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Stock Assessment Updates of the Bottomfish Management Unit Species of American Samoa, the Commonwealth of the Northern Mariana Islands, and Guam in 2015 Using Data through 2013

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ABSTRACT

In this report, we conduct a strict stock assessment update of the Bottomfish Management Unit Species (BMUS) complexes in American Samoa, the Commonwealth of the Northern Mariana Islands, and Guam, using the same base case production model as used in the previous stock assessment (Brodziak et al., 2012), but with an additional 3 years of catch and nominal catch-per-unit-effort (CPUE) as input data. A Bayesian statistical framework is applied to estimate parameters of a Schaefer production model fit to a time series of annual nominal CPUE statistics to provide direct estimates of parameter uncertainty for status determination. The surplus production model is a state-space model, including both process error in biomass production dynamics and observation error in the catch-per-unit effort data. Overall, the American Samoa, the Commonwealth of the Northern Mariana Islands, and the Guam bottomfish complexes were not overfished (overfished is defined as B < 0.7*BMSY) and were not experiencing overfishing (overfishing is defined as H > HMSY) in 2013, the most recent year of the stock assessment estimates.

We conducted stock projections for 2016 and 2017, which projected a range of hypothetical two-year catches and calculated corresponding future risks of overfishing. For the American Samoa BMUS complex, the 2017 catch level that would produce a 50% risk of overfishing in 2017 was 115 thousand pounds. For the Commonwealth of the Northern Mariana Islands BMUS complex, the 2017 catch level that would produce a 50% risk of overfishing in 2017 was 250 thousand pounds. For the Guam BMUS complex, the 2017 catch level that would produce a 50% risk of overfishing in 2017 was 71 thousand pounds. All of these catch values associated with a 50% risk of overfishing in 2017 are much higher than actual bottomfish landings in 2013 for American Samoa, the Commonwealth of the Northern Mariana Islands, and Guam which were approximately 24 thousand, 23 thousand, and 30 thousand pounds, respectively.

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INTRODUCTION

Deep-slope finfish resources are found around all central and western Pacific Islands and reefs where they support small vessel hook and line fisheries. The Western Pacific Regional Fishery Management Council manages these resources within the US Exclusive Economic Zone (EEZ) surrounding American Samoa, the Commonwealth of the Northern Mariana Islands (CNMI), and Guam under the Archipelagic Fishery Ecosystem Plans (FEPs) for American Samoa and the Marianas. The set of Bottomfish Management Unit Species (BMUS) identified within the FEP is comprised of 19 species of snappers, groupers, emperors, and jacks, 17 of which are found in the western Pacific (Table 1). Bottomfish resources are managed around each territory as one multi-species complex. These multi-species stocks are managed as a unit straddling both territorial and federal waters. Although managed as a multi-species stock, in the western Pacific, the BMUS can be further divided, albeit with considerable overlap, into shallow and deep components. In Hawaii, species of the shallow component (e.g., lethrinids and *Lutjanus* spp) are largely lacking compared to American Samoa, CNMI, and Guam. Amendment 6 of the FEP establishes 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. Overfished is defined as the stock biomass B falling below the Minimum Stock Size Threshold (MSST) of (1-M)*BMSY, where M is the natural mortality rate and BMSY is the biomass that produces the maximum sustainable yield. In the previous assessment, M was defined as 0.30, so the overfished definition is defined as B < 0.7*BMSY. Overfishing is defined as a fishing/harvest rate H that exceeds the Maximum Fishing Mortality Threshold (MFMT) of HMSY, the harvest rate that produces maximum sustainable yield. The fishery status with respect to these criteria is reported to Congress annually and mandatory management measures are required when overfishing or overfished thresholds are breached according to the Magnuson-Stevens Fishery Conservation and Management Act. These status determinations are applicable to the multi-species stocks as a whole and not to their shallow and deep components separately.

In this report, we update the status of BMUS complexes of American Samoa, CNMI, and Guam using the same production model as was used in the previous stock assessment (Brodziak et al., 2012, Moffitt et al., 2007). The production model relies on fishery-dependent data collected by territorial agencies (American Samoa Department of Marine and Wildlife Resources, CNMI Division of Fish and Wildlife, and Guam Division of Aquatic and Wildlife Resources) and shared with the Western Pacific Fisheries Information Network (WPacFIN). Currently, there are no fishery-independent measures of relative or absolute bottomfish abundance. The surplus production model is a state-space model that includes both process error in biomass production dynamics and observation error in the catch-per-unit effort data. We calculate status determinations resulting from the production model and stock projection results.

Description of the Fisheries

American Samoa

Prior to European contact, indigenous fishers of the Samoan Islands fished for subsistence from canoes using pearl shell hooks and sennit lines. They caught many fish species including some BMUS. By the 1950s, the Samoa fleet had adopted small boats equipped with outboard engines and fished with steel hooks and monofilament lines, but the fishery remained for subsistence only. Surveys conducted in the late 1960s by the American Samoa Office of Marine Resources revealed substantial deep bottomfish resources around the island of Tutuila, and by the early 1970s a small commercial fishery was established. In an attempt to develop local fisheries, 2 subsidized boat building programs, the dory program in the 1970s and the *alia* program in the 1980s, provided fishers with low cost vessels. The bottomfish fleet expanded in the mid-1980s with a government subsidized project aimed at exporting deep-water snappers to Hawaii (Itano 1996). At the fishery's peak in 1984, 48 vessels fished for bottomfish. Declines in participation in this fishery can be attributed to shifts in the importance of bottomfish fishing compared to trolling and longlining for pelagic species and to the periodic impact of hurricanes. In 1987, for example, hurricane Tusi damaged or destroyed a large segment of the small boat fishing fleet. In 2005, a total of 16 part-time vessels participated in the bottomfish fishery (WPRFMC, 2006). Most vessels are small aluminum *alia* catamarans (< 30 ft) with low-tech fishing practices (e.g., no depth sounders, electric or hydraulic reels, global positioning systems, or ice chilling capability) (WPRFMC, 2006). In recent years, however, a number of larger (> 35 ft) vessels with higher technological capability have been entering the fishery (WPRFMC, 2006). As in Guam, during the period 1986-2005, fishing effort (in line hours) spent targeting the shallow bottomfish component was nearly double that spent on the deep component.

Commonwealth of the Northern Mariana Islands

The CNMI consists of a series of islands in the long Mariana Islands chain, excluding Guam, extending approximately 500 nm in a north- south direction, paralleled by a chain of seamounts about 150 nm to the west. Most of the fishing activity occurs around the population centers of Rota, Tinian, and Saipan and extends north to Zealandia Bank, approximately 120 nm north of Saipan. In 2005, a total of 62 vessels ranging in size from small skiffs to boats 70 feet in length reported commercial catches of bottomfish. It is likely, however, that in addition to commercial fishing many more small skiffs conduct bottomfishing for subsistence. The shallow BMUS component, dominated by *Lethrinus rubrioperculatus*, is fished both commercially and for subsistence with most fishing trips made by small vessels using handlines or homemade hand or electric reels and lasting a single day. In contrast, the deep BMUS component is fished primarily commercially. In the late 1980s to early 1990s there were 12-15 large vessels (~ 70 ft) on Saipan that would fish around Saipan but also to the Northern Islands, while currently the fishing effort includes two large vessels that fish seasonally. The larger vessels conduct multi-day trips and employ electric or hydraulic reels.

Guam

Guam is the largest and southernmost of the Mariana Islands. In Guam, bottomfish are caught by a combination of recreational, subsistence, and small-scale commercial fishing operations. In 2005, a total of 233 vessels were reported to participate in bottomfishing activities. Most of the fleet consists of vessels less than 25 ft in length that target the shallow species components around Guam for recreational or subsistence purposes. Some recreational vessels (< 25 ft) also target the deep component at the offshore banks and other areas offshore of Guam where deep bottomfish habitat occurs. Larger vessels (> 25 ft) fishing commercially target the deep species components at offshore banks (e.g., Galvez and Santa Rosa Banks to the south and Rota Bank to the north). From 1982 to 2005, the fishing effort exerted on the shallow component was nearly double that spent on the deep component.

METHODS

In all 3 territory areas, creel surveys are used to collect fishery data by territorial agencies and then passed to the Western Pacific Fisheries Information Network. Participation in the surveys by the fishers is voluntary. Survey coverage and quality of data collected vary both by location and over time. The current American Samoa Offshore Creel Survey was initiated in October 1985, and records landings and effort of commercial, recreational, and subsistence fishers. The CNMI creel survey is a more recent program, with data available starting in 2000. Prior to the creel survey, data were collected through the voluntary Commercial Purchase Database program, which provided data starting in 1983. Under this program, first-level purchasers of local fresh fish provided records of purchases by species categories that did not necessarily correspond to BMUS. Guam has been collecting voluntary fishery creel data since the late 1960s, although only boat-based creel data collected since 1982 are being used for analysis. Data collected prior to 1982 are not as extensive as required to apply the expansion algorithm used in the current database program, although efforts to incorporate species composition data and CPUE data (catch-per-unit-effort) for years prior to 1982 are ongoing. Collection of bottomfish catch data from the east side of the island is hampered by logistical problems and lack of voluntary reporting. The east side of the island is heavily fished for both shallow and deep bottomfish species during the calmer summer months. The current statistical expansion of fishery data, however, adjusts for this to the extent possible.

For each territory, catch data from the surveyed subset of fishing trips are expanded to estimate total catch for the territory. This assessment uses data on catch and effort from each territory to calculate total BMUS catch and CPUE for each territory. While there are other datasets available such as the WPacFIN biosampling program and the federal permit logbook dataset of catch and effort for bottomfishing, those data were not considered for use in this stock assessment because it was conducted as a strict update. Future benchmark stock assessments will consider alternative and additional data sources. However, investigation of the federal logbook dataset of catch and effort for bottomfishing in each of the territories revealed that the data are sparse, starting in 2009 with only 0-5 permit holders reporting annually. Until there is a higher reporting rate, this dataset is likely not useful for future stock assessment purposes.

We will estimate BMSY by using independent estimates of MSY-level landings reported in Our Living Oceans report (OLO) (Humphreys and Moffitt, 1999; Moffitt and Humphreys, 2009), which used methods developed by Polovina and Ralston (1986). Determinations of overfishing and overfished status can then be made by comparing current biomass and harvest rates to MSY-level reference points. In accordance with the FEP, these status determinations are made for the multi-species BMUS stock as a whole for each territory, and not for their deep and shallow components separately.

Calculating Catch

Catch is calculated using the same methods employed in the previous assessment (Brodziak et al., 2012) and further described below.

For American Samoa, we first selected catch of all BMUS species listed in Table 1, using expanded species annual catch files from WPacFIN. We then divided catch from miscellaneous species groupings (categories such as “grouper”, “snapper”, and “bottomfish”) into BMUS and non-BMUS portions using a ratio of 75% BMUS to non-BMUS, as determined in the previous assessment, based on data from years with the most extensive reporting of species composition statistics. Total annual BMUS catch for American Samoa was calculated as the sum of expanded catch for all BMUS species and the estimated BMUS portion of expanded catch for miscellaneous bottomfish groupings. We calculated annual catch of bottomfish in American Samoa for 2006-2013, and compared catch estimates from 2006 to 2010 to catch estimates from the previous assessment to double check against current methods.

For CNMI, the previous assessments used commercial purchase data instead of creel survey data to calculate catch because of the shorter duration of creel survey data availability. In these data, landings are for all species caught with bottomfishing gear and include more species than those included in BMUS (Table 1). This commercial purchase dataset was again used to calculate annual BMUS catch in CNMI. We calculated annual catch of bottomfish in CNMI for 2006-2013, and compared catch estimates for 2006-2010 to catch estimates from the previous assessment to double check against current methods.

For Guam, we used the expanded species annual catch files from WPacFIN to extract total annual catch of all BMUS species listed in Table 1. We calculated annual catch of bottomfish in Guam for 2006-2013, and compared catch estimates from 2006 to 2010 to catch estimates from the previous assessment to double check against current methods.

Calculating CPUE

Nominal CPUE is also calculated using the same methods employed in the previous assessment (Brodziak et al., 2012) and described here. For American Samoa and Guam, we used the WPacFIN non-expanded interview data on catch and effort, and calculated annual nominal CPUE in units of lbs/line hour. For CNMI, we used the WPacFIN commercial purchase dataset and calculated annual nominal CPUE in units of lbs/trip.

For each territory except CNMI, we first selected trips where 50% or more of the catch was BMUS. In CNMI, we selected trips that reported using bottomfishing gear. Then we calculated the pounds of BMUS species (Table 1) caught in each of these bottomfishing trips, and divided this catch by the total effort reported for each trip (line hours for American Samoa and Guam, and trip for CNMI). We calculated annual nominal CPUE of bottomfish for each territory for 2006-2013, and compared catch estimates from 2006 to 2010 to catch estimates from the previous assessment to ground-truth current methods. The catch time series are nominal and have not been standardized, so they do not account for factors other than changes in stock abundance that may be influencing CPUE.

Production Model Assessment Method

The bottomfish surplus production model used in this report is a state-space model with explicit process and observation error terms (see Meyer and Millar, 1999). This Bayesian model has been used in some groundfish assessments where more complex assessment approaches were not successful due to limited data or other factors (see, for example, Brodziak et al., 2001; Brodziak et al., 2011). In this approach, the unobserved biomass states are estimated from the observed relative abundance indices (CPUE) and catches based on an observation error likelihood function and prior distributions for model parameters (θ). The observation error likelihood measures the discrepancy between observed and model predictions of CPUE.

The process dynamics are based on a Schaefer surplus production model with an annual time step and a time horizon of N years. Under this 2-parameter model, current biomass (B_T) depends on the previous biomass, catch (C_{T-1}), the intrinsic growth rate (r) and carrying capacity (K) for T = 2, …, N as

(1) $$B_T = B_{T-1} + rB_{T-1}\left(1 - \frac{B_{T-1}}{K}\right) - C_{T-1}$$

Maximum surplus production occurs when biomass is equal to ½ of K. The values of biomass and harvest rate that maximize surplus production are relevant for fishery management; the biomass that maximizes surplus production is BMSY=K/2. The corresponding harvest rate that maximizes surplus production is HMSY=r/2 and the maximum surplus production is MSY = rK/4.

The production model can be reparameterized by considering the ratio (or proportion) of stock biomass to carrying capacity (P=B/K) to improve the efficiency of the Markov Chain Monte Carlo estimation algorithm. Given this parameterization, the process dynamics are

(2) $$P_T = P_{T-1} + rP_{T-1}(1 - P_{T-1}) - \frac{C_{T-1}}{K}$$

The process dynamics are subject to natural variation due to fluctuations in life history parameters, trophic interactions, environmental conditions, and other factors. In this context, the process error can be assumed to represent the joint effect of a large number of random multiplicative events which combine to form a multiplicative lognormal process under the Central Limit Theorem. Given this assumption, the process error terms are independent and lognormally distributed random variables $\eta_T = e^{U_T}$ where the U_T are normal random variables with mean 0 and variance σ^2.

The state equations define the stochastic process dynamics by relating the unobserved biomass states to the observed catches and the population dynamics parameters. Given the lognormal process error assumption, the state equations for the initial time period T = 1 and subsequent periods T > 1 are

(3)
$$P_1 = \eta_1$$
$$P_T = \left(P_{T-1} + rP_{T-1}(1 - P_{T-1}) - \frac{C_{T-1}}{K} \right)\eta_T$$

These equations set the prior distribution for the ratio of biomass to carrying capacity, $p(P_T)$, in each time period T, conditioned on the previous proportion.

Observation Error Model

There are two components to the observation error model. The first component relates the observed fishery CPUE to the biomass of the bottomfish complex. Here it will be assumed that the CPUE index (I) is proportional to biomass with catchability coefficient Q:

(4) $$I_T = QB_T = QKP_T$$

The observed CPUE dynamics are also subject to sampling variation which is assumed to be lognormally distributed. The observation errors are $\nu_T = e^{v_T}$ where the v_T are iid normal random variables with mean 0 and variance τ^2. Given this, the observation equations for T = 1,…, N are

(5) $$I_T = QKP_T \nu_T$$

This specifies the CPUE observation error likelihood function $p(I_T|\theta)$ for each period.

The second component of the observation error model relates to previously developed estimates of the maximum sustainable yield for the Guam, American Samoa, and CNMI bottomfish complexes to the model parameters r and K. Published estimates of MSY based on research conducted in the Marianas (Polovina et al., 1985), and extended to include American Samoa, are found in the Our Living Oceans report (OLO) by Humphreys and Moffitt (1999) and Moffitt and Humphreys (2009). The methods used to estimate MSY are described in Polovina and Ralston (1986), and are a fishery-independent estimate which combines 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. The results are extrapolated along pre-determined isobaths for each territory.

These OLO MSY estimates are 75,000 pounds, 172,000 pounds, and 55,000 pounds respectively for American Samoa, CNMI, and Guam. Each MSY estimate (MSY_{OBS}) is taken to be a data point and compared to the prediction of the MSY value (MSY_{PRED}) for each territory. The predicted MSY value is a function of r and K with $MSY_{PRED} = rK/4$. The observation error for the MSY value is assumed to be $\omega = e^W$ where W is a normal random variable with mean 0 and variance w^2. Given this, the observation equation for the MSY data is

(6) $$MSY_{OBS} = \frac{rK}{4}\omega$$

This specifies the MSY observation error likelihood function p(MSY| θ). Given this, the product of the CPUE error likelihood and the MSY observation error likelihood is the complete observation error model.

Prior Distributions

To use this Bayesian approach, prior distributions are needed to quantify existing knowledge, or the lack thereof, for each parameter and the unobserved biomass state. The model parameters consist of the carrying capacity, intrinsic growth rate, catchability, the process and observation error variances, and ratio of initial biomass to carrying capacity. The unobserved states are the ratios of biomass to carrying capacity, P_T, for $T > 1$, each conditioned on the previous proportion. Table 2 contains a summary of the assumed prior distribution values for all parameters used, and a detailed description of each prior follows.

Prior for Carrying Capacity

The prior distribution for the carrying capacity p(K) of bottomfish for each territory was chosen to be a diffuse (noninformative) normal distribution with mean (μ_K) variance (σ^2_K) parameters:

(7) $$p(K) = \frac{1}{\sqrt{2\pi}\sigma_K}\exp\left(-\frac{(K-\mu_K)^2}{2\sigma_K^2}\right)$$

Initial mean values of the K parameters for each area were 700 thousand, 1400 thousand, and 300 thousand pounds for American Samoa, CNMI, and Guam respectively, based on the base case values of the previous stock assessment (Brodziak et al., 2012) which explored alternative starting values for K before choosing base case values based on goodness-of-fit. The coefficient of variation of K was set to 20% for each territory to allow for a range of fitted carrying capacity estimates.

Prior for Intrinsic Growth Rate

The prior distribution for intrinsic growth rate p(r) was chosen to be a beta distribution with parameters c and d:

(8) $$p(r) = \frac{\Gamma(c+d)}{\Gamma(c)\Gamma(d)}x^{(c-1)}(1-x)^{(d-1)}$$

This choice constrained the intrinsic growth rate estimate to be within the interval [0, 1] which was considered to be a reasonable range given the life history of species in the bottomfish complexes. The values of c and d were chosen to produce a mean of $\mu_r = 0.46$ for each territory, with a coefficient of variation of 50%. This mean value is the same for all territories and was used in the base case model in the previous stock assessment (Brodziak et al., 2012) based on r values estimated in an earlier stock assessment (Moffitt et al., 2006). This prior for intrinsic growth rate was moderately informative and allowed for variation about the mean value.

Prior for Catchability

The prior for catchability p(Q) in each territory was chosen to be a diffuse (noninformative) inverse-gamma distribution with scale parameter λ and shape parameter k.

(9) $$p(Q) = \frac{\lambda^k Q^{-(k+1)}}{\Gamma(k)} \exp\left(\frac{-\lambda}{Q}\right)$$

The scale and shape parameters were set to be λ = k = 0.001. This choice of parameters gives the inverse of Q a mean of 1 and a variance of 1000. As a result, the prior for catchability is approximately p(Q) is proportional to Q^{-1}. Since 1/Q is unbounded at Q = 0, the MCMC sampler was constrained to ensure that Q was in the interval $[10^{-5}, 10^{5}]$.

Priors for Error Variances

Priors for the process error variance $p(\sigma^2)$ and observation error variance $p(\tau^2)$ for each territory were chosen to be moderately informative inverse-gamma distributions with scale parameter $\lambda > 0$ and shape parameter $k > 0$:

(10) $$p(\sigma^2) = \frac{\lambda^k (\sigma^2)^{(-k-1)} \exp\left(\frac{-\lambda}{\sigma^2}\right)}{\Gamma(k)}$$

The inverse-gamma distribution is a useful choice for priors that describe model error variances (see, for example, Congdon, 2001). The scale parameter was set to λ = 0.1 and the shape parameter was k = 0.2 for the process error variance prior. For this choice of parameters, the expected value of the inverse-gamma distribution is not bounded, and we used the mode for σ^2, denoted as $\mathrm{MODE}[\sigma^2] = 1/12 \approx 0.083$ to measure the central tendency of the distribution. For the observation error variance prior, the scale parameter was set to λ = 1 and the shape parameter was k = 0.2. As a result, the mode of τ^2 was $\mathrm{MODE}[\tau^2] = 10/12 \approx 0.83$. The ratio of the modes of the observation error prior to the process error prior was $\mathrm{MODE}[\tau^2]/\mathrm{MODE}[\sigma^2] = 10$ and the central tendency of the observation error variance prior was assumed to be about tenfold greater than the process error variance prior. The choice of the process error prior matched the expected scaling of process errors which were on the order of 0.1 for the state equations describing changes in the proportion of carrying capacity. Similarly, the choice of the observation error prior matched the expected scaling of observation errors which were on the order of 1 to 10 for the observation equations describing the model fit to the observed CPUE. In summary, the prior for the observation error variance was assumed to be an order of magnitude greater than the process error variance.

Priors for Ratios of Biomass to Carrying Capacity

The prior distributions for the time series of the ratio of biomass to carrying capacity, $p(P_T)$, were determined by the lognormal distributions for the process error dynamics. The priors for the initial proportion of carrying capacity P[1] in each territory were the same as in the base case assessment model from the previous assessment (Brodziak et al., 2012). For American Samoa, CNMI, and Guam, the P[1] prior was modeled as a lognormal distribution with mean $\mu_{P[1]}$ set to 0.80, 0.45, and 0.75 respectively, and a CV of 20% for each territory:

(11) $$p(P[1]) = \frac{1}{\sqrt{2\pi}P[1]\sigma_{P[1]}} \exp\left(-\frac{(\log(P[1] - \mu_{P[1]})^2}{2\sigma_{P[1]}^2} \right)$$

Posterior Distribution

The posterior distribution was calculated to make inferences about the model parameters given the data, the likelihood, and the priors. In particular, the joint posterior distribution given catch, MSY, and CPUE data D, p(θ|D), was proportional to the product of the priors and the observation error likelihood:

(12) $$p(\theta|D) \propto p(K)\,p(r)\,p(Q)\,p(\sigma^2)\,p(\tau^2)\prod_{T=1}^{N} p(P_T)\prod_{T=1}^{N} p(I_T|\theta)\,p(MSY|\theta)$$

There was no closed form expression to calculated parameter estimates from the posterior distribution and we used standard methods to numerically simulate samples from the posterior distribution.

