabilities, or model weight, were calculated based on the out-of-sample forecast accuracies for recruitment values in 2017–2018, as described in Brodziak and Sculley (2020). This led to calculated mixing probabilities of 0.92 and 0.08 for the short-term and long-term scenarios, respectively, based on 2019 assessment results. When this analysis was redone using updated 2021 assessment results, the mixing probabilities for the short-term and long-term scenarios were recalculated to be 0.97 and 0.03, respectively. These mixing probabilities for the 2-ensemble recruitment model were used for the 2021 rebuilding analyses.

Recruitment dynamics were reexamined based on the 2023 benchmark assessment information. Recruitment had a long-term declining trend (Figure 8) as observed in previous assessments. We applied a change point analysis (Killick et al. 2011) to the estimates of recruitment and spawning stock biomass from the 2023 assessment. The change point analysis was configured to detect whether there were apparent change points in either the mean or variance in the recruitment (age-0 fish) and spawning biomass (thousand mt) time series in . We used the pruned exact linear time method (Killick year) to evaluate the potential change points during 1977-2020. The results indicated that there was a change point in the recruitment time series in 1993, corresponding to a sharp decline in recruitment strength (Figure) . Results for the spawning biomass time series showed change points in 1978 and 1995 (Figure). We interpreted the 1978 as an artifact of the numerical search for an optimal solution near the beginning boundary of the time series. However, the 1995 change point for spawning biomass was logically consistent with finding the 1993 change point in the recruitment time series. This was because the recruits from 1993 would begin to contribute to spawning biomass as mature fish at about age-2 and both series show sharp declines from their change point to the end of the assessment time horizon.

Overall, the change point analyses suggested there was a change in both the recruitment and spawning biomass time series during 1993-1995.

We examined the trends in recruitment based on the sequences of short-term 5-year and medium-term 20-year ECDFs. The 5-year moving average of recruitment decreased from about 460 thousand recruits in 1991 to around 140 thousand in 2013 and then fluctuated around 150 thousand during 2014 to 2021 (Figure 9). The coefficient of variation 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 9) 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 long-term decline in recruitment from the 1990s to the 2010s (Figure 10). 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 increased to range from 42%-49% during 2005-2021. The trends in the 20-year mean and median recruitments were also very consistent and provided similar measures of declines in recruitment strength for the sequence of ECDFs (Figure 10). These observations showed that the choice of time period for setting the short-term and medium-term recruitment ECDFs would have some influence on projected recruitments. 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, with the consideration of setting aside the two most recent recruitments for evaluating out-of-sample predictions.

We evaluated the weight of evidence for applying the short-, medium-, and long-term recruitment models based on the 2023 assessment information. Here the short-term and medium-term models are the ECDFs for recruitment during 2014-2018 and 1999-2018 and the long-term model is the fitted stock-recruitment curve with lognormal error. Point predictions based on the expected values of each model were compared to the estimated recruitment values during 1978-2021. The recruitment residuals showed different patterns for the medium-term (Figure), short-term (Figure) and long-term (Figure) models. The long-term recruitment model had the smallest set of residuals, as expected, but showed a stronger pattern of overestimating recruitment strength from 2005-2021. The short-term recruitment model produced substantial underestimates of recruitment prior to 2005 and 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 residuals indicated that the three models were better at predicting the estimates of recruitment in different periods of the assessment time horizon.

We used the squared residuals from each model as a measure of their predictive accuracy for recruitment in each year of the assessment. The results showed that the long-term recruitment model generally produced the smallest errors prior to 2005. From 2005 to 2021, the overall prediction errors were somewhat smaller and the short-term and medium-term models produced better predictions than the long-term model in many years. We used the squared residuals for each model to calculate an inverse error-variance model weight by year. The results showed that the recruitment models produced different accuracies by year (Figures x, y, z), as expected. The long-term recruitment model generally produced the highest annual model weights prior to 2005. However, from 2005-2021, the short-term and medium-term models generally produced the 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). Overall, the temporal patterns in the model weights reflected the nonstationary nature of the recruitment time series.

We used the set of squared residuals for each model to calculate inverse error-variance model weights for different periods to characterize the temporal changes in predictive accuracy by recruitment model (Table). 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 had 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 later time 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 temporal patterns of model weights by period 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 and over 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 the support for them as individual 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). 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 model 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. That is, the expected values of natural mortality rates at age, growth in length at age, female maturity at age and length-weight relationships for age classes 1 through 14 and the plus group of age-15 and older were set to the values from the 2023 stock assessment (Table, 2023 Values for WCNPO). The calculated mean weights at age for the rebuilding analyses are shown in Figure 18 along with the comparable mean weights used in the 2019 assessment. The mean weights at age were larger for the 2023 assessment because the Brody growth coefficient was k=0.26 versus k=0.24 in the 2019 assessment. The proportion of mature females at age for the rebuilding analyses are shown in Figure 19 along with the comparable female proportions mature at age for the 2019 assessment. The female proportions mature at age were higher in the 2023 assessment because the median female length at maturity was set at L50 = 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 161 cm EFL (ISC BILLWG 2019). 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 and weights set 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 representative longline and drift gillnet fleets (ISC BILLWG 2019). The aggregate fishery selectivities at age were higher for ages 2-5 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 higher in the 2023 assessment while spawning potential ratio at F was lower. However, there was no practical difference in the mean generation times for the 2023 and 2019 life history parameters which indicated that population turnover rates were similar for both assessments.

Fishery Dynamics

We characterized the fleet dynamics for fisheries that harvested WCNPO striped marlin for the rebuilding analyses. There were a total of 25 fishing fleets with reported catch used in the 2023 benchmark stock assessment (Table 7). This total 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-targeted 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 for 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 selectivities used for the rebuilding analyses were (Tables 7 and 8 and Figure 25):

- The Japanese longline fleet group operating in Subarea 1 in Quarter 1 (F1)
- The Japanese longline fleet group operating in Subarea 2 in Quarter 1 (F2)
- The Japanese longline fleet group operating in Subarea 1 in Quarter 2 (F4)
- The Japanese longline fleet group operating in Subarea 1 in Quarter 3 (F5)
- The Japanese longline fleet group operating in Subarea 1 in Quarter 4 (F6)
- The Japanese driftnet fleet group operating in Quarters 1 and 4, late (F13)
- The Japanese driftnet fleet group operating in Quarters 2 and 3, late (F14)
- The USA longline fleet group (F16)
- The Taiwanese distant-water longline fleet group (F18)

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 there were differences in fishery characteristics between the fleet groups. In particular, 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 and these differences in fleet dynamics 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 the sections above. In each projection, 2,000 simulations were run for each bootstrap replicate to characterize the effects of process errors in future recruitment, life history, and fishery parameters. This gave 132,000 total simulated trajectories to evaluate the central tendency and variability of population and fishery quantities of interest, such as spawning biomass and catch biomass, in each projection. The stochastic projections employed model estimates of the multi-fleet, multi-season, size- and age-selectivity, and structural complexity in the assessment model to produce consistent results. Life history parameters for the projections were based on the exact same values as were used in the 2019 assessment (ISC Billfish WG 2019). This included natural mortality at age, maturity at age, and mean spawning weights at age. Mean fishery catch weights at age were calculated as a weighted average of the catch weights at age for the representative dome-shaped (95%) and flat-topped (5%) selectivity fleets based on the revised 2021 assessment 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

Four alternative harvest scenarios were developed to rebuild the striped marlin stock and satisfy the rebuilding goals. The four alternatives were all based on the default 3- model recruitment ensemble with 0.84, 0.12, and 0.04 mixing probabilities for the medium-, short-, and long-term recruitment models, respectively. The four rebuilding scenarios were:

A constant F rebuilding scenario, or constant fishing mortality rate scenario:
The constant F scenario was designed to determine the constant 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 rebuilding goals. The constant F to rebuild to 60% is a unique solution by the mean value theorem.

A constant quota rebuilding scenario, or constant catch biomass scenario: The constant quota scenario was designed to determine the constant catch biomass quota to be applied during 2022–2034 to rebuild the stock with at least 60% probability in 2034. This constant level of catch quota was iteratively calculated to meet the rebuilding goals. There will be one solution to the search for a constant quota that produced a 60% probability of rebuilding.

A phased F rebuilding scenario: The phased fishing mortality rebuilding scenario was designed to gradually reduce harvest quotas for the aggregate international fleet in order to rebuild the stock and to provide some periods of temporal stability for bycatch for the aggregate longline fleet. The initial phased F strategy was set up for 2 periods, 2025-2027 and 2028-2034 with a higher F in the first period to phase-in a higher F reduction in the second period. The number of phases was arbitrarily set to two but is limited by the length of the rebuilding time frame.

A phased quota rebuilding scenario: The phased quota rebuilding scenario also consisted of setting harvest amount for two time periods: 2025-2027 and 2028-2034. The magnitudes of the quotas were iteratively determined to rebuild the stock to the target spawning biomass with at least 60% probability in 2034 with a small reduction in the first phase followed by a larger catch reduction in the second phase. Identifying feasible rebuilding strategy parameters under the 3-model ensemble for recruitment was the main goal of the stock projections in this paper.

Sensitivity Analyses:
We also wanted to characterize how robust the rebuilding scenario results were to the choice to use a 3-model ensemble versus using the single-model recruitment models. To address this issued we ran the constant F and constant quota strategies separately under each of the recruitment models. That is, the sensitivity analyses were:

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

And

(2) The constant quota scenario based on medium-, short-, or long-term recruitment

These sensitivity analyses showed how different the outcomes would be under each of the individual working hypotheses about recruitment, i.e., the short-, medium-, and long-term recruitment scenarios.

Results

The probable distributions of projected catch biomasses were calculated for each of the rebuilding scenarios. The central tendencies, or medians, of annual catch biomasses during 2021-2024 were roughly 2,900, 3,400, 3,300, and 3,000 mt under each scenario.

The results of the four rebuilding scenario analyses were:

- The constant F scenario to achieve the target was F = 0.373

- The constant quota scenario to achieve the target was catch quota = 2,175 mt

- The phased F scenario to achieve the target was F = (0.55, 0.37) during 2025-2027 and 2028-2034

- The phased quota scenario to achieve the target was catch quotas = (2,400, 2,150) mt during 2025-2027 and 2028-2034

The distribution of catch biomass results for the constant F, constant quota, phased F, and phased quota scenarios are shown in Tables 10.1-10.4 and Figures 36.1-36.4, respectively. Comparison of the catch biomass results under each of the four rebuilding scenarios are provided in Table 10.5 and Figure 36.5.

The distributions of spawning stock biomass results for the constant F, constant quota, phased F, and phased quota rebuilding scenarios are shown in Tables 11.1-11.4 and Figures 37.1-37.4, respectively. Comparison of the spawning stock biomass results under each of the four rebuilding scenarios are provided in Table 11.5 and Figure 37.5.

The distribution of fishing mortality results for the constant F, constant quota, phased F, and phased quota rebuilding scenarios are shown in Tables 12.1-12.4 and Figures 38.1-38.4, respectively. Comparison of the fishing mortality results under each of the four rebuilding scenarios are provided in Table 12.5 and Figure 38.5.

The 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 phased, constant F, and constant quota rebuilding scenarios are provided in Table 13 and Figure 39.

The 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 phased, constant F, and constant quota rebuilding scenarios relative to the even odds reference of not overfishing are provided in Table 14 and Figure 40.

The results of the sensitivity analyses for the medium-term recruitment model were:

- The constant F scenario to achieve the target was F = 0.38

- The constant quota scenario to achieve the target was catch quota = 2,200 mt

The distribution of catch biomass results under medium-term recruitment for the constant F and constant quota rebuilding scenarios are provided in Table 15 and Figure 41.1.

The distribution of spawning stock biomass results under medium-term recruitment for the constant F and constant quota rebuilding scenarios are provided in Table 15 and Figure 42.1.

The distribution of fishing mortality results under medium-term recruitment for the constant F and constant quota rebuilding scenarios are provided in Table 15.

A comparison of the probabilities of achieving the rebuilding and probabilities of overfishing under the medium-term recruitment model for the constant F rebuild = 0.38, constant quota rebuild = 2,200 mt are provided in Table 16 and Figures 43.1 and 44.1.

The results of the sensitivity analyses for the short-term recruitment model were:

- The constant F scenario to achieve the target was F = 0.26
- The constant quota scenario to achieve the target was catch quota = 1,400 mt

The distribution of catch biomass results under short-term recruitment for the constant F and constant quota rebuilding scenarios are provided in Table 17 and Figure 41.2.

The distribution of spawning stock biomass results under short-term recruitment for the constant F and constant quota rebuilding scenarios are provided in Table 17 and Figure 42.2.

The distribution of fishing mortality results under short-term recruitment for the constant F and constant quota rebuilding scenarios are provided in Table 17.

A comparison of the probabilities of achieving the rebuilding and probabilities of overfishing under the short-term recruitment model for the constant F rebuild = 0.26, constant quota rebuild = 1,400 mt are provided in Table 18 and Figures 43.2 and 44.2.

The results of the sensitivity analyses for the long-term recruitment model were:

- The constant F scenario to achieve the target was F = 0.56
- The constant quota scenario to achieve the target was catch quota = 2,500 mt

The distribution of catch biomass results under long-term recruitment for the constant F and constant quota rebuilding scenarios are provided in Table 19 and Figure 41.3.

The distribution of spawning stock biomass results under long-term recruitment for the constant F and constant quota rebuilding scenarios are provided in Table 19 and Figure 42.3.

The distribution of fishing mortality results under long-term recruitment for the constant F and constant quota rebuilding scenarios are provided in Table 19.

A comparison 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 quota rebuild = 2,500 mt are provided in Table 20 and Figures 43.3 and 44.3.

Overall, these rebuilding analyses indicate that the target spawning biomass could be achieved with 60% probability under each of the management strategies examined.

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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 stock 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
$F_{Initial} = F_{2018\text{-}2020}$	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
$SSB_{2018\text{-}2020}$	1,359 mt
$C_{20\%SSB(F=0)}$	4,468 mt
MSY	4,512 mt
$C_{2018\text{-}2020}$	2,428 mt
$SPR_{20\%SSB(F=0)}$	22%
SPR_{MSY}	18%
SPR_{2020}	20%
$SPR_{2018\text{-}2020}$	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 inverse error-variance weights calculated under the 3-model recruitment ensemble for five periods.

	Inverse Variance Weights		
Period	Medium-term Recruitment	Short-term Recruitment	Long-term Recruitment
1977-1992	0.146	0.111	0.743
1977-2000	0.166	0.123	0.710
1977-2020	0.251	0.188	0.561
1993-2020	0.453	0.314	0.233
2001-2020	0.460	0.374	0.165

Table 5. Results of the inverse error-variance weights calculated under each single-model forecasts of the 2020 and 2021 age-1 recruitment values.

Combined Forecast Weight for 2020 and 2021 Recruitment by Point Prediction	Unweighted Mean Squared Error (MSE)	Combined Inverse Variance with Equal Annual Weighting	Inverse Variance Weights by Model with Equal Annual Weighting
Short-term ECDF R	2598.0	0.000385	0.12
Medium-term ECDF R	367.6	0.002720	0.84
Long-term SRR	8337.8	0.000120	0.04
Total	11303.4	0.003225	1

Table 6. Key life history parameters and model structures for the three Pacific striped marlin stock areas Western and Central North Pacific Ocean [WCNPO], Southwest Pacific Ocean [SWPO], and Eastern Pacific Ocean [EPO]) as well as the life history parameters used in the 2019 WCNPO striped marlin stock assessment with values used in the 2023 WCNPO striped marlin stock assessment highlighted in boldface.

Parameter	**2019 Value**	**2023 Value**		
	WCNPO	**WCNPO**	SWPO	EPO
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)**	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)
Reference age ($A_{\min}$)	0.3	**0.5**	0.5	0.5
Maximum age ($A_{\max}$)	15	**15**	15	15
Length at $A_{\min}$ (cm, EFL)	104	**110.9**	115	74
Length at $A_{\max}$ (cm, EFL)	214	**215.5**	212	184
Growth rate (k)	0.24	**0.26**	0.64	0.23
CV of Length at $A_{\min}$	0.14	**0.14**	0.14	0.14
CV of Length at $A_{\max}$	0.08	**0.10**	0.08	0.08
L_{inf} (cm, EFL)	217.3	**217.8**	212.0	188.1
t_0	-2.413	**NA***	-0.722	-1.674
Weight-at-length	$W=4.68e\text{-}006\times L^{3.16}$	$\mathbf{W=4.68e\text{-}006\times L^{3.16}}$	$W=4.68e\text{-}006\times L^{3.16}$	$W=4.68e\text{-}006\times L^{3.16}$
Size-at-50% Maturity	161	**152.2**	178.4	166.5
Age-at-50% Maturity	3.2	**2.3**	2.2	7.7
L_{50}/L_{inf}	74%	**70%**	84%	89%
Size-at-95% Maturity	196.9	**166.6**	192.8	180.9
Age-at-95% Maturity	7.4	**3.2**	3.0	12.6
L_{95}/L_{inf}	91%	**90%**	91%	96%
Slope of maturity ogive	-0.082	**-0.204**	-0.204	-0.204
Fecundity	Proportional to spawning biomass	**Proportional to spawning biomass**	Proportional to spawning biomass	Proportional to spawning biomass
Spawning season (quarter)	2	**2**	2	2
Spawner-recruit relationship	Beverton-Holt	**Beverton-Holt**	Beverton-Holt	Beverton-Holt

Spawner-recruit steepness (h)	0.87	**0.87**	0.87	0.87
Recruitment variability (σ_R)	0.6	**0.6**	0.6	0.6

Table 7. Descriptions of fisheries catch and abundance indices included in the base case model for the stock assessment including fishing countries, time-period, and reference sources for CPUE standardizations used in the 2023 stock assessment and rebuilding analyses.

Catch Index	Abundance Index	Fleet Name	Time Period	Source
F1	S1	JPNLL_Q1A1_Late	1994-2020	Ijima and Koike 2
F2	-	JPNLL_Q1A2	1975-2020	
F3	-	JPNLL_Q1A3	1975-2020	
F4	-	JPNLL_Q2A1	1975-2020	
F5	S2	JPNLL_Q3A1_Late	1994-2020	Ijima and Koike 2
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, 1994-2020	
F14	-	JPNDF_Q23_EarlyLate	1975-1976, 1994-2020	
F15	-	JPN_Others	1975-2020	
F16	S3	US_LL	1987-2020	Sculley 2021
F17	-	US_Others	1987-2020	
F18	S4	TWN_DWLL	1967-2020	Lee *et al.*, 2021a; Le 2021b
F19	-	TWN_STLL	1958-2020	
F20	-	TWN_Others	1958-2020	
F21	-	WCPFC_Others	1975-2020	
F22	S5	JPNLL_Q1A1_Early	1975-1993	Ijima and Koike 2
F23	S6	JPNLL_Q3A1_Early	1975-1993	Ijima and Koike 2
F24	-	JPNDF_Q14_Mid	1977-1993	
F25	-	JPNDF_Q23_Mid	1977-1993	

Table 8. 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 and italics. 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 F2
F4	***Double-normal***
F5	***Double-normal***
F6	***Double-normal***
F7	Mirror F2
F8	Mirror F4
F9	Mirror F5
F10	Mirror F6
F11	Mirror F6
F12	Mirror F4
F13	***Asymptotic lognormal***
F14	***Asymptotic lognormal***
F15	Mirror F4
F16	***Double-normal – Time Varying***
F17	Mirror F16
F18	***Asymptotic lognormal***
F19	Mirror F18
F20	Mirror F14
F21	Mirror F12
F22	Mirror F1
F23	Mirror F5
F24	Mirror F1
F25	Mirror F5
S1	Mirror F1
S2	Mirror F5
S3	Mirror F16
S4	Mirror F18
S5	Mirror F1
S6	Mirror F5

Table 9. Proportions of WCNPO striped marlin fishing mortalities (top) and catch biomasses (bottom) by fishing fleet group (Table 8) for 5 periods 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 10.1. The central tendency of projected annual catch biomasses (median, mt) under the 3-model recruitment ensemble for a constant F = 0.373 rebuilding scenario along with percentiles of the catch biomass distributions (P05, P10, P25, P75, P90, P95).

Catch Biomass (mt)							
Constant F =0.373 Rebuilding Scenario							
Year	P05	P10	P25	Median	P75	P90	P95
2021	2355	2452	2664	2912	3230	3553	3777
2022	2580	2724	2992	3384	3747	4205	4490
2023	2390	2547	2891	3313	3789	4241	4520
2024	2062	2246	2581	3015	3499	3956	4242
2025	1156	1267	1480	1748	2034	2310	2480
2026	1322	1448	1698	2006	2332	2650	2857
2027	1438	1583	1844	2163	2519	2847	3052
2028	1508	1659	1921	2251	2603	2950	3166
2029	1554	1692	1962	2288	2655	3011	3237
2030	1565	1711	1973	2315	2680	3036	3259
2031	1565	1717	1986	2319	2686	3033	3248
2032	1566	1716	1993	2316	2688	3029	3255
2033	1566	1706	1978	2319	2688	3032	3254
2034	1565	1714	1980	2323	2689	3037	3246

Table 10.2. The central tendency of projected annual catch biomasses (median, mt) under the 3-model recruitment ensemble for a constant quota = 2175 mt rebuilding scenario along with percentiles of the catch biomass distributions (P05, P10, P25, P75, P90, P95).

Catch Biomass (mt)							
Constant Catch Quota =2175 mt Rebuilding Scenario							
Year	P05	P10	P25	Median	P75	P90	P95
2021	2352	2459	2663	2916	3236	3548	3800
2022	2578	2723	3000	3383	3754	4212	4498
2023	2379	2557	2893	3328	3796	4243	4531
2024	2059	2247	2594	3043	3505	3949	4242
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. The central tendency of projected annual catch biomasses (median, mt) under the 3-model recruitment ensemble for a phased F = (0.55, 0.37) rebuilding scenario along with percentiles of the catch biomass distributions (P05, P10, P25, P75, P90, P95).

Catch Biomass (mt)							
Phased F = (0.55, 0.37) Rebuilding Scenario							
Year	P05	P10	P25	Median	P75	P90	P95
2021	2352	2459	2663	2916	3236	3548	3800
2022	2578	2723	3000	3383	3754	4212	4498
2023	2379	2557	2893	3328	3796	4243	4531
2024	2059	2247	2594	3043	3505	3949	4242
2025	1618	1761	2057	2433	2831	3218	3471
2026	1665	1827	2142	2542	2963	3375	3626
2027	1712	1870	2200	2594	3034	3443	3708
2028	1230	1355	1591	1883	2200	2498	2685
2029	1370	1500	1760	2082	2430	2749	2948
2030	1461	1594	1867	2196	2557	2898	3107
2031	1512	1650	1925	2257	2611	2962	3190
2032	1541	1680	1945	2284	2644	2994	3235
2033	1554	1697	1959	2300	2667	3024	3240
2034	1558	1700	1971	2308	2666	3015	3248

Table 10.4. The central tendency of projected annual catch biomasses (median, mt) under the 3-model recruitment ensemble for a phased quota = (2400, 2150) mt rebuilding scenario along with percentiles of the catch biomass distributions (P05, P10, P25, P75, P90, P95).

Catch Biomass (mt)							
Phased Catch Quota = (2400, 2150) mt Rebuilding Scenario							
Year	P05	P10	P25	Median	P75	P90	P95
2021	2352	2456	2668	2916	3228	3550	3786
2022	2579	2722	2994	3377	3743	4203	4488
2023	2389	2552	2887	3312	3792	4231	4533
2024	2066	2235	2571	3020	3513	3991	4271
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. Comparison of the central tendencies of projected annual catch biomasses (median catch, mt) under the constant F, constant quota, phased F and phased quota rebuilding scenarios along with the average catch, total catch, and percent of the maximum total catch during 2021–2034.

Catch Biomass (mt)					
Year	Constant F Rebuild	Constant Quota Rebuild	Phased F Rebuild	Phased Quota Rebuild	Constant Fmsy
2021	2912	2916	2916	2916	2916
2022	3384	3383	3383	3377	3383
2023	3313	3328	3328	3312	3328
2024	3015	3043	3043	3020	3043
2025	1748	2175	2433	2400	2710
2026	2006	2175	2542	2400	2723
2027	2163	2175	2594	2400	2724
2028	2251	2175	1883	2150	2731
2029	2288	2175	2082	2150	2725
2030	2315	2175	2196	2150	2713
2031	2319	2175	2257	2150	2721
2032	2316	2175	2284	2150	2717
2033	2319	2175	2300	2150	2716
2034	2323	2175	2308	2150	2718
Average 2025-2034	2205	2175	2288	2225	2720
Total 2025-2034	22048	21750	22878	22250	27197
Percent of Maximum	96%	95%	100%	97%	119%

Table 11.1. The central tendency of projected annual spawning stock biomasses (median, mt) under the 3-model recruitment ensemble for a constant F = 0.373 rebuilding scenario along with percentiles of the catch biomass distributions (P05, P10, P25, P75, P90, P95).

Spawning Stock Biomass (mt)								
Constant F = 0.373 Rebuilding Scenario								
Year	P05	P10	P25	P40	Median	P75	P90	P95
2021	1729	1830	1999	2136	2230	2518	2818	3035
2022	1960	2083	2313	2481	2576	2859	3190	3402
2023	2064	2212	2496	2719	2872	3306	3765	4076
2024	1680	1821	2123	2359	2507	2970	3416	3669
2025	1746	1920	2255	2525	2703	3232	3738	4082
2026	2047	2257	2676	3013	3231	3859	4443	4824
2027	2276	2506	2975	3340	3573	4260	4892	5262
2028	2432	2681	3137	3519	3758	4433	5086	5480
2029	2516	2739	3229	3612	3846	4533	5204	5637
2030	2547	2795	3270	3637	3880	4586	5294	5728
2031	2544	2806	3282	3674	3912	4616	5300	5748
2032	2562	2811	3284	3668	3912	4605	5284	5690
2033	2557	2813	3281	3657	3923	4612	5285	5700
2034	2556	2801	3274	3660	3914	4624	5290	5698

Table 11.2. The central tendency of projected annual spawning stock biomasses (median, mt) under the 3-model recruitment ensemble for a constant quota = 2175 mt rebuilding scenario along with percentiles of the catch biomass distributions (P05, P10, P25, P75, P90, P95).

Spawning Stock Biomass (mt)								
Constant Catch Quota = 2175 mt Rebuilding Scenario								
Year	P05	P10	P25	P40	Median	P75	P90	P95
2021	1728	1832	2004	2138	2228	2514	2807	3029
2022	1964	2086	2313	2480	2576	2854	3205	3404
2023	2077	2212	2493	2724	2872	3307	3777	4078
2024	1684	1832	2130	2373	2530	2991	3411	3681
2025	1428	1620	2033	2359	2581	3175	3770	4135
2026	1222	1507	2122	2604	2908	3824	4713	5252
2027	1143	1513	2257	2868	3256	4366	5420	6109
2028	1139	1554	2424	3092	3516	4739	5960	6746
2029	1134	1622	2543	3258	3729	5029	6338	7195
2030	1190	1665	2635	3394	3877	5256	6611	7471
2031	1237	1730	2710	3499	3989	5395	6766	7663
2032	1264	1771	2774	3578	4091	5493	6918	7890
2033	1303	1815	2844	3630	4140	5579	7066	8035
2034	1338	1878	2874	3686	4191	5674	7117	8118

Table 11.3. The central tendency of projected annual spawning stock biomasses (median, mt) under the 3-model recruitment ensemble for a phased F = (0.55, 0.37) rebuilding scenario along with percentiles of the catch biomass distributions (P05, P10, P25, P75, P90, P95).

Spawning Stock Biomass (mt)								
Phased F = (0.55, 0.37) Rebuilding Scenario								
Year	P05	P10	P25	P40	Median	P75	P90	P95
2021	1728	1832	2004	2138	2228	2514	2807	3029
2022	1964	2086	2313	2480	2576	2854	3205	3404
2023	2077	2212	2493	2724	2872	3307	3777	4078
2024	1684	1832	2130	2373	2530	2991	3411	3681
2025	1605	1753	2068	2326	2496	2973	3440	3727
2026	1667	1841	2186	2452	2636	3167	3662	3965
2027	1717	1888	2254	2536	2729	3275	3768	4083
2028	1905	2096	2500	2814	3032	3620	4172	4538
2029	2160	2387	2855	3198	3432	4124	4720	5098
2030	2349	2591	3060	3441	3674	4393	5041	5460
2031	2463	2712	3181	3571	3807	4514	5189	5609
2032	2517	2754	3238	3621	3877	4580	5250	5714
2033	2548	2795	3267	3656	3906	4619	5284	5719
2034	2559	2807	3292	3681	3936	4645	5308	5753

Table 11.4. The central tendency of projected annual spawning stock biomasses (median, mt) under the 3-model recruitment ensemble for a phased quota = (2400, 2150) mt rebuilding scenario along with percentiles of the catch biomass distributions (P05, P10, P25, P75, P90, P95).

Spawning Stock Biomass (mt)								
Phased Catch Quota = (2400, 2150) mt Rebuilding Scenario								
Year	P05	P10	P25	P40	Median	P75	P90	P95
2021	1729	1834	1997	2136	2229	2510	2809	3027
2022	1966	2088	2306	2473	2574	2858	3197	3421
2023	2071	2210	2488	2717	2871	3299	3755	4054
2024	1672	1819	2112	2360	2511	2978	3413	3665
2025	1328	1539	1938	2262	2470	3125	3721	4093
2026	996	1281	1866	2353	2669	3593	4500	5082
2027	860	1185	1894	2469	2857	3966	5040	5757
2028	859	1255	2048	2672	3087	4319	5503	6305
2029	936	1385	2254	2934	3381	4655	5940	6779
2030	1015	1499	2429	3162	3607	4934	6297	7160
2031	1107	1592	2566	3318	3796	5194	6523	7468
2032	1152	1713	2681	3449	3955	5350	6801	7723
2033	1236	1779	2782	3573	4069	5474	6935	7861
2034	1325	1848	2878	3669	4157	5598	7071	7992

Table 11.5. Comparison of the central tendencies of projected annual spawning stock biomasses (median catch, mt) under the constant F, constant quota, phased F and phased quota rebuilding scenarios along with the average SSB, total SSB, and percent of the maximum total SSB during 2021–2034.

Spawning Stock Biomass (mt)					
Year	Constant F Rebuild	Constant Quota Rebuild	Phased F Rebuild	Phased Quota Rebuild	Constant Fmsy
2021	2230	2228	2228	2229	2228
2022	2576	2576	2576	2574	2576
2023	2872	2872	2872	2871	2872
2024	2507	2530	2530	2511	2530
2025	2703	2581	2496	2470	2399
2026	3231	2908	2636	2669	2405
2027	3573	3256	2729	2857	2427
2028	3758	3516	3032	3087	2436
2029	3846	3729	3432	3381	2422
2030	3880	3877	3674	3607	2409
2031	3912	3989	3807	3796	2422
2032	3912	4091	3877	3955	2408
2033	3923	4140	3906	4069	2414
2034	3914	4191	3936	4157	2422
Average 2025-2034	3665	3628	3353	3405	2416
Total 2025-2034	36653	36276	33525	34048	24163
Percent of Maximum	100%	99%	91%	93%	66%

Table 12. Comparison of the central tendencies of fishing mortalities (median, yr^{-1}) under the constant F, constant quota, phased F and phased quota rebuilding scenarios along with the average SSB, total SSB, and percent of the maximum total SSB during 2021–2034.

