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U.S. Department of Commerce | National Oceanic and Atmospheric Administration | National Marine Fisheries Service | Pacific Islands Fisheries Science Center

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Executive Summary

A stock assessment of the bottomfish management unit species (BMUS) in the Commonwealth of the Northern Mariana Islands (CNMI) was conducted using data from 2000 through 2023. Bottomfish resources in CNMI are managed as a single 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 CNMI was a benchmark assessment published in 2019 using data through 2017.

The stock assessment described in this document is an update stock assessment; therefore, all components of the analyses (selection of data sets, data filtering, catch-per-unit-effort [CPUE] standardization, stock assessment model, and model fitting) were identical to those used in the 2019 benchmark stock assessment. Estimated annual catch and catch variance for 2000–2017 were taken directly from the data used in the 2019 benchmark stock assessment, and the update years 2018–2023 values were estimated using an identical approach. For the CPUE time series, the boat-based creel survey interviews from 2000–2017 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 CNMI. The Bayesian 95% posterior density of 2023 stock status suggests BMUS in CNMI were likely not overfished and were not experiencing overfishing in 2023. Limited boat-based creel survey bottomfishing interviews between 2014 and 2019 caused large uncertainty in the terminal year 2017 stock status in the previous benchmark assessment. More interviews were available for the terminal year 2023, allowing for less uncertainty in the stock status estimates. The addition of greater numbers of bottomfishing interviews, particularly in 2020–2022, also influenced the underlying stock dynamics parameters in the update assessment, including a 11.9% reduction in MSY due to lower estimated stock productivity and equilibrium biomass, although the 95% posterior confidence intervals of all assessment model parameters overlapped between the benchmark and the update assessments.

Stock projections were conducted for 2026–2030 for a range of hypothetical 5-year catches and incorporated uncertainty in surplus production model parameters and the 2023 stock status. These update stock assessment catch projections indicate annual catches of 71,000–76,000 lb per year over the next 5 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 the Commonwealth of the Northern Mariana Islands (CNMI) under the Fishery Ecosystem Plan (FEP) for the Mariana Archipelago (FEP; WPRFMC, 2009). The bottomfish fisheries around CNMI were first included in federal management in 2006 (71 FR 53605) when they were added to the Fishery Management Plan for the Bottomfish and Seamount Groundfish Fisheries of the Western Pacific Region, which named 19 bottomfish management unit species (BMUS; 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 fishers and fisheries scientists to be most in need of conservation and management.

Eight of the 13 species of CNMI BMUS are snappers in the family Lutjanidae and are often caught at depths ranging to 800 feet or deeper. Bottomfishers report *Aphareus rutilans*, *Pristipomoides auricilla*, *P. sieboldii*, and *P. zonatus* are caught at mid-range depths (400–800 ft), 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 opakapaka (*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,* Nichols (2023)). Snappers of the genus *Etelis* are regarded as being among the deepest bottomfishes. 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 fishers and NOAA Fisheries scientists confirm *E. boweni* are present in the Mariana Islands (Dahl et al., 2024; Iwane et al., 2023) and have likely been previously misidentified as *E. carbunculus*.

CNMI 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 bottomfishers at relatively shallow depths (300 ft or less), and are considered less desirable than the deeper-dwelling snappers and other 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 bottomfishers indicate these species do not have high market value, but emperors including *L. rubrioperculatus* may be targeted by fishers 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 CNMI 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 & 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 & Dahl, 2023).

The CNMI BMUS are currently managed as one multi-species complex. A final amendment to 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 being 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 $(1 – M) × B_{MSY}$, where M is the natural mortality rate of the complex and B_{MSY} is the biomass that produces the maximum sustainable yield. As in the previous assessment, M was set at 0.30, so the overfished definition is biomass below $0.7*B_{MSY}$ ($B < 0.7 × B_{MSY}$). 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 ($B > 0.7 × B_{MSY}$), then the MFMT equals the harvest rate that produces maximum sustainable yield (H_{MSY}). If the stock biomass falls below the MSST ($B < 0.7 × B_{MSY}$), 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

The CNMI is a long line of islands and subsurface seamounts that stretches approximately 500 nmi from Rota in the south to Farallon de Pajaros, also known as Uracus, in the north (Figure 2). The archipelago is paralleled by a chain of seamounts about 150 nmi to the west. Most of the fishing activity occurs around the population centers of Rota, Tinian, and Saipan and extends to Zealandia Bank, approximately 120 nm north of Saipan.

The CNMI small boat fisheries are a mix of subsistence, cultural, recreational, and quasi-commercial fishers whose fishing behaviors provide evidence of the importance of fishing to the people of the CNMI (Hospital & Beavers, 2014). The shallower BMUS, primarily *Lethrinus rubrioperculatus*, are fished both commercially and for subsistence with most fishing trips made by small vessels (<25 ft) using handlines or homemade hand or electric reels and lasting a single day (WPRFMC & PIFSC, 2016). In contrast, the deeper BMUS, including the *Etelis* and *Pristipomoides* spp., are mostly fished commercially using larger (>25 ft) vessels (WPRFMC & PIFSC, 2016).

Previous Stock Assessments

Informal Assessments Before 2007

The CNMI BMUS were initially assessed in a complex that included all species caught by bottomfishing because catches were not identified to species before 2000. These first assessments used an informal index-based assessment method whereby annual nominal catch rates as the total estimated lb of bottomfishes caught each year divided by the total estimated fishing effort (in line × hours) each year were compared to an established indicator level equal to 50% of peak nominal catch rates. According to these early assessment methods, bottomfishes in CNMI were believed to have been not experiencing overfishing for most years between 1985–1999, and were likely overfished in only a few years over the time series (Moffitt et al., 2007).

Benchmark Stock Assessment in 2007

The first formal stock assessment of CNMI bottomfishes was completed in 2007 (Moffitt et al., 2007). Nominal catch rates of all bottomfishes from commercial purchase records for 1983–2005 were used. There were insufficient data on species to allow an assessment of the specific members of the BMUS complex. It was noted in this assessment that the CNMI creel survey program began in 2000; however, these data were not used due to the short time series. 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, 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 bottomfishes, as a complex, were not overfished and not experiencing overfishing in 2005 (Moffitt et al., 2007).

As with any modeling approach, the 2007 benchmark stock assessment made a number of assumptions regarding model structure and data treatment. Regarding 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 & 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 1983–2005 and included in the discussion a recognition of the potential downfalls of using nominal CPUE. Further, it was noted that catch data from commercial purchase records were prone to error due to incomplete records of the fishery and species mis-identification commonly associated with voluntary reporting.

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 time series; however, CPUE data were not added beyond 2005 due to suspected changes in reporting methodology of the commercial purchase records. As in the 2007 benchmark assessment, although the CNMI creel survey data were available, only data from the commercial purchase records were used. The findings of the 2012 assessment update were similar to the 2007 stock assessment; bottomfishes in CNMI were not overfished and 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 commercial purchase records. Three new years of data were added to the catch used in the 2012 stock assessment update; however, the CPUE time series was not extended beyond 2005, and creel survey data were not used. The findings of the 2016 assessment update were similar to the 2012 assessment update and 2007 stock assessment; bottomfishes in CNMI were not overfished and not experiencing overfishing in 2013.

The 2016 assessment update was the first assessment of CNMI bottomfishes to go through the Western Pacific Stock Assessment Review (WPSAR) process. This peerreview 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 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 input data streams, analytical approach, and assessment methodology.

The 2019 benchmark stock assessment was the first to use data from the CNMI Department of Land and Natural Resources (DLNR), Division of Fish and Wildlife (DFW) creel surveys, which began in 2000 for boat-based and 2005 for shore-based fishing. The greater level of species identification in the creel surveys allowed for the estimation of catch and CPUE for the 13 species in the BMUS complex, not all bottomfishes as had been done in previous assessments. Catches for 2000–2017 included the sum of BMUS landings estimated from both the boat-based and shore-based creel surveys; however, in 2003 and 2014, the recorded bottomfishes catch from the commercial purchase records was used because it was greater than the creel-survey expanded catch. CPUE was calculated from interviews reporting use of bottomfishing gear in the boat-based creel survey for 2000–2017. 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 (‘Lutjanidae’, ‘assorted bottomfish’, etc.) was 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. In addition to the year effect, both processes included 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, and vessel name. The selected model for the presence/absence process included year, depth, and type of day and the selected model for the positive process included year, area, depth, type of day, 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 CNMI bottomfish assessments included the Bayesian computation software that was used; JABBA relies on JAGS (Just Another Gibbs Sampler). The JABBA modeling environment also 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. Polovina and Ralston's (1986) methodology was also used to inform on the prior distribution of carrying capacity (K) as was done in previous assessments. The productivity function was constrained to the symmetric Schaeffer form by fixing value of the shape (m) parameter equal to 2.

The 2019 benchmark stock assessment indicated that in 2017, the CNMI BMUS were not overfished (median B_{2017} / B_{MSY} = 1.08) and were not experiencing overfishing (median H_{2017} / H_{MFMT} = 0.79). The WPRFMC relied on the projected catch corresponding to an overfishing probability of 40% to set an annual catch limit (ACL) of 84,000 lb and an annual catch target (ACT) of 78,000 lb for 2020–2023 (86 FR 24511). The ACL was reduced to 82,000 lb and the ACT to 75,000 lb (corresponding to overfishing probabilities of 39% and 34% for the ACL and ACT, respectively) for 2024–2025 (89 FR 61356).

Current Update Stock Assessment

This update stock assessment includes data from 2000–2023 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 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 2000–2017 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 time series. For the CPUE time series, the boat-based creel survey interviews from 2000–2017 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 2000–2023 interview set to calculate the standardized CPUE index.

Methods

Data Sources

Catch

Aggregate BMUS catch and coefficient of variation estimates for 2000–2017 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). Although 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) 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 (weekday or weekend/holiday), 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 domain-specific catch rates and summed across domains to estimate the annual total catch of all species and groups combined.

Species-level catch was computed by allocating the total catch across all species according to the relative species composition in interviews. However, the boat-based and shore-based interview data also included common-name species groups (e.g., bottomfish) that incorporate multiple species and could contain BMUS. Although catch is identified to the species-level whenever possible, interviews are voluntary, and for large catches, species groups 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.

When estimating the proportion of catch of each species group believed to contain BMUS in a given year, we assumed that the composition of group-level catch matched the composition of species-level catch during that year for the species contained in the group. If no individual species of a group was caught within a certain year but was caught in other years, then species-level catch was aggregated across all years to estimate the proportion. If no BMUS within a group was caught or no information for any species within that group was available across all years, then the proportion of catch from that group applied to BMUS catch was zero.

We assumed six species groups recorded in the boat-based and shore-based creel surveys could contain BMUS: Emperor (mafute/misc.), Grouper (misc.), Jacks (misc.), EE: Juvenile Jacks, Snapper (misc. shallow), and Bottom Fish. General rules were applied to determine the member species for each group. Emperor (mafute/misc.), Grouper (misc.), and Snapper (misc. shallow) included all species within the families Lethrinidae, Serranidae, and Lutjanidae, respectively. Jacks (misc.) and EE: Juvenile Jacks included all members of the family Carangidae, with the exception of *Decapterus macarellus* and *Selar crumenophthalmus,* which are smaller-bodied scads unlikely to be caught with bottomfishing gear. The broadest species group, Bottom Fish, included all species belonging to the other five species groups, as well as species of the families Berycidae (alfonsino), Bramidae (pomfret), and Priacanthidae (bigeyes).

The commercial purchase invoice program provides a lower bound on annual total catch by summing all recorded catch within each year. We excluded resale catches, which were catches already reported in the commercial purchase data set, and imported catches, which were from sources outside the stock area. Commercial purchase invoices included five common name categories that could contain BMUS: “jacks,” “assorted bottomfish,” “shallow snappers,” “groupers,” and “emperors.” 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.

Once catch from species groups was added to catch of individual BMUS, a total catch time series was calculated for each source: boat-based creel survey, shore-based creel survey, and commercial purchase invoice program. The two creel surveys represent catch from different fishing sectors, so total expanded yearly catch from the boat-based and shore-based data were summed to obtain a total expanded creel survey catch estimate.

Commercial purchase data can overlap with catch from the creel surveys; therefore, it represents a separate estimate of catch. Consequently, catch from the commercial purchase data set was compared to the summed catch from the two creel surveys. To obtain a final catch time series, the maximum of the two catch values was used as the final catch value in each year (Table 2, Figure 3). Catch estimates from the commercial purchase invoices were only used for three years: 2003, 2014, and 2018.

Catch Variance

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 0) 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.

We applied the same group proportions that were applied to catches of species groups 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 also added to the total variance for BMUS and was scaled by the square of the percentage of BMUS catch for each species group.

Because BMUS catch overwhelmingly comes from boat-based creel surveys and variance estimates are not available for commercial purchase invoice data, we used bootstrapped coefficient of variation estimates from the boat-based creel survey to represent total catch variance in each year. Given 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. 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

As in the previous benchmark assessment, non-expanded interview data from the boat-based creel survey were used as the basis for CPUE calculations. 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. We used the same set of boat-based creel survey interviews from 2000–2017 that were used in the previous benchmark assessment for this update (4,062 interviews). For the years 2018–2023, we acquired boat-based survey interviews from the Western Pacific Fisheries Information Network WPacFIN (N = 932).

Non-expanded interview data contained both species-specific codes and aggregated family-level or species category codes. There were 382 interviews (7.6% of total interviews) from 2000–2023 that reported catch of species groups. Consequently, 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 data sets were applied to determine the catch of BMUS from species groups in the non-expanded interview data sets. 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 2000–2023 interview set using the same methods as in the previous benchmark assessment. The interview data were filtered to retain only fishing trips that were expected to target BMUS. Including fishing trips that were not targeting BMUS, for example when fishers were trying to catch reef fish, would inaccurately reflect BMUS CPUE patterns over time. Interviews do not contain information on which species the fisher was targeting; hence, we only kept interviews using bottomfishing gear (i.e., fishing method '2') as the primary indicator of trips targeting bottomfish. After filtering by gear, there were 1,227 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 87 vessels and 106 interviews from the data set. We also removed 348 interviews from charter fishing trips, which were most often designated in shallow water, and had much higher number of gears and slightly fewer hours of fishing, and therefore much lower CPUE values. The primary reason charter fishing trips were excluded was that they are different enough from the majority of CNMI bottomfishing vessels that these data would not reflect BMUS fishing on the whole. After filtering for gear type, fishing history, and charter, there were 773 interviews remaining.