Bayesian parameter estimation for multi-parameter nonlinear models, such as the bottomfish production model, is typically based on simulating a set of independent samples from the posterior distribution. For the production model, we used Markov Chain Monte Carlo (MCMC) simulation (Gilks et al., 1996) to numerically generate a sequence of samples from the posterior distribution. The WINBUGS software (version 1.4, Spiegelhalter et al., 2003) was called up using the R Language (R Development Core Team, 2009) and R2WinBUGS package (Sturtz et al., 2005) to set the initial conditions, perform the MCMC calculations, and summarize the MCMC results. Generic code for running this Bayesian state-space surplus production model is provided in Appendix A, and input data files for each territory are provided in Appendix B with the same data also provided in Table 3. Note that due to the nature of MCMC sampling, it is not possible to replicate results exactly, but results should be fairly close.

MCMC simulations were conducted in an identical manner for each of the models used for each territory. Three chains of 260,000 samples were simulated in each model run. The first 10,000 samples of each chain were excluded from the inference process as a burn-in period to remove any dependence of the MCMC samples on the initial conditions. Each chain was also thinned by 25 to remove autocorrelation; every twenty-fifth sample was used for inference. As a result, there were 30,000 samples from the posterior for summarizing model results.

Model and Convergence Diagnostics

Convergence of the MCMC simulations to the posterior distribution was checked using the Brooks-Gelman-Rubin (BGR) convergence diagnostic (Brooks and Gelman, 1998). This diagnostic was monitored using WinBUGS for key model parameters (intrinsic growth rate, carrying capacity, catchability, initial ratio of biomass to carrying capacity, process and observation error variances) with values near unity indicating convergence. Convergence of the MCMC samples to the posterior distribution was also checked using the Gelman and Rubin (1992), Geweke (1992), and Heidleberger and Welch (1992) diagnostics as implemented in the R language (R Development Core Team 2014) and the CODA package (Plummer et al., 2006).

Residuals from the model fits to CPUE were used to determine the goodness-of-fit of the production models. Any non-random patterns in the CPUE residuals could indicate that the observed CPUE may not conform to one or more model assumptions. Model residuals were tested for significant time trends. Residuals for the CPUE series are the log-scale observation errors ε_T:

(13) $$\varepsilon_T = \ln(I_T) - \ln(QKP_T)$$

Projection Methods

Stock projections were conducted to provide information on the risk that each territorial Bottomfish Management Unit Species complex would experience overfishing and/or become overfished under alternative future catches in fishing years 2016-2017. The stock projections started with the model-estimated parameters and 2013 stock biomass for each territory, and in this way they included uncertainty in the distribution of model-estimated parameters. To bridge the gap between 2013, the most recent year of the assessment, and the projected future years of 2016 and 2017, we assumed that the 2014-2015 harvest rate for each territory was equal to a normal distribution with a mean and standard deviation calculated from the model-estimated harvest rates from 2011-2013, and randomly drew from this normal distribution during the MCMC iterations. The projections included process error.

For the 2016-2017 projections, we used a grid of possible future catches ranging from 0 to 600,000 pounds in increments of 1,000 pounds. Each projection was sampled using the same setup as for the base case models: three chains of 260,000 samples were simulated, with the first 10,000 samples of each chain excluded as a burn-in period and each chain thinned by 25 to remove autocorrelation. As a result, there were 30,000 samples from the posterior for each territory's projection for summarizing model results.

In the projections, we assumed that the 2016 catch was equal to the 2017 catch. To translate the projection results for management purposes, it is helpful to consider that these projected catch levels are equal to the ACLs and that 100% of the ACLs are caught. For each territory's projection we calculated the biomass, harvest rate, and risks of overfishing and being overfished, under each alternative future catch.

RESULTS

Input Data: Catch and CPUE

Fishery-dependent catch and effort data for assessing the bottomfish complexes were tabulated using the most recent and best available data from the Western Pacific Fisheries Information Network (WPacFIN). The processed data for American Samoa, CNMI, and Guam was finalized for use in the stock assessment update on 12 March 2015.

American Samoa

We compared estimates of American Samoa bottomfish catch from the previous 2012 assessment and the 2015 assessment update for the years 2006-2010 and found that they were generally similar (Fig. 1), indicating methods used to calculate catch were similar. As a result, for this assessment we retained the catch time series from 1986 to 2010 used in the previous assessment and added new years of catch data for 2011-2013. The annual bottomfish catch used in the current assessment update averaged approximately 24,000 pounds during 1986-2013 and ranged from 7,913 to 64,587 pounds with a coefficient of variation of about 53% (Table 3, Fig. 2). Recent average yield (2011-2013 average) for American Samoa bottomfish was approximately 21,000 pounds.

Estimates of American Samoa bottomfish CPUE (lbs/line hr) were calculated using the same approach as used in the 2012 assessment. We compared CPUE estimates from the previous assessment and the 2015 assessment update for the years 2006-2010, and found the general trend and magnitude in CPUE was similar (Fig. 1). As a result, for this assessment we retained the catch time series from 1986 to 2010 used in the previous assessment, and added new years of CPUE data for 2011-2013. This choice should have a negligible impact on the assessment results because the differences in CPUE are small, and production model fit to CPUE often averages out fluctuations (see Base Case Model Fit to CPUE section in Results, and Figs. 7-8). Bottomfish CPUE fluctuated around its long-term average of 3.83 lbs/line hr during 1986-2013 (Table 3, Fig. 2) and ranged from 2.44 to 6.53 lbs/line hr with a CV of 30%. Recent average CPUE from 2011 to 2013 was 4.65 lbs/line hr.

Commonwealth of the Northern Mariana Islands

We compared estimates of the Commonwealth of the Northern Mariana Islands bottomfish catch from the previous 2012 assessment and the 2015 assessment update for the years 2006-2010 and found that they were generally similar (Fig. 3), indicating methods to calculate catch were similar. As a result, for this assessment we retained the catch time series from 1983 to 2010 used in the previous assessment, and added new years of catch data for 2011-2013. The annual bottomfish catch used in the current assessment update averaged approximately 38,221 pounds during 1983-2013 and ranged from 7,092 to 71,256 pounds with a coefficient of variation of about 47% (Table 3, Fig. 4). Recent average yield (2011-2013 average) for CNMI bottomfish was approximately 20,100 pounds.

Estimates of CNMI bottomfish CPUE (lbs/trip) were calculated using the same approach as used in the 2012 assessment. We compared CPUE estimates from the previous assessment and the 2015 assessment update for the years 2006-2010. In the 2012 assessment, CPUE starting in 2006 was not included in the assessment because the values were very different from CPUE prior to 2006, likely due to changes in the reporting method and sampling frame to collect CPUE data. We found a similar result in our CPUE calculations for recent years (Fig. 3). As a result and for consistency with the previous assessment, for this assessment update we retained the catch time series from 1983 to 2005 used in the previous assessment and did not add additional years of CPUE data because doing so would require modifications to the assessment model which are not generally done with a strict assessment update. The model fits the parameters to the CPUE data for the 23-year time series from 1983 to 2005, and then uses these fitted parameters to calculate biomass and harvest rates for 2006-2013 according to the production model equation. Note that recent data is included in the assessment in the form of catch data from 2006-2013. Table 5 indicates that adding a few years of additional CPUE information does not drastically change assessment results. The addition of CPUE values starting in 2006 is possible for future assessments and will be explored in the next benchmark assessment of territorial bottomfish. Bottomfish CPUE fluctuated around its long-term average of 98 pounds/trip during 1983-2005 (Table 3, Fig. 4) and ranged from 43 to 181 pounds/trip with a CV of 40%. The average CPUE of most recently used values from 2003 to 2005 was 90 pounds/trip.

Guam

We compared estimates of Guam bottomfish catch from the previous 2012 assessment and the 2015 assessment update for the years 2006-2010 and found that they were generally similar (Fig. 5), indicating methods to calculate catch were similar. As a result, for this assessment we retained the catch time series from 1982 to 2010 used in the previous assessment, and added new years of catch data for 2011-2013. The annual bottomfish catch used in the current assessment update averaged approximately 40,292 pounds during 1982-2013 and ranged from 19,322 to 66,666 pounds with a coefficient of variation of about 31% (Table 3, Fig. 6). Recent average yield (2011-2013 average) for Guam bottomfish was approximately 37,183 pounds.

Estimates of Guam bottomfish CPUE (pounds/line hr) were calculated using the same approach as used in the 2012 assessment. We compared CPUE estimates from the previous assessment and the 2015 assessment update for the years 2006-2010 and found the general trend and magnitude in CPUE was similar (Fig. 5). As a result, for this assessment we retained the catch time series from 1982 to 2010 used in the previous assessment, and added new years of CPUE data for 2011-2013. This choice should have a negligible impact on the assessment results because the differences in CPUE are small, and production model fit to CPUE often averages out fluctuations (see Base Case Model Fit to CPUE section in Results, and Figs. 11-12).Bottomfish CPUE fluctuated around its long-term average of 3.1 pounds/line hr during 1986-2013 (Table 3, Fig. 6) and ranged from 1.3 to 11.7 pounds/line hr with a CV of 57%. Recent average CPUE from 2011 to 2013 was 3.4 pounds/line hr.

Base Case Model Convergence Diagnostics

American Samoa

Convergence diagnostics were calculated from the three chains used in the MCMC simulations for the base case model. The diagnostics were computed for nine key model parameters: K, r, Q, σ^2, τ^2, P[1], BMSY, HMSY, and MSY. The Geweke Z-score diagnostic values were less than 2 in absolute value for all 27 tests, which indicated that there were no significant differences in means for the first and last sets of iterations of the chains. The Gelman and Rubin potential scale reduction factors were identically 1 for each of the 9 parameters which also indicated convergence. Each of the 9 parameters passed the Heidelberger and Welch stationary and half-width diagnostic tests. Overall, the convergence results indicated that the MCMC chains produced representative samples from the joint posterior distribution of model parameters.

Commonwealth of the Northern Mariana Islands

Convergence diagnostics were calculated from the three chains used in the MCMC simulations for the base case model. The diagnostics were computed for nine key model parameters: K, r, Q, σ^2, τ^2, P[1], BMSY, HMSY and MSY. The Geweke Z-score diagnostic values were less than 2 in absolute value for 26 out of 27 tests, which indicated that there were no significant differences in means for the first and last sets of iterations of the chains. The sole exception was Q, where 1 of the 3 chains had a Geweke Z-score of -2.188. The Gelman and Rubin potential scale reduction factors were identically 1 for each of the nine parameters, which also indicated convergence. Each of the nine parameters passed the Heidelberger and Welch stationary and half-width diagnostic tests. Overall, the convergence results indicated that the MCMC chains produced representative samples from the joint posterior distribution of model parameters.

Guam

Convergence diagnostics were calculated from the three chains used in the MCMC simulations for the base case model. The diagnostics were computed for nine key model parameters: K, r, Q, σ^2, τ^2, P[1], BMSY, HMSY and MSY. The Geweke Z-score diagnostic values were less than 2 in absolute value for 25 out of 27 tests, which indicated that there were no significant differences in means for the first and last sets of iterations of the chains. The only exceptions were for BMSY and K, where 1 of the 3 chains had a Geweke Z-score slightly above 2. The Gelman and Rubin potential scale reduction factors were identically 1 for each of the nine parameters, which also indicated convergence. Last, each of the nine parameters passed the Heidelberger and Welch stationary and half-width diagnostic tests. Overall, the convergence results indicated that the MCMC chains produced representative samples from the joint posterior distribution of model parameters.

Base Case Model Fit to CPUE

American Samoa

The predicted CPUE from the base case model fit reasonably well and produced a smooth fit to the observed CPUE data (Fig. 7). The standardized log-scale residuals from the CPUE fit were all within two standard errors of zero although there were some time blocks of positive and negative residuals (Fig. 8). Regression of the standardized log-scale residuals on time indicated there was no significant time trend and tests indicated that the residuals were normally distributed with constant variance. Overall, the CPUE diagnostics indicated that the observation errors likely conformed to the statistical assumptions of the production model.

Commonwealth of the Northern Mariana Islands

The predicted CPUE from the base case model fit the observed CPUE trends reasonably well (Fig. 9). The standardized log-scale residuals from the CPUE fit were all within two standard errors of zero although there were some time blocks of positive and negative residuals (Fig. 10). Regression of the standardized log-scale residuals on time indicated there was no significant time trend and tests indicated that the residuals were normally distributed with constant variance. Overall, the CPUE diagnostics indicated that the residuals were likely consistent with the assumed statistical formulation of the production model.

Guam

The predicted CPUE from the base case model fit the observed CPUE data reasonably well, except for the spike in the observed CPUE in 1984 (Fig. 11). The standardized log-scale residuals from the CPUE fit were within two standard errors of zero in all years except for 1982, which was slightly above two (Fig. 12). Regression of the standardized log-scale residuals on time indicated there was no significant time trend however; tests indicated that the residuals were not normally distributed but did have constant variance. Overall, the CPUE diagnostics indicated that the observation errors were generally consistent with the statistical assumptions of the production model.

Base Case Model Parameter Estimates

Model-estimated posterior mean parameter values and reference points, along with standard errors, are provided in Table 4 for each territory.

American Samoa

The posterior means (± 1 standard error) of K, r, and P[1] from the base case model were: K = 667.5 ± 130.6 thousand pounds, r = 0.48 ± 0.13, and P[1] = 0.81 ± 0.14. Posterior mean estimates of biological reference points from the base case model were: BMSY = 333.7 ± 65.3 thousand pounds, HMSY = 0.24 ± 0.06, and MSY = 76.7 ± 14.1 thousand pounds (Table 4). The posterior mean of MSY was 1.74 thousand pounds higher than the input OLO estimate of MSY = 75.0 thousand pounds. Table 5 provides a comparison of model-estimated parameters and reference points from this assessment with estimates from the previous 2012 assessment (Brodziak et al., 2012), and indicates that values are similar.

Estimates of American Samoa bottomfish exploitable biomass have fluctuated around 600 thousand pounds since 1986, and estimates of relative biomass indicate that the mean biomass of the American Samoa bottomfish complex has been above BMSY during 1986-2013 (Table 6, Fig. 13). Biomass increased moderately in the 1990s, declined slightly from 1996 through 2010, and has increased slightly since. Lower bounds of the 95% confidence intervals for biomass show that, while there is overlap in the majority of years, estimates of biomass remained above 0.7*BMSY throughout the 1986 to 2013 period.

Estimates of American Samoa bottomfish annual harvest rate have fluctuated around 5% since the late-1980s, increased to about 10% in 2009, and declined to less than 5% in 2013 (Table 6, Fig. 14). Estimates of relative harvest rate and upper bounds of the 95% confidence intervals for harvest rate indicate that the annual harvest rate has been below HMSY from 1986 to 2013.

The biomass status of the American Samoa bottomfish complex in 2013 was healthy, with a < 1 % risk that the stock was overfished (defined as B < BMSY). Similarly, in 2013 there was a low < 1% risk that overfishing was occurring (defined as H > HMSY). The trends in stock status over time are provided in a Kobe plot in Figure 15. Overall, the production model results suggest that the American Samoa bottomfish complex was not overfished and did not experience overfishing during 1986-2013 (Table 6, Fig. 15).

Commonwealth of the Northern Mariana Islands

The posterior means (± 1 standard error) of K, r, and P[1] from the base case model were: K = 1367.0 ± 253.3, r = 0.53 ± 0.13, and P[1] = 0.46 ± 0.08. Posterior mean estimates of biological reference points from the base case model were: BMSY = 683.5 ± 126.7 thousand pounds, HMSY = 0.26 ± 0.06, and MSY = 173.1 ± 32.2 thousand pounds (Table 4). The posterior mean of MSY was 1.1 thousand pounds higher than the input OLO estimate of MSY = 172 thousand pounds. Table 5 provides a comparison of model-estimated parameters and reference points from this assessment with estimates from the previous 2012 assessment (Brodziak et al., 2012), and indicates that values are similar.

Estimates of CNMI bottomfish exploitable biomass have fluctuated around 1200 thousand pounds since 1983. Estimates of relative biomass indicate that the mean biomass of the CNMI bottomfish complex was slightly below BMSY in 1983 and has likely been above BMSY during 1984-2013 (Table 7, Fig. 16). Biomass increased moderately from 1983 to 1988 and then declined through 1991. Biomass increased again from 1991 to 1999 and then fluctuated through 2013. Lower bounds of the 95% confidence intervals for biomass show that, while there is overlap in the majority of years, estimates of biomass remained above 0.7*BMSY throughout the 1986 to 2013 period.

Estimates of CNMI bottomfish annual harvest rate have fluctuated around 4% since 1983 (Table 7, Fig. 17). Estimates of relative harvest rate and upper bounds of the 95% confidence intervals for harvest rate indicate that the annual harvest rate has been below HMSY from 1983 to 2013. The biomass status of the CNMI bottomfish complex in 2013 was healthy, with only a 2.5% risk of the stock being overfished (defined as B < 0.7*BMSY). Similarly, in 2013 there was a low < 1% risk that overfishing was occurring, defined as (H > HMSY). The trends in stock status over time are provided in a Kobe plot in Figure 18. Overall, the production model results suggest that the CNMI bottomfish complex was not overfished and did not experience overfishing during 1983-2013 (Table 7, Fig. 18).

Guam

The posterior means (± 1 standard error) of K, r, and P[1] from the base case model were: K = 324.5 ± 47.5, r = 0.703 ± 0.119, and P[1] = 0.768 ± 0.136. Posterior mean estimates of biological reference points from the base case model were: BMSY = 162.3 ± 23.8 thousand pounds, HMSY = 0.352 ± 0.059, and MSY = 56.13 ± 7.79 thousand pounds (Table 4). The posterior mean of MSY was 1.1 thousand pounds higher than the input OLO estimate of MSY = 55.0 thousand pounds. Table 5 provides a comparison of model-estimated parameters and reference points from this assessment with estimates from the previous 2012 assessment (Brodziak et al., 2012), and indicates that values are similar.

Estimates of Guam bottomfish exploitable biomass have fluctuated around 240 thousand pounds since 1982.Estimates of relative biomass indicate that the mean biomass of the Guam bottomfish complex has likely been above BMSY during 1982-2013, except for 1997 when the relative biomass was 0.96 (Table 8, Fig. 19). Biomass decreased moderately from a high in 1984 to a low in 1997 and has risen slightly and leveled off since then. Lower bounds of the 95% confidence intervals for biomass show that generally, estimates of biomass remained above 0.7*BMSY with the exception of 1990 to 2002, when there was very low risk of the stock being overfished (< 16%) .

Estimates of Guam bottomfish annual harvest rate increased from a low of about 10% throughout the late 1980s and 1990s until they reached a peak of about 35% in 2000 (Table 8, Fig. 20). In 2000, the harvest rate was at HMSY. After 2000, harvest rates suddenly decreased and have fluctuated around 15% through 2013. Estimates of relative harvest rate and upper bounds of 95% confidence intervals for harvest rate indicate that the annual harvest rate has been below HMSY for all years, except for 1987 to 2002 and 2011 when there was a low to moderate risk that harvest rate was at or above HMSY.

The biomass status of the Guam bottomfish complex in 2013 was healthy; there was a low < 1% risk that the stock was overfished (defined as B < 0.7*BMSY). Similarly, in 2013 there was a low < 1% risk that overfishing was occurring (defined as H > HMSY). The trends in stock status over time are provided in a Kobe plot in Figure 21. Overall, the production model results suggest that the Guam bottomfish complex was not overfished and did not experience overfishing during 1982-2013, with the possible exception of 2000 when overfishing may have occurred (Table 8, Fig. 21).

Base Case Model Projection Results

American Samoa

The constant 2-year catch projection scenarios for American Samoa bottomfish from 2016 to 2017 resulted in projected probabilities of overfishing, relative biomasses, and probabilities of being overfished (Table 9, Fig. 22). The 2017 catch level corresponding to a 50% risk of overfishing in 2017 (i.e., H > HMSY) was 115 thousand pounds, which is 5 times higher than recent average catch of 21 thousand pounds from the past 3 years. For comparison, the 2017 catch that would lead to a lower 25% risk of overfishing in 2017 was 97 thousand pounds. If the recent average catch of 21 thousand pounds was harvested in 2016 and 2017, the 2017 risks of overfishing and being overfished are < 1%.

Commonwealth of the Northern Mariana Islands

The constant 2-year catch projection scenarios for CNMI bottomfish from 2016-2017 resulted in projected probabilities of overfishing, relative biomasses, and probabilities of being overfished (Table 10, Fig. 23). The 2017 catch level corresponding to a 50% risk of overfishing in 2017 (i.e., H > HMSY) was 250 thousand pounds, which is over 10 times higher than recent average catch of 20 thousand pounds from the past 3 years. For comparison, the 2017 catch that would lead to a lower 25% risk of overfishing in 2017 was 206 thousand pounds. If the recent average catch of 20 thousand pounds was harvested in 2016 and 2017, the 2017 risks of overfishing and being overfished are < 1%.

Guam

The constant 2-year catch projection scenarios for Guam bottomfish from 2016 to 2017 resulted in projected probabilities of overfishing, relative biomasses, and probabilities of being overfished (Table 11, Fig. 24). The 2017 catch level corresponding to a 50% risk of overfishing in 2017 (i.e., H > HMSY) was 71 thousand pounds, which is 2 times higher than recent average catch of 33 thousand pounds from the past 3 years. For comparison, the 2017 catch that would lead to a lower 25% risk of overfishing in 2017 was 61 thousand pounds. If the recent average catch of 33 thousand pounds was harvested in 2016 and 2017, the 2017 risks of overfishing and being overfished are < 1%.

DISCUSSION

Overall, this assessment determines that the Bottomfish Management Unit Species (BMUS) complexes of the territories of American Samoa, the Commonwealth of the Northern Mariana Islands, and Guam are not overfished and overfishing is not occurring. The stock statuses are in good condition and recent average catch levels are sustainable and below MSY.

There are several caveats to mention for interpreting the production model results. First, the production model fits are conditioned on OLO previous estimates of MSY for each island group (Humphreys and Moffitt, 1999; Moffitt and Humphreys, 2009, using methods from Polovina and Ralston, 1986). If these estimates are not accurate, then the scale of the production model estimates of biomass and harvest rate may change, even though the relative scale of biomass to BMSY and harvest rate to HMSY may not change substantially.

Second, there are several potential problems with the fishery-dependent data for the three island groups that also warrant consideration in developing management advice. A primary concern is that the estimates of total fishery removals may be incomplete or inconsistent due to the voluntary nature of catch reporting, changes in data collection protocols, misidentification of species, or other potential issues. If the fishery removals are inaccurate, then the production model results will include this problem. In this context, the previous 2012 assessment investigated the effect of changes in magnitude of catch on model results if fishery removals are underestimated. Those analyses generally found that if catch levels are higher than reported in data from the WPacFIN, then the calculated stock status might be in poorer condition (risks of being overfished and overfishing would increase) and the resulting projected future catch levels corresponding to 50% risks of overfishing would decrease (Brodziak et al., 2012).

Third, the quality and coverage of the input data provide a challenge for moving to more complicated models. Besides uncertainty in catch, there is also uncertainty around effort measurements used as input data. Additionally, there is little contrast in the data series, meaning there is not much information contained in them for the model to estimate parameters with high confidence. As an example, the CPUE data were not particularly informative about the ratio of initial biomass to carrying capacity P[1], and posterior estimates of P[1] are likely informed by the chosen prior values. The selection of the prior values for P[1] can affect estimates of stock status. The prior values for P[1] used in this assessment are the values chosen for base case models in the 2012 assessment, which were determined after statistical comparison of several models with varying prior P[1] values (Brodziak et al., 2012).