Fishing Mortality					
Year	Constant F Rebuild Catch	Constant Quota Rebuild Catch	Phased F Rebuild Catch	Phased Quota Rebuild Catch	Constant Fmsy Catch
2021	0.68	0.68	0.68	0.68	0.68
2022	0.68	0.68	0.68	0.68	0.68
2023	0.68	0.68	0.68	0.68	0.68
2024	0.68	0.68	0.68	0.68	0.68
2025	0.373	0.482	0.55	0.546	0.63
2026	0.373	0.434	0.55	0.516	0.63
2027	0.373	0.399	0.55	0.490	0.63
2028	0.373	0.373	0.37	0.412	0.63
2029	0.373	0.356	0.37	0.383	0.63
2030	0.373	0.344	0.37	0.360	0.63
2031	0.373	0.335	0.37	0.346	0.63
2032	0.373	0.329	0.37	0.335	0.63
2033	0.373	0.325	0.37	0.326	0.63
2034	0.373	0.322	0.37	0.320	0.63
Average 2025-2034	0.373	0.370	0.424	0.404	0.630

Table 13. Comparison of the projected probabilities of achieving the rebuilding target under the constant F, constant quota, phased F and phased quota rebuilding scenarios 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	Constant F Rebuild	Contant Quota Rebuild	Phased F Rebuild	Phased Quota Rebuild
2021	0.02	0.02	0.02	0.02
2022	0.02	0.02	0.02	0.02
2023	0.12	0.13	0.13	0.13
2024	0.05	0.05	0.05	0.05
2025	0.12	0.12	0.06	0.11
2026	0.32	0.29	0.10	0.24
2027	0.46	0.40	0.12	0.31
2028	0.54	0.47	0.24	0.37
2029	0.58	0.51	0.41	0.44
2030	0.59	0.54	0.51	0.49
2031	0.60	0.57	0.56	0.53
2032	0.60	0.58	0.59	0.56
2033	0.60	0.59	0.60	0.58
2034	0.60	0.61	0.61	0.60

Table 14. Comparison of the projected probabilities of overfishing under the constant F, constant quota, phased F and phased quota rebuilding scenarios along with the first year when the probability of overfishing the stock was less than or equal to 50% (green shade).

Probability of Overfishing				
Year	Constant F Rebuild	Contant Quota Rebuild	Phased F Rebuild	Phased Quota Rebuild
2021	1	1	1	1
2022	1	1	1	1
2023	1	1	1	1
2024	1	1	1	1
2025	0	0.37	1	0.54
2026	0	0.30	1	0.47
2027	0	0.26	1	0.43
2028	0	0.23	0	0.30
2029	0	0.21	0	0.25
2030	0	0.20	0	0.22
2031	0	0.18	0	0.20
2032	0	0.18	0	0.18
2033	0	0.17	0	0.16
2034	0	0.16	0	0.15

Table 15. Comparison of central tendencies of catch biomasses, spawning stock biomasses and fishing mortalities under the medium-term recruitment model for the constant F rebuild = 0.38, constant quota rebuild = 2200 mt, and constant F = Fmsy scenarios along with the average SSB, catch and F, the total SSB and catch, and the percent of the maximum total SSB and total catch during 2021–2034.

WCNPO Striped Marlin Rebuilding Scenarios Under Medium-term Recruitment

Catch Biomass (mt)				Spawning Stock Biomass (mt)				Fishing Mortality			
Year	Constant F Rebuild	Constant Quota Rebuild	Constant Fmsy	Year	Constant F Rebuild	Constant Quota Rebuild	Constant Fmsy	Year	Constant F Rebuild Catch	Constant Quota Rebuild Catch	Constant Fmsy Catch
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. Comparison of the probabilities of achieving the rebuilding and probabilities of overfishing under the medium-term recruitment model for the constant F rebuild = 0.56, constant quota rebuild = 2200 mt, and constant F = Fmsy scenario along with the average SSB, catch and F, the total SSB and catch, and the percent of the maximum total SSB and total catch during 2021–2034.

WCNPO Striped Marlin Rebuilding Scenarios Under Medium-term Recruitment

Probability of Rebuilding					Probability of Overfishing			
Year	Constant F Rebuild	Contant Quota Rebuild	Fmsy		Year	Constant F Rebuild	Contant Quota Rebuild	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. Comparison of central tendencies of catch biomasses, spawning stock biomasses and fishing mortalities under the short-term recruitment model for the constant F rebuild = 0.56, constant quota rebuild = 2200 mt, and constant F = Fmsy scenarios along with the average SSB, catch and F, the total SSB and catch, and the percent of the maximum total SSB and total catch during 2021–2034.

WCNPO Striped Marlin Rebuilding Scenarios Under Short-term Recruitment

Catch Biomass (mt)

Year	Constant F Rebuild	Constant Quota Rebuild	Constant Fmsy
2021	2913	2908	2908
2022	3321	3319	3319
2023	3013	3013	3013
2024	2503	2514	2514
2025	997	1400	2114
2026	1194	1400	2063
2027	1332	1400	2053
2028	1414	1400	2051
2029	1460	1400	2053
2030	1488	1400	2045
2031	1499	1400	2051
2032	1501	1400	2045
2033	1505	1400	2043
2034	1503	1400	2046
Average 2025-2034	1389	1400	2056
Total 2025-2034	13892	14000	20563
Percent of Maximum	99%	100%	147%

Spawning Stock Biomass (mt)

Year	Constant F Rebuild	Constant Quota Rebuild	Constant Fmsy
2021	2227	2228	2228
2022	2570	2574	2574
2023	2751	2750	2750
2024	2149	2161	2161
2025	2288	2151	1901
2026	2855	2526	1845
2027	3285	2892	1829
2028	3543	3193	1831
2029	3682	3416	1822
2030	3768	3602	1818
2031	3808	3737	1823
2032	3834	3845	1824
2033	3839	3929	1824
2034	3840	3989	1823
Average 2025-2034	3474	3328	1834
Total 2025-2034	34743	33279	18339
Percent of Maximum	100%	96%	53%

Fishing Mortality

Year	Constant F Rebuild Catch	Constant Quota Rebuild Catch	Constant Fmsy Catch
2021	0.68	0.68	0.68
2022	0.68	0.68	0.68
2023	0.68	0.68	0.68
2024	0.68	0.68	0.68
2025	0.26	0.377	0.63
2026	0.26	0.332	0.63
2027	0.26	0.296	0.63
2028	0.26	0.273	0.63
2029	0.26	0.256	0.63
2030	0.26	0.245	0.63
2031	0.26	0.237	0.63
2032	0.26	0.231	0.63
2033	0.26	0.228	0.63
2034	0.26	0.224	0.63
Average 2025-2034	0.260	0.270	0.630

Table 18. Comparison of the probabilities of achieving the rebuilding and probabilities of overfishing under the short-term recruitment model for the constant F rebuild = 0.256, constant quota rebuild =1400 mt, and constant F = Fmsy scenario along with the average SSB, catch and F, the total SSB and catch, and the percent of the maximum total SSB and total catch during 2021–2034.

WCNPO Striped Marlin Rebuilding Scenarios Under Short-term Recruitment

Probability of Rebuilding					Probability of Overfishing			
Year	Constant F Rebuild	Contant Quota Rebuild	Fmsy		Year	Constant F Rebuild	Contant Quota Rebuild	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. Comparison of central tendencies of catch biomasses, spawning stock biomasses and fishing mortalities under the long-term recruitment model for the constant F rebuild = 0.56, constant quota rebuild = 2500 mt, and constant F = Fmsy scenarios along with the average SSB, catch and F, the total SSB and catch, and the percent of the maximum total SSB and total catch during 2021–2034.

WCNPO Striped Marlin Rebuilding Scenarios Under Long-term Recruitment

Catch Biomass (mt)					Spawning Stock Biomass (mt)					Fishing Mortality			
Year	Constant F Rebuild	Constant Quota Rebuild	Constant Fmsy		Year	Constant F Rebuild	Constant Quota Rebuild	Constant Fmsy		Year	Constant F Rebuild Catch	Constant Quota Rebuild Catch	Constant Fmsy Catch
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. Comparison 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 quota rebuild = 2500 mt, and constant F = Fmsy scenario along with the average SSB, catch and F, the total SSB and catch, and the percent of the maximum total SSB and total catch during 2021–2034.

WCNPO Striped Marlin Rebuilding Scenarios Under Long-term Recruitment

Probability of Rebuilding					Probability of Overfishing			
Year	Constant F Rebuild	Contant Quota Rebuild	Fmsy		Year	Constant F Rebuild	Contant Quota Rebuild	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.

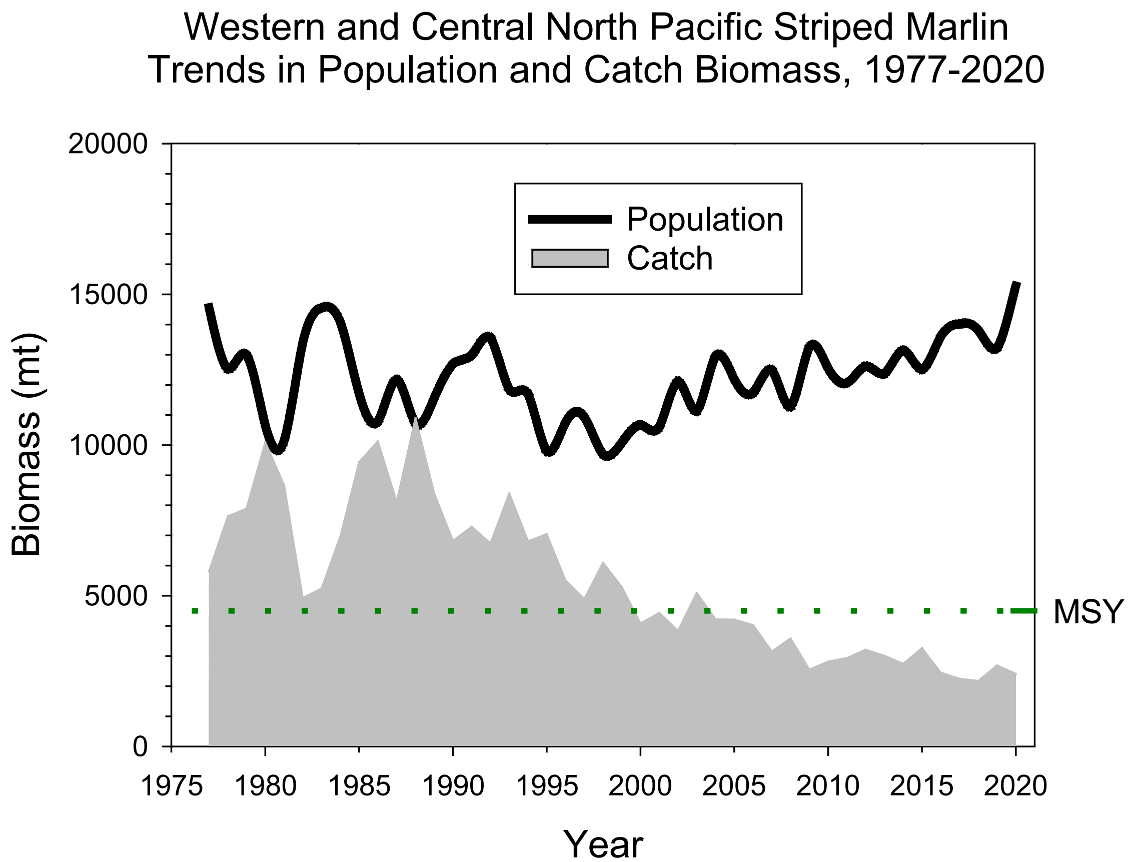


Figure 2. Time series of estimates of spawning biomass of WCNPO striped marlin (*Kajikia audax*) from the revised 2023 benchmark stock assessment (solid black circles) with 80% confidence intervals relative to B_{MSY} (dashed green line) and unfished spawning biomass (solid blue triangle with 80% confidence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

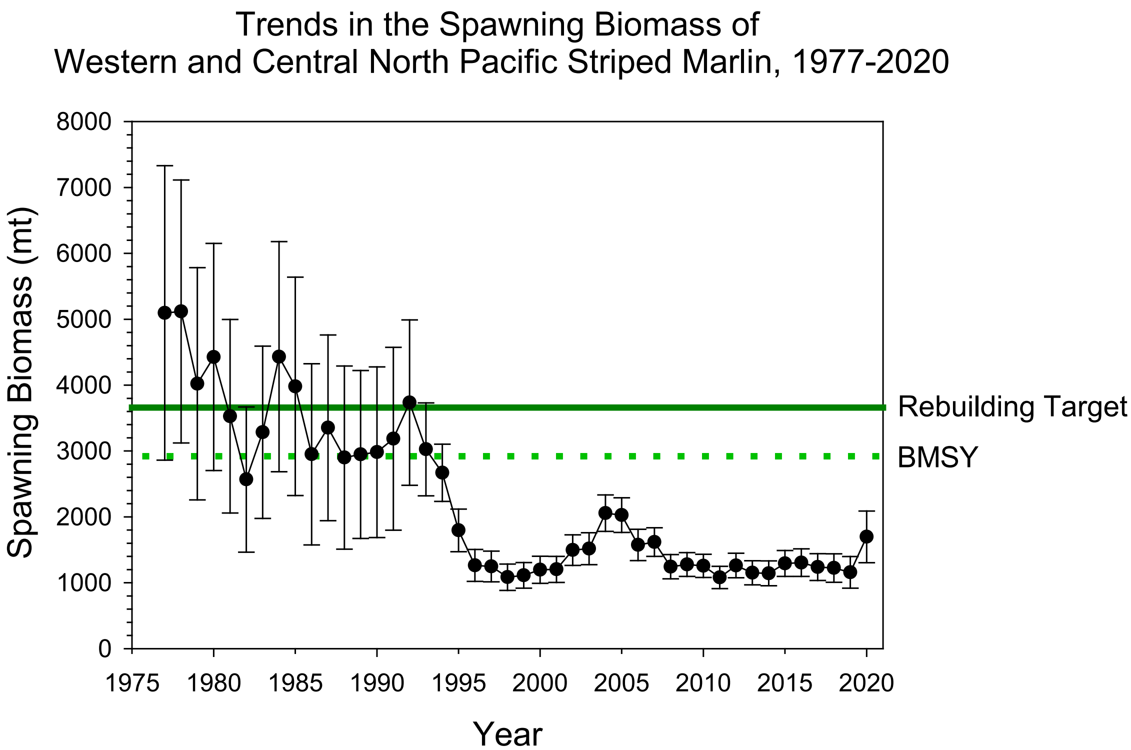


Figure 3. Time series of estimates of fishing mortality rates (average for age 3-12, yr^{-1}) for WCNPO striped marlin (*Kajikia audax*) from the 2023 benchmark stock assessment (solid black circles) with 80% confidence intervals relative to F_{MSY} (dashed red line).

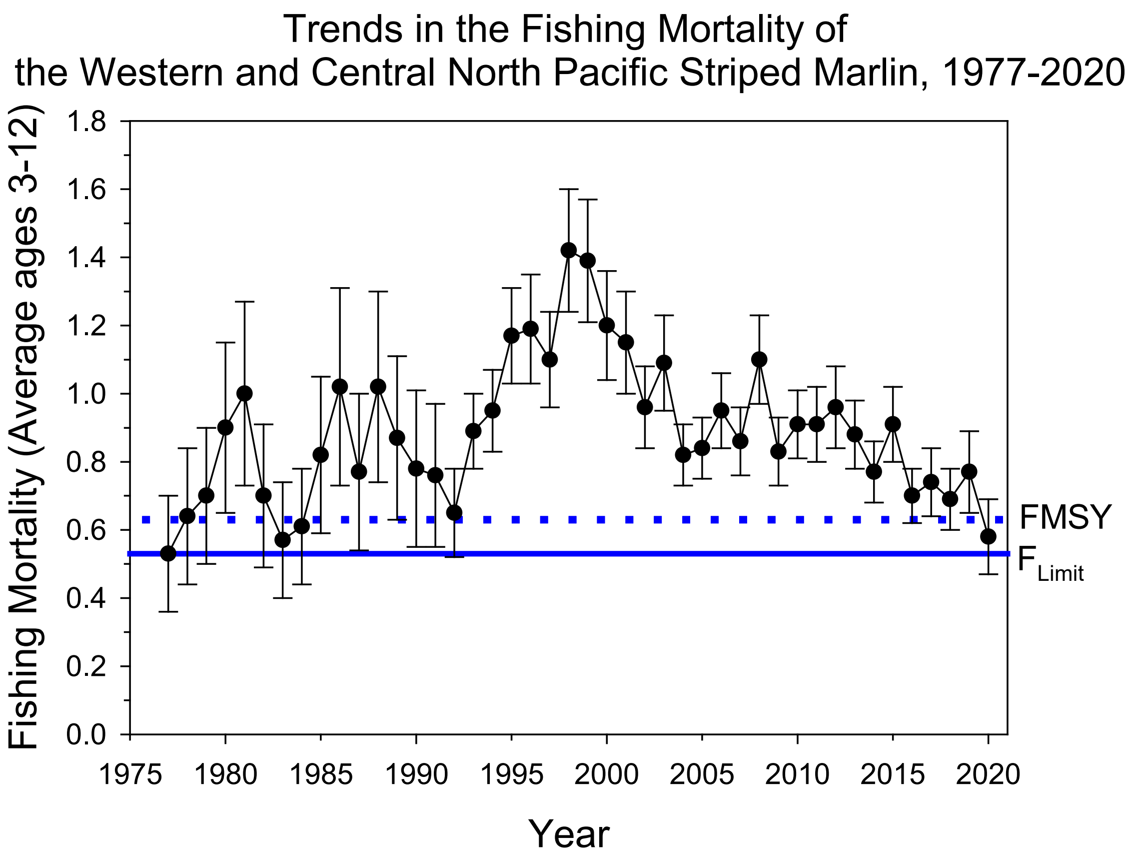
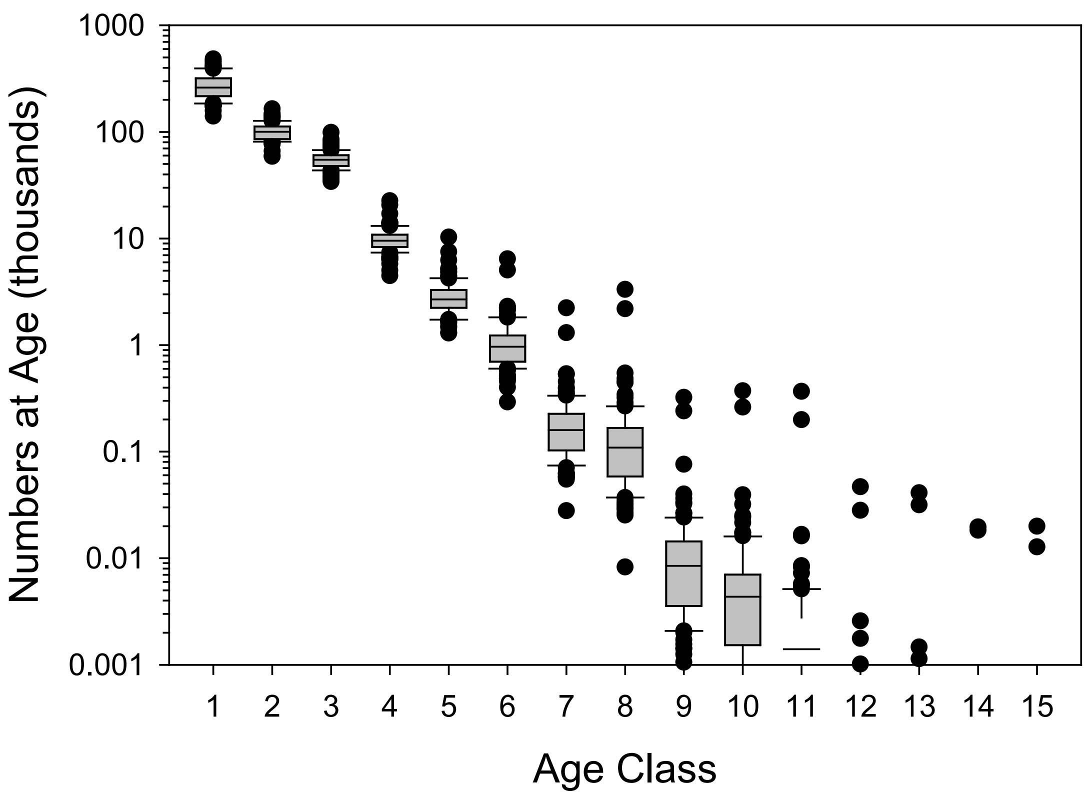
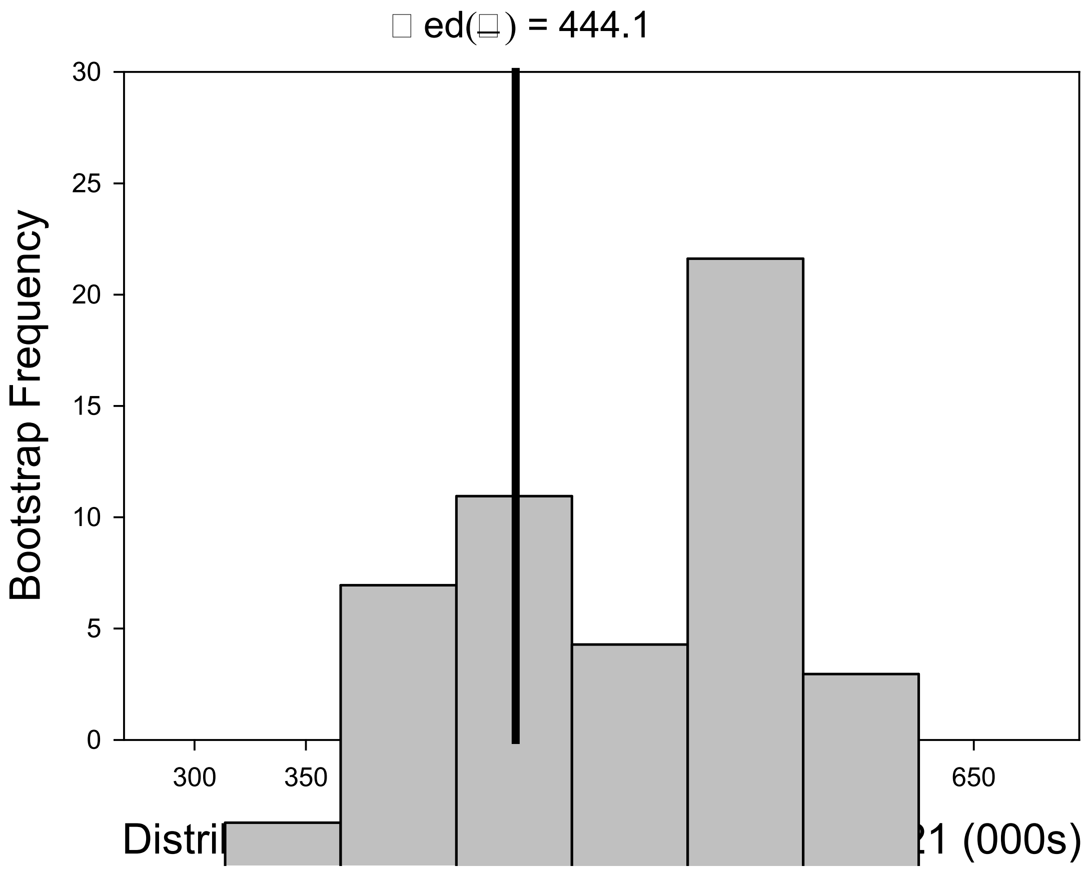


Figure 4. Boxplots of WCNPO striped marlin population numbers at age in 2021 on $\log_{10}$ scale (a) and a histogram (b) of total population sizes (N̲) from the bootstrap resampling of the 2023 stock assessment model where age class 15 is the plus group and Med(.) denotes the median function.

(a)



(b)



ed( ) = 444.1
Bootstrap Frequency
30
25
20
15
10
5
0
300
350
650
Distri
21 (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).

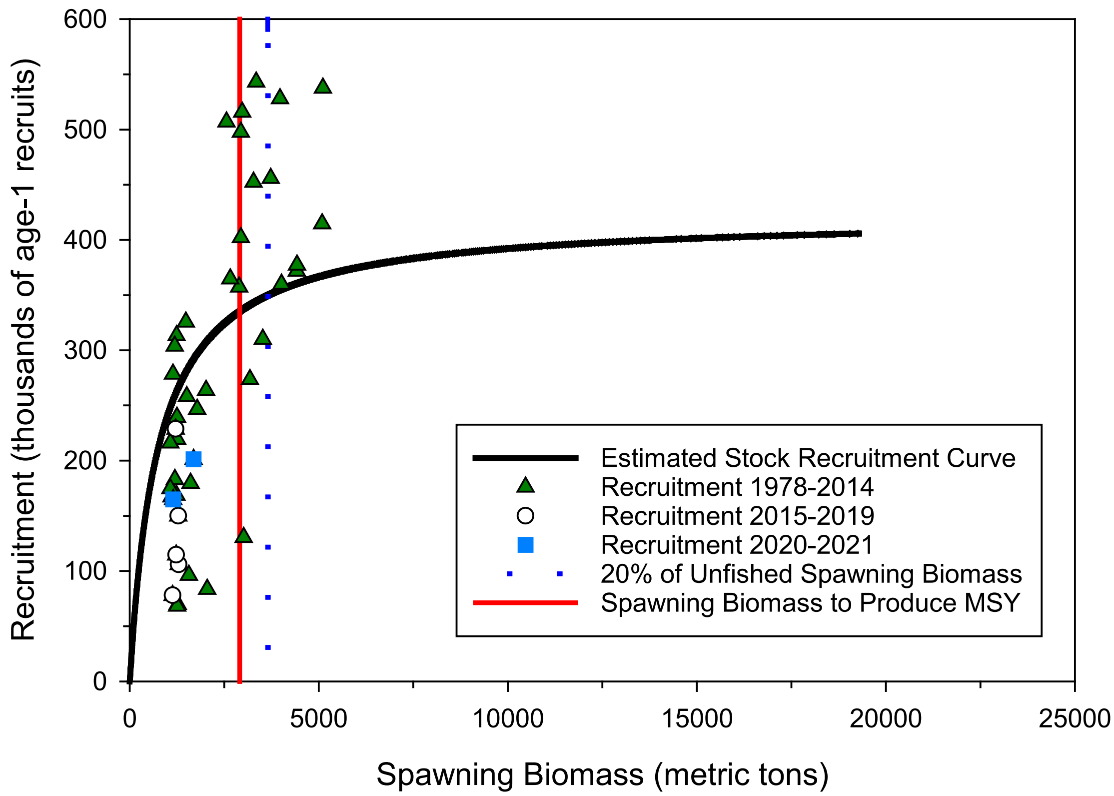


Figure 6. Time series of recruitment estimates (age-1 fish, solid black circles) for WCNPO striped marlin with 80% confidence intervals along with the expected magnitude of recruitment under the short-term (solid red line) and long-term (dashed green line) scenarios from the 2023 benchmark stock assessment.

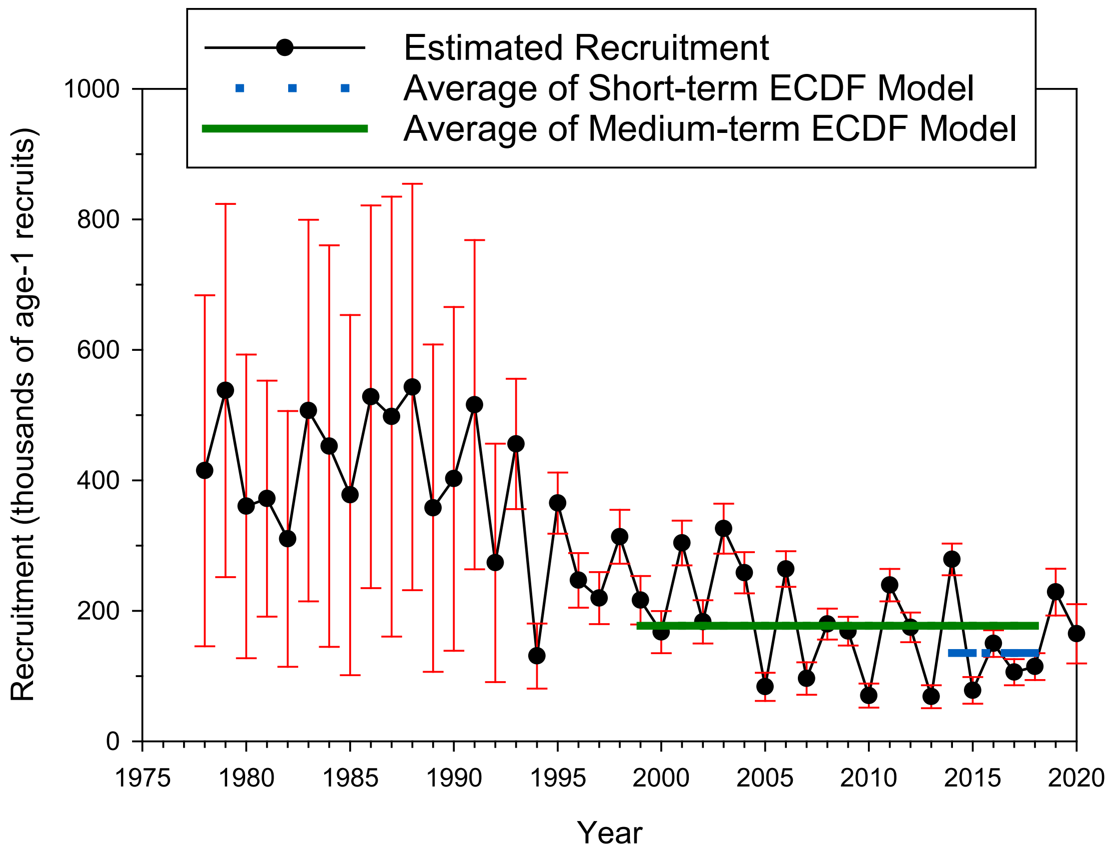


Figure 7. Empirical cumulative distribution functions of recruitment of WCNPO striped marlin under the short-term (dashed blue line) and long-term (solid green line) recruitment scenarios from the 2023 benchmark stock assessment.

