Stock Assessment Update of the Bottomfish Management Unit Species of Guam, 2024

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Department of Commerce | National Oceanographic and Atmospheric Administration | National Marine Fisheries Service | Pacific Islands Fisheries Science Center

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Executive Summary

Stock assessments of the bottomfish management unit species (BMUS) in Guam were conducted through 2023. Bottomfish resources in Guam are managed as one multi-species complex, which includes 13 species specified by the Fishery Ecosystem Plan (FEP) for the Mariana Archipelago. The most recent stock assessment of BMUS in Guam was a benchmark stock assessment published in 2019 using data through 2017.

The stock assessment described in this document was conducted as an update stock assessment; therefore, all components of the assessment analyses (selection of datasets, data filtering, catch-per-unit-effort (CPUE) standardization, stock assessment model, and model fitting) were identical to the 2019 benchmark stock assessment. Estimated annual catch and catch variance for 1982–2017 were taken directly from the 2019 benchmark stock assessment, and the update years 2018–2023 were estimated using an identical approach and added to the existing catch timeseries. For the CPUE timeseries, the boat-based creel survey interviews from 1982–2017 that were used in the 2019 benchmark assessment were pooled with boat-based creel survey interviews from 2018–2023 and used to calculate the standardized CPUE index.

This update stock assessment provides estimates of annual exploitable stock biomass and harvest rate, both in absolute values and relative to the maximum sustainable yield-based management reference points specified for the BMUS of Guam. The Bayesian 95% posterior density of 2023 stock status suggests BMUS in Guam were not overfished and were not experiencing overfishing in 2023. This represents a change in stock status from the previous benchmark stock assessment, which concluded BMUS in Guam were overfished (but not experiencing overfishing) in 2017. It is apparent smaller catches in 2017–2020 (average 22.6 thousand lbs per year) relative to the suggested catch limits from the 2019 benchmark assessment (31 thousand lbs per year) allowed the stock biomass to increase. However, higher catches in 2021–2023 (average 40.0 thousand lbs per year) appear to have reduced stock biomass in the most recent years.

Stock projections were conducted for 2024–2029 for a range of hypothetical six-year catches and incorporated uncertainty in surplus model production parameters and the 2023 stock status. These update stock assessment catch projections provided similar conclusions to the previous benchmark stock assessment: annual catches of 31–33 thousand lbs per year over the next six years would be associated with an approximately 40% probability of overfishing.

Introduction

The Western Pacific Regional Fishery Management Council (WPRFMC) manages bottomfish resources in federal waters surrounding Guam under the Fishery Ecosystem Plan (FEP) for the Mariana Archipelago (FEP; WPRFMC 2009). The FEP supersedes the 1986 Fishery Management Plan for the Bottomfish and Seamount Groundfish Fisheries of the Western Pacific Region, which named 19 bottomfish management unit species (BMUS) across Guam, Hawai‘i, and American Samoa (WPRFMC 1986). The 2009 FEP specified 205 species or families of fish and invertebrates, including 17 species of bottomfish requiring management with catch limits or other regulations. However, most species within the FEP were reclassified as “ecosystem component species” in 2019, leaving only 13 BMUS that required management by the WPRFMC in the Mariana Archipelago (84 FR 2767). These 13 species (Table 1) were retained as BMUS because they were considered by local fishermen and fisheries scientists to be most in need of conservation and management.

Guam BMUS include two species of jacks *Caranx ignobilis* and *C. lugubris*, which—together with other large-bodied members of family Carangidae—may be caught by bottomfishermen at relatively shallow depths (300 ft or less). These two jack species are considered less desirable than the deeper-dwelling bottomfishes (Iwane et al. 2023). *C. ignobilis* are relatively long-lived (maximum age 31 years), slow-growing, and late-maturing (Pardee et al. 2021). Studies of *C. lugubris* life history are limited, but this species is likely shorter-lived and faster growing than *C. ignobilis* (Fry et al. 2006). Members of the family Lethrinidae (emperors, including *Lethrinus rubrioperculatus*), and snappers of the genus *Lutjanus* (including *Lutjanus kasmira*) are also caught at relatively shallow depths. Similar to the large jacks, Guam bottomfishermen indicate these species do not have high market value, but emperors including *L. rubrioperculatus* may be targeted by fishermen for family or community consumption (Iwane et al. 2023). Both *L. rubrioperculatus* and *L. kasmira* are likely relatively short-lived and fast-growing species (maximum estimated age 15 and 8, respectively, Loubens 1980; Pardee et al. 2020). The only grouper among the Guam BMUS, *Variola louti*, may be caught at similar depths to the jacks and emperors, as well as somewhat deeper. Although this species is regarded as potentially ciguatoxic, it is preferred as an eating fish by some (Iwane et al. 2023). Life history studies of *V. louti* suggest it is fast-growing and early-maturing relative to other larger-bodied groupers (Schemmel and Dahl 2023). *V. louti* and *L. rubrioperculatus* are both sequential hermaphrodites, maturing first as female then transitioning to male at a later age (Pardee et al. 2020; Schemmel and Dahl 2023).

The remaining eight Guam BMUS, all snappers in the family Lutjanidae, are often caught at depths ranging to 800 feet or deeper. Guam fishermen report *Aphareus* *rutilans*, *Pristipomoides auricilla*, *P. sieboldii*, and *P. zonatus* are caught at mid-range depths (from 400 to 800 feet), but may also co-occur with the more shallow species of jacks and emperors (Iwane et al. 2023). The BMUS known by the common name ʻōpakapaka (*P. flavipinnis* and *P. filamentosus*) are generally caught at deeper depths than the other *Pristipomoides*, and are among the most marketable (Iwane et al. 2023). These five species of *Pristipomoides* and *A. rutilans* are generally long-lived: maximum age ranging from 28 years for P. *flavipinnis* (O'Malley et al. 2019), to 50 years for *P. filamentosus* (Ryan Nichols, NOAA Fisheries, *unpublished*).

Snappers of the genus *Etelis* are regarded as being among the deepest bottomfishes in Guam. They are also among the longest-lived, slowest-growing, and latest-maturing (Reed et al. 2023). The FEP for the Mariana Archipelago includes two species of *Etelis* in the BMUS: *E. carbunculus* and *E. coruscans*. A third species of *Etelis*, *E. boweni*, is very similar in appearance to *E. carbunculus* and has only recently been described (Andrews et al. 2021). Accounts provided by fishermen, Guam Department of Agriculture and Wildlife Resources (DAWR) staff, and NOAA Fisheries scientists confirm *E. boweni* are present in Guam (Iwane et al. 2023; Dahl et al. 2024) and have likely been previously misidentified as *E. carbunculus*.

The Guam BMUS are currently managed as one multi-species complex. A final rule to amend the FEP was approved in 2011 to establish methods for determining fishing mortality and stock biomass reference values and, by a comparison of current conditions to the reference values, determining if the stock is overfished and if overfishing is occurring (76 FR 37285).

Overfished is defined as the stock biomass B falling below the minimum stock size threshold (MSST) of $(1 - M) \times B_{MSY}$, where M is the natural mortality rate of the complex and B_{MSY} is the biomass that produces the maximum sustainable yield. As was done in the previous assessment, M was set at 0.30, so the overfished definition is defined as biomass below $0.7 \times B_{MSY}$ $(B < 0.7 \times B_{MSY})$.

Overfishing is defined as an instantaneous fishing mortality rate (F) or discrete fishing mortality rate, (H = catch / exploitable biomass, also known as the harvest rate) that exceeds the maximum fishing mortality threshold (MFMT). According to the FEP, the MFMT varies depending on whether biomass is above or below the MSST (Figure 1). If the stock biomass is above the MSST $(B > 0.7 \times B_{MSY})$, then the MFMT equals the harvest rate that produces maximum sustainable yield (H_{MSY}), whereas if the stock biomass falls below the MSST $(B < 0.7 \times B_{MSY})$, then H_{MFMT} declines from H_{MSY} in proportion to the ratio of biomass to the MSST.

Throughout this report, we refer to status in relation to H_{MFMT} instead of H_{MSY} to reflect the harvest control rule as stated in the Mariana Archipelago FEP.

Description of Fisheries

Guam is the largest and southernmost island of the Mariana Archipelago. The total land area is 212 square miles, and it has a limestone plateau covering the northern region of the island and ancient volcanic hills covering the southern region. The total Guam population was 153,836 in 2020, including approximately 21,700 U.S. military personnel and their families (U.S. Census Bureau 2022; U.S. Defense Department 2022).

Fishing in Guam is important for contributing to the subsistence needs of the people, preserving history and identity, and maintaining cultural practices (Allen and Bartram 2008). Bottomfishes in Guam are caught by a combination of recreational, subsistence, and small-scale commercial fishing operations using hook and line with electric or manually operated reels depending on fishing depth. Ninety-three unique vessels are known to have engaged in bottomfishing (across all species) in 2022 with a preliminary estimated catch of 54,916 lb (WPRFMC 2023). Most bottomfishing vessels are less than 25 feet in length and target shallower bottomfish species for recreational or subsistence purposes. Some of these vessels, as well as most larger vessels, also target the deeper bottomfish species at the offshore banks and other areas around Guam where deep bottomfish habitat occurs.

Previous Stock Assessments

Informal Assessments Before 2007

The Guam BMUS were initially assessed as a complex (i.e., all 13 BMUS species were combined) using an informal index-based assessment method. For this approach, annual nominal catch rates as the total estimated lb of BMUS caught each year divided by the total estimated number of hours fished each year were compared to an established indicator level equal to 50% of average nominal catch rates over 1982–1984. According to these early assessment methods, the BMUS complex was believed to have been experiencing overfishing from the mid-1990s through 2000, and, furthermore, was overfished in 1997 and 1998 (Moffitt et al. 2007).

Benchmark Stock Assessment in 2007

The first formal stock assessment of Guam bottomfishes was completed in 2007 (Moffitt et al. 2007). This assessment improved upon the index-based assessment method and relied on a Bayesian surplus production model (BSP) which directly accounted for process and observation error, and estimated MSY-based reference points, trajectories of biomass and harvest rate, and stock status. The model used WinBUGS software to calculate posterior density distributions for model parameters and derived model quantities to capture uncertainty in status determinations. The benchmark assessment indicated the BMUS complex was not overfished and not experiencing overfishing in 2005 (Moffitt et al. 2007).

As with any modeling approach, the 2007 benchmark stock assessment made several assumptions regarding model structure and data treatment. In regards to model structure, a Schaefer (symmetrical) surplus production function was assumed. To help inform parameter estimates, the BSP was fit to estimates of MSY calculated from independent studies that combined life history assumptions (von Bertalanffy growth, constant natural mortality, and constant recruitment) with data on length-frequency, CPUE, and an estimate of catchability from an intensive fishing experiment in the Mariana Archipelago (Polovina and Ralston 1986).

Assumptions around catch and CPUE data were also made. The 2007 benchmark assessment model used nominal CPUE data (no standardizations were considered) from 1982–2005, and included in the discussion a recognition of the potential downfalls of using nominal CPUE. The creel survey interviews used in the nominal CPUE estimates were also filtered to only include interviews with greater than 50% of BMUS by weight.

Stock Assessment Update in 2012

The 2012 stock assessment update used data through 2010 and relied on a similar treatment of data, analytical approach, and assessment methodology as the 2007 benchmark assessment (Brodziak et al. 2012). Five years of data were added to the catch and CPUE time series from those used in the previous benchmark assessment. The findings of the 2012 assessment update were similar to the 2007 stock assessment; the BMUS complex was not overfished and was not experiencing overfishing in 2010.

Stock Assessment Update in 2016

The 2016 stock assessment update used data through 2013 and relied on similar treatment of data, analytical approach, and assessment methodology as the 2012 assessment update and 2007 benchmark assessment (Yau et al. 2016). Catch and CPUE were calculated using the offshore (boat-based) creel survey dataset. Three new years of data were added to the catch and CPUE time series used in the 2012 stock assessment update. The findings of the 2016 assessment update were similar to the 2012 assessment update and 2007 stock assessment; the BMUS complex was not overfished and not experiencing overfishing in 2013.

The 2016 assessment update was the first assessment of Guam bottomfishes to go through the Western Pacific Stock Assessment Review (WPSAR) process. This peer-review process produced a number of recommendations for improvements to the stock assessments for bottomfishes in all territories (Chaloupka et al. 2015). Many of the improvements were incorporated into the 2019 benchmark stock assessment.

Benchmark Stock Assessment in 2019

The 2019 benchmark stock assessment (Langseth et al. 2019) relied on the same general data streams and the underlying BSP model used in previous assessments to estimate MSY-based reference points, provide trajectories of biomass and harvest rates, and determine stock status. However, there were several improvements made in the treatment of the data, analytical approach, and assessment methodology.

As was done previously, estimated annual catch of BMUS in Guam was based on the Guam DAWR creel surveys, but was broadened to include landings estimated from shore-based gears in addition to the primary BMUS-catching boat-based gears. CPUE data were still derived from the boat-based creel survey, however, all boat-based interviews reporting use of bottomfishing gear were considered, irrespective of the species composition of the catch for that interview. Some interviews were excluded based on the catch history of each vessel, whereas any vessel that never recorded catching BMUS or species groups potentially containing BMUS (e.g., Lutjanidae, assorted bottomfish, etc.) were removed from the interview set. Finally, interviews recorded as charter fishing trips were excluded.

The 2019 benchmark stock assessment included a CPUE standardization, whereby a modeling approach was used to account for the potential effects of time-variable catchability on catch rates. The CPUE standardization used a delta-type approach to model CPUE as the product of two linear models: a presence/absence process assuming binomial error that modeled the probability of positive catches, and a positive process assuming lognormal error that modeled CPUE given a positive catch. Within both processes, in addition to the year effect, there was a stepwise exploration of the effects of multiple covariates indicative of variable catchability on the response, including time of year, area, type of day, depth, wind speed, and vessel name. The selected model for the presence/absence process included year, area, and depth and the selected model for the positive process included year, area, depth, and a random intercept term of vessel name.

The 2019 benchmark stock assessment was implemented using Just Another Bayesian Biomass Assessment (JABBA), which is an open-source modeling framework for conducting state-space Bayesian surplus production models (Winker et al. 2018). The primary difference between JABBA and the previous iterations of the BSP for the Guam bottomfish assessments included the Bayesian computation software that was used; JABBA relies on Just Another Gibbs Sampler (JAGS). Additionally, the JABBA modeling environment offered greater flexibility in setting model parameters and production functions, was widely available, and enabled the exploration of extensive sensitivity analyses to understand the implications of prior assumptions on model results.

All parameter prior distributions were reconsidered using updated information for the 2019 benchmark stock assessments. In contrast to the previous BSP, the JABBA model for the 2019 benchmark did not fit to the external estimate of MSY derived by Polovina and Ralston (1986), but, instead, estimated a posterior distribution for MSY based on model input data and parameters. The methodology of Polovina and Ralston (1986) were also used to inform on the prior distribution of carrying capacity (*K*) as was done in previous assessments. The productivity function was allowed to depart from the symmetric Schaeffer form by including a prior distribution and estimation of the shape (*m*) parameter.

The 2019 benchmark stock assessment indicated that in 2017, the Guam BMUS were overfished (median $B_{2017}/B_{MSY} = 0.57$) but not experiencing overfishing (median $H_{2017}/H_{CR} = 0.81$). The WPRFMC implemented a rebuilding plan contained in Amendment 6 to the Mariana Archipelago FEP, relying on the projected catch corresponding to an overfishing probability of 40% to set an annual catch limit of 31,000 lbs beginning in 2022 (87 FR 9271).

Current Update Stock Assessment

This update stock assessment includes data from 1982–2023 and provides estimates of the 2023 stock status and projected catches through 2029. The BSP model was implemented in JABBA following the same code structure, identical model set-up, and prior parameter specifications as used for the 2019 benchmark stock assessment. The only exception was a minor change to the Markov chain Monte Carlo (MCMC) specifications (including a longer MCMC burn-in period,) which was necessary due to slower convergence of the MCMC chains than was observed during the 2019 benchmark stock assessment.

Estimated annual catch and catch variance for 1982–2017 were taken directly from the 2019 benchmark stock assessment, and the update years 2018–2023 were estimated using an identical approach and added to the existing catch timeseries. For the CPUE timeseries, the boat-based creel survey interviews from 1982–2017 that were used in the 2019 benchmark assessment were pooled with boat-based creel survey interviews from 2018–2023 (filtered for targeting and incomplete information following the same criteria.) The selected delta binomial-lognormal general linear models from the 2019 benchmark assessment were applied to the full 1982–2023 interview set to calculate the standardized CPUE index.

Methods

Data Sources

Catch

Aggregate BMUS catch and a measure of relative error for 1982–2017 were taken directly from the 2019 benchmark assessment. Updated catch and variance estimates for 2018–2023 were formulated following an identical approach, as summarized in Langseth et al. (2019) and detailed in Ma et al. (2022). Though Ma et al. (2022) describe an updated method to directly compute the variance of species-level catch, the original bootstrap method used by Langseth et al. (2019) was replicated for 2018–2023.

Total catch rates (catch per trip, summed over all species and groups, as kg landed per trip or interview) were estimated from both the boat-based and shore-based creel surveys for expansion domains which may include (depending on boat- vs. shore-based creel survey): port, gear type, day type, time of day, and charter status. The total number of fishing trips for each expansion domain was estimated from the participation survey, then multiplied by catch rates within each expansion domain and summed across domains to give the estimated annual total catch of all species and groups combined. Species- and group-level catch was computed by allocating the total catch across all species according to the relative species and group composition in interviews.

Both the boat-based and shore-based creel survey data included family-level and common-name categories that could contain BMUS. Though catch is identified to the species-level whenever possible, interviews are voluntary and for large catches group codes may be used to expedite the interview process. We estimated the total catch of BMUS as the sum of catches of individual BMUS plus a percentage of catch from species groups believed to contain BMUS.