Fourth, another potential problem is that changes in the bottomfish fishery CPUE over time may not be proportional to changes in the relative abundance of bottomfish due to changes in fishing practices, fleet composition, or other factors that could alter standard measures of effective fishing effort on bottomfish. This assessment uses nominal, non-standardized CPUE time series because of the challenges of standardizing CPUE given data scarcity and quality. Thus the nominal CPUE series do not account for factors that could be affecting CPUE other than relative changes in stock abundance. If the nominal CPUE indices are inaccurate and if they do not reflect relative changes in stock abundance, then the trends from the production model will include this problem.

Finally, this assessment was a strict update of the 2012 assessment, meaning that the exact same model configuration, methods, and assumptions from the previous assessment were used.The only difference is the addition of 3 more years of catch and nominal CPUE data. There are more analyses that can be done to improve future iterations of territorial bottomfish assessments. Since the assessments rely so heavily on the fishery-dependent data from the WPacFIN, it would be useful to continue to improve the bottomfish fishery catch reporting systems of the three island groups to account for potential problems mentioned above. Further, it is notable that the data reporting systems in the island groups have begun to collect some length frequency samples of individual bottomfish species in biosampling programs. This ongoing data collection program will provide additional information on the average size of fish in the catch, which can eventually be incorporated into future assessments.

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Table 1.--List of Bottomfish Management Unit Species (BMUS) of American Samoa, Guam, and the Commonwealth of the Northern Mariana Islands that are identified in relevant Fishery Ecosystem Plans and assessed in this document.

Species name	**Common name**	**Deep or shallow component**
Aphareus rutilans	Lehi	Deep
Aprion virescens	Uku	Shallow
Caranx ignobilis	Giant trevally	Shallow
Caranx lugubris	Black trevally	Deep
Epinephelus fasciatus	Blacktip grouper	Shallow
Etelis carbunculus	Ehu	Deep
Etelis coruscans	Onaga	Deep
Lethrinus amboinensis	Ambon emperor	Shallow
Lethrinus rubrioperculatus	Redgill emperor	Shallow
Lutjanus kasmira	Blueline snapper	Shallow
Pristipomoides auricilla	Yellowtail snapper	Deep
Pristipomoides filamentosus	Opakapaka	Deep
Pristipomoides flavipinnis	Yelloweye opakapaka	Deep
Pristipomoides sieboldii	Kalekale	Deep
Pristipomoides zonatus	Gindai	Deep
Seriola dumerili	Amberjack	Shallow
Variola louti	Lunartail grouper	Deep

Table 2.--Assumed prior distribution values for parameters in the production models for Bottomfish Management Unit Species in American Samoa, Commonwealth of the Northern Mariana Islands (CNMI), and Guam. Values are the same as those used in base case models of the previous stock assessment.

			Prior mean			
Parameter	*Description (units)*	*Distribution*	*American Samoa*	*CNMI*	*Guam*	*Prior CV*
R	*Intrinsic growth rate (1/yr)*	*Beta*	*0.46*	*0.46*	*0.46*	*50%*
K	*Carrying capacity (1000 lbs)*	*Diffuse normal*	*700*	*1400*	*300*	*20%*
P[1]	*Ratio of biomass to K in initial year*	*Lognormal*	*0.8*	*0.45*	*0.75*	*20%*
Q	*Catchability*	*Diffuse inverse gamma*	*1*	*1*	*1*	*32%*
τ^2	*Observation error variance*	*Inverse gamma*	*0.83*	*0.83*	*0.83*	*NA*
σ^2	*Process error variance*	*Inverse gamma*	*0.083*	*0.083*	*0.083*	*NA*

Table 3.--Annual estimates of catch and nominal CPUE of Bottomfish Management Unit Species (BMUS) in American Samoa, the Commonwealth of the Northern Marianas (CNMI), and Guam. These data were used as an input for this stock assessment update. The values for 1982-2010 are the same as those used in the previous assessment, and the values for 2011-2013 are new for this assessment and were calculated in April 2015. Data source is the Western Pacific Fisheries Information Network (WPacFIN) boat-based creel survey data for American Samoa and Guam, and WPacFIN commercial purchase data for CNMI. See Appendix B for this same input data provided in a format for use with Appendix A, generic stock assessment model code.

Year	American Samoa BMUS Catch (lbs)	American Samoa BMUS CPUE (lbs/line hr)	CNMI BMUS Catch (lbs)	CNMI BMUS CPUE (lbs/trip)	Guam BMUS Catch (lbs)	Guam BMUS CPUE (lbs/line hr)
1982					26384	3.05
1983			28529	43	40782	2.66
1984			42665	70	19322	11.66
1985			40974	117	49195	2.46
1986	64587	3.26	29912	104	20427	3.57
1987	19628	2.98	49714	169	29301	3.98
1988	33726	6.35	47313	181	46318	2.37
1989	32647	4.02	24439	73	58582	2.28
1990	11332	3.54	12929	81	42384	3.4
1991	13010	2.64	7092	47	39596	2
1992	9985	2.44	10598	59	50394	2.25
1993	14554	3.27	18461	84	55609	2.98
1994	33845	3.16	25470	74	49055	2.73
1995	27699	4.24	36100	93	40855	2.05
1996	30808	6.53	66388	119	54186	2.26
1997	32308	3.82	64143	137	30611	1.32
1998	12413	3.96	59024	148	37687	1.65

Year	American Samoa BMUS Catch (lbs)	American Samoa BMUS CPUE (lbs/line hr)	CNMI BMUS Catch (lbs)	CNMI BMUS CPUE (lbs/trip)	Guam BMUS Catch (lbs)	Guam BMUS CPUE (lbs/line hr)
1999	15857	3.67	55991	156	53339	1.88
2000	19816	4.57	45258	56	66666	1.89
2001	37847	4.95	71256	68	54352	3.25
2002	34149	2.45	46765	101	24044	2.87
2003	19199	5.42	41903	89	43253	4.26
2004	17206	4.31	54475	104	36915	2.77
2005	16329	3.13	70404	76	36529	4.81
2006	7913	2.65	29340		38054	3.78
2007	21874	2.57	39476		27459	2.32
2008	34812	2.9	42070		37316	1.93
2009	47458	3.62	41176		40222	3.17
2010	9509	2.96	22395		28958	3.65
2011	26277	3.95	22487		59618	3.62
2012	13110	5.75	15302		22085	3.47
2013	23630	4.25	22510		29848	3.15

Table 4.--Model-estimated mean and standard error for parameters and reference points from production models for Bottomfish Management Unit Species in American Samoa, Commonwealth of the Northern Mariana Islands (CNMI), and Guam.

Parameter	**Description**	**American Samoa estimated mean**	**American Samoa estimated standard error**	**CNMI estimated mean**	**CNMI estimated standard error**	**Guam estimated mean**	**Guam estimated standard error**
r	Intrinsic growth rate (1/yr)	0.477	0.125	0.525	0.126	0.703	0.119
K	Carrying capacity (1000 lbs)	667.5	130.6	1367.0	253.3	324.5	47.5
P[1]	Ratio of biomass to K in initial year	0.808	0.141	0.458	0.082	0.768	0.136
Q	Catchability	0.00674	0.00175	0.0859	0.0230	0.0129	0.0028
τ^2	Observation error variance	0.165	0.055	0.225	0.089	0.194	0.062
σ^2	Process error variance	0.0560	0.0306	0.0881	0.0525	0.0629	0.0344
Reference Point	**Description**	**American Samoa estimated mean**	**American Samoa estimated standard error**	**CNMI estimated mean**	**CNMI estimated standard error**	**Guam estimated mean**	**Guam estimated standard error**
MSY	Maximum sustainable yield (1000 lbs)	76.74	14.06	173.10	32.19	56.13	7.79
HMSY	Harvest rate that produces MSY	0.238	0.062	0.261	0.063	0.352	0.059
BMSY	Biomass that produces MSY (1000 lbs)	333.7	65.3	683.5	126.7	162.3	23.8

Table 5.--Comparison of model-estimated mean and standard error for parameters and stock reference points from production models for Bottomfish Management Unit Species in American Samoa, Commonwealth of the Northern Mariana Islands (CNMI), and Guam. 2012 values come from the previous assessment (Brodziak et al., 2012), and 2015 values come from this assessment.

		American Samoa				CNMI				Guam			
Para-meter	**Description**	**2012 mean**	**2012 stand error**	**2015 mean**	**2015 stand error**	**2012 mean**	**2012 stand error**	**2015 mean**	**2015 stand error**	**2012 mean**	**2012 stand error**	**2015 mean**	**2015 stand error**
r	Intrinsic growth rate (1/yr)	0.47	0.12	0.477	0.125	0.52	0.13	0.525	0.126	0.70	0.12	0.703	0.119
K	Carrying capacity (1000 lbs)	670.7	132.3	667.5	130.6	1367.0	256.4	1367.0	253.3	324.5	48.1	324.5	47.5
P[1]	Ratio of biomass to K in initial year	0.82	0.14	0.808	0.141	0.46	0.08	0.458	0.082	0.77	0.14	0.768	0.136
Q	Catchability	0.01	0.002	0.00674	0.00175	0.09	0.023	0.0859	0.0230	0.01	0.0030	0.0129	0.0028
τ^2	Observation error variance	0.18	0.06	0.165	0.055	0.22	0.09	0.225	0.089	0.22	0.07	0.194	0.062
σ^2	Process error variance	0.06	0.04	0.0560	0.0306	0.09	0.05	0.0881	0.0525	0.07	0.04	0.0629	0.0344

		American Samoa				CNMI				Guam			
Ref Point	**Description**	**2012 mean**	**2012 stand error**	**2015 mean**	**2015 stand error**	**2012 mean**	**2012 stand error**	**2015 mean**	**2015 stand error**	**2012 mean**	**2012 stand error**	**2015 mean**	**2015 stand error**
MSY	Maximum sustainable yield (1000 lbs)	76.2	14.3	76.74	14.06	172.9	32.2	173.10	32.19	55.9	7.9	56.13	7.79
HMSY	Harvest rate that produces MSY	0.24	0.06	0.238	0.062	0.26	0.06	0.261	0.063	0.35	0.06	0.352	0.059
BMSY	Biomass that produces MSY (1000 lbs)	335.4	66.1	333.7	65.3	683.6	128.2	683.5	126.7	162.2	24.03	162.3	23.8
H2010	Harvest rate in 2010	0.02	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.12	0.04	0.12	0.04
B2010	Biomass in 2010 (1000 lbs)	533.2	180.6	547.0	174.2	1216.0	530.4	1217.0	521.4	259.2	82.68	264.2	78.8

Table 6.--American Samoa Bottomfish Management Unit Species: Base case production model estimates of mean exploitable biomass, relative biomass, risk of being overfished (B < 0.7*BMSY), harvest rate, relative harvest rate, and risk of overfishing (H > HMSY) from 1986 to 2013.

Year	Exploitable biomass (B, units of 1000 pounds)	Relative biomass (B/BMSY)	Risk of being overfished (B < 0.7*BMSY)	Harvest rate (H, an annual proportion)	Relative harvest rate (H/HMSY)	Risk of overfishing (H > HMSY)
1986	539.7	1.62	0.000	0.129	0.56	0.014
1987	547.7	1.64	0.000	0.039	0.17	0.000
1988	659.2	1.98	0.000	0.056	0.25	0.000
1989	608.6	1.82	0.000	0.059	0.26	0.000
1990	558.9	1.67	0.001	0.022	0.10	0.000
1991	520.5	1.56	0.003	0.028	0.12	0.000
1992	513.3	1.54	0.003	0.022	0.09	0.000
1993	554.9	1.66	0.002	0.029	0.13	0.000
1994	587.5	1.76	0.001	0.063	0.28	0.001
1995	639.1	1.91	0.000	0.048	0.21	0.000
1996	707.1	2.12	0.000	0.048	0.21	0.000
1997	641.4	1.92	0.000	0.056	0.24	0.000
1998	625.8	1.87	0.000	0.022	0.09	0.000
1999	631.3	1.89	0.000	0.028	0.12	0.000
2000	661.5	1.98	0.000	0.033	0.14	0.000
2001	657.5	1.97	0.000	0.063	0.28	0.001
2002	574.2	1.72	0.001	0.066	0.28	0.000
2003	635.4	1.90	0.000	0.033	0.15	0.000
2004	613.3	1.84	0.000	0.031	0.14	0.000
2005	554.8	1.66	0.001	0.032	0.14	0.000
2006	516.5	1.55	0.003	0.017	0.07	0.000
2007	515.7	1.55	0.003	0.047	0.20	0.000
2008	532.3	1.60	0.002	0.072	0.31	0.001
2009	556.4	1.67	0.001	0.094	0.41	0.005
2010	547.0	1.64	0.002	0.019	0.08	0.000
2011	624.0	1.87	0.000	0.046	0.20	0.000
2012	682.7	2.04	0.000	0.021	0.09	0.000
2013	661.3	1.98	0.000	0.039	0.17	0.000

Table 7.--Commonwealth of the Northern Mariana Islands (CNMI) Bottomfish Management Unit Species: Base case production model estimates of mean exploitable biomass, relative biomass, risk of being overfished (B < 0.7*BMSY), harvest rate, relative harvest rate, and risk of overfishing (H > HMSY) from 1983 to 2013.

Year	Exploitable biomass (B, units of 1000 pounds)	Relative biomass (B/BMSY)	Risk of being overfished (B < 0.7*BMSY)	Harvest rate (H, an annual proportion)	Relative harvest rate (H/HMSY)	Risk of overfishing (H > HMSY)
1983	627	0.92	0.076	0.049	0.193	0.000
1984	882	1.29	0.013	0.054	0.213	0.000
1985	1160	1.70	0.003	0.040	0.158	0.000
1986	1293	1.89	0.001	0.026	0.103	0.000
1987	1509	2.20	0.001	0.037	0.147	0.000
1988	1518	2.22	0.001	0.035	0.141	0.000
1989	1143	1.67	0.006	0.024	0.096	0.000
1990	1058	1.55	0.013	0.014	0.055	0.000
1991	928	1.36	0.034	0.009	0.035	0.000
1992	974	1.43	0.024	0.012	0.050	0.000
1993	1084	1.59	0.010	0.019	0.077	0.000
1994	1126	1.65	0.007	0.025	0.102	0.000
1995	1235	1.81	0.003	0.033	0.130	0.000
1996	1372	2.01	0.001	0.054	0.214	0.000
1997	1443	2.10	0.001	0.050	0.197	0.000
1998	1469	2.14	0.001	0.045	0.179	0.000
1999	1425	2.08	0.001	0.045	0.177	0.000
2000	1075	1.57	0.009	0.048	0.189	0.000
2001	1082	1.58	0.008	0.074	0.295	0.002
2002	1166	1.71	0.005	0.045	0.180	0.000
2003	1181	1.73	0.004	0.040	0.159	0.000
2004	1214	1.78	0.003	0.050	0.201	0.000
2005	1139	1.67	0.007	0.070	0.278	0.002
2006	1172	1.71	0.018	0.030	0.118	0.000
2007	1211	1.77	0.022	0.039	0.156	0.001
2008	1219	1.78	0.025	0.042	0.166	0.002
2009	1216	1.78	0.027	0.041	0.165	0.002
2010	1217	1.78	0.029	0.023	0.090	0.001
2011	1237	1.81	0.028	0.022	0.089	0.001
2012	1248	1.83	0.026	0.015	0.061	0.000
2013	1262	1.85	0.025	0.022	0.088	0.001

Table 8.--Guam Bottomfish Management Unit Species: Base case production model estimates of mean exploitable biomass, relative biomass, risk of being overfished (B < 0.7*BMSY), harvest rate, relative harvest rate, and risk of overfishing (H > HMSY) from 1982 to 2013.

Year	Exploitable biomass (B, units of 1000 pounds)	Relative biomass (B/BMSY)	Risk of being overfished (B < 0.7*BMSY)	Harvest rate (H, an annual proportion)	Relative harvest rate (H/HMSY)	Risk of overfishing (H > HMSY)
1982	249.6	1.54	0.00	0.112	0.322	0.00
1983	280.3	1.72	0.00	0.156	0.448	0.00
1984	361.1	2.22	0.00	0.059	0.171	0.00
1985	276.9	1.70	0.00	0.192	0.553	0.01
1986	264.2	1.62	0.00	0.084	0.243	0.00
1987	279.8	1.72	0.00	0.114	0.330	0.00
1988	249.0	1.53	0.00	0.202	0.583	0.02
1989	231.0	1.42	0.00	0.275	0.794	0.17
1990	223.4	1.37	0.01	0.208	0.602	0.04
1991	208.6	1.28	0.02	0.208	0.601	0.04
1992	214.9	1.32	0.01	0.256	0.741	0.13
1993	218.7	1.35	0.01	0.279	0.808	0.20
1994	203.4	1.25	0.02	0.266	0.770	0.16
1995	185.9	1.14	0.04	0.243	0.702	0.11
1996	180.6	1.11	0.06	0.330	0.957	0.39
1997	156.3	0.96	0.16	0.218	0.630	0.06
1998	172.2	1.06	0.08	0.241	0.697	0.10
1999	190.7	1.18	0.03	0.305	0.882	0.29
2000	201.6	1.24	0.01	0.358	1.037	0.49
2001	214.4	1.32	0.01	0.278	0.804	0.20
2002	224.6	1.38	0.01	0.118	0.342	0.00
2003	271.1	1.67	0.00	0.175	0.507	0.01
2004	257.2	1.58	0.00	0.156	0.452	0.00
2005	283.6	1.74	0.00	0.141	0.408	0.00
2006	267.5	1.64	0.00	0.156	0.451	0.00
2007	232.5	1.43	0.01	0.129	0.373	0.00
2008	230.6	1.42	0.01	0.176	0.510	0.01
2009	250.6	1.54	0.00	0.174	0.505	0.01
2010	264.2	1.62	0.00	0.119	0.345	0.00
2011	277.6	1.71	0.00	0.233	0.673	0.07
2012	251.7	1.55	0.00	0.096	0.277	0.00
2013	264.7	1.63	0.00	0.123	0.356	0.00

Table 9.--American Samoa Bottomfish Management Unit Species: Results of projections through 2017, including 2016 and 2017 risks of overfishing (H > HMSY), the corresponding catch level, harvest rate in 2016, relative biomass in 2017, and risk of being overfished (B < 0.7*BMSY) in 2017.

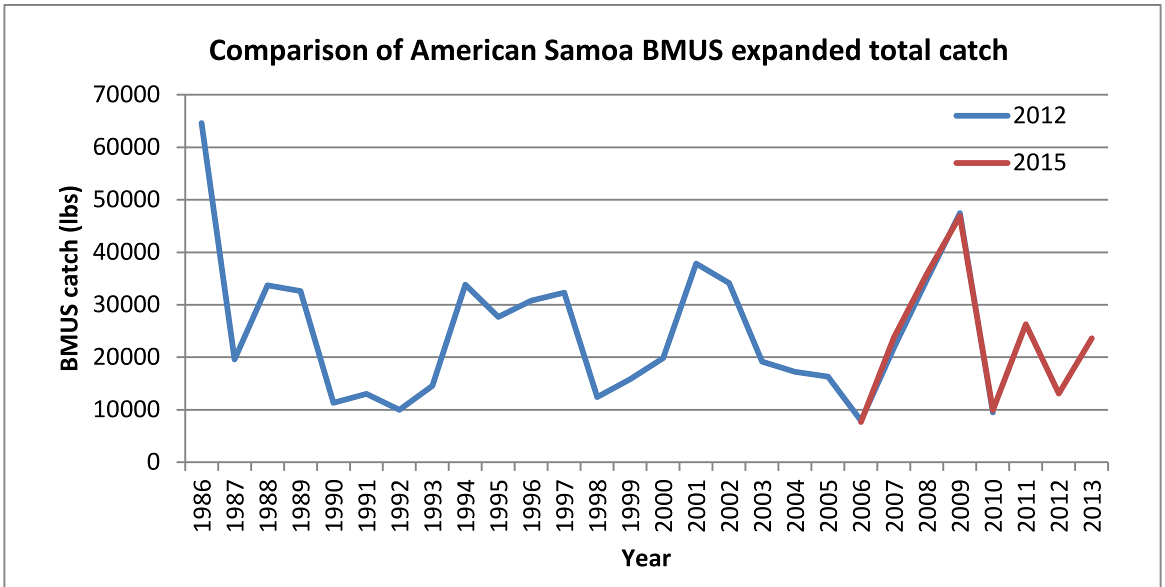
Catch (lbs) of American Samoa bottomfish in 2016 and 2017	Risk of overfishing (H > HMSY) in 2016	Risk of overfishing (H > HMSY) in 2017	Harvest rate in 2016	Relative biomass (B/BMSY) in 2017	Risk of being overfished (B < 0.7*BMSY) in 2017
50,000	1.0%	1%	0.09	1.69	0.5%
69,000	4.2%	5%	0.13	1.64	0.7%
80,000	7.7%	10%	0.15	1.60	0.8%
87,000	10.9%	15%	0.16	1.58	0.9%
92,000	13.5%	20%	0.17	1.56	1.0%
97,000	16.6%	25%	0.18	1.55	1.0%
98,000	17.2%	27%	0.18	1.55	1.1%
99,000	18.0%	28%	0.18	1.54	1.1%
100,000	18.6%	29%	0.18	1.54	1.1%
101,000	19.3%	30%	0.19	1.54	1.1%
102,000	19.9%	31%	0.19	1.53	1.1%
103,000	20.7%	33%	0.19	1.53	1.2%
104,000	21.5%	34%	0.19	1.53	1.2%
105,000	22.3%	35%	0.19	1.52	1.2%
106,000	22.9%	37%	0.19	1.52	1.2%
107,000	23.7%	38%	0.20	1.52	1.3%
108,000	24.5%	40%	0.20	1.51	1.3%
109,000	25.4%	41%	0.20	1.51	1.3%
110,000	26.1%	42%	0.20	1.51	1.3%
111,000	26.9%	44%	0.20	1.50	1.3%
112,000	27.8%	45%	0.21	1.50	1.4%
113,000	28.6%	47%	0.21	1.50	1.4%
114,000	29.4%	48%	0.21	1.50	1.4%
115,000	30.2%	50%	0.21	1.49	1.5%

Table 10.--Commonwealth of the Northern Mariana Islands (CNMI) Bottomfish Management Unit Species: Results of projections through 2017, including 2016 and 2017 risks of overfishing (H > HMSY), the corresponding catch level, harvest rate in 2016, relative biomass in 2017, and risk of being overfished (B < 0.7*BMSY) in 2017.

