PACIFIC ISLANDS FISHERIES SCIENCE CENTER

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October 2007

Administrative Report H-07-04

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ABSTRACT

In previous studies, the status of bottomfish stocks in Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands was determined by comparing annual fishery catch-per-unit effort (CPUE) and effort with CPUE-based proxies for B_{MSY} and F_{MSY}. This index-based approach assumes that CPUE provides a relative abundance index for bottomfish and that the B_{MSY} proxy, determined as a proportion of 5-year averages of maximal historic CPUE values, is an appropriate biomass target. An updated status determination using the index method was computed for comparison to a new stock assessment approach described below. In addition, a graphical approach was used to compare the catch, CPUE, and effort distributions of shallow and deep bottomfish components of the bottomfish complexes of Guam and American Samoa.

In this report, the status of bottomfish complexes in Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands is assessed using a surplus production model. A Bayesian statistical framework is applied to estimate parameters of a Schaefer model fit to a time series of annual CPUE statistics. This approach provides direct estimates of parameter uncertainty for status determination. The surplus production model includes both process error in biomass production dynamics and observation error in the catch-per-unit effort data. Alternative models with differing prior assumptions about carrying capacity and the ratio of initial stock biomass (at the beginning of the assessment time period) to carrying capacity are evaluated using the Akaike Information Criterion. The sensitivity of status determination results to prior distributions and model assumptions is also evaluated. Stock status determinations based on the models with the closest fits to the CPUE data appear relatively robust.

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INTRODUCTION

Important 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 Fishery Management Council manages these resources within the US Exclusive Economic Zone (EEZ) surrounding American Samoa, the Commonwealth of the Northern Mariana Islands (CNMI), Guam, and Hawaii under the Bottomfish and Seamount Groundfish Fisheries Fishery Management Plan (FMP). The bottomfish management unit species (BMUS) identified within the FMP are 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 as single multi-species complexes for each of the above mentioned geo-political areas. These multi-species stocks are managed as a unit straddling both local and federal waters. Although managed as a single 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 are largely lacking (e.g. lethrinids and Lutjanus spp). Amendment 6 of the FMP 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. The fishery status with respect to these criteria is reported to the Congress annually and mandatory management measures are required when overfishing or overfished thresholds are breached. These status determinations are applicable to the multi-species stocks as a whole and to not their shallow and deep components. The status of Hawaiian bottomfish was recently addressed in Moffitt et al. (2006).

In this report the status of bottomfish resources of American Samoa, CNMI, and Guam is assessed using a dynamic surplus production model. In previous assessments, an index-based method was used. Accordingly, an updated index-based status determination for each island bottomfish stock was also computed for comparison with the new production model assessment. Since the deep and shallow components of the bottomfish complexes of the three island areas are generally fished by different sectors of the fishing fleet and, therefore, subject to differing fishing pressures, a graphical approach is presented to show differences in relative abundance and catch for these components.

The index method previously used involves a simple examination of time series of catch and effort data resulting in point estimates of relative biomass and fishing effort (mortality) reference values. The index method and production model both rely on fishery-dependent data collected by local island agencies 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 includes both process error in biomass production dynamics and observation error in the catch-per-unit effort data. Alternative models with differing prior assumptions about the production model parameters – the stock's carrying capacity and the ratio of stock biomass at the beginning of the assessment time period to carrying capacity – are evaluated using the Akaike Information Criterion (AIC). The sensitivity of status determinations to prior distributions of the parameters and model assumptions is also evaluated. Status determinations resulting from the new surplus production model and the old index-based approach are compared and discussed.

Description of the Fisheries

Guam

In Guam, bottomfish are caught by a combination of recreational, subsistence, and small-scale commercial fishing operations. In 2006, a total of 261 vessels were reported to participate in bottomfishing activities. Most of the fleet consists of vessels less than 25 feet 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). In addition to those caught during bottomfishing activities, significant quantities of BMUS, particularly the shallow component species, are targeted and caught by other fishing methods (e.g. gill netting, cast netting, and spear fishing – both SCUBA and free diving). Jacks (trevallys), in particular, are targeted over all life stages including heavy seasonal targeting of juveniles. From 1982 to 2005, the fishing effort exerted on the shallow component was nearly double that spent on the deep component.

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, two subsidized boat building programs, the dory program in the 1970s and the alia program in the 1980s, provided fishermen 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, forty-eight 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 foot) 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 (Table 2.2).

Commonwealth of the Northern Mariana Islands

The CNMI is a long chain of island 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 and the fishing effort includes a substantial number of large vessels. The larger vessels conduct multi-day trips and employ electric or hydraulic reels.

METHODS

CPUE Data Sources

In all three island areas, creel surveys are used to collect fishery data. Participation in the surveys by the fishermen 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 fishermen. Guam has been collecting voluntary fishery creel data since the late 1960s, although only shore- and 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 CPUE data and species composition data 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, although calm days on the eastern side of the island can occur during all months of the year, with fishing activity increasing significantly during these days. The current statistical expansion of fishery data, however, adjusts for these sampling problems to the extent possible. 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. For all island areas, catch data from the surveyed subset of fishing trips are expanded to estimate total catch for the area.

Index-based Assessment Method

In accordance with Amendment 6 of the Bottomfish and Seamount Groundfish FMP, CPUE and effort can be used as proxies for stock biomass and fishing mortality, respectively, when estimating maximum sustainable yield (MSY) reference values and resource status metrics. When no better reference value exists, a multi-year average of CPUE can be used to estimate the MSY biomass reference value. In this report, landings of the multi-species BMUS complex, and its shallow and deep components, were calculated using expanded creel survey data, with landings of miscellaneous species groupings (e.g., grouper or miscellaneous bottomfish) divided into BMUS and non-BMUS portions based on data from years with the most extensive reporting of species composition statistics. Annual CPUE estimates were calculated using screened trip-level data from the creel surveys and expressed as pounds of BMUS caught per line-hour, again with miscellaneous species groupings allocated to BMUS and non-BMUS portions. Trips were screened to include only those where 50% or more of the catch was BMUS. Since the CNMI creel survey data series is of short duration, the longer time series of commercial purchase data was used to estimate MSY reference values. In this data set, landings are for all species caught with bottomfishing gear and include much more than just BMUS. Also, effort (and CPUE) in this data set is expressed in terms of trips rather than line-hours. Standardized effort for each year was calculated by dividing total expanded landings by the mean CPUE.