The final filtering step was to exclude interviews with incomplete catch and effort information. In total, 28 interviews were removed based on incomplete field values, resulting in 745 interviews remaining. This interview set included 566 interviews for 2000–2017, as detailed in Langseth et al. (2019), plus the additional 179 interviews added from 2018–2023 for this update assessment.

CPUE was calculated for each interview as catch divided by effort. Effort was calculated as the product of hours fished and number of gears, as done in the previous benchmark stock assessments (Langseth et al., 2019; Moffitt et al., 2007).

Covariates for Standardization

The previous benchmark assessment included a full exploration of potential covariates in CPUE standardization, including month, area, type of day, depth, 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, type of day, and vessel as covariates. Areas followed the grid numbering used in the boat-based creel surveys (Figure 4). These areas were not necessarily distinct because general cardinal directions were reported as well as ordinal directions, e.g., area code 5 represented the ordinal direction north and could also include either areas 1 (northwest) or 2 (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 explored aggregating fishing grids into groups that were distinct from one another. Ultimately, it was decided to keep interview recorded fishing grids as they were reported without further adjustment to maintain as fine a scale as possible. The previous benchmark assessment did not consider second order interactions between area-year because of the possibility of over-parameterizing the standardization models given the limited number of interview data points, and because there was no visual pattern suggesting fishing areas had shifted over time.

Type of day, depth, and vessel name were explored in the standardization because this information was available in the data sets, and these covariates were believed to potentially influence CPUE independent of changes in BMUS abundance. Type of day was reported as either weekend/holiday or weekday interviews and was included in the standardization to capture potential differences between full-time fishers which we assumed fished primarily on weekdays versus part-time or “weekend” fishers, which we assumed fished primarily on weekends and holidays. Depth was reported in four categories: deep, mixed, shallow, and unknown; and all were explored within the standardization. Depth was included to account for differences among nearer shore versus farther offshore habitat and species within the BMUS complex. Lastly, vessel information was included in the standardization as an attempt to determine differences among individual fishers/vessels. Fisher-specific information such as name was not reported in the creel-survey database; vessel name was used as a proxy to account for differences among vessels. We assumed vessel names are unique and that 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 87.4% of all interviews). The model for the presence/absence process selected in the 2019 benchmark assessment and used in this update included year, depth, and type of day, and reduced deviance by 24.0% from the null model (intercept only). The model for the positive process selected in the 2019 benchmark assessment and used in this update included year, area, depth, type of day, and a random intercept term of vessel name, and reduced deviance by 8.6% from the null model (intercept only).

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 of the quantiles of the standardized residuals to 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 & Smyth (1996).

Diagnostic residual plots indicated the model for each process was appropriate (Figure 5, Figure 6). 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 we also considered this 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 Brodziak & 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 (Campbell, 2015; Goodman, 1960). 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 lb per line-hour [lb/(line × hour)] are shown in Figure 7.

Assessment Model

This update stock assessment uses 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). JABBA uses R to set up the model and call the software program JAGS (Just Another Gibbs Sampler; 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 Markov Chain Monte Carlo (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 CNMI 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 two chains of 250,000 iterations total. After the initial burn-in of 150,000 iterations, every 5th 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 & Welch, 1983). The set of convergence diagnostics was 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. Non-random 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). This 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, re-estimating model parameters, and comparing the resulting biomass and harvest rate time series between each truncated time series model and the 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 time series 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. Although not used for model validation, 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 estimate the probability of overfishing (P^*—the probability that H is greater than H_{MFMT}) from 2026–2030 under a range of future catches and accounted for uncertainty in the distribution of estimates of model parameters from the posterior of the assessment model. The projected total catch scenarios ranged from 0 to 90,000 lb per year in 1,000-lb increments and were applied beginning in 2026 assuming each value for the future annual catch was constant through all projection years. In addition to catch, corresponding quantities of interest, including stock biomass, harvest rate, and probability of the stock being overfished ($B/B_{MSY} < 0.7$) were also calculated.

Years 2024 and 2025 were not included in the projections because this update stock assessment will not be available to inform catch limits until 2026. Further, missing and incomplete creel survey data precluded catch estimates from being available for 2024 and 2025. Instead, 2024 and 2025 catch was assumed fixed at 37,200 thousand lb per year, which was equal to 80% of the average annual 2021–2023 catch. This assumption was based on indications from CNMI fishers that catches in recent years have declined relative to the higher bottomfish catches during the pandemic.

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 8).

The estimated CPUE from the model provided a mediocre fit to the standardized CPUE index observations (Figure 9). Although the 95% confidence intervals of model-estimated CPUE included the standardized CPUE index in most years, the model did not fully capture variability in the index over time, such as peaks in 2002–2004 and 2016–2017, or low values in 2008–2009. The runs test indicated residuals, although generally large, did not exhibit patterns in sign over the time series (Figure 10; p = 0.52).

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 K, whereas the posterior was more informed by the prior distribution for ψ (Table 4, Table 6, Figure 11). 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. The prior distributions for derived quantities MSY, B_{MSY}, and H_{MSY}, which are calculated from the priors for r and K, were also generally consistent with the posterior distributions (Figure 12). Surplus production as a function of biomass was assumed symmetrical in this assessment model (i.e., the Schaeffer form was used). Hence, the parameter m was fixed equal to 2; therefore, the derived posterior quantity B_{MSY}/K is a point estimate equal to 0.5.

Parameter correlations aligned with expectations for a production model and therefore did not suggest problems with parameter estimation. The strongest correlation (–0.466) occurred among carrying capacity K and intrinsic population growth rate r (Figure 13) which are typically confounded in surplus production models. Correlations among all other parameters were less than 0.40 in magnitude. Total observation error variance peaked in 2011, 2013, and 2015, but was generally less than 0.5 over the time series and was primarily comprised of estimated observation error (Figure 14).

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: maximum sustainable yield (MSY) = 82,500 lb and 95% CI = 45,1000–181,100 lb; the harvest rate to produce maximum sustainable yield (H_{MSY}) = 0.152 and 95% CI = 0.077–0.300; and the exploitable biomass to produce maximum sustainable yield (B_{MSY}) = 550,400 lb and 95% CI = 264,900–1,232,400 lb. The estimated MSST = 0.7*B_{MSY} = 385,300 lb.

Model-estimated time series indicate exploitable stock biomass declined from 581,000 lb (which was 53% of carrying capacity, K) in 2000 to just below the MSST in 2008 (Table 7, Figure 15). Biomass has generally increased since 2008 to stabilize just below B_{MSY} in recent years. Estimated harvest rate has been highly variable, but generally less than H_{MFMT} throughout the time series, while H was less than 0.05 in several years and peaked at approximately twice the H_{MFMT} in 2000 and 2012.

The updated stock assessment model results indicated the BMUS stock in CNMI was not overfished in 2023, with 66.1% of the posterior 95% CI falling above the MSST (Figure 16). Estimated BMUS catch was relatively low in 2023; hence, the majority of the posterior 95% CI for harvest rate was below the MFMT (90.2%), indicating that BMUS in CNMI were not subject to overfishing in 2023. Stock status trajectory over the previous 8 years (2016–2023) indicates fairly stable B/B_{MSY} with H/H_{MSY} declining far below H_{MFMT} in 2023 (Figure 17).

Retrospective Analysis

Retrospective analysis of the estimated biomass and harvest rate from the assessment model for CNMI indicate the model outputs did not exhibit substantial retrospective patterns (Figure 18). Mohn's rho values were +0.03 and -0.06 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 (-0.01 and -0.09 for B/B_{MSY} and H/H_{MSY}, respectively) likewise did not indicate poor model performance (Figure 19). Hindcasted B/B_{MSY} and H/H_{MSY} suggested that the assessment model for terminal years 2017–2019 provided a slightly higher B/B_{MSY} and slightly lower H/H_{MSY} estimates in recent years; however, hindcast behavior of the assessment model for terminal years 2020–2023 was generally more consistent (Figure 20, Figure 21).

Catch Projections

The constant 5-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 CNMI during 2026–2030 (Table 8). Projections indicated the CNMI BMUS catch that would produce approximately a

40% chance of overfishing in any year from 2026 through 2030 was from 71,000–76,000 lb, depending on the terminal projection year. The BMUS catch to achieve a lower risk of overfishing (e.g., 34% chance of overfishing) in any year from 2026 through 2030 was from 64,000–66,000 lb, depending on the terminal projection year (Table 9).

Discussion

This update stock assessment of BMUS in CNMI indicates that exploitable stock biomass has been relatively stable since the previous stock assessment in 2017. The stock is classified as not overfished in this update, which agrees with the conclusion of the previous benchmark stock assessment. According to the previous benchmark stock assessment, the stock was also likely not experiencing overfishing: there was a 40.8% probability that the BMUS of CNMI were experiencing overfishing in 2017. Compared to the relatively high catches of BMUS in 2017 (greater than 70 thousand lb), 2023 catch was small (12,600 lb); hence, the probability of the stock experiencing overfishing in 2023 was just 9.8%.

The most notable difference between this update and the previous benchmark stock assessment may be the apparent decrease in the magnitude of uncertainty around the terminal year stock status. The 50% credible interval of 2017 stock status was wide: B/B_{MSY} was approximately 0.55 to 1.7 and H/H_{MSY} was approximately 0.2 to 1.2 (See Figure 37 in Langseth et al., 2019). In contrast, the 50% credible interval of the 2023 stock status is 0.57 to 1.27 for B/B_{MSY} and 0.10 to 0.32 for H/H_{MSY} (Figure 17). This improvement in precision was likely due to both the smaller B/B_{MSY} and H/H_{MSY} in 2023 as well as the greater number of boat-based creel survey interviews collected in 2023. In particular, the number of boat-based creel survey bottomfishing interviews increased from 6 in 2017 (catch CV = 0.83) to 15 in 2023 (catch CV = 0.41).

There are no indications of consistent directional bias in retrospective or hindcast patterns over the last 5 years of the data that would indicate model misspecification. However, the retrospective analysis does show that the terminal data year caused variability in estimated model parameters which caused variability in estimated stock status. For example, based on the retrospective analysis using terminal year 2017 data, B_{2017} / B_{MSY} = 0.95 and H_{2017} / H_{MSY} = 0.91; however, using terminal year 2023 data, B_{2017} / B_{MSY} = 1.03 and H_{2017} / H_{MSY} = 1.04 (Figure 21). This is likely a manifestation of high uncertainty in the estimation of model parameters as shown by the wide confidence intervals (Table 6), driven primarily by limited information from the small number of boat-based creel survey bottomfishing interviews available to inform the CPUE and catch estimates (Table 2, Table 3). In addition, the CNMI boat-based creel survey began in 2000; hence, the previous benchmark assessment included 18 years of data and 566 bottomfishing interviews. This update assessment included 24 years of data and 745 interviews, representing a 32% increase in the amount of data available to the model.

The relatively large addition of data to this update assessment compared to the data available to the previous benchmark assessment did cause some changes in derived parameter values and projected results. In particular, smaller estimates for both r and K

parameters led to a decline in median estimated *MSY* from approximately 93,600 to 82,500 lb. As expected, the update stock assessment catch projections indicate that lower annual catches of 71,000–76,000 lb per year (compared to 84,000–92,000 lb per year in the benchmark stock assessment) over the next 5 years would be associated with an approximately 40% probability of overfishing.

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 done in preliminary analyses of species-level catch in CNMI, there is a range of apparent trends and very high interannual variation in the catches of each BMUS over time. For example, the average annual catch of *L. rubrioperculatus*, *L. kasmira*, and *P. flavipinnis* each decreased by approximately 75% from the first 5 years (2000–2004) to the last 5 years (2019–2023) of the time series. Most other BMUS did not show a clear trend.

Considered proportionally, these contrasting catch trends created a shift in the species composition of the aggregate BMUS from a roughly equal contribution of relatively shallow BMUS (particularly *L. rubrioperculatus* and *L. kasmira*) and deep BMUS towards catch dominated by the deep BMUS (*Etelis* and *Pristipomoides* spp.; Figure 22). The factors driving such a shift in the species composition of the bottomfish catch are not well understood; however, discussions with fishers suggest that tourism can play a role in market demand for certain bottomfishes. For example, Guam bottomfishers reported 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). Regardless of the mechanisms responsible, this observed variation in species composition of catch over time and possible interactions with changes in bottomfishing effort over time provide motivation to explore the stock dynamics of individual BMUS in future CNMI 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
Pristipomoides filamentosus	Buninas, falaghal-maroobw	Opakapaka, crimson jobfish	PRFI
Pristipomoides flavipinnis	Buninas, falaghal-maroobw	Yelloweye opakapaka, 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 lb., 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
2000	176.129	0.50
2001	77.861	0.15
2002	34.006	0.28
2003	20.119	0.50
2004	76.132	0.23
2005	57.854	0.20
2006	35.294	0.19
2007	57.995	0.21
2008	22.908	0.24
2009	74.587	0.22
2010	67.944	0.12
2011	30.203	0.23
2012	140.631	0.41
2013	29.229	0.47
2014	13.889	0.53
2015	11.281	0.59
2016	59.774	0.39
2017	70.228	0.83
2018	10.81	0.02
2019	30.346	0.24
2020	46.445	0.24
2021	74.669	0.15
2022	52.159	0.18
2023	12.567	0.41

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

Year	CPUE	SE	N interviews
2000	5.82	0.218	17
2001	1.20	0.195	28
2002	2.80	0.153	27
2003	5.89	0.107	16
2004	4.32	0.106	34
2005	2.15	0.128	75
2006	1.07	0.117	70
2007	1.96	0.165	64
2008	0.58	0.107	39
2009	0.87	0.161	50
2010	2.92	0.141	27
2011	2.02	0.385	23
2012	6.86	0.244	21
2013	1.37	0.611	25
2014	1.51	0.294	13
2015	2.16	0.540	9
2016	4.69	0.148	14
2017	3.48	0.203	6
2018	NA	NA	NA
2019	2.74	0.215	11
2020	1.33	0.145	35
2021	2.23	0.122	68
2022	4.15	0.146	41
2023	0.97	0.366	15

Table 4. Prior distributions for the 2025 update assessment model for bottomfish management unit species in CNMI. 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	1495.652	0.50
m	fixed	fixed at 2	NA
ψ	lognormal	0.45	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 2025 update assessment model for bottomfish management unit species in CNMI. Diagnostics apply to the 20,000 iterations in each of 2 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 ($\sigma_{\tau estimated}^2$). The production shape parameter, *m*, was fixed equal to 2; hence, MCMC convergence diagnostics are not applicable.