Catch (lbs) of CNMI bottomfish in 2016 and 2017	**Risk of overfishing (H > HMSY) in 2016**	**Risk of overfishing (H > HMSY) in 2017**	**Harvest rate in 2016**	**Relative biomass (B/BMSY) in 2017**	**Risk of being overfished (B < 0.7*BMSY) in 2017**
78,000	1.0%	1%	0.07	1.69	1.7%
134,000	4.7%	5%	0.13	1.60	2.3%
162,000	8.5%	10%	0.15	1.56	2.7%
180,000	12.1%	15%	0.17	1.54	3.0%
194,000	15.2%	20%	0.18	1.51	3.1%
206,000	18.1%	25%	0.20	1.50	3.3%
208,000	18.7%	26%	0.20	1.49	3.4%
210,000	19.1%	27%	0.20	1.49	3.4%
212,000	19.7%	28%	0.20	1.49	3.4%
214,000	20.2%	29%	0.20	1.48	3.5%
216,000	20.8%	30%	0.21	1.48	3.5%
218,000	21.3%	31%	0.21	1.48	3.5%
220,000	21.9%	32%	0.21	1.48	3.6%
222,000	22.5%	33%	0.21	1.47	3.7%
224,000	23.1%	34%	0.21	1.47	3.7%
226,000	23.6%	35%	0.21	1.47	3.7%
228,000	24.2%	36%	0.22	1.46	3.8%
230,000	24.9%	37%	0.22	1.46	3.8%
232,000	25.6%	38%	0.22	1.46	3.8%
234,000	26.2%	40%	0.22	1.45	3.9%
236,000	26.8%	41%	0.22	1.45	3.9%
238,000	27.4%	42%	0.23	1.45	4.0%
240,000	28.1%	43%	0.23	1.45	4.0%
242,000	28.7%	45%	0.23	1.44	4.1%
244,000	29.3%	46%	0.23	1.44	4.1%
246,000	30.0%	47%	0.23	1.44	4.2%
248,000	30.6%	48%	0.24	1.43	4.2%
250,000	31.2%	50%	0.24	1.43	4.3%

Table 11.--Guam Bottomfish Management Unit Species: Results of projections through 2017, including 2016 and 2017 risks of overfishing (H > HMSY), the corresponding catch level, harvest rate in 2016, relative biomass in 2017, and risk of being overfished (B < 0.7*BMSY) in 2017.

Catch (lbs) of Guam bottomfish in 2016 and 2017	**Risk of overfishing (H > HMSY) in 2016**	**Risk of overfishing (H > HMSY) in 2017**	**Harvest rate in 2016**	**Relative biomass (B/BMSY) in 2017**	**Risk of being overfished (B < 0.7*BMSY) in 2017**
33,000	1.2%	1%	0.15	1.50	1.0%
45,000	5.0%	5%	0.20	1.42	1.6%
51,000	8.9%	10%	0.23	1.39	2.0%
55,000	12.3%	15%	0.25	1.36	2.2%
58,000	15.2%	20%	0.26	1.34	2.4%
61,000	18.6%	25%	0.27	1.32	2.7%
62,000	19.8%	26%	0.28	1.32	2.8%
63,000	21.0%	29%	0.28	1.31	2.9%
64,000	22.3%	31%	0.29	1.30	3.1%
65,000	23.7%	33%	0.29	1.30	3.2%
66,000	25.0%	36%	0.30	1.29	3.3%
67,000	26.4%	38%	0.30	1.28	3.4%
68,000	27.8%	41%	0.31	1.28	3.5%
69,000	29.2%	44%	0.31	1.27	3.6%
70,000	30.7%	46%	0.32	1.27	3.7%
71,000	32.1%	49%	0.32	1.26	3.9%



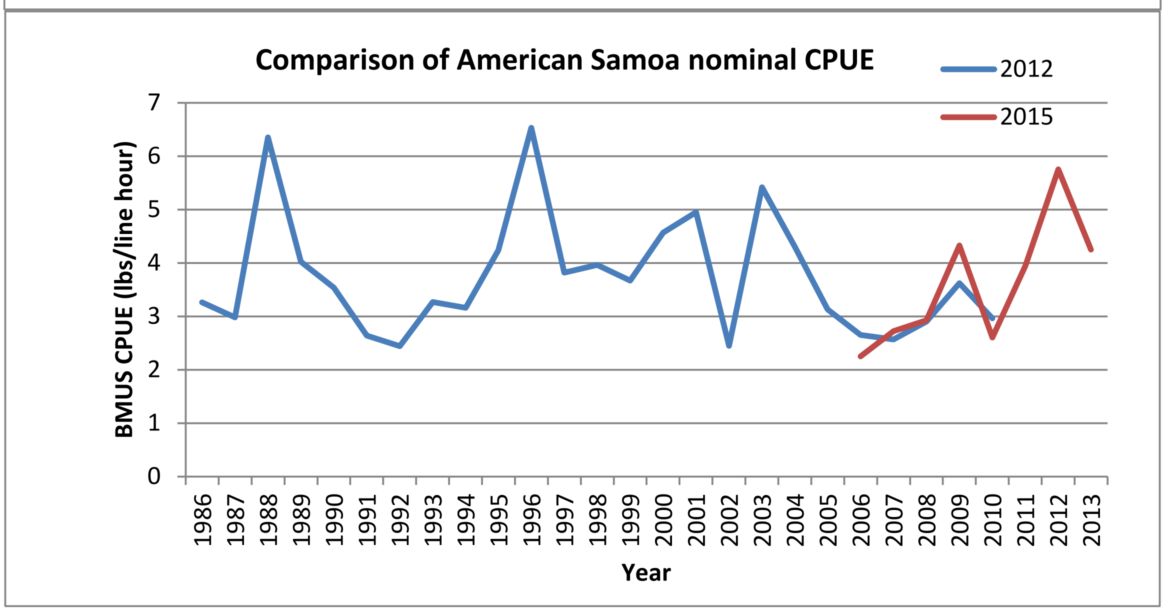


Figure 1.--(top) Comparison of catch calculated for American Samoa BMUS (Bottomfish Management Unit Species complex) for the 2012 assessment (blue line) and in 2015 (red line). The catch time series are very similar in the years they overlap, from 2006 to 2010. For this assessment update, newly calculated catch for 2011-2013 was added to the original time series of catch for 1986-2010 calculated in 2012.

(bottom) Comparison of nominal catch per unit effort (CPUE, in lbs/line hour) calculated for American Samoa BMUS for the 2012 assessment (blue line) and in 2015 (red line). The time series are very similar in magnitude and trend in the years they overlap, from 2006 to 2010. For this assessment update, newly calculated CPUE for 2011-2013 was added to the original time series of CPUE for 1986-2010 calculated in 2012.

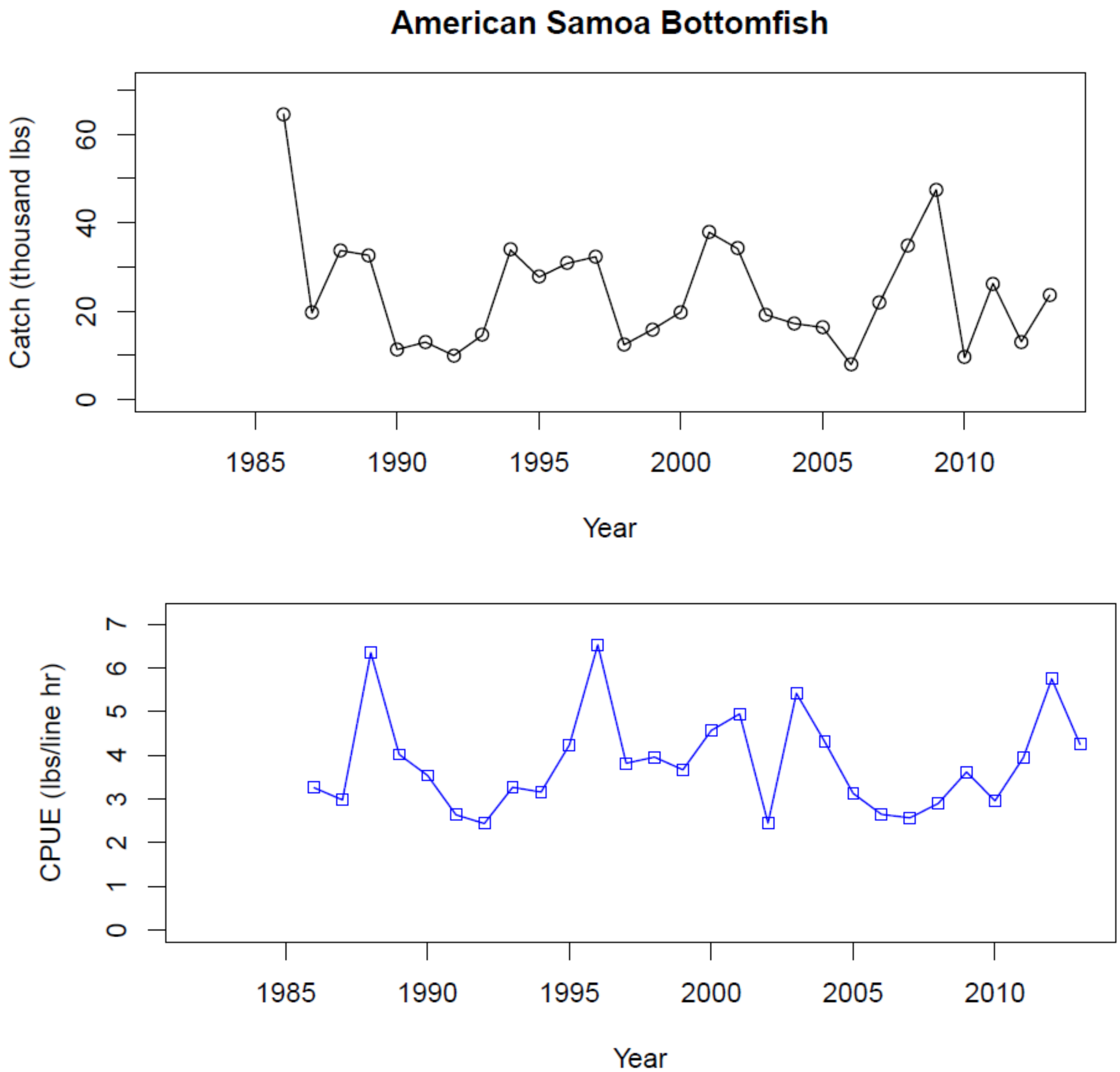
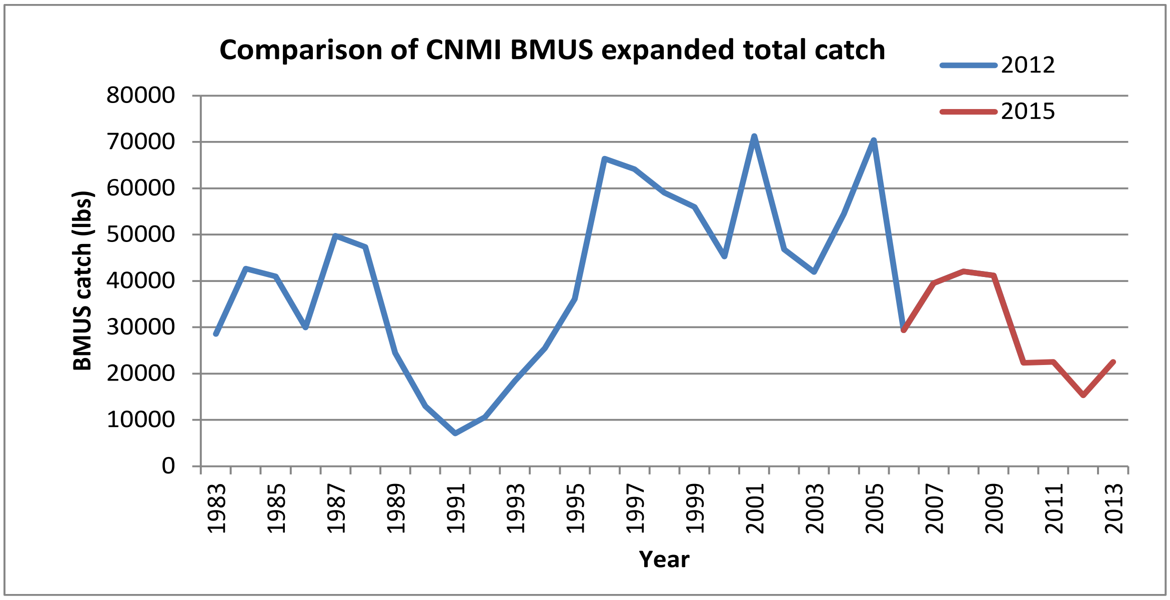


Figure 2.--(top) Final catch (thousand lbs) of American Samoa BMUS (Bottomfish Management Unit Species Complex) from 1986-2013 used in this stock assessment update.

(bottom) Final nominal catch per unit effort (CPUE, in lbs/line hour) of American Samoa BMUS (Bottomfish Management Unit Species Complex) from 1986 to 2013 used in this stock assessment update.



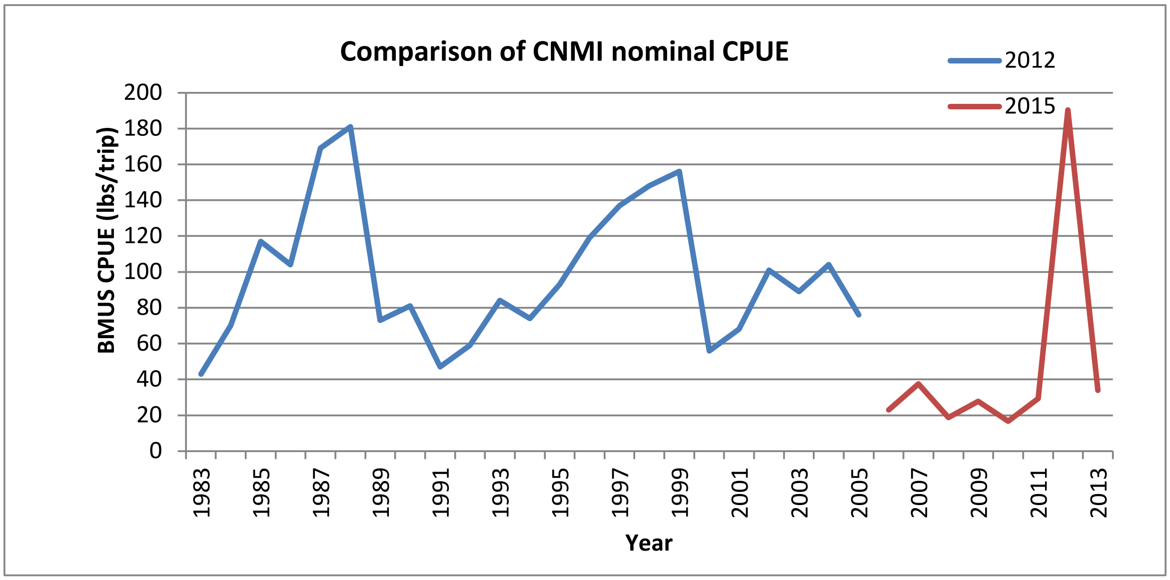


Figure 3.--(top) Comparison of catch calculated for CNMI BMUS (Bottomfish Management Unit Species complex) for the 2012 assessment (blue line) and in 2015 (red line). The catch time series are extremely similar in the years they overlap, from 2006 to 2010. For this assessment update, newly calculated catch for 2011-2013 was added to the original time series of catch for 1983-2010 calculated in 2012.

(bottom) Comparison of nominal catch per unit effort (CPUE, in lbs/trip) calculated for CNMI BMUS for the 2012 assessment (blue line) and in 2015 (red line). The time series are very different in magnitude, likely due to changes in reporting method and sampling frame. For this assessment update, the original time series of CPUE for 1983-2005 was used.

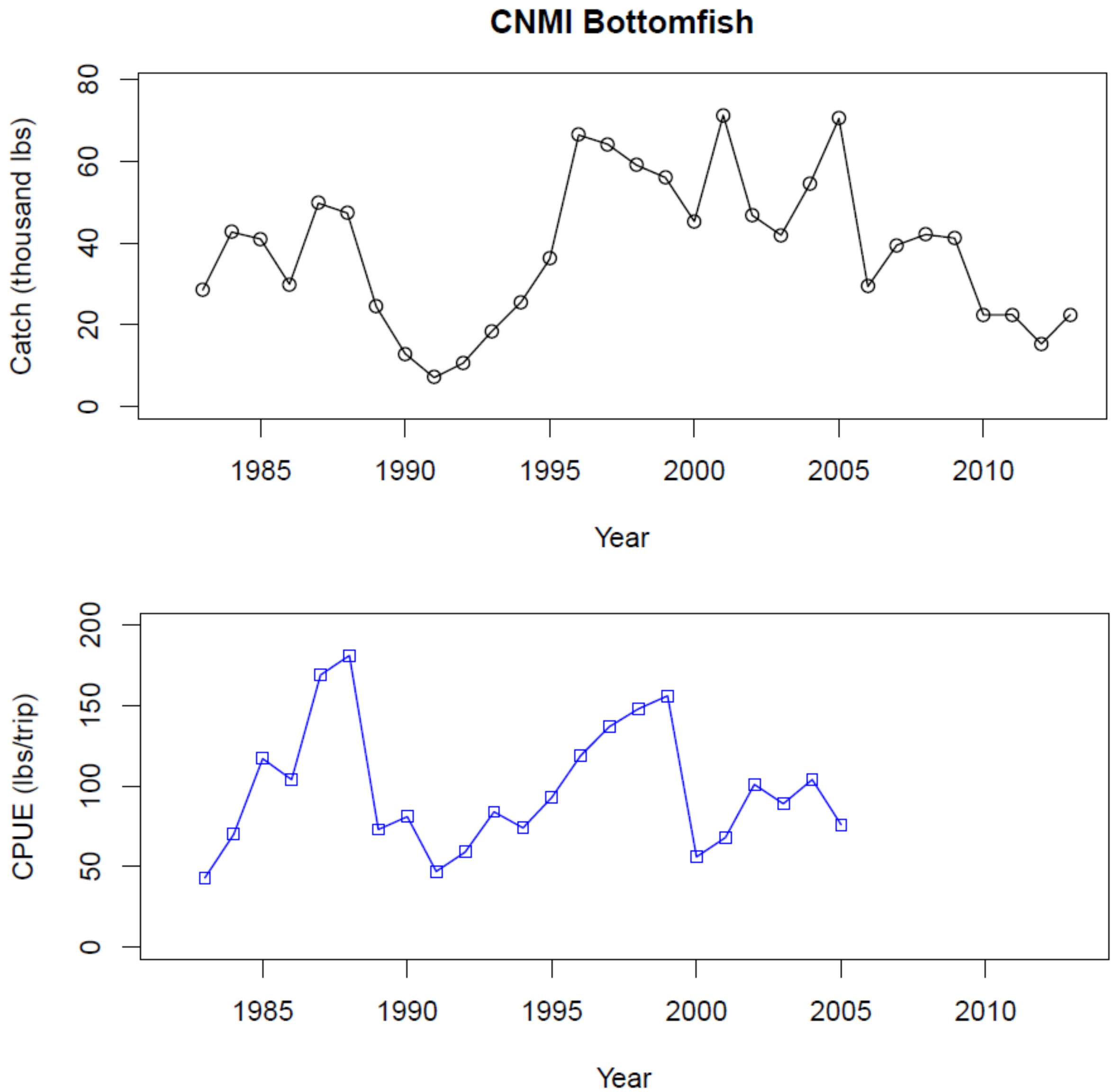
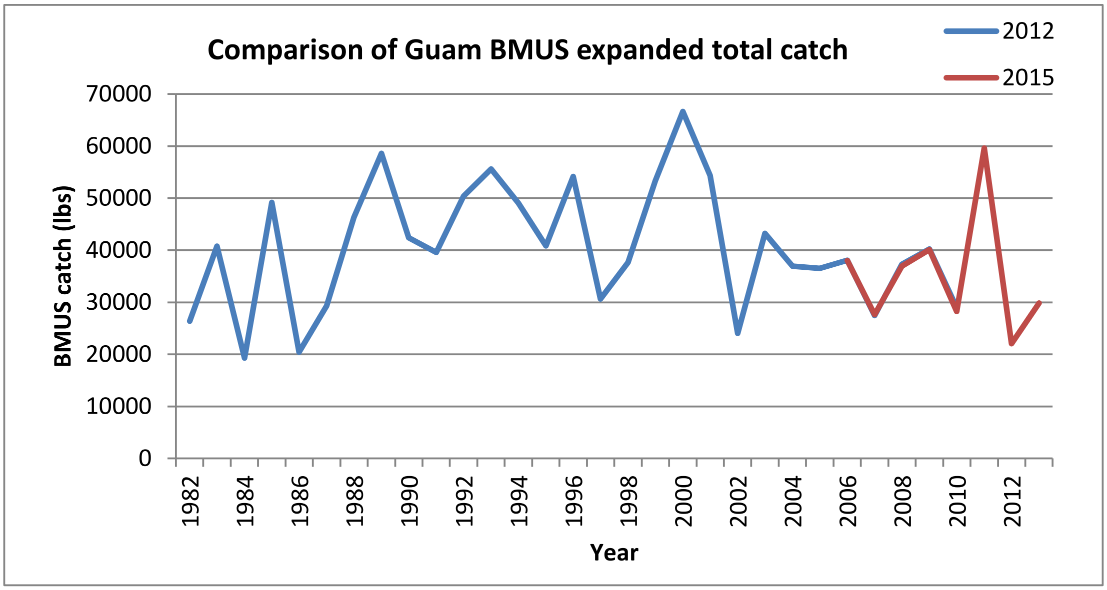


Figure 4.--(top) Final catch (thousand lbs) of CNMI (Commonwealth of the Northern Mariana Islands) BMUS (Bottomfish Management Unit Species Complex) from 1983 to 2013 used in this stock assessment update.

(bottom) Final nominal catch per unit effort (CPUE, in lbs/trip) of CNMI BMUS (Bottomfish Management Unit Species Complex) from 1983 to 2005 used in this stock assessment update.



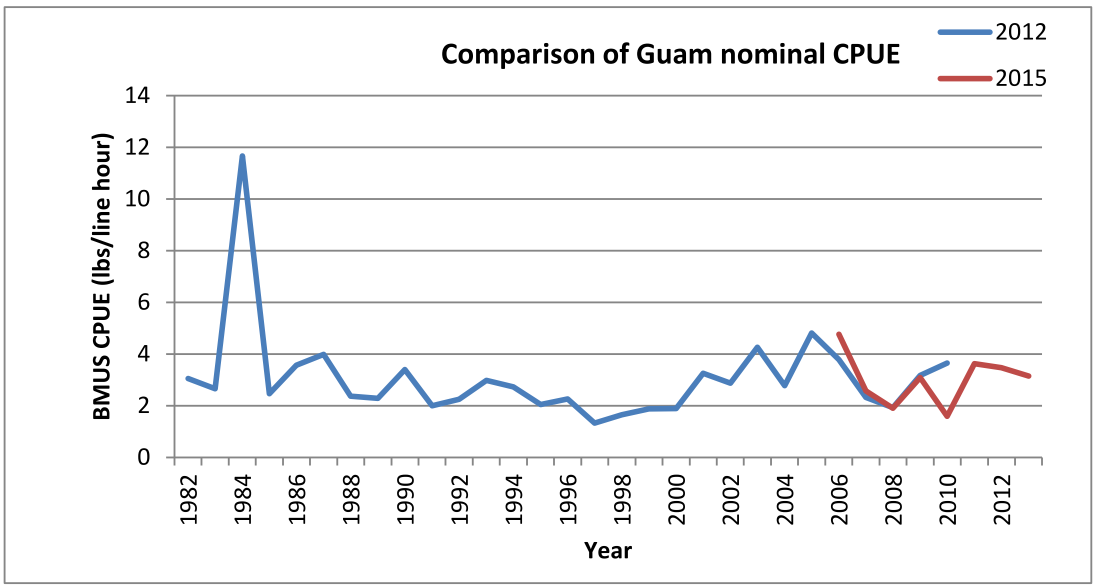


Figure 5.--(top) Comparison of catch calculated for Guam BMUS (Bottomfish Management Unit Species complex) for the 2012 assessment (blue line) and in 2015 (red line). The catch time series are very similar in the years they overlap, from 2006 to 2010. For this assessment update, newly calculated catch for 2011-2013 was added to the original time series of catch for 1982-2010 calculated in 2012.