A five-year running average of CPUE was then calculated and the maximum value of the series taken as an estimate of the relative biomass of the unfished stock. The CPUE at MSY ($CPUE_{MSY}$), a measure of relative stock biomass at MSY, was calculated as 50% of this maximum value and the minimum stock size threshold (MSST), as defined in the FMP, was calculated as 70% of $CPUE_{MSY}$. In accordance with the FMP, the maximum fishing mortality threshold (MFMT), as measured by the estimated effort at MSY (E_{MSY}), can be calculated as the long-term average of fishing effort experienced prior to the CPUE dropping below the $CPUE_{MSY}$ reference level. Unfortunately, this method does not work well in situations where a fishery is still developing or effort has been well below the E_{MSY} level for many years. In this study we will look at a couple of additional methods to estimate effort at MSY. First, we will include only effort values from years with CPUE at or near $CPUE_{MSY}$. Finally, we will estimate E_{MSY} by using independent estimates of MSY-level landings reported in Our Living Oceans (OLO) (Humphreys and Moffitt, 1999). Determinations of overfishing and overfished status can then be made by comparing current CPUE and effort to MSY-level reference values of relative stock biomass and fishing mortality. In accordance with the FMP, these status determinations are made for the multi-species BMUS stock as a whole for each island area and not for their deep and shallow components separately.

Graphical Distribution Method

For each of the island groups, the distributions of annual bottomfish catch, CPUE, and fishing effort were divided into fifths. For Guam and American Samoa, the distribution quintiles of these statistics were also computed for shallow and deep bottomfish components. Time series of the grouped data were plotted using a pie chart format created using the NOAA National Fisheries Toolbox program Visual Report Designer (version 1.5). These plots were intended to provide a concise graphical display of the changes in catch, CPUE, and fishing effort through time.

Surplus 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). 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 (B_{MSY}) is B_{MSY}=K/2. The corresponding harvest rate that maximizes surplus production (H_{MSY}) is H_{MSY}=r/2 and the maximum surplus production (MSY) 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) $$P_T = P_{T-1} + rP_{T-1}\left(1-P_{T-1}\right) - \frac{C_{T-1}}{K}$$

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

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 zero mean and variance τ^2. Given this, the observation equations for T=1,…, N are

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

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

The second component of the observation error model relates previously developed estimates of the maximum sustainable yield for the Guam, American Samoa, and CNMI bottomfish complexes (Humphreys and Moffitt 1999) to the model parameters r and K. In this case, the MSY estimate (MSY_{OBS}) is taken to be a data point and compared to the prediction of the MSY value (MSY_{PRED}) for each island group. 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 zero mean and variance w^2. Given this, the observation equation for the MSY data is

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

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.

Prior for Carrying Capacity

The prior distribution for the carrying capacity p(K) of bottomfish for each island group was chosen to be a diffuse normal distribution with mean (μ_K) and variance (σ_K^2) parameters:

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

Initial estimates of the K parameters for each area were 400 thousand, 600 thousand, and 1,376 thousand pounds for Guam, American Samoa, and CNMI, respectively. These initial guesses were based on two assumptions. First, MSY was approximately 55 thousand, 75 thousand, and 172 thousand pounds for Guam, American Samoa, and CNMI as reported in Our Living Oceans (Humphreys and Moffitt, 1999). Second, the intrinsic growth rate was about r=0.5, similar to the estimate of r=0.46 for the Hawaiian bottomfish complex in the assessment report Moffitt et al. (2006). The variance of K was set to 10,000 thousand pounds for each island group to allow for a range of fitted carrying capacity estimates. The impact of selecting alternative mean values for the prior on K was also evaluated.

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

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 bottomfishes. The central tendency of the intrinsic growth rate prior was approximated using the estimate of $r \approx 0.46$ from Moffitt et al. (2006). The values of c and d were set to be (c,d)=(7.67,9.0); this produced a mean of $\mu_r = 0.46$ with a coefficient of variation of approximately 25%. This prior for intrinsic growth rate was informative but allowed for variation about the mean value.

Prior for Catchability

The prior for catchability p(Q) was chosen to be a diffuse 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 $\lambda = k = 0.001$. This choice of parameters implies that 1/Q has a mean of 1 and a variance of 1000. As a result, the prior for catchability is effectively $p(Q) \propto Q^{-1}$. Since 1/Q is unbounded at Q=0, we imposed the numerical constraint that Q lie within the interval [0.00001, 10].

Priors for Error Variances

The priors for the process error variance $p(\sigma^2)$ and observation error variance $p(\tau^2)$ were chosen to be inverse-gamma distributions, a natural choice for dispersion priors (Congdon, 2001). For the process error variance prior, the scale parameter was set to $\lambda=4$ and the shape parameter was k=0.01. This choice of parameters produces an 80% confidence interval of approximately [0.04, 0.08] for σ. Similarly, for the observation error variance prior, the scale parameter was set to $\lambda=2$ and the shape parameter was k=0.01. This choice of parameters gives an 80% confidence interval of approximately [0.05, 0.14] for τ. Overall, the observation error variance was assumed to be 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 specified in the process dynamics. The initial mean ratio of biomass to carrying capacity for the initial time period was set to be P_1=0.63. The effect of assuming alternative mean values for the initial ratio of biomass to carrying capacity was evaluated using a goodness-of-fit criterion to select a best-fitting model for each island group.