The percentage of catch of each species group believed to contain BMUS in each year was calculated based on the ratio of the catch of identified BMUS to the catch of identified non-BMUS within each species group for that year. If no BMUS within a group were caught, or no species-specific information other than that group was available, then the proportion of catch from that group applied to BMUS catch was zero. If no individual species of a group were caught within a year, but were caught in other years, then the overall average ratio of BMUS to non-BMUS across all years within that species group was used for that year. We assumed 10 species groups recorded in the boat-based and shore-based creel surveys could contain BMUS: Carangidae, Caranx i'e', Lethrinidae, Lutjanidae, Serranidae, assorted bottomfish, shallow bottomfish, deep bottomfish, shallow snappers, and deep snappers.

General rules were applied to determine the member species for each group. Family-level groups Lethrinidae and Lutjanidae included all species within those families. Serranidae included all members of the taxonomic Serranidae family, except basslets and soapfish. Carangidae included all members of the taxonomically defined Carangidae family, excluding scads (i.e., genera *Decapterus*, *Selar*, and *Selaroides*). Several pairs of groups were considered to include an identical set of species: Carangidae and Caranx i'e', shallow bottomfish and deep bottomfish, and shallow snappers and deep snappers. Snappers were defined as species in the family Lutjanidae and groupers were defined as all members of the taxonomic Serranidae family, except basslets and soapfish. Assorted bottomfish were defined as species in the families Lutjanidae and Lethrinidae, the groups Serranidae and Carangidae, and included the large-headed scorpionfish (*Pontinus macrocephalus*), alphonsin (*Beryx decadactylus*), oilfish (*Ruvettus pretiosus*), species of the family Bramidae, and species of the family Priacanthidae. These additional species were added based on the assumption that these species were likely to be reported as bottomfish by fishers.

Once catch from species groups was added to catch of individual BMUS for each data source, a single total catch time series was calculated for each source (Figure 2). The two creel surveys represent catch from different fishing sectors. Thus, total expanded yearly catch from the boat-based and shore-based data were combined to obtain a total expanded creel survey catch estimate. Shore-based BMUS catch from 1982–1985 (prior to the commencement of the shore-based survey) was assumed equal to the average of shore-based catches across 1986–2017. This approach, therefore, assumed that shore-based catch likely occurred during years when data were not collected.

The commercial purchase invoice program can be used to estimate catch separately from the creel survey estimates by summing all recorded catch together within each year. Prior to calculating commercial purchase catch, we excluded resale catches, which were catches already reported in the commercial purchase dataset, and imported catches, which were from sources outside the stock area. Commercial purchase invoices included common name categories that could contain BMUS: jacks, bottomfish, deep bottomfish, grouper, emperor, and two groupings of snapper (tagafi and snapper). Species-level catch was estimated from these groups following the same methodology as the boat-based creel survey. The species-grouping rules were also the same with both tagafi and snapper grouped identically to snapper, jack as Carangidae, and emperor as all species in the family Lethrinidae.

Commercial purchase data can overlap with catch from the creel surveys, which represents a separate estimate of catch. Consequently, catch from the commercial purchase dataset was compared to the summed catch from the two creel surveys (Figure 3). To obtain a final catch time series, the maximum of the total expanded creel survey catch and the total catch from the commercial purchase data in each year was used as the final yearly catch value for use in the stock assessment models (Table 2 and Figure 4). For all years, catch estimated from the commercial purchase invoices was less than the sum of expanded catch from the creel surveys in overlapping years.

Catch Variance

Total catch of BMUS as reported in Table 2 was derived from expanded boat-based and shore-based interview data. Although total expanded creel survey catch had an associated variance estimate, variances of species-specific creel survey catch estimates did not have explicit variance formulations at the time of the 2019 benchmark stock assessment. To obtain variance estimates at a species level, the data were bootstrapped to generate uncertainty around species-specific catches. Within each bootstrap repetition, the value for expanded catch was drawn from a truncated (at zero) normal distribution with mean and standard deviation equal to the value and standard deviation of the original boat-based survey expanded catch estimate. Interview data were resampled with replacement, which were then used together with the redrawn expanded catch estimate to calculate species-specific expanded catch. This process was repeated 1,000 times to estimate the variance around species-specific catches.

Initially, the bootstrap procedure was run separately for total expanded creel survey catch (in years with both shore-based and boat-based data), and for boat-based expanded catch. This choice assumed that the species-specific coefficients of variation for the boat-based data were the same as for the shore-based data. Given the much higher catch of BMUS in the boat-based survey, we chose to use only the boat-based bootstrap estimates of variance. We felt this choice was better than using the combined shore-based and boat-based variance in overlapping years and applying an imputation algorithm to determine variance in years with catch estimates instead of bootstrap estimates. Variance estimates were not available for commercial purchase data; therefore, in years where commercial purchase catch data were used—i.e., commercial purchase catch was greater than the sum of boat- and shore-based creel survey expanded catch—we applied the coefficient of variation from the boat-based data to the total catch value. In other words, we used variance estimates from the expanded boat-based creel survey catch estimates to represent total catch variance in every year. Given that the purpose was to capture general as opposed to exact variance, we believe the choice of using variance estimates from just the boat-based creel survey data was appropriate.

We applied the same group proportions that were applied to catches of species groups for the boat-based data when calculating variance. Species-specific variance estimates for each BMUS within a year were summed to obtain total BMUS variance, which required an assumption of independence among species catches. The variance of each species group believed to contain BMUS was added into the total variance for BMUS, and it was scaled by the square of the percentage of BMUS to non-BMUS catch for each species group. Estimates of uncertainty applied to total catches, as reported using the coefficients of variation based on boat-based creel survey data, are provided in Table 2.

CPUE

Non-expanded interview data from the boat-based creel survey were used as the basis for CPUE calculations, as was done in the previous benchmark assessment. The interview data contained catch by species, measures of fishing activity that were used to determine fishing effort, and additional environmental and fishing related covariates that were used to account for changes in fishing conditions not related to changes in the underlying fish abundance. For this update assessment, we used the same set of boat-based creel survey interviews for 1982–2017 as for the previous benchmark assessment (30,533 interviews). For the update years 2018–2023, we acquired boat-based survey interviews from the Western Pacific Fisheries Information Network WPacFIN (*N*=4,206).

There were 878 interviews (2.5% of total interviews) from 1982–2023 that reported catch of species groups.As was the case for the expanded catch datasets, non-expanded interview data contained both species-specific codes and aggregated family-level or species category codes. As a result, catch of BMUS plus a portion of the catches from aggregated species codes within each interview were used to determine the catch of BMUS for CPUE. The same proportions used to determine catches of BMUS from aggregated groups in the expanded catch datasets were applied to determine the catch of BMUS from species groups in the non-expanded interview datasets. These proportions were calculated as the ratio of known (species-specific) catches of BMUS in a year to known catches of non-BMUS in a year.

We filtered the 1982–2023 interview set following identical criteria as the previous benchmark assessment. The interview data were filtered to retain only fishing trips that were reasonably expected to target BMUS. This is because including fishing trips that were not targeting BMUS—for example when fishermen were trying to catch reef fish—would inaccurately reflect CPUE patterns over time for BMUS. We kept only interviews using gear type (i.e., fishing method) “bottomfishing” as the primary indicator of trips targeting bottomfish. After filtering by gear, there were 6,090 interviews remaining. Next, we removed any interviews from vessels that never caught any BMUS. Catches of aggregated species codes were already adjusted to reflect expected catches of BMUS and were included when considering whether a vessel caught any BMUS. In total, this removed 337 vessels and 491 interviews from the dataset.

Additionally, we removed 791 interviews from charter fishing trips. Charter fishing trips differ from non-charter fishing trips because they were most often reported in shallow water, had much higher number of gears, and were of shorter duration. As a result, including these data in the CPUE standardization might not reflect BMUS fishing overall. After these filtering steps of gear type, fishing history, and charter, there were 4,808 interviews remaining.

The final step in filtering the CPUE dataset was to exclude interviews with incomplete catch and effort information. In total, 483 interviews were removed based on incomplete field values, resulting in 4,325 interviews remaining. An additional 31 interviews reporting fishing location as either an invalid area code (e.g., 0, 1, 9, 22), or the northern Mariana Islands (99, additional details below; Figure 5), were also removed from the dataset.

At the time of these analyses, 2023 boat-based creel survey interview data were preliminary. Eight interviews were removed that contained fish numbers, catch rates, or sizes that were suggestive of a possible data entry or sampling error. Once data filtering was complete, with 4,286 interviews remaining, CPUE was calculated as catch divided by effort. Effort was calculated as the product of hours fished and number of gears, as was done in the previous benchmark stock assessments (Moffitt et al. 2007; Langseth et al. 2019).

Covariates for Standardization

The previous benchmark assessment included a full exploration of potential covariates in CPUE standardization including month, area, type of day, depth, wind speed, and vessel name. These covariates were considered to have a possible effect on BMUS CPUE independently from changes in annual stock abundance. For example, spatial distribution of fish through the season or effectiveness of fishing effort. For this update assessment, we did not re-evaluate covariates for standardization, but instead relied on the models used in the 2019 benchmark assessment, which included area, depth, and vessel as covariates.

Areas followed the grid numbering used in the boat-based creel surveys (Figure 5). These areas were not necessarily distinct because both cardinal and ordinal directions were reported, e.g., area code 20 was for the cardinal direction north and is not distinct from either of the ordinal directions northwest (area code 10) and northeast (area code 30). areas 10 (northwest) or 30 (northeast). Furthermore, individual areas such as banks or reefs within a general direction were also reported.

The previous benchmark assessment acknowledged that a lack of distinction among reported areas could mask any individual area effect, and, thus, included an exploration of aggregating fishing grids into groups that were distinct from one another. Ultimately, it was decided to keep reported fishing grids to maintain as fine of a scale as possible, because they were reported without further adjustment. The previous benchmark assessment did not consider interactions between area and year because of the possibility of over-parameterizing the standardization models given the limited number of interview data points relative to the large number of areas, and because there was no visual pattern suggesting shifts in fishing effort over area and time.

Depth and vessel name were explored in the standardization because information on them was available in the datasets, and these covariates were believed to potentially influence CPUE independent of changes in BMUS abundance. Depth is recorded in BBS interviews by four categories: deep, mixed, shallow, and unknown. These categories describe the type of bottomfishing that a fishermen engaged in and indicate the which bottomfishes the fisherman may targeted. Lastly, vessel information was included in the standardization as an attempt to determine difference among individual fishers/vessels. Fisher-specific information such as fisher name was not reported in the creel survey database. Vessel was used as a proxy to account for differences among vessels, assuming vessel names are unique and fishers do not switch vessels.

CPUE Standardization

We used a delta-type approach to model CPUE as the product of two linear models: a presence/absence process assuming binomial error that modeled the probability of positive catch, and a positive process assuming lognormal error that modeled CPUE given a positive catch (which was 81.2% of all interviews). The model for the presence/absence process for the 2019 benchmark assessment and this update included year, area, and depth, and reduced deviance by 22.7% from the null (intercept only) model. The model for the positive process selected in the 2019 benchmark assessment and used in this update included year, area, depth, and a random intercept term of vessel name, and reduced deviance by 5.0% from the null model.

CPUE Model Diagnostics

Regression diagnostics were used to qualitatively check assumptions of the models used for CPUE standardization. Model fit was assessed through visual comparison of residuals plotted against predicted values of the response variable and against values of the predictor variables. A histogram of the residuals was plotted to assess normality for both processes. Plots comparing the quantiles of the standardized residuals against the quantiles of a standard normal distribution were also used to assess assumptions of normality for models for the positive process. Pearson residuals were used for all models for the positive processes. Quantile residuals were used for all models for the binomial process as recommended by (Dunn and Smyth 1996).

Diagnostic residual plots indicated the model for each process was appropriate (Figures 6 and 7). There was a slight reduction in the range of residuals at lower predicted probabilities for the presence/absence process, and some patterning of residuals with area values, but we considered these minor. Diagnostics for the positive process indicated a slightly heavier lower tail of the residuals than expected for a normal distribution, but this, too, we considered minor.

CPUE Index Calculation

Values of the response for both model processes were calculated for each observation using the predict function in R, and the mean and variance of the predictions within a year were calculated. The mean predicted values from the positive process were multiplied by the exponential of one-half the residual variance to correct for bias when back-transforming from ln(CPUE) to CPUE, following the methods of Brodziak and Walsh (2013). The index was then calculated as the product of the two processes by year. The variance of the index was calculated as the variance of the product of two independent random variables (Goodman 1960; Campbell 2015). The variance of the index was then divided by the sample size (number of interviews) in each year and used to obtain CVs around the mean index. CVs of the mean (CV_{mean}) were converted to standard error (SE) on the scale of the natural logarithm (SE_{Ln}), which are required for assessment model input, following $SE_{Ln} = \sqrt{Ln\left({CV_{mean}}^2 + 1\right)}$. The yearly indices and SE on the scale of the logarithm used as input into the assessment models are provided in Table 3 and the yearly indices and 95% confidence intervals in the response scale of lbs per line-hour [lb / (line × hour)] are shown in Figure 8.

Assessment Model

This update stock assessment uses JABBA, which is an open-source modeling framework for conducting state-space Bayesian surplus production models (Winker et al. 2018). JABBA uses R to set up the model and call the software program JAGS (Plummer 2003) using the R package “rjags” (Plummer 2023). JABBA explicitly estimates both process error variance and observation error variance, and estimates Bayesian posterior distributions of model outputs using MCMC simulation.

All model structure, including the R script used to initiate and run the JAGS computational engine (e.g., JABBAv1.2.R), are identical to the base model for Guam BMUS used in the 2019 benchmark stock assessment. The mechanics of the JABBA operating (biomass dynamics) model, process and observation error models, and MCMC simulation of the posterior distributions are described in extensive detail in Langseth et al. (2019). The MCMC included 2 chains of 250,000 iterations total. After the initial burn-in of 150,000 iterations, every fifth iteration was saved, resulting in

40,000 total MCMC iterations used for the posterior distributions. All prior parameter distributions used in this update stock assessment are identical to those used in the 2019 benchmark stock assessment and are detailed in Table 4.

Convergence of the simulated MCMC samples to the posterior distribution was assessed via visual inspection of the trace and autocorrelation plots, and confirmed using the Geweke convergence diagnostic (Geweke 1992) and the Heidelberger and Welch stationarity and half-width diagnostics (Heidelberger and Welch 1983). The set of convergence diagnostics were applied to key model parameters (intrinsic growth rate, carrying capacity, production function shape parameter, ratio of initial biomass to carrying capacity, catchability coefficients, and error variances) to verify convergence of the MCMC chains to the posterior distribution.

Residuals from the base case model fit to CPUE were used to measure the goodness of fit of the production model. Nonrandom patterns in the CPUE residuals would suggest that the observed CPUE may not have conformed to one or more model assumptions. We tested patterns in the sign of the residuals using a runs test with an alpha-value of 0.05.

A retrospective analysis was conducted to assess whether there were consistent patterns in model-estimated outputs based on decreasing periods of data (Mohn 1999). The retrospective analysis was conducted by successively removing the catch and CPUE data for years 2023 to 2018 in one-year increments, such that the terminal years of the model ranged from 2022 to 2017. For each model, the parameters were re-estimated and the resulting biomass and harvest rate timeseries were compared to the full terminal year 2023 model.

The magnitude of the retrospective pattern was assessed using Mohn’s rho (ρ; Mohn 1999), which quantifies the degree of directional bias in relative patterns of deviations for each model with respect to the full data model (2023 terminal year). Hindcast timeseries were generated for each model period by operating the process model forward through the missing years of data using the observed catches to estimate biomass, harvest rate, B/B_{MSY}, and H/H_{MSY} for the hindcast years. The hindcast analysis was useful for illustrating differences between the 2019 benchmark assessment model (terminal data year 2017) and the current 2024 update stock assessment model (terminal data year 2023).

Catch Projections

Estimated posterior distributions of assessment model parameters were used in forward projections for 2024–2029 to estimate the probability of overfishing (P^*, which is the probability that H is greater than H_{MFMT}) from 2024 to 2029 under a range of future catches. The projection results accounted for uncertainty in the distribution of estimates of model parameters from the posterior of the assessment model.

The projections were conducted assuming each value for the future catch was constant through all projection years. The projected total catch scenarios ranged from 1000 to 150,000 lb per year in 1,000-lb increments. In addition to catch, corresponding quantities of interest—including stock biomass, harvest rate, and probability that the stock is overfished ($B/B_{MSY} < 0.7$)—were also calculated.

Results

Model Diagnostics

Convergence diagnostics indicated the MCMC simulation to estimate the posterior distribution of production model parameters converged, passing all diagnostic tests for both chains (Table 5). Visual inspection of trace plots of parameters did not reveal convergence issues and indicated the MCMC sampler did not frequently encounter boundaries of the parameter space (Figure 9).

The predicted CPUE from the base case model provided a satisfactory fit to the standardized CPUE observations (Figure 10). The runs test indicated residuals (Figure 11) did not exhibit patterns in sign (p=0.21).

Comparisons of assumed prior distributions and estimated posterior distributions showed the priors were less informative relative to the information in the data for r and ψ, whereas the posteriors were more informed by the prior distributions for K and m (Tables 4 and 6, Figure 12). Posterior distributions for catchability, process error, and the estimable component of observation error were substantially different from prior distributions, which were chosen to be uninformative (Tables 4 and 6, Figure 12). The prior distributions for derived quantities MSY, B_{MSY}, H_{MSY}, and B_{MSY}/K, which are derived from the priors for r, K, and m, were also generally consistent with the posterior distributions (Figure 13).

Parameter correlations aligned with expectations for a production model and, therefore, did not suggest problems with parameter estimation. The greatest correlation (–0.746) occurred among carrying capacity K and catchability q (Figure 14), which both scale biomass to the relative CPUE index. Correlations among all other parameters were less than 0.50 in magnitude. Total observation error variance was generally less than 0.09 over the timeseries and was primarily comprised of estimated observation error (Figure 15).