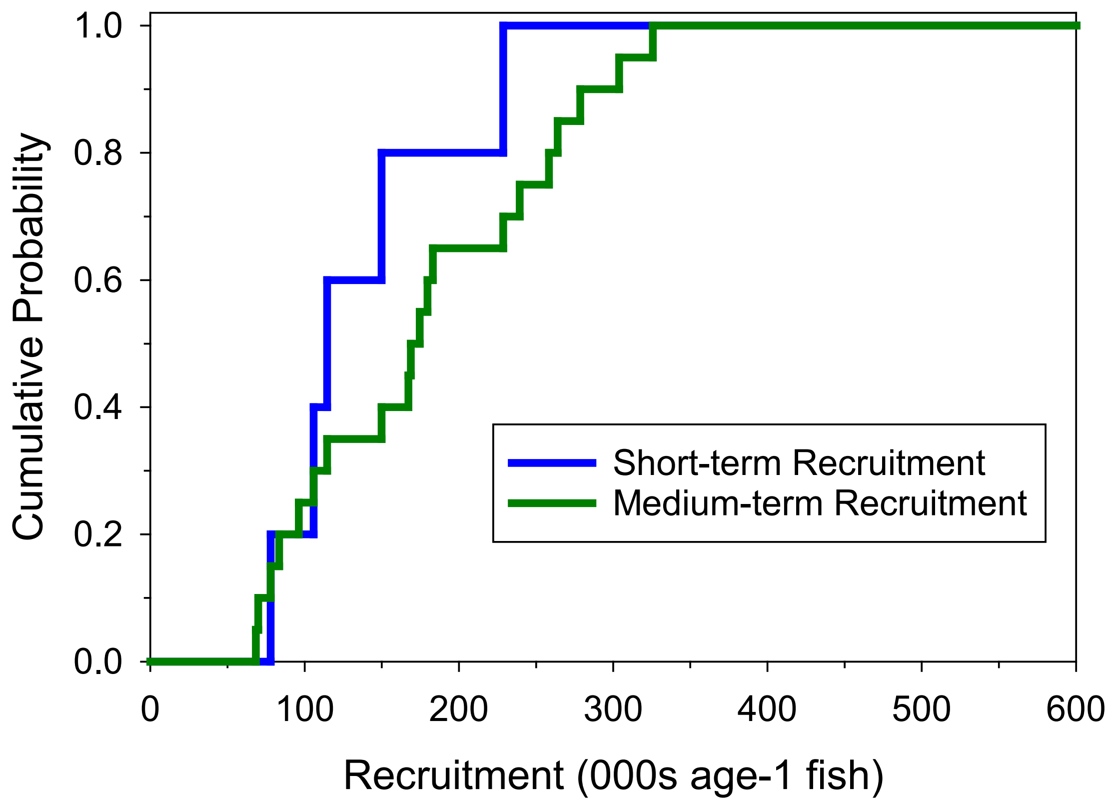


Figure 8. Trends and variabilities of recruitment estimates (age-1 fish, solid black circles) for WCNPO striped marlin with 80% confidence intervals in relation to the estimated unfished recruitment from the stock-recruitment relationship estimated in the 2023 benchmark stock assessment.

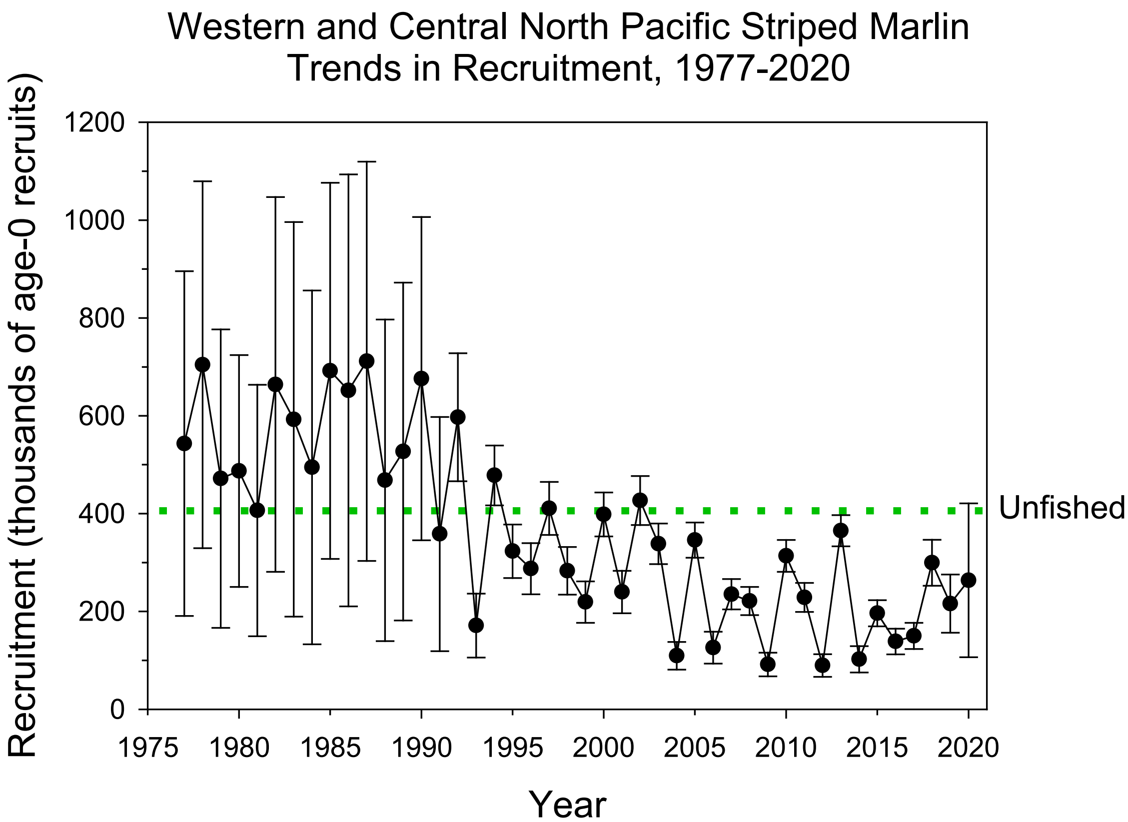


Figure 9. Results of change point analyses of recruitment estimates (age-1 fish, solid black circles) for WCNPO striped marlin with an estimated change in mean recruitment or variance in 1993.

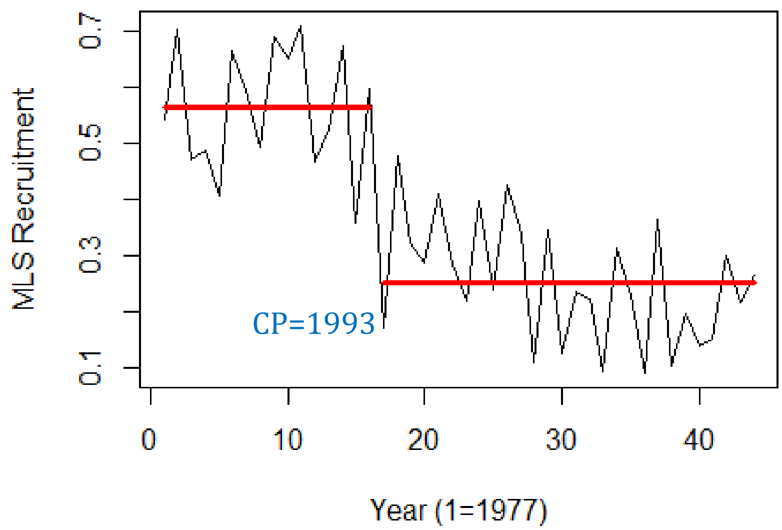


Figure 10. Results of change point analyses of spawning stock biomass estimates (thousand mt, solid black circles) for WCNPO striped marlin with an estimated change in mean spawning stock biomass or variance in 1995.

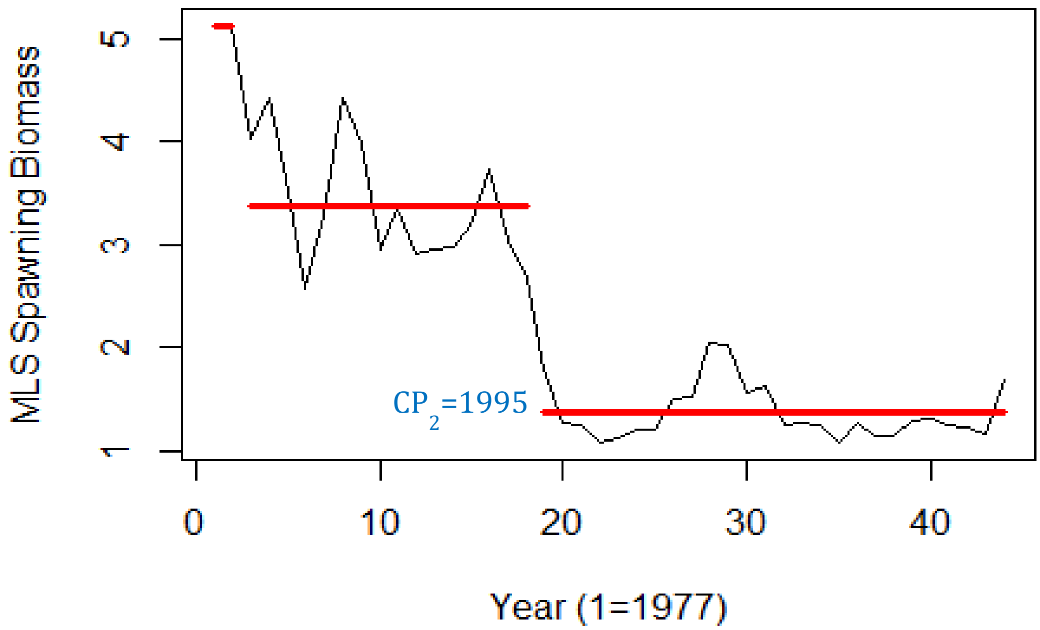


Figure 11. Sequence of mean and median values of 5-year empirical cumulative distribution functions of age-1 recruitment during 1982 to 2021 for WCNPO striped marlin along with the mean of the 5-year ECDF for 2019 used for the short-term recruitment scenario.

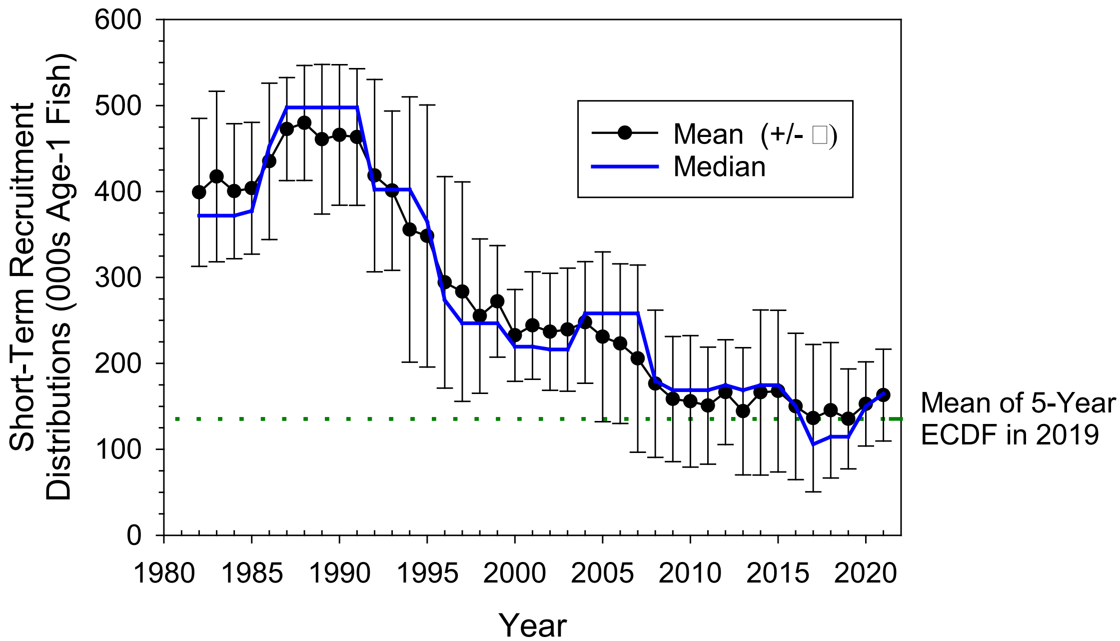


Figure 12. Sequence of mean and median values of 20-year empirical cumulative distribution functions of age-1 recruitment during 1997 to 2021 for WCNPO striped marlin along with the mean of the 20-year ECDF for 2019 used for the short-term recruitment scenario.

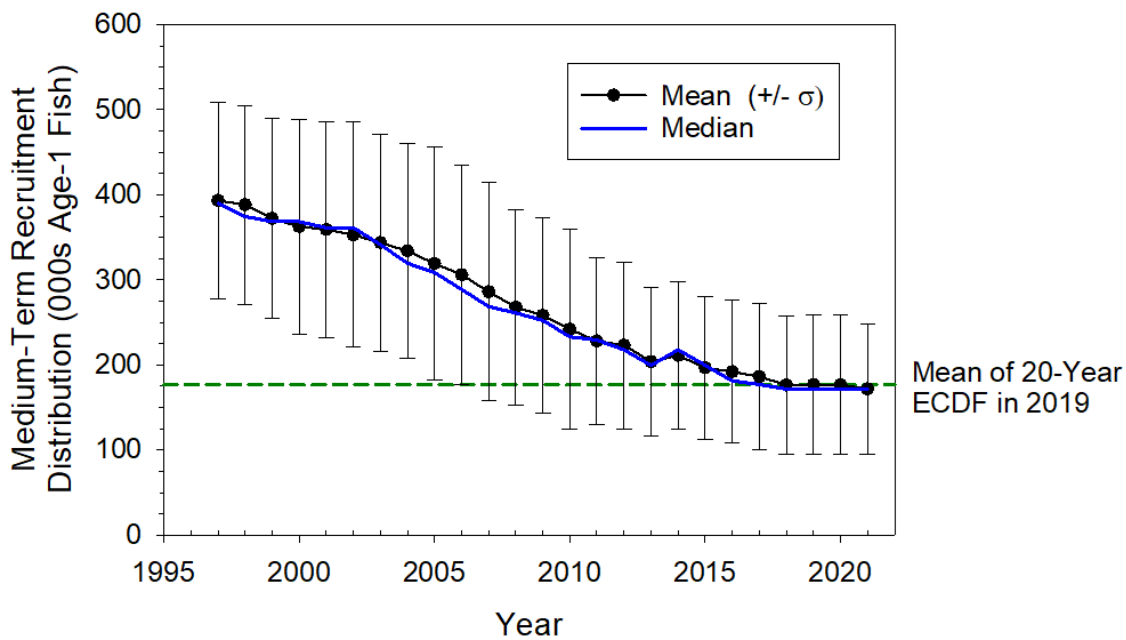
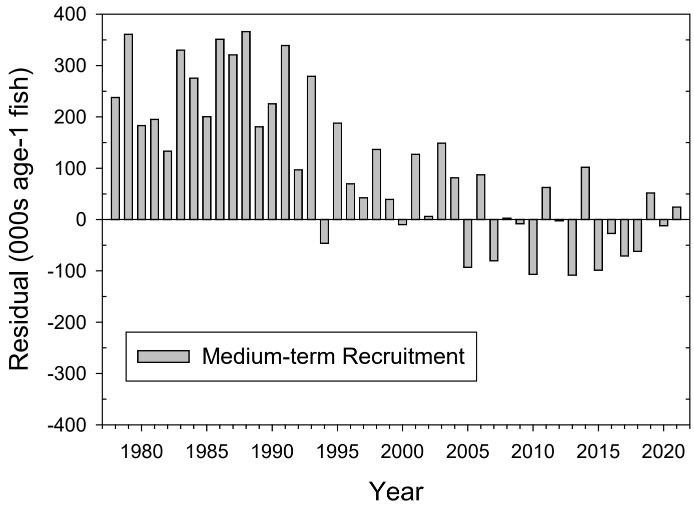
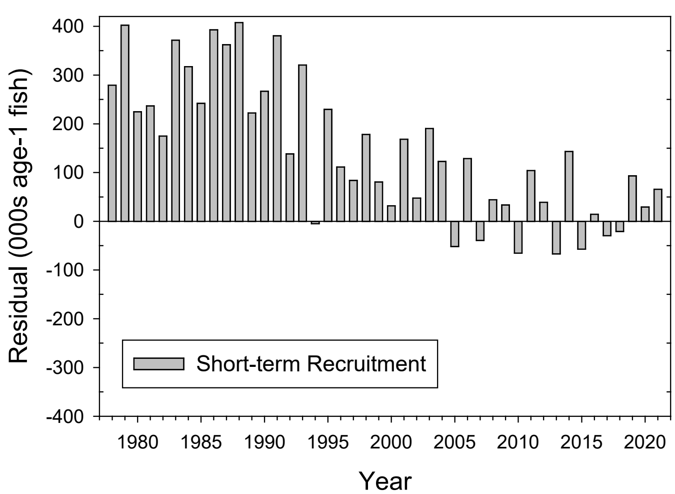


Figure 13. Recruitment residuals (age-1) for medium-term (top), short-term (middle) and long-term (bottom) recruitment model point predictions of estimated recruitment from the 2023 benchmark stock assessment during 1978-2021.





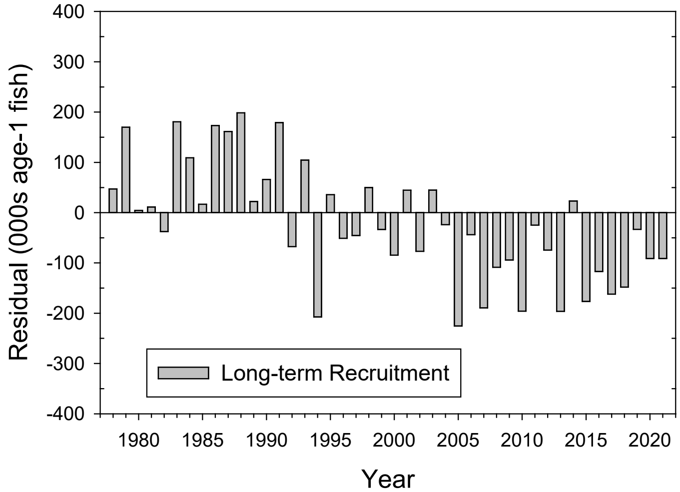

400
300
200
100
0
-100
-200
-300
-400
Residual (000s age-1 fish)
Long-term Recruitment
1980
1985
1990
1995
2000
2005
2010
2015
2020
Year

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.

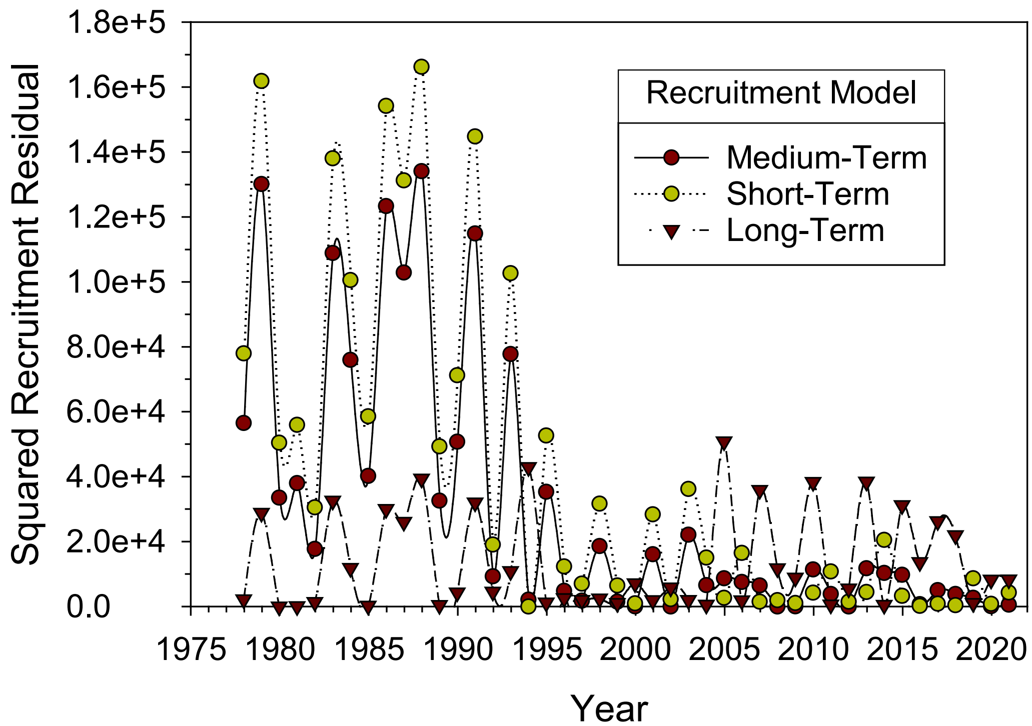


Figure 15. Inverse error-variance weights for medium-term, short-term and long-term recruitment model point predictions of estimated recruitment from the 2023 benchmark stock assessment during 1978-2021.

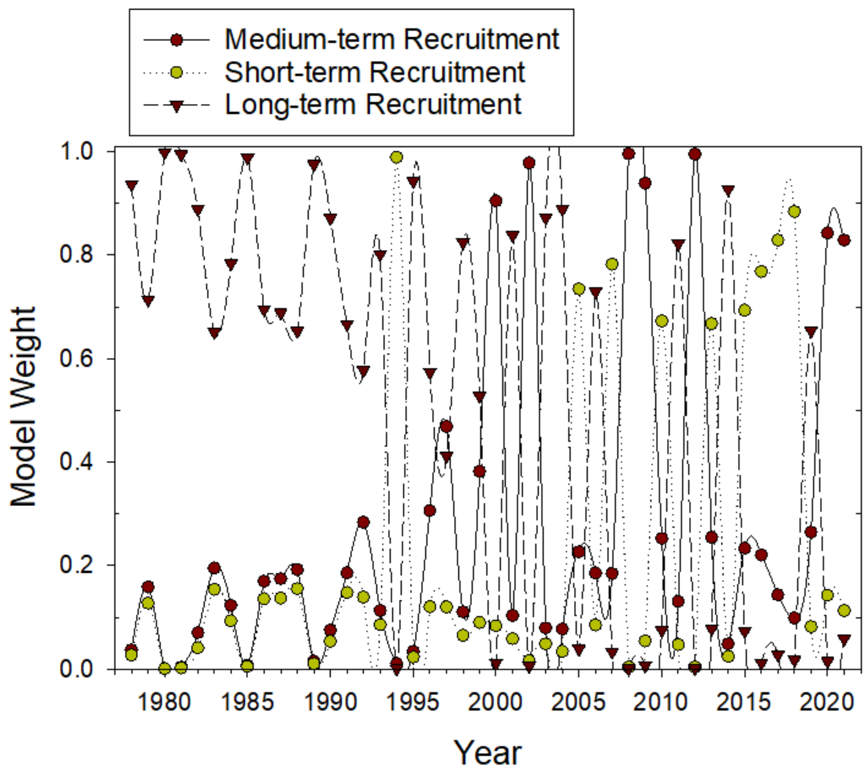


Figure 16. Inverse error-variance weights for medium-term, short-term and long-term recruitment model point predictions of estimated recruitment from the 2023 benchmark stock assessment during 1978-2021.

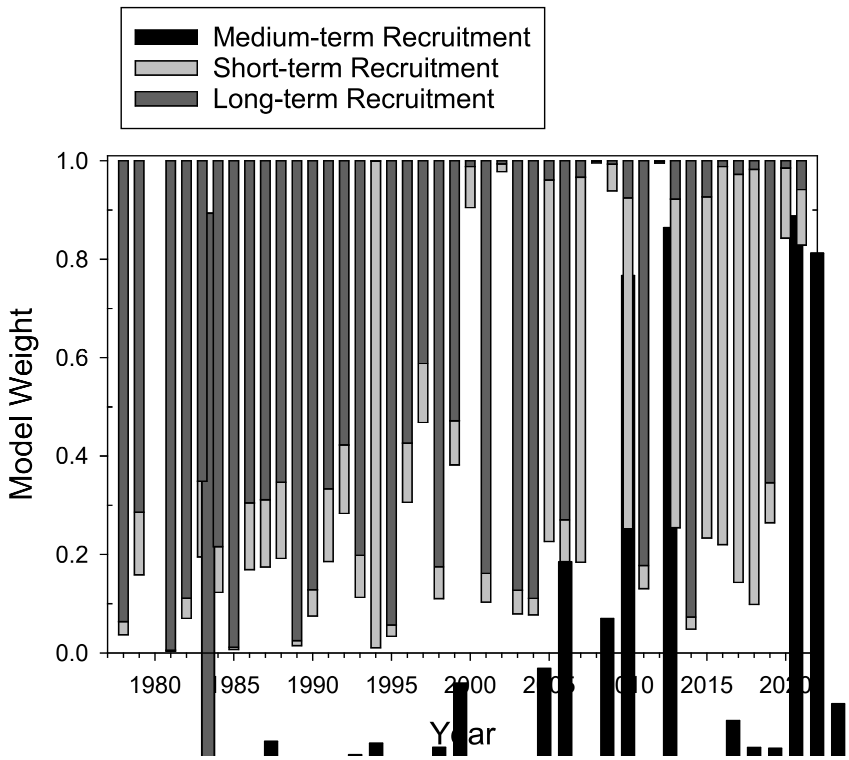


Figure 17. Inverse error-variance weights for medium-term, short-term and long-term recruitment model point predictions of estimated recruitment from the 2023 benchmark stock assessment during 1978-2021.

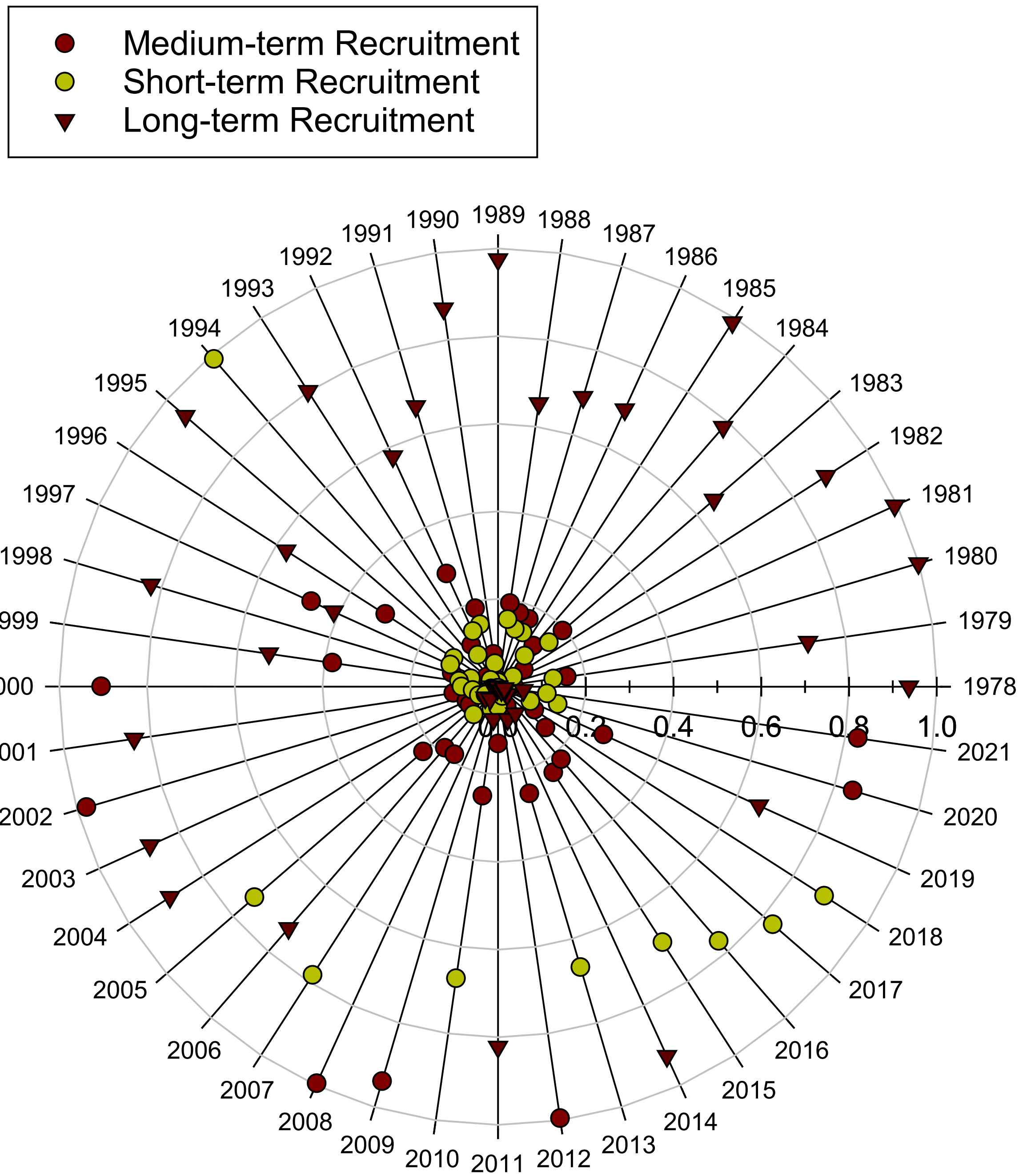


Figure 18. Comparison of aggregated mean weights at age across fleets based on the 2019 and 2023 WCNPO striped marlin stock assessments.