Posterior Distribution

The posterior distribution was needed to make inferences about the model parameters. From Bayes' theorem, the posterior distribution given catch, MSY, and CPUE data D, p(θ|D), is proportional to the product of the priors and the observation error likelihood:

(10)

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

Since there was no closed form expression to determine parameter estimates from the posterior distribution, we used numerical methods to generate samples from the posterior distribution.

Bayesian parameter estimation for multiparameter nonlinear models, such as the bottomfish surplus production model, is typically based on simulating a large number of independent samples from the posterior distribution. In this case, Markov Chain Monte Carlo (MCMC) simulation (Gilks et al., 1996) was applied to numerically generate a sequence of samples from the posterior distribution. We used the WINBUGS software (version 1.4, Spiegelhalter et al., 2003) to set the initial conditions, perform the MCMC calculations, and summarize the results.

MCMC simulations were conducted in an identical manner for each of the alternative models described below. Two chains of 150,000 samples were simulated in each model run. The first 50,000 samples of each chain were excluded from the inference process. This burn-in period removed any dependence of the MCMC samples on the initial conditions. Each chain was also thinned by 2 to remove autocorrelation. That is, every other sample was used for inference. As a result, there were 100,000 samples from the posterior for summarizing model results. 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 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.

Alternative Production Models

For each island group, alternative production models were fit to the bottomfish catch and CPUE data to select a best-fitting model. The alternative models were developed to assess the effect of differing assumptions about the prior mean for carrying capacity and the initial ratio of biomass to carrying capacity. The baseline values of the prior means of K were K=400, 600, and 1400 for Guam, American Samoa, and CNMI, respectively. For the initial ratio of biomass to carrying capacity at the start of the assessment time horizon, P[1], the values was set to be P[1]=0.63 for each island group. Several alternative pairs of K and P[1] were developed for each group to reflect a range of possible values.

Guam

A total of ten alternative pairs of prior means for (K, P[1]) were evaluated for Guam. These were: (200, 0.63), (300, 0.63), (500, 0.63), (600, 0.63), (300, 0.30), (300, 0.45), (300, 0.75), (500, 0.30), (500, 0.45), and (500, 0.75).

As a sensitivity analysis, alternative models were also developed for the deep and shallow Guam bottomfish components separately. Prior mean pairs of (K, P[1]) for the deep complex were: (300, 0.40), (400, 0.40), (500, 0.40), (600, 0.40), (300, 0.63), (400, 0.63), (500, 0.63), (600, 0.63), (300, 0.80), (400, 0.80), (500, 0.80), and (600, 0.80) while for the shallow complex, prior means were (50, 0.20), (100, 0.20), (150, 0.20), (50, 0.40), (100, 0.40), (150, 0.40), (50, 0.20), (100, 0.40), and (150, 0.60). The status results from the production model analyses of the deep and shallow components were generally similar to those for the entire Guam bottomfish complex and are not reported here.

American Samoa

For American Samoa, alternative prior mean pairs for (K, P[1]) were: (400, 0.40), (500, 0.40), (600, 0.40), (700, 0.40), (800, 0.40), (900, 0.40), (400, 0.63), (500, 0.63), (600, 0.63), (700, 0.63), (800, 0.63), (900, 0.63), (400, 0.80), (500, 0.80), (600, 0.80), (700, 0.80), (800, 0.80), and (900, 0.80).

Commonwealth of the Northern Mariana Islands

For CNMI, alternative prior mean pairs for (K, P[1]) were: (1000, 0.45), (1400, 0.45), (1700, 0.45), (1000, 0.63), (1400, 0.63), (1700, 0.63), (1000, 0.80), (1400, 0.80), and (1700, 0.80).

For each island group, the alternative model assumptions bracketed the baseline prior assumptions for K and P[1] and, along with the baseline models, they constituted the set of alternative bottomfish production models.

Model Diagnostics and Selection

CPUE residuals were used to rank the goodness of fit of the alternative production models. Residuals for the CPUE series are the log-scale observation errors ε_T:

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

Non-random patterns in the residuals were an indication that the observed CPUE did not conform to one or more model assumptions. The root-mean squared error (RMSE) provided a summary diagnostic of each model's goodness of fit:

(12) $$RMSE = \sqrt{\frac{\sum_{T=1}^{N} \varepsilon_T^2}{N}}$$

The model with the lowest RMSE value gave the best fit to the data since the alternative models had the same number of parameters. The relative importance of differences in the CPUE fit of the alternative models was evaluated using an AIC statistic based on the CPUE observation error likelihood. Given that the alternative models had the same number of parameters p, the difference between the AIC values of the j^{th} ranked model and the best fitting model (Δ_j) was

(13) $$\Delta_j = N \cdot \ln\left(\frac{MSE_j}{MSE_{MIN}}\right)$$

where N is the number of CPUE data points, MSE_j is the mean-squared error of the j^{th} alternative model and MSE_{MIN} is the mean-squared error of the best fitting model. As a rough guide, values of Δ_j less than 2 indicate that the two models provide pretty similar fits to the CPUE data while Δ_j values greater than 2 indicate a poorer fit to the CPUE data (see, for example, Burnham and Anderson, 2002).

RESULTS

CPUE Data Sources

Fishery dependent catch data for assessing the bottomfish complexes were tabulated using the most recent and best available data.

Guam

Commercial catch data for BMUS were available for 1982-2005 (Table 2.1). Associated estimates of CPUE for Guam bottomfish were derived for all BMUS and for shallow and deep water species components for these years (Table 2.1 and Fig. 1.1). The number of qualifying BMUS trips for each year is presented in Table 2.4. Total CPUE declined during 1982-1997 and has increased moderately since then. Trends in CPUE for deep BMUS were similar to those for all BMUS while CPUE for shallow BMUS varied without trend (Fig. 1.1). Overall, total bottomfish fishing effort was relatively high in the mid to late1990s while associated CPUE was relatively low (Fig. 2.1). The deep and shallow BMUS components exhibit similar patterns although the pattern is more pronounced for the shallow BMUS.