Parameter Estimates and Stock Status

Estimated model parameters from the current update stock assessment were very similar to parameter values estimated from the previous benchmark assessment (Table 6).

Median estimates and 95% confidence intervals (CIs) for derived model quantities were:

1. maximum sustainable yield for the catch (MSY)=42.4 thousand lbs and 95% CI=30.8 – 64.9 thousand lbs;

2. the harvest rate to produce maximum sustainable yield (H_{MSY})=0.176 and 95% CI=0.078–0.367;
3. and the exploitable biomass to produce maximum sustainable yield (B_{MSY})=242.6 thousand lbs. and 95% CI=109.8–626.7 thousand lbs.

Model-estimated timeseries indicate exploitable stock biomass declined from 444 thousand lbs (86% of carrying capacity, K) in 1982 to below the minimum stock size threshold (MSST; $0.7 \times B_{MSY}$=169.8 thousand lbs) in 1995 (Table 7, Figure 16). Biomass increased above the MSST, but remained below B_{MSY}, from 2004–2013, until dropping to 154.4 thousand lbs in 2014. Since 2017, stock biomass has shown an overall positive trend with a high of 209.8 thousand lbs in 2021. Stock biomass exceeded the MSST in 2019 and remained above MSST through 2023. Estimated harvest rate increased from 0.06 in 1982 to a peak of 0.42 in 2000, then declined to variable levels around the H_{MFMT} with periodic high H years between 2002–2023.

The updated stock assessment model results indicated the BMUS stock in Guam was not overfished in 2023 with 66.2% of the posterior 95% CI falling above the MSST (Figure 17). Given the marked decrease in estimated catch in 2023, the majority of the posterior 95% CI for harvest rate was below the MFMT, indicating that BMUS in Guam were not subject to overfishing in 2023. Stock status trajectory over the previous eight years (2016–2023) indicates an overall increasing trend in B/B_{MSY} and variable H/H_{MSY} around the H_{MFMT} (Figure 18).

Retrospective Analysis

Retrospective analysis of the estimated biomass and harvest rate from the assessment model for Guam indicated the model outputs did not exhibit substantial retrospective patterns (Figure 18). Mohn's rho values were -0.02 and +0.03 for absolute exploitable stock biomass and harvest rate, respectively, which are within the range of -0.15 to +0.20 suggested by Hurtado-Ferro et al. (2015) for biomass of long-lived species. Retrospective bias for relative exploitable biomass and harvest rate (-0.04 and +0.06 for B/B_{MSY} and H/H_{MSY}, respectively) was slightly higher, but still not indicative of poor model performance (Figure 19). Hindcasted B/B_{MSY} and H/H_{MSY} suggested recent years of data did contribute to variability in model behavior, although the influence was not consistently directional across terminal data years (Figures 20 and 21).

Catch Projections

The constant five-year catch projections showed the distribution of outcomes for probability of overfishing, biomass, harvest rates, and probability of being overfished that would likely occur under alternative catch levels in Guam during 2024–2029 (Table 8). Projections indicated the Guam BMUS catch that would produce approximately a

40% chance of overfishing in any year from 2024 through 2028 was from 31–33 thousand lbs, depending on the terminal projection year. The BMUS catch to achieve a lower risk of overfishing (e.g., 20% chance of overfishing) in any year from 2024 through 2029 was from 23–27 thousand lbs, depending on the terminal projection year.

Discussion

This update stock assessment of BMUS in Guam indicates the exploitable stock biomass has increased since the previous stock assessment in 2017 when the stock was classified as overfished, and in 2023 the stock was larger than the MSST and, therefore, was not overfished. Relatively low catches during 2017–2020 (average 22.6 thousand lbs, range 15.9–30.8 thousand lbs annually) corresponding to harvests rates approximately equal to or less than the MFMT allowed the stock to increase from the 2017 overfished levels (B/B_{MSY}=0.57) to peak B/B_{MSY}=0.86 in 2021 and 2022. Catches increased markedly in 2021 and 2022, to 1.41 and 1.25 times the MFMT, concurrent with a slight reduction in exploitable biomass in 2023. Preliminary estimated 2023 catch was 23.9 thousand lbs, which is below the MFMT, hence the stock was not experiencing overfishing in 2023.

Although there are no indications of consistent directional change in retrospective or hindcast patterns over the last five years of the data, it is evident models with higher terminal year CPUE values (e.g., range 0.99–1.4 in 2021–2023) suggested a more productive Guam BMUS stock, meaning the *m* and *K* parameter values were estimated to be smaller compared to models with lower terminal year CPUE values (e.g., range 0.62–0.70 in 2017, 2018, and 2020). As a result, the hindcast analyses suggest 2023 stock status would be classified as not overfished (B/B_{MSY} range 0.73–0.88) based on the 2021–2023 terminal year models, but would be classified as overfished (B/B_{MSY} range 0.61–0.76) based on the 2017, 2018, and 2020 terminal year models (Figure 21). The variability in terminal year B/B_{MSY} indicated by the retrospective analyses is also represented in the 95% credible intervals for 2023 stock status (Figure 17): although the majority (66%) of the posterior probability density of B_{2023}/B_{MSY} is above the MSST (not overfished), 34% of the posterior probability density of B_{2023}/B_{MSY} is below the MSST (overfished).

Projected annual catch corresponding to an overfishing probability of 0.4 in 2024 is 31 thousand lbs, which is equal to the projected catch stated in the previous benchmark stock assessment based on terminal data year 2017 (Langseth et al. 2019).

This update assessment maintained the approach used by the 2019 benchmark assessment of modeling the stock dynamics of all 13 BMUS as an aggregated biomass. However, when catch is estimated by single species, as is done for ongoing catch monitoring, there are a range of apparent trends and high variation in the catches of each BMUS over time. For example, the catch of *L. rubrioperculatus* decreased from a high of 32.9 thousand lbs in 1985 (average 18.5 thousand lbs per year, 1982–1989) to an average annual catch of less than 4 thousand lbs during 2019–2023 (Figure 23; see Bohaboy and Matthews (*in review*) for methods and complete catch timeseries). During the same time period, the catch of *E. coruscans* increased from 2.4 thousand lbs per year for 1982–1989 to 13.1 thousand lbs per year during 2019–2023.

Considered proportionally, these contrasting catch trends create a noticeable shift in the relative species composition of the aggregate BMUS from a roughly equal contribution of relatively “shallow” and “deep” BMUS towards catch dominated by the “deep” BMUS (Figure 24). Guam bottomfishermen report that fishing in deep waters, including at the offshore banks around Guam, has increased in recent years, especially since the COVID-19 pandemic (Iwane et al. 2023). This observed variation in species composition of catch over time and possible interactions with changes in bottomfishing effort over time provides motivation to explore the stock dynamics of individual BMUS in future benchmark stock assessments.

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Tables

Table 1. Mariana Archipelago bottomfish management unit species.

Species	**Local names**	**Hawaiian and English common names**	**Code**
Aphareus rutilans	Maroobw, lehi	Lehi, rusty jobfish	APRU
Caranx ignobilis	Mamulan, tarakitu, etam	‘Ulua aukea, giant trevally	CAIG
Caranx lugubris	Tarakiton attelong, orong (tarakito, tarakiton atilong, yorong)	‘Ulua la‘uli, black trevally, black jack	CALU
Etelis carbunculus	Buninas agaga’, falaghal moroobw	Ehu, ruby snapper	ETCA
Etelis coruscans	Buninas, taighulupegh	Onaga, deepwater longtail red snapper	ETCO
Lethrinus rubrioperculatus	Mafute’, atigh	Redear, redgill, spotcheek emperor	LERU
Lutjanus kasmira	Funai, saas	Ta'ape, bluestripe snapper	LUKA
Pristipomoides auricilla	Buninas, falaghal-maroobw	Yelloweye / gold flag snapper	PRAU
Pristipomoide filamentosus	Buninas, falaghal-maroobw	‘Ōpakapaka, crimson jobfish	PRFI
Pristipomoides flavipinnis	Buninas, falaghal-maroobw	Yelloweye ‘ōpakapaka, golden eye jobfish	PRFL
Pristipomoides sieboldii	Buninas, falaghal-maroobw	Von Siebold’s snapper	PRSE
Pristipomoides zonatus	Buninas rayao amiriyu, falaghal-maroobw	Gindai, oblique-banded snapper	PRZO
Variola louti	Gadau matingon/bwele	Yellow-edged lyretail grouper	VALO

Table 2. Annual total catch of bottomfish management unit species, in thousand lbs, and coefficient of variation (CV) used as input into the update stock assessment. See the Methods section *Catch* in the text for the description of how catch and catch variance were calculated.

Year	Catch	CV
1982	27.357	0.12
1983	44.593	0.16
1984	52.018	0.12
1985	68.251	0.10
1986	29.560	0.18
1987	37.000	0.14
1988	50.455	0.11
1989	47.796	0.11
1990	37.223	0.10
1991	42.767	0.12
1992	46.714	0.16
1993	53.233	0.22
1994	54.128	0.14
1995	35.031	0.17
1996	51.242	0.12
1997	28.032	0.17
1998	29.480	0.15
1999	47.084	0.24
2000	66.447	0.17
2001	46.427	0.17
2002	21.727	0.19
2003	29.835	0.31
2004	25.236	0.24
2005	29.046	0.32
2006	34.917	0.27
2007	18.186	0.43
2008	34.249	0.14
2009	40.735	0.16
2010	26.544	0.16
2011	54.062	0.18
2012	19.714	0.25
2013	30.243	0.19
2014	20.554	0.19
2015	11.711	0.28
2016	30.192	0.18
2017	15.864	0.22
2018	26.579	0.32
2019	30.791	0.26
2020	17.277	0.20
2021	51.894	0.18
2022	44.265	0.15
2023	23.879	0.18

Table 3. Annual index of standardized catch per unit effort (CPUE, in lbs per gear × hour) from boat-based creel survey data for bottomfish management unit species in Guam. Uncertainty around the standardized indices in the form of standard errors (SE) on the scale of the logarithm is also provided. Both the index and the measure of uncertainty were used as input into the assessment model.

Year	CPUE	SE
1982	3.26	0.044
1983	2.20	0.047
1984	3.77	0.031
1985	1.84	0.036
1986	1.82	0.060
1987	2.06	0.052
1988	1.27	0.042
1989	1.93	0.049
1990	1.52	0.052
1991	1.76	0.049
1992	1.12	0.051
1993	1.27	0.061
1994	1.13	0.073
1995	0.70	0.055
1996	1.17	0.069
1997	0.53	0.073
1998	0.61	0.056
1999	0.64	0.061
2000	0.71	0.067
2001	0.73	0.105
2002	0.81	0.112
2003	0.82	0.093
2004	1.29	0.076
2005	1.64	0.098
2006	1.37	0.122
2007	0.61	0.103
2008	1.29	0.101
2009	1.52	0.085
2010	0.68	0.071
2011	1.88	0.132
2012	1.46	0.104
2013	1.29	0.098
2014	0.77	0.097
2015	0.57	0.125
2016	0.81	0.109
2017	0.62	0.061
2018	0.70	0.109
2019	1.33	0.054
2020	0.67	0.091
2021	1.23	0.068
2022	1.41	0.059
2023	0.99	0.087

Table 4. Prior distributions for the 2024 update assessment model for bottomfish management unit species in Guam. Parameters are intrinsic growth rate (r), carrying capacity (K), production shape parameter (m), ratio of initial biomass to carrying capacity (ψ), catchability (q), process error (σ_{η}^2), and the estimable component of the observation error ($\sigma_{\tau estimated}^2$).

Parameter	**Distribution**	**Prior mean or [bounds]**	**CV**
r	lognormal	0.46	0.50
K (thousand lb.)	lognormal	478.261	0.50
m	lognormal	2	0.50
ψ	lognormal	0.75	0.50
q	uniform	[10^{-10}, 10]	-
σ_{η}^2	inverse gamma	0.083*	-
$\sigma_{\tau estimated}^2$	inverse gamma	0.083*	-

*Value is mode rather than mean parameter

Table 5. MCMC convergence diagnostics for the 2024 update assessment model for bottomfish management unit species in Guam. Diagnostics apply to the 20,000 iterations in each of two MCMC chains used to formulate the posterior distribution for current stock status and catch projections. Diagnostics included the standard error (SE) divided by the mean, Geweke's convergence diagnostic (p-value), Heidelberger and Welch's stationarity diagnostic (p-value), and Heidelberger and Welch's halfwidth divided by the mean. Parameters are intrinsic growth rate (*r*), carrying capacity (*K*), production shape parameter (*m*), ratio of initial biomass to carrying capacity (ψ), catchability (*q*), process error (σ_{η}^{2}), and the estimable component of the observation error ($\sigma_{\tau estimated}^{2}$).

Parameter	SE / Mean	Geweke Convergence *p*-value	HW Stationarity *p*-value	Halfwidth / Mean
	MCMC Chain 1			
r	0.002	>0.99	0.94	0.005
K	0.003	0.91	0.43	0.005
m	0.003	0.71	0.62	0.007
ψ	0.002	0.21	0.48	0.003
q	0.002	0.44	0.70	0.005
σ_{η}^{2}	0.001	0.38	0.10	0.003
$\sigma_{\tau estimated}^{2}$	0.002	0.57	0.57	0.005
	MCMC Chain 2			
r	0.002	0.10	0.14	0.005
K	0.003	0.89	0.17	0.005
m	0.003	0.52	0.46	0.006
ψ	0.002	0.51	0.06	0.003
q	0.002	0.42	0.19	0.005
σ_{η}^{2}	0.001	0.85	0.60	0.003
$\sigma_{\tau estimated}^{2}$	0.002	0.06	0.05	0.005

Table 6. Parameter estimates for the 2019 benchmark assessment and 2024 update assessment models for bottomfish management unit species in Guam. Parameters are intrinsic growth rate (*r*), carrying capacity (*K*), shape parameter (*m*), ratio of initial biomass to carrying capacity (*ψ*), catchability (*q*), process error (σ_η^2), and estimable component of observation error ($\sigma_{\tau estimated}^2$). Derived quantities are maximum sustainable yield (*MSY*), harvest rate at maximum sustainable yield (H_{MSY}), biomass at maximum sustainable yield (B_{MSY}), and proportion of carrying capacity at maximum sustainable yield (B_{MSY}/K). *K*, B_{MSY}, and *MSY* are reported in thousand lbs.

	2019 Benchmark Assessment		**2024 Update Assessment**	
Parameter	**Median**	**95% CI**	**Median**	**95% CI**
r	0.29	0.15–0.58	0.29	0.15–0.55
K	533.7	290.2–1104.6	530.6	297.2–1100.5
m	1.73	0.73–4.29	1.65	0.73–4.00
ψ	0.86	0.53–1.04	0.86	0.54–1.04
q	0.006	0.003–0.010	0.006	0.003–0.010
σ_η^2	0.035	0.019–0.044	0.035	0.019–0.044
$\sigma_{\tau estimated}^2$	0.077	0.039–0.157	0.077	0.041–0.147
MSY	42.1	29.3–65.5	42.4	30.8–64.9
H_{MSY}	0.170	0.071–0.382	0.176	0.078–0.367
B_{MSY}	248.8	107.1–636.8	242.6	109.8–626.7
B_{MSY}/K	0.47	0.31–0.64	0.46	0.37–0.57

Table 7. Estimates of median exploitable biomass in thousand lbs, median relative exploitable biomass (B/B_{MSY}), probability of being overfished ($B/B_{MSY}<0.7$), median harvest rate (H), median harvest rate relative to the control rule (H/H_{MFMT}), and probability of overfishing ($H/H_{MFMT}>1$) for bottomfish management unit species in Guam 1982–2023.

Year	Biomass	B/B_{MSY}	Probability of being Overfished	H	H/H_{MFMT}	Probability of Overfishing
1982	444.3	1.84	<0.01	0.06	0.35	<0.01
1983	427.3	1.77	<0.01	0.1	0.59	0.03
1984	433.3	1.79	<0.01	0.12	0.68	0.09
1985	371.7	1.53	<0.01	0.18	1.05	0.57
1986	326.3	1.34	0.01	0.09	0.52	0.02
1987	325.6	1.34	0.02	0.11	0.65	0.08
1988	298.4	1.23	0.03	0.17	0.96	0.45
1989	296.4	1.22	0.03	0.16	0.93	0.40
1990	274.9	1.13	0.05	0.14	0.78	0.20
1991	267.9	1.10	0.07	0.16	0.92	0.40
1992	235.3	0.97	0.13	0.20	1.15	0.67
1993	217.6	0.90	0.20	0.25	1.45	0.85
1994	188.7	0.78	0.35	0.29	1.72	0.95
1995	157.1	0.64	0.62	0.22	1.44	0.81
1996	157.3	0.65	0.61	0.33	2.11	0.98
1997	126.3	0.52	0.86	0.22	1.74	0.85
1998	131.0	0.53	0.83	0.22	1.69	0.85
1999	142.9	0.59	0.74	0.31	2.12	0.96
2000	148.8	0.61	0.68	0.42	2.77	1.00
2001	136.7	0.56	0.79	0.33	2.37	0.97
2002	138.7	0.57	0.76	0.15	1.10	0.57
2003	164.0	0.67	0.55	0.17	1.08	0.57
2004	193.5	0.79	0.34	0.13	0.77	0.27
2005	217.2	0.89	0.22	0.14	0.81	0.32
2006	207.6	0.85	0.26	0.18	1.05	0.54
2007	180.8	0.74	0.43	0.10	0.60	0.19
2008	210.0	0.86	0.25	0.16	0.95	0.44
2009	215.2	0.88	0.22	0.19	1.12	0.62

Year	Biomass	B/B_{MSY}	Probability of being Overfished	H	H/H_{MFMT}	Probability of Overfishing
2010	193.7	0.79	0.34	0.14	0.80	0.29
2011	226.8	0.93	0.18	0.24	1.39	0.82
2012	201.9	0.82	0.30	0.10	0.60	0.14
2013	188.3	0.77	0.38	0.17	1.00	0.50
2014	154.4	0.63	0.63	0.14	0.90	0.42
2015	139.2	0.57	0.75	0.08	0.61	0.22
2016	147.8	0.60	0.68	0.21	1.41	0.75
2017	139.0	0.57	0.75	0.11	0.82	0.37
2018	157.2	0.64	0.61	0.16	1.07	0.55
2019	178.1	0.73	0.44	0.18	1.08	0.56
2020	173.0	0.71	0.49	0.10	0.61	0.17
2021	209.8	0.86	0.25	0.24	1.41	0.83
2022	207.6	0.86	0.26	0.21	1.25	0.73
2023	194.8	0.80	0.34	0.12	0.72	0.25

Table 8. Projection results where the specified median probability of overfishing (H/H_{MFMT}>1, ranging from 0.1 to 0.5) was reached for bottomfish management unit species in Guam. The annual catch and median biomass (in thousands of lbs), median harvest rate, and median probability the stock is overfished (B/B_{MSY}<0.7) are provided in each section of the table. Catch values for a given probability of overfishing in any terminal year were applied to all previous years from 2024 to the terminal year.