Parameter	SE / Mean	Geweke Convergence p-value	HW Stationarity p-value	Halfwidth / Mean
	MCMC Chain 1			
r	0.003	0.212	0.095	0.005
K	0.003	0.089	0.223	0.006
m	NA	NA	NA	NA
ψ	0.003	0.059	0.059	0.005
q	0.004	0.568	0.109	0.008
σ_{η}^2	0.001	0.205	0.72	0.003
$\sigma_{\tau estimated}^2$	0.003	0.983	0.828	0.005
	MCMC Chain 2			
r	0.002	0.068	0.45	0.005
K	0.003	0.436	0.673	0.006
m	NA	NA	NA	NA
ψ	0.002	0.33	0.131	0.005
q	0.004	0.21	0.693	0.008
σ_{η}^2	0.001	0.167	0.078	0.003
$\sigma_{\tau estimated}^2$	0.003	0.928	0.387	0.005

Table 6. Parameter estimates for the 2019 benchmark assessment and 2025 update assessment models for bottomfish management unit species in CNMI. 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		**2025 Update Assessment**	
Parameter	**Median**	**95% CI**	**Median**	**95% CI**
r	0.33	0.17–0.63	0.30	0.15–0.60
K	1141.2	543.7–2574.0	1100.8	529.7–2464.8
m	2.0	-	2.0	-
ψ	0.48	0.20–0.94	0.56	0.23–0.98
q	0.006	0.002–0.015	0.005	0.002–0.014
σ_{η}^{2}	0.035	0.019–0.045	0.035	0.018–0.044
$\sigma_{\tau estimated}^{2}$	0.394	0.168–0.896	0.374	0.183–0.787
MSY	93.6	48.8–205.3	82.5	45.1–181.1
H_{MSY}	0.167	0.084–0.315	0.152	0.077–0.300
B_{MSY}	570.6	271.8–1287.0	550.4	264.9–1232.4
B_{MSY}/K	0.5	-	0.5	-

Table 7. Estimates of median exploitable biomass in thousand lb, 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 CNMI 2000–2023.

Year	Biomass	B/B_{MSY}	Probability of being Overfished	H	H/H_{MFMT}	Probability of Overfishing
2000	581.2	1.12	0.15	0.31	2.08	0.87
2001	439.4	0.86	0.34	0.18	1.23	0.63
2002	443.1	0.87	0.35	0.08	0.54	0.23
2003	483.2	0.95	0.30	0.04	0.30	0.10
2004	488.2	0.96	0.28	0.16	1.12	0.56
2005	417.4	0.82	0.39	0.14	1.01	0.50
2006	375.1	0.73	0.47	0.09	0.70	0.35
2007	374.1	0.73	0.47	0.16	1.17	0.57
2008	347.4	0.68	0.52	0.07	0.50	0.26
2009	392.3	0.77	0.43	0.19	1.34	0.65
2010	416.1	0.82	0.39	0.16	1.15	0.58
2011	431.8	0.85	0.37	0.07	0.49	0.22
2012	493.3	0.98	0.28	0.30	2.06	0.82
2013	389.7	0.77	0.44	0.08	0.56	0.31
2014	414.4	0.82	0.40	0.03	0.24	0.12
2015	470.1	0.94	0.33	0.02	0.17	0.06
2016	530.7	1.06	0.25	0.11	0.78	0.38
2017	516.2	1.03	0.27	0.16	1.11	0.54
2018	455.6	0.90	0.35	0.02	0.16	0.06
2019	481.1	0.96	0.31	0.06	0.44	0.19
2020	479.7	0.96	0.31	0.10	0.66	0.31
2021	489.4	0.97	0.29	0.15	1.04	0.52
2022	477.0	0.95	0.32	0.11	0.75	0.37
2023	463.8	0.92	0.34	0.03	0.19	0.10

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 CNMI.The annual catch (thousand lb), and median biomass (thousands of lb), harvest rate, and 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 2026 to the terminal year.

Terminal Year	**Probability of overfishing (H/H_{MFMT} > 1) in terminal year**				
	0.1	**0.2**	**0.3**	**0.4**	**0.5**
	Catch (1,000 lb) Constant in all years from 2026–terminal year				
2026	19	42	59	76	90
2027	22	43	60	74	88
2028	24	45	59	73	86
2029	26	45	59	72	84
2030	28	46	59	71	82
	Biomass (1,000 lb)				
2026	585.4	590.5	590.7	588.8	591.6
2027	629.2	611.7	592.4	577.0	563.8
2028	667.8	627.0	599.9	572.8	547.6
2029	688.6	641.3	602.2	568.5	536.2
2030	715.6	653.3	607.8	565.8	525.4
	Harvest rate				
2026	0.03	0.07	0.10	0.13	0.15
2027	0.03	0.07	0.10	0.13	0.16
2028	0.04	0.07	0.10	0.13	0.16
2029	0.04	0.07	0.10	0.13	0.16
2030	0.04	0.07	0.10	0.13	0.16
	Probability stock is overfished ($B/B_{MSY} < 0.7$)				
2026	0.22	0.22	0.22	0.22	0.22
2027	0.19	0.21	0.22	0.24	0.25
2028	0.17	0.20	0.23	0.25	0.28
2029	0.15	0.19	0.23	0.27	0.30
2030	0.14	0.19	0.23	0.28	0.32

Table 9. Projection results showing annual catch of CNMI BMUS (1000 lb) applied across all years from 2026 to the terminal year where the specified probability of overfishing (harvest rate exceeds the maximum fishing mortality threshold; $H/H_{MFMT} > 1$) was reached in the terminal year.

Probability of overfishing	**Terminal Year**					**Probability of overfishing**	**Terminal Year**				
	2026	**2027**	**2028**	**2029**	**2030**		**2026**	**2027**	**2028**	**2029**	**2030**
0.01	0	0	1	1	1	0.26	53	53	54	54	55
0.02	2	3	4	5	6	0.27	55	55	55	55	56
0.03	4	5	7	8	9	0.28	56	57	57	56	57
0.04	6	8	9	11	12	0.29	59	59	58	58	58
0.05	8	10	11	13	16	0.30	59	60	59	59	59
0.06	10	12	14	16	18	0.31	61	61	61	61	60
0.07	12	15	17	19	20	0.32	63	62	62	62	62
0.08	14	17	19	21	23	0.33	64	64	64	63	63
0.09	16	19	22	24	26	0.34	66	65	65	64	64
0.10	19	22	24	26	28	0.35	67	67	66	66	65
0.11	21	24	26	29	30	0.36	69	68	68	67	66
0.12	23	26	29	31	32	0.37	71	70	69	68	68
0.13	26	29	31	33	34	0.38	72	71	70	69	69
0.14	28	31	33	35	36	0.39	74	72	71	70	70
0.15	31	33	35	37	38	0.40	76	74	73	72	71
0.16	33	35	38	39	40	0.41	77	76	74	73	72
0.17	35	38	39	40	41	0.42	78	76	76	74	73
0.18	38	39	41	42	43	0.43	80	78	76	76	74
0.19	39	42	43	44	45	0.44	82	80	77	76	76
0.20	42	43	45	45	46	0.45	84	81	79	78	77
0.21	44	45	46	47	48	0.46	85	83	80	79	78
0.22	46	47	48	48	49	0.47	87	84	81	80	79
0.23	48	49	50	50	50	0.48	88	85	83	81	80
0.24	49	51	51	51	52	0.49	90	87	84	82	81
0.25	52	52	52	53	53	0.50	90	88	86	84	82

Figures

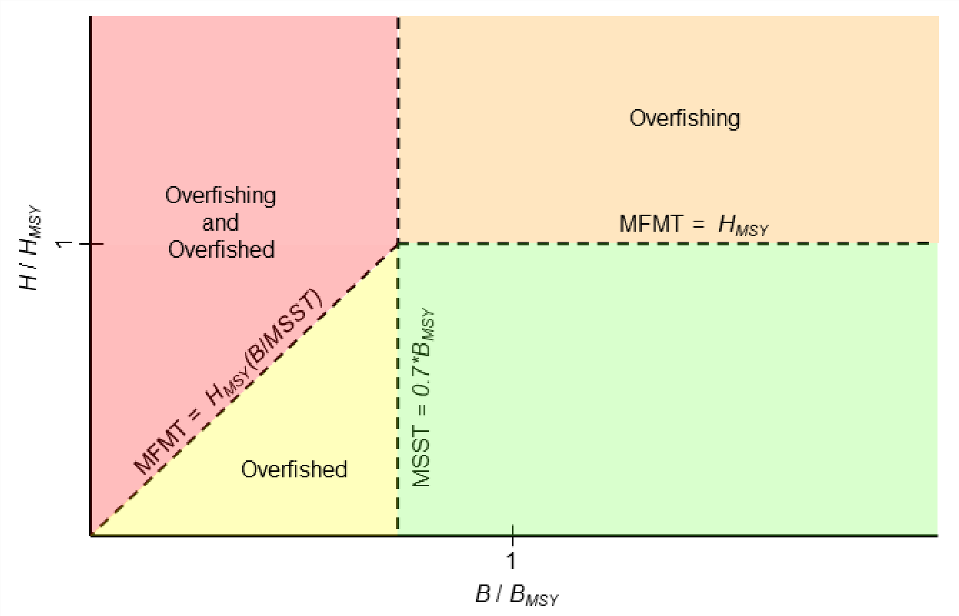

Figure 1. A harvest control rule for CNMI, expressed as a function of stock biomass (*B*) relative to stock biomass at maximum sustainable yield (B_{MSY} ; B / B_{MSY}) and harvest rate (*H*) relative to harvest rate at maximum sustainable yield (H_{MSY} ; H / H_{MSY}). The Minimum Stock Size Threshold (MSST) is 1 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.

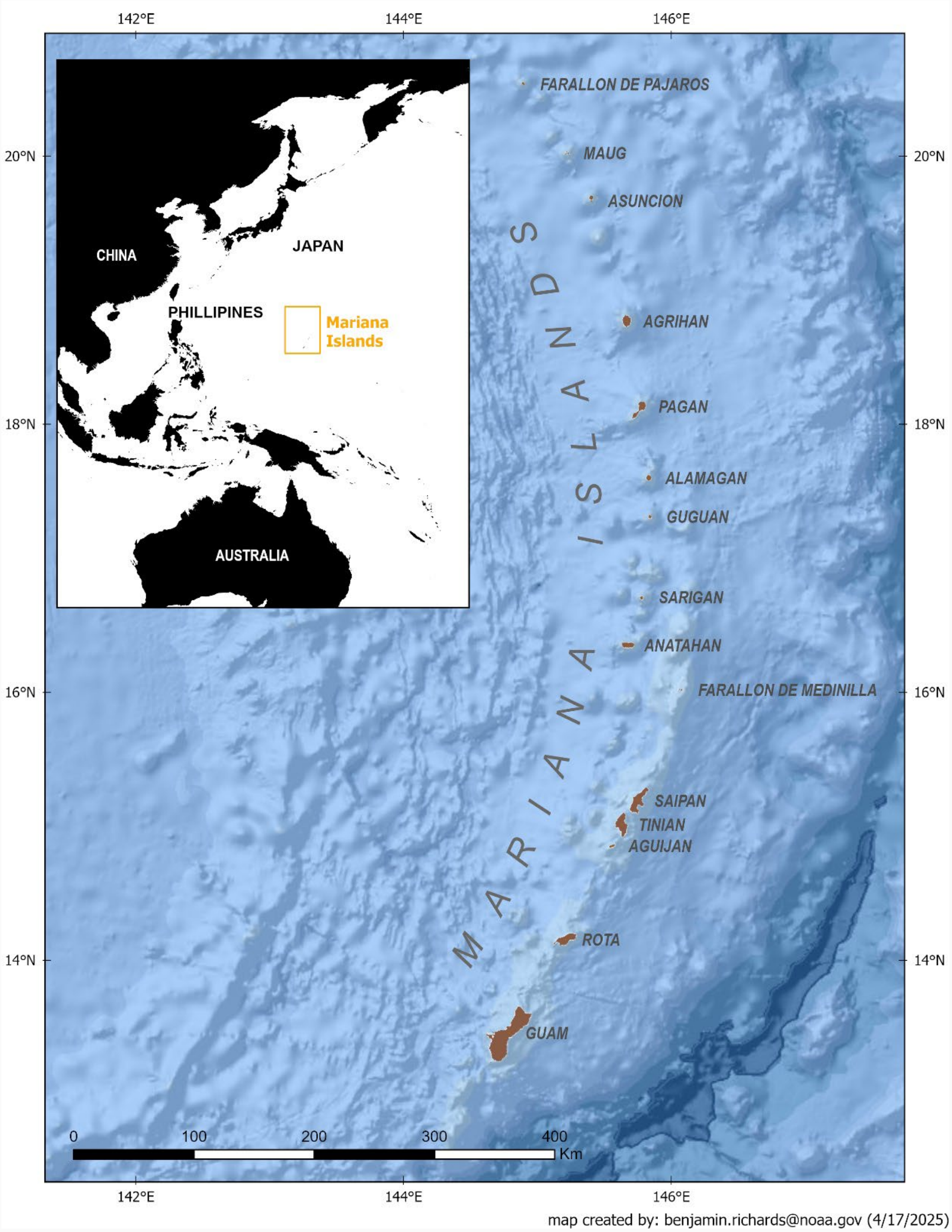

Figure 2. Map of the Marianas Islands Archipelago in the Western Pacific Ocean.