American Samoa

Commercial catch data for the American Samoa bottomfish were available for 1986-2005 (Table 2.2). Commercial fishery CPUE was derived for all BMUS and for shallow and deep BMUS components for the years 1986-2005 (Table 2.2 and Fig. 1.2) with the number of qualifying trips for each year presented in Table 2.4. Overall BMUS CPUE varied without trend during 1982-2005 with peaks in 1988 and 1996. CPUE for deep BMUS decreased from a peak in 1996 to a minimum in 2000 and has increased moderately since then. Catch, effort, and CPUE were relatively low for deep and shallow BMUS in the early 1990s (Fig. 2.2). Since then, catch, effort and CPUE have varied but catch and effort were consistently higher in 2004-2005 (Fig. 2.2).

Commonwealth of the Northern Mariana Islands

Nominal commercial catch data for the CNMI bottomfish were available for 1983-2005 (Table 2.5). Commercial fishery CPUE was derived for all bottomfish, not just BMUS, because adequate species identification information was not available prior to 2000. The more detailed BMUS data collected since 2000 is presented in Tables 2.2 and 2.4, but due to the short time series of data are not used in our stock assessments. CPUE has fluctuated since 1983 with peaks in 1988 and 1999 (Fig. 1.3). Catch, CPUE, and effort were all low in the early 1990s and increased in the late-1990s (Fig. 2.3).

Index-based Assessment Method

Bottomfish landings, CPUE, and fishing effort for Guam (Table 2.1), American Samoa (Table 2.2), and the Commonwealth of the Northern Mariana Islands (Tables 2.3 and 2.5) were analyzed to apply the index-based assessment method. Fishery data are presented for the entire BMUS complex and separately for deep and shallow components. The number of qualifying trips in each category is presented in Table 2.4. Blank cells in the tables of CPUE or effort time series (Tables 2.1-2.3) represent years where no qualifying BMUS trips occurred in that category. Five year running means of CPUE and resulting point estimates of $CPUE_{MSY}$ and MSST were calculated using these time series (Table 2.6).

Establishing effort reference levels is much more difficult than estimating $CPUE_{MSY}$ and MSST using these catch and effort time series. The Bottomfish Fishery Management Plan indicates that a mean value of effort prior to onset of an overfished condition can be used as an estimate of effort at MSY. Unfortunately, in a developing fishery where MSY has not been reached a mean of effort values would be much lower than the effort associated with MSY and would result in a very low reference threshold, essentially ensuring an inappropriate overfishing determination. When an estimate of MSY estimate is available, an estimate of standardized effort at MSY could be obtained by dividing the MSY estimate by $CPUE_{MSY}$. Published estimates of MSY based on research conducted in the Marianas (Polovina et al., 1985), and extended to include American Samoa, are found in Humphreys and Moffitt (1999). These estimates are 55,000 pounds, 172,000 pounds, and 75,000 pounds respectively for Guam, the CNMI, and American Samoa. Although these estimates of MSY refer specifically to species of the deep component only, in this report we have applied them as representing both the deep component and the entire BMUS complex without attempting to expand the estimates to include the shallow components. These values were used for computing BMUS status determination criteria for the three island groups. Updated status determination criteria values were used to evaluate the bottomfish status for each of the island groups.

Guam

The index-based assessment method indicates that Guam bottomfish did not experience overfishing and were not overfished in 2005 (Fig. 3.1). Guam bottomfish were, however, experiencing overfishing during the mid-1990s through 2000 and would have been considered overfished in 1997-1998 using the updated criteria.

American Samoa

The index-based assessment results indicate that American Samoa bottomfish were not overfished or experiencing overfishing in 2005, or any year in the assessment time series (Fig. 3.2).

Commonwealth of the Northern Mariana Islands

In 2005, the CNMI bottomfish were not overfished but were experiencing overfishing (high effort expressed as the number of trips) based on the index assessment results (Fig. 3.3). Overall, the status determination values for CNMI bottomfish exhibit considerable variation since 1983. As mentioned earlier, the establishment of an appropriate overfishing threshold is very difficult using this method and the results of the new production model method are likely to give a more accurate status determination.

Surplus Production Model Assessment Method

Bottomfish landings, CPUE, and fishing effort for Guam (Table 2.1), American Samoa (Table 2.2), and the Commonwealth of the Northern Mariana Islands (Tables 2.3 and 2.4) were analyzed using surplus production models. Alternative models for each island group were ranked by their goodness of fit to the CPUE data.

Model Diagnostics and Selection

Guam

The RMSE diagnostic was smallest for the model with prior means of K=300 and P[1]=0.75 (Table 3.1), indicating that this model provided the best fit to the CPUE data. There were six other models with alternative prior means for K and P[1] that provided similar fits to the CPUE data with values of $\Delta < 2$ (Table 3.1). Together, these seven models formed a credible set of alternative models that was used to bound the uncertainty in estimates of K, r, P[1], and current stock status. Overall, the set of credible models accounted for about 87% of the Akaike weights (Table 3.1) which suggests that this set of models was over 6-fold more likely than the set of four models with $\Delta > 2$.

The BGR diagnostics of the credible models indicated that the MCMC chains converged to the posterior distribution. Plots of the BGR statistics for the best fitting model, which had prior means of K=300 and P[1]=0.75, were typical (Appendix, Figure A.1.1) with the BGR values approaching unity for each parameter (R, K, Q, P[1], σ^2, τ^2).