	Probability of overfishing (H/H_{MFMT}>1) in terminal year				
	0.1	**0.2**	**0.3**	**0.4**	**0.5**
Terminal Year	**Catch (1,000 lbs) Constant in all years from 2024–terminal year**				
2024	18	23	28	31	34
2025	18	24	28	32	35
2026	20	25	29	32	35
2027	20	26	30	33	36
2028	21	26	30	33	36
2029	21	27	30	33	36
	Biomass (1,000 lbs)				
2024	217.2	211.6	206.2	203.4	199.6
2025	240.3	227.8	219.4	210.1	204.3
2026	256.4	242.0	228.8	218.1	209.3
2027	277.8	252.3	235.2	222.2	209.3
2028	292.4	266.5	245.7	228.5	211.9
2029	310.0	273.9	255.0	234.0	214.3
	Harvest rate				
2024	0.08	0.11	0.13	0.15	0.17
2025	0.08	0.11	0.13	0.15	0.17
2026	0.08	0.10	0.13	0.15	0.17
2027	0.07	0.10	0.13	0.15	0.17
2028	0.07	0.10	0.12	0.15	0.17
2029	0.07	0.10	0.12	0.14	0.17
	Probability stock is overfished (B/B_{MSY}<0.7)				
2024	0.26	0.29	0.31	0.32	0.34
2025	0.21	0.25	0.28	0.32	0.34
2026	0.19	0.23	0.27	0.31	0.35
2027	0.16	0.22	0.27	0.31	0.36
2028	0.15	0.20	0.26	0.31	0.36
2029	0.14	0.20	0.25	0.31	0.37

Figures

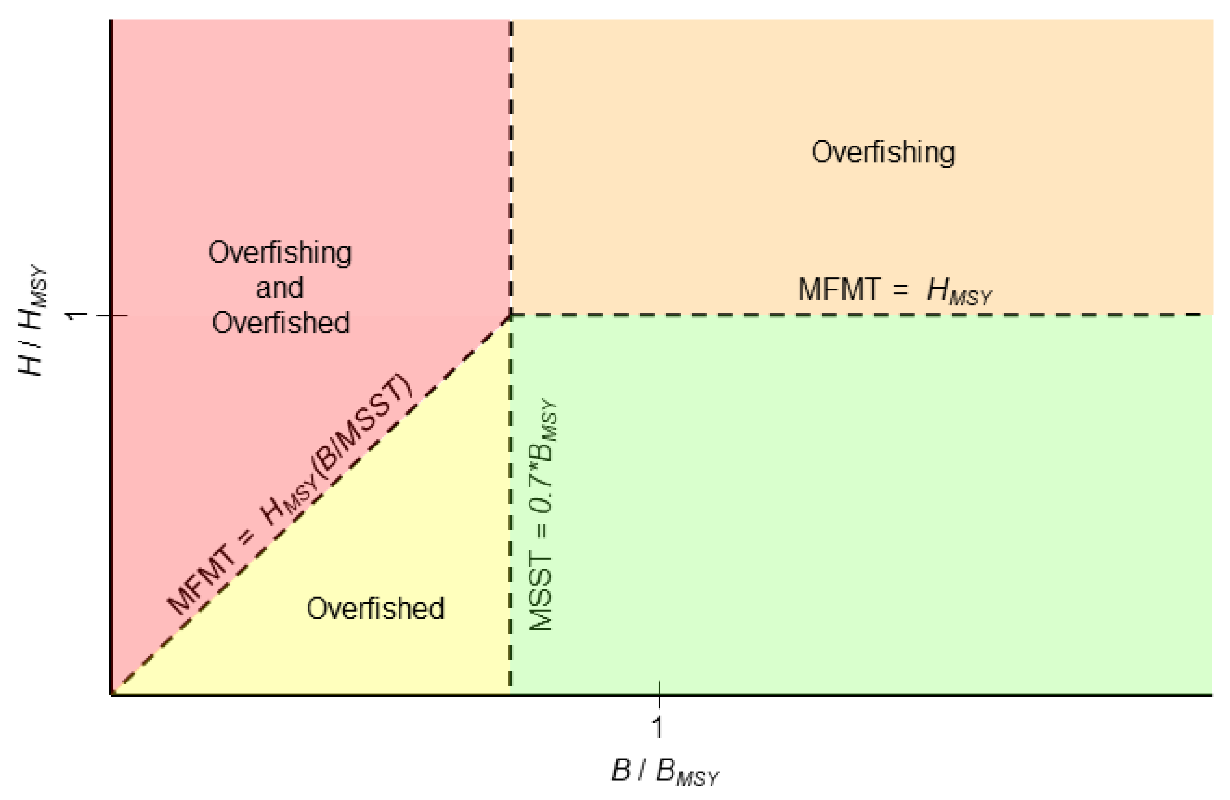

Figure 1. A harvest control rule for Guam, expressed as a function of stock biomass (B) relative to stock biomass at maximum sustainable yield (B_{MSY}; B/B_{MSY}) and harvest rate (H) relative to harvest rate at maximum sustainable yield (H_{MSY}; H/H_{MSY}). The minimum stock size threshold (MSST) is one minus the rate of natural mortality (M; assumed equal to 0.3) multiplied by B_{MSY}. The stock is considered to be overfished if B/B_{MSY}<MSST. The maximum fishing mortality threshold (MFMT) is equal to H_{MSY} when B/B_{MSY}>MSST and is H_{MSY}×(B/B_{MSST}) when B/B_{MSY}<MSST. The stock is considered to be experiencing overfishing if H/H_{MSY}>MFMT.

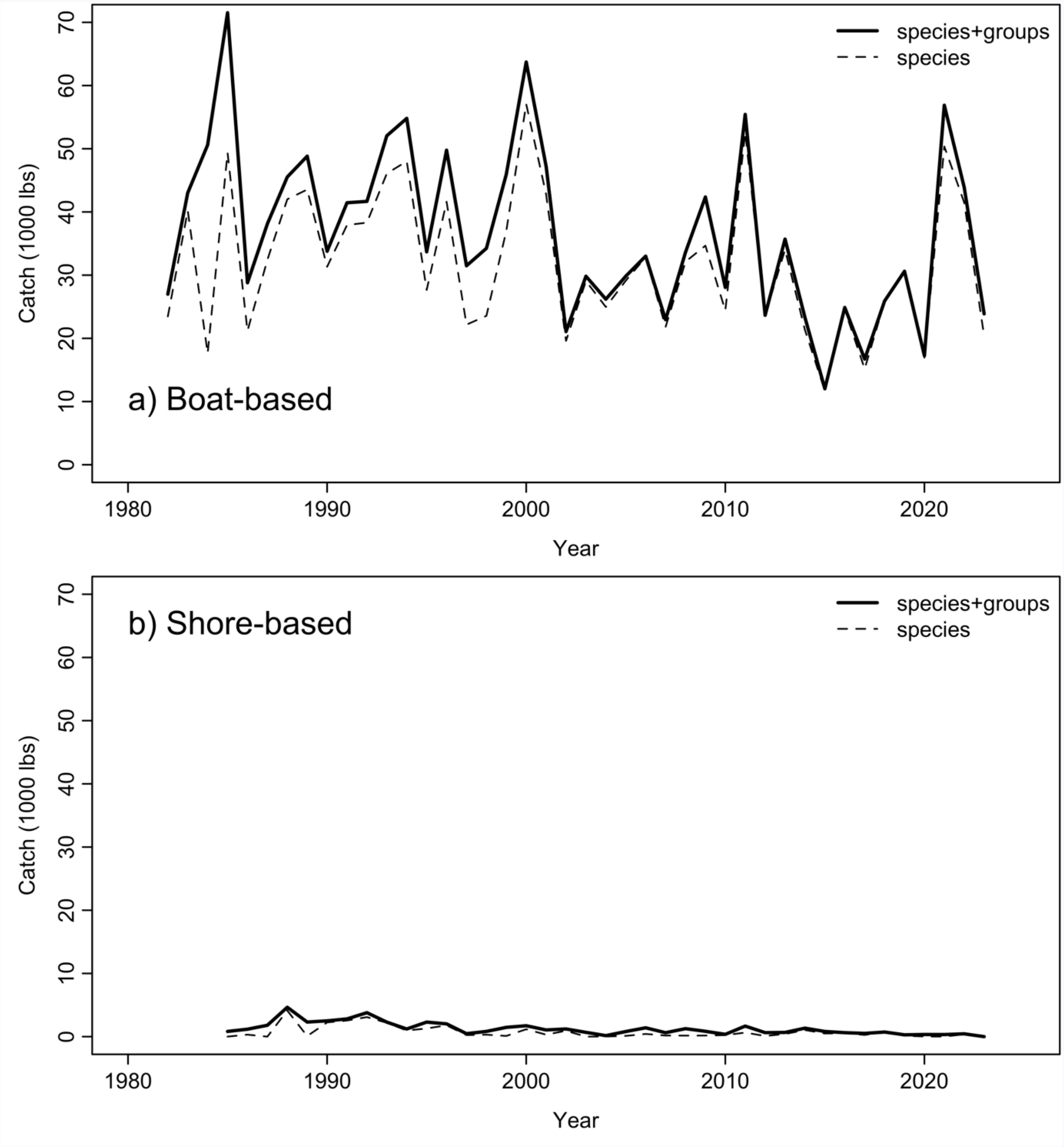

Figure 2. Total catch of identified bottomfish management unit species (BMUS; species; dashed line) and aggregate catch of BMUS with added portion from species groups believed to contain BMUS (species + groups; solid line) for the a) boat-based survey, and b) shore-based survey.

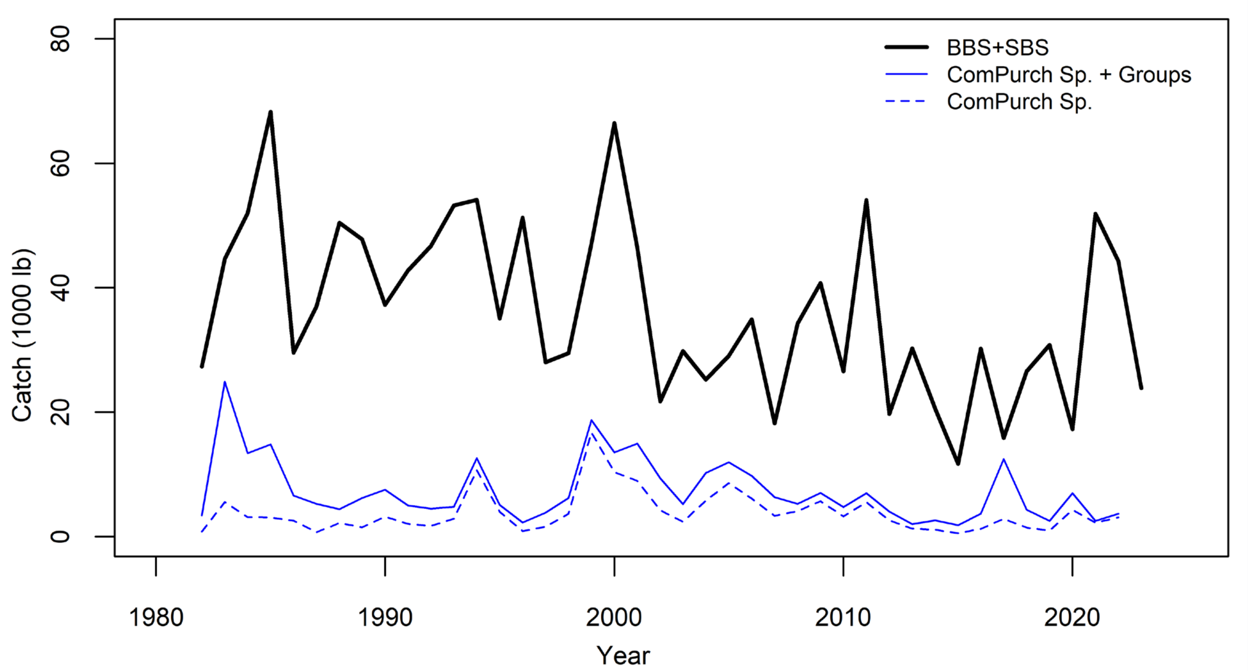

Figure 3. Estimated total catch of Guam bottomfish management unit species (BMUS) based on the combined boat-based and shore-based creel surveys (BBS + SBS; solid black line). Recorded bottomfish landings from the commercial purchase invoice program are shown in blue: identified BMUS only (ComPurch Sp.; dashed blue line) and estimated BMUS from group catch records summed with identified BMUS (ComPurch Sp. + Groups; solid blue line). At the time this report was written, commercial purchase invoice program data were not available for 2023.

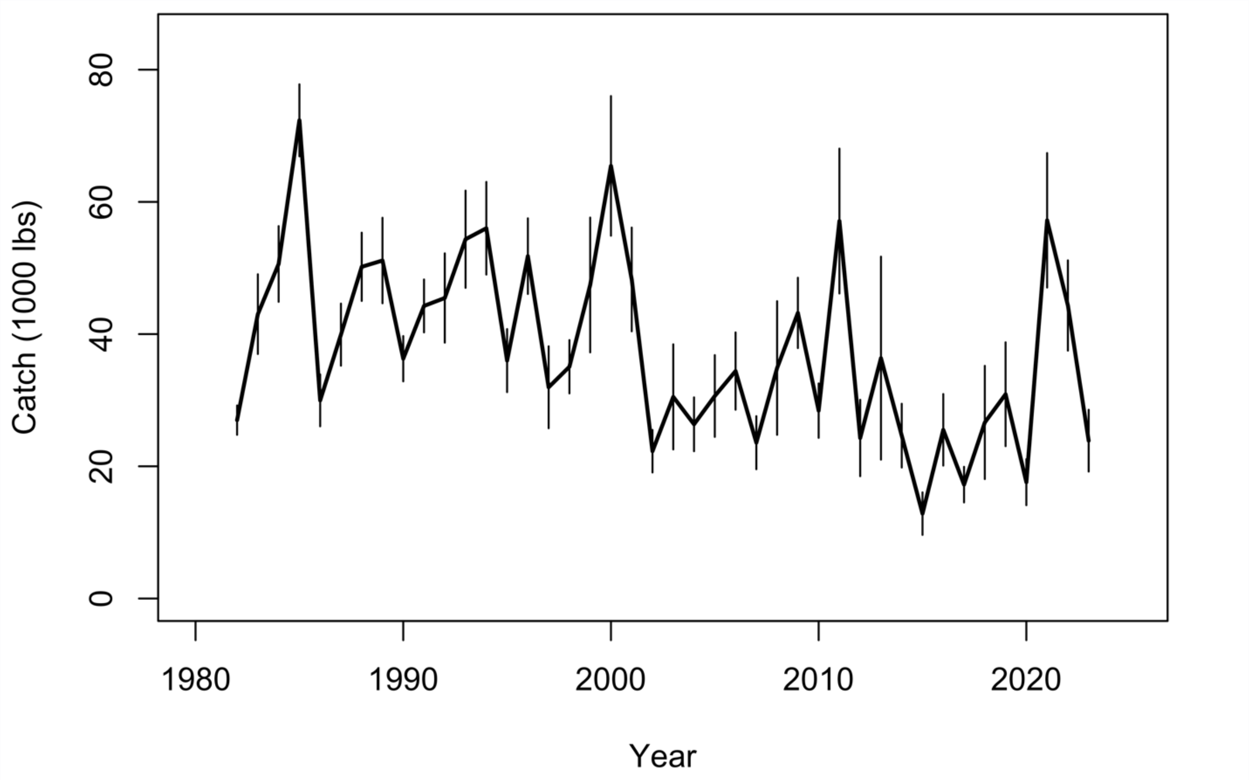

Figure 4. Total catch used as input to the 2024 update assessment for bottomfish management unit species (BMUS) in Guam. Error bars are +/- 1 standard deviation.