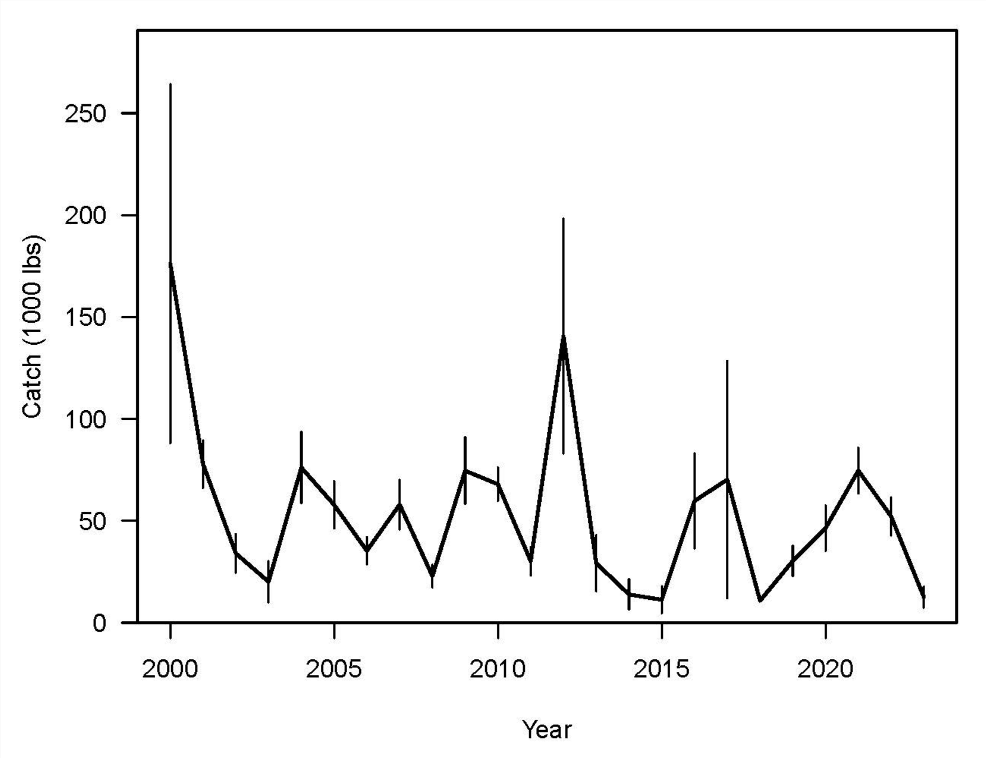

Figure 3. Total catch used as input to the 2025 update assessment for bottomfish management unit species in CNMI. Error bars are +/- 1 standard deviation.

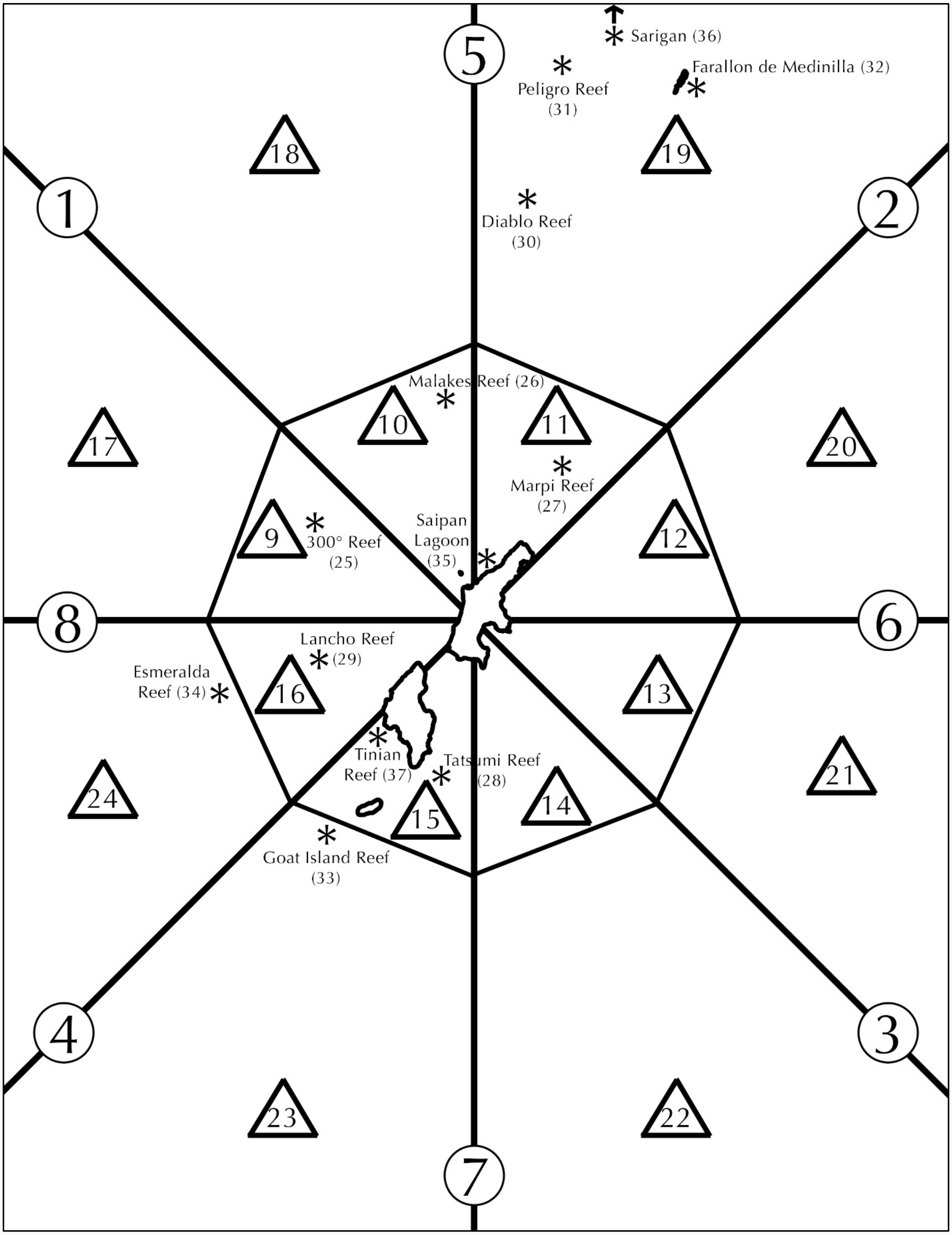

Figure 4. Map of offshore fishing grids used in the CPUE standardization for CNMI.

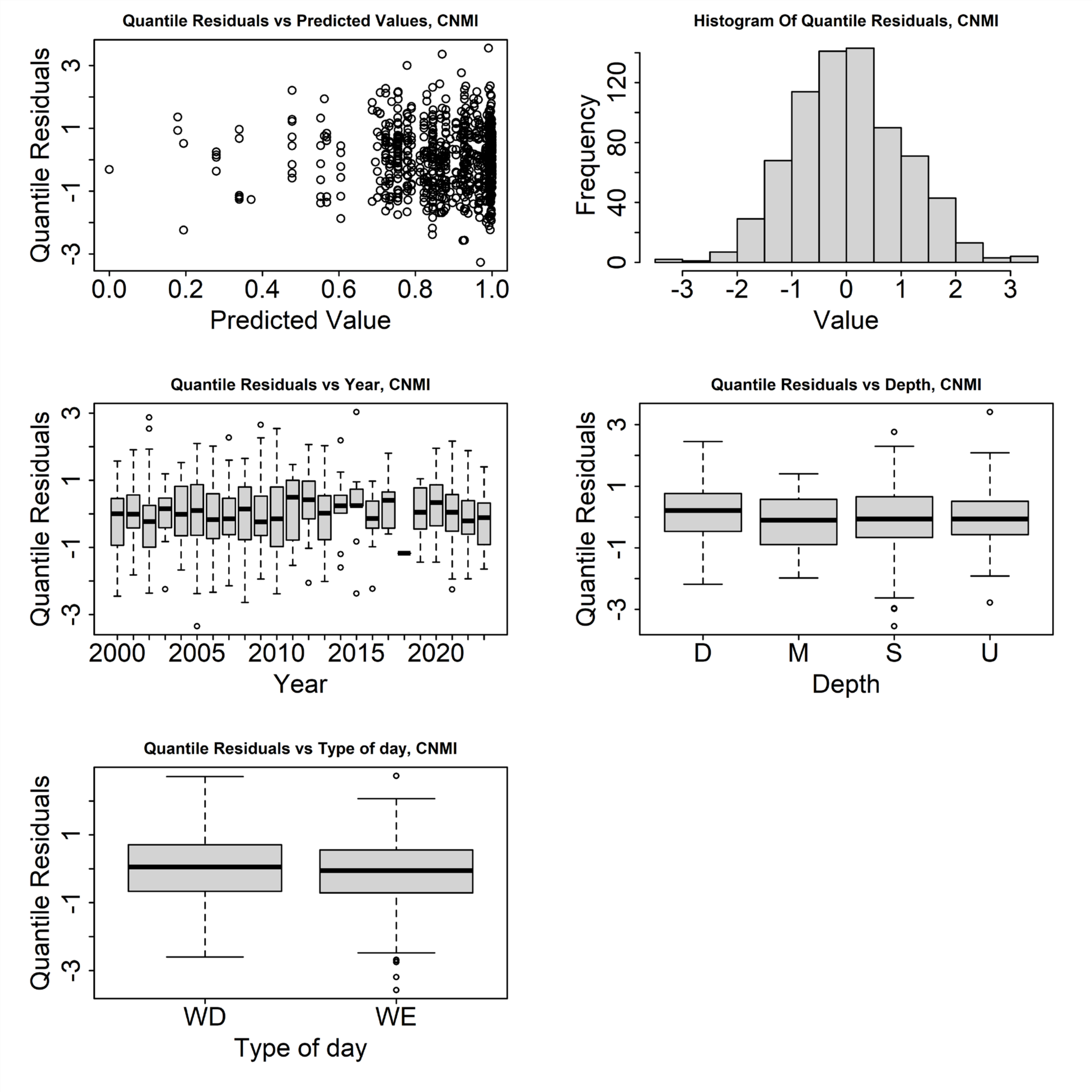

Figure 5. Model diagnostics for the presence/absence process model. Diagnostic plots include plots of quantile residuals against model-predicted values (to assess heteroscedasticity), a histogram of quantile residuals (to assess normality), and plots of quantile residuals against values of each covariate (to assess patterning in the covariates).

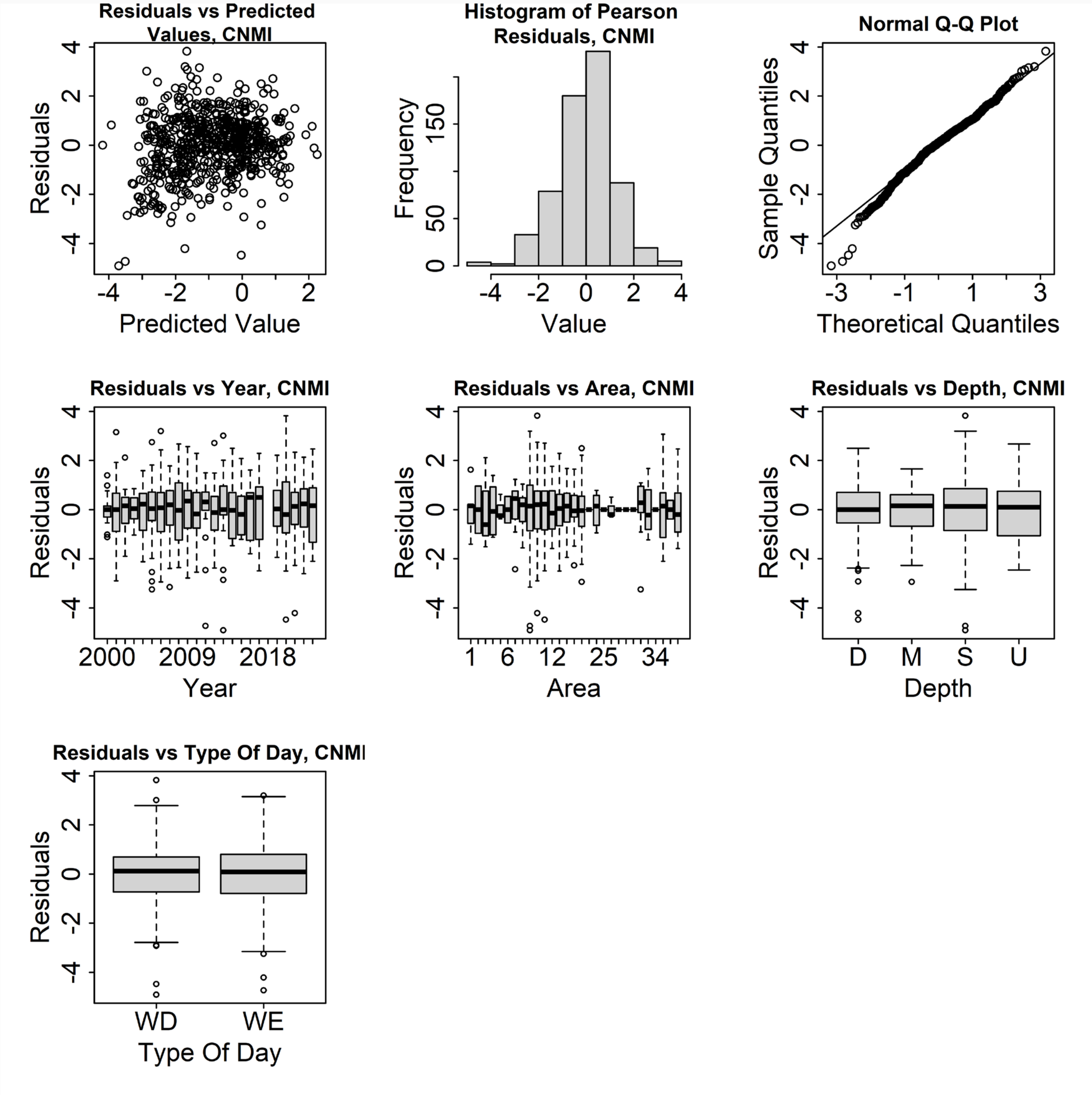

Figure 6. Model diagnostics for the positive process model. Diagnostic plots include plots of residuals against model-predicted values (to assess heteroscedasticity), a histogram of residuals and the quantile-quantile plot (to assess normality), and plots of residuals against values of each covariate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