The residuals of the best-fitting Guam production model were relatively small which indicated a good fit to the CPUE data (Appendix, Fig. A.2.1). The residual patterns of the credible models were also similar, reflected by the moderate differences in RMSE among these models. There was a very large positive standardized residual in 1984 across models, indicating that the predicted CPUE was anomalously low in that year. A block of negative residuals during 1995-2000 followed by a block of positive residuals from 2001 onwards suggested that either the model structure or the reported logbook CPUE data deviated from model assumptions during this period.

Parameter estimates from the best-fitting Guam model were moderately correlated ($|\rho|<0.25$), with two exceptions. The intrinsic growth rate and the carrying capacity had a strong negative correlation ($\rho = -0.50$). Similarly, the carrying capacity and catchability had a strong negative correlation ($\rho = -0.85$).

American Samoa

The best-fitting model had prior means of K=900 and P[1]=0.80 (Table 3.2), although there was no practical difference between this model and those with K=700 or K=800 with P[1]=0.8. Twelve of the eighteen models were credible and each of the credible models had a prior mean for P[1]>0.5. In this case, the set of credible models accounted for about 92% of the Akaike weights (Table 3.2) which suggests that this set was over 10-fold more likely than the remaining set of six models with $\Delta > 2$.

The BGR statistics of the best fitting model (Appendix, Fig. A.1.2) had values approaching unity for each parameter (R, K, Q, P[1], σ^2, τ^2). This provided evidence that the MCMC chains converged.

The residual pattern of the best fitting model indicated that there was a close match between observed and predicted CPUE (Appendix, Fig. A.2.2). The model did have relatively large standardized residuals in 1988, 1996 and 2002, however. Overall, the residual pattern did not appear to be systematically non-random.

Parameter estimates from the best-fitting American Samoa model were moderately correlated ($|\rho|<0.25$) except that the carrying capacity and catchability had a strong negative correlation ($\rho = -0.84$).

Commonwealth of the Northern Mariana Islands

The best-fitting model had prior means of K=1400 and P[1]=0.45 (Table 3.3). Two of the remaining eight models were credible, with values of $\Delta<2$. Overall, each of the credible models had a prior mean for initial ratio of biomass to carrying capacity of P[1]<0.5. In this case, the set of credible models accounted for about 97% of the Akaike weights (Table 3.3) which suggests that the set of credible models was over 30-fold more likely than the remaining set of six models that had $\Delta > 2$.

The BGR values of the best fitting model (Appendix, Fig. A.1.3) approached unity for each parameter (R, K, Q, P[1], σ^2, τ^2), indicating that the MCMC chains converged.

The residuals of the best fitting model indicated that the model provided a close fit to the CPUE data (Appendix, Fig. A.2.3). Nonetheless, the residuals exhibited some patterning that appeared nonrandom, i.e., the block of positive residuals during 1984-1988, the block of negative residuals during 1989-1995, and the block of positive residuals during 1996-1999. Overall this pattern suggested that either the model structure or the reported CPUE data may have deviated from model assumptions during this period.

Parameter estimates from the best-fitting CNMI model were moderately correlated ($|\rho|<0.25$), with two exceptions. Carrying capacity and catchability estimates had a strong negative correlation ($\rho = -0.61$) while catchability and initial proportion of carrying capacity were negatively correlated ($\rho = -0.31$).

Parameter Estimates

Guam

The posterior means for carrying capacity from the set of credible models indicated that estimates of K ranged from 347 to 591 thousand pounds (Table 3.1). The posterior means for intrinsic growth rate suggested that estimates of r were between 0.47 and 0.58 while estimates of the initial ratio of biomass to carrying capacity were between 0.64 and 0.76. The posterior mean of MSY was MSY = 53.0 ± 9.5 thousand pounds which was very close to the input OLO estimate of MSY = 55.0 thousand pounds. Based on the best-fitting model, the biomass status of the Guam bottomfish complex in 2005 was positive with a probability of $p \geq 0.99$ that biomass was above B_{MSY}. Similarly, the probability that the harvest rate in 2005 exceeded the overfishing threshold was $p \leq 0.01$.

Estimates of Guam bottomfish biomass have fluctuated between 250-300 thousand pounds since 1982 (Fig. 5.1). Biomass declined in the late-1980s to 2000 and has increased since then. Estimates of exploitation rate increased from less than 10% in the early-1980s to a peak of 27% in 2000. Since 2000, exploitation rates have decreased to about 10% in 2005.

Estimates of relative biomass (B_{year}/B_{MSY}) indicate that biomass of the Guam bottomfish complex was above B_{MSY} during 1982-2005 (Table 4, Fig. 6.1). Lower bounds of the 80% confidence intervals for relative biomass show that the annual probability that biomass exceeded B_{MSY} was 90% or greater throughout the time period (Fig. 5.1). Similarly, the estimates of relative exploitation rate (H_{year}/H_{MSY}) indicate that the annual harvest rate has been below H_{MSY} since 1982, with the exception of 2000. Upper bounds of the 80% confidence intervals for relative exploitation rate show that the annual probability that harvest rate was below H_{MSY} was 90% or greater, with the exception of the year 2000 when there was roughly a 50% chance that exploitation rate was at or above H_{MSY}. Overall, the production model results suggest that the Guam bottomfish complex has not been overfished since 1982 and has not experienced overfishing, except perhaps in 2000 (Fig. 6.1).

American Samoa

Carrying capacity estimates from the set of credible models indicated that K ranged from 432 to 906 thousand pounds (Table 3.2). The posterior means for intrinsic growth rate suggested that estimates of r were between 0.45 and 0.48. Estimates of initial ratio of biomass to carrying capacity were between 0.64 and 0.80 over the set of credible models. The posterior mean of MSY was MSY = 109.0 ± 29.7 thousand pounds which was higher than the input OLO estimate of MSY = 75.0 thousand pounds. The biomass status of the American Samoa bottomfish complex in 2005 was healthy, with a probability of $p>0.99$ that biomass was above B_{MSY} based on the best-fitting model. Similarly, the probability that the harvest rate in 2005 exceeded the overfishing threshold was $p<0.01$.