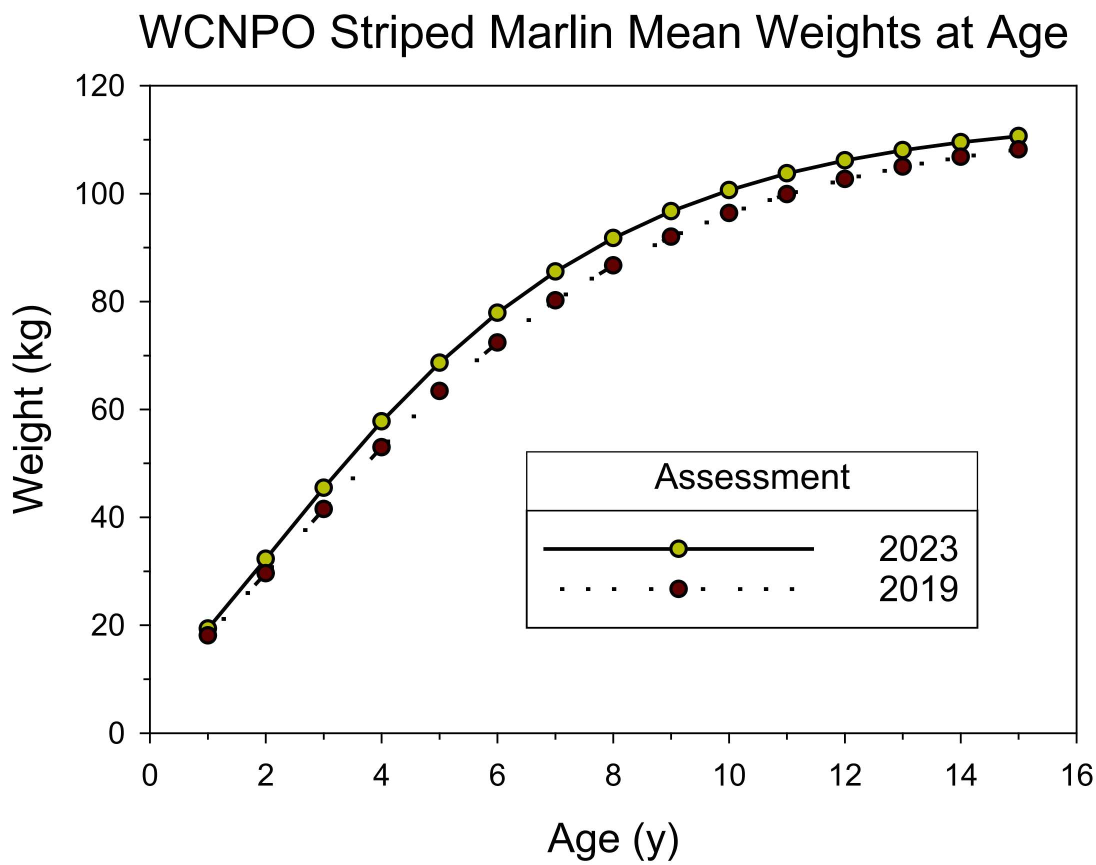


Figure 19. Comparison of female maturity at age ogives based on the 2019 and 2023 WCNPO striped marlin stock assessments.

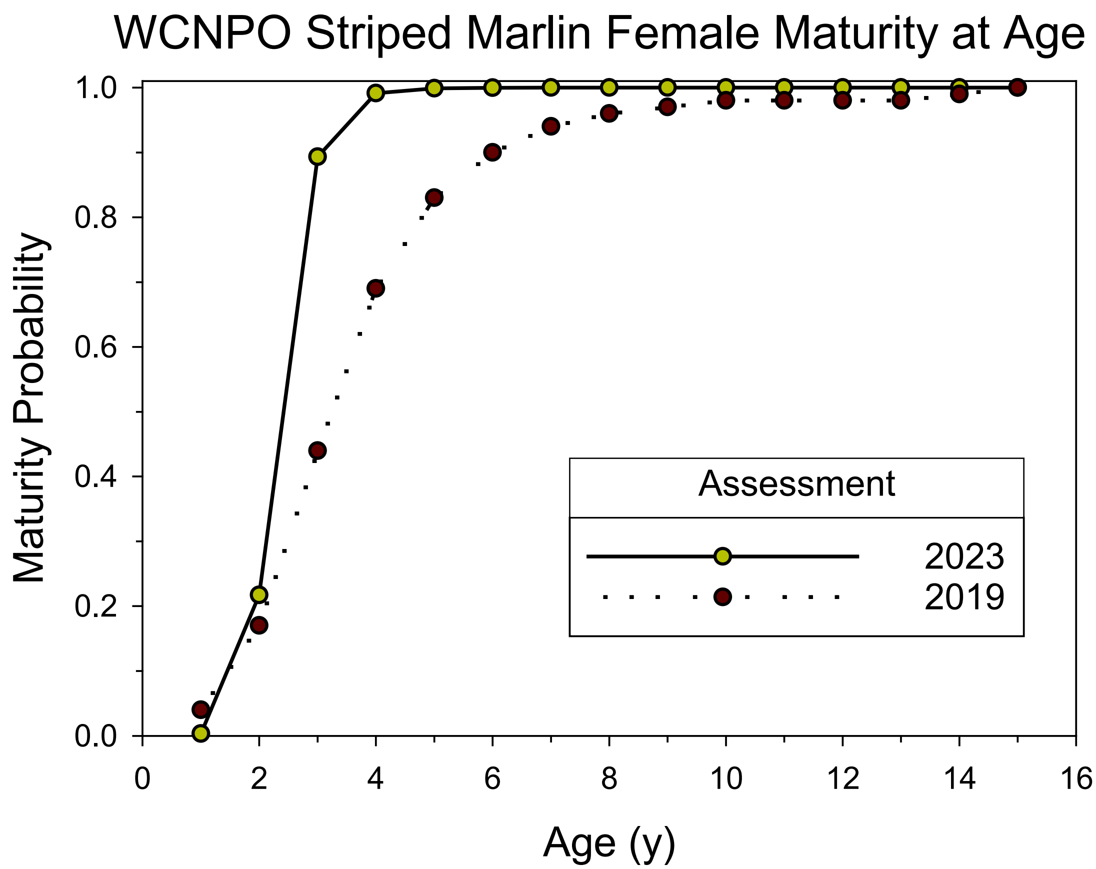


Figure 20. Comparison of aggregated fishery selectivities at age across fleets based on the 2019 and 2023 WCNPO striped marlin stock assessments.

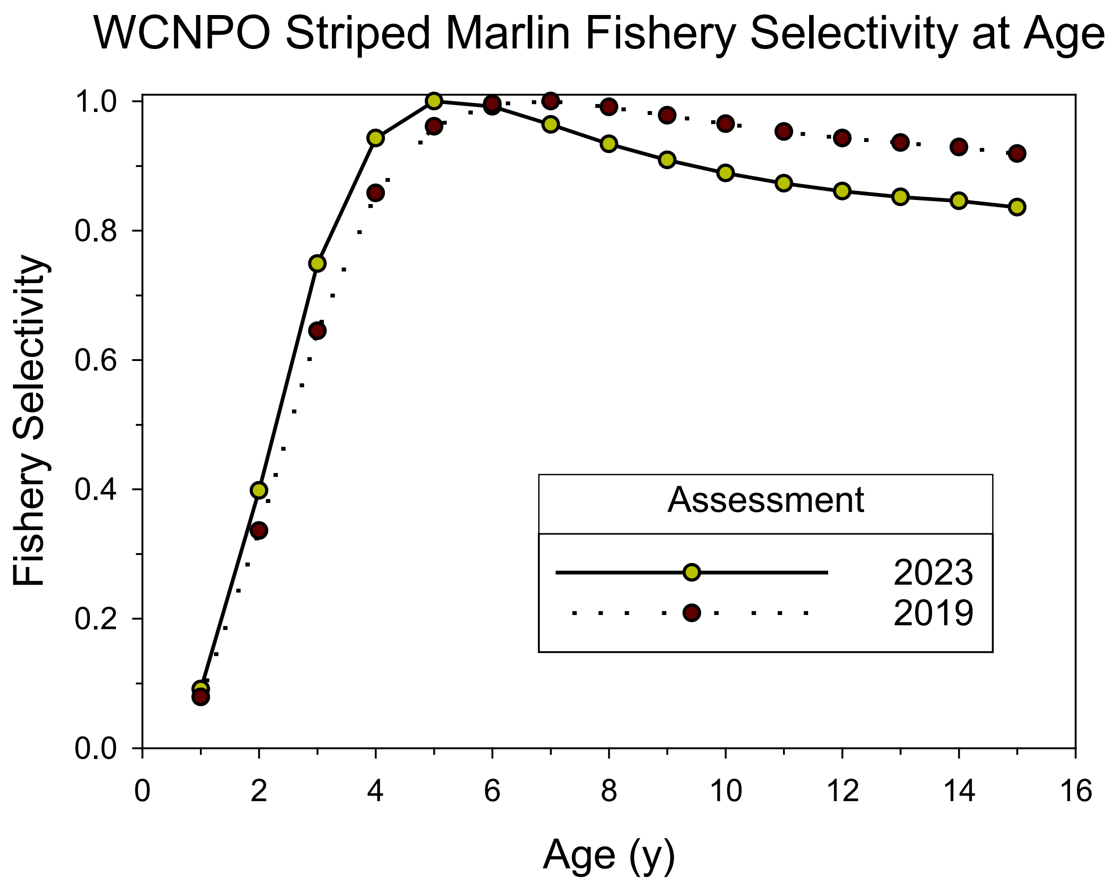


Figure 21. Comparison of aggregated fishery yield per recruit as a function of fishing mortality based on the 2019 and 2023 WCNPO striped marlin stock assessments.

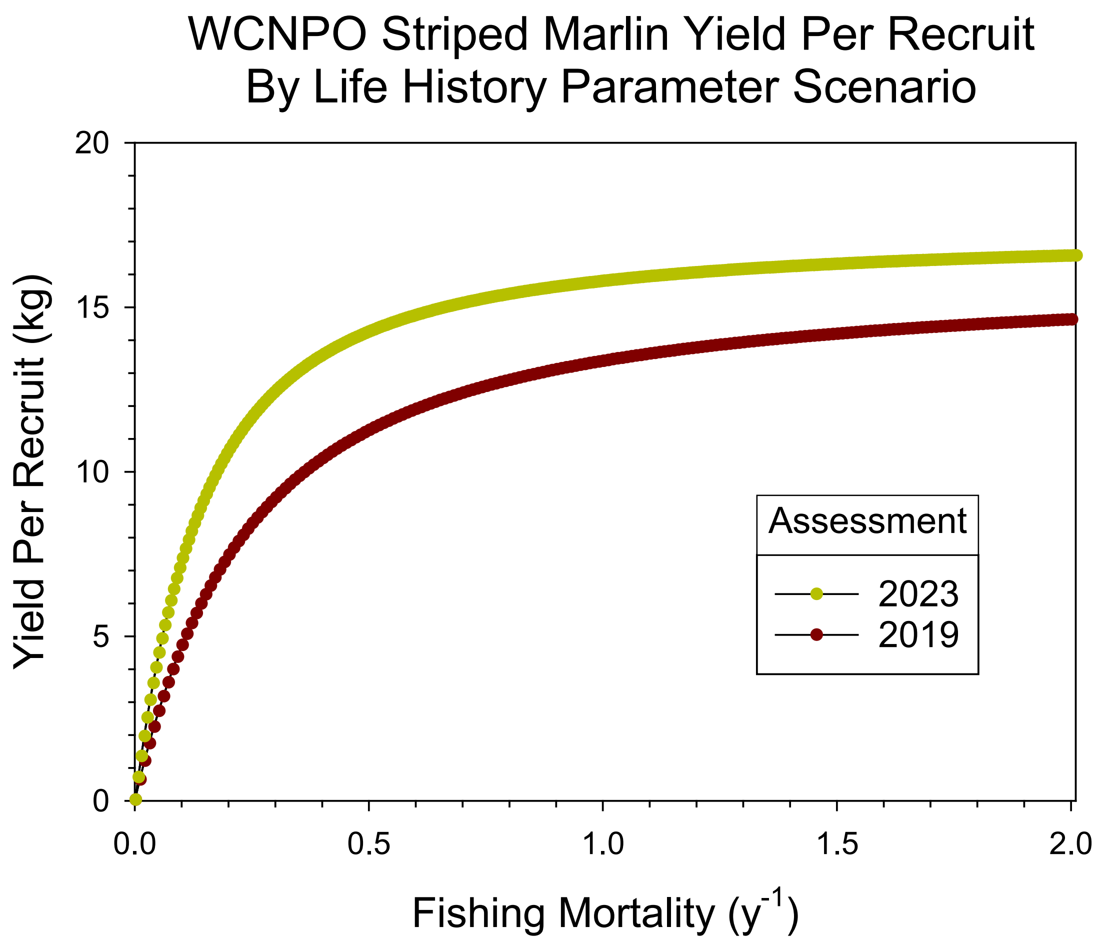


Figure 22. Comparison of aggregated fishery spawning biomass per recruit as a function of fishing mortality based on the 2019 and 2023 WCNPO striped marlin stock assessments.

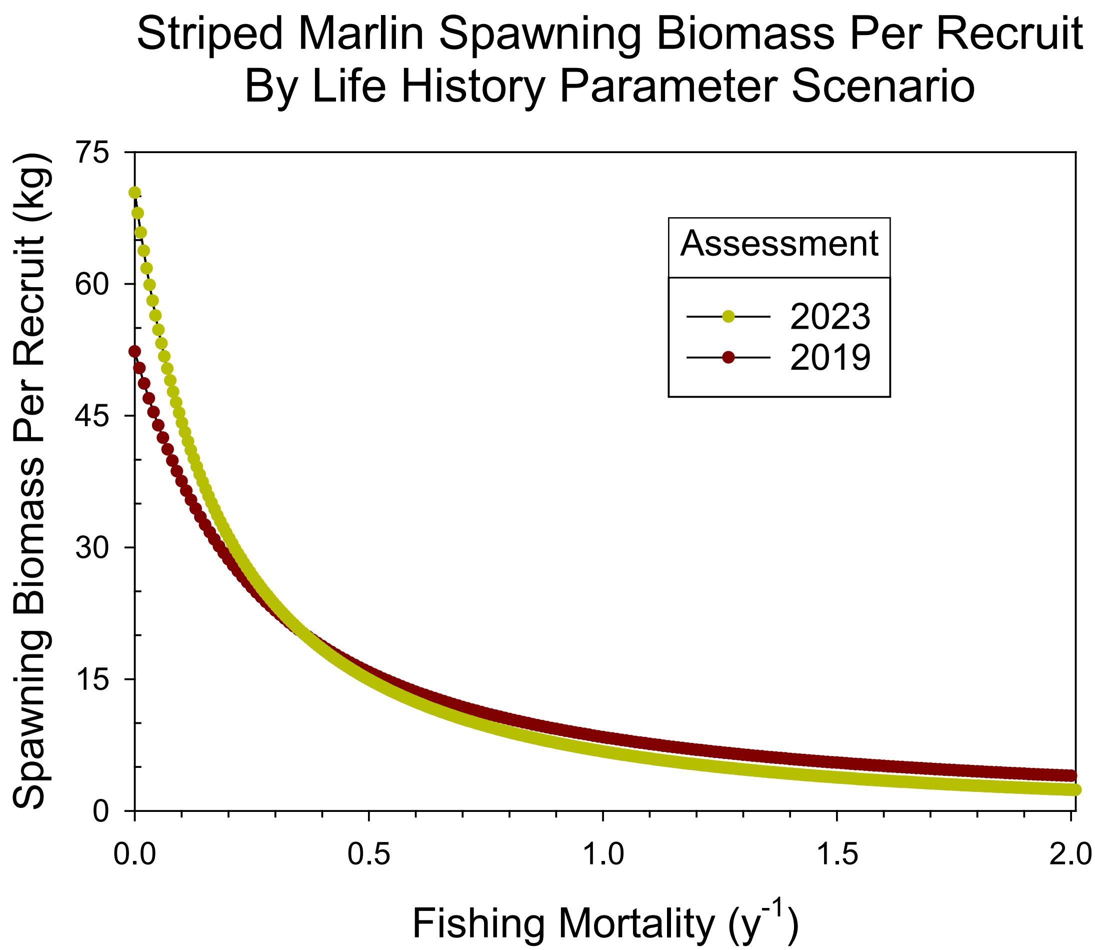


Figure 23. Comparison of estimates of mean generation time for WCNPO striped marlin based on the 2019 and 2023 stock assessments.

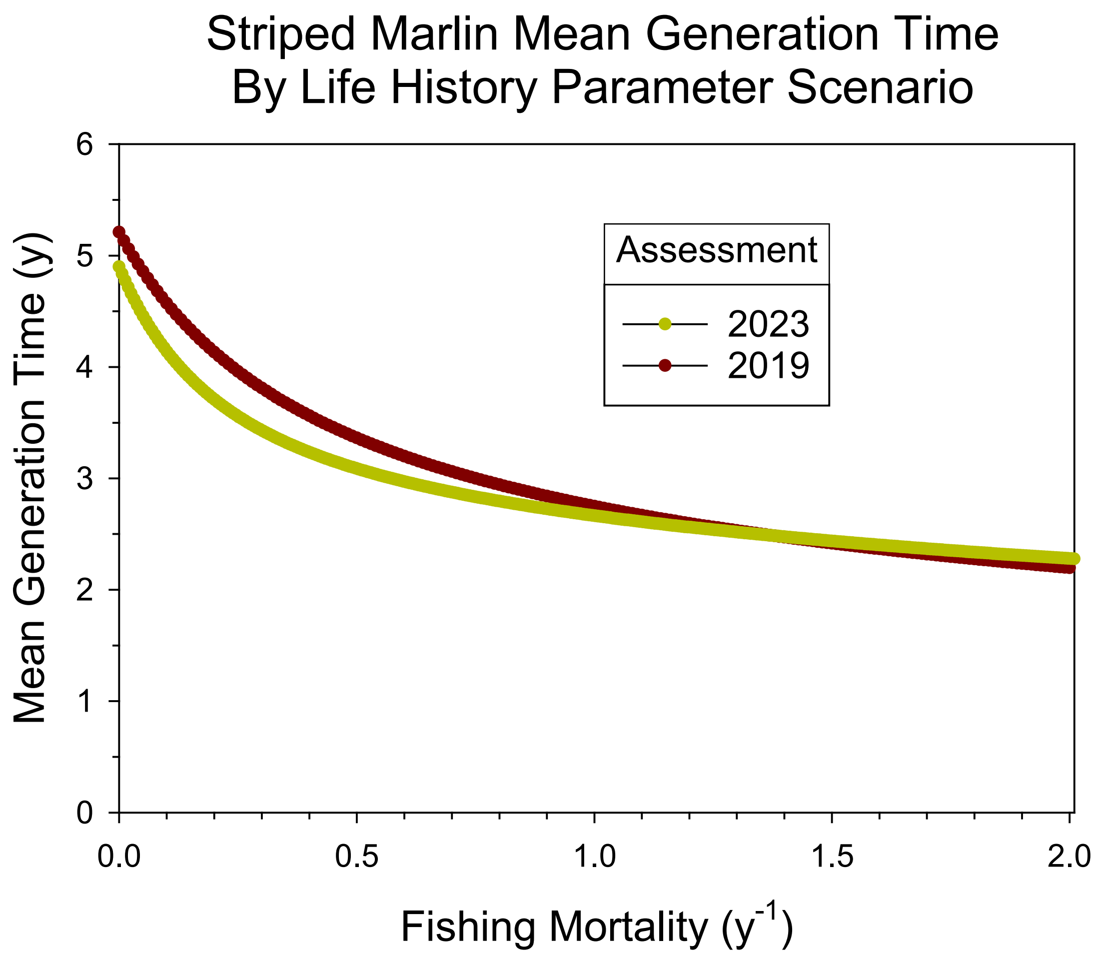


Figure 24. Comparison of aggregated fishery spawning potential ratio as a function of fishing mortality based on the 2019 and 2023 WCNPO striped marlin stock assessments.

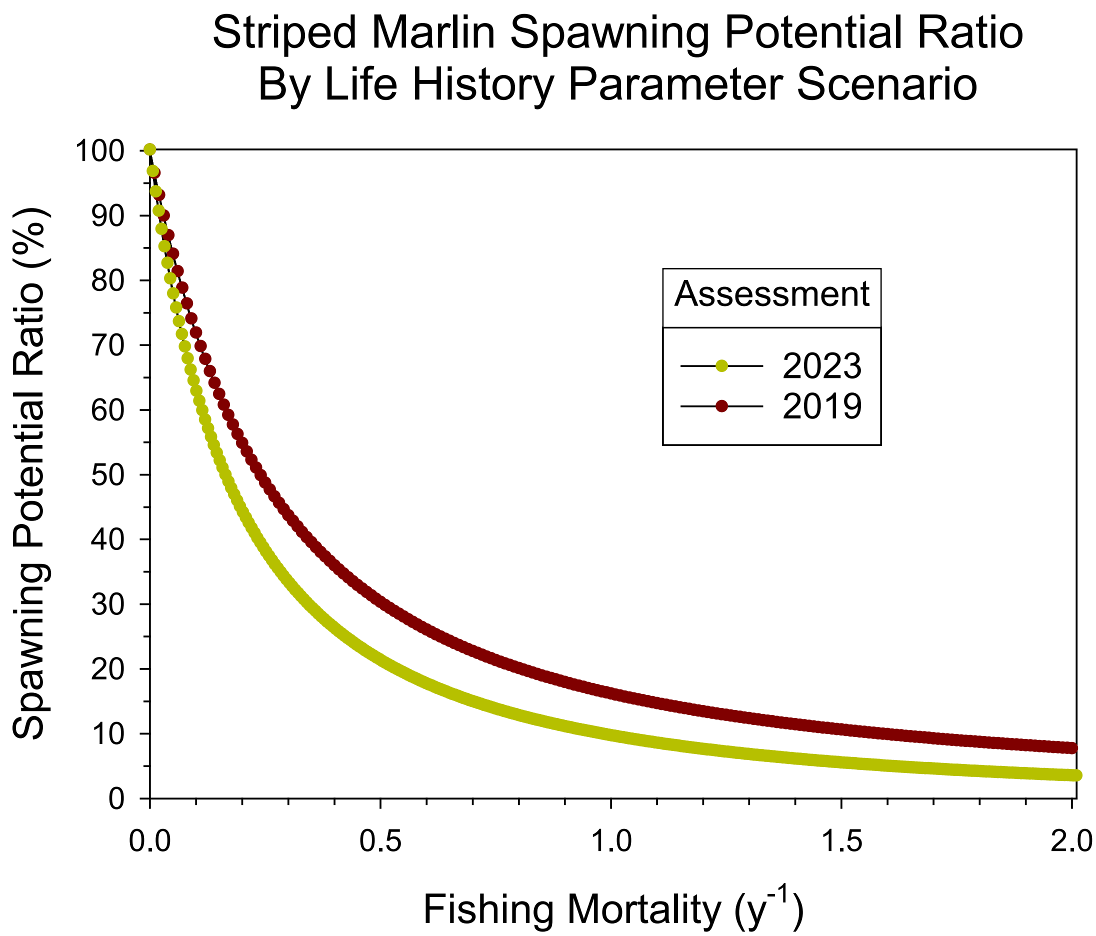


Figure 25. Diagram of the shared fishery selectivities for the 9 fleet groups where the representative fleet is circled in black. Fleet groups with flat-topped fishery selectivity are shaded green and fleet groups with time-varying fishery selectivity are shaded in orange.

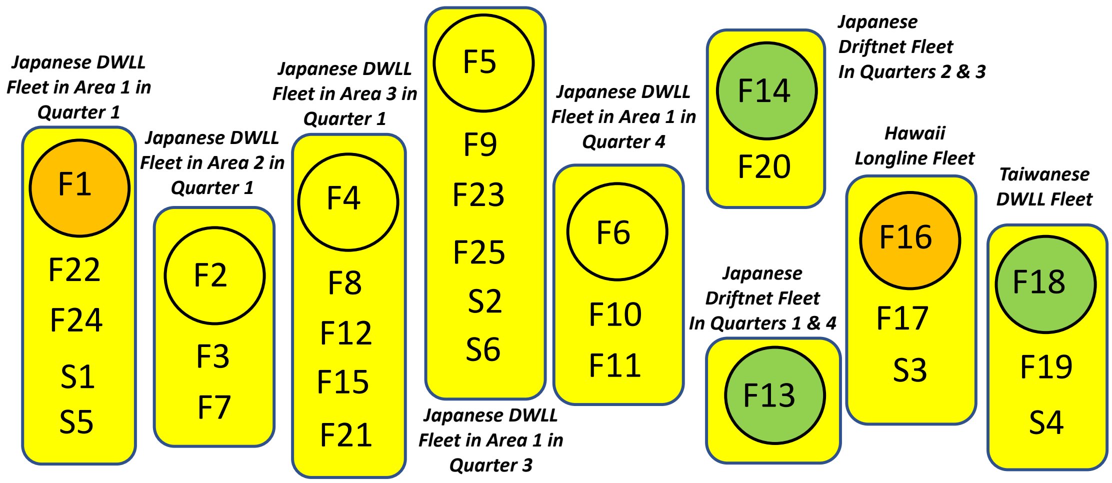
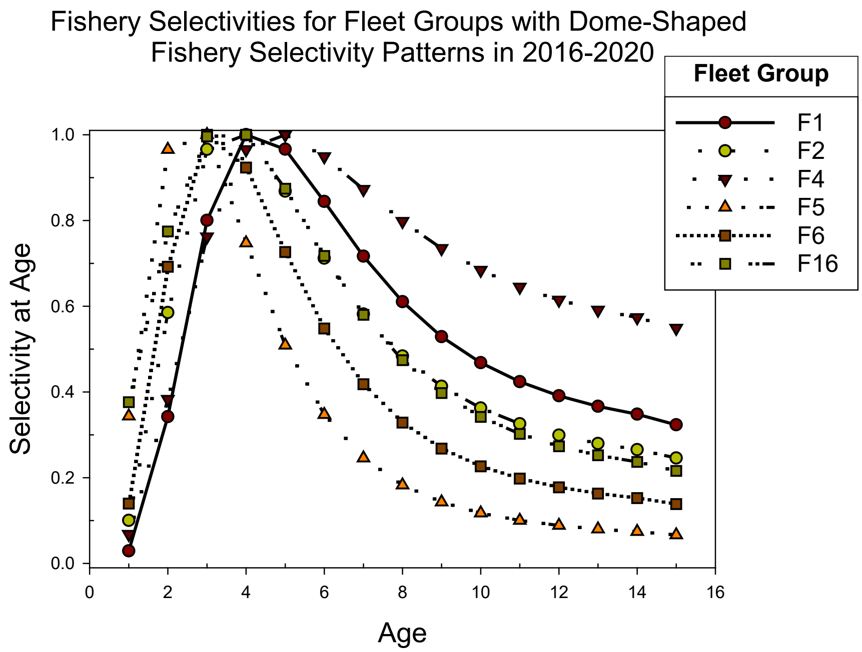


Figure 26. Average fishery selectivities at age during 2016-2020 (top) and 1994-2020 (bottom) from the 2023 stock assessment for fleet groups with domed selectivity patterns.



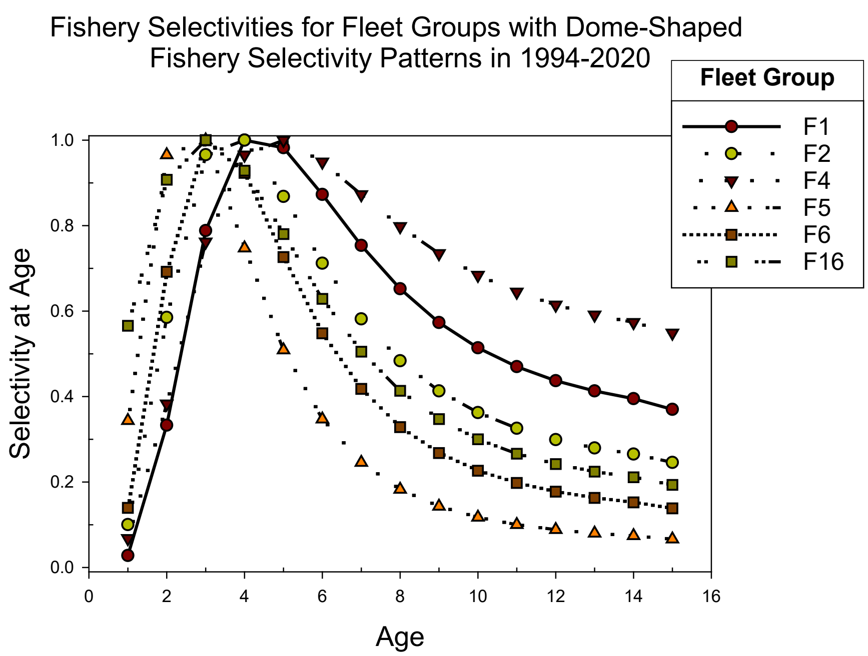
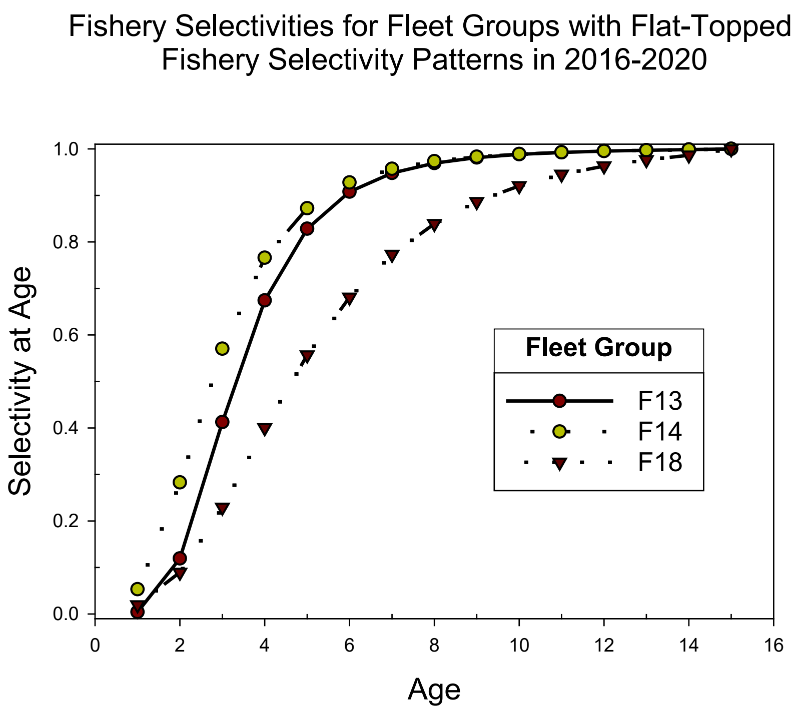


Figure 27. Average fishery selectivities at age during 2016-2020 (top) and 1994-2020 (bottom) from the 2023 stock assessment for fleet groups with flat-topped selectivity patterns.



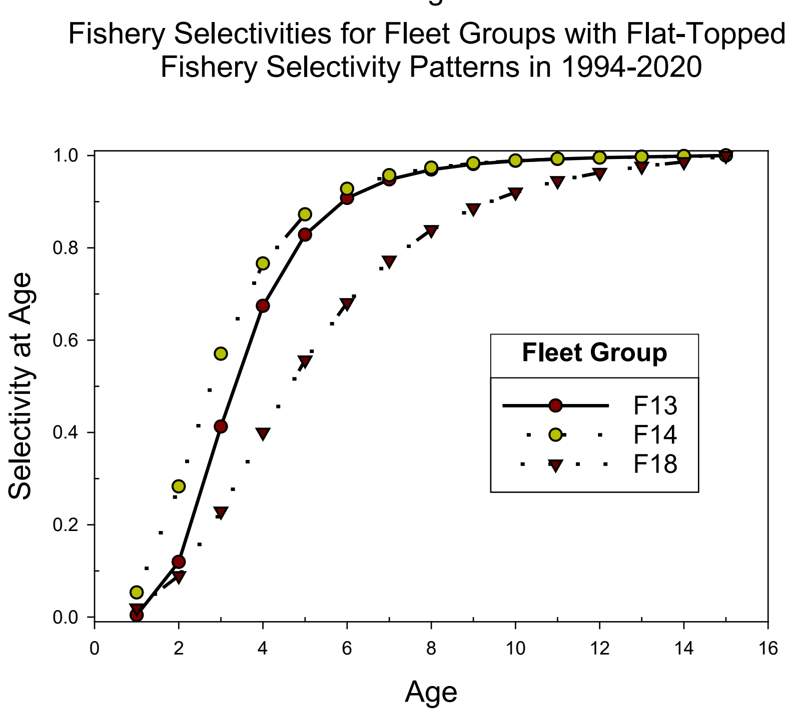


Figure 28. Annual proportions of total fishing mortality for fleet groups with domed selectivities at age during 1977-2020.