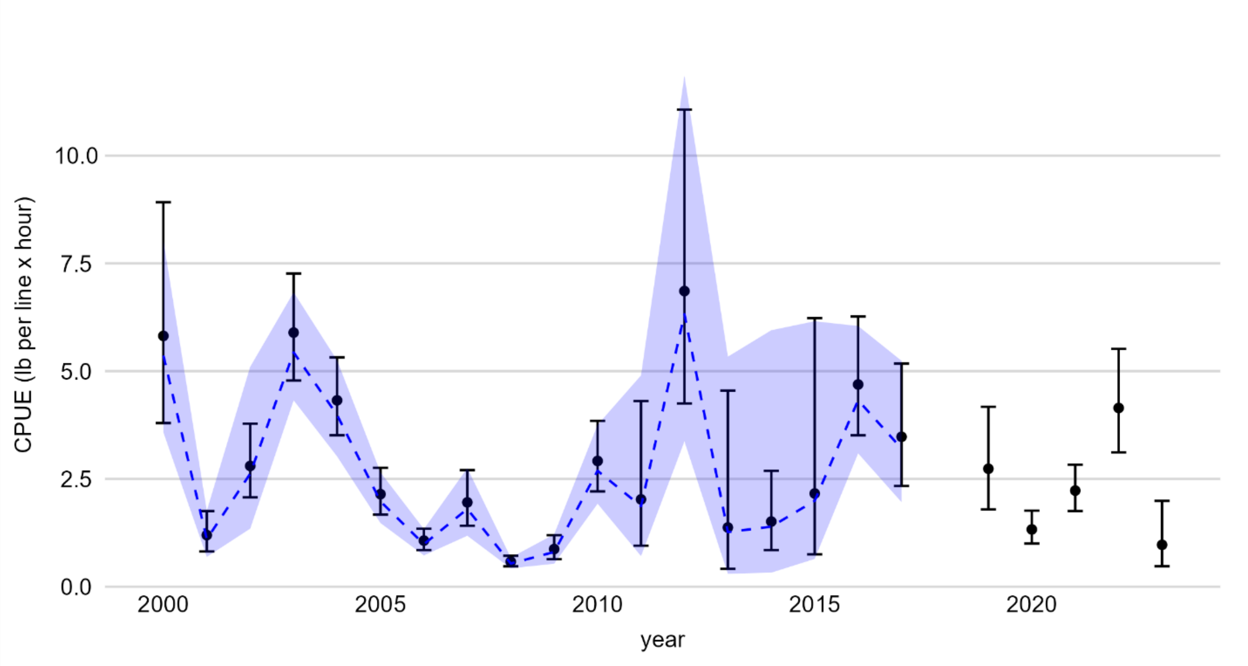

Figure 7. Standardized CPUE index for CNMI BMUS in the current update stock assessment (black points with error bars) and the 2019 benchmark assessment (blue line with shaded ribbon). The error bars and shaded ribbon represent the estimated 95% confidence intervals.

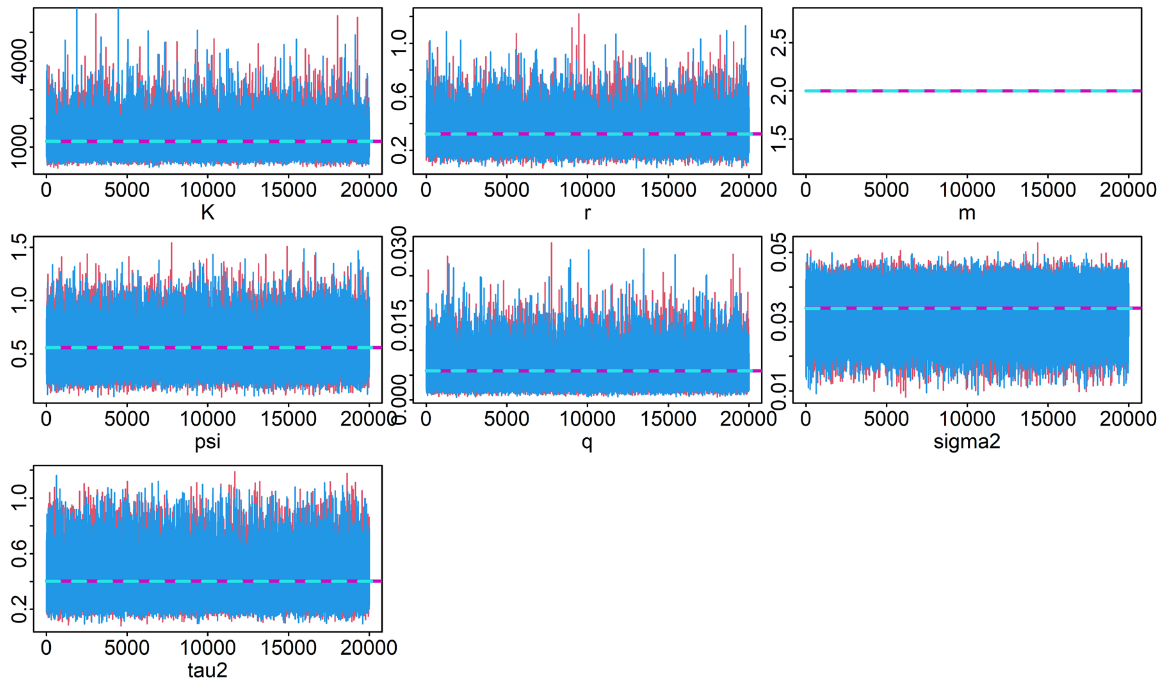

Figure 8. MCMC simulation values for model parameters for bottomfish management unit species in CNMI including carrying capacity (*K*), intrinsic growth rate (*r*), shape parameter (*m*), ratio of initial biomass to carrying capacity (*psi, ψ*), catchability (*q*), process error variance (*sigma2*), and the estimable component of observation error variance (*tau2*). Two MCMC chains of 20,000 iterations each are shown overlaid in red and blue.

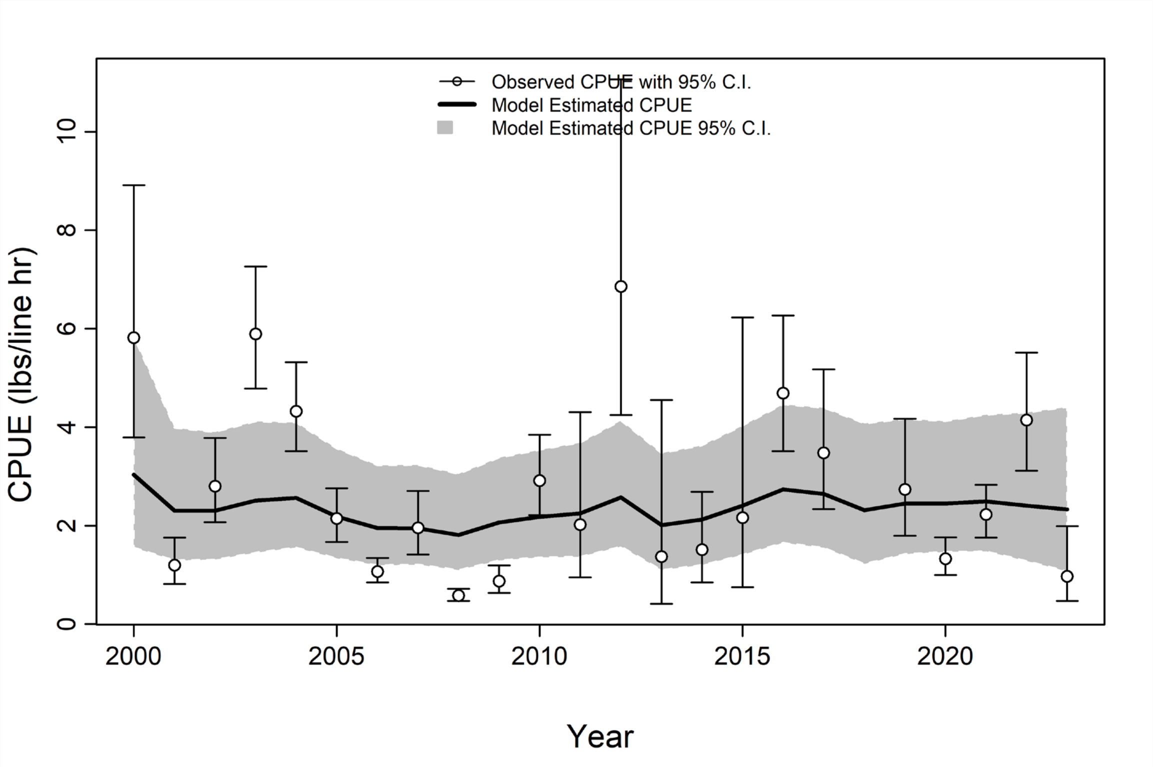

Figure 9. Observed (standardized CPUE) and the CPUE series estimated from the production model for bottomfish management unit species in CNMI from 2000–2023.

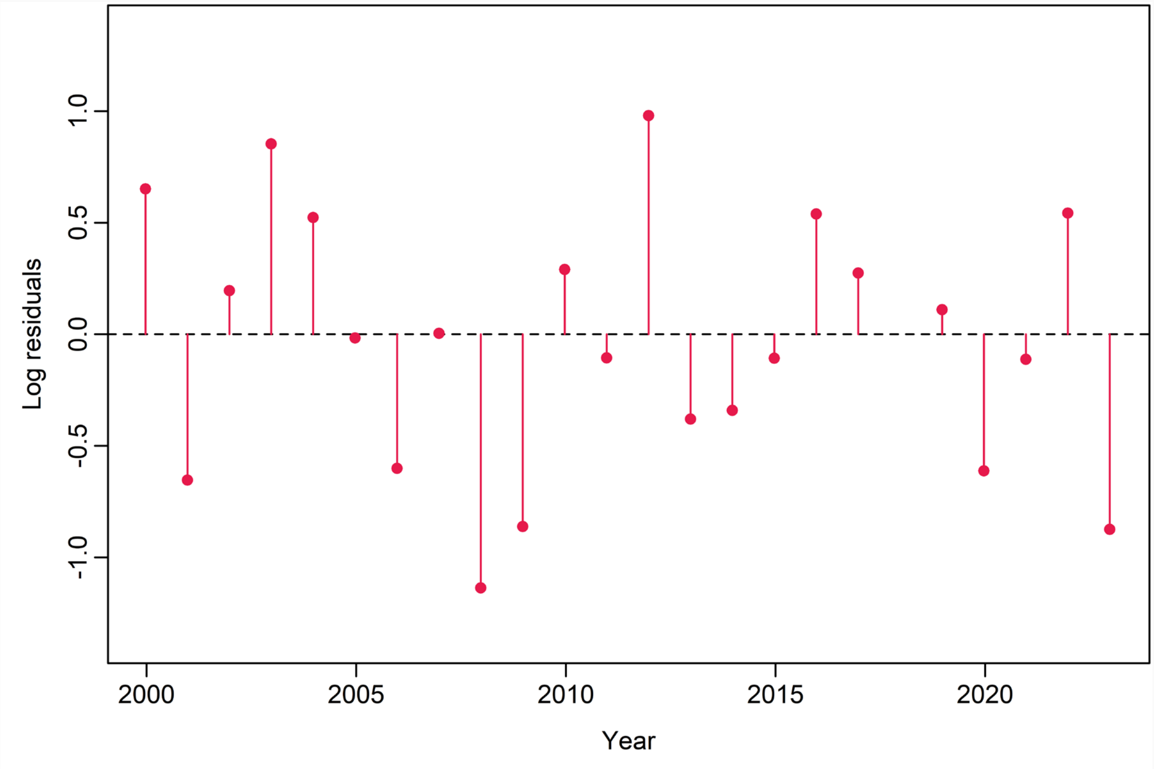

Figure 10. Residuals of production model fit to standardized CPUE for bottomfish management unit species in CNMI from 2000–2023.