Estimates of American Samoa bottomfish biomass have fluctuated around 800 thousand pounds since 1988 (Fig. 5.2). Biomass increased moderately in the in the 1990s and has been relatively stable since then. Estimates of exploitation rate decreased to less than 5% in the late-1980s and remained low until 2004 when they increased to about 8%.

Estimates of relative biomass indicate that the biomass of the American Samoa bottomfish complex has been above B_{MSY} during 1986-2005 (Table 4, Fig. 6.1). Similarly, estimates of relative exploitation rate indicate that the annual harvest rate has been below H_{MSY} since 1986. Lower bounds of the 80% confidence intervals for relative biomass show that the annual probability of biomass being at or above B_{MSY} was 90% or greater throughout the time period (Fig. 5.2). Similarly, upper bounds of the 80% confidence intervals for relative exploitation rate indicate that the annual probability of harvest rate being at or below H_{MSY} was 90% or greater. Overall, the production model results suggest that the American Samoa bottomfish complex has was not overfished and did not experience overfishing during 1986-2005 (Fig. 6.2).

Commonwealth of the Northern Mariana Islands

Carrying capacity estimates from the set of credible models indicated that K ranged from 1027 to 1713 thousand pounds (Table 3.2). Estimates of intrinsic growth rate suggested that r was roughly 0.57. Estimates of the initial ratio of biomass to carrying capacity were 0.45 over the set of credible models, indicating that the model had no information to change the prior assumption for this parameter. The posterior mean of MSY was MSY = 200.5 ± 40.5 thousand pounds which was higher than the input OLO estimate of MSY = 172.0 thousand pounds. The biomass status of the CNMI bottomfish complex in 2005 appeared to be healthy with a probability of $p>0.99$ that biomass was above B_{MSY} over the set of credible models. Similarly, the probability that the harvest rate in 2005 exceeded the overfishing threshold was $p<0.06$.

Estimates of CNMI bottomfish biomass have fluctuated around 1300 thousand pounds since 1988 (Fig. 5.3). Biomass increased in the mid-1990s and has been relatively stable since then. Estimates of exploitation rate decreased from about 5% in the early 1980s to less than 5% in the early 1990s. Since then exploitation rates have increased to around 5%.

Estimates of relative biomass indicate that biomass of the CNMI bottomfish complex has been above B_{MSY} since 1984 (Table 4, Fig. 6.1). Similarly, the estimates of relative exploitation rate indicate that the annual harvest rate was below H_{MSY} during 1983-2005. Lower bounds of the 80% confidence intervals for relative biomass show that the annual probability that biomass exceeded B_{MSY} was 90% or greater throughout most of the time period (Fig. 5.3). Similarly, upper bounds of the 80% confidence intervals for relative exploitation rate indicate that the annual probability of harvest rate being at or below H_{MSY} was 90% or greater. Overall, the production model results suggest that the CNMI bottomfish complex was not overfished and did not experience overfishing during 1986-2005 (Fig. 6.3).

DISCUSSION

Stock status determinations based on models with the closest fits to the CPUE data appear relatively robust. Even though the CPUE data were not particularly informative about the ratio of initial biomass to carrying capacity, the set of credible models for each island group provided a consistent evaluation of current bottomfish status. This is important because the CPUE data for each island group lacked sufficient contrast to estimate the ratio of initial biomass to carrying capacity (P[1]) and the prior assumptions for P[1] primarily determine its value. In this case, the goodness of fit to the CPUE data provided an objective way to rank the alternative prior assumptions about P[1] and K for each island group. This ranking is not a statistically significant result, however, and depends on the judgment that the set of models adequately approximates the dynamics of the bottomfish complex.

A comparison of the new production model results and the CPUE index-based results shows that both provide similar status determinations for 2005, with the exception of the overfishing status for CNMI. This similarity might be expected given that both methods use the same data and assume that the CPUE series are proportional to relative bottomfish abundance. There are three important differences between the two approaches, however. First, the production model is based on a simple structural model of bottomfish dynamics that relates fishery removals to population growth rate and carrying capacity parameters. In contrast, the index-based approach does not explicitly consider information about fishery removals. As a result, the index-based results are more variable because they do not include the smoothing effects of a population dynamics process. Second, the index-based approach requires an assumption that bottomfish abundance was at or near carrying capacity during the observed CPUE series. In contrast, the production model does not require this assumption, and includes an explicit term to represent the initial ratio of biomass to carrying capacity which improves the approximation of resource dynamics. Third, the production model approach provides a statistical framework to characterize the uncertainty in parameter estimates and status determination while the index-based approach does not. As a result, the production modeling approach provides a more useful framework for analytical assessment, although both approaches are limited by the quality of the input fishery-dependent data.

There are two caveats to mention for interpreting the production model results. First, the production model fits are conditioned on previous estimates of MSY for each island group (Humphreys and Moffitt, 1999). 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 might be unaffected. Second, there are some blocks of positive and negative residuals for the Guam and CNMI models that give an indication of a lack of model fit to the CPUE data. The reason for this difference between observed and predicted CPUE is unknown but could be due to changes in population dynamics, multispecies interactions, fishery dynamics, or environmental conditions, for example. Nonetheless, the residuals for these two models are rather small in magnitude which supports their use for bottomfish assessment.

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, or misidentification of species. If the fishery removals are inaccurate then the production model results will reflect this problem. Another potential problem is that changes in the 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. If the relative abundance index is inaccurate then the trends from the production model will reflect this problem. Overall, it would be useful to improve the fishery catch reporting systems of the three island groups to account for these potential problems. Further, it would be helpful to augment the data reporting systems to collect length frequency samples of individual bottomfish species. This would provide additional information on the average size and age of fish in the catch and support more sophisticated assessment methods.

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Table 1.--List of bottomfish management unit species (BMUS) landed in western Pacific island areas of Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands.