(bottom) Comparison of nominal catch per unit effort (CPUE, in lbs/line hour) calculated for Guam BMUS for the 2012 assessment (blue line) and in 2015 (red line). The time series are very similar in magnitude and trend in the years they overlap, from 2006 to 2010. For this assessment update, newly calculated CPUE for 2011-2013 was added to the original time series of CPUE for 1982-2010 calculated in 2012.

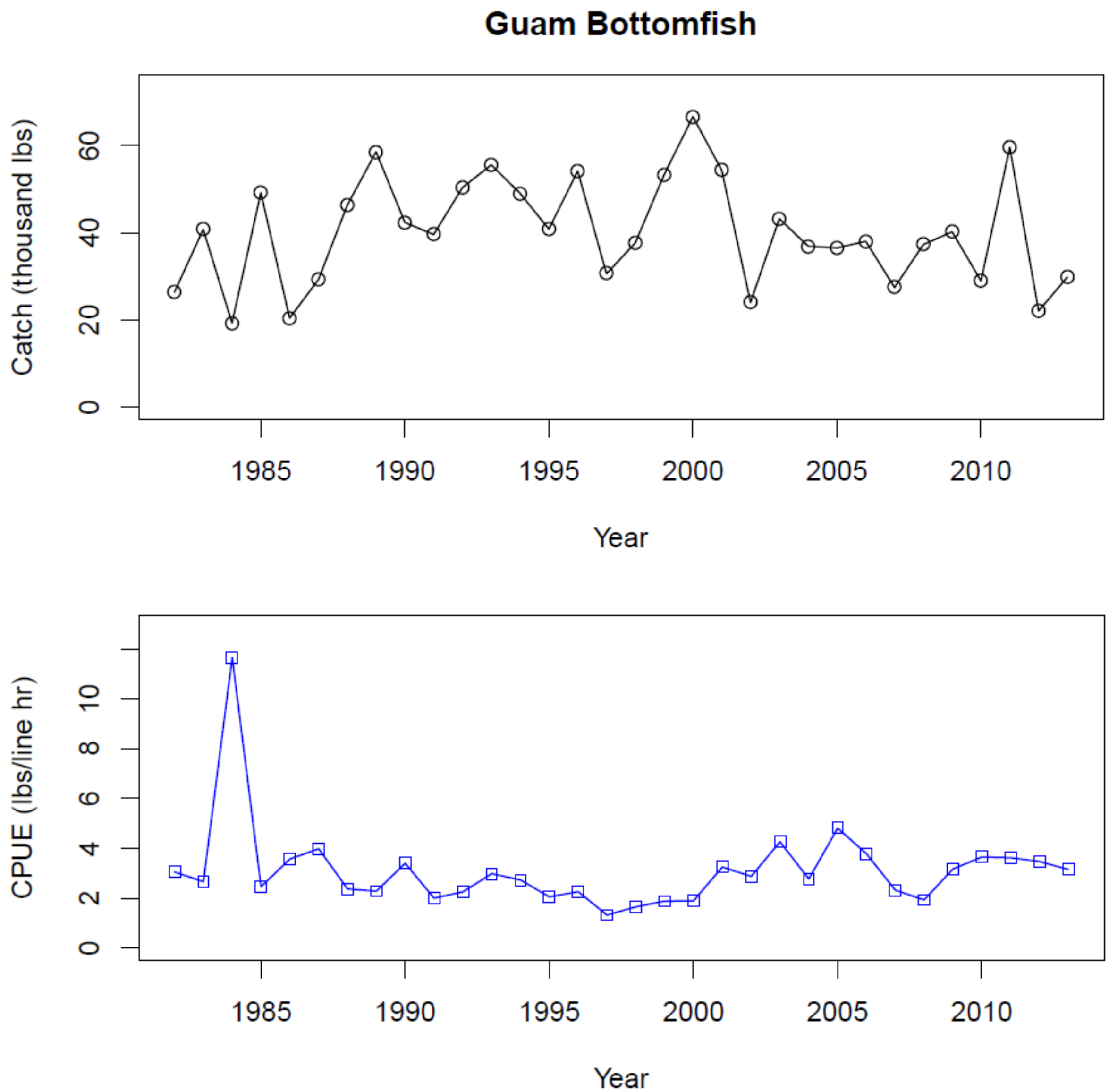


Figure 6.--(top) Final catch (thousand lbs) of Guam BMUS (Bottomfish Management Unit Species Complex) from 1982 to 2013 used in this stock assessment update.

(bottom) Final nominal catch per unit effort (CPUE, in lbs/line hour) of Guam BMUS (Bottomfish Management Unit Species Complex) from 1982 to 2013 used in this stock assessment update.

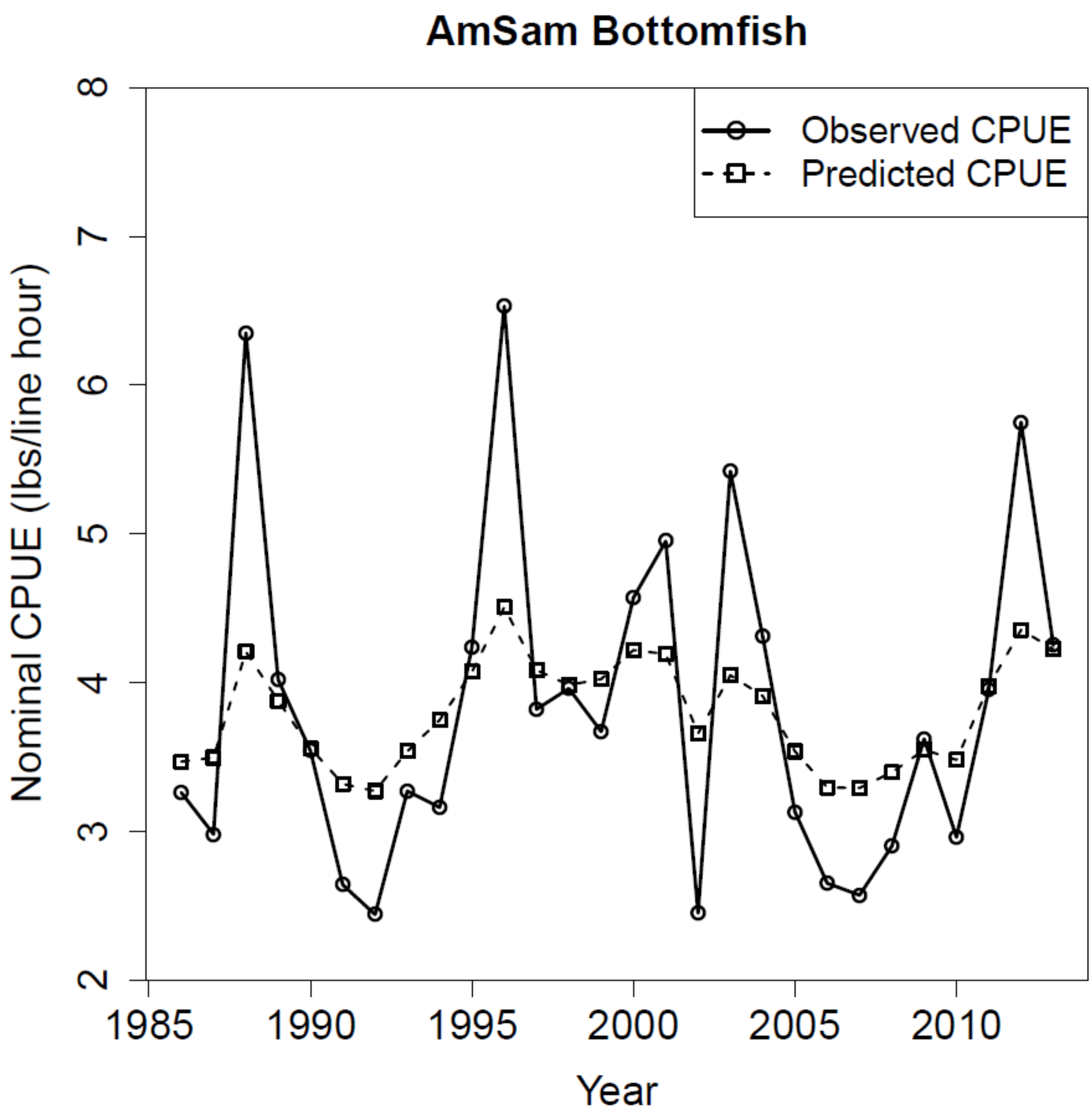


Figure 7.--Comparison of observed nominal CPUE (circles with solid line) with model-predicted nominal CPUE (squares with dotted line) of American Samoa bottomfish, 1986-2013.

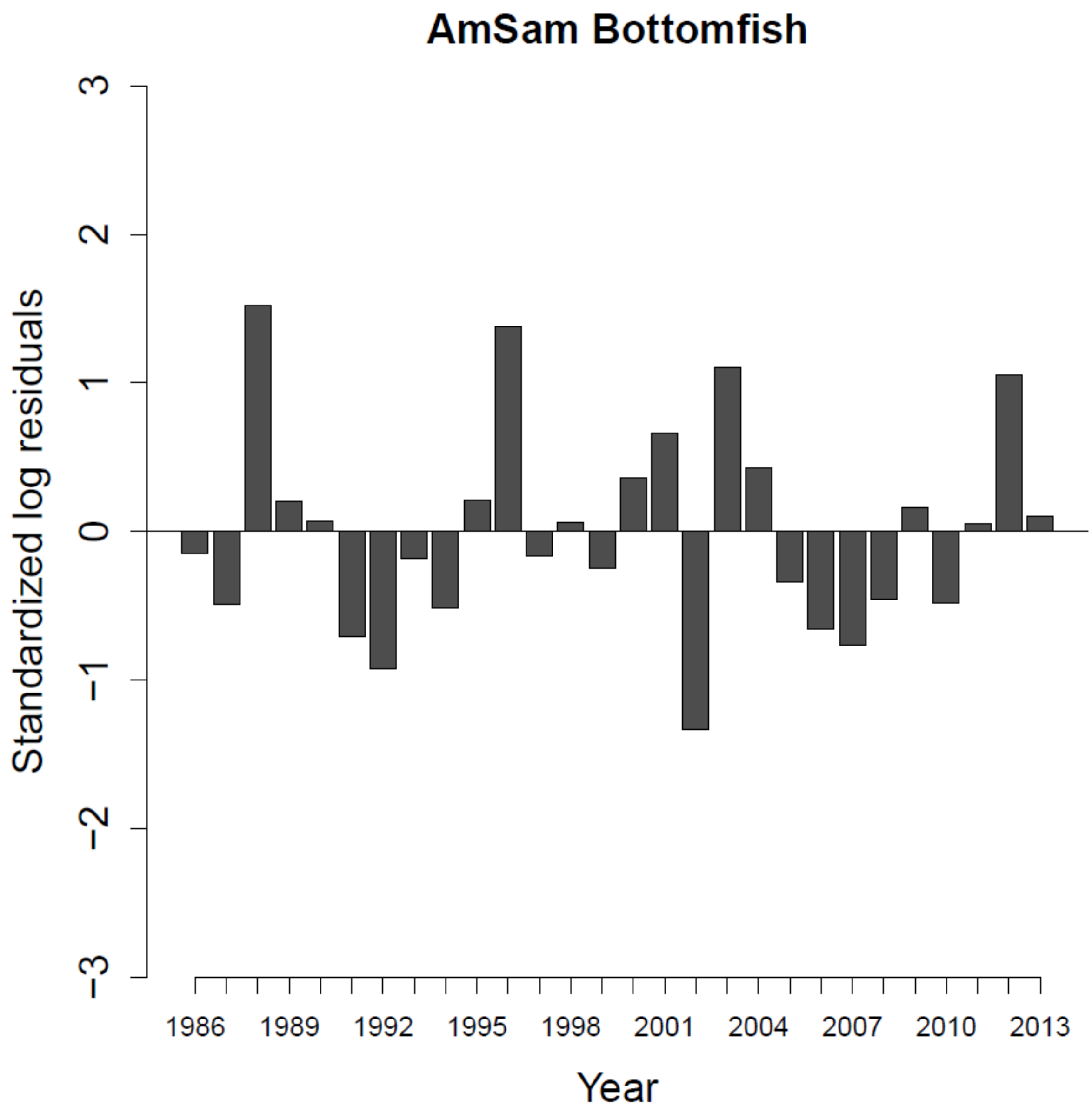


Figure 8.--Residuals of production model fit to nominal observed CPUE for American Samoa bottomfish, 1986-2013.

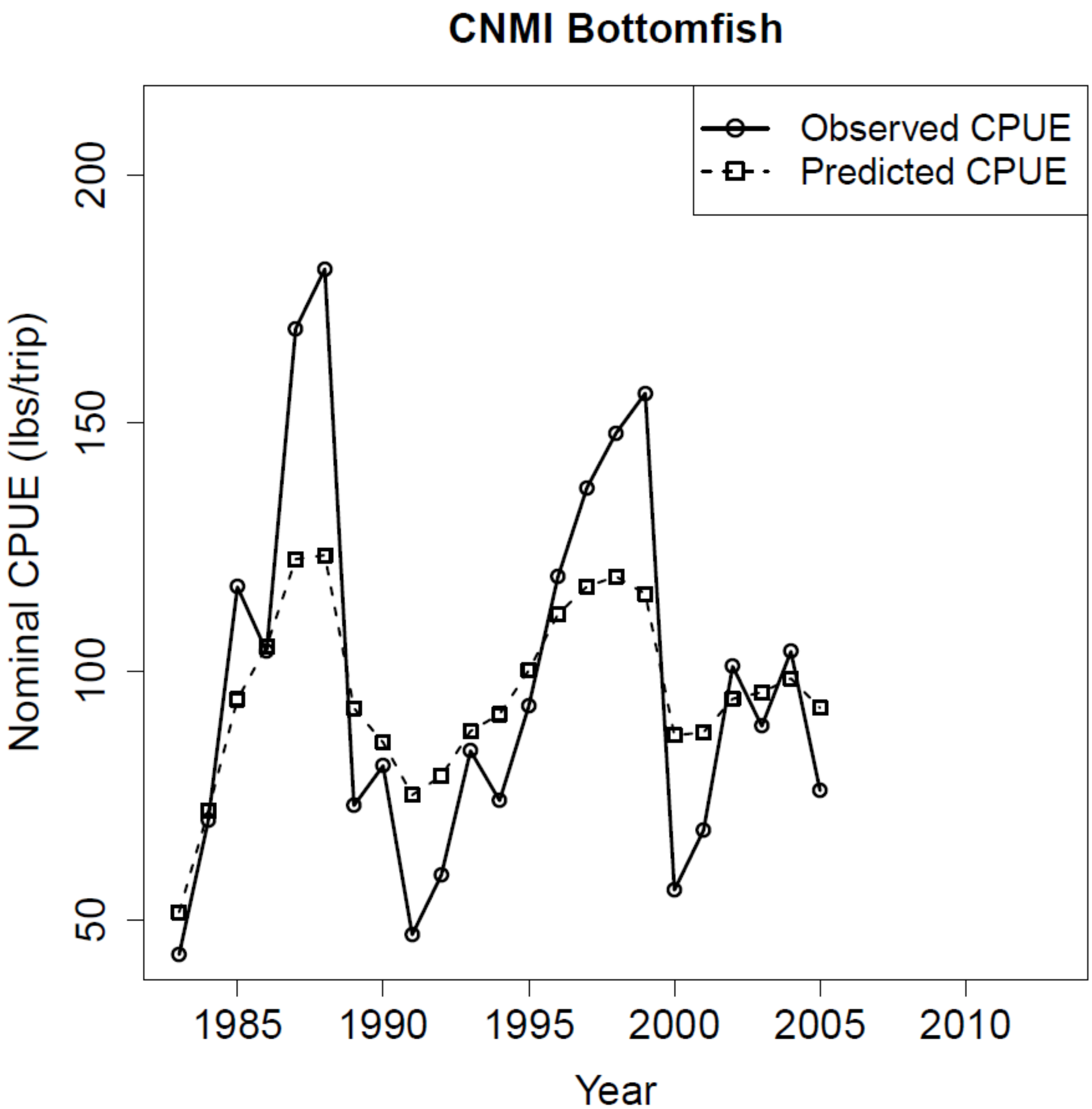


Figure 9.--Comparison of observed nominal CPUE (circles with solid line) with model-predicted nominal CPUE (squares with dotted line) of CNMI bottomfish, 1983-2005.

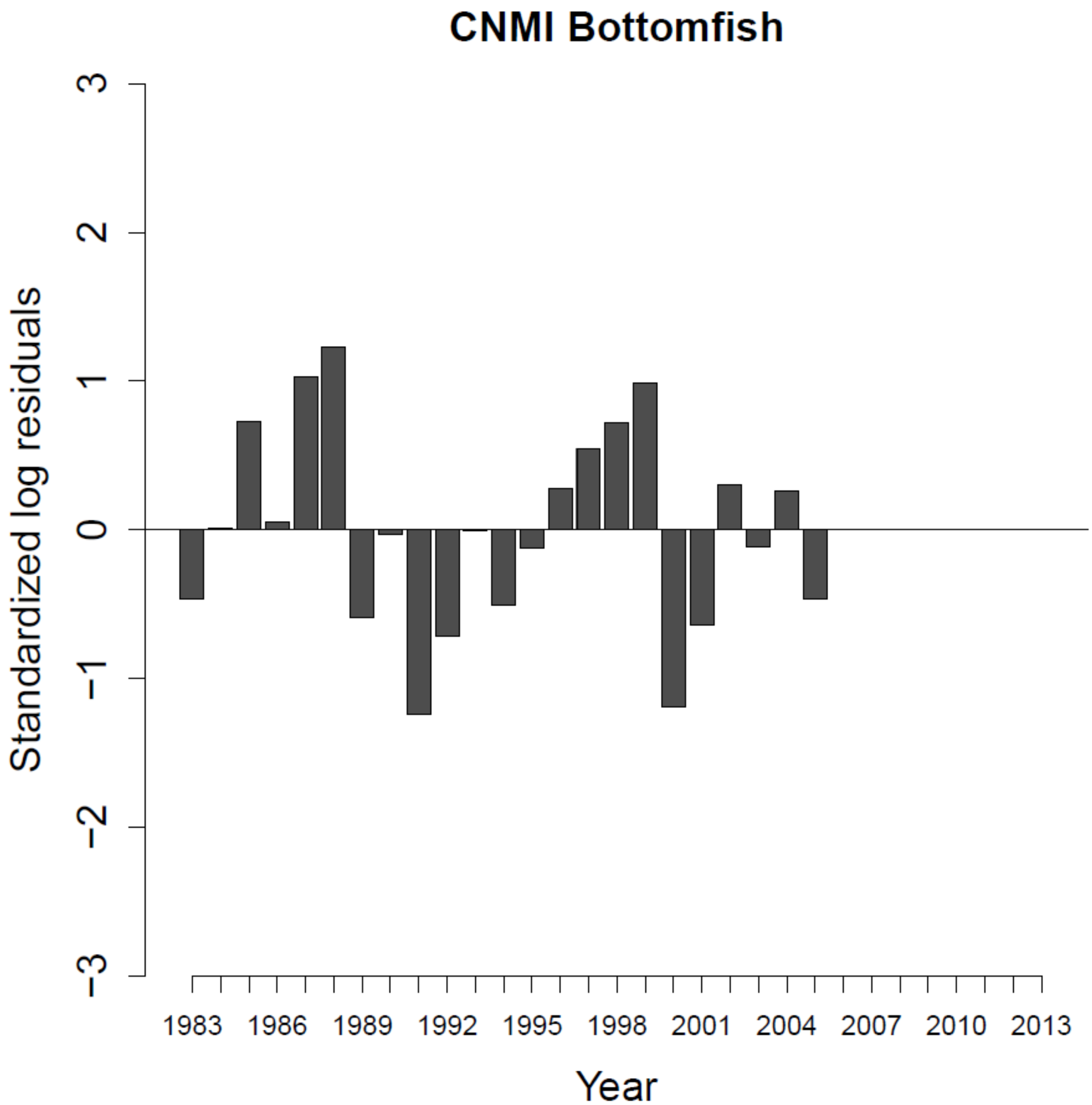


Figure 10.--Residuals of production model fit to nominal observed CPUE for CNMI bottomfish, 1983-2005.

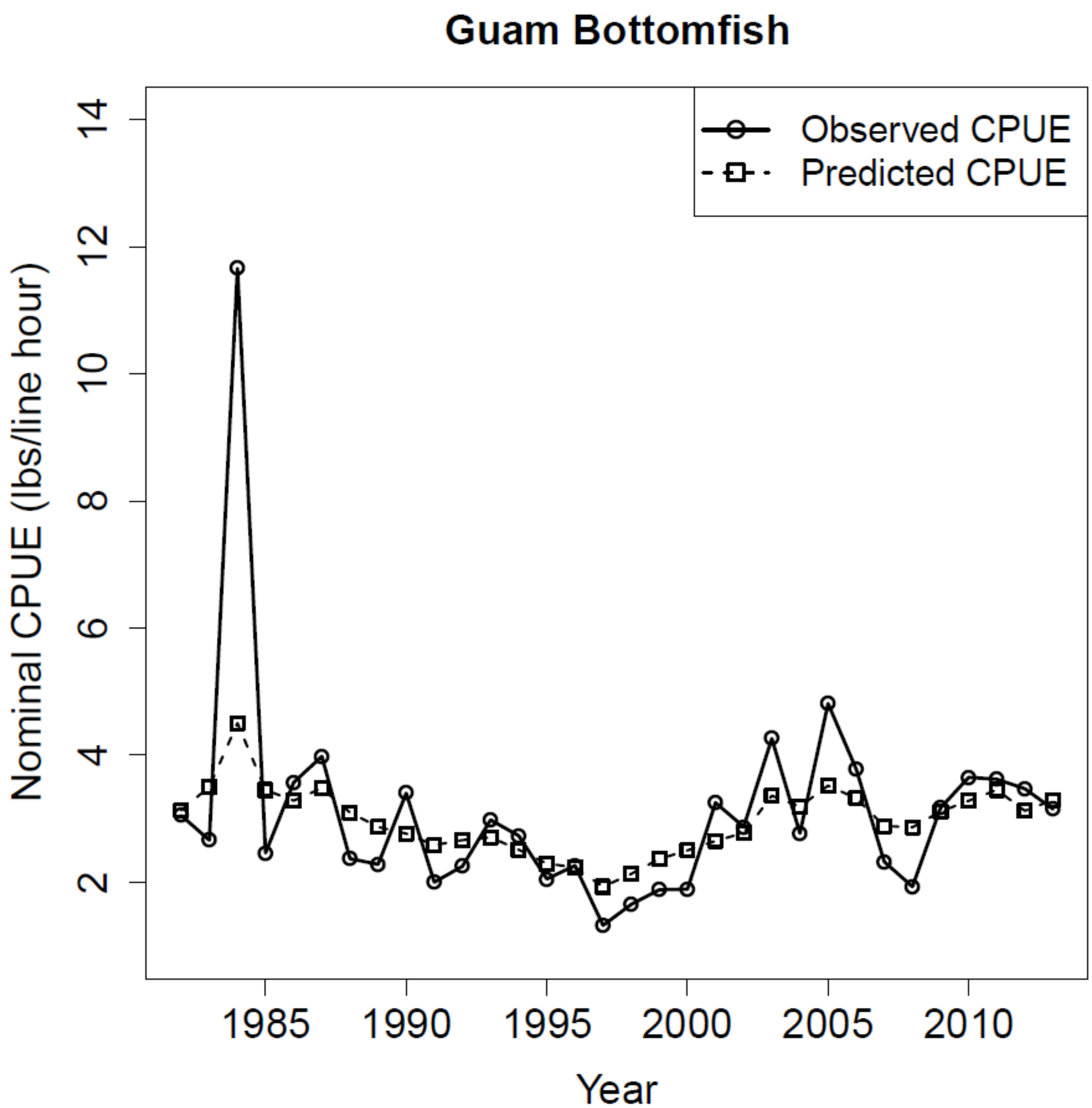


Figure 11.--Comparison of observed nominal CPUE (circles with solid line) with model-predicted nominal CPUE (squares with dotted line) of Guam bottomfish, 1982-2013.