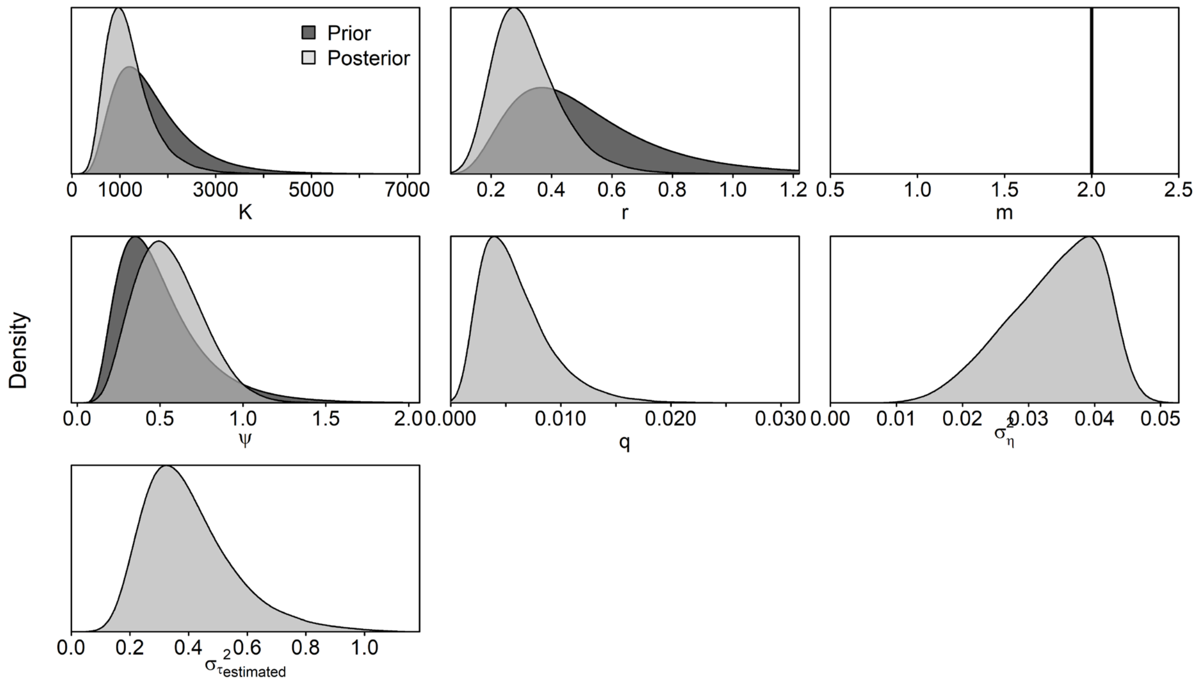

Figure 11. Prior distributions (dark gray) and posterior densities (light gray) for model parameters for bottomfish management unit species in CNMI including carrying capacity (*K*), intrinsic growth rate (*r*), shape parameter (*m*), ratio of initial biomass to carrying capacity (*ψ*), catchability (*q*), process error variance (σ_η^2), and the estimable component of observation error variance ($\sigma_{\tau estimated}^2$). Note that the parameter value for *m* was fixed = 2.

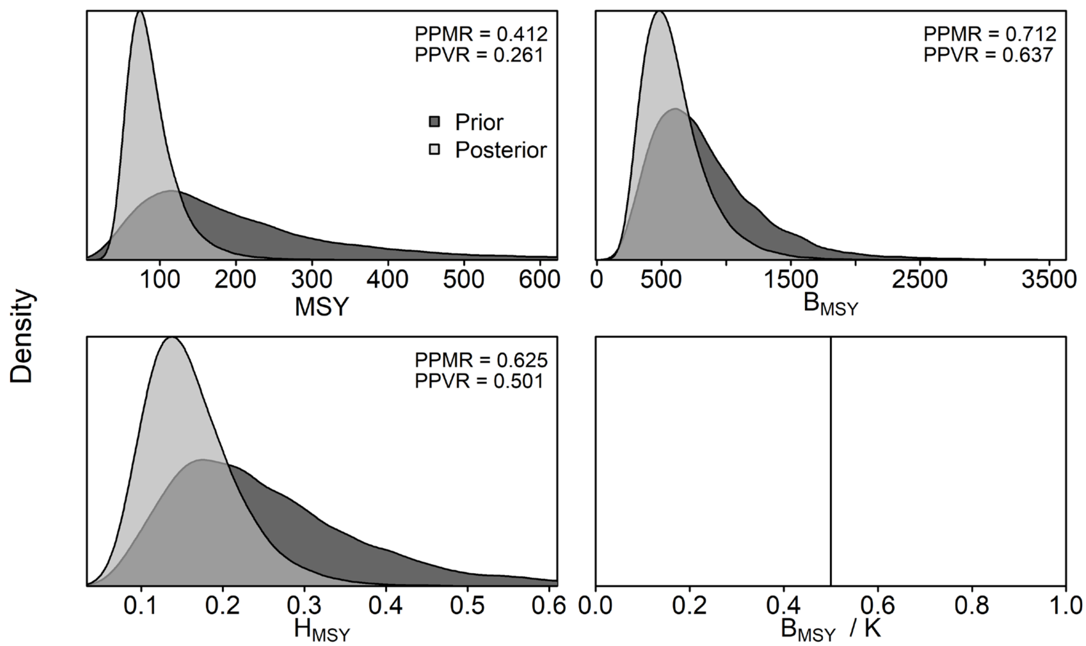

Figure 12. Prior distributions (dark gray) and posterior densities (light gray) for model-derived parameters for bottomfish management unit species in CNMI including maximum sustainable yield (*MSY*), biomass at maximum sustainable yield (B_{MSY}), harvest rate at maximum sustainable yield (H_{MSY}), and biomass at maximum sustainable yield divided by carrying capacity (B_{MSY} / K).

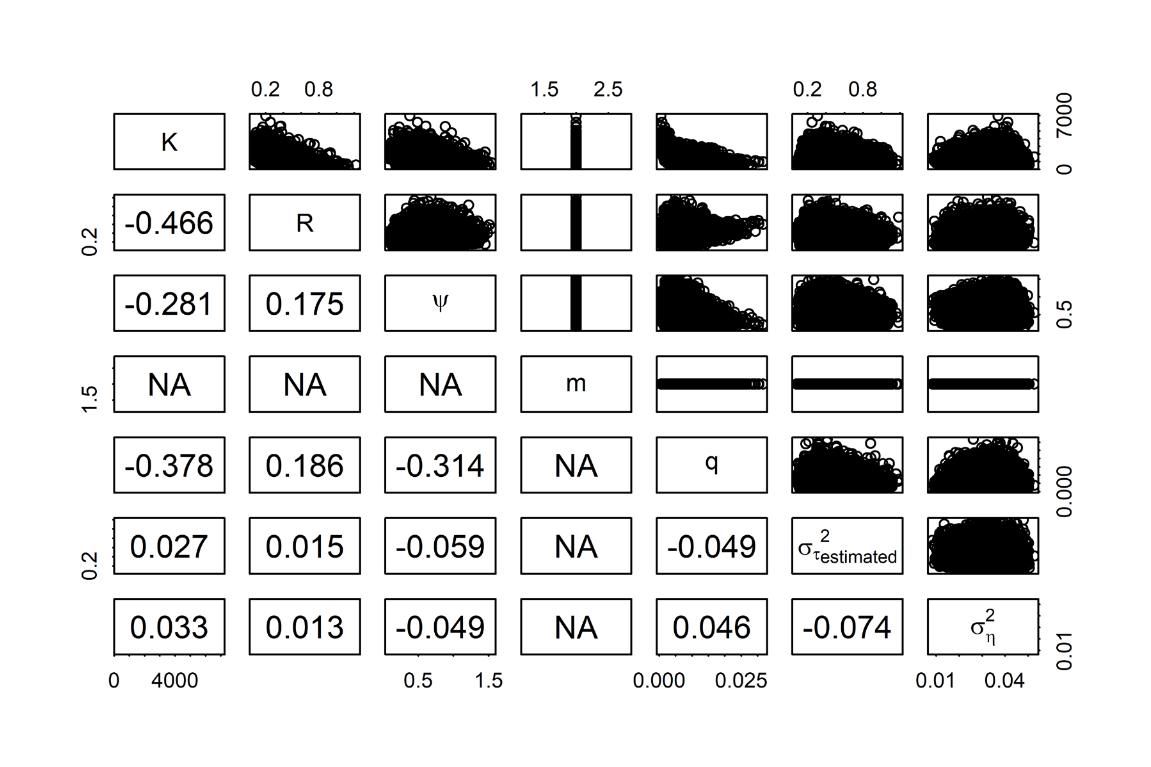

Figure 13. Pairwise scatterplots and correlations for parameter estimates for bottomfish management unit species in CNMI. Parameters are carrying capacity (*K*), intrinsic rate of increase (*R*), ratio of initial biomass to carrying capacity (ψ), shape parameter (*m*), catchability (*q*), the estimable component of observation error variance ($\sigma_{\tau estimated}{}^2$), and observation error variance ($\sigma_\eta{}^2$).

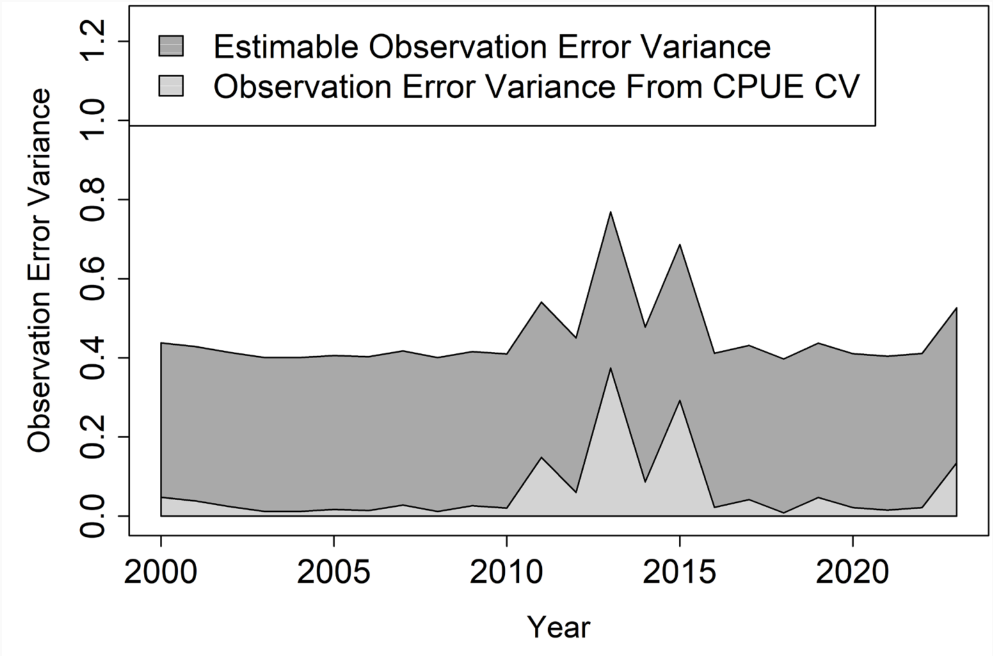

Figure 14. Total observation error variance by year for bottomfish management unit species in CNMI from 2000 through 2023, partitioned into minimum observation error (set to 0), observation error from CPUE (light gray) and estimable observation error (dark gray).

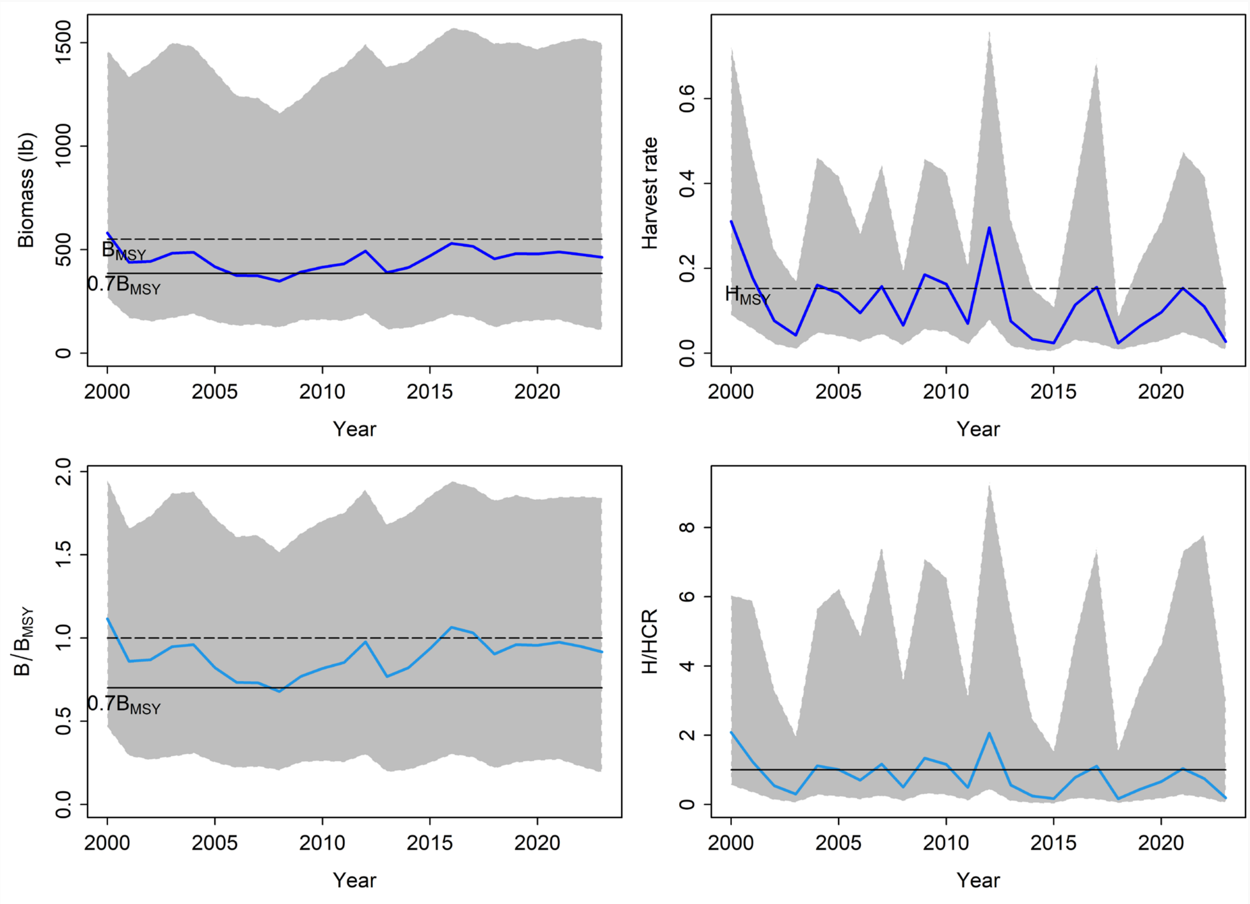

Figure 15. Estimated biomass, harvest rate, relative biomass (B/B_{MSY}), and relative harvest rate (H/H_{CR}) for bottomfish management unit species in CNMI from 2000 through 2023 with 95% credible intervals (shaded area). Solid horizontal lines delineate reference points for biomass ($0.7{*}B_{MSY}$) and harvest rate (H/H_{CR}=1). Dashed horizontal lines delineate B_{MSY} and H_{MSY}.