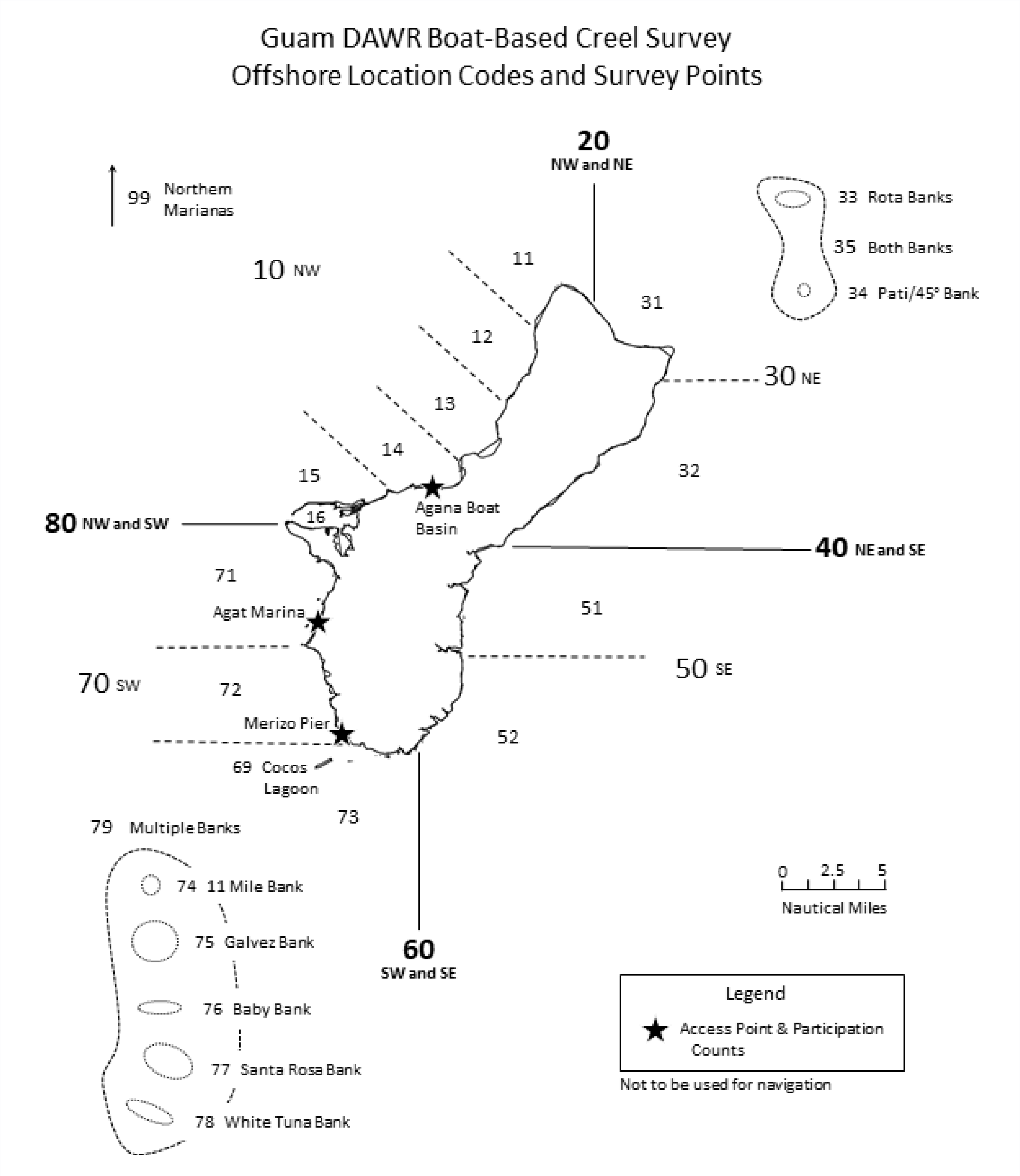

Figure 5. Map of offshore fishing grids used in the CPUE standardization for Guam.

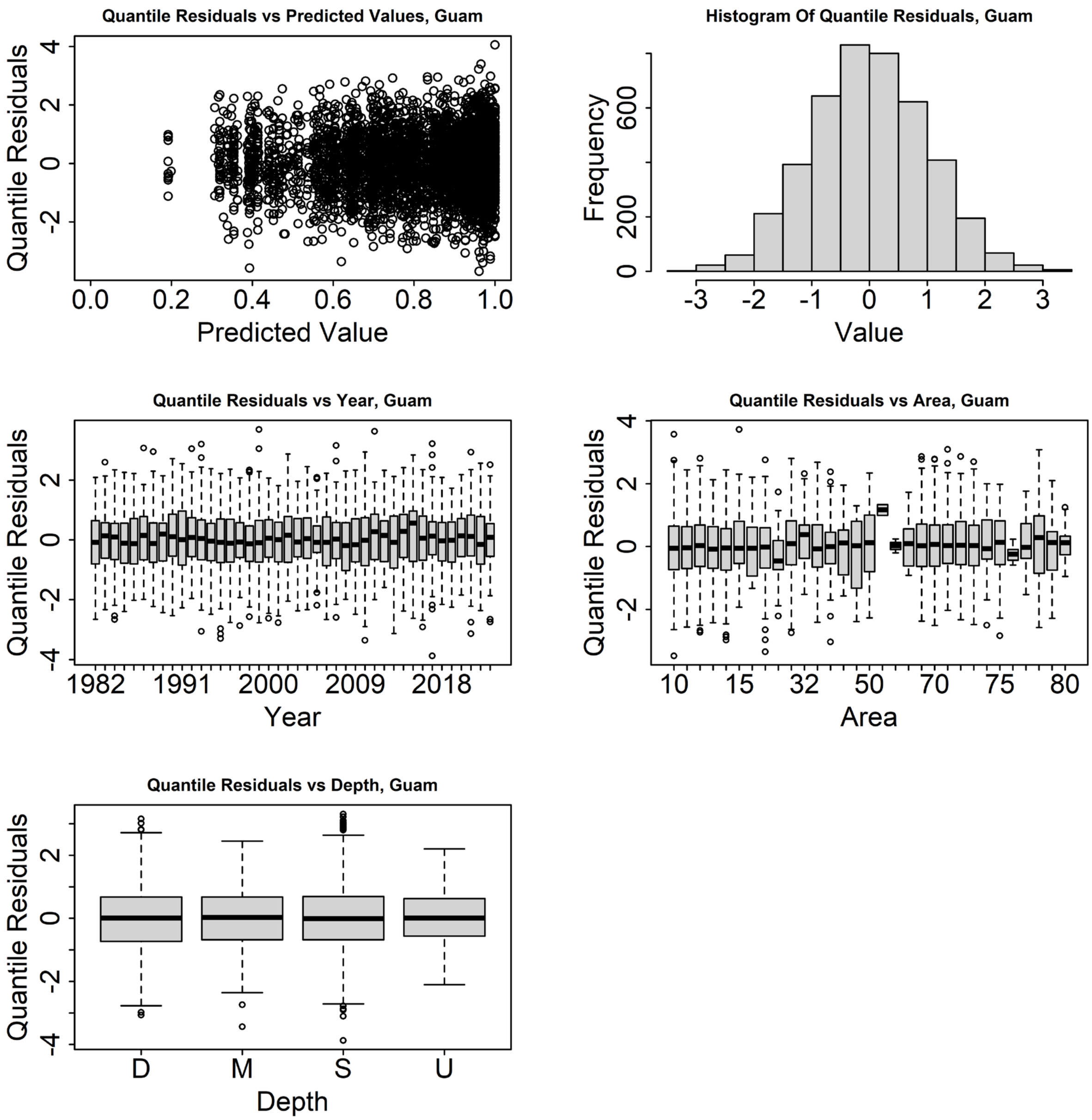

Figure 6. Model diagnostics for the presence/absence process model. Diagnostic plots include plots of quantile residuals against model predicted values (to assess heteroscedasticity), a histogram of quantile residuals (to assess normality), and plots of quantile residuals against values of each covariate (to assess patterning in the covariates).

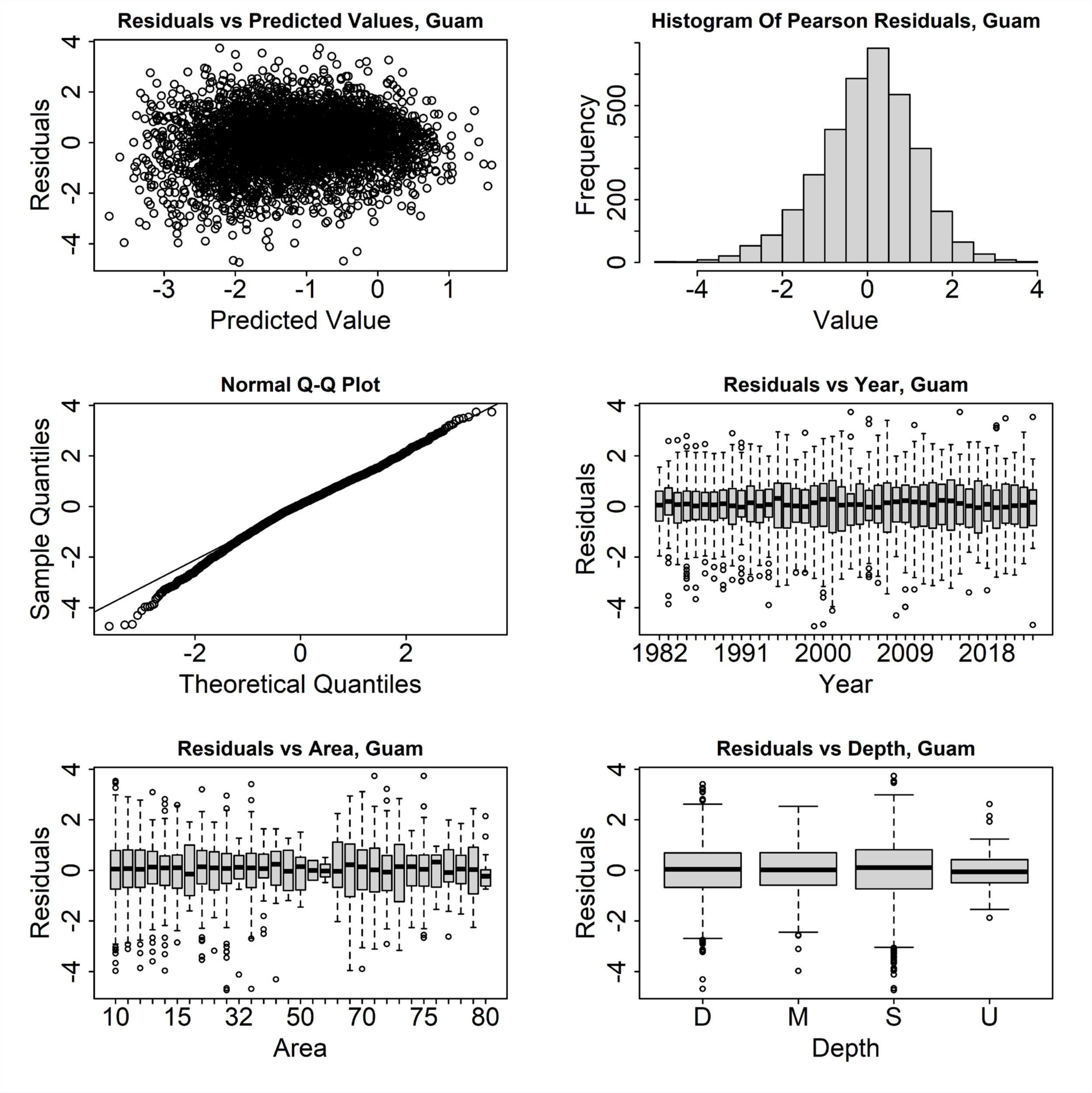

Figure 7. Model diagnostics for the positive process model. Diagnostic plots include plots of residuals against model predicted values (to assess heteroscedasticity), a histogram of residuals and the quantile-quantile plot (to assess normality), and plots of residuals against values of each covariate (to assess patterning in the covariates).

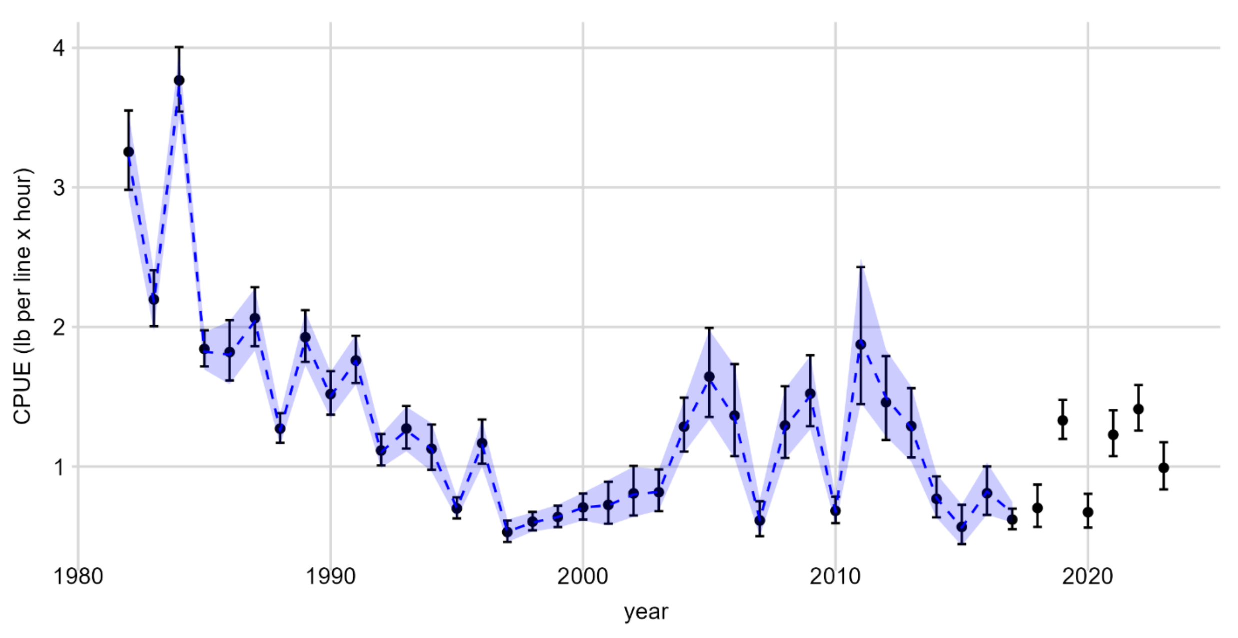

Figure 8. Standardized CPUE index for Guam BMUS in the current update stock assessment (black points with error bars) and the 2019 benchmark assessment (blue line with shaded ribbon). The error bars and shaded ribbon represent the estimated 95% confidence intervals.

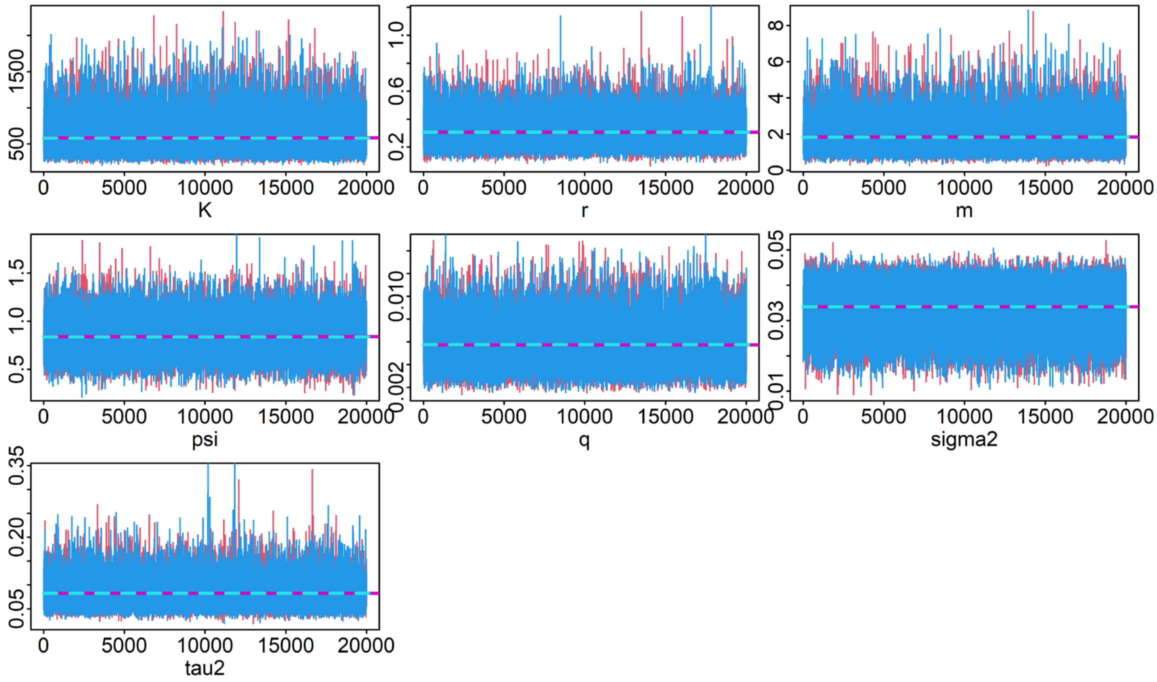

Figure 9. MCMC simulation values for model parameters for bottomfish management unit species in Guam including carrying capacity (*K*), intrinsic growth rate (*r*), shape parameter (*m*), ratio of initial biomass to carrying capacity (*psi,* ψ), catchability (*q*), process error variance (*sigma2*), and the estimable component of observation error variance (*tau2*). Two MCMC chains of 20,000 iterations each are shown overlaid in red and blue.