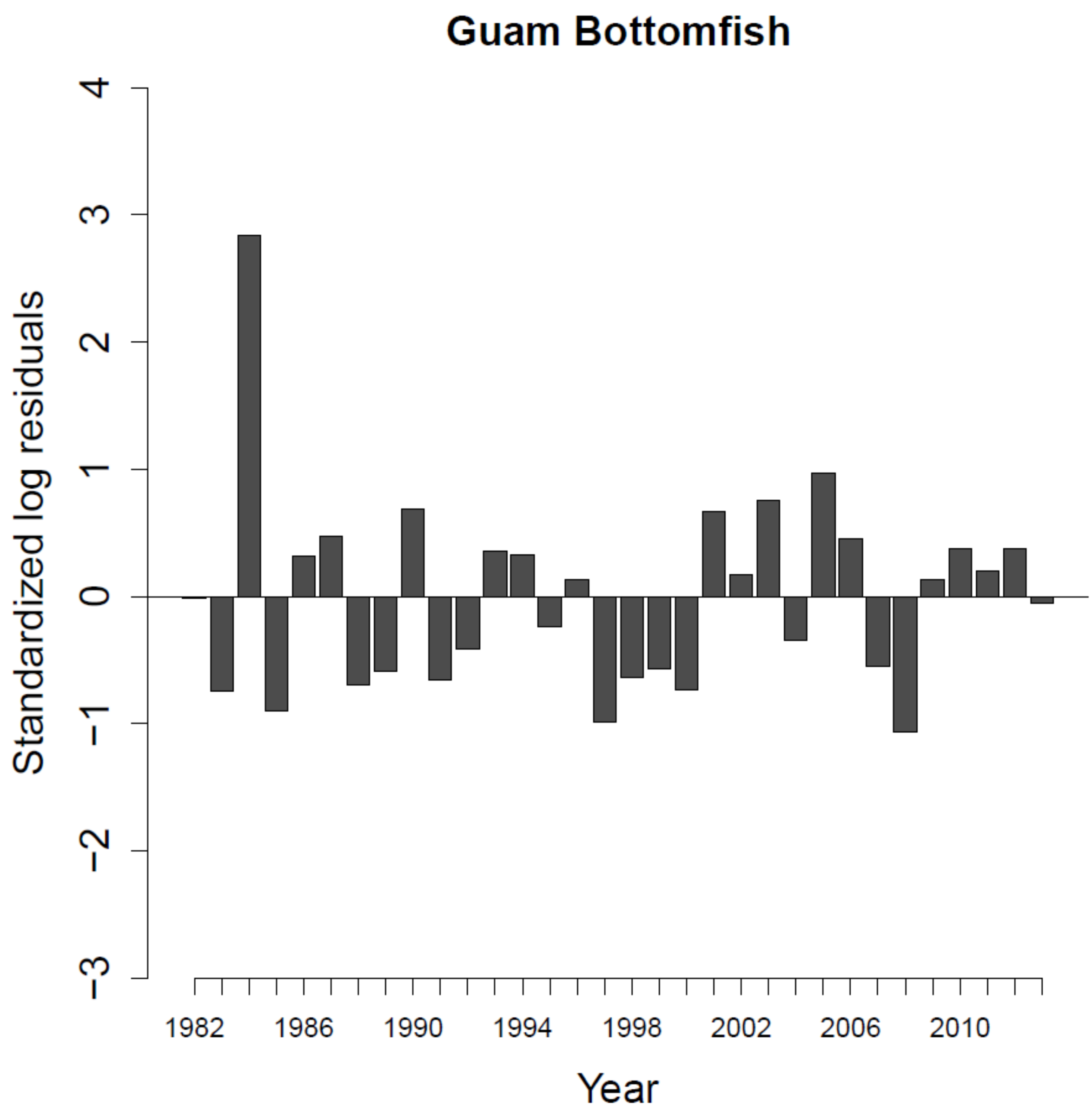


Figure 12.--Residuals of production model fit to nominal observed CPUE for Guam bottomfish, 1982-2013.

American Samoa Bottomfish

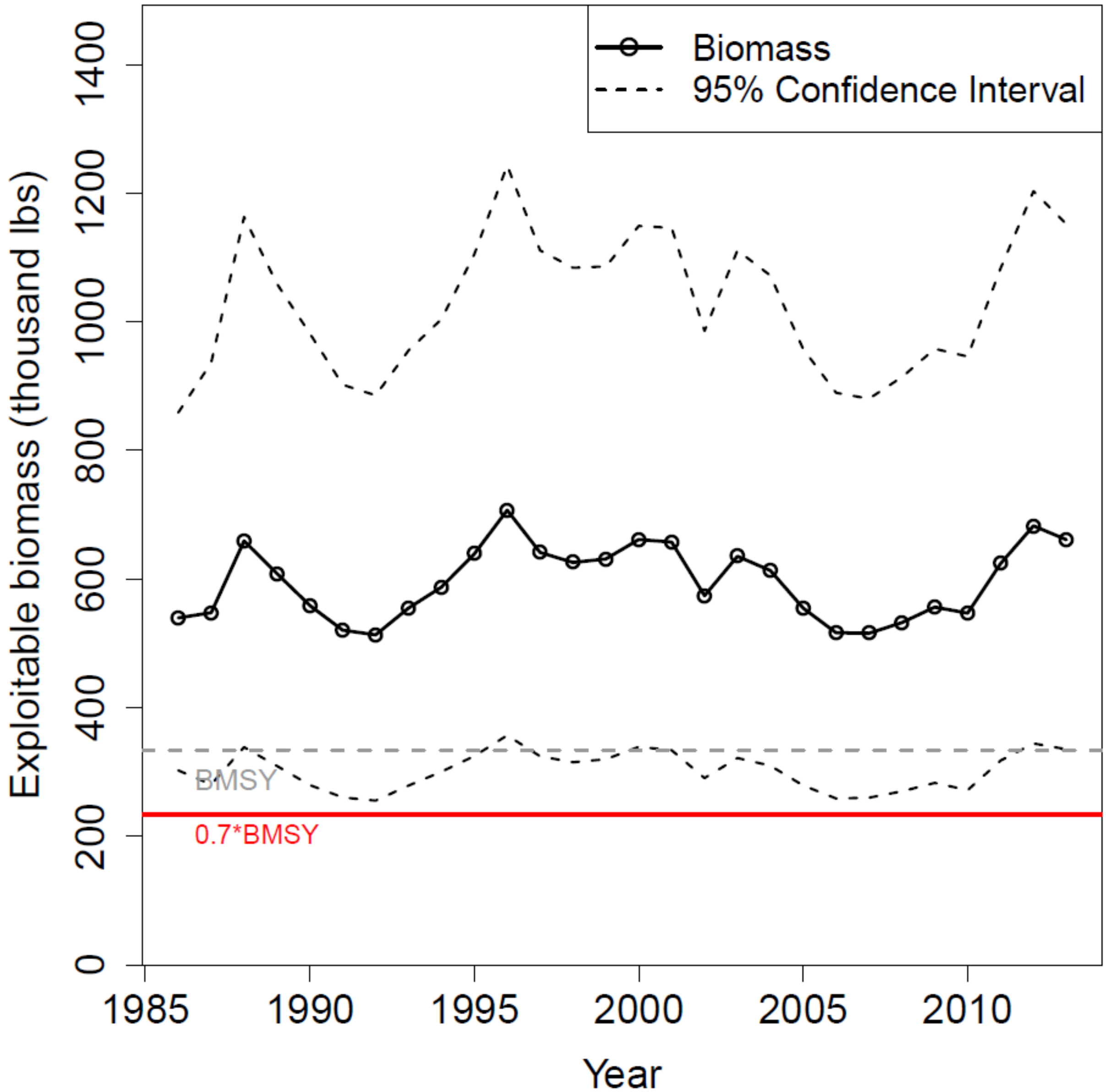


Figure 13.--American Samoa bottomfish biomass: Model-estimated trends in mean values (black circles, solid line) with 95% confidence intervals (black dotted line). BMSY is indicated with a horizontal gray dotted line, and the overfished limit of 0.7*BMSY is indicated with a horizontal solid red line. Biomass estimates were generally above the overfished limit, indicating stock status was not and is not overfished.

American Samoa Bottomfish

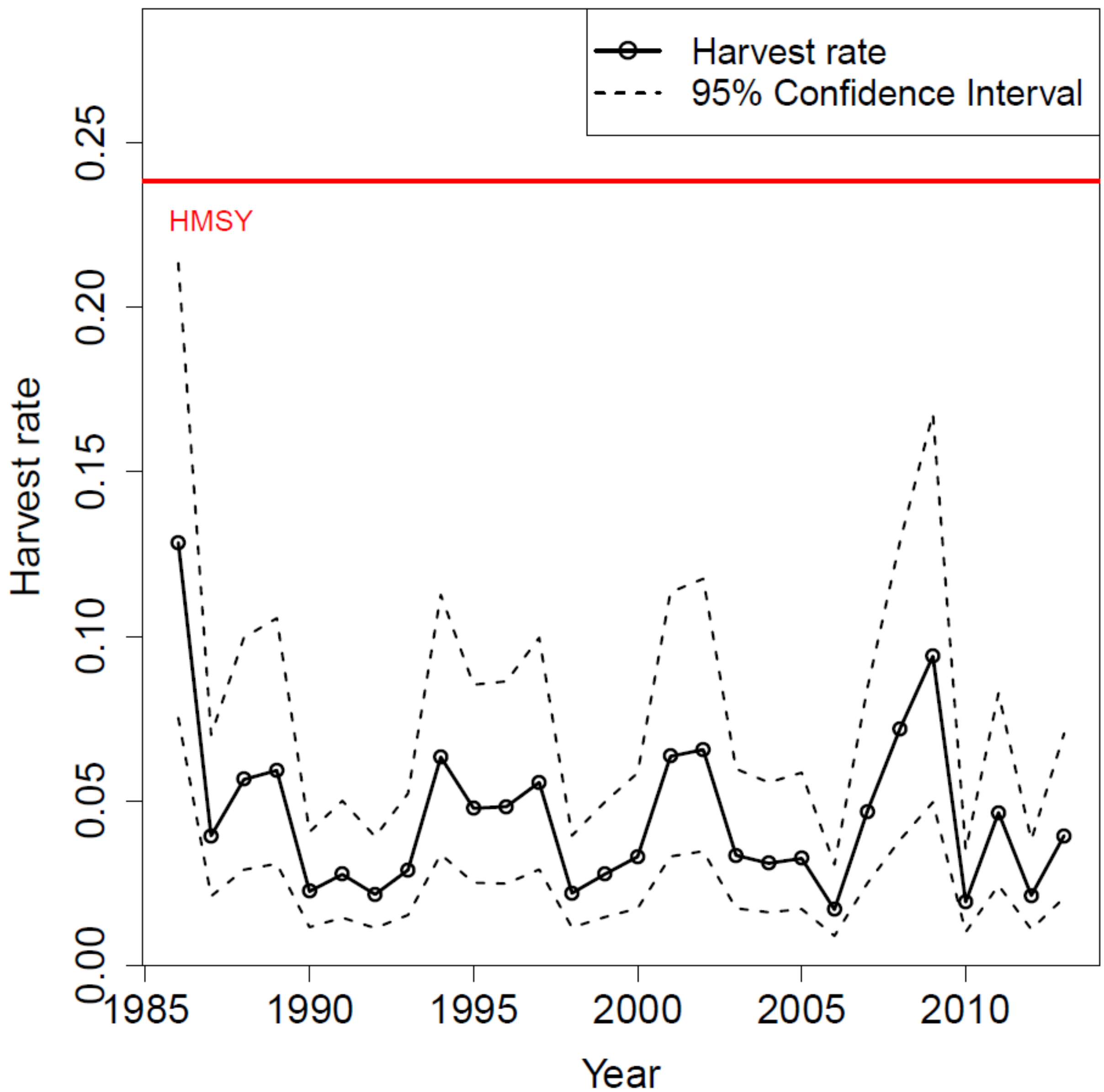


Figure 14.--American Samoa bottomfish harvest rates: Model-estimated trends in mean annual harvest rate (black circles, solid line) with 95% confidence intervals (black dotted line). The overfishing limit of HMSY is indicated with a horizontal solid red line. Harvest rate estimates were generally below the overfishing limit, indicating overfishing was not and is not occurring.

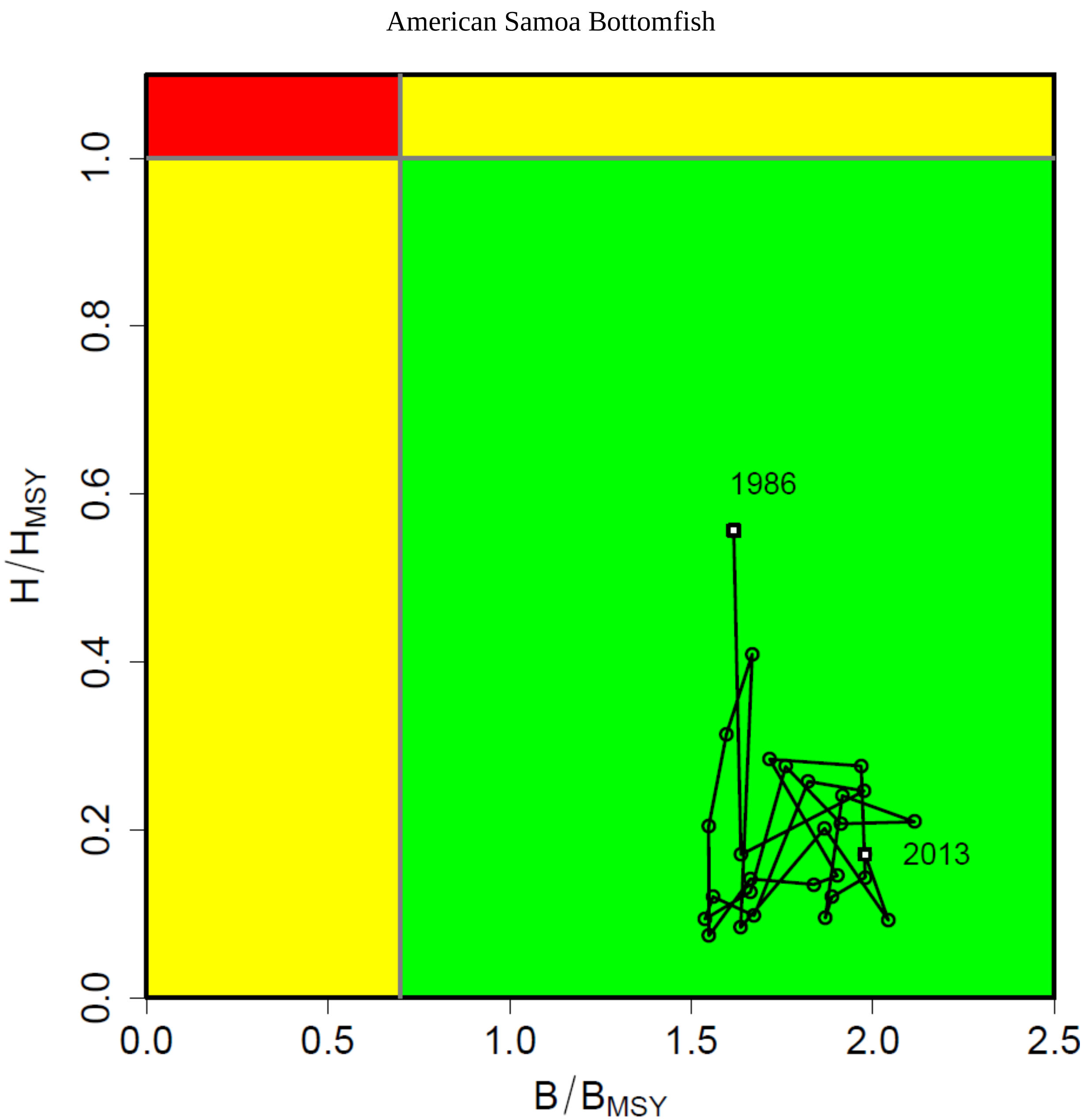


Figure 15.--American Samoa bottomfish stock status: Kobe plot indicating annual stock status over time, from 1986 to 2013. The ratio of B/BMSY was generally > 0.7 and the ratio of H/HMSY was generally < 1, indicating that the stock status over time was not overfished and overfishing was not occurring.

CNMI Bottomfish

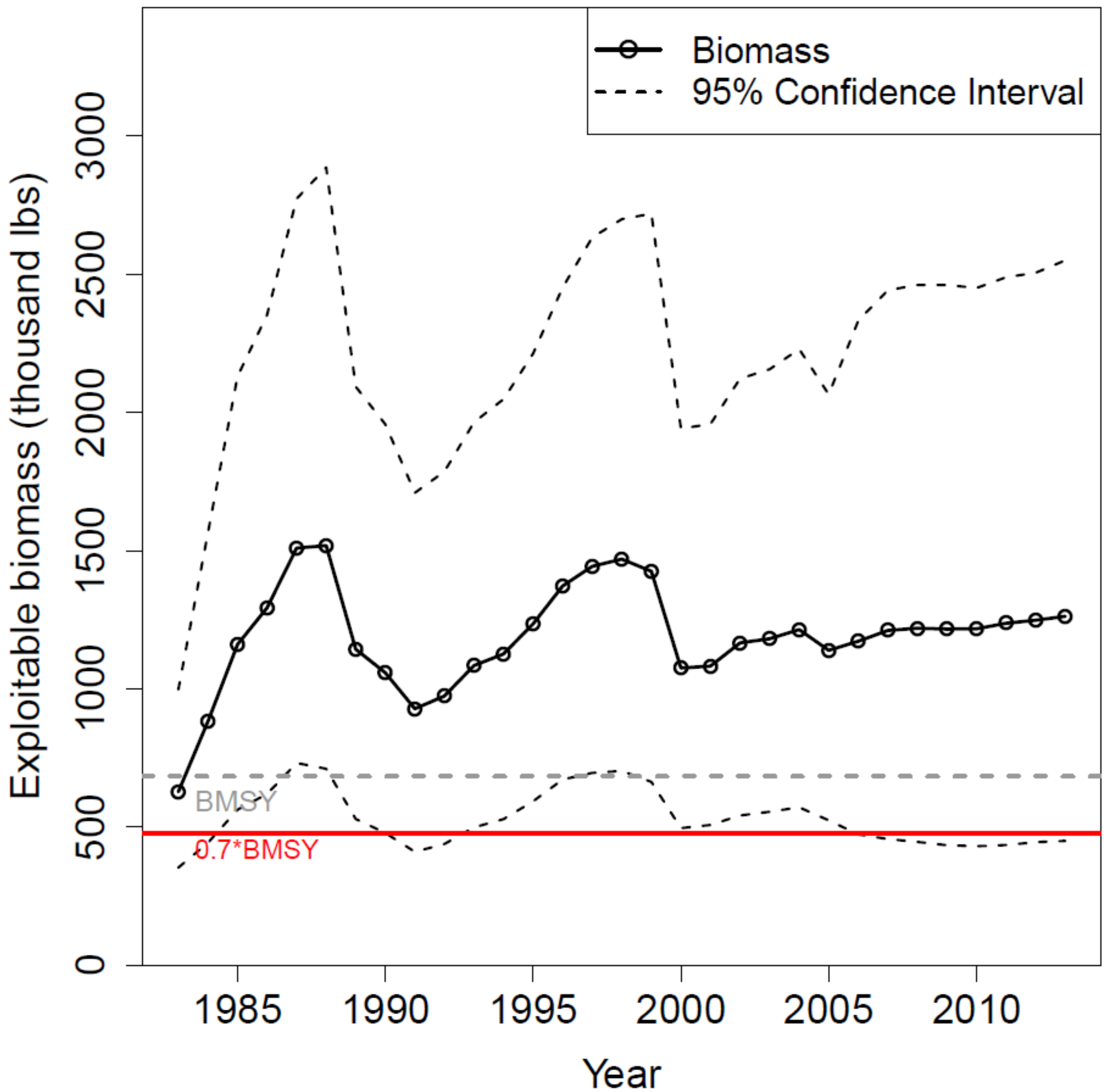


Figure 16.--CNMI bottomfish biomass: Model-estimated trends in mean values (black circles, solid line) with 95% confidence intervals (black dotted line). BMSY is indicated with a horizontal gray dotted line, and the overfished limit of 0.7*BMSY is indicated with a horizontal solid red line. Biomass estimates were generally above the overfished limit with the exception of a few years. In recent years the stock status is not considered to be overfished.

CNMI Bottomfish

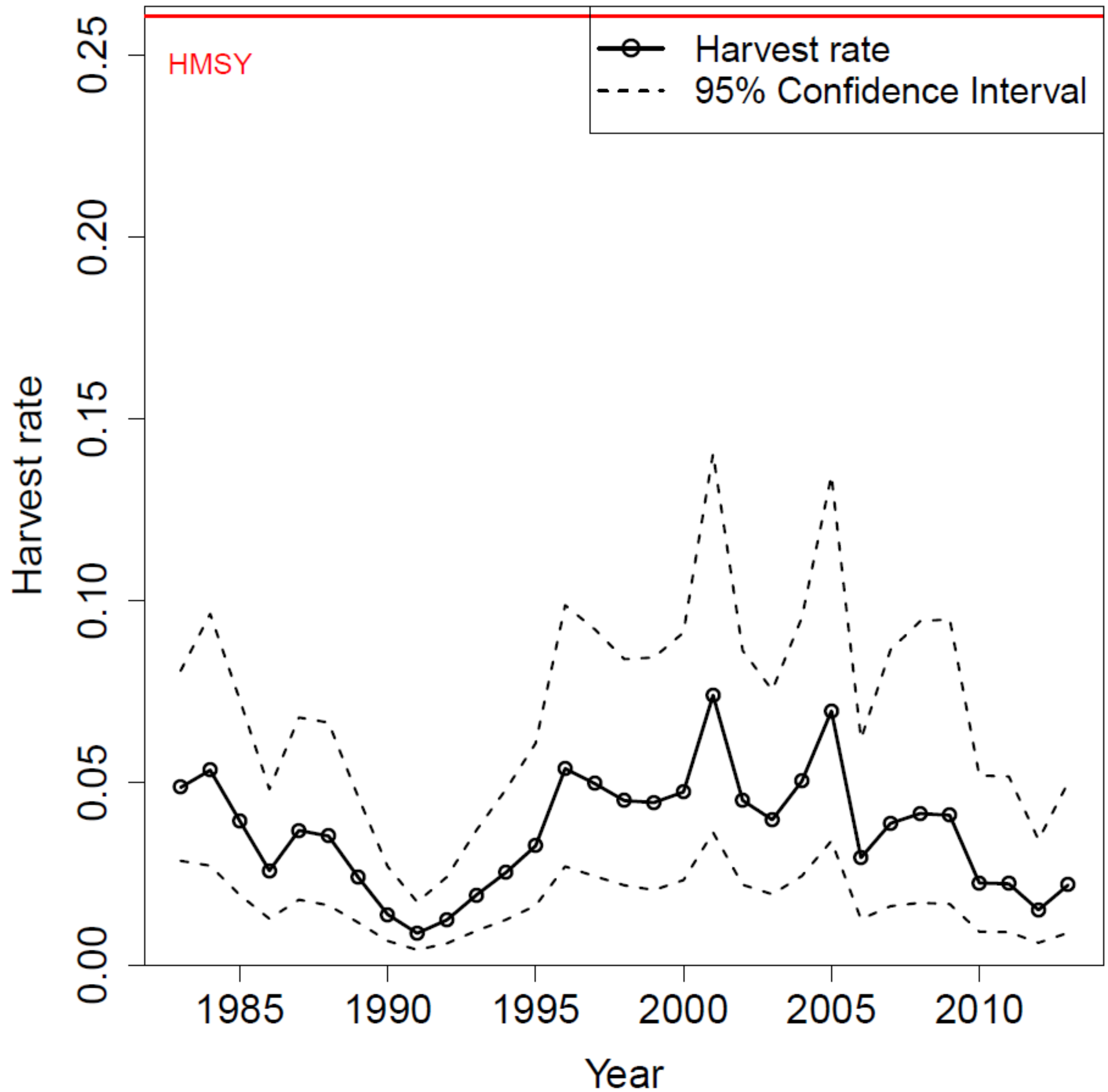


Figure 17.--CNMI bottomfish harvest rates: Model-estimated trends in mean annual harvest rate (black circles, solid line) with 95% confidence intervals (black dotted line). The overfishing limit of HMSY is indicated with a horizontal solid red line. Harvest rate estimates were generally below the overfishing limit, indicating overfishing was not and is not occurring.