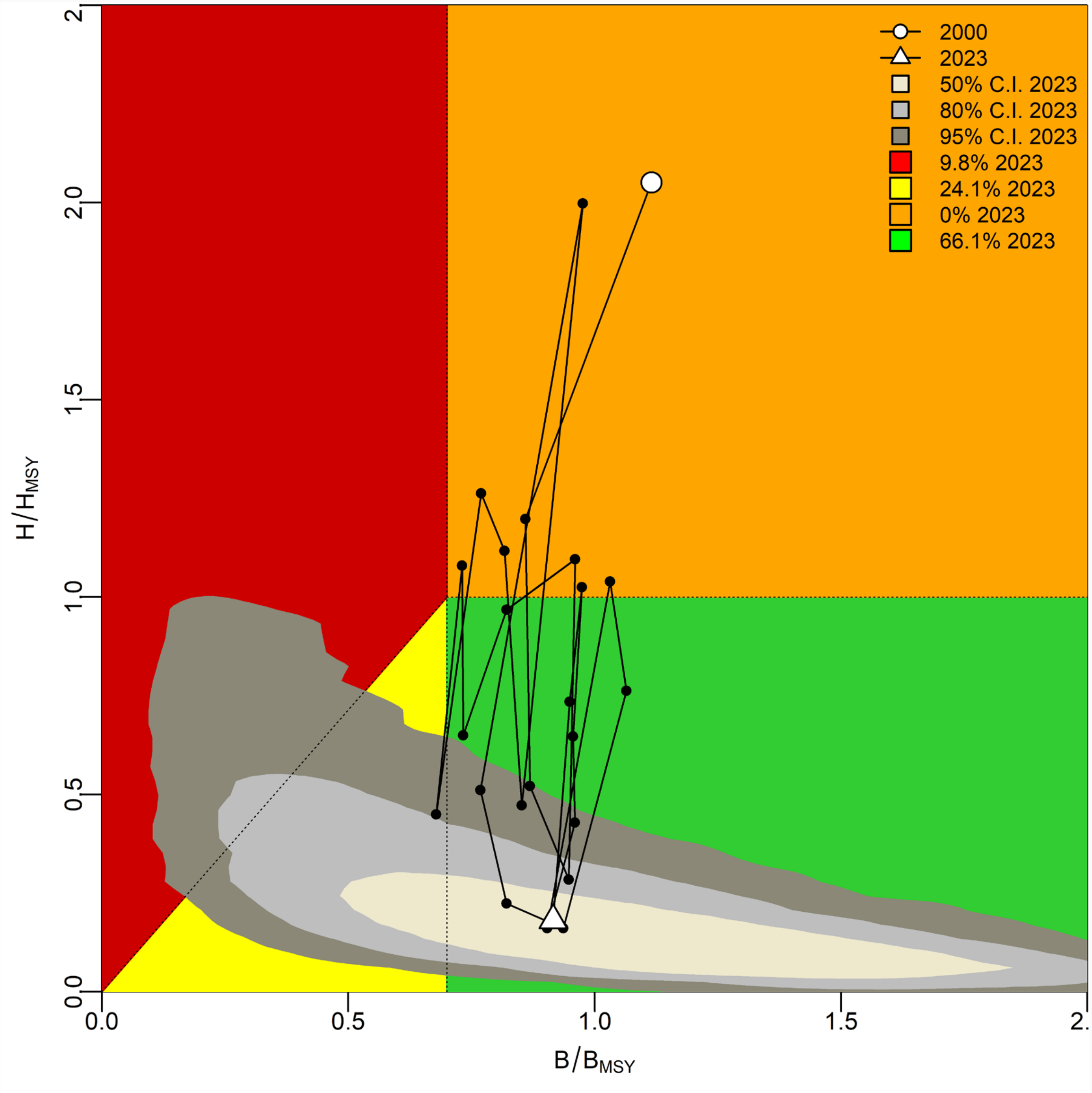

Figure 16. Estimated stock status for bottomfish management unit species in CNMI from 2000 through 2023. The circle denotes the start year, and the triangle denotes the final year. Outer bounds of gray shaded area delineate the 95% credible interval for 2023. Colored areas delineate stock statuses (red = 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.

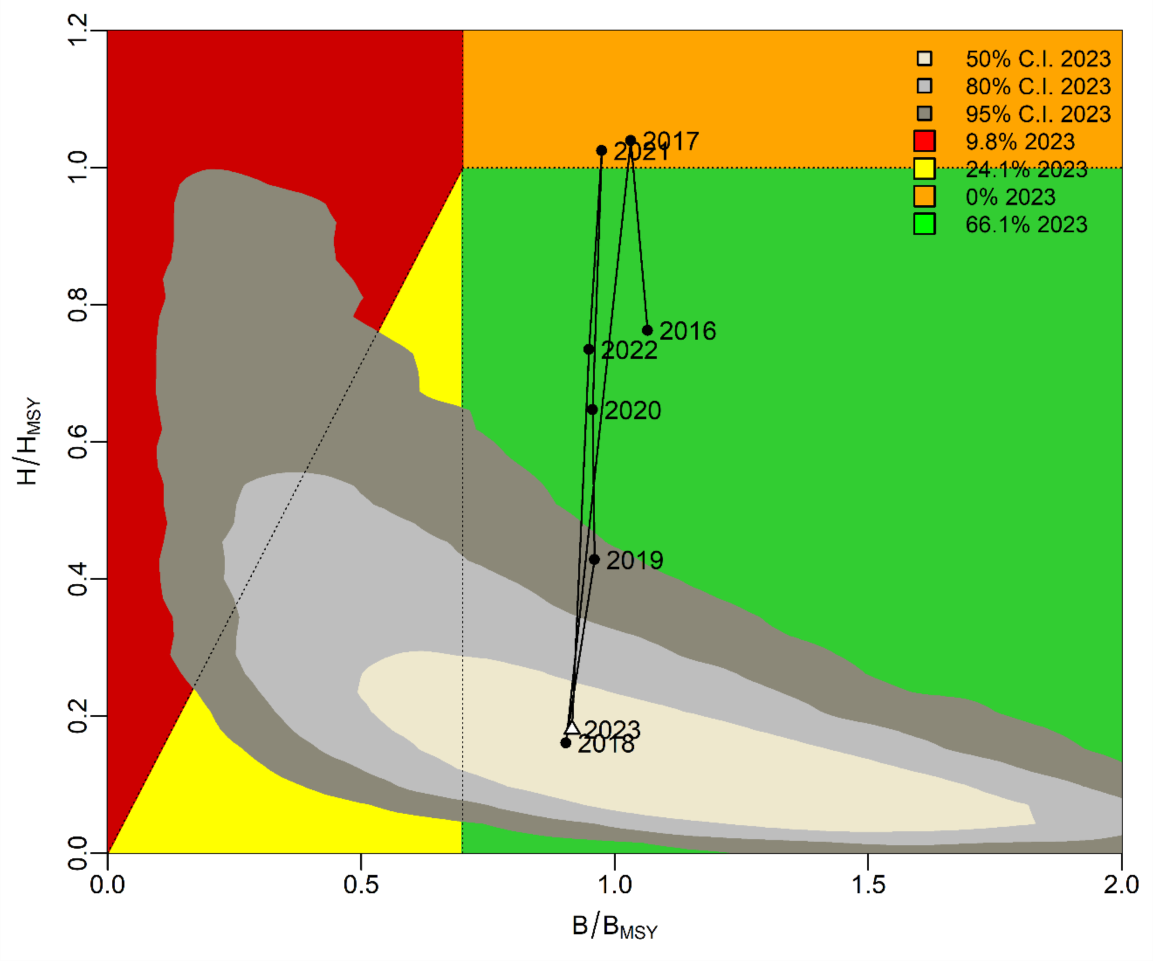

Figure 17. Estimated stock status for bottomfish management unit species in CNMI from 2016 through 2023.Outer bounds of gray shaded area delineate the 95% credible interval for 2023. Colored areas delineate stock statuses (red = overfished and overfishing, yellow = overfished but not overfishing, orange = 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.

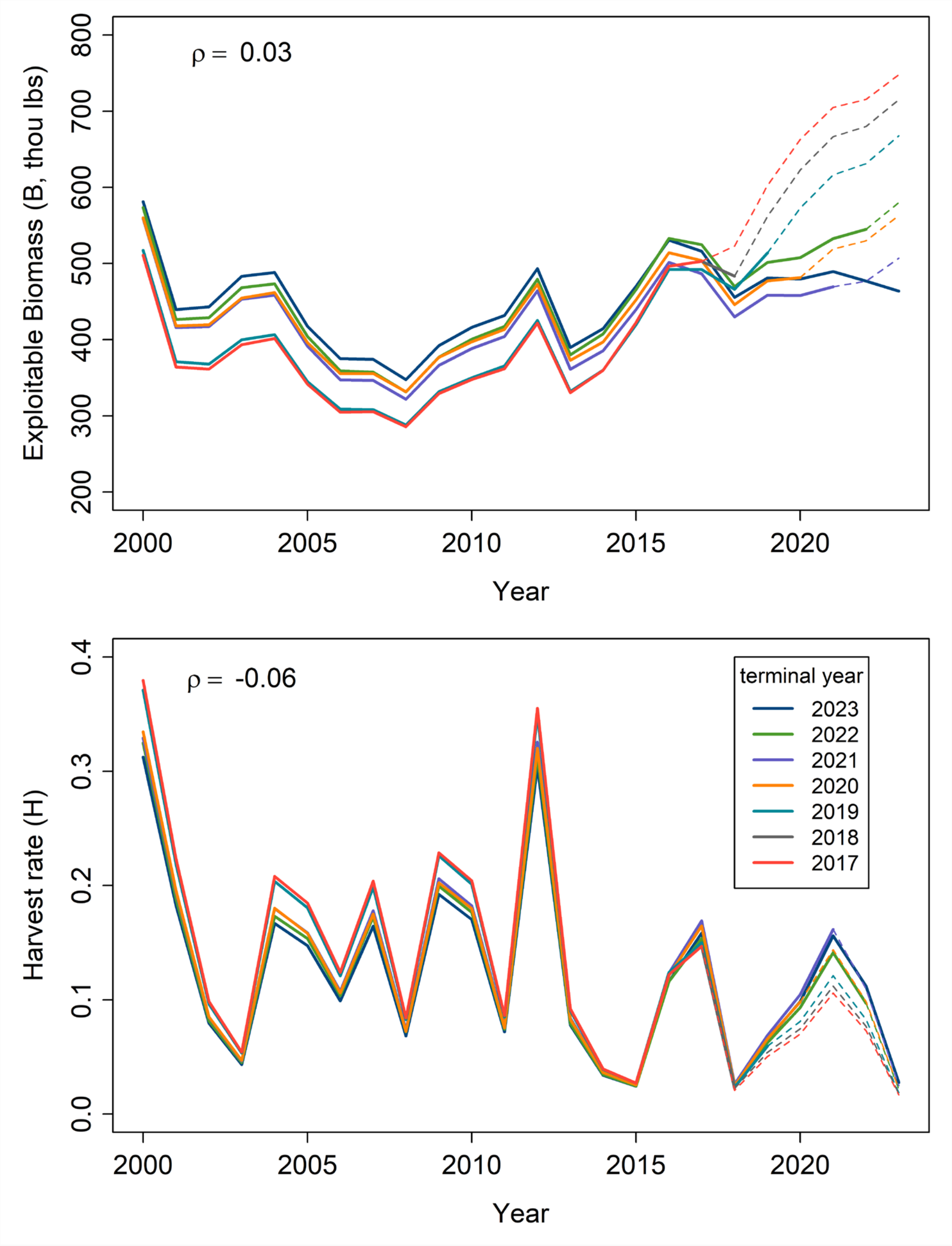

Figure 18. Production model estimated exploitable biomass (*B*) and harvest rate (*H*) time series for bottomfish management unit species in CNMI. Models are shown for truncated time series ranging from the full data set (terminal year 2023; dark blue) to the data years available during the previous 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.