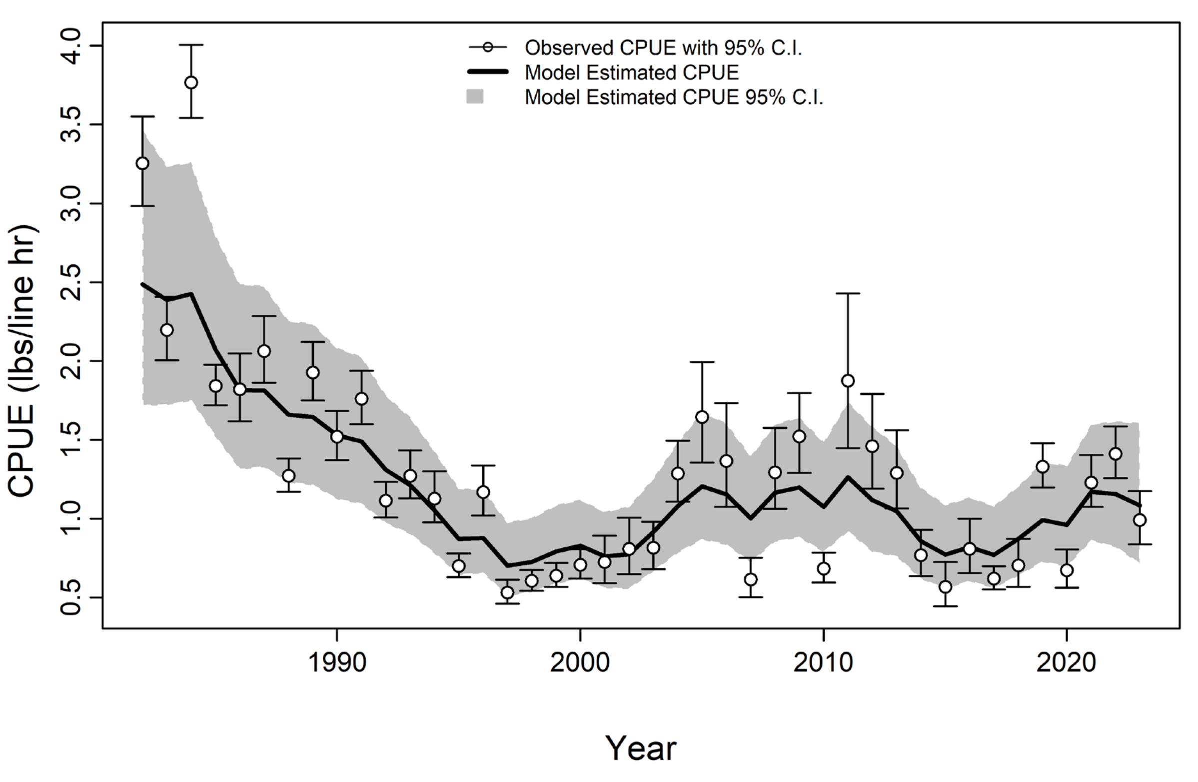

Figure 10. Observed (standardized CPUE) and the CPUE series estimated from the production model for bottomfish management unit species in Guam from 1982–2023.

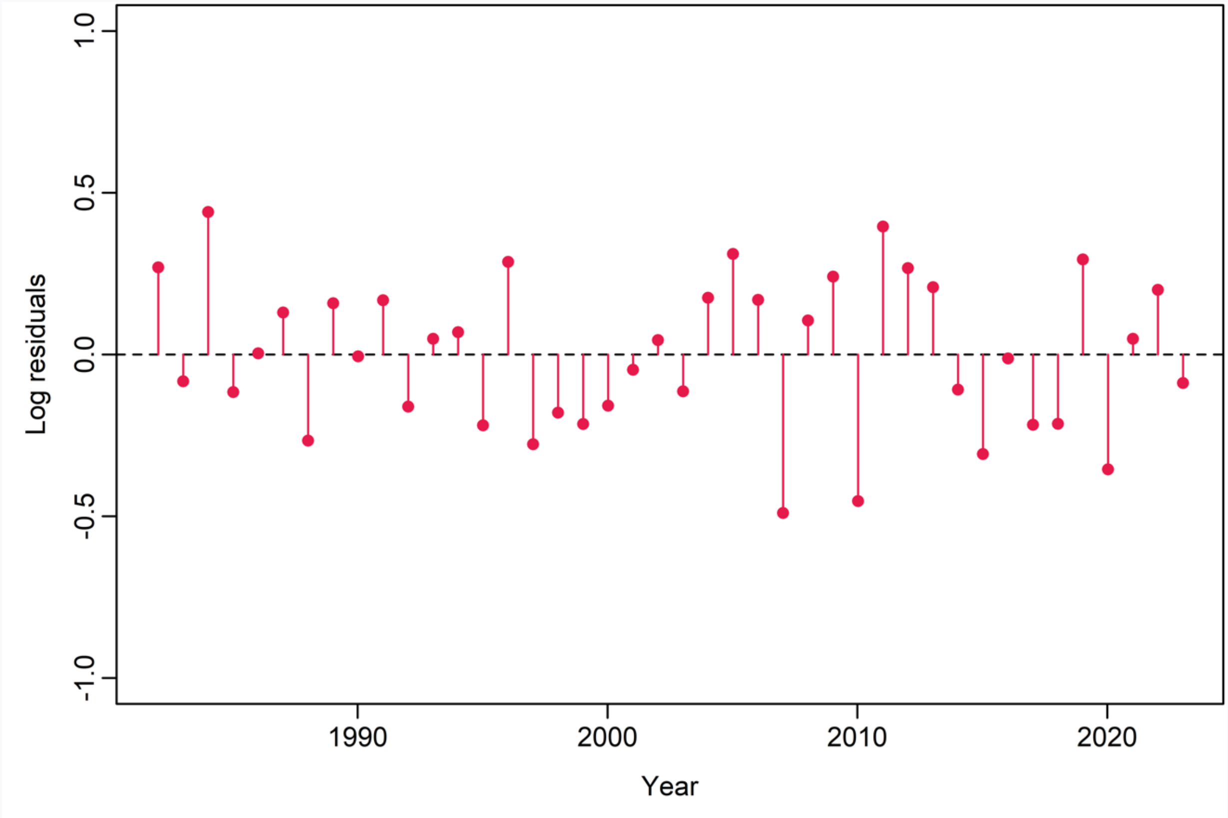

Figure 11. Residuals of production model fit to standardized CPUE for bottomfish management unit species in Guam from 1982–2023.

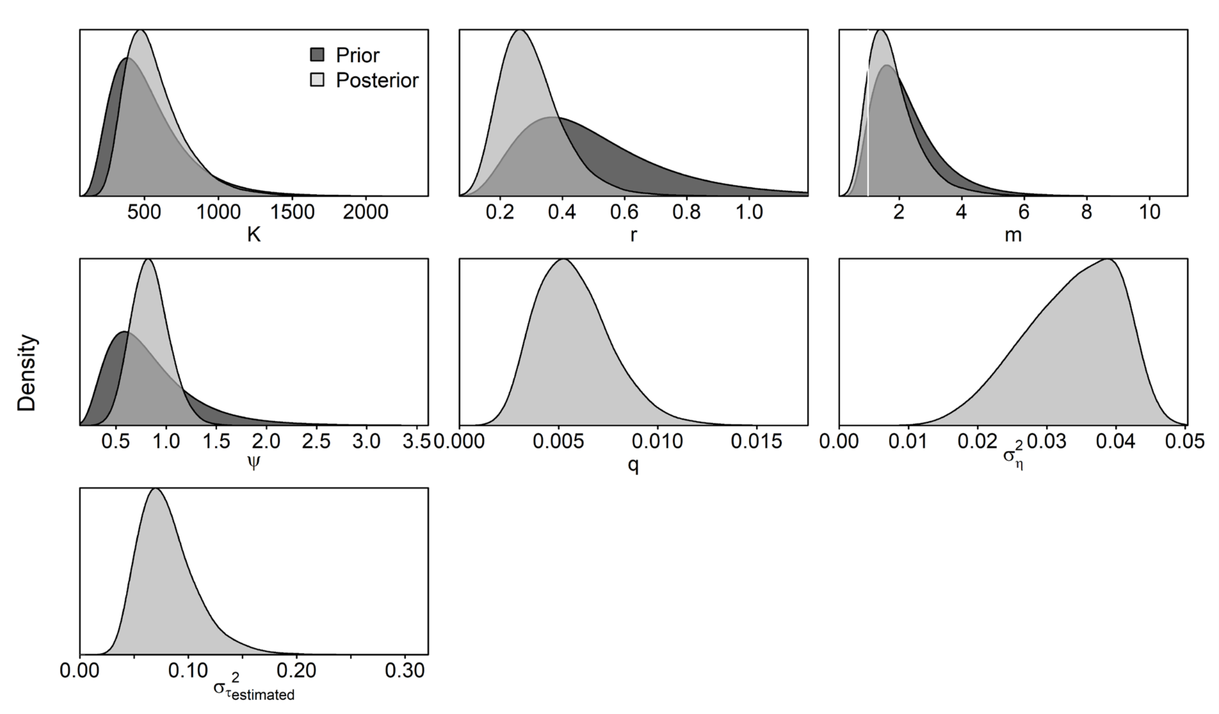

Figure 12. Prior distributions (dark gray) and posterior densities (light gray) for model parameters for bottomfish management unit species in Guam including carrying capacity (*K*), intrinsic growth rate (*r*), shape parameter (*m*), ratio of initial biomass to carrying capacity (ψ), catchability (*q*), process error variance (σ_η^2), and the estimable component of observation error variance ($\sigma_{\tau estimated}^2$). The vertical white line in the shape parameter panel indicates that the Pella-Tomlinson production function is undefined at *m*=1.

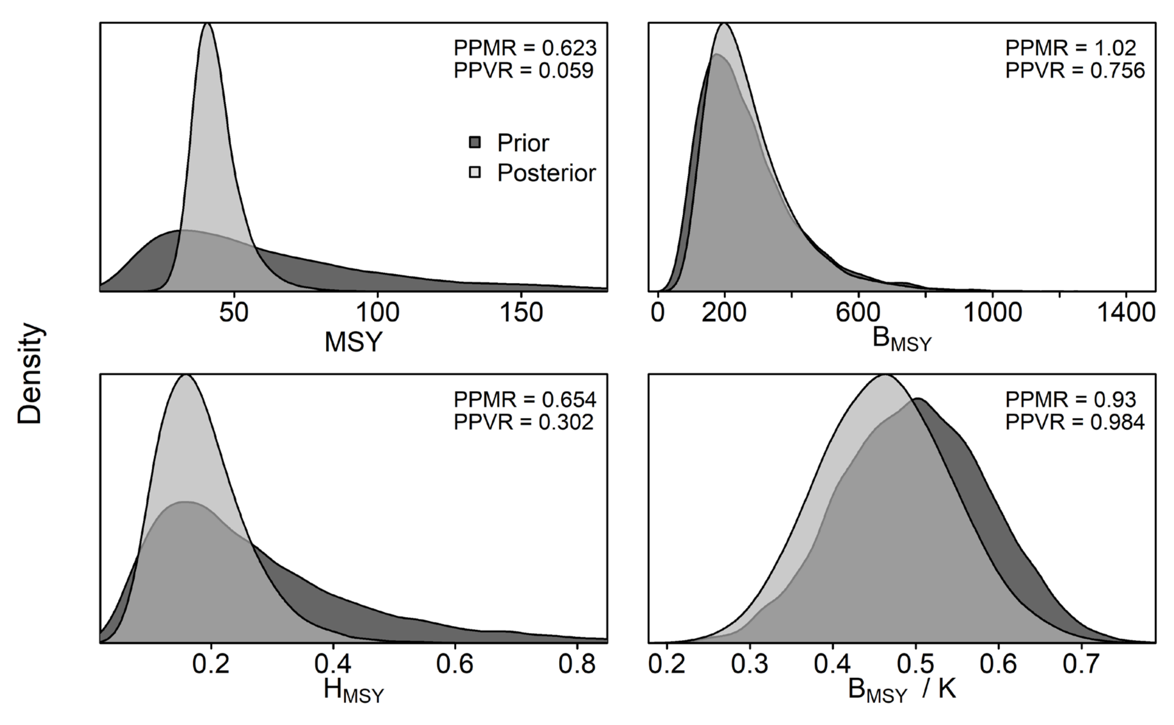

Figure 13. Prior distributions (dark gray) and posterior densities (light gray) for model derived parameters for bottomfish management unit species in Guam including maximum sustainable yield (*MSY*), biomass at maximum sustainable yield (B_{MSY}), harvest rate at maximum sustainable yield (H_{MSY}), and biomass at maximum sustainable yield divided by carrying capacity (B_{MSY}/K).

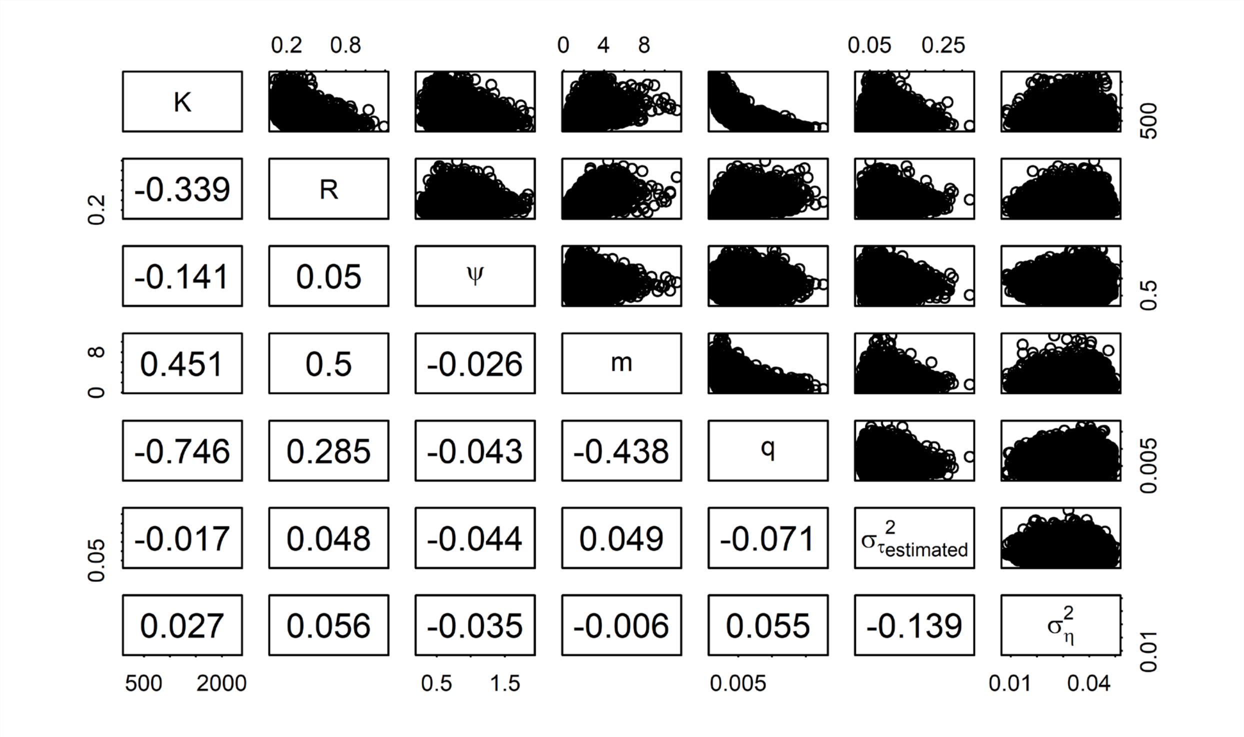

Figure 14. Pairwise scatterplots and correlations for parameter estimates for bottomfish management unit species in Guam. Parameters are carrying capacity (*K*), intrinsic rate of increase (*R*), ratio of initial biomass to carrying capacity (ψ), shape parameter (*m*), catchability (*q*), the estimable component of observation error variance ($\sigma_{\tau estimated}{}^2$), and observation error variance ($\sigma_\eta{}^2$).

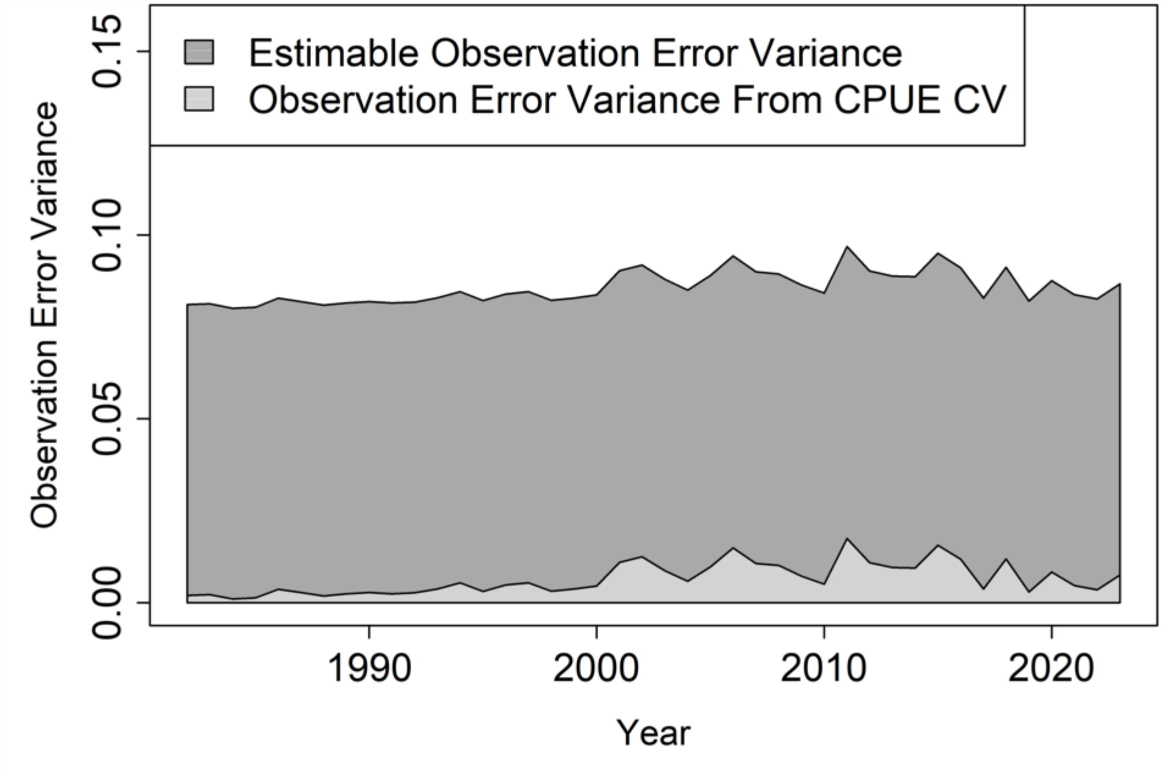

Figure 15. Total observation error variance by year for bottomfish management unit species in Guam from 1982 through 2023, partitioned into minimum observation error (set to 0), observation error from CPUE (light gray) and estimable observation error (dark gray).