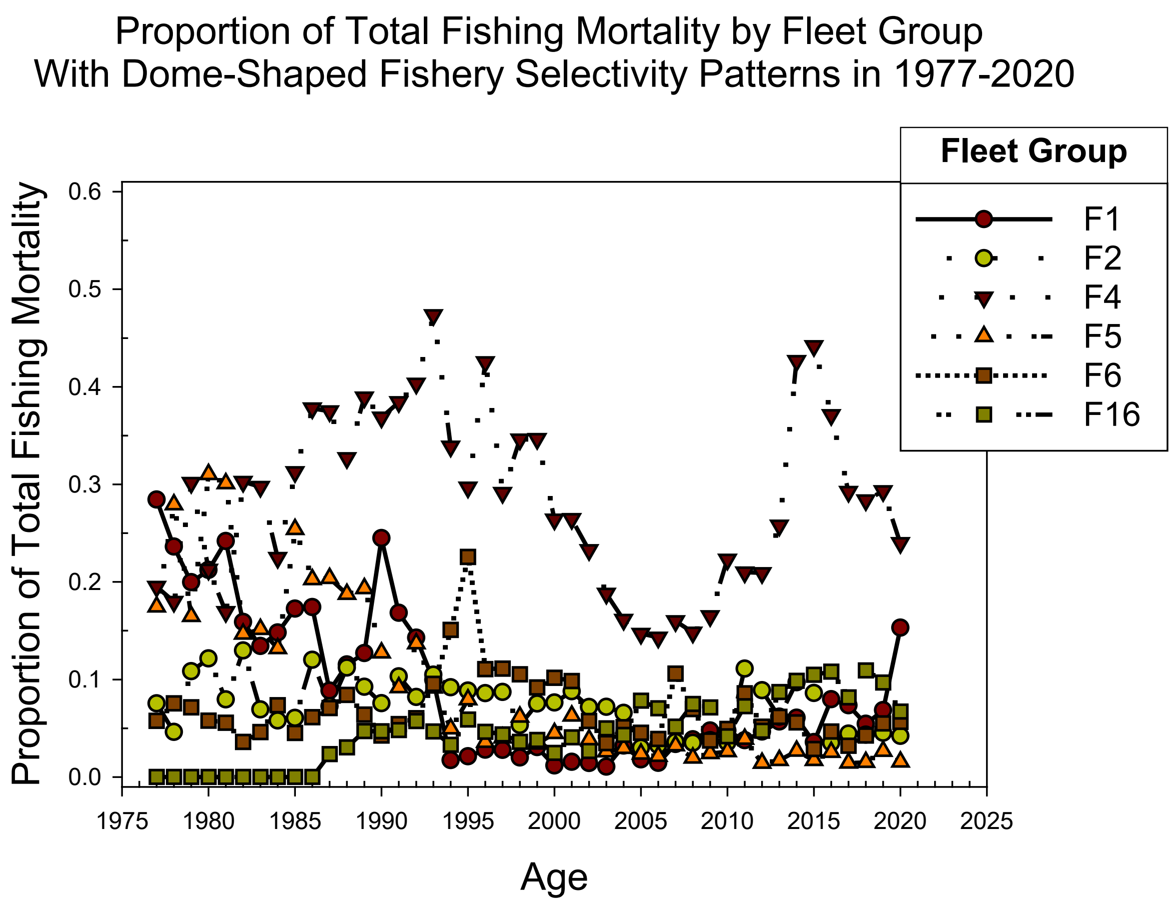


Figure 29. Annual proportions of total fishing mortality for fleet groups with flat-topped selectivities at age during 1977-2020.

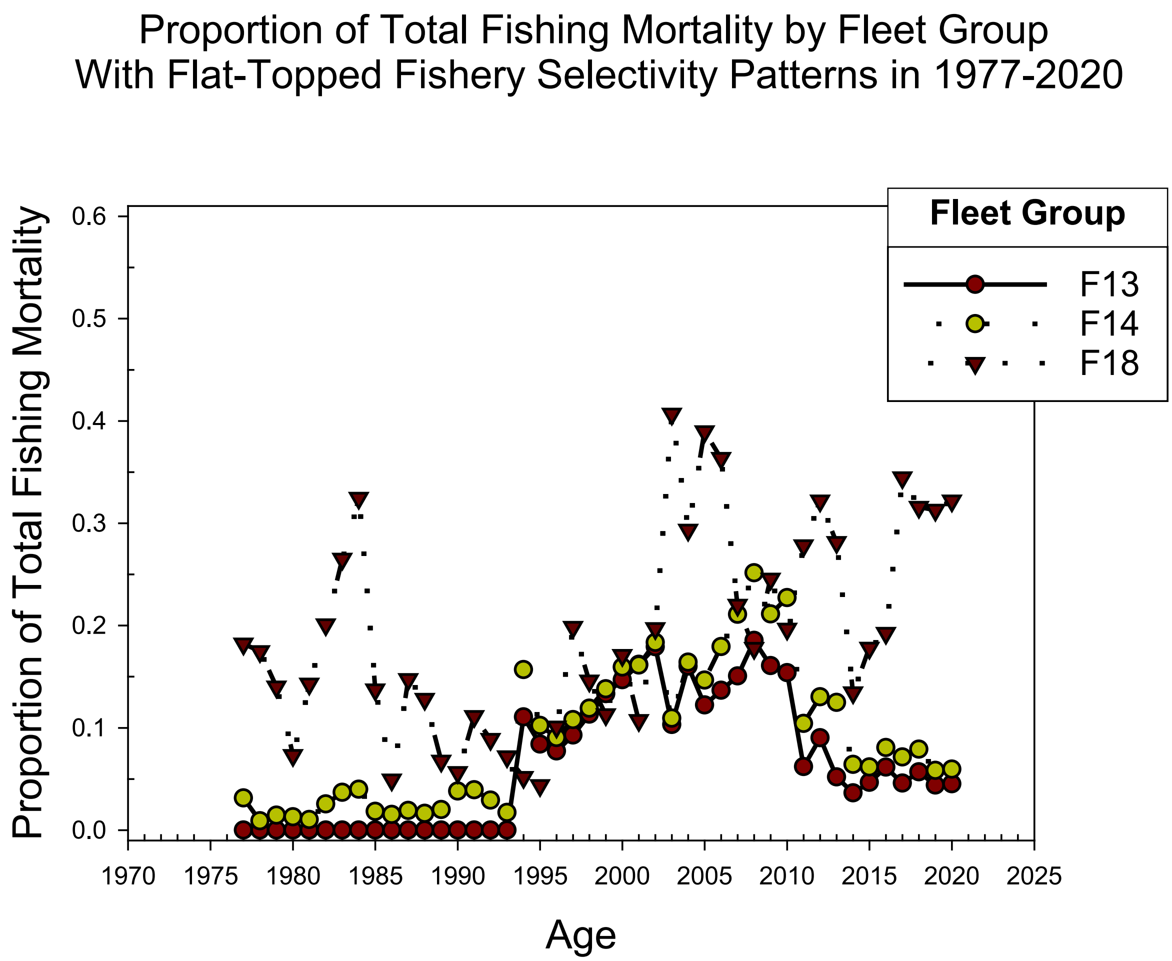
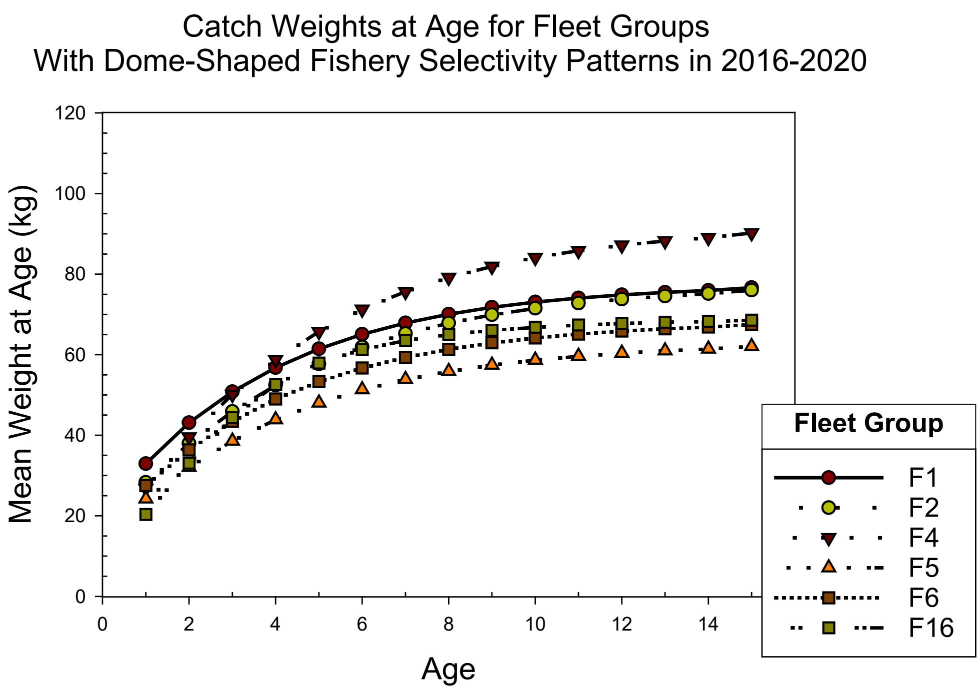


Figure 30. Mean fishery catch weights at age during 2016-2020 (top) and 1994-2020 (bottom) from the 2023 stock assessment for fleet groups with domed selectivity patterns.



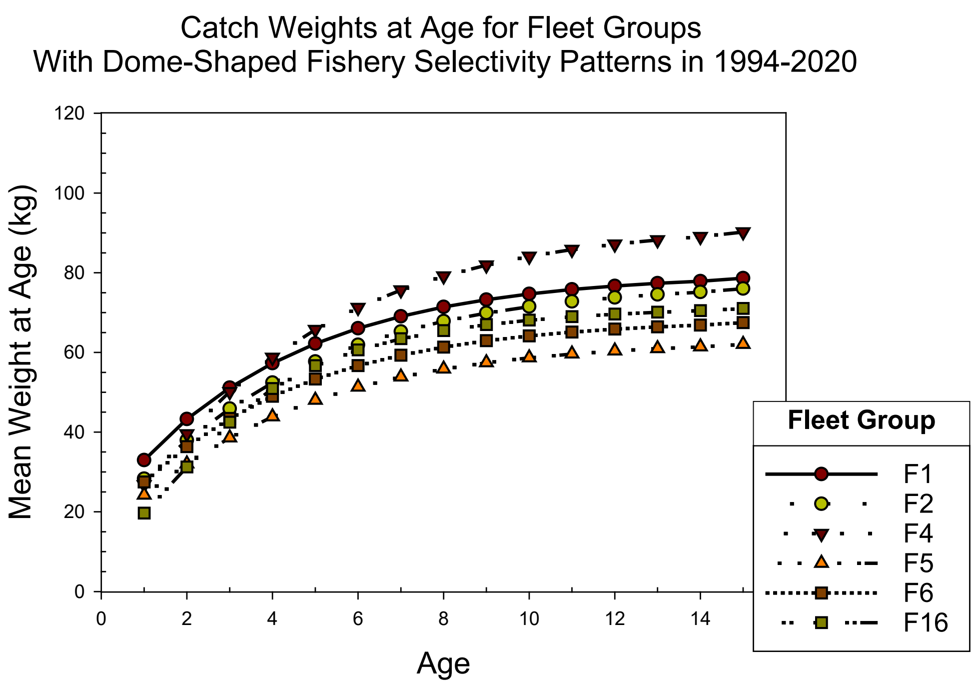
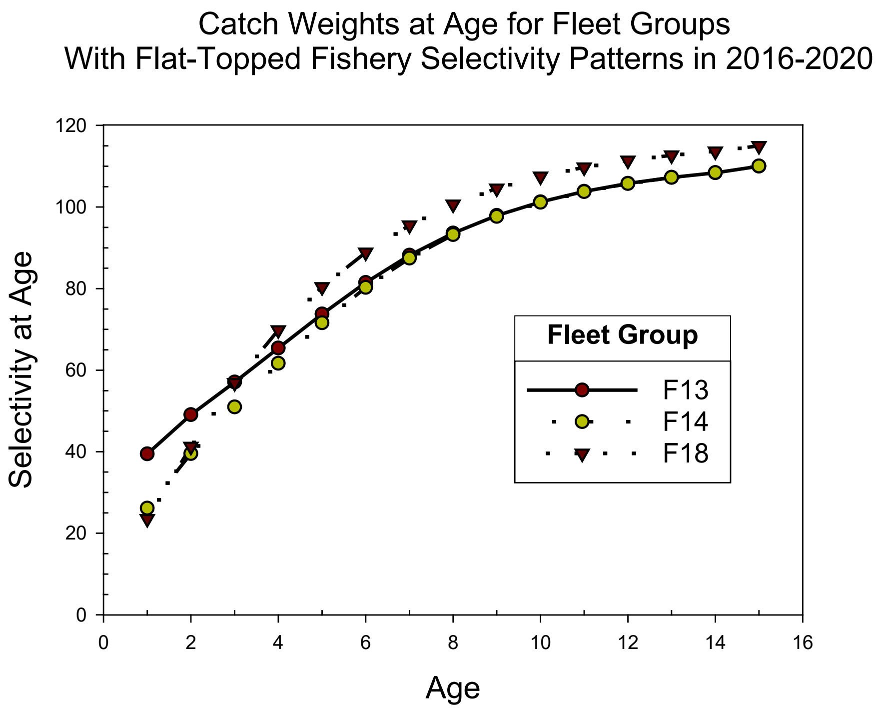


Figure 31. Mean fishery catch weights at age during 2016-2020 (top) and 1994-2020 (bottom) from the 2023 stock assessment for fleet groups with flat-topped selectivity patterns.



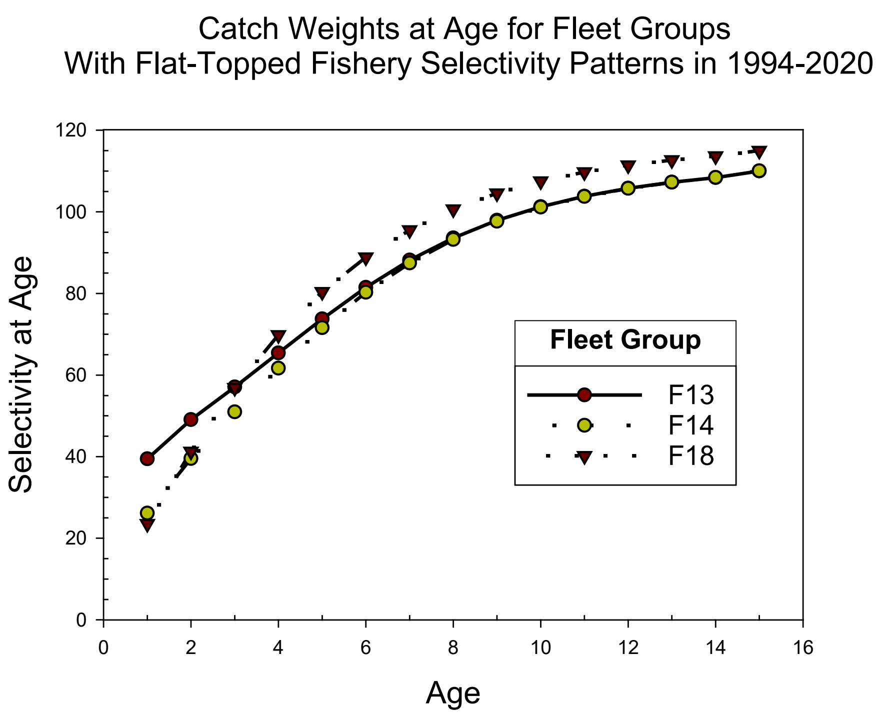


Figure 32. Annual catch biomasses of WCNPO striped marlin for fleet groups with domed selectivities at age during 1977-2020.

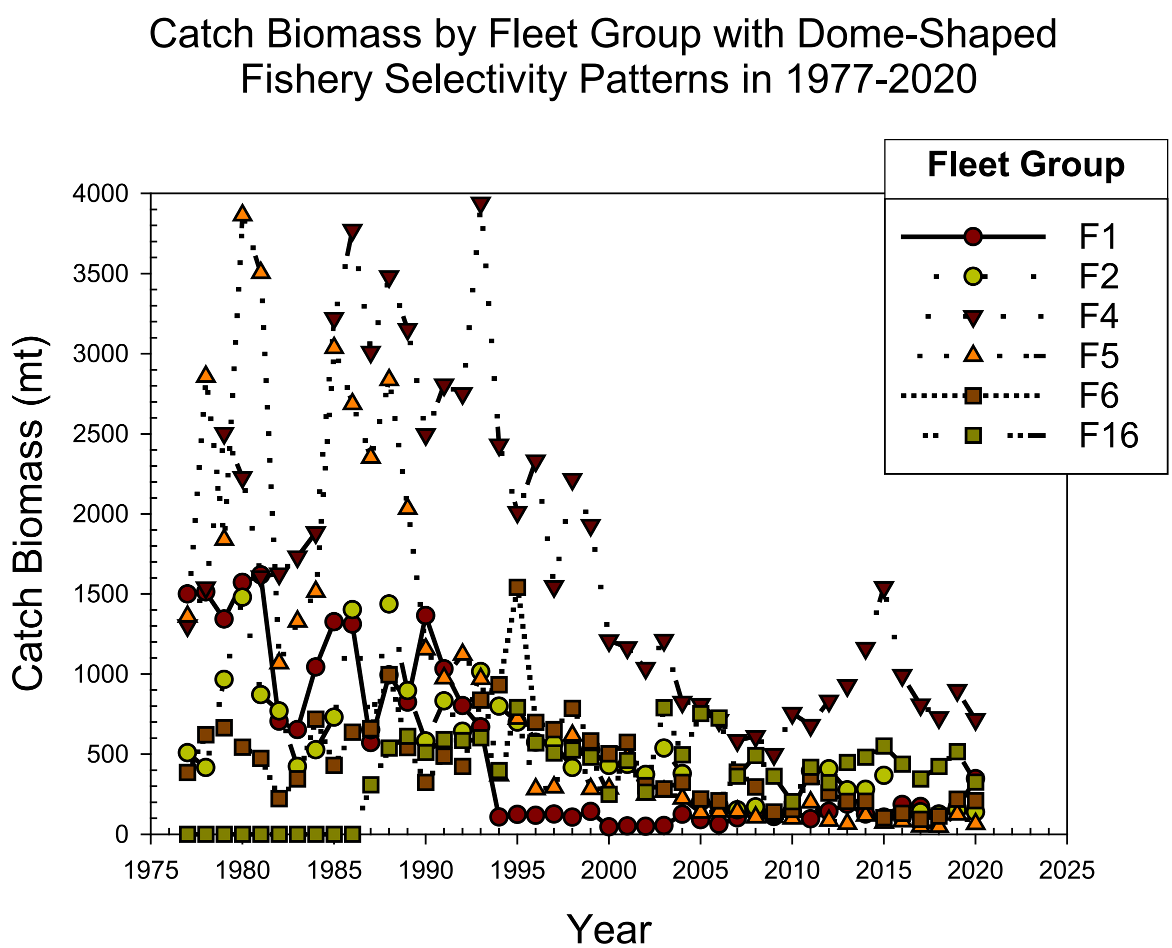


Figure 33. Annual catch biomasses of WCNPO striped marlin for fleet groups with flat-topped selectivities at age during 1977-2020.

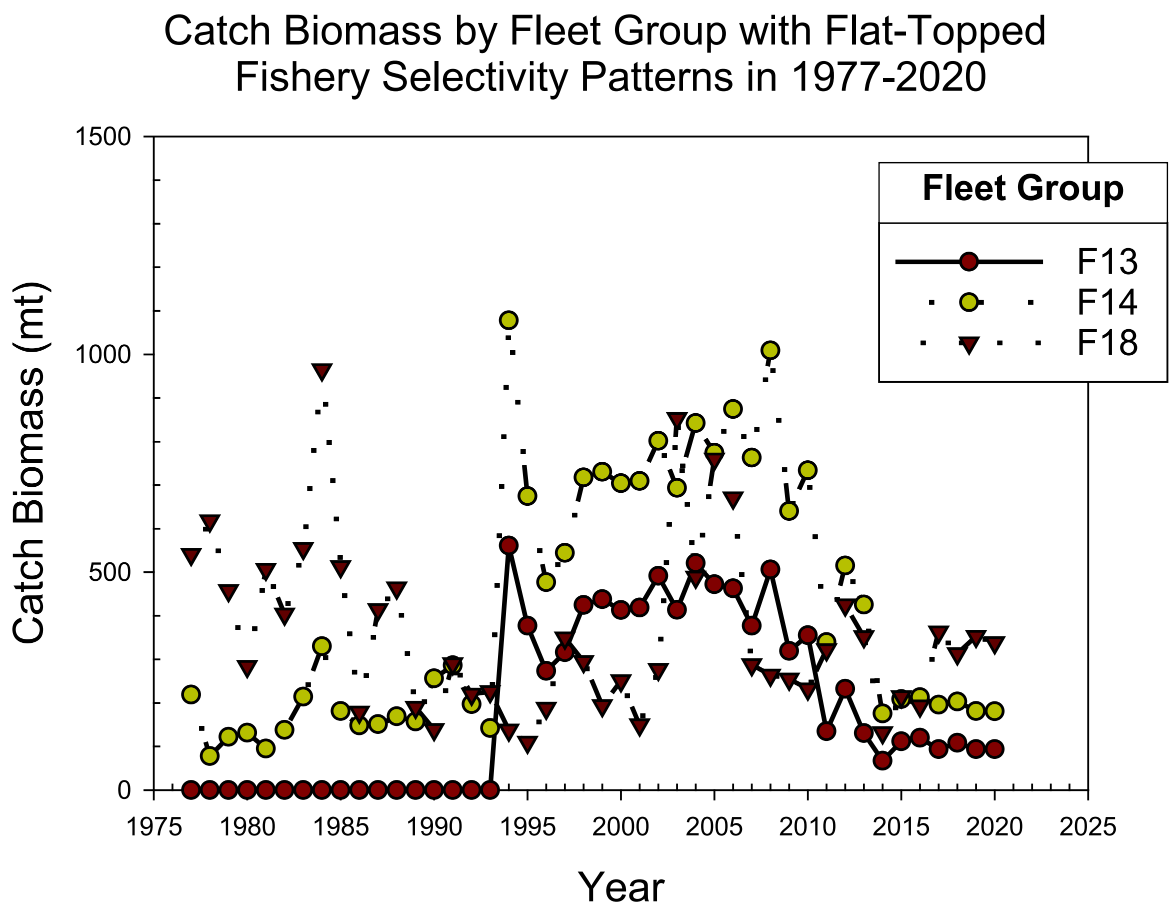


Figure 34. Annual proportions of total catch biomass for fleet groups with domed selectivities at age during 1977-2020.

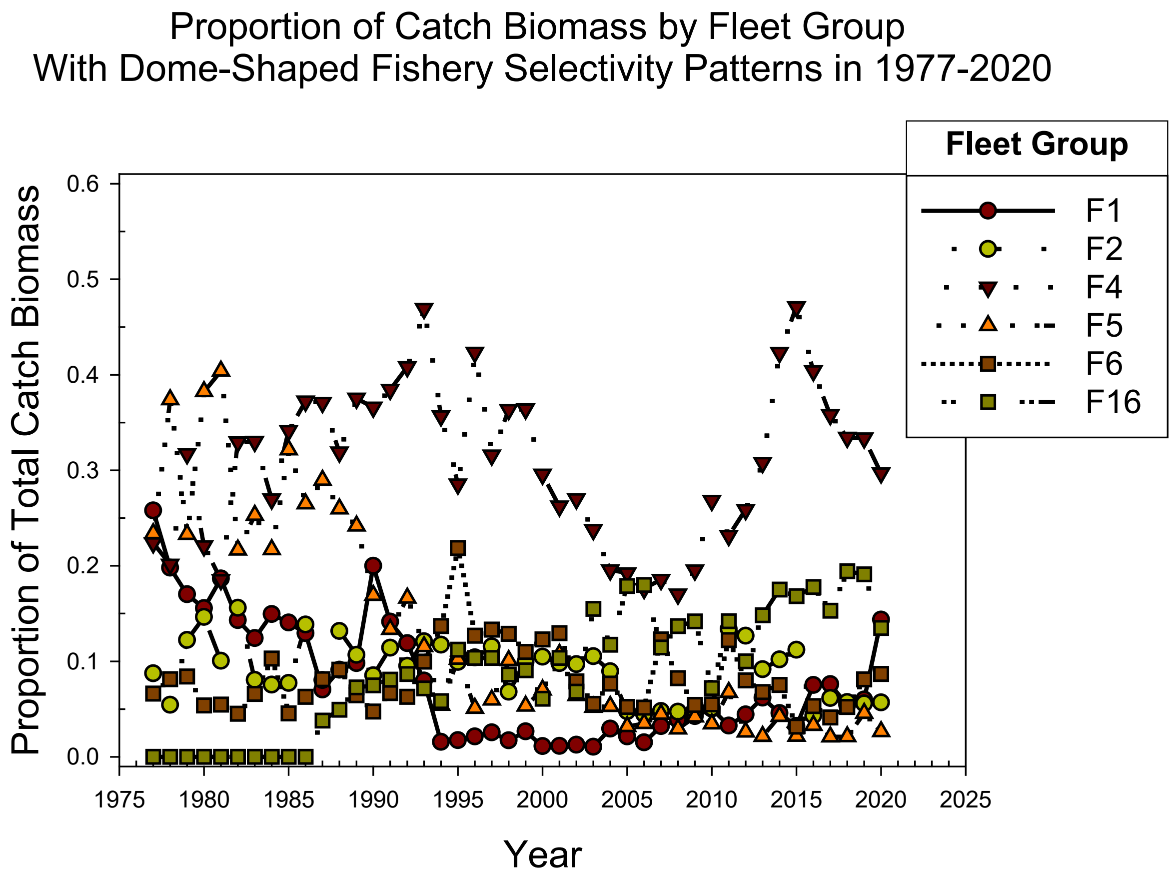


Figure 35. Annual proportions of total fishing mortality for fleet groups with flat-topped selectivities at age during 1977-2020.

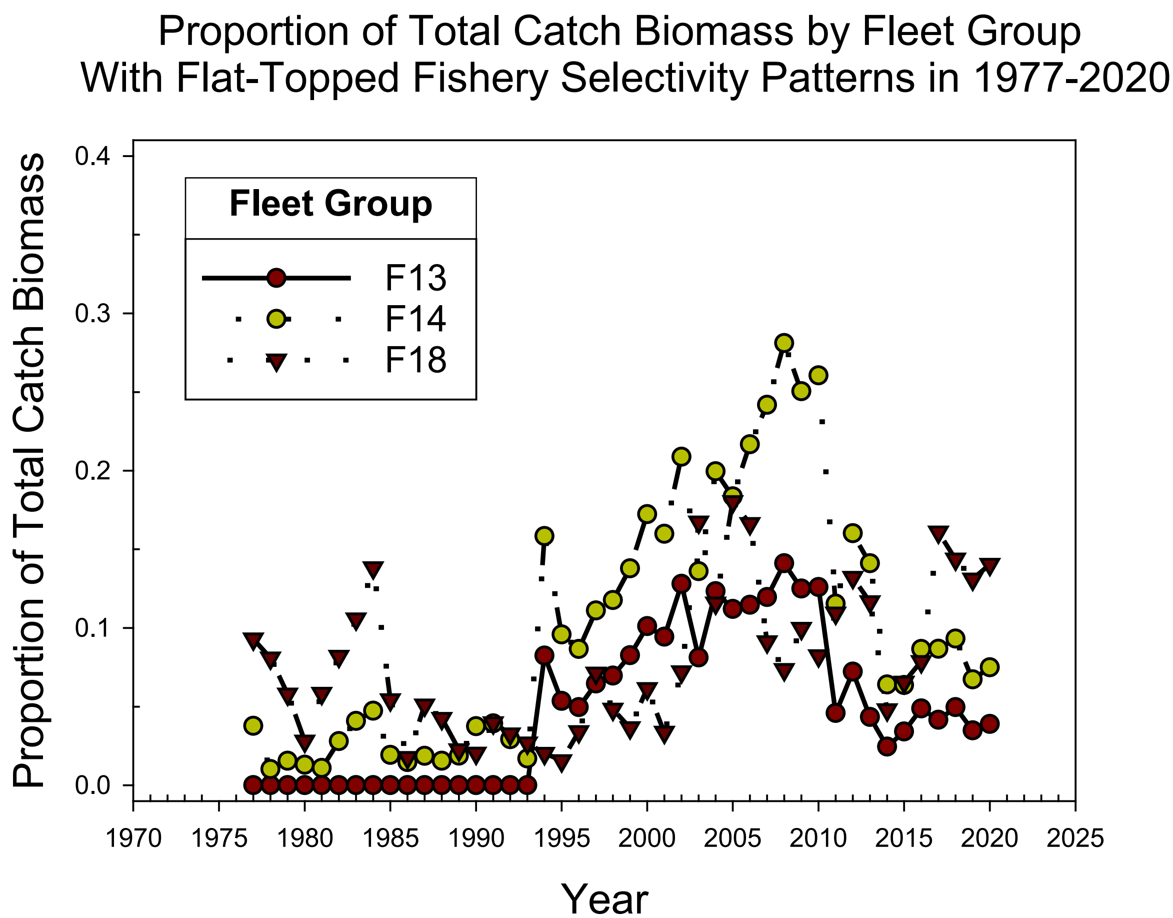


Figure 36.1. The time series of median catch biomass quotas to rebuild the stock under the constant F = 0.373 rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the annual catch biomass distributions relative to the recent average yield during 2018–2020 of 2,428 mt.