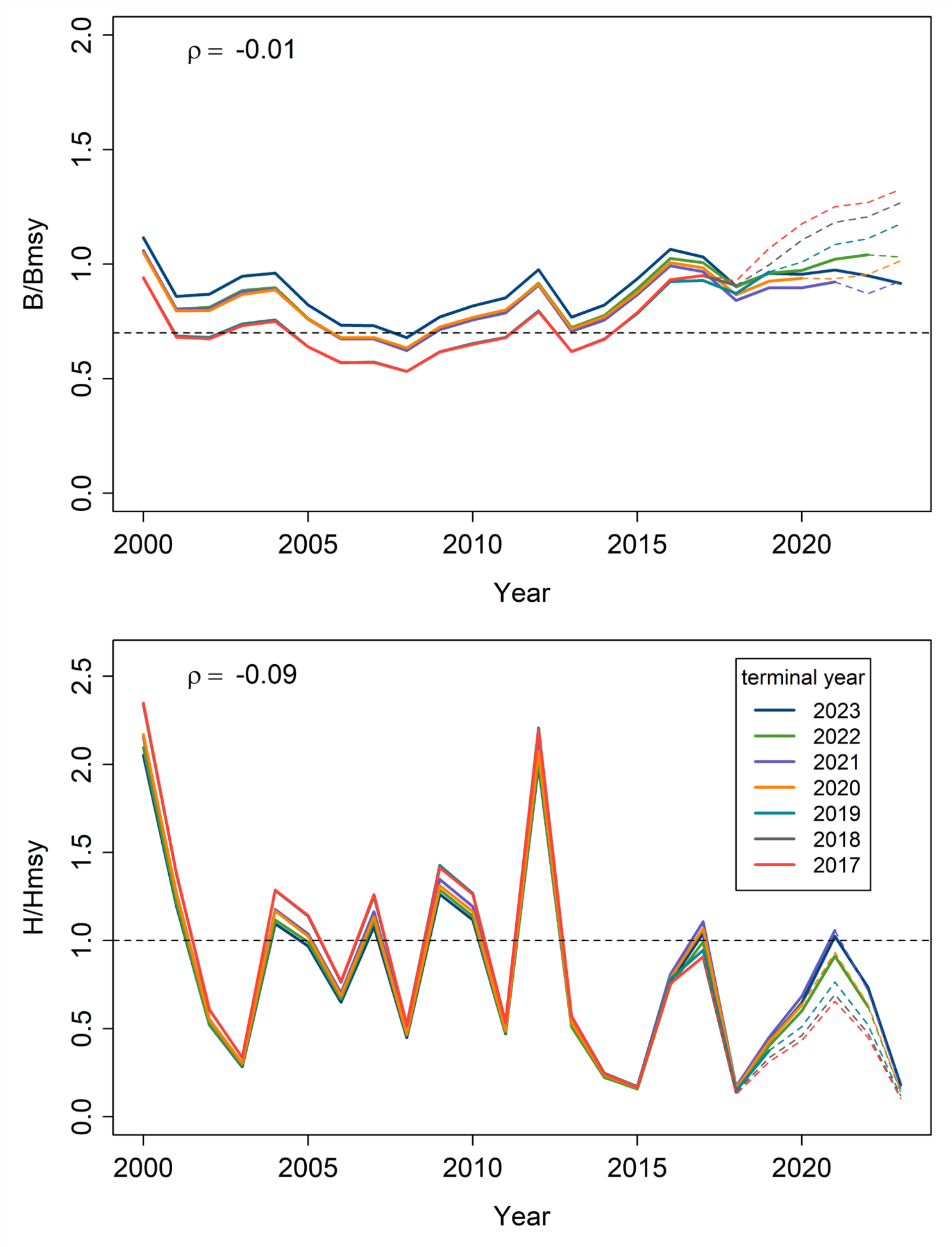

Figure 19. Production model estimated relative biomass (B/B_{MSY}) and harvest rate (H/H_{MSY}) time series for bottomfish management unit species in CNMI. Models are shown for truncated time series ranging from the full data set (terminal year 2023; dark blue) to the data years available during the 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.

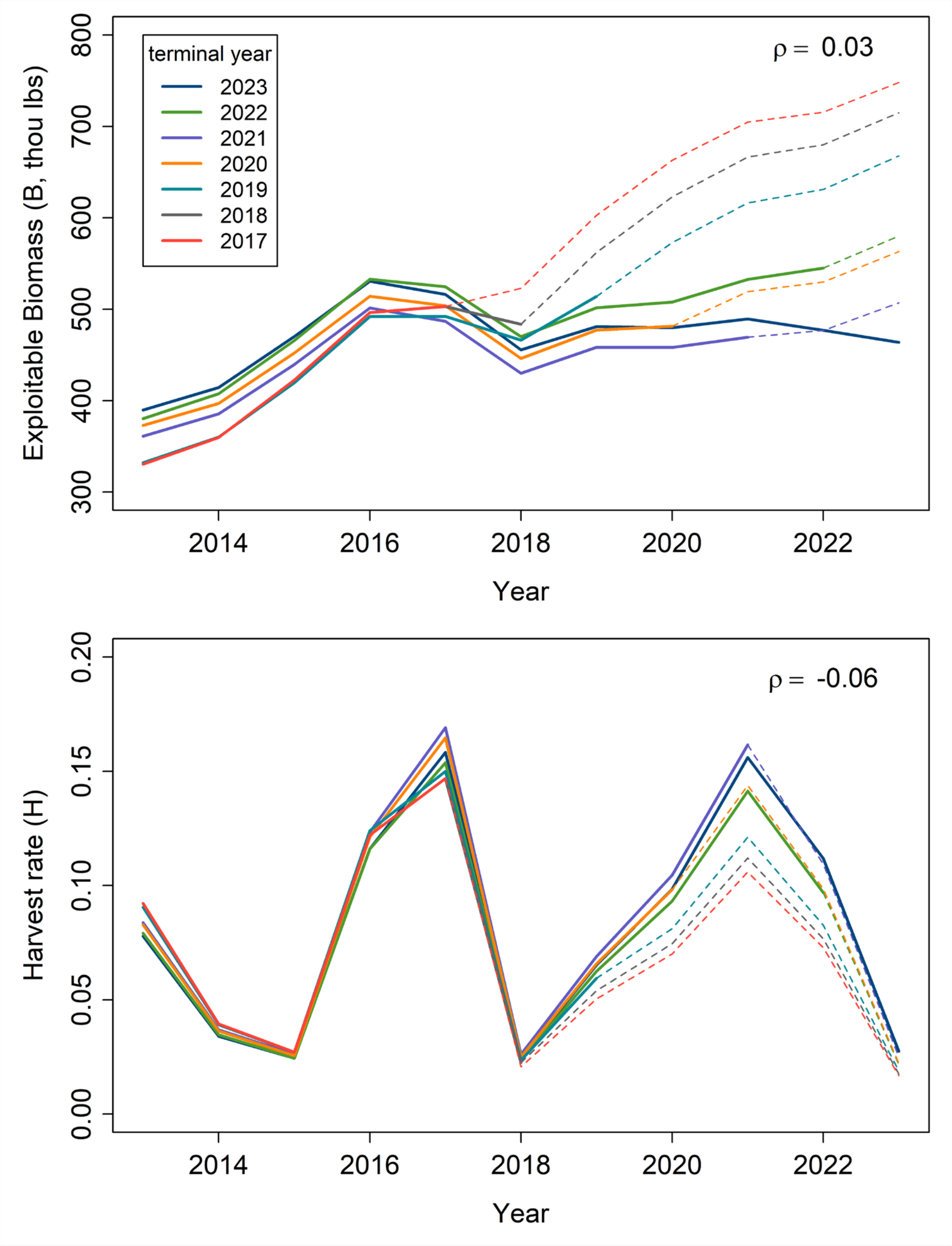

Figure 20. Production model estimated exploitable biomass (*B*) and harvest rate (*H*) from 2013–2023 for bottomfish management unit species in CNMI. Models are shown for truncated time series ranging from the full data set (terminal year 2023; dark blue) to the data years available during the previous 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.

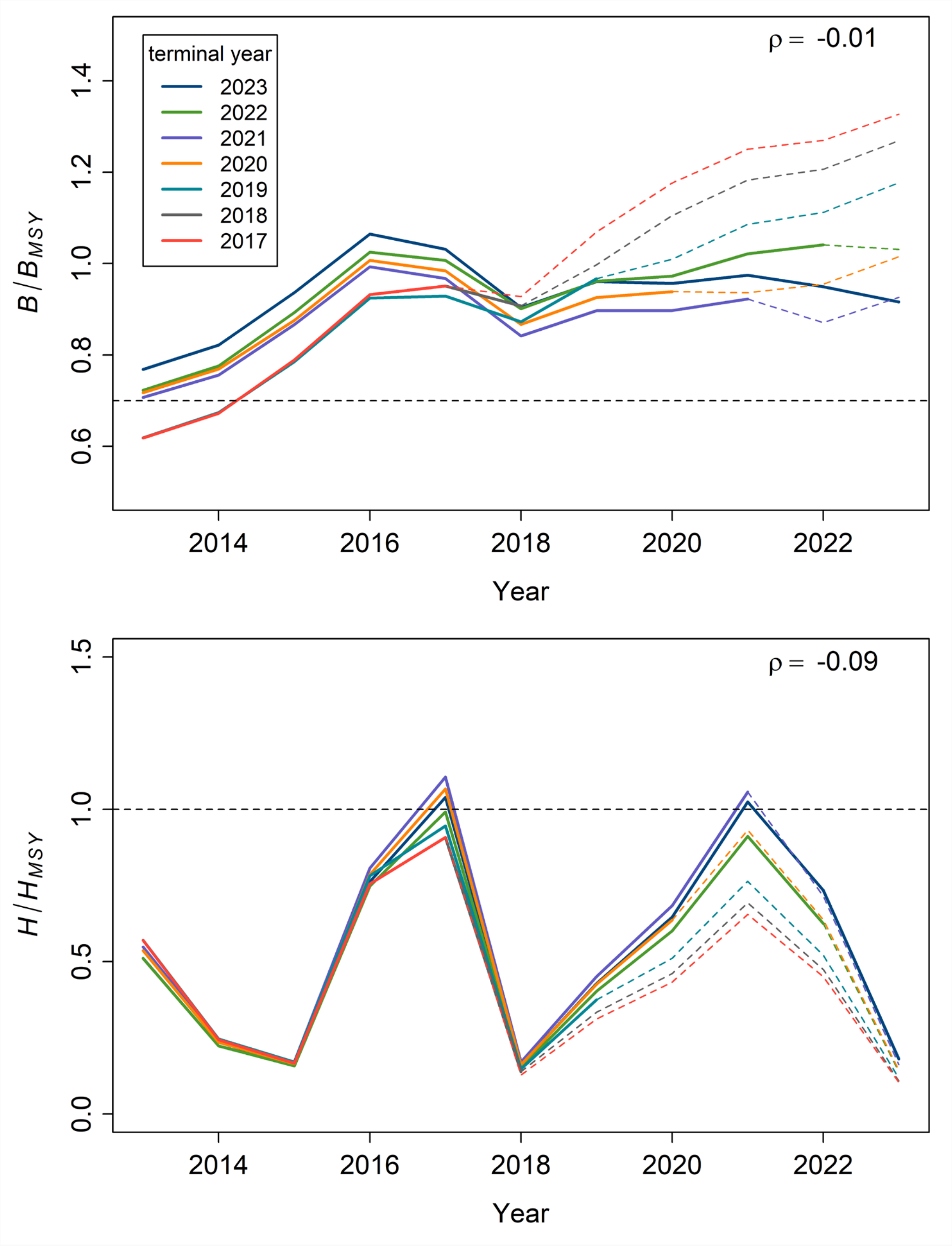

Figure 21. Production model estimated relative biomass (*B/B_{MSY}*) and harvest rate (*H/H_{MSY}*) from 2013–2023 for bottomfish management unit species in CNMI.Models are shown for truncated time series ranging from the full data set (terminal year 2023; dark blue) to the data years available during 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.

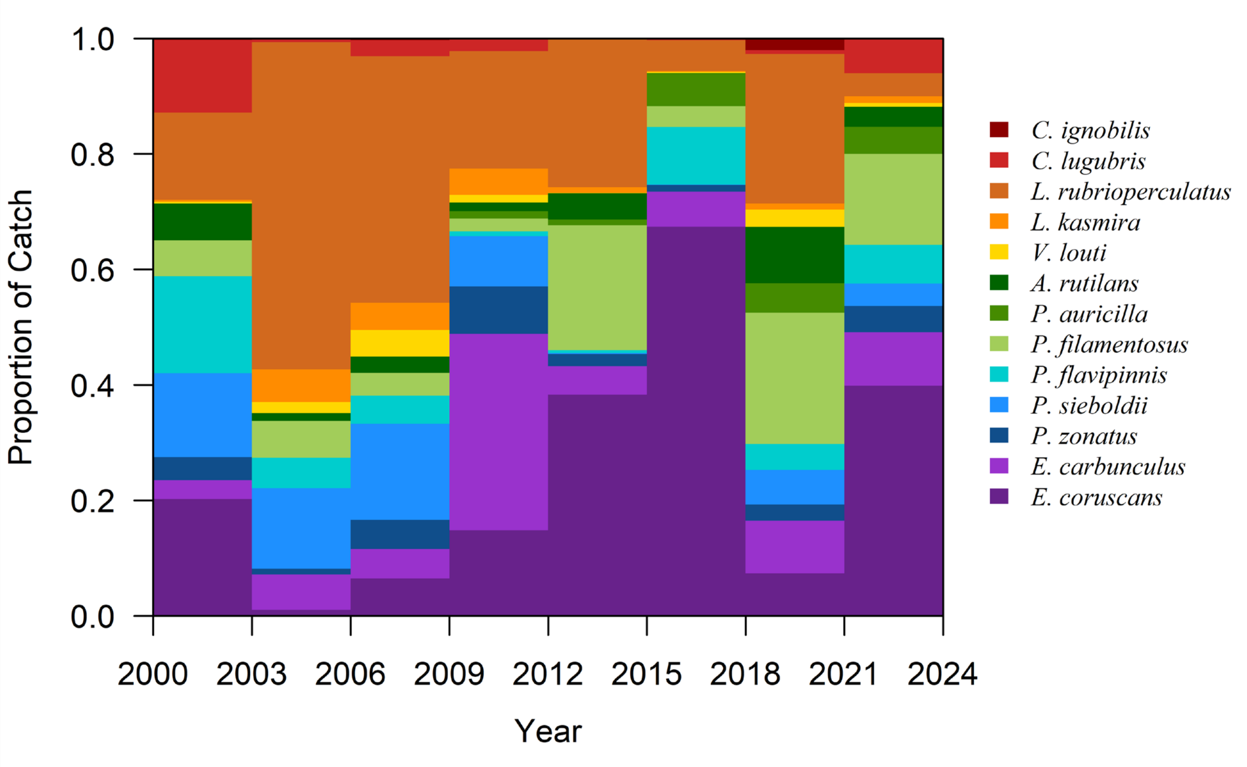

Figure 22. Relative catch composition of CNMI bottomfish management unit species (BMUS), aggregated to three-year periods (2000–2002, 2003–2005, etc.). BMUS are roughly ordered by depth of occurrence within each bar, with warmer colors near the top representing relatively shallower species and cooler colors near the bottom representing relatively deeper species.