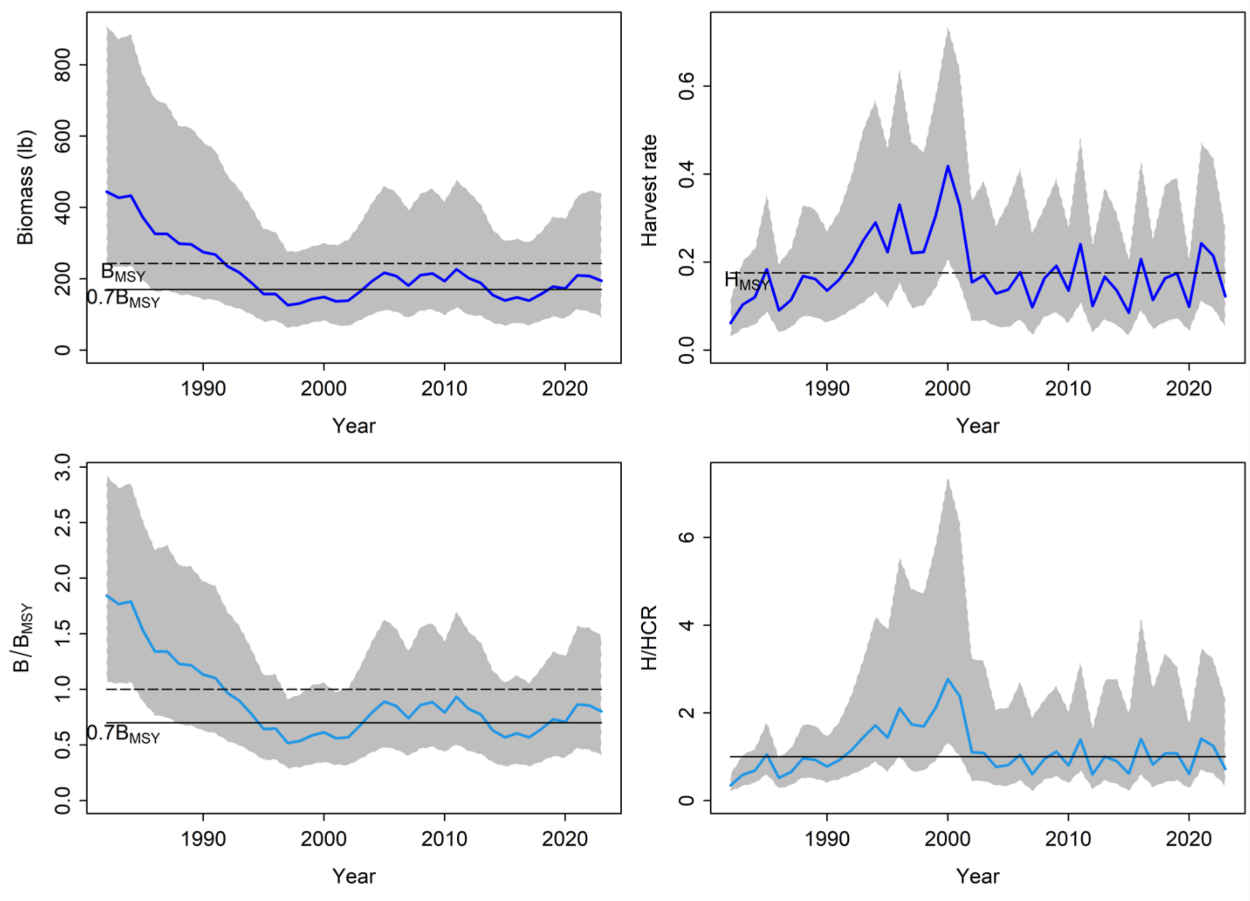

Figure 16. Estimated biomass, harvest rate, relative biomass (B/B_{MSY}), and relative harvest rate (H/H_{CR}) for bottomfish management unit species in Guam from 1982 through 2023 with 95% credible intervals (shaded area). Solid horizontal lines delineate reference points for biomass ($0.7*B_{MSY}$) and harvest rate (H/H_{CR}). Dashed horizontal lines delineate B_{MSY} and H_{MSY}.

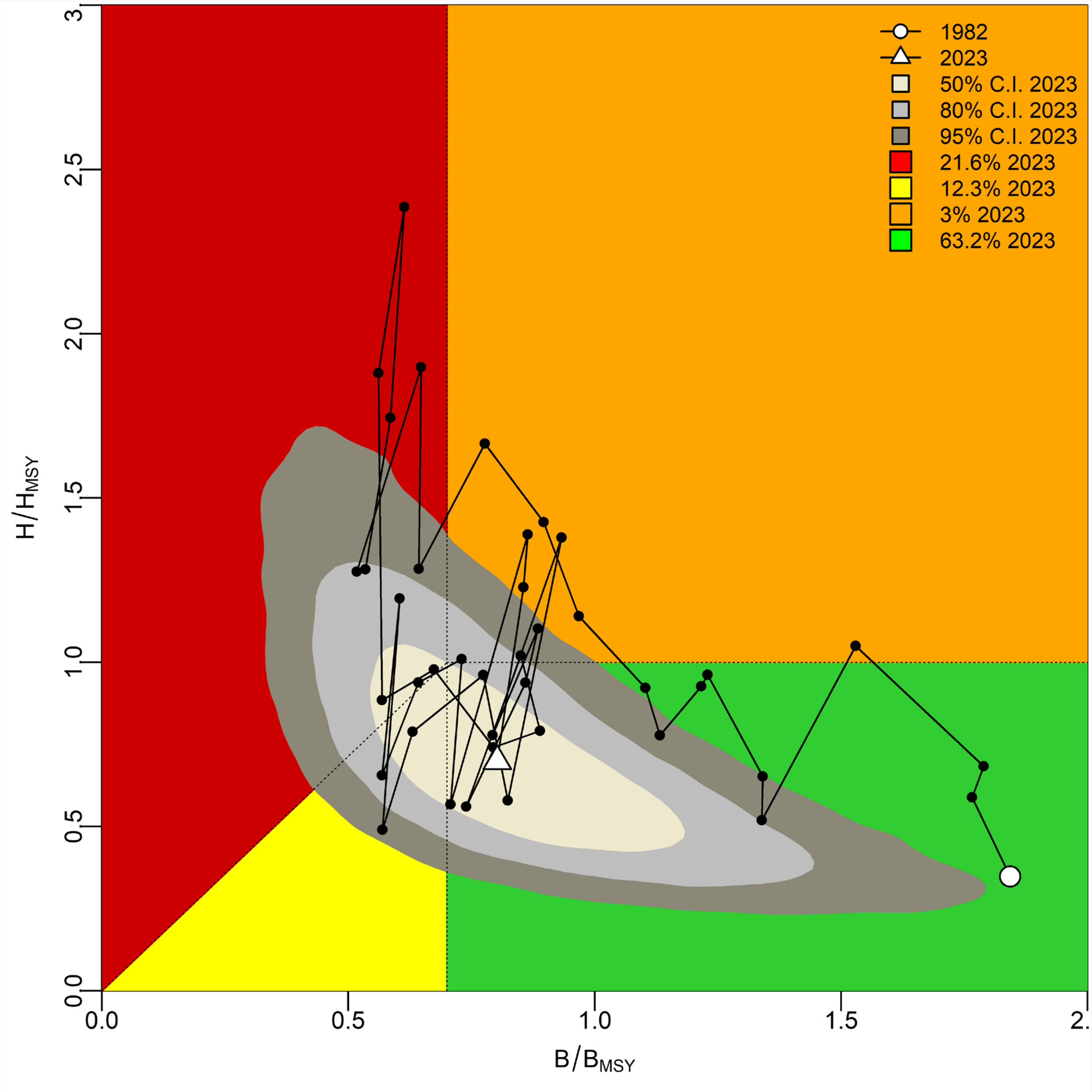

Figure 17. Estimated stock status for bottomfish management unit species in Guam from 1982 through 2023. The circle denotes the start year and the triangle denotes the final year. Outer bounds of gray shaded area delineate the 95% credible interval for 2023. Colored areas delineate stock statuses (red = overfished and overfishing, yellow = overfished but not overfishing, orange = overfishing but not overfished, and green = not overfished and not overfishing). The probability of stock status in 2023 occurring in each area is displayed in the legend.

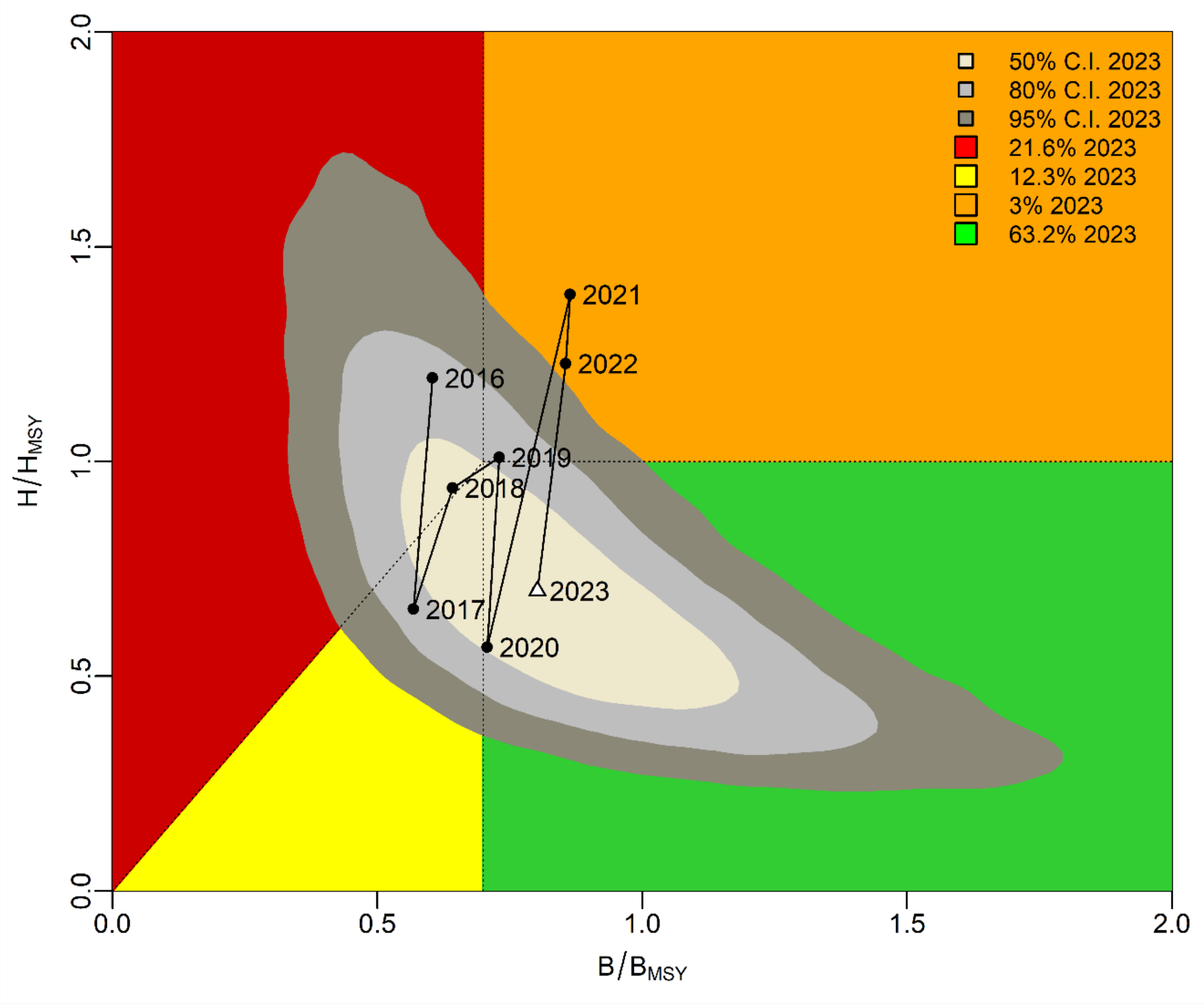

Figure 18. Estimated stock status for bottomfish management unit species in Guam from 2016 through 2023. Outer bounds of gray shaded area delineate the 95% credible interval for 2023. Colored areas delineate stock statuses (red = overfished and overfishing, yellow = overfished but not overfishing, orange = overfishing but not overfished, and green = not overfished and not overfishing). The probability of stock status in 2023 occurring in each area is displayed in the legend.

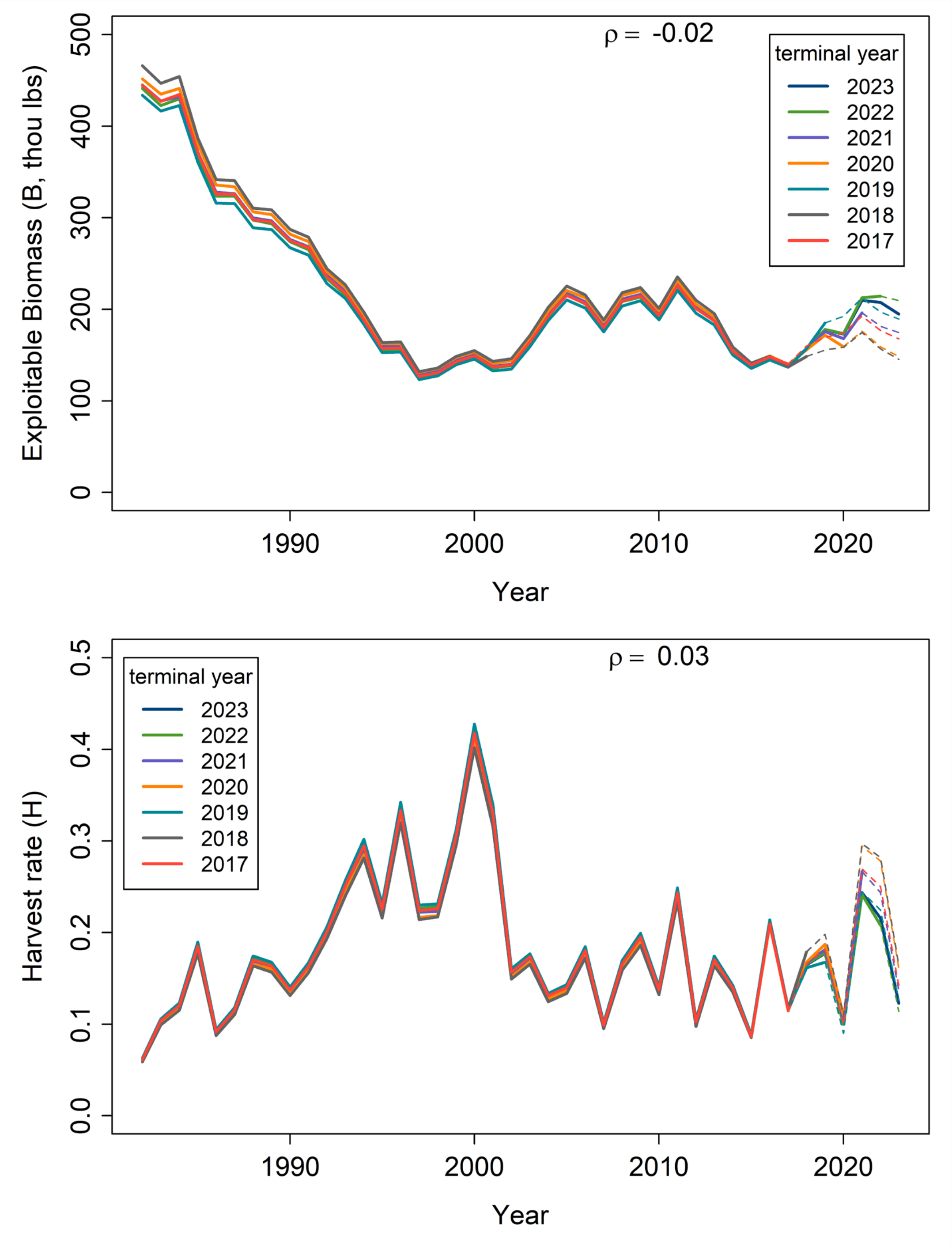

Figure 19. Production model estimated exploitable biomass (*B*) and harvest rate (*H*) timeseries for bottomfish management unit species in Guam. Models are shown for truncated timeseries ranging from the full dataset (terminal year 2023; dark blue) to the data years available during the previous 2019 benchmark assessment (terminal year 2017; bright red). Solid lines represent years with CPUE index values included in the fitting of the production model and dashed lines are model projected values given the observed catches. Values of Mohn's rho (ρ), as a measure of model retrospective bias, are shown.