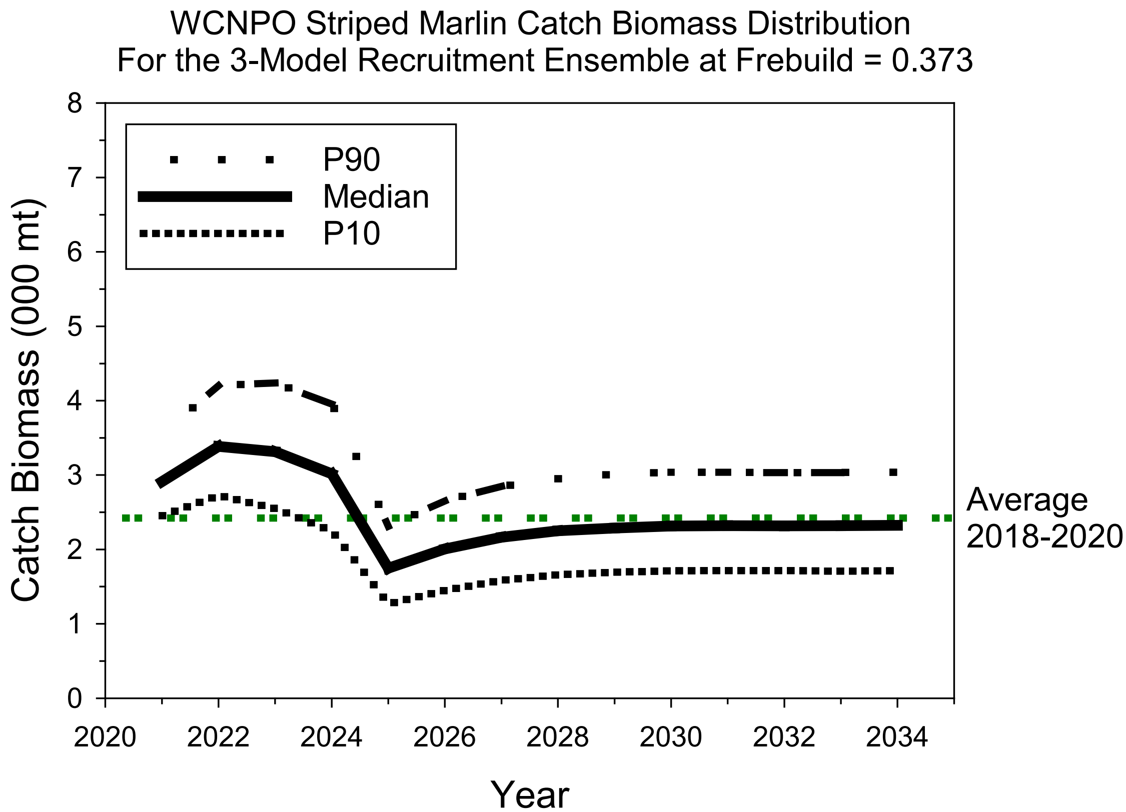


Figure 36.2. The time series of median catch biomass quotas to rebuild the stock under the constant quota rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the annual catch biomass distributions relative to the recent average yield during 2018–2020 of 2,077 mt.

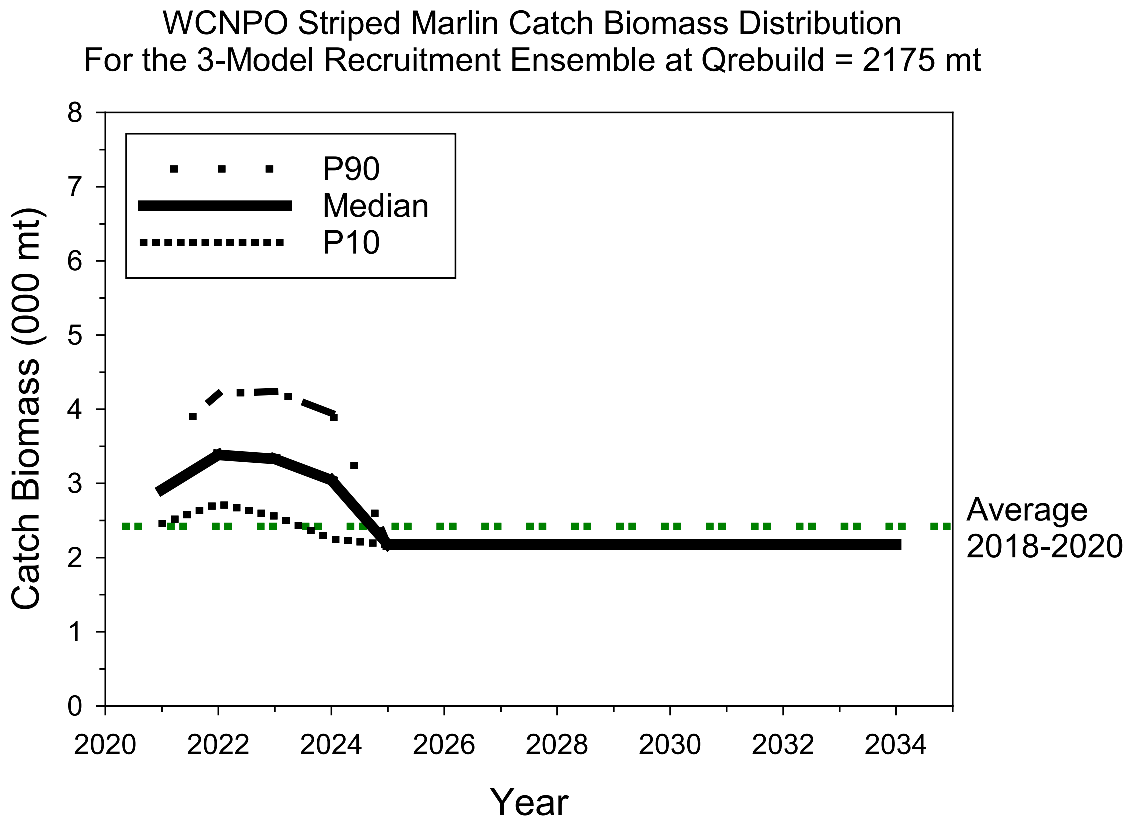


Figure Catch.3 The time series of median catch biomass quotas to rebuild the stock under the phased-F rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the annual catch biomass distributions relative to the recent average yield during 2018–2020 of 2,428 mt.

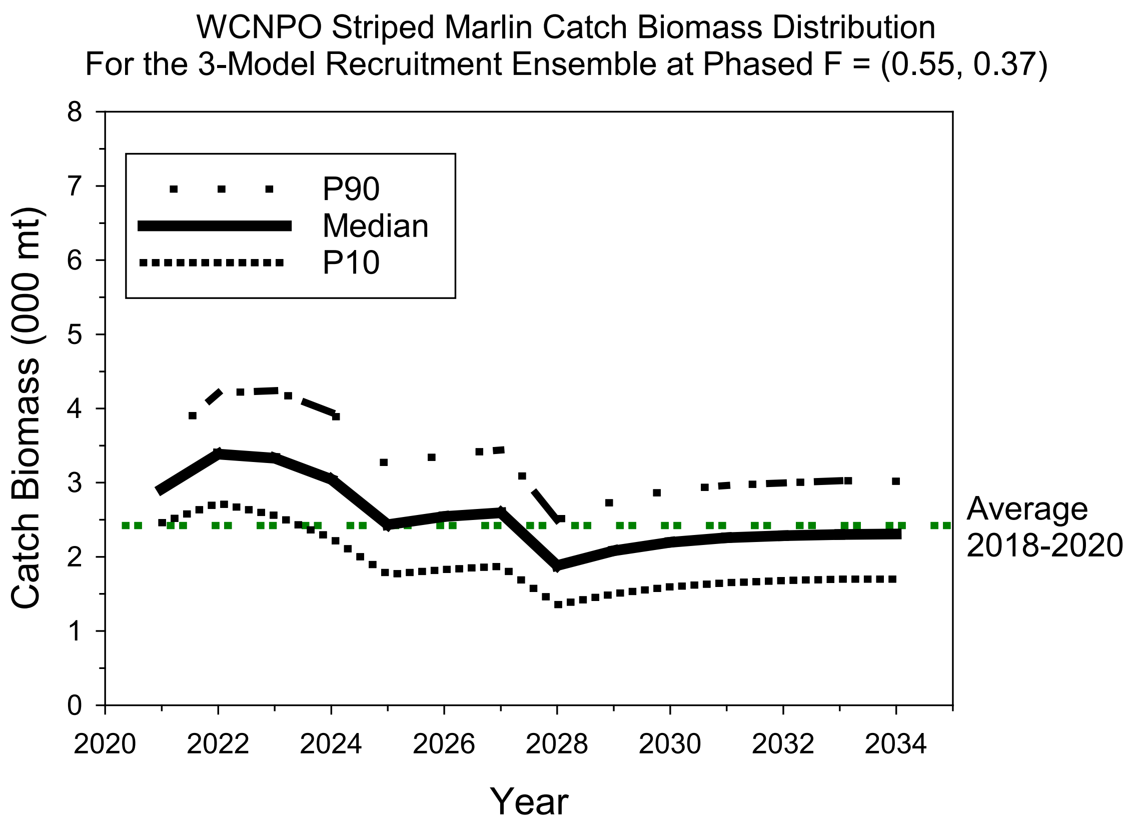


Figure 36.4. The time series of median catch biomass quotas to rebuild the stock under the phased-quota rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the annual catch biomass distributions relative to the recent average yield during 2018–2020 of 2,428 mt.

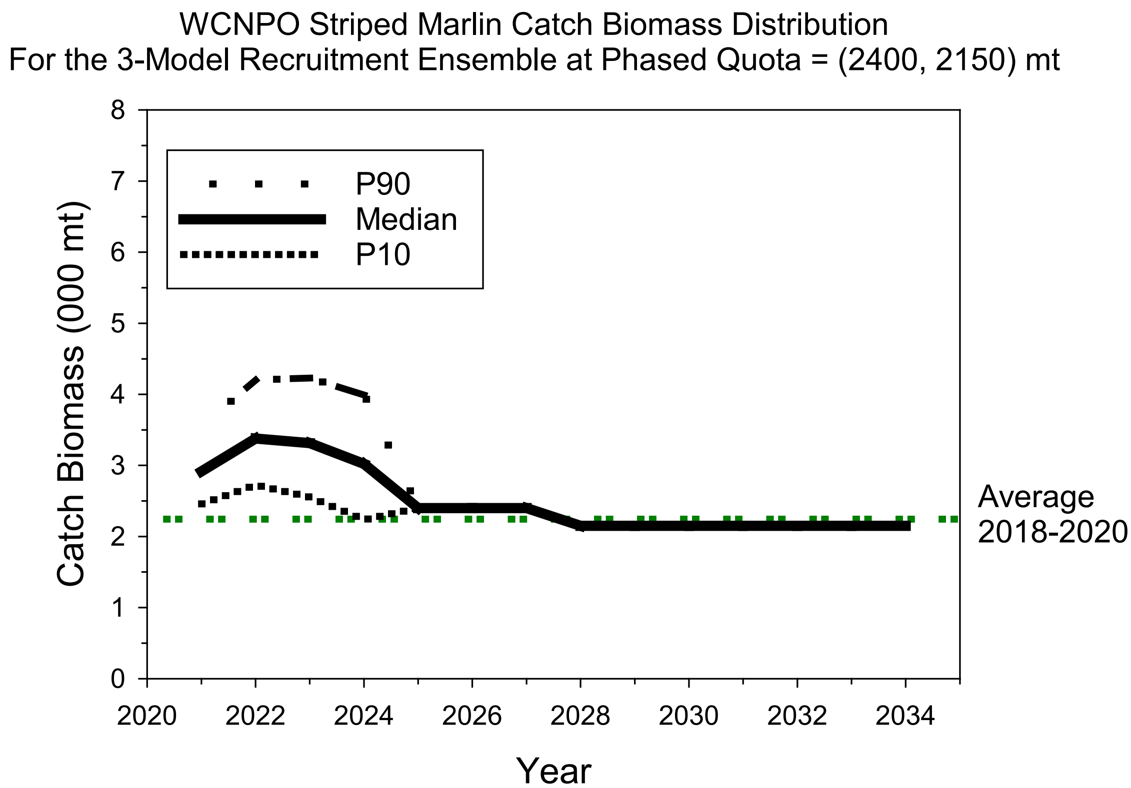


Figure 36.5. Comparison of the time series of median catch biomass quotas to rebuild the stock under the phased, constant F, and constant quota rebuilding scenarios relative to the recent average yield during 2018–2020 of 2,428 mt.

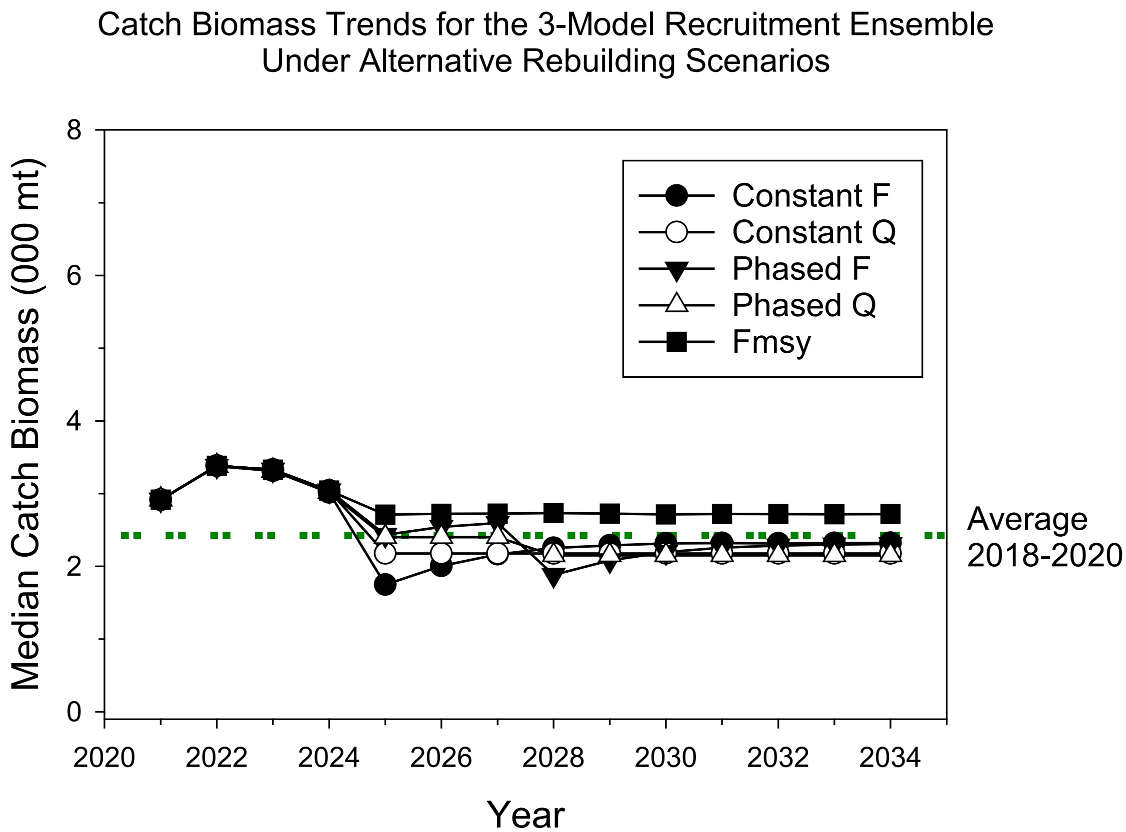


Figure 37.1. The time series of median spawning biomasses to rebuild the stock under the constant F rebuilding scenario (SSB Rebuild, P60) along with the 10th (P10), median, and 90th (P90) percentiles of the annual spawning biomass distributions relative to the rebuilding target of 3,660 mt.

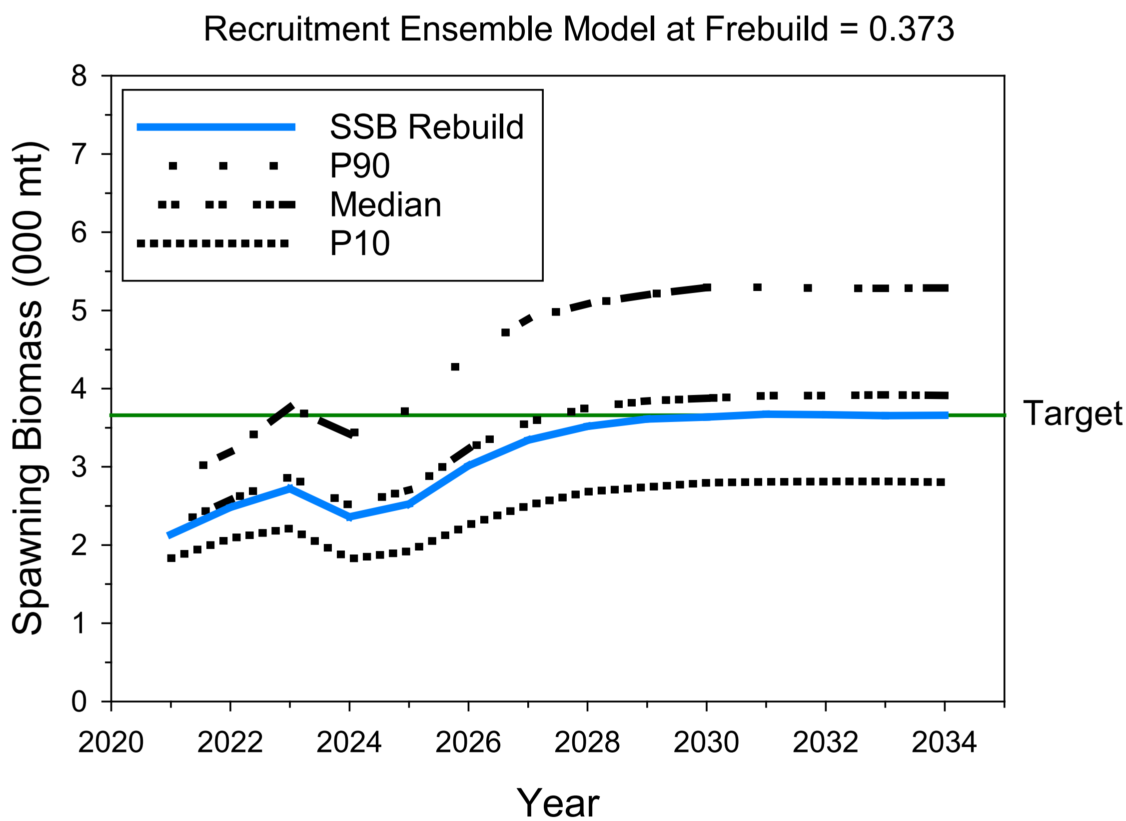


Figure 37.2. The time series of median spawning biomasses to rebuild the stock under the constant quota rebuilding scenario (SSB Rebuild, P60) along with the 10th (P10), median, and 90th (P90) percentiles of the annual spawning biomass distributions relative to the rebuilding target of 3,660 mt.

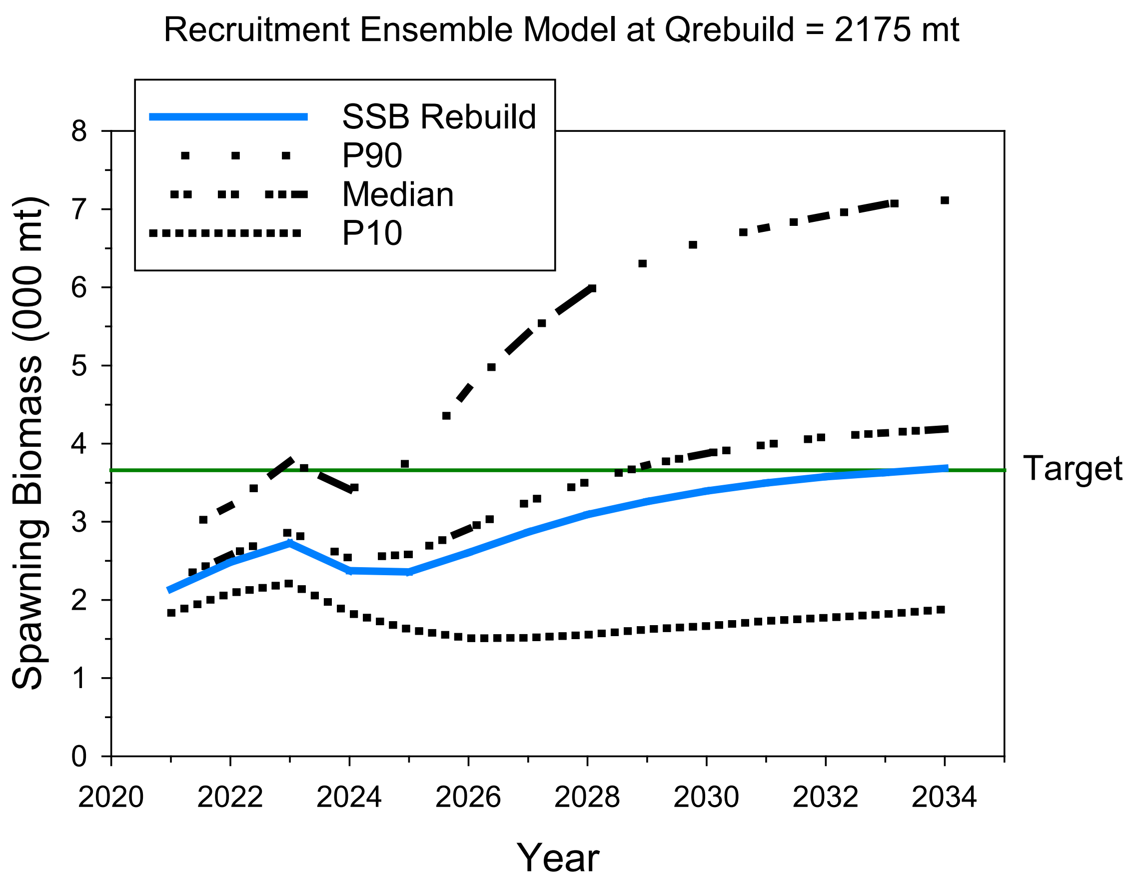


Figure 37.3. The time series of median spawning biomasses to rebuild the stock under the phased-F rebuilding scenario (SSB Rebuild, P60) along with the 10th (P10), median, and 90th (P90) percentiles of the annual spawning biomass distributions relative to the rebuilding target of 3,660 mt.

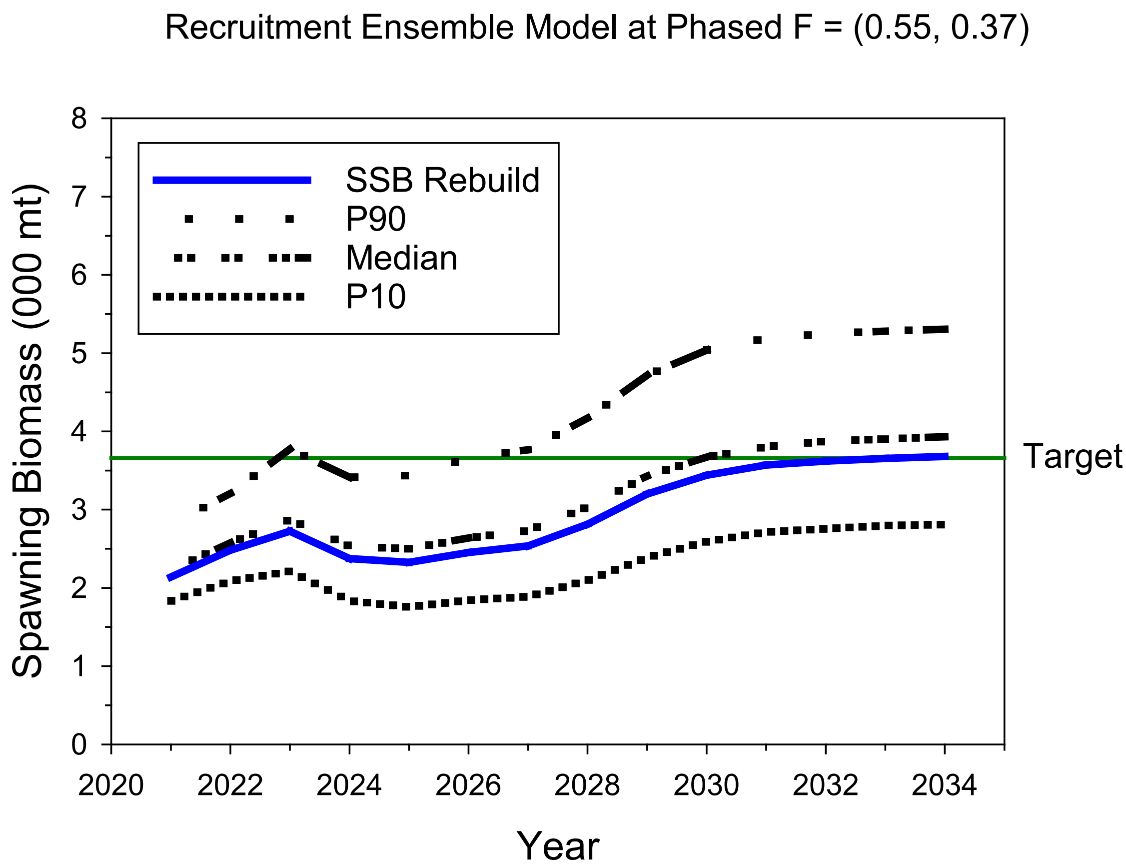


Figure 37.4. The time series of median spawning biomasses to rebuild the stock under the phased-quota rebuilding scenario (SSB Rebuild, P60) along with the 10th (P10), median, and 90th (P90) percentiles of the annual spawning biomass distributions relative to the rebuilding target of 3,660 mt.

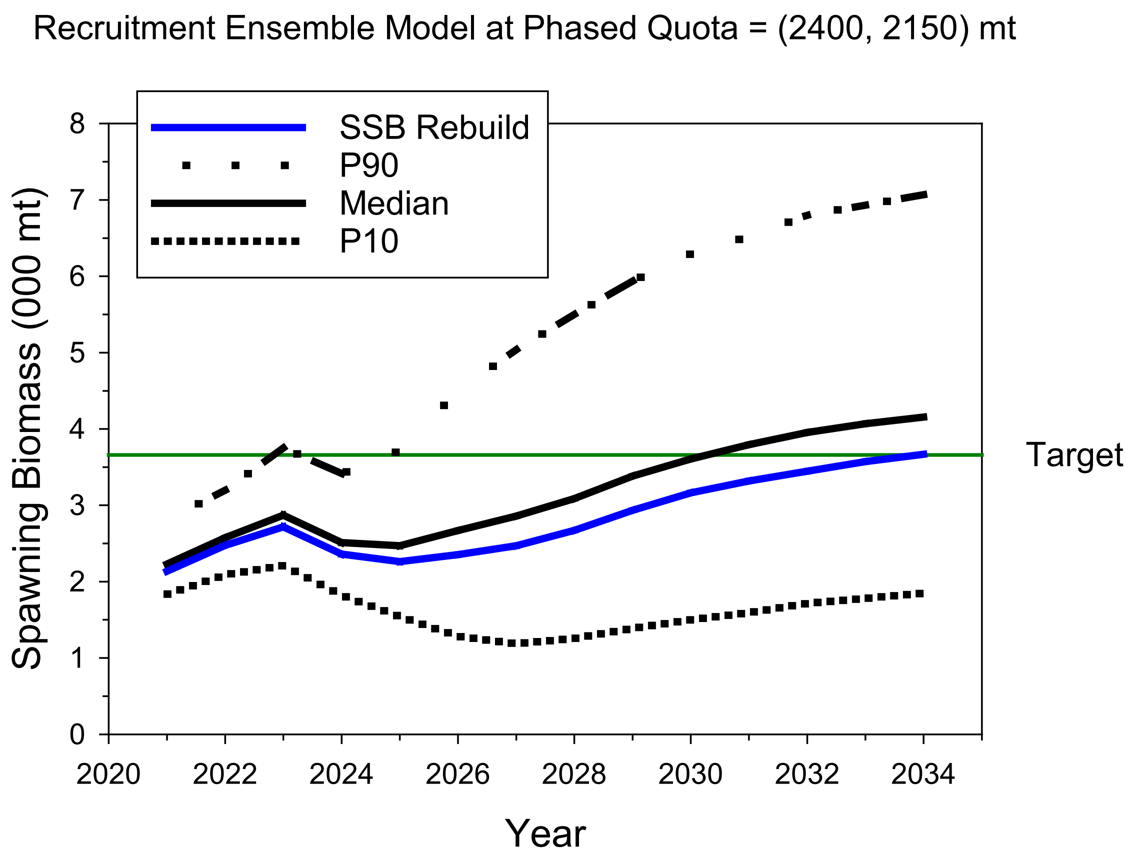


Figure 37.5. Comparison of the central tendencies of spawning stock biomass distributions to rebuild the stock under the phased, constant F, and constant quota rebuilding scenarios relative to the rebuilding target of 3,660 mt.

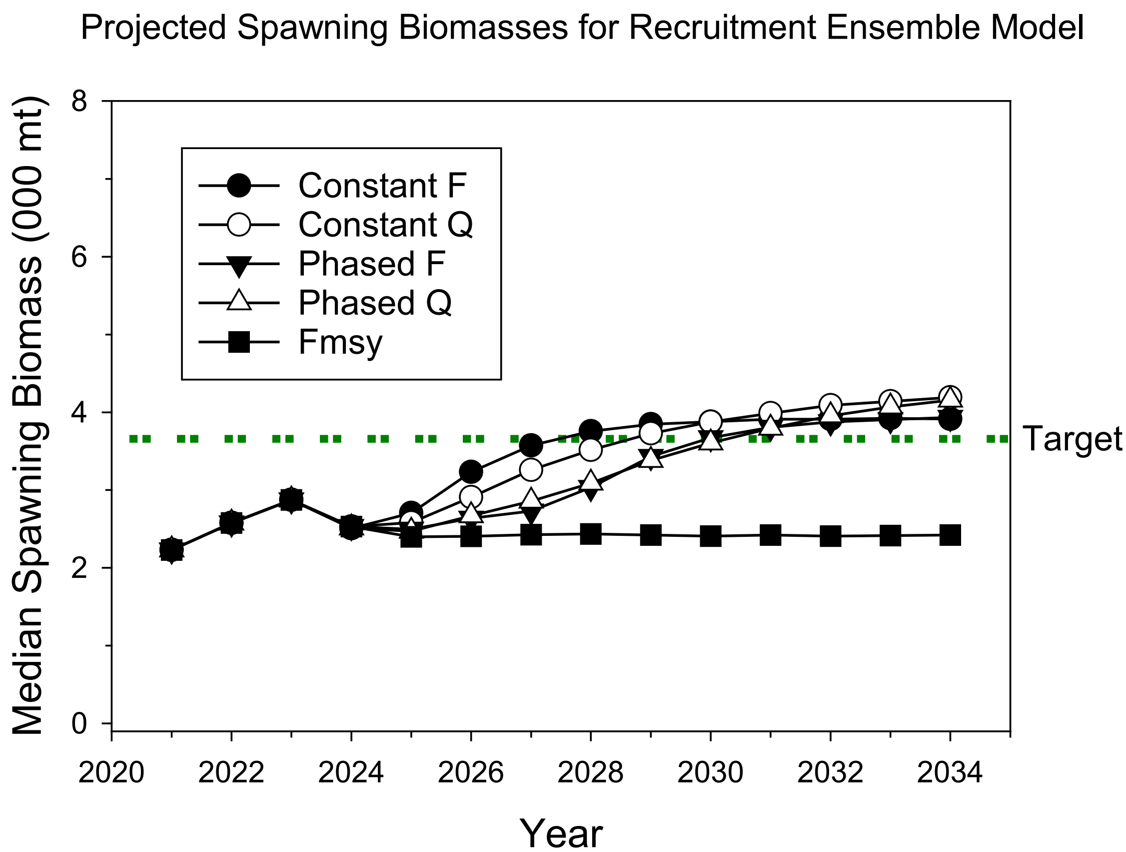


Figure 38.1. Central tendencies of fishing mortalities to rebuild the stock under the constant F rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the annual fishing mortality distributions relative to the potential overfishing reference point of $F_{20\%SSB(F=0)}$=0.53.