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 seiboldi	Kalekale	Deep
Pristipomoides zonatus	Gindai	Deep
Seriola dumerili	Amberjack	Shallow
Variola louti	Lunartail grouper	Deep

Table 2.1.--Guam bottomfish landings, CPUE, and standardized effort (in line-hours) for all managed bottomfish species (All BMUS), the deep water component (Deep Component) and the shallow water component (Shallow Component) during 1982-2005.

	All BMUS			Deep Component			Shallow Component		
Year	Landings	CPUE	Std Effort	Landings	CPUE	Std Effort	Landings	CPUE	Std Effort
1982	18404	3.05	6042	14228	2.89	4928	4176	2.55	1636
1983	33082	2.66	12448	26980	2.76	9774	6102	3.02	2022
1984	20130	11.66	1726	13340	11.66	1144	6790		
1985	36584	2.46	14863	24249	2.96	8180	12336	1.09	11362
1986	18866	3.57	5286	11746	4.21	2788	7120	1.35	5285
1987	16282	3.98	4092	9472	4.91	1929	6811	2.17	3138
1988	29318	2.37	12388	19073	3.89	4903	10245	0.82	12526
1989	38279	2.28	16787	28213	2.42	11638	10066	2.29	4399
1990	32078	3.40	9432	23530	3.18	7406	8547	4.71	1813
1991	36007	2.00	18028	22507	2.49	9057	13500	0.85	15956
1992	38266	2.25	16993	22645	2.67	8482	15622	1.65	9458
1993	53481	2.98	17934	28877	3.51	8230	24604	2.10	11732
1994	52248	2.73	19141	36710	3.97	9255	15537	0.66	23573
1995	39313	2.05	19178	18046	3.71	4859	21268	0.71	30159
1996	52702	2.26	23322	30152	2.70	11178	22550	1.21	18596
1997	35510	1.32	26828	14048	1.80	7793	21462	0.88	24464
1998	37927	1.65	22942	17497	2.15	8150	20430	1.03	19891
1999	52104	1.88	27724	32128	2.62	12255	19977	0.77	25783
2000	68846	1.89	36432	44505	2.46	18106	24341	1.03	23609
2001	45746	3.25	14067	28411	4.94	5750	17335	0.93	18606
2002	23704	2.87	8248	13779	4.24	3248	9925	0.93	10712
2003	38466	4.26	9031	25312	6.11	4142	13154	1.80	7317
2004	25819	2.77	9327	18223	2.98	6108	7596	1.90	4000
2005	31758	4.81	6607	26598	6.14	4329	5160	0.94	5518

Table 2.2.--American Samoa bottomfish landings, CPUE, and standard effort (in line-hours) for all managed bottomfish species (All BMUS), the deep water component (Deep Component) and the shallow water component (Shallow Component) during 1986-2005.

	All BMUS			Deep Component			Shallow Component		
Year	Landings	CPUE	Std Effort	Landings	CPUE	Std Effort	Landings	CPUE	Std Effort
1986	66447	3.26	20394	33134	3.82	8681	33313		
1987	22132	2.98	7418	10458			11674	1.70	6867
1988	44879	6.35	7066	22315	7.63	2924	22564	3.73	6055
1989	30678	4.02	7637	11434	4.25	2690	19244	4.01	4804
1990	10782	3.54	3044	3096	3.53	877	7687	4.23	1819
1991	12341	2.64	4675	4369	2.65	1649	7972	2.14	3717
1992	10472	2.44	4287	3697	1.63	2273	6775	2.88	2355
1993	13056	3.27	3996	5952	3.61	1649	7104	2.17	3270
1994	31801	3.16	10074	14171	2.92	4846	17630	1.52	11589
1995	26248	4.24	6191	14343	4.45	3221	11905	3.43	3473
1996	28844	6.53	4420	14114	6.08	2322	14730	4.95	2973
1997	30576	3.82	7996	16530	3.09	5352	14046	3.68	3815
1998	12245	3.96	3091	9860	3.70	2668	2386	4.04	591
1999	12731	3.67	3469	9723	3.08	3153	3008	3.98	757
2000	18910	4.57	4135	4865	1.84	2646	14045	9.25	1518
2001	37368	4.95	7554	17248	3.70	4658	20119	5.09	3952
2002	30771	2.45	12583	11928	3.04	3927	18843	1.21	15589
2003	17536	5.42	3235	9887	5.12	1932	7649	2.63	2905
2004	74822	4.31	17362	22598	2.70	8378	52224	2.56	20420
2005	53556	3.13	17104	32464	4.28	7578	21092	1.35	15633

Table 2.3.--Commonwealth of the Northern Mariana Islands bottomfish landings, CPUE, and standard effort (in line-hours) for all managed bottomfish species (All BMUS), the deep water component (Deep Component) and the shallow water component (Shallow Component) during 2000-2005.

	All BMUS			Deep Component			Shallow Component		
Year	Landings	CPUE	Std Effort	Landings	CPUE	Std Effort	Landings	CPUE	Std Effort
2000	62339	10.50	5939	49579	9.48	5232	12760	12.37	1032
2001	32923	4.51	7295	26421	4.68	5644	6501	3.82	1700
2002	24245	5.85	4144	19854	8.10	2451	4391	1.74	2519
2003	7564	4.13	1833	6293	3.64	1730	1272	4.95	257
2004	13660	3.84	3556	9624	3.38	2843	4036	4.08	989
2005	18746	3.94	4762	14786	4.15	3562	3960	3.91	1014

Table 2.4.--Number of qualifying bottomfishing trips per year by island area and depth component.