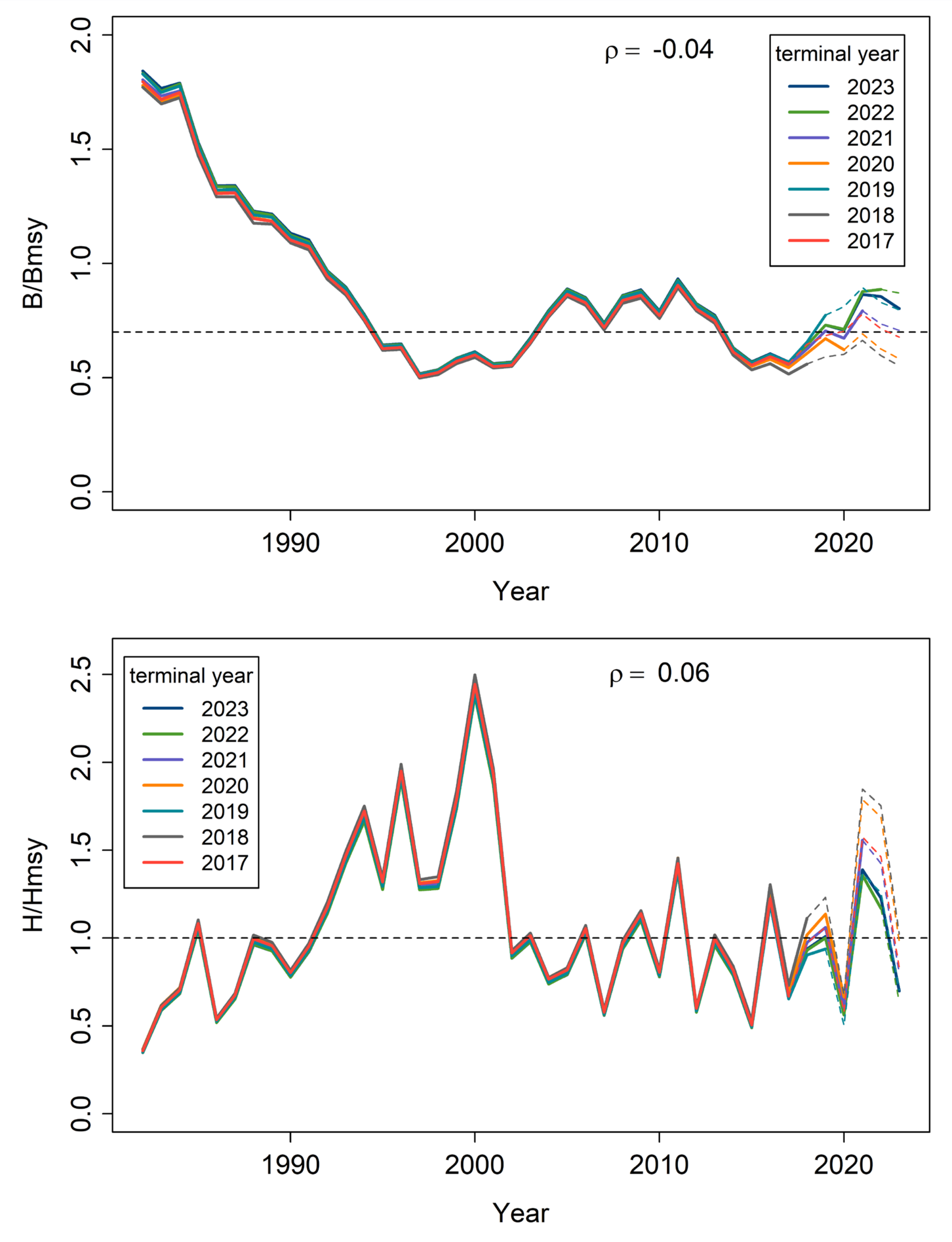

Figure 20. Production model estimated relative biomass (B/B_{MSY}) and harvest rate (H/H_{MSY}) timeseries for bottomfish management unit species in Guam. Models are shown for truncated timeseries ranging from the full dataset (terminal year 2023; dark blue) to the data years available during the previous 2019 benchmark assessment (terminal year 2017; bright red). Solid lines represent years with CPUE index values included in the fitting of the production model and dashed lines are model projected values given the observed catches. Values of Mohn's rho (ρ), as a measure of model retrospective bias, are shown.

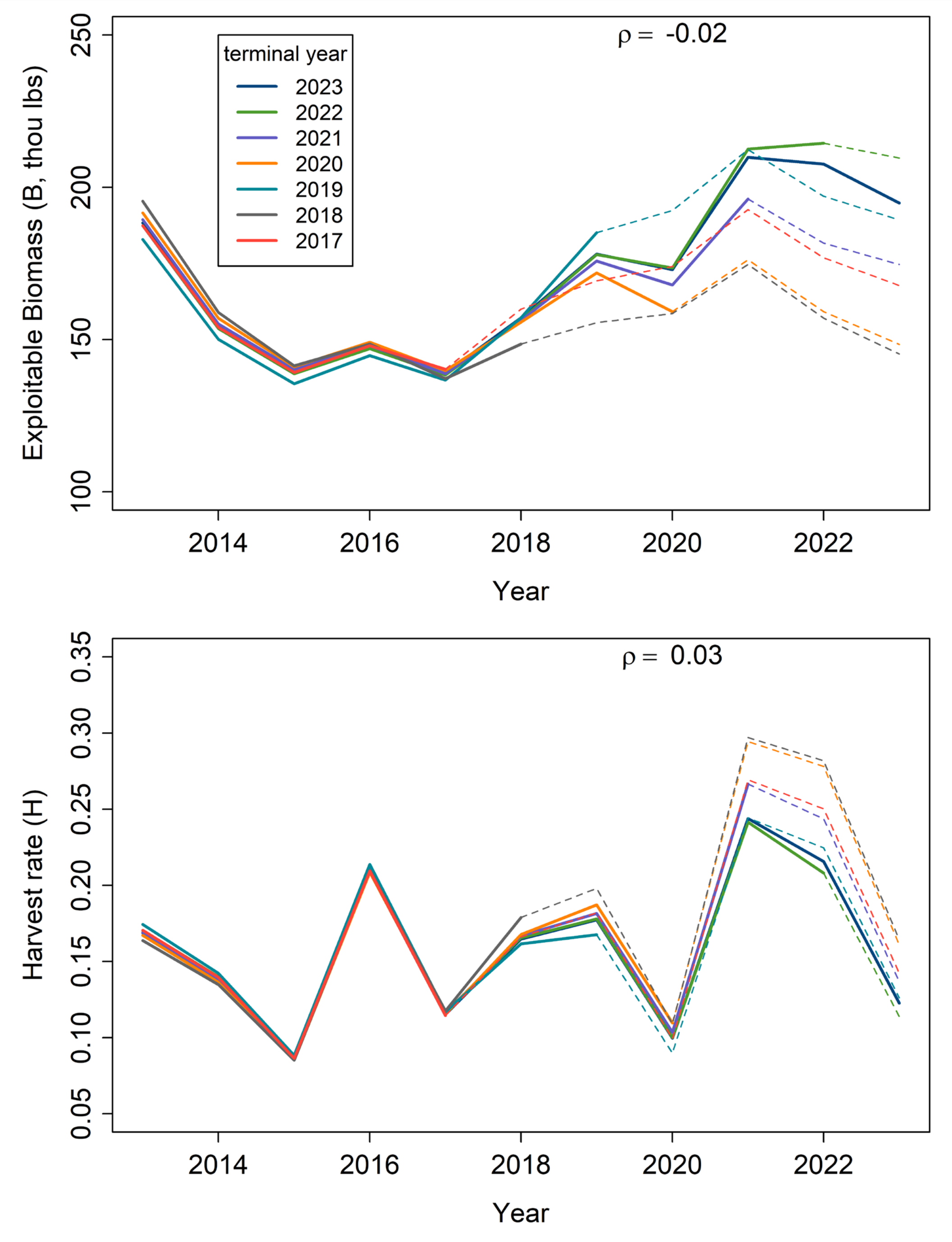

Figure 21. Production model estimated exploitable biomass (*B*) and harvest rate (*H*) from 2013–2023 for bottomfish management unit species in Guam. Models are shown for truncated timeseries ranging from the full dataset (terminal year 2023; dark blue) to the data years available during the previous 2019 benchmark assessment (terminal year 2017; bright red). Solid lines represent years with CPUE index values included in the fitting of the production model and dashed lines are model projected values given the observed catches. Values of Mohn's rho (ρ), as a measure of model retrospective bias, are shown.

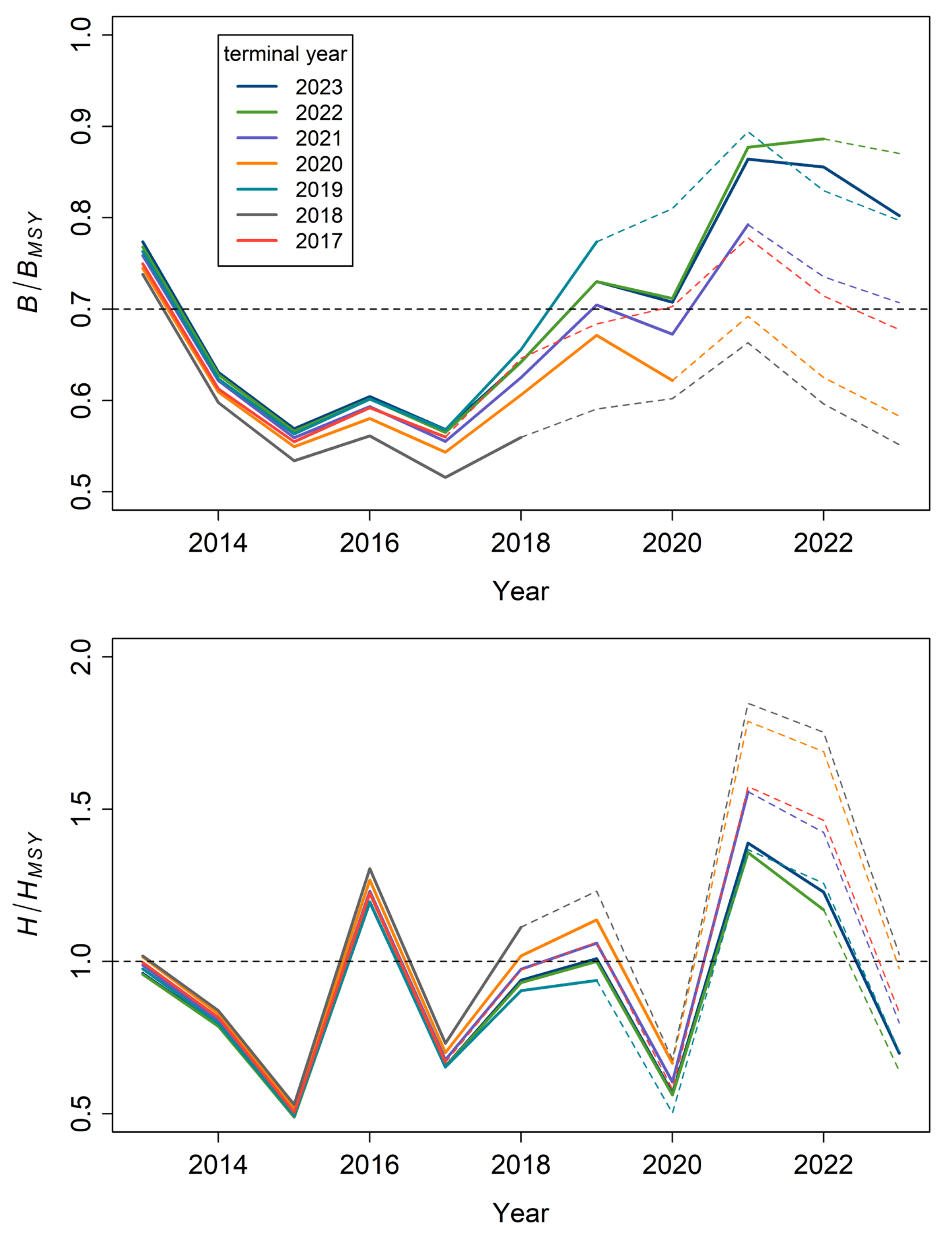

Figure 22. Production model estimated relative biomass (*B/B*$_{MSY}$) and harvest rate (*H/H*$_{MSY}$) from 2013–2023 for bottomfish management unit species in Guam. Models are shown for truncated timeseries ranging from the full dataset (terminal year 2023; dark blue) to the data years available during the previous 2019 benchmark assessment (terminal year 2017; bright red). Solid lines represent years with CPUE index values included in the fitting of the production model and dashed lines are model projected values given the observed catches.

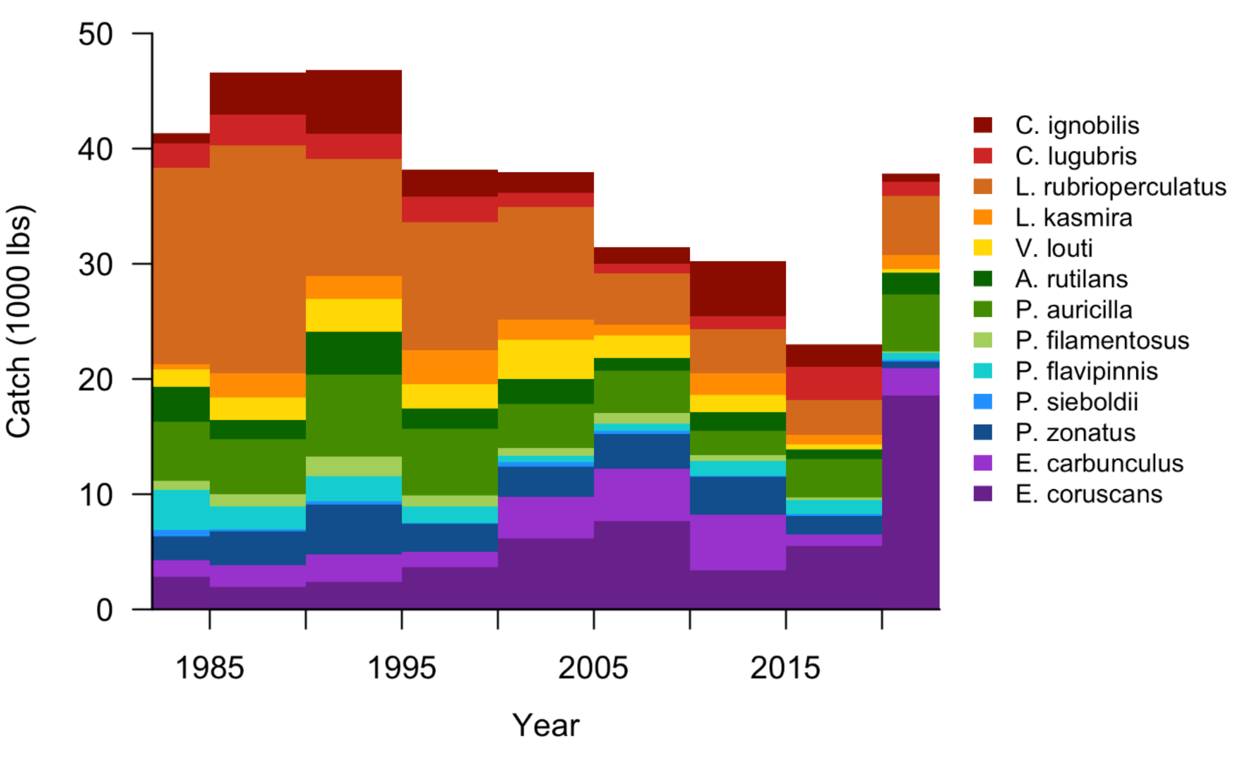

Figure 23. Average annual catch of Guam bottomfish management unit species (BMUS, in thousand lbs.), aggregated to three- to five-year periods (e.g., 1982–1984, 1985–1989, 1990–1994, etc.). BMUS are roughly ordered by depth of occurrence within each bar, with warmer colors near the top representing relatively shallower species and cooler colors near the bottom representing relatively deeper species.

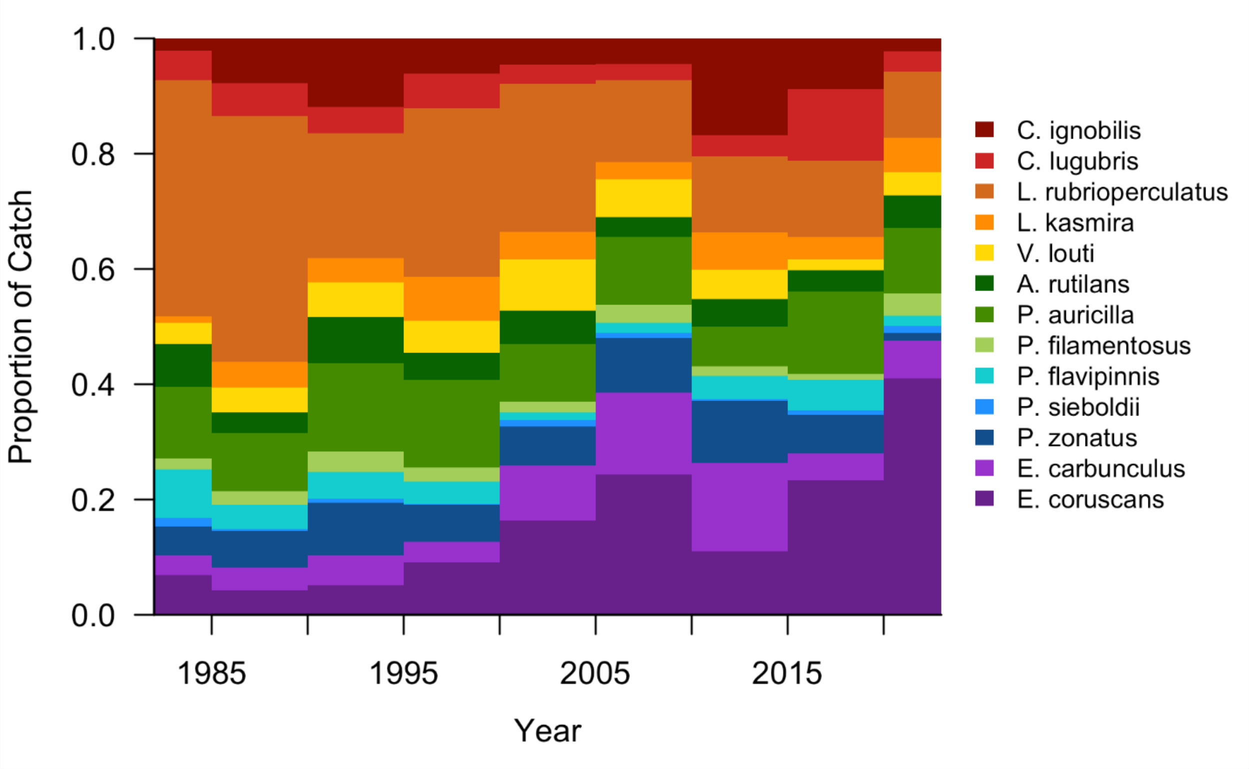

Figure 24. Relative catch composition of Guam bottomfish management unit species (BMUS), aggregated to three- to five-year periods (e.g., 1982–1984, 1985–1989, 1990–1994, etc.). BMUS are roughly ordered by depth of occurrence within each bar, with warmer colors near the top representing relatively shallower species and cooler colors near the bottom representing relatively deeper species.