CNMI Bottomfish

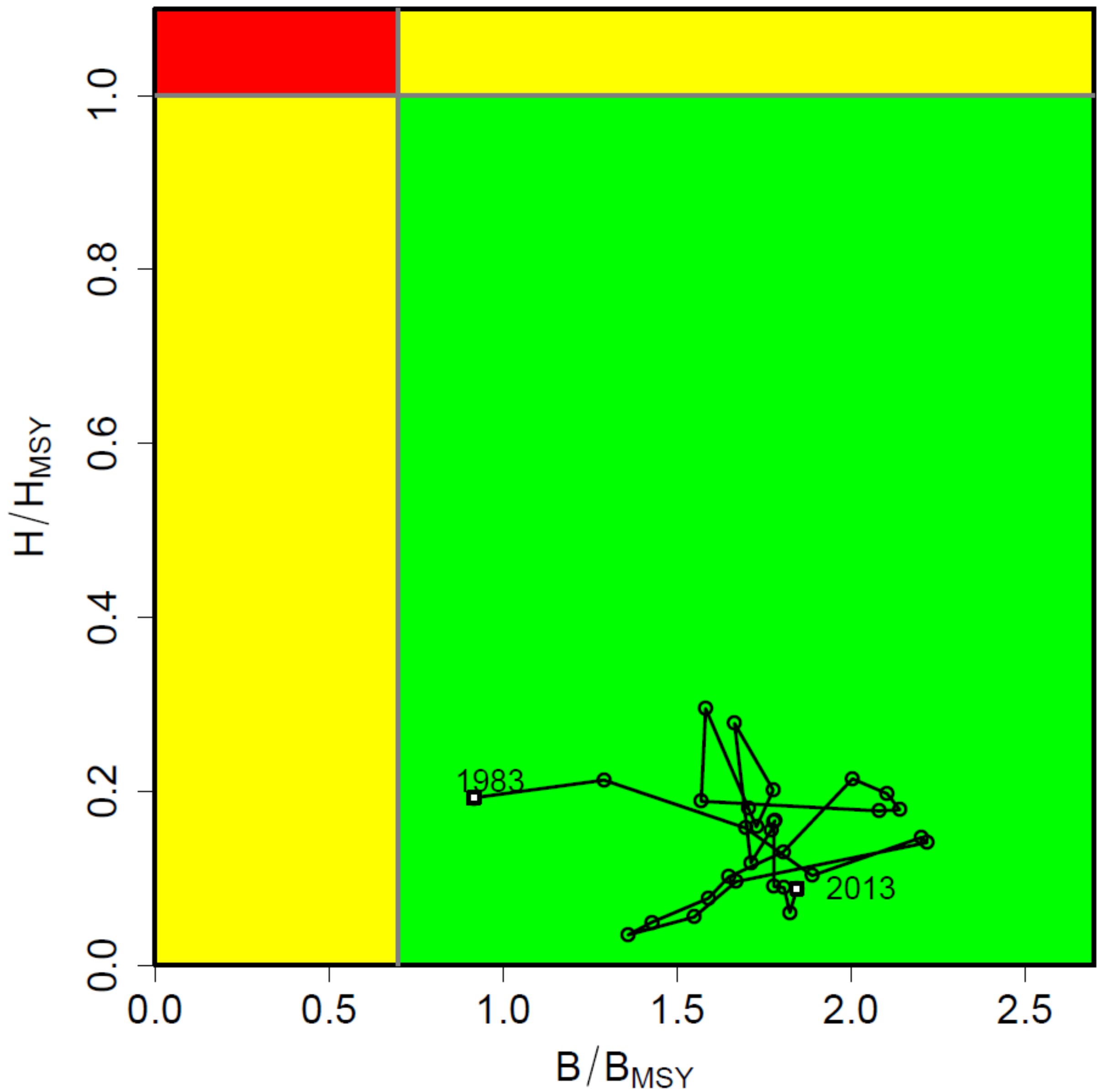


Figure 18.--CNMI bottomfish stock status: Kobe plot indicating annual stock status over time, from 1983 to 2013. The ratio of B/BMSY was generally > 0.7, and the ratio of H/HMSY was generally < 1, indicating that the stock status over time was not overfished and overfishing was not occurring.

Guam bottomfish

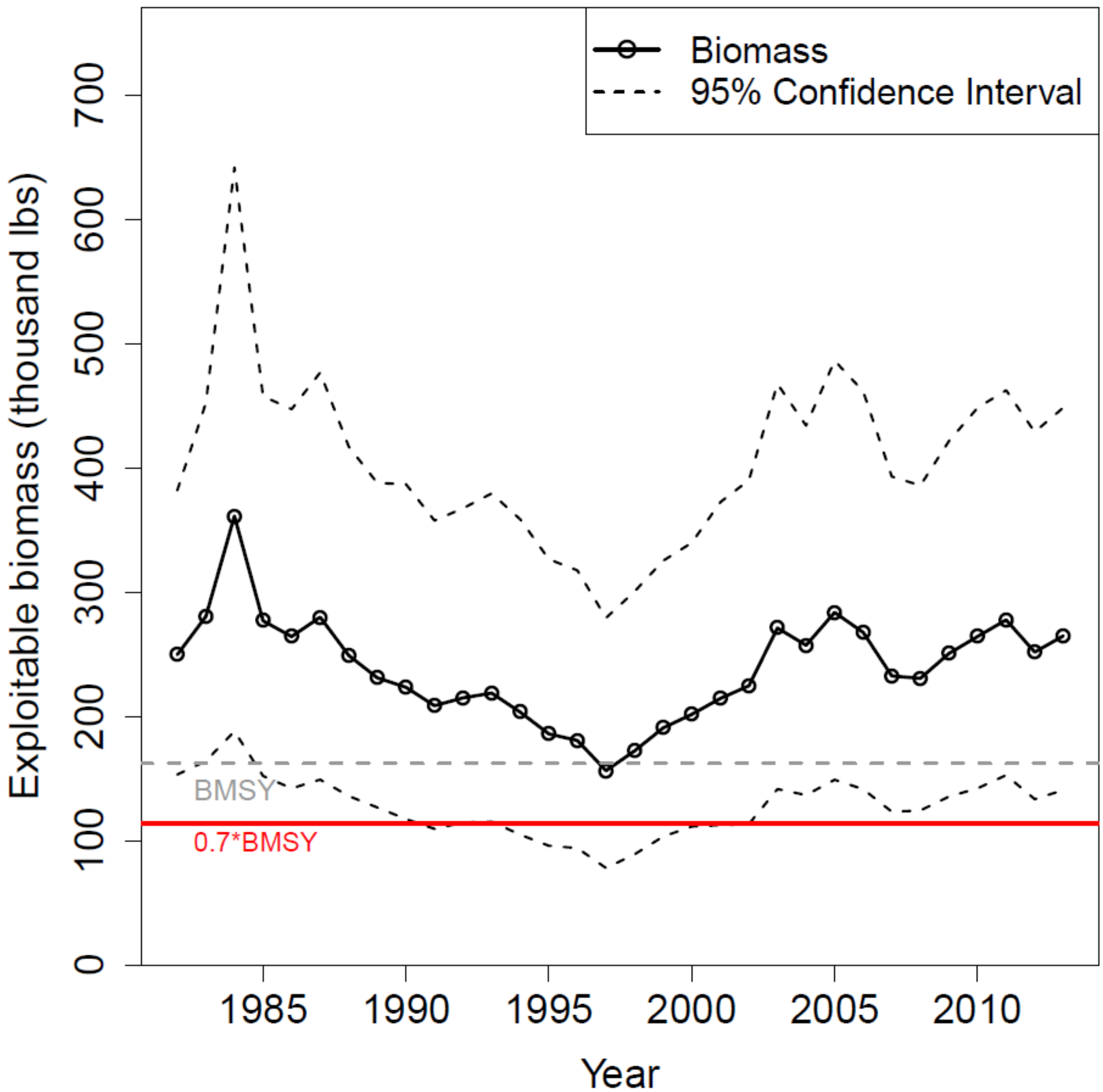


Figure 19.--Guam bottomfish biomass: Model-estimated trends in mean values (black circles, solid line) with 95% confidence intervals (black dotted line). BMSY is indicated with a horizontal gray dotted line, and the overfished limit of 0.7*BMSY is indicated with a horizontal solid red line. Biomass estimates were generally above the overfished limit, with the exception of a few years in the mid-1990s. In recent years the stock status is not overfished.

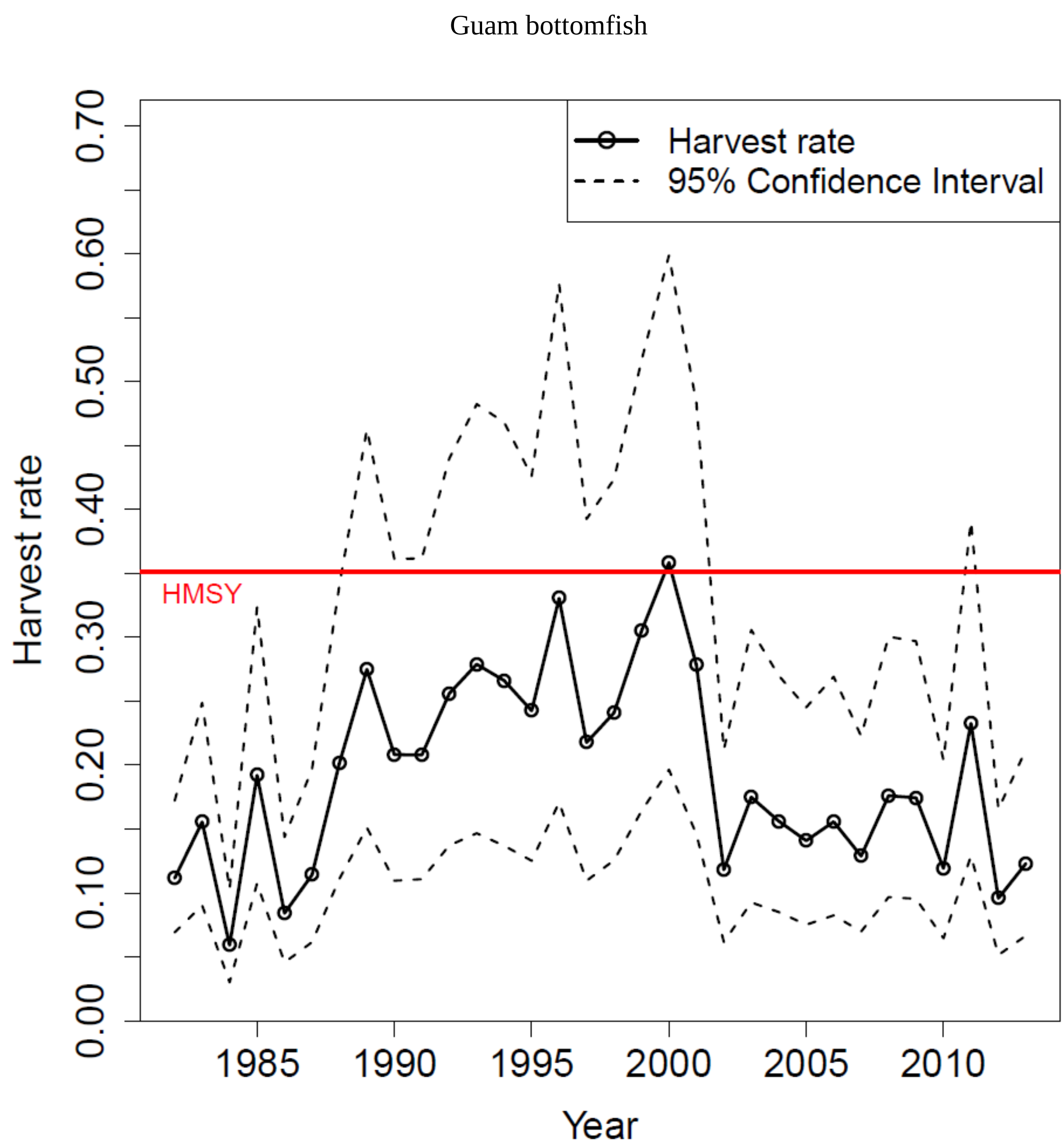


Figure 20.--Guam bottomfish harvest rates: Model-estimated trends in mean annual harvest rate (black circles, solid line) with 95% confidence intervals (black dotted line). The overfishing limit of HMSY is indicated with a horizontal solid red line. Harvest rate estimates were generally below the overfishing limit, possibly with the exception of a few years in the 1990s. In recent years, overfishing is not occurring.

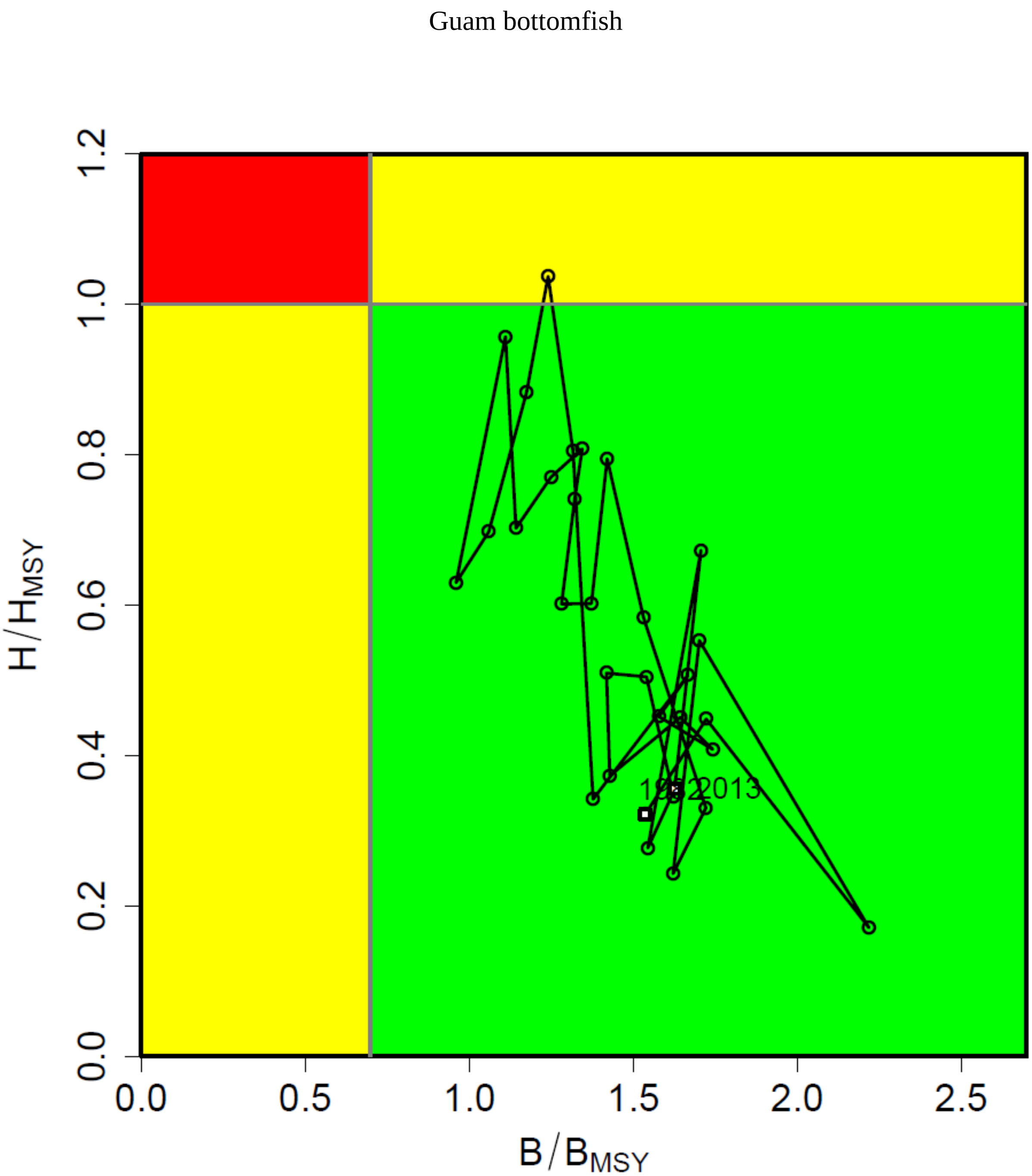
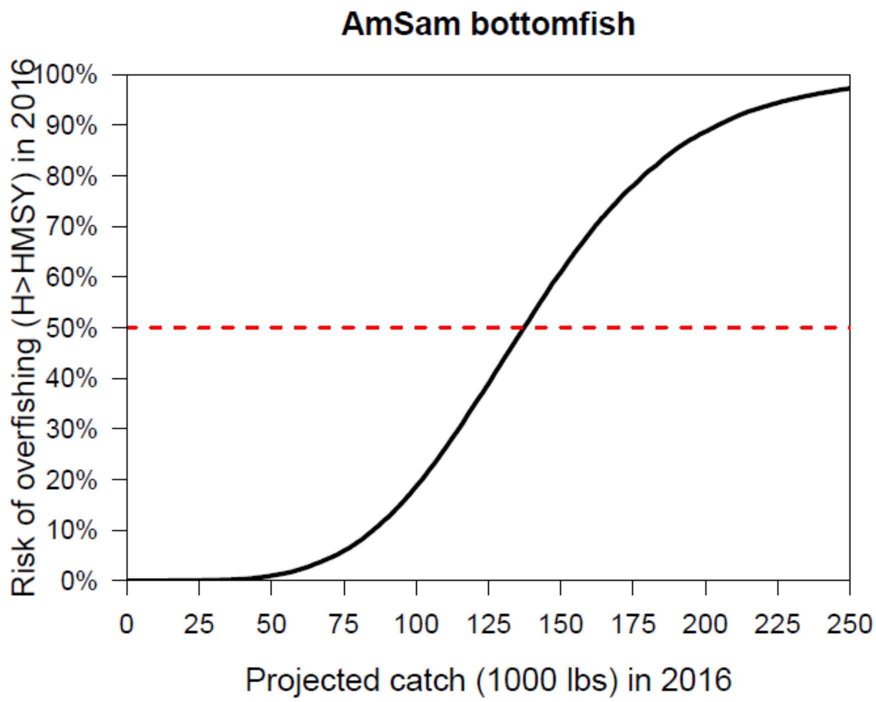


Figure 21.--Guam bottomfish stock status: Kobe plot indicating annual stock status over time, from 1982 to 2013. The ratio of B/BMSY was generally > 0.7, and the ratio of H/HMSY was generally < 1, indicating that the stock status over time was not overfished and overfishing was not occurring.



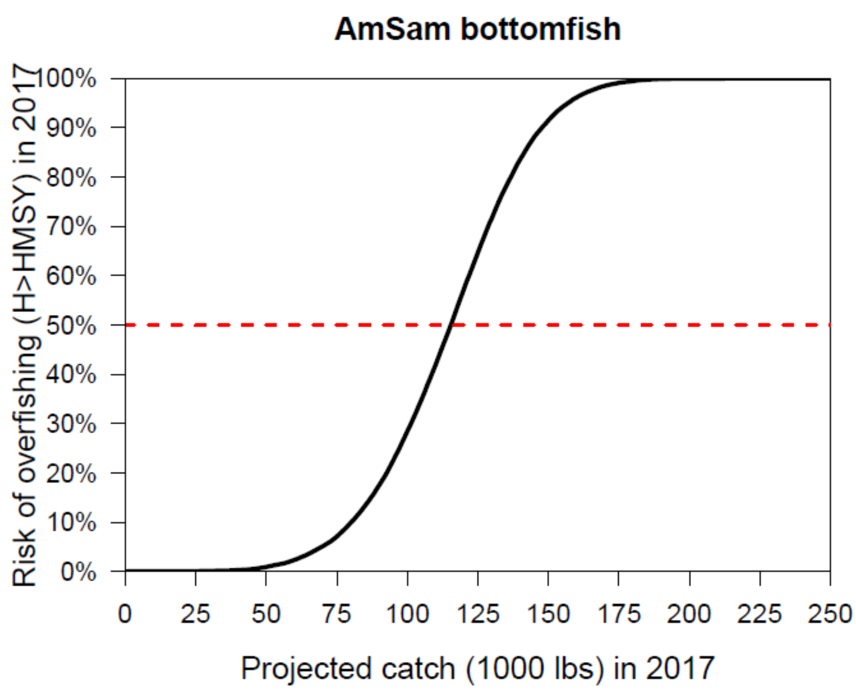


Figure 22.--Projections of catch in 2016 and 2017 for American Samoa bottomfish and associated risks of overfishing (H > HMSY) in each corresponding year (blue line).