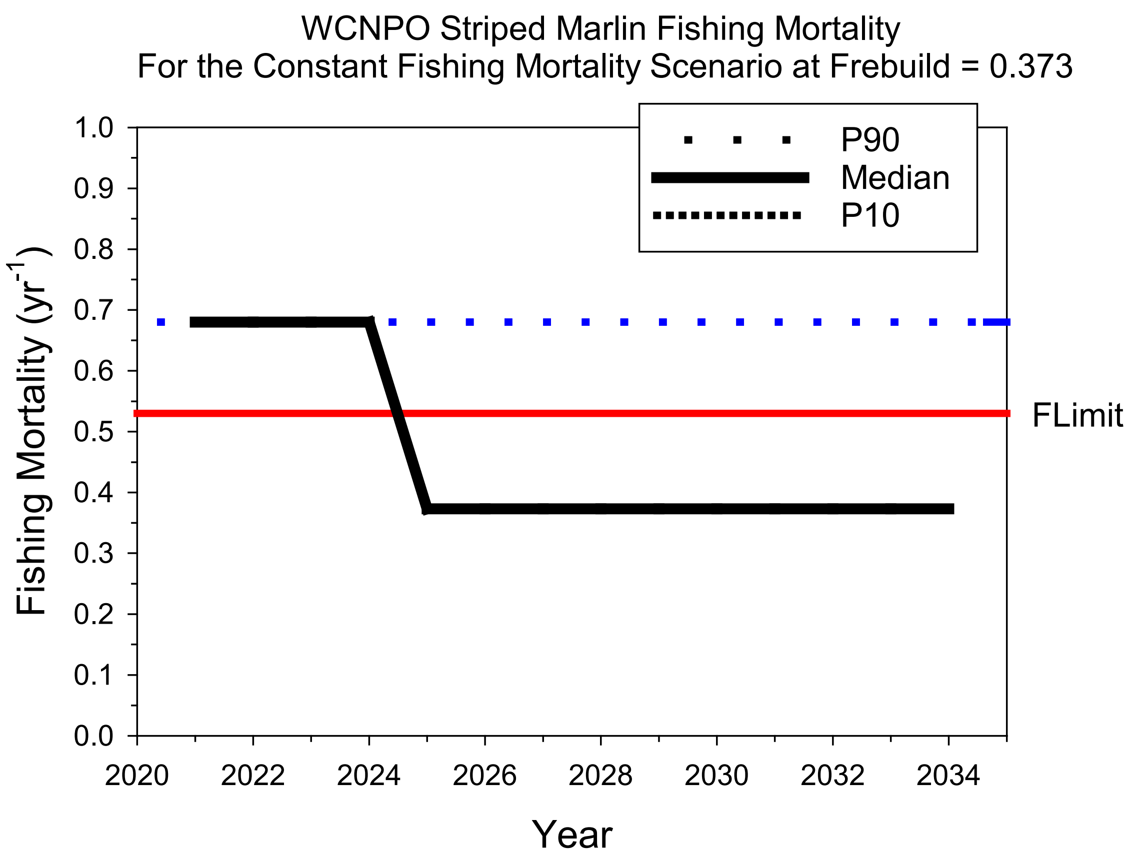


Figure 38.2. Central tendencies of fishing mortalities to rebuild the stock under the constant quota rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the annual fishing mortality distributions relative to the potential overfishing reference point of $F_{20\%SSB(F=0)}$=0.53.

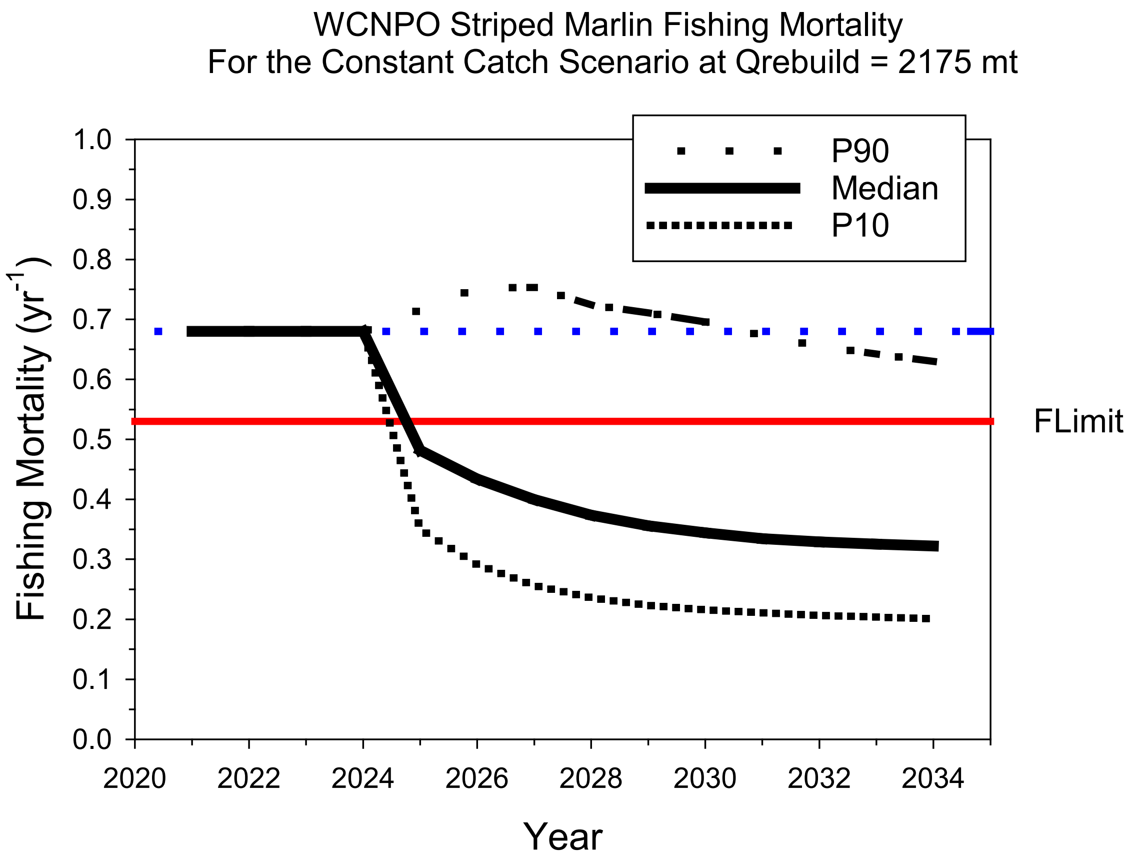


Figure 38.3. Central tendencies of fishing mortalities to rebuild the stock under the phased-F rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the annual fishing mortality distributions relative to the potential overfishing reference point of $F_{20\%SSB(F=0)}$=0.53.

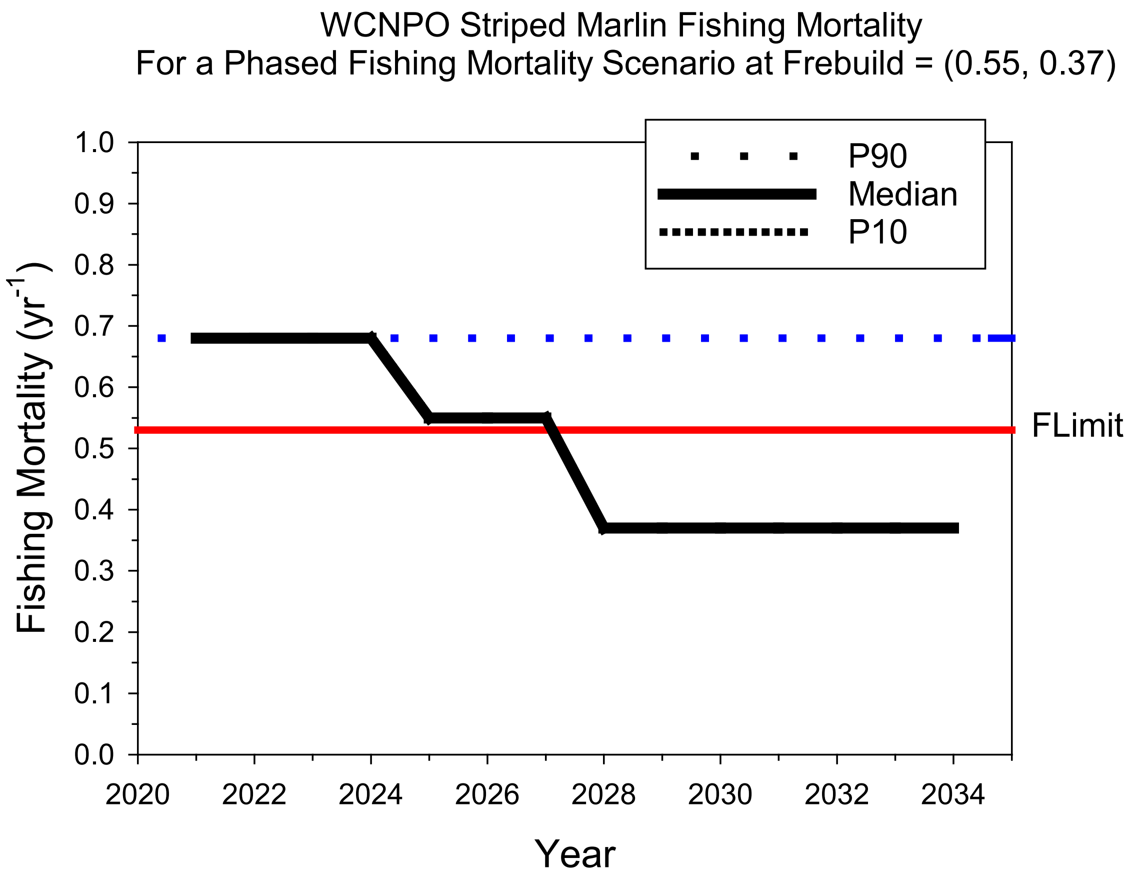


Figure 38.4. Central tendencies of fishing mortalities to rebuild the stock under the phased-quota rebuilding scenario along with the 10th (P10) and 90th (P90) percentiles of the annual fishing mortality distributions relative to the potential overfishing reference point of F20%SSB(F=0)=0.53.

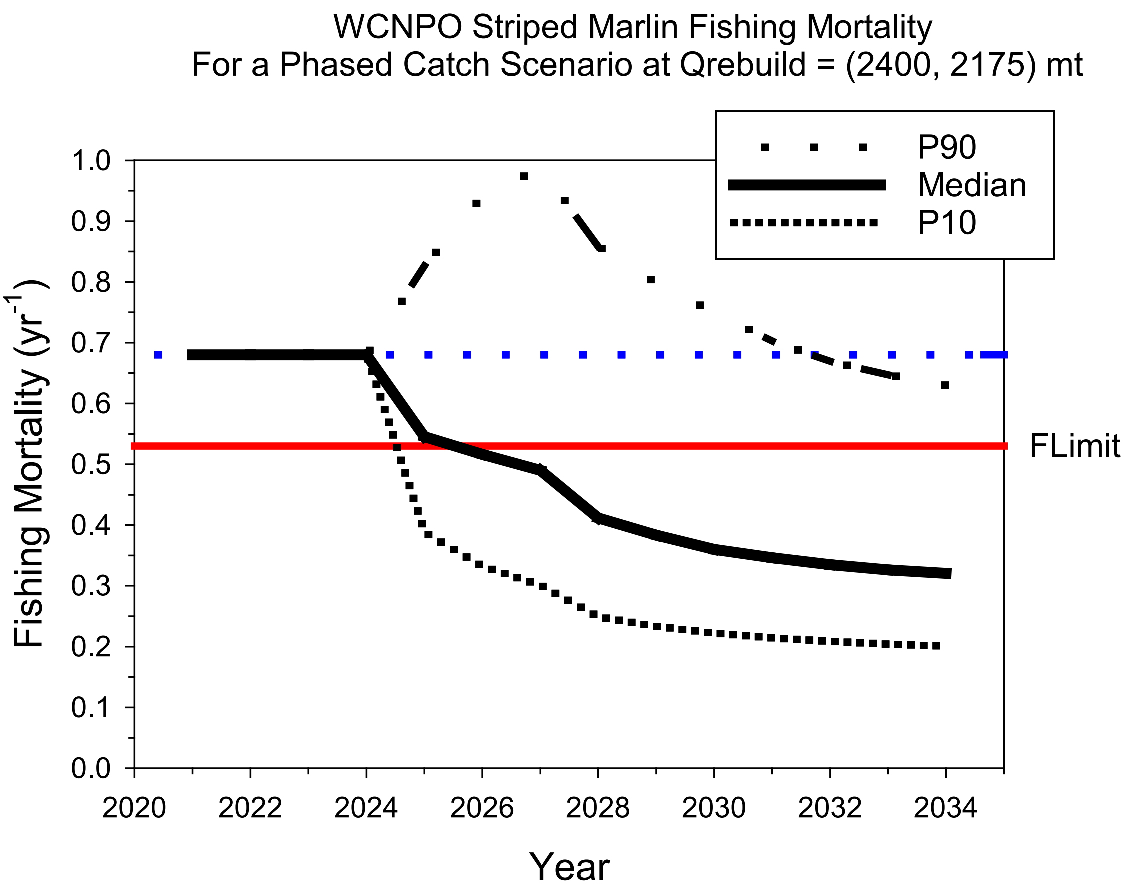


Figure 38.5. Comparison of the central tendencies of fishing mortalities to rebuild the stock under the phased, constant F, and constant quota rebuilding scenarios relative to the potential overfishing reference point of $F_{20\%SSB(F=0)}$=0.53.

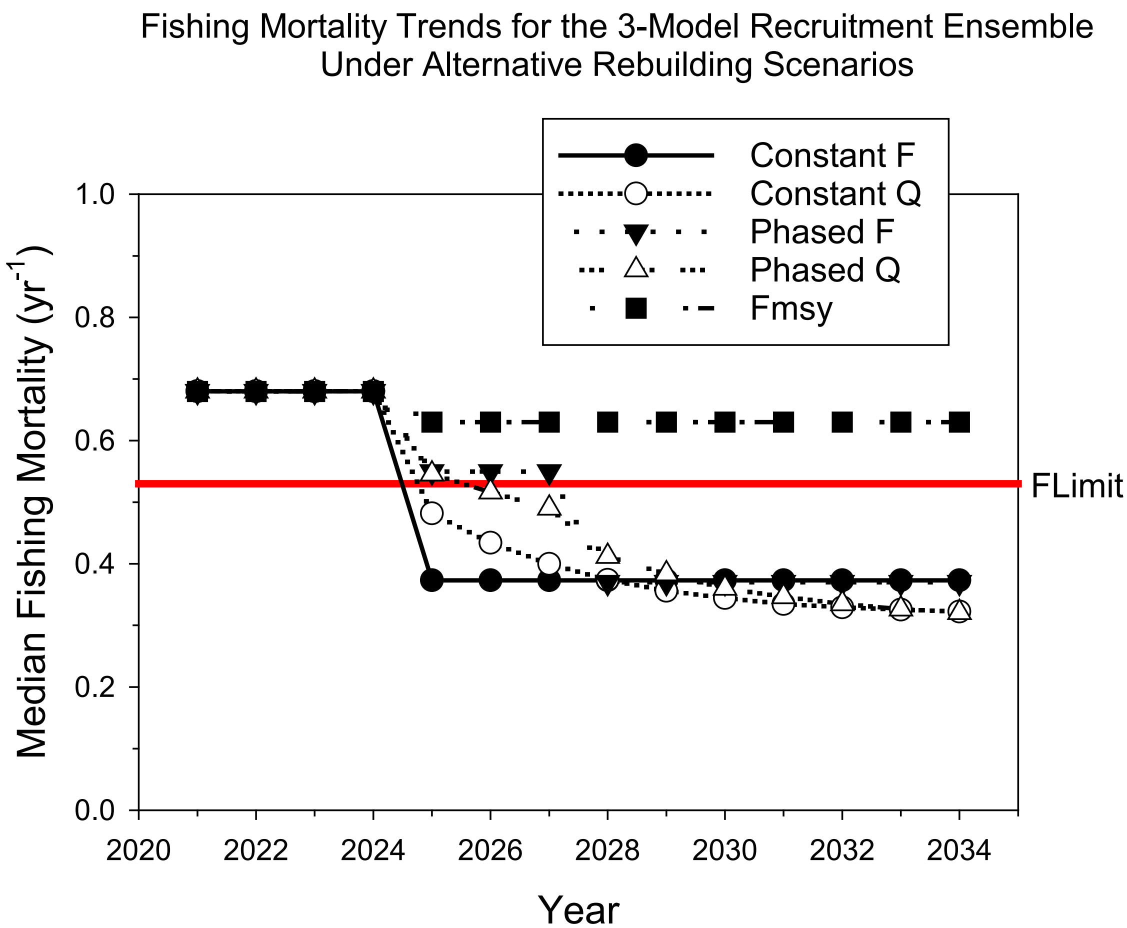


Figure 39. Comparison of annual probabilities of achieving the rebuilding target of 3,660 mt of spawning biomass with at least 60% probability during 2021–2034 under the phased, constant F, and constant quota rebuilding scenarios.

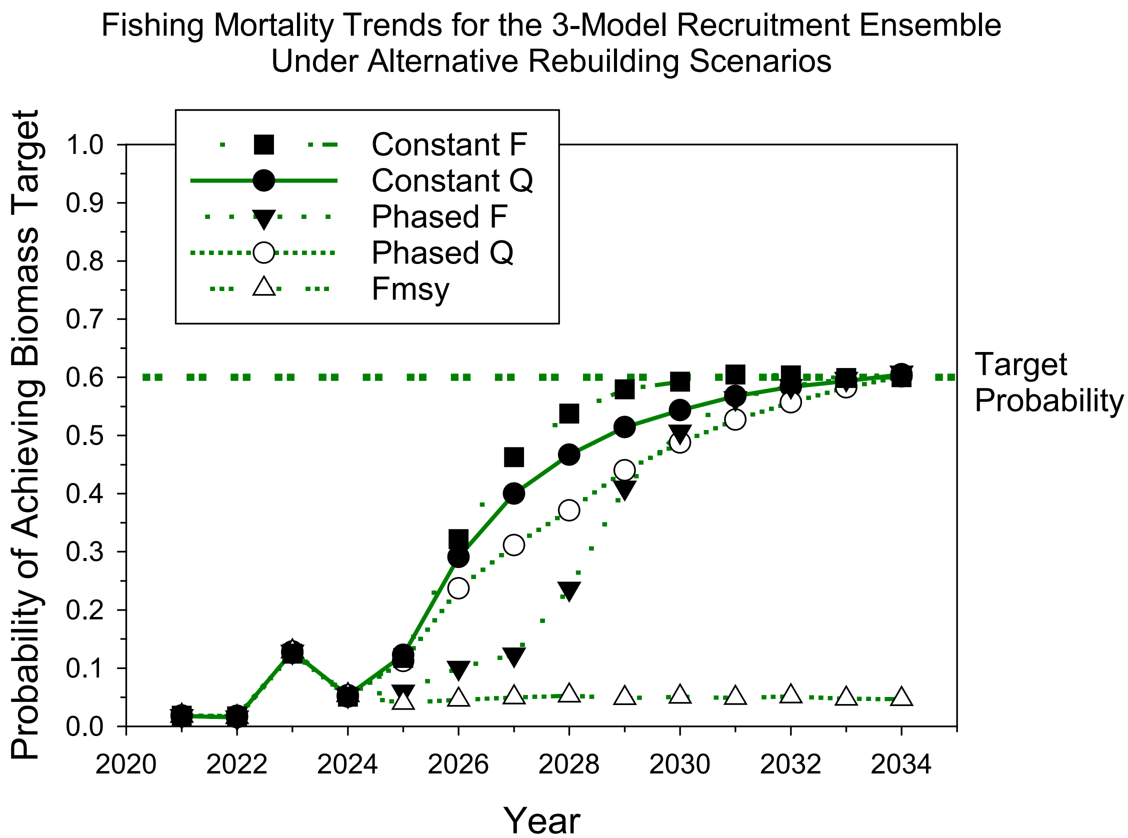


Figure 40. Comparison of the annual probabilities of exceeding the potential overfishing reference point of $F_{20\%SSB(F=0)}$=0.53 during 2021–2034 under the phased, constant F, and constant quota rebuilding scenarios relative to the even odds reference of not overfishing (red dash-dot line).

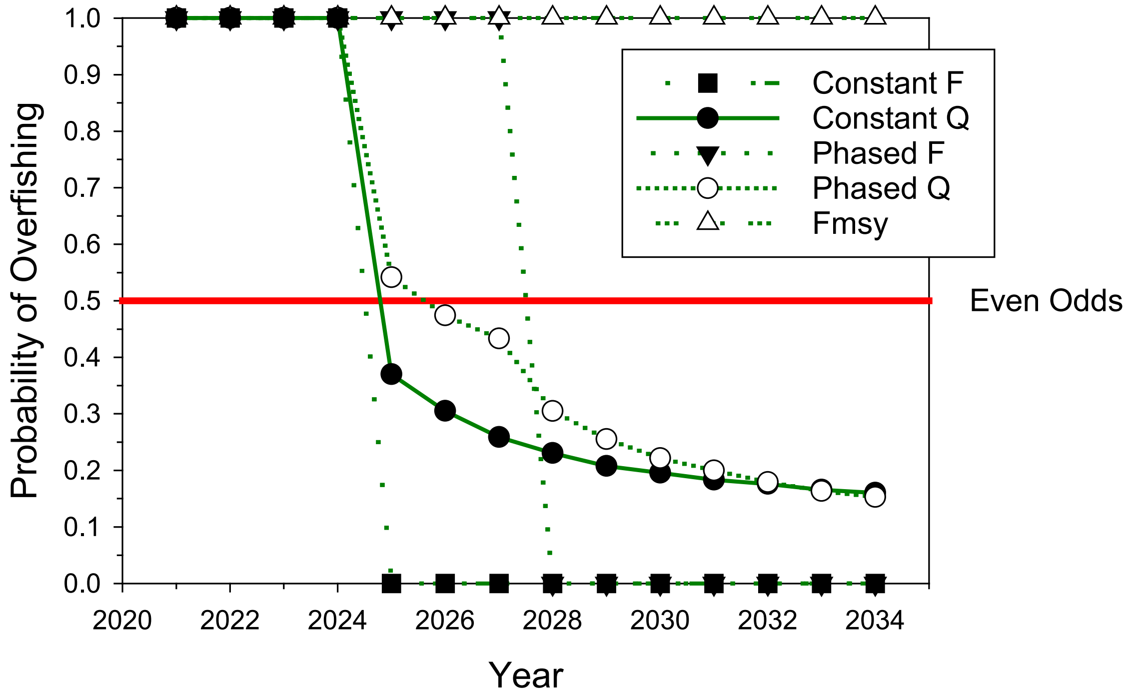


Figure 41.1. Comparison of the time series of median catch biomass quotas to rebuild the stock under the constant F and constant quota rebuilding and F_{msy} scenarios for the medium-term recruitment model relative to the recent average yield during 2018–2020 of 2,428 mt.

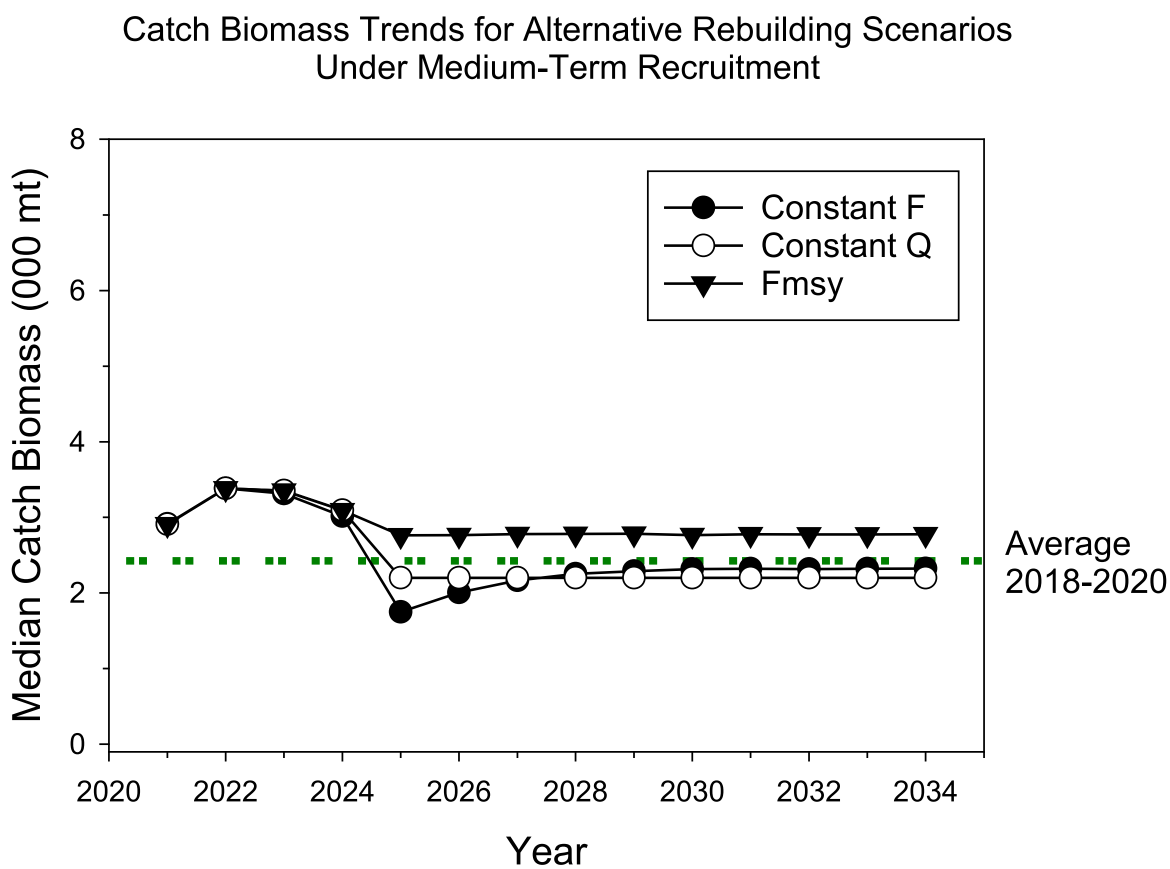


Figure 41.2. Comparison of the time series of median catch biomass quotas to rebuild the stock under the constant F and constant quota rebuilding and F_{msy} scenarios for the short-term recruitment model relative to the recent average yield during 2018–2020 of 2,428 mt.

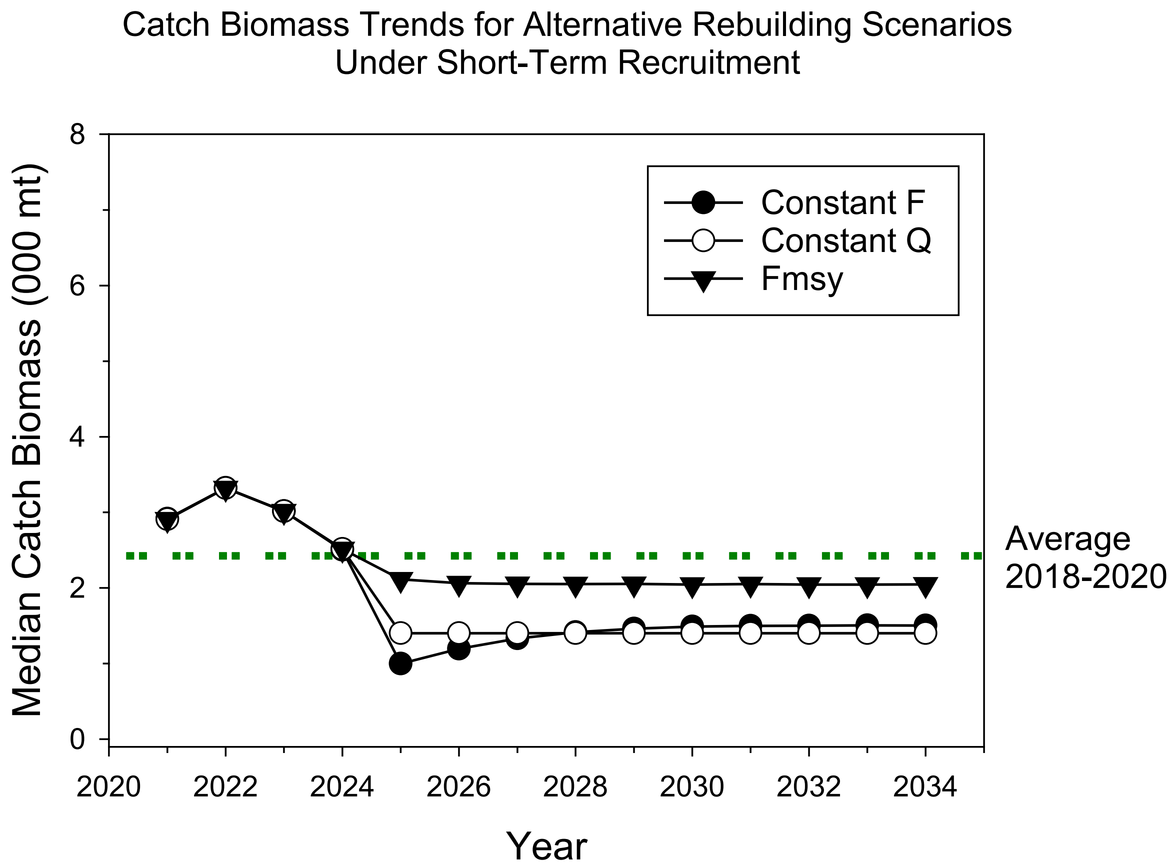


Figure 41.3. Comparison of the time series of median catch biomass quotas to rebuild the stock under the constant F and constant quota rebuilding and F_{msy} scenarios for the long-term recruitment model relative to the recent average yield during 2018–2020 of 2,428 mt.

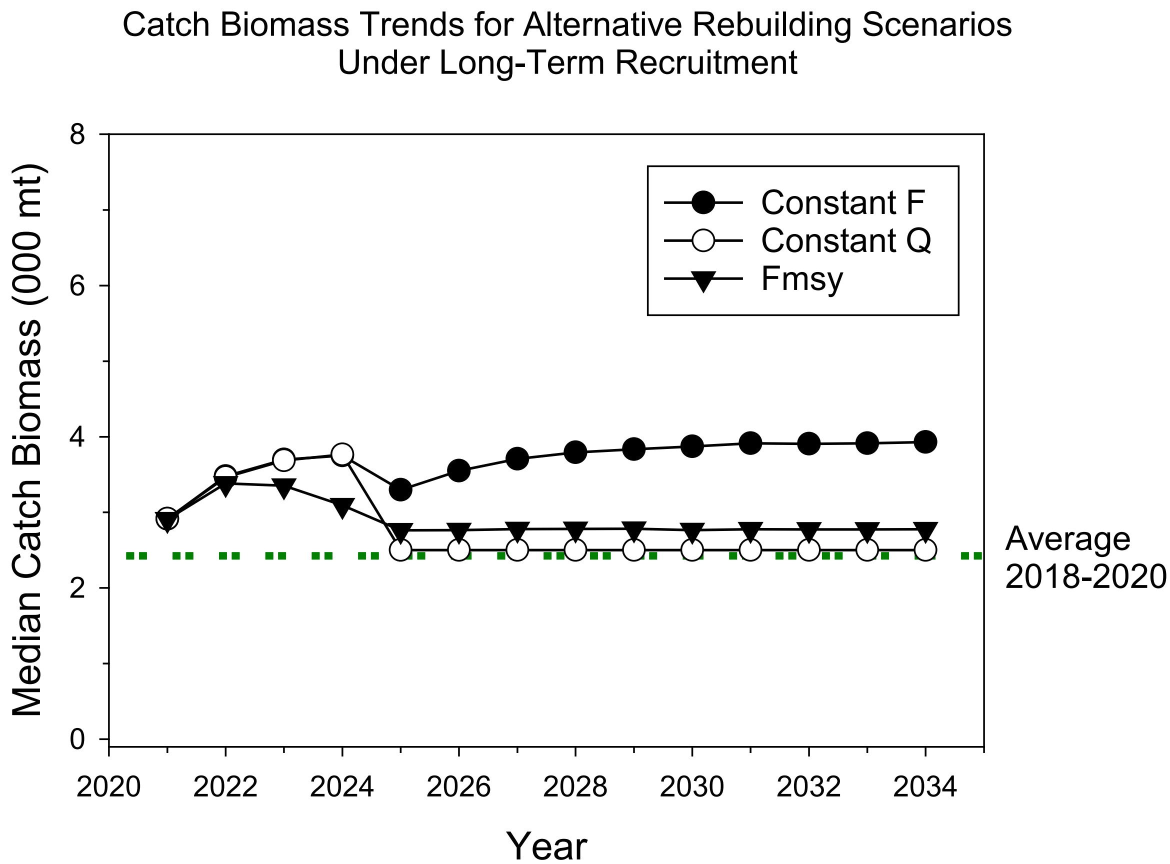


Figure 42.1. Comparison of the time series of median spawning stock biomasses to rebuild the stock under the constant F and constant quota rebuilding and F_{msy} scenarios for the medium-term recruitment model relative to the recent average spawning stock biomass during 2018–2020 of 1,359 mt.

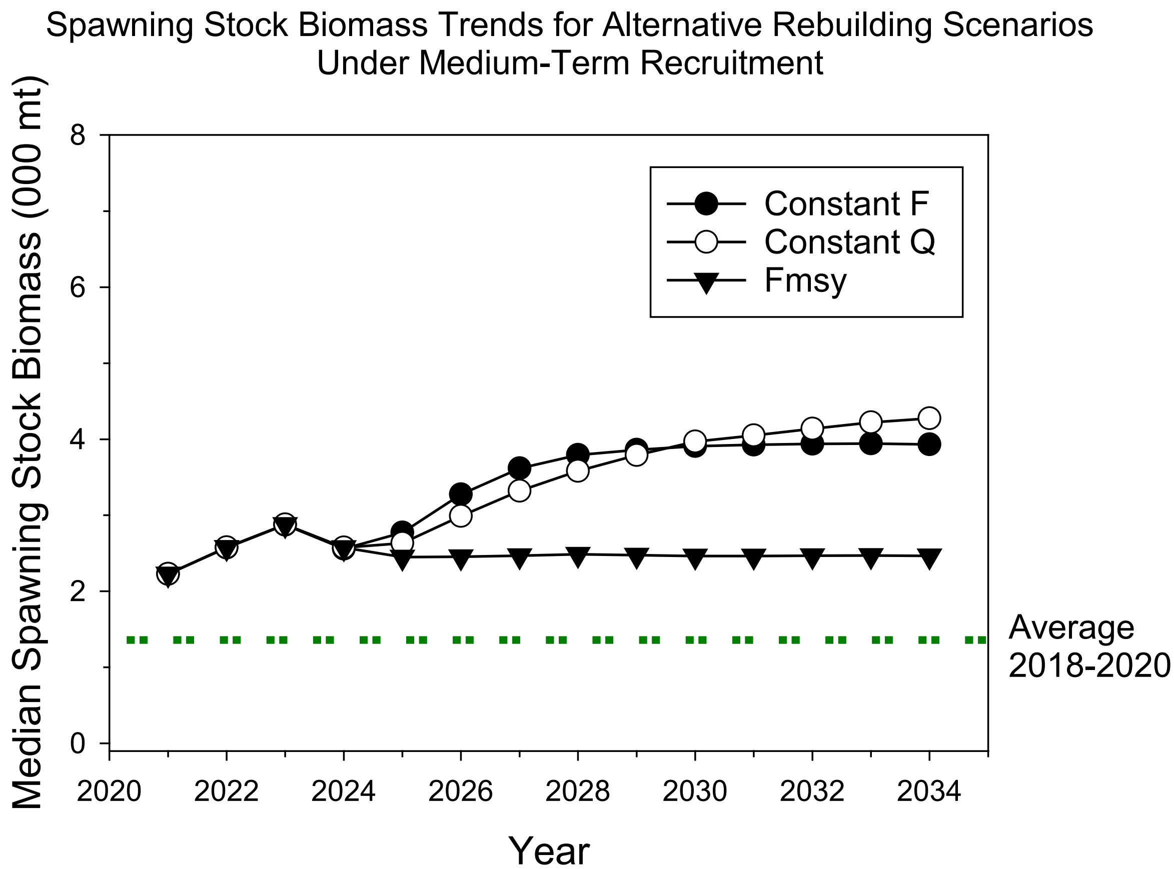


Figure 42.2. Comparison of the time series of median spawning stock biomasses to rebuild the stock under the constant F and constant quota rebuilding and F_{msy} scenarios for the short-term recruitment model relative to the recent average spawning stock biomass during 2018–2020 of 1,359 mt.

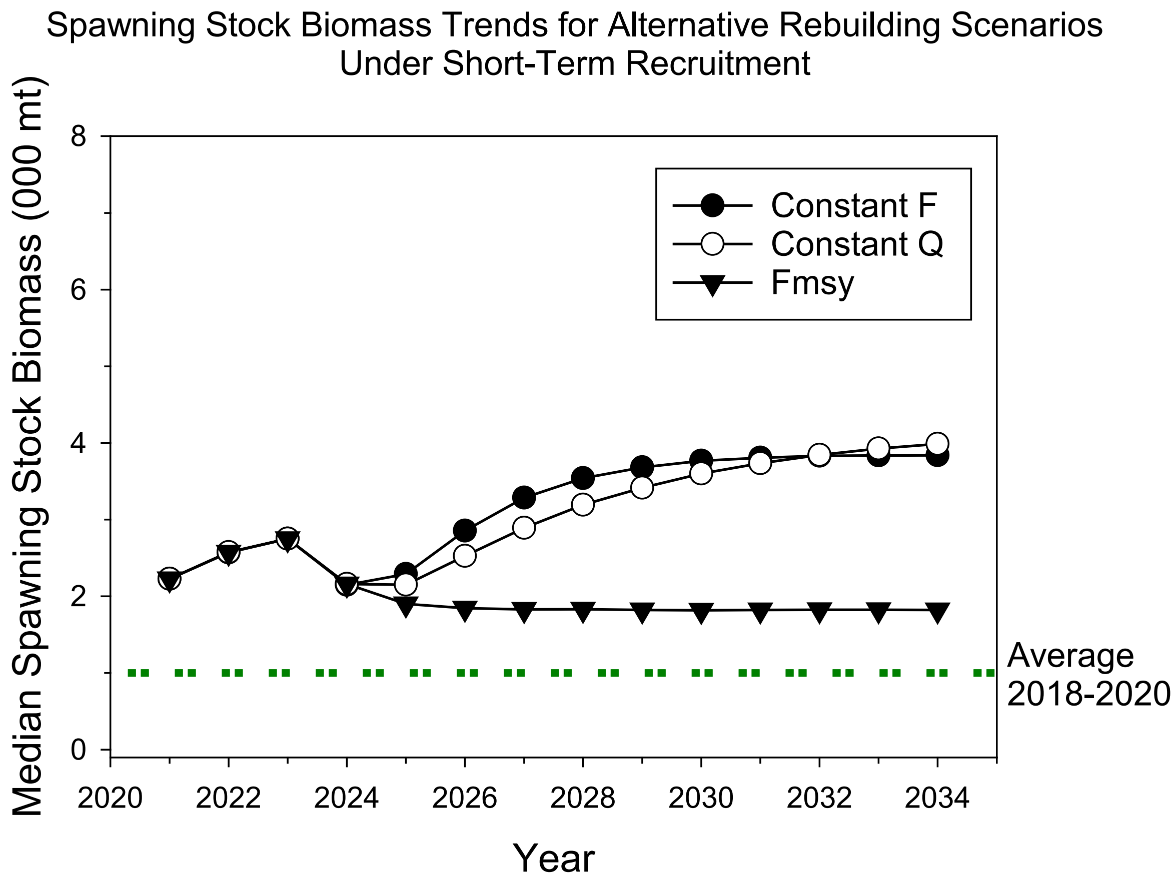


Figure 42.3. Comparison of the time series of median spawning stock biomasses to rebuild the stock under the constant F and constant quota rebuilding and F_{msy} scenarios for the medium-term recruitment model relative to the recent average spawning stock biomass during 2018–2020 of 1,359 mt.

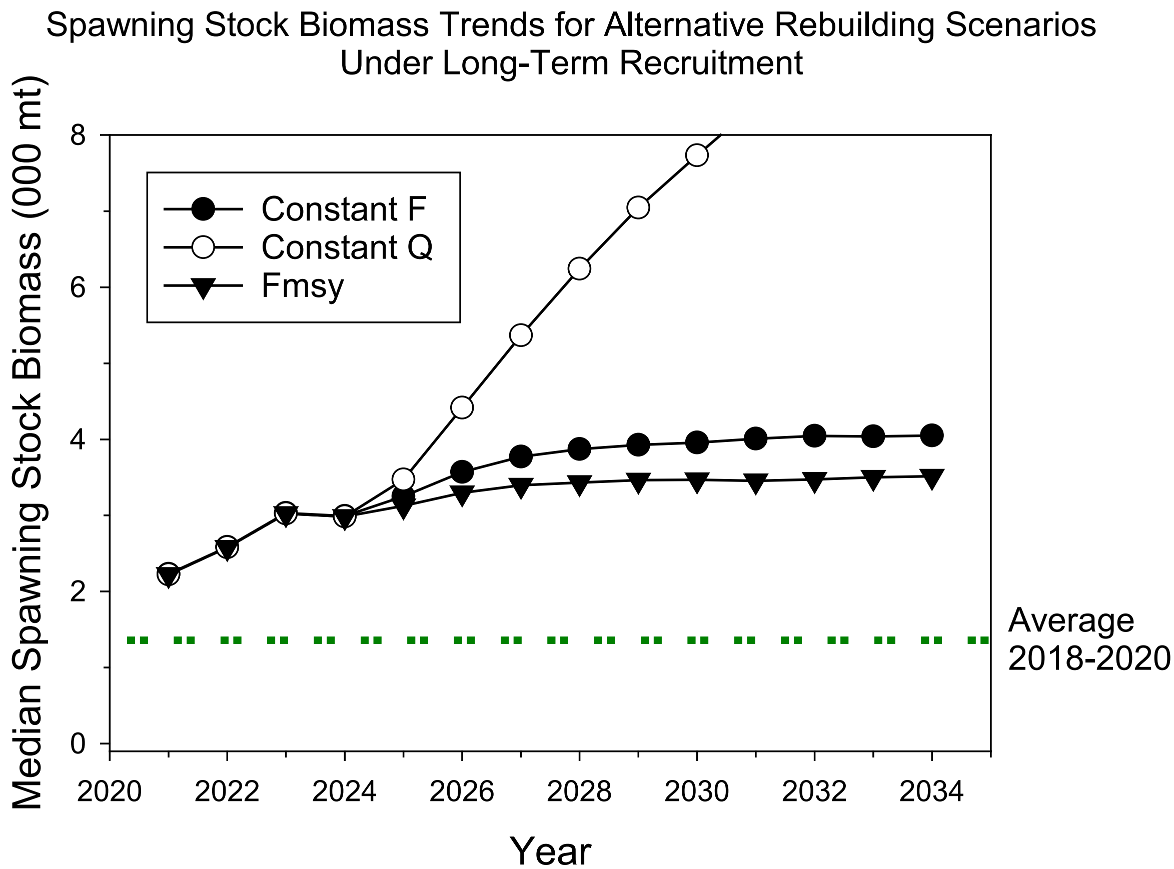


Figure 43.1. Comparison of annual probabilities of achieving the rebuilding target of 3,660 mt of spawning biomass with at least 60% probability for the medium-term recruitment model during 2021–2034 under the phased, constant F, and constant quota rebuilding scenarios.

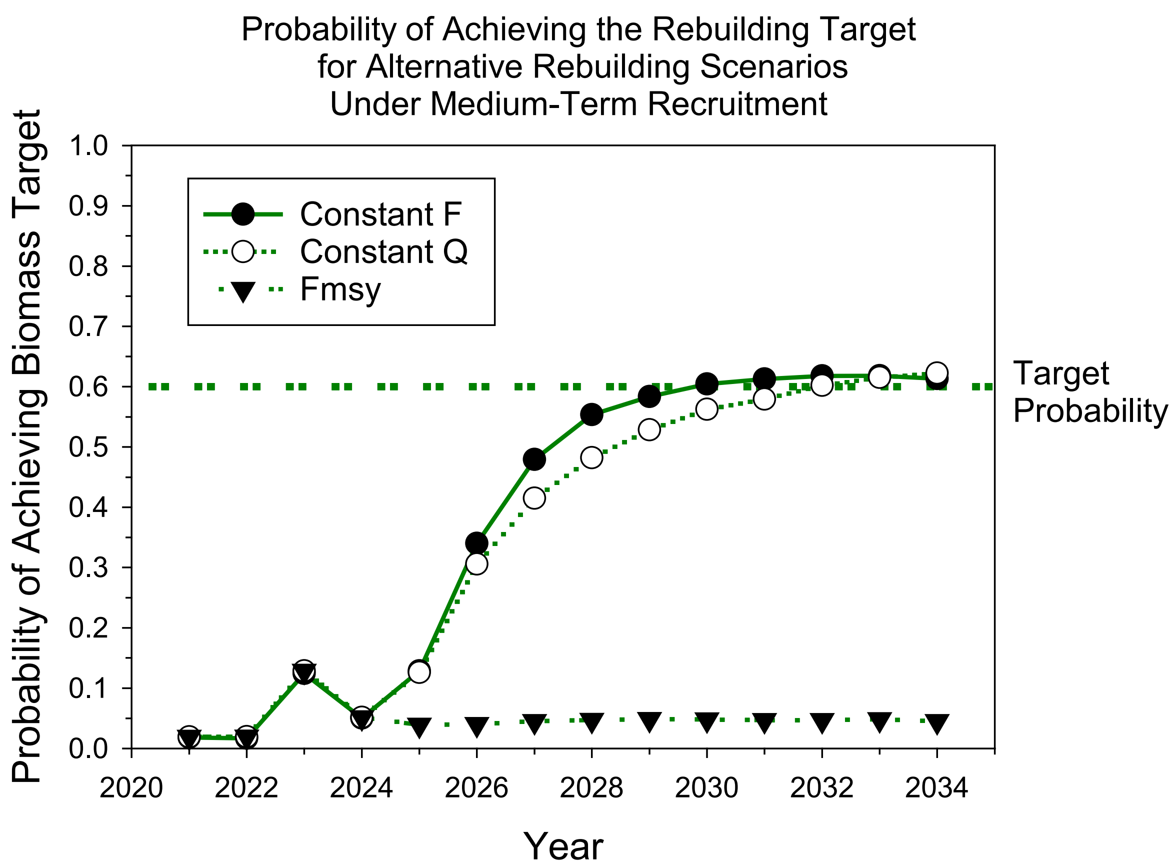


Figure 43.2. Comparison of annual probabilities of achieving the rebuilding target of 3,660 mt of spawning biomass with at least 60% probability for the short-term recruitment model during 2021–2034 under the phased, constant F, and constant quota rebuilding scenarios.

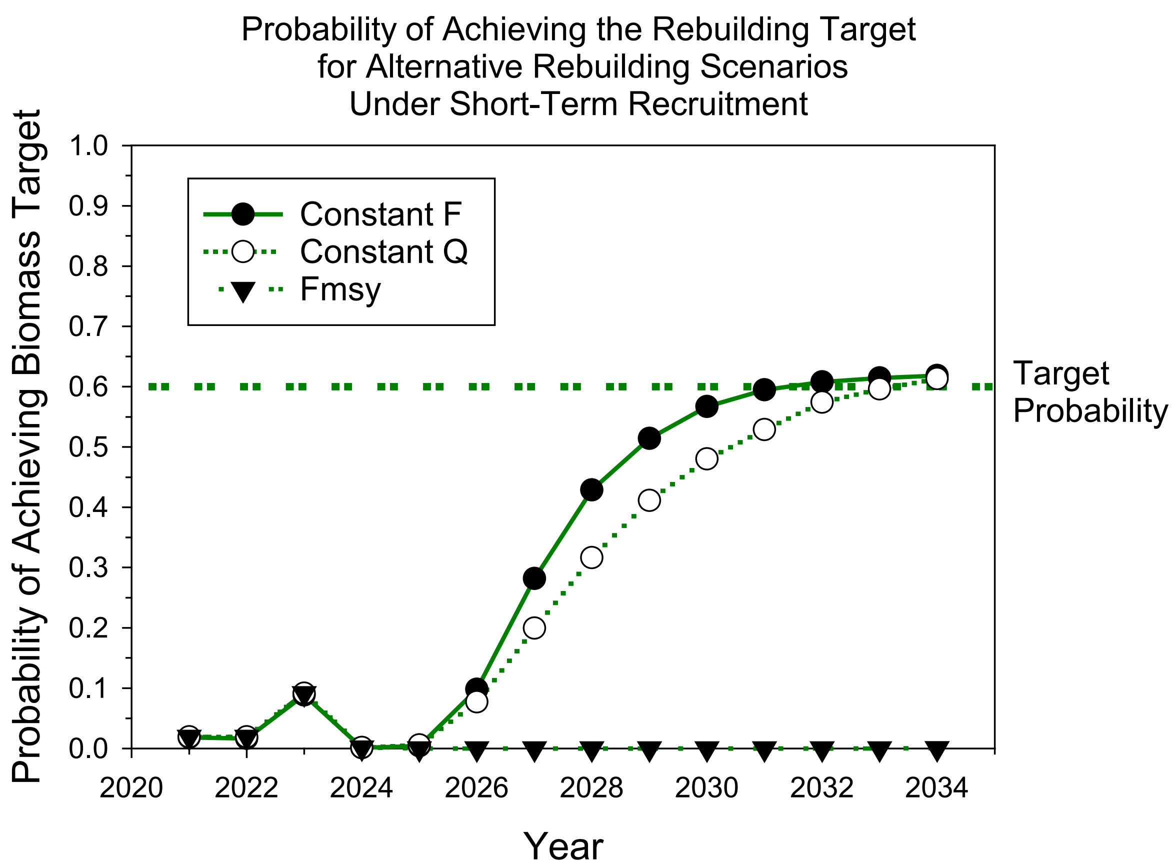


Figure 43.3. Comparison of annual probabilities of achieving the rebuilding target of 3,660 mt of spawning biomass with at least 60% probability for the long-term recruitment model during 2021–2034 under the phased, constant F, and constant quota rebuilding scenarios.

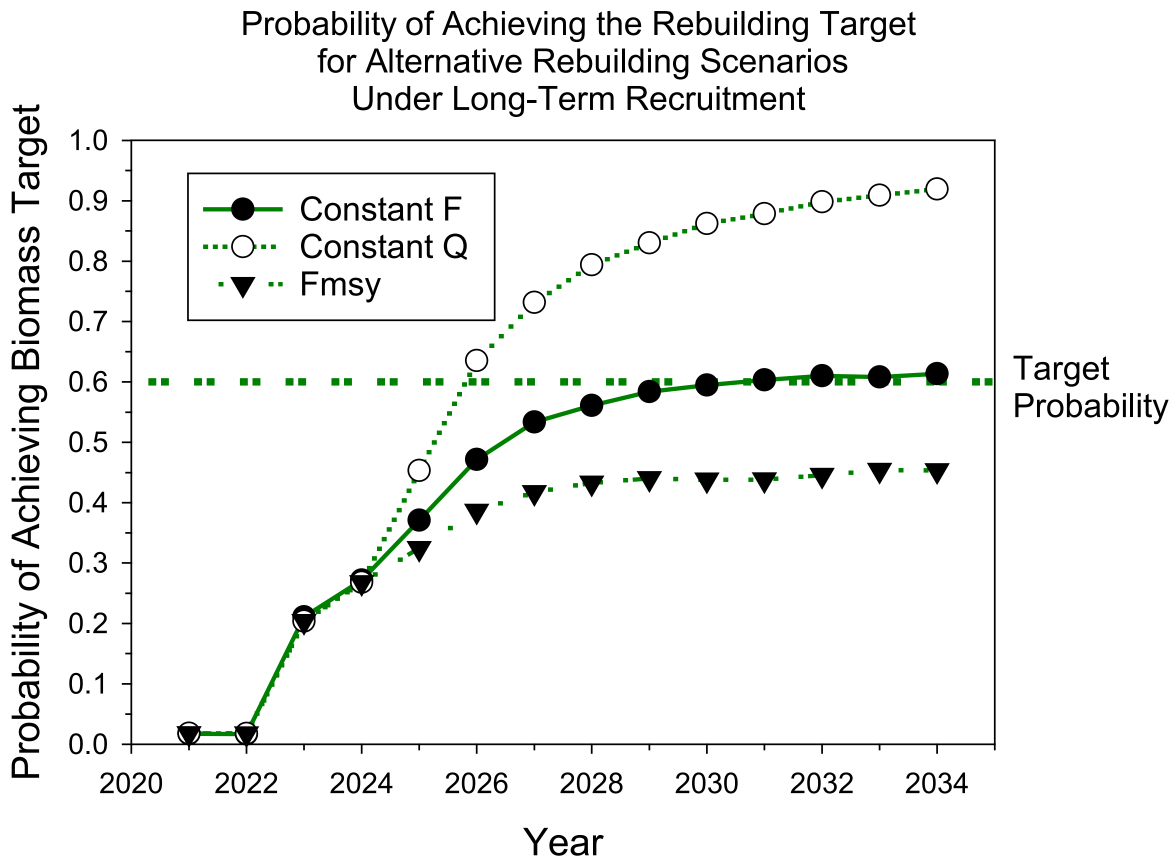


Figure 44.1. Comparison of the annual probabilities of exceeding the potential overfishing reference point of $F_{20\%SSB(F=0)}=0.53$ during 2021–2034 for the medium-term recruitment model during 2021–2034 under the constant F and constant quota rebuilding and F_{msy} scenarios.

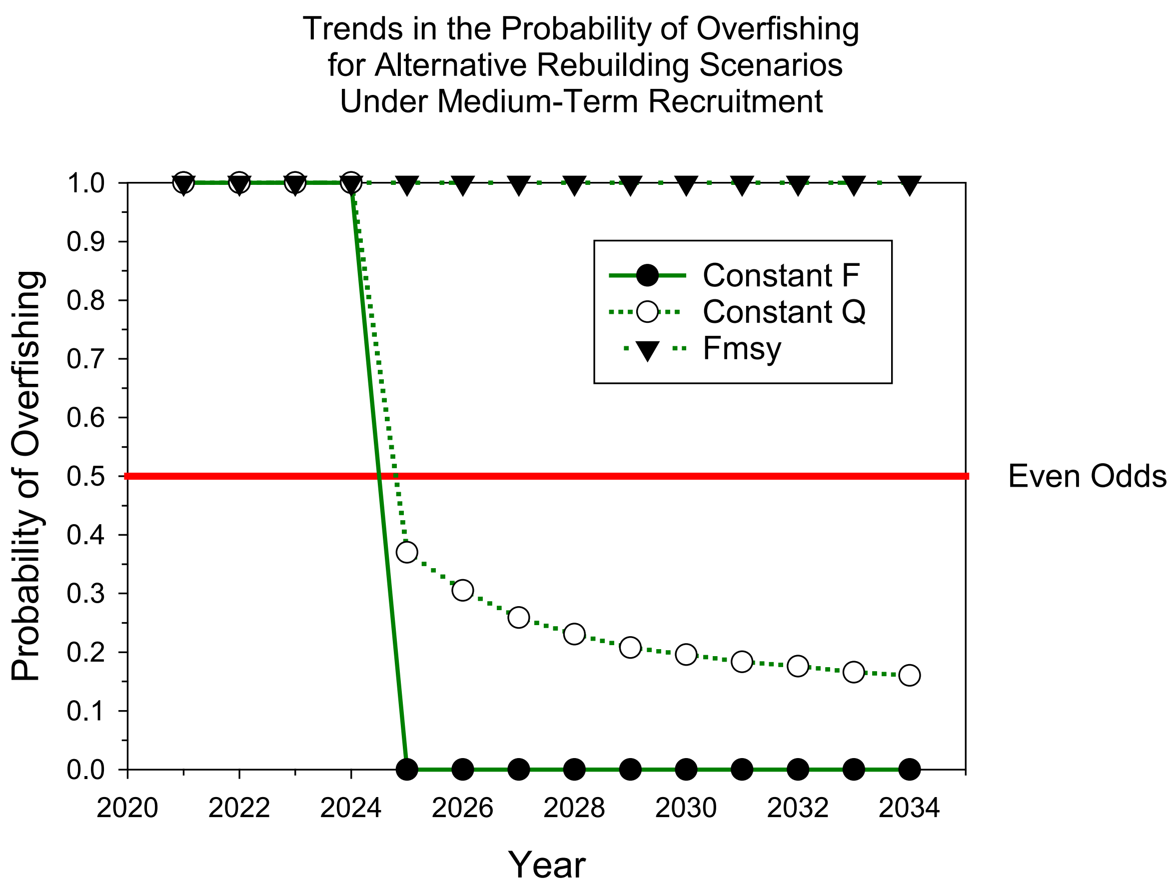


Figure 44.2. Comparison of the annual probabilities of exceeding the potential overfishing reference point of $F_{20\%SSB(F=0)}$=0.53 during 2021–2034 for the short-term recruitment model during 2021–2034 under the constant F and constant quota rebuilding and F_{msy} scenarios.

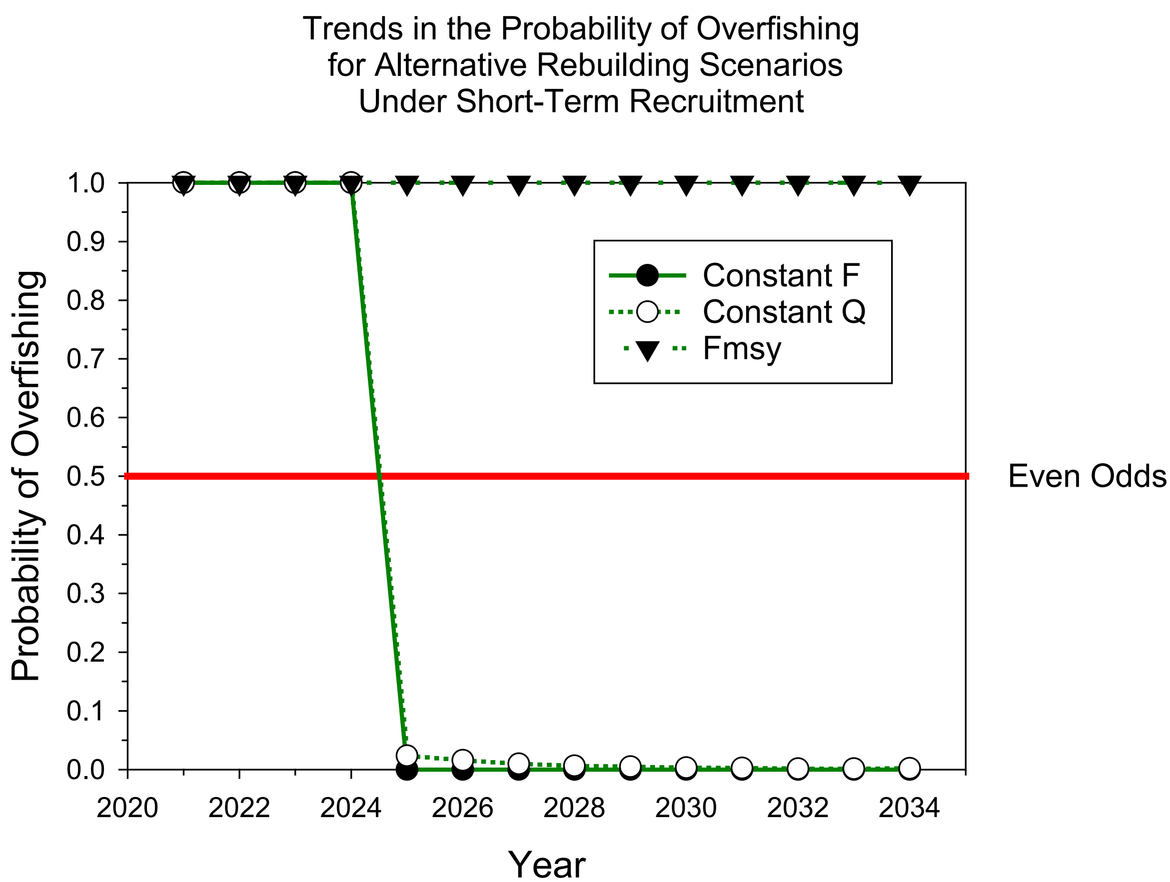


Figure 44.3. Comparison of the annual probabilities of exceeding the potential overfishing reference point of $F_{20\%SSB(F=0)}$=0.53 during 2021–2034 for the long-term recruitment model during 2021–2034 under the constant F and constant quota rebuilding and F_{msy} scenarios.