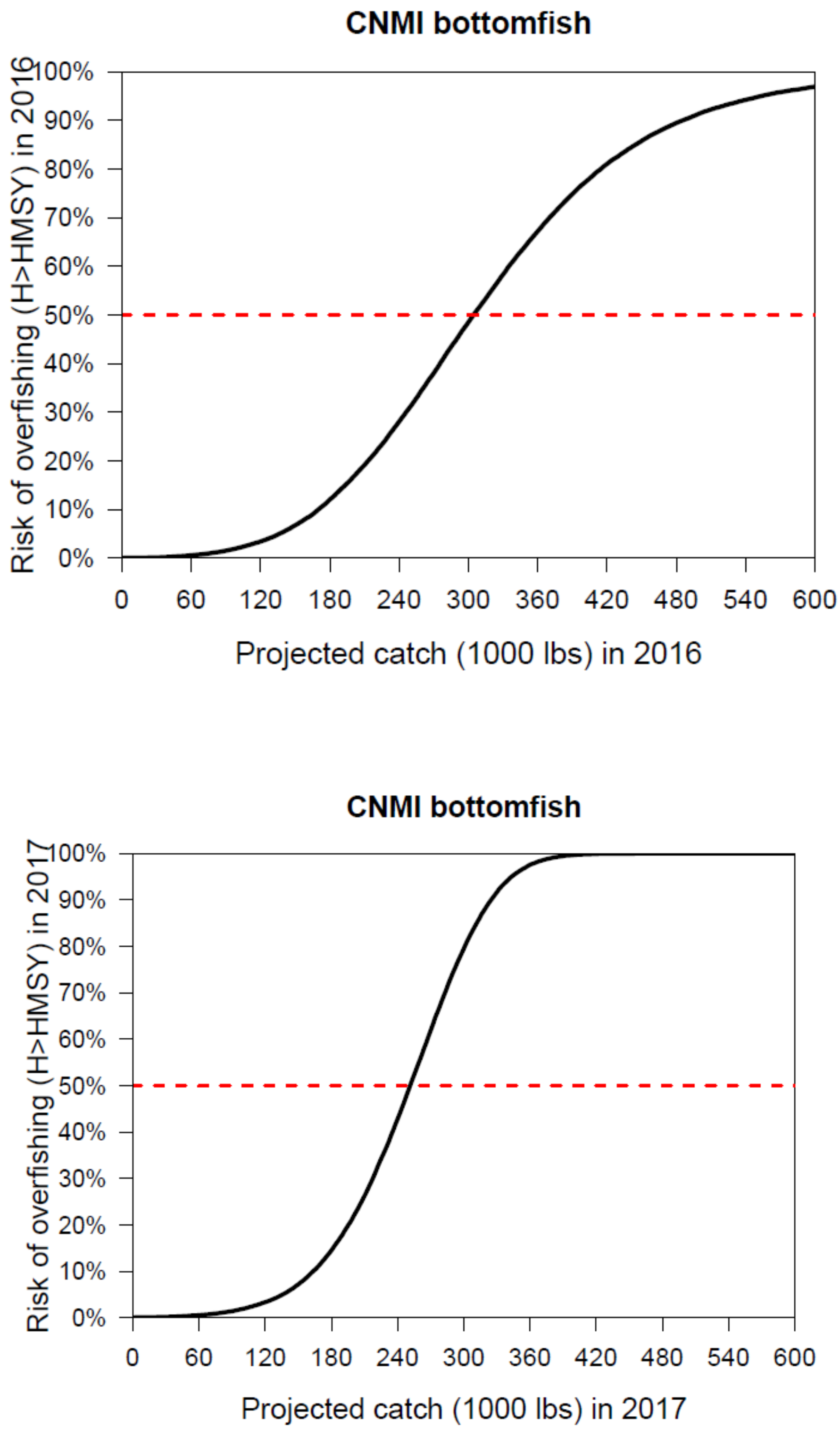
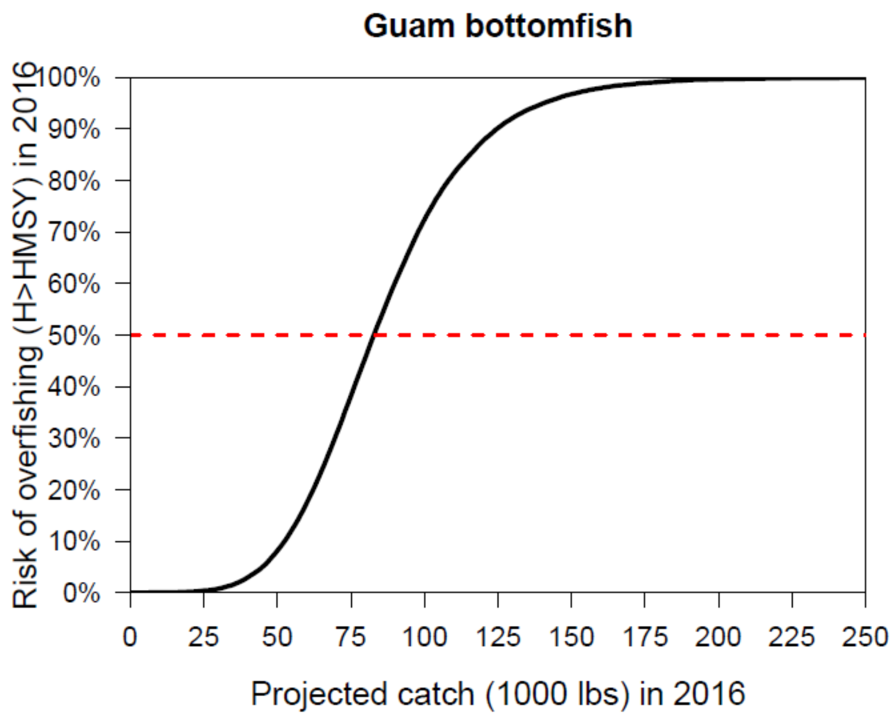


Figure 23.--Projections of catch in 2016 and 2017 for CNMI bottomfish and associated risks of overfishing (H > HMSY) in each corresponding year (blue line).



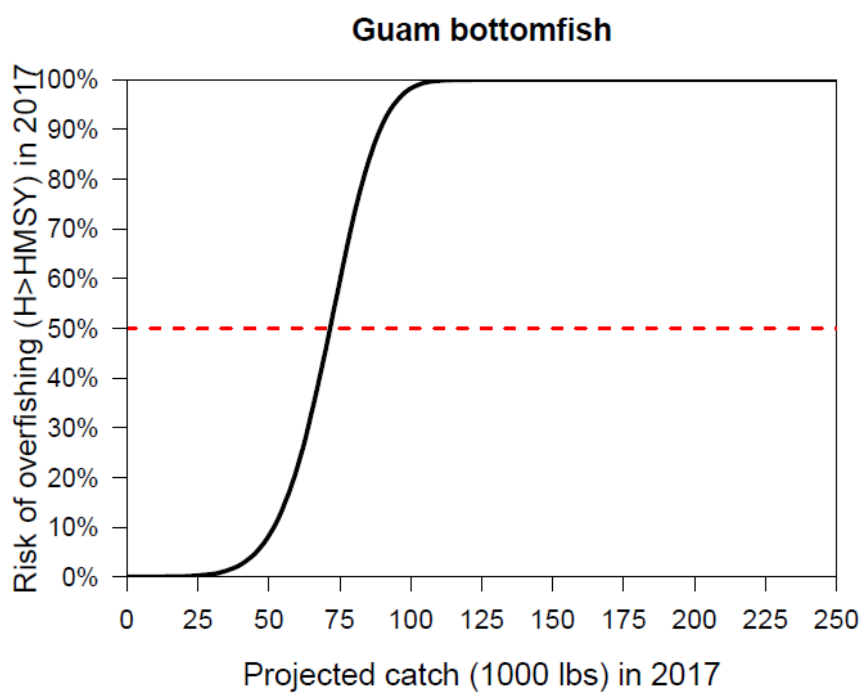


Figure 24.--Projections of catch in 2016 and 2017 for Guam bottomfish and associated risks of overfishing (H > HMSY) in each corresponding year (blue line).

APPENDIX A

This is generic code for running Bayesian state-space surplus production models, used to conduct stock assessment updates for the Bottomfish Management Unit Species (BMUS) complexes of American Samoa, the Commonwealth of the Northern Mariana Islands, and Guam. Code as it’s currently set up will run an assessment for American Samoa BMUS. Please do not reproduce or distribute without authors’ written consent. If you use this code or a major part of this code to produce results for a final product such as a document or presentation, please acknowledge and cite this document.

```
################################################################

# Generic code for running Bayesian Schaefer production models

# for Territorial bottomfish

# 2-parameter production model (r and K)

#

# Original WinBUGS code by Jon Brodziak

# Last modified March 2012

#

# Modified into R2WinBUGS format by Annie Yau

# November 2014

# last modified April 9, 2015

#

# Catch is in thousands of pounds

# CPUE for American Samoa and Guam is in pounds / line-hour

# CPUE for CNMI is in pounds / trip

#

# Guam time period 1982-2013

# American Samoa time period 1986-2013
```

```
# CNMI time period 1983-2013

#

# Constant catchability, no catch error

# Includes likelihood for observed MSY based on calculation from

# 1999 Our Living Oceans report, Humphreys & Moffitt 1999

##################################################################

 rm(list=ls())

 terr = "AmSam" # "CNMI" # "Guam"; # Select territory of assessment, change accordingly

  addname <- paste0(terr,'_base')   ##<--------name of model---------- # change accordingly

 src.dir <- paste('X:/AYau/Bottomfish/TerritAssess_2015/2015assess/',addname,'/',sep="") #
Change accordingly

setwd(src.dir)

 DATA = read.csv( paste0(src.dir,terr,"BF_data.csv"),header=T) # import data file

 head(DATA)

 library(R2WinBUGS)                    # Load the R2WinBUGS library

 nc  <- 3 # of chains

 nt  <- 25     # Thinning rate

 nb  <- 10000*nt # nt*numbertoburnin # round(ni*(1/10)) # Num of draws to discard as burn in

 ni  <- 30000/nc*nt + nb # Number of total iterations per chain, including burn-in =  num
samples/nc*nt _nb.

 ## WinBUGS code equivalent:

 ## A total of 30,000 samples, 10,000 per chain for 3 chains. Discard every 25, burn-in 10,000
total.

###########################################################################

 # DATA

 # Model variable set-up
```

```
##########################################################################
# Vector Catch() is total catch weight in thousands of pounds
# Vector S1() is the CPUE index in thousands of pounds / trip-hour
# sigma2 is process error
# tau2 is observation error by survey
 NTIME <- length(DATA$Catch)
 Catch <- DATA$Catch
 OBS_CPUE <- DATA$CPUE
 NCPUE <- length(DATA$CPUE[!is.na(DATA$CPUE)]) # Total CPUE obs, minus NAs
 ##########################
 # Model parameters
 ##########################
  K_Prior_Avg <- 700 # AmSam=700, Guam=300, CNMI=1400
  CV_K <- 0.2 # 0.20 for all territories
  r_Prior_Avg <- 0.46 # 0.46 for all territories
  CV_r <- 0.50 # 0.50 for all territories
  Target_P1_Prior_Avg <- 0.80 # AmSam=0.80, Guam=0.75, CNMI=0.45
  CV_P1 <- 0.2 # 0.20 for all territories
  OLO_MSY <- 75.0 # AmSam=75.0, Guam=55.0, CNMI=172.0
  CV_OLO_MSY <- 0.20 # 0.20 for all territories
  process_shape <- 0.2
  process_scale <- 0.1
  observation_shape <- 0.2
  observation_scale <- 1.0
  q_shape <- 0.001
```

```
  q_scale <- 0.001
  pLIM_B <- 0.70 # same for all territories
####################################################################
# Bundle Data
####################################################################
 win.data <- list(
  NTIME = NTIME,
  Catch = Catch,
  OBS_CPUE = OBS_CPUE,
  NCPUE = NCPUE,
    K_Prior_Avg = K_Prior_Avg,
  CV_K = CV_K,
  r_Prior_Avg = r_Prior_Avg,
  CV_r = CV_r,
  Target_P1_Prior_Avg = Target_P1_Prior_Avg,
  CV_P1 = CV_P1,
    OLO_MSY = OLO_MSY,
  CV_OLO_MSY = CV_OLO_MSY,
  process_shape = process_shape,
  process_scale = process_scale,
  observation_shape = observation_shape,
  observation_scale = observation_scale,
  q_shape = q_shape,
  q_scale = q_scale,
```

```
  pLIM_B = pLIM_B
  ) # end data list
## END DATA
######################################################################
# Sampling using WinBUGS
# Define model written in WinBUGS code
 sink("model.txt")
 cat("
 model
 {
##################################################################################
# PRIOR DISTRIBUTIONS
##################################################################################
# Diffuse normal prior for carrying capacity parameter, K
#(PRIOR 1)####################################################################
 K_Prior_Precision <- 1.0/pow(K_Prior_Avg*CV_K,2.0)
 K ~ dnorm(K_Prior_Avg,K_Prior_Precision)I(0.00001,100000.0)
 K_prior ~ dnorm(K_Prior_Avg,K_Prior_Precision)I(0.00001,100000.0)
# Beta prior for intrinsic growth rate parameter, r
#(PRIOR 2)####################################################################
 tmp1 <- (1.0 - r_Prior_Avg)/r_Prior_Avg
 tmp2 <- CV_r*CV_r
 r_prior_a <- (tmp1-tmp2)/(tmp1*tmp2+tmp2)
 r_prior_b <- r_prior_a*tmp1
 r ~ dbeta(r_prior_a,r_prior_b)
```

```
 r_prior ~ dbeta(r_prior_a,r_prior_b)
# Proper inverse-gamma prior for CPUE catchability coefficient
# proportional to 1/q within interval (0.00001,100000)
#(PRIOR 3)#################################################################
  q_inverse ~ dgamma(q_shape,q_scale)I(0.00001,100000)
  q <- 1/q_inverse
  q_prior <- 1/q_inverse
# Inverse gamma prior for process error variance, sigma2
#(PRIOR 4)#################################################################
  Process_Precision ~ dgamma(process_shape,process_scale)I(0.00001,100000)
  sigma2 <- 1/Process_Precision
  sigma2_prior <- 1/Process_Precision
# inverse gamma prior for observation error variance, tau2
#(PRIOR 5)###############################################################
  CPUE_Precision ~ dgamma(observation_shape,observation_scale)I(0.00001,100000)
  tau2   <- 1/CPUE_Precision
  tau2_prior   <- 1/CPUE_Precision
# Lognormal priors for time series of proportions of K, P[]
#(PRIOR 6)################################################################
  P1_Prior_Precision <- 1.0/log(1.0+CV_P1*CV_P1)
  P1_Prior_Avg <-log(Target_P1_Prior_Avg) - (0.5/P1_Prior_Precision)
  P[1] ~ dlnorm(P1_Prior_Avg,P1_Prior_Precision) I(0.0001,10000)
  P_prior ~ dlnorm(P1_Prior_Avg,P1_Prior_Precision) I(0.0001,10000)
# Process dynamics for proportions of carrying capacity
#(PRIOR 7)################################################################
```

```
  for (i in 2:NTIME) {
    PRED_P[i] <- log(max(P[i-1] + r*P[i-1]*(1-P[i-1]) - Catch[i-1]/K,0.0001))
    P[i]  ~ dlnorm(PRED_P[i],Process_Precision)I(0.0001,10000)
  }
# Normal likelihood for observed MSY estimate from 1999 OLO
#(LIKELIHOOD 1)################################################################
# MSY LIKELIHOOD 1999 OLO_MSY
  BMSY <- K/2.0
  BMSY_prior <- K/2.0
  PRED_MSY <- r*BMSY/2.0
  OBS_MSY <- OLO_MSY
  OLO_MSY_Precision <- 1.0/pow(OLO_MSY*CV_OLO_MSY,2.0)
  OBS_MSY ~ dnorm(PRED_MSY, OLO_MSY_Precision)
  RESID_MSY <- OBS_MSY - PRED_MSY
  STD_RESID_MSY <- RESID_MSY*sqrt(OLO_MSY_Precision)
# Lognormal likelihood for observed CPUE indices
#(LIKELIHOOD 2)################################################################
# CPUE LIKELIHOOD with OBS_CPUE
 for (i in 1:NCPUE) {
   LOG_PRED_CPUE[i] <- log(q*K*P[i])
   OBS_CPUE[i] ~ dlnorm(LOG_PRED_CPUE[i],CPUE_Precision)
   LOG_RESID[i] <- log(OBS_CPUE[i]) - LOG_PRED_CPUE[i]
 }
# Compute RSS and RMSE for CPUE in log-scale
 LOG_RSS <- inprod(LOG_RESID[], LOG_RESID[])
```

```
 LOG_RMSE <- sqrt(LOG_RSS/NTIME)
# Compute standardized log-scale residuals, predicted CPUE, and CPUE residuals
 for (i in 1:NTIME) {
   STD_LOG_RESID[i] <- LOG_RESID[i]/LOG_RMSE
   PRED_CPUE[i] <- exp(LOG_PRED_CPUE[i])
   RESID[i] <- OBS_CPUE[i] - PRED_CPUE[i]
 }
# Compute RSS and RMSE for CPUE
 RSS <- inprod(RESID[], RESID[])
 RMSE <- sqrt(RSS/NTIME)
# Compute standardized CPUE residuals
 for (i in 1:NTIME) {
   STD_RESID[i] <- RESID[i]/RMSE
 }
# Compute exploitable biomass and exploitation rate time series
# (DERIVED OUTPUT 1)############################################################
# Compute B and H with P
 for (i in 1:NTIME) {
   B[i] <- P[i]*K
   H[i] <- min(Catch[i]/B[i],0.999)
 }
  Pnext <- max(P[NTIME]+r*P[NTIME]*(1-P[NTIME])-Catch[NTIME]/K,0.0001)
  Bnext <- Pnext*K
# Compute MSY-based biological reference points
# (DERIVED OUTPUT 2)############################################################
```

```
  MSY <- r*K/4.0
  HMSY <- r/2.0
  PMSY <- BMSY/K
  FMSY <- -log(1-HMSY)
  INDEXMSY <- q*BMSY
  MSY_prior <- r*K/4.0
  HMSY_prior <- r/2.0
  PMSY_prior <- BMSY/K
  FMSY_prior <- -log(1-HMSY)
  INDEXMSY_prior <- q*BMSY
# Compute overfished and overfishing status and biomass production for 1982-2013
# (DERIVED OUTPUT 3)#################################################################
for (i in 1:NTIME) {
   BSTATUS[i] <- B[i]/BMSY
   HSTATUS[i] <- H[i]/HMSY
   production[i] <- r*B[i]*(1.0-(B[i]/K))
 }
  BSTATUSnext <- Bnext/BMSY
# Compute probabilities of overfishing and overfished
# (DERIVED OUTPUT 4)################################################################
 for (i in 1:NTIME) {
   pOFL_H[i] <- step(HSTATUS[i] - 1.0)
   pBMSY_B[i] <- step(1.0 - BSTATUS[i])
   pOFL_B[i] <- step(pLIM_B - BSTATUS[i])
}
```

```
###############################################################################
}
## END OF WinBUGS MODEL
",fill=TRUE)
 sink()      # ends the last diversion
###################################################################
# END OF CODE/MODEL
###################################################################
########################################################################
############ Create list of inits for WinBUGS use #####################
########################################################################
inits <- list(    # create inits list of functions
  ## Initial Condition 1
list(
  K=700.0,
  r=0.70,
  P=c(rep(0.80,15), rep(0.70, NTIME-15)),
  K_prior = 500.0,
  P_prior = 0.70,
  r_prior = 0.65,
  q_inverse=10,
  Process_Precision=100,


  CPUE_Precision=100
```

```
  )##END init 1
  ,
  ## Initial Condition 2
list(
  K=500.0,
  r=0.60,
  P=c(rep(0.80,15), rep(0.7, NTIME-15)),
  K_prior = 600.0,
  P_prior = 0.70,
  r_prior = 0.45,
  q_inverse=10,
  Process_Precision=100,
  CPUE_Precision=100
  )##END init 2
  ,
  ##  Initial Condition 3
list(
  K=700.0,
  r=0.40,
  P=c(rep(0.80,15), rep(0.7, NTIME-15)),
  K_prior = 700.0,
  P_prior = 0.70,
  r_prior = 0.50,
  q_inverse=10,
    Process_Precision=100,
```

```
  CPUE_Precision=100
  )##END init 3
)  ## close list of functions
##### end initials function ###############################################
##########################################################################
## Parameters to estimate
##########################################################################
params <- c(
## model parameters ##
 "K","r","q","sigma2","tau2",
## time-series derived variables ##
 "P","B","H","PRED_CPUE","Pnext","Bnext",
 "PRED_P","production",
## management metrics ##
 "MSY", "PRED_MSY","RESID_MSY","STD_RESID_MSY", #"OBS_MSY",
 "PMSY","BMSY","HMSY","BSTATUS","HSTATUS","FMSY","BSTATUSnext",
 "pOFL_H","pOFL_B", "pBMSY_B",
## statistics and diagnoses ##
 "STD_LOG_RESID", "STD_RESID",
 "LOG_RESID", "RESID",
 "LOG_RSS", "LOG_RMSE",
 "RSS", "RMSE"
)
```

```
#  Check that number of Markov chains equals number of inits
 if (nc != length(inits)) {
  print("WARNING!!!! Num of inits does not equal num of chains")
  } else {
  print("Number of inits = number of chains")
 }
begin_time = proc.time()[3]
##################################################################
 # Start Gibbs sampling, cycle through the initials
bugs(win.data,inits,params,"model.txt",n.chains=nc,n.iter=ni,n.burnin=nb,n.thin=nt,
     debug=FALSE,codaPkg=FALSE,working.directory=src.dir)
##################################################################
end_time = proc.time()[3]
 print(paste("RUN_COST = ",(end_time-begin_time)/60," mins",sep=""))
######################################################################
```

APPENDIX B

Input data tables for running Bayesian state space surplus production models for the Bottomfish Management Unit Species of each of the 3 U.S. Pacific territories of American Samoa, the Commonwealth of the Northern Mariana Islands, and Guam, using data through 2013. These tables provide the same data as in Table 3, but formatted by each territory for use with Appendix A, generic stock assessment model code.

American Samoa Bottomfish Management Unit Species

Year	Catch	CPUE
1986	64.587	3.26
1987	19.628	2.98
1988	33.726	6.35
1989	32.647	4.02
1990	11.332	3.54
1991	13.01	2.64
1992	9.985	2.44
1993	14.554	3.27
1994	33.845	3.16
1995	27.699	4.24
1996	30.808	6.53
1997	32.308	3.82
1998	12.413	3.96
1999	15.857	3.67
2000	19.816	4.57
2001	37.847	4.95
2002	34.149	2.45
2003	19.199	5.42
2004	17.206	4.31
2005	16.329	3.13
2006	7.913	2.65
2007	21.874	2.57
2008	34.812	2.9
2009	47.458	3.62
2010	9.509	2.96
2011	26.277	3.95
2012	13.11	5.75
2013	23.63	4.25

Commonwealth of the Northern Mariana Islands Bottomfish Management Unit Species

Year	Catch	CPUE
1983	28.529	43
1984	42.665	70
1985	40.974	117
1986	29.912	104
1987	49.714	169
1988	47.313	181
1989	24.439	73
1990	12.929	81
1991	7.092	47
1992	10.598	59
1993	18.461	84
1994	25.47	74
1995	36.1	93
1996	66.388	119
1997	64.143	137
1998	59.024	148
1999	55.991	156
2000	45.258	56
2001	71.256	68
2002	46.765	101
2003	41.903	89
2004	54.475	104
2005	70.404	76
2006	29.34	NA
2007	39.476	NA
2008	42.07	NA
2009	41.176	NA
2010	22.395	NA
2011	22.487	NA
2012	15.302	NA
2013	22.51	NA

Guam Bottomfish Management Unit Species

Year	Catch	CPUE
1982	26.384	3.05
1983	40.782	2.66
1984	19.322	11.66
1985	49.195	2.46
1986	20.427	3.57
1987	29.301	3.98
1988	46.318	2.37
1989	58.582	2.28
1990	42.384	3.4
1991	39.596	2
1992	50.394	2.25
1993	55.609	2.98
1994	49.055	2.73
1995	40.855	2.05
1996	54.186	2.26
1997	30.611	1.32
1998	37.687	1.65
1999	53.339	1.88
2000	66.666	1.89
2001	54.352	3.25
2002	24.044	2.87
2003	43.253	4.26
2004	36.915	2.77
2005	36.529	4.81
2006	38.054	3.78
2007	27.459	2.32
2008	37.316	1.93
2009	40.222	3.17
2010	28.958	3.65
2011	59.618	3.62
2012	22.085	3.47
2013	29.848	3.15

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