	American Samoa			Guam			CNMI		
	Shallow	Deep	All BMUS	Shallow	Deep	All BMUS	Shallow	Deep	All BMUS
1982				5	29	37			
1983				5	25	34			
1984				0	6	6			
1985				17	31	52			
1986	0	20	163	8	16	27			
1987	1	0	37	7	14	23			
1988	15	15	51	21	25	55			
1989	17	9	54	18	46	73			
1990	12	8	36	8	32	47			
1991	12	9	32	12	28	45			
1992	12	13	33	15	19	42			
1993	12	16	42	20	28	50			
1994	17	45	73	24	34	66			
1995	11	45	70	30	25	58			
1996	16	54	82	32	39	75			
1997	16	47	77	27	22	51			
1998	4	24	30	32	34	71			
1999	2	42	54	23	31	59			
2000	13	24	47	18	31	52	5	10	15
2001	10	31	53	20	33	57	4	11	15
2002	13	23	59	17	23	40	5	7	12
2003	5	36	70	16	19	36	4	7	11
2004	30	18	75	8	24	35	13	12	26
2005	7	28	57	9	37	50	26	13	44

Table 2.5.--Commonwealth of the Northern Mariana Islands bottomfish landings, CPUE, and standard effort (in # of trips) for all reported bottomfish species during 1983-2005.

Year	Landings	CPUE	Std Effort
1983	28529	43	663
1984	42664	70	609
1985	40975	117	350
1986	29911	104	288
1987	49715	169	294
1988	47313	181	261
1989	24438	73	335
1990	12927	81	160
1991	7093	47	151
1992	10598	59	180
1993	18461	84	220
1994	25469	74	344
1995	36101	93	388
1996	66387	119	558
1997	64143	137	468
1998	59022	148	399
1999	55991	156	359
2000	45258	56	808
2001	71256	68	1048
2002	46765	101	463
2003	41903	89	471
2004	54474	104	524
2005	70034	76	922

Table 2.6.--CPUE and effort reference estimates using index methods.

	$CPUE_{MSY}$ (lbs/line-hr)	$CPUE_{MSST}$ (lbs/line-hr)	$Effort_{MFMT}$ mean method (line-hours)	$Effort_{MFMT}$ OLO method (line-hours)
American Samoa				
All BMUS	2.26	1.58	7,787	33,238
Deep BMUS	2.19	1.53	3,759	34,271
Shallow BMUS	2.60	1.82	5,900	
Guam				
All BMUS	2.43	1.70	11,935-16,134	14,953
Deep BMUS	2.76	1.93	6,917-8,701	19,944
Shallow BMUS	1.16	0.81	7,211-14,197	
CNMI				
All BMUS	2.88	2.02	4,588	59,665
Deep BMUS	2.93	2.05	3,577	58,743
Shallow BMUS	2.70	1.89	1,252	
	(Lbs/trip)	(Lbs/trip)	(# of trips)	(# of trips)
CNMI (Trip based)	65	46	446	2,634

Table 3.1.--Alternative production models for Guam bottomfish ranked by root mean-squared error (RMSE) along with posterior mean values of carrying capacity (K), catchability (q), intrinsic growth rate (r), ratio of initial biomass to carrying capacity (P[1]), process error variance (sigma2), observation error variance (tau2), probability that biomass in 2005 exceeds B_{MSY} (p(B>BMSY)), probability that harvest rate in 2005 exceeds H_{MSY} (p(H>HMSY)), CPUE-based AIC difference (Δ_j) from the best-fitting model, relative likelihood, and Akaike weight.

Alternative Guam Models Ranked by RMSE: Prior Means for K and P[1]	K	q	r	P[1]	sigma2	tau2	p(B>BMSY)	p(F>FMSY)	RMSE	N*log(MSE)	Δj	Relative Likelihood	Akaike Weight
K=300, P=0.75	391	0.010	0.55	0.76	0.004	0.153	0.99	0.00	0.405	-43.3	0	1	0.19
K=500, P=0.75	513	0.007	0.49	0.76	0.005	0.154	1.00	0.00	0.406	-43.2	0.1	0.95	0.18
K=200, P=0.63	347	0.012	0.58	0.64	0.005	0.160	0.99	0.00	0.414	-42.3	1.0	0.60	0.11
K=400, P=0.63	435	0.009	0.52	0.64	0.005	0.162	0.99	0.00	0.416	-42.1	1.2	0.54	0.10
K=300, P=0.63	384	0.011	0.55	0.64	0.005	0.162	0.99	0.00	0.416	-42.1	1.2	0.54	0.10
K=500, P=0.63	505	0.008	0.49	0.64	0.005	0.162	0.99	0.00	0.417	-42.0	1.3	0.52	0.10
K=600, P=0.63	591	0.006	0.47	0.65	0.005	0.165	0.99	0.00	0.419	-41.8	1.6	0.46	0.09
K=500, P=0.30	519	0.011	0.43	0.36	0.026	0.189	0.72	0.08	0.426	-41.0	2.4	0.31	0.06
K=500, P=0.45	500	0.009	0.47	0.48	0.009	0.184	0.95	0.01	0.440	-39.4	3.9	0.14	0.03
K=300, P=0.45	377	0.012	0.54	0.47	0.007	0.184	0.96	0.01	0.442	-39.2	4.1	0.13	0.02
K=300, P=0.30	386	0.014	0.52	0.35	0.023	0.205	0.81	0.05	0.449	-38.4	4.9	0.09	0.02

Table 3.2.--Alternative production models for American Samoa bottomfish ranked by root mean-squared error (RMSE) along with posterior mean values of carrying capacity (K), catchability (q), intrinsic growth rate (r), ratio of initial biomass to carrying capacity (P[1]), process error variance (sigma2), observation error variance (tau2), probability that biomass in 2005 exceeds B_{MSY} (p(B>BMSY)), probability that harvest rate in 2005 exceeds H_{MSY} (p(H>HMSY)), CPUE-based AIC difference (Δ_j)from the best-fitting model, relative likelihood, and Akaike weight.

Alternative American Samoa Models Ranked by RMSE: Prior Means for K and P[1]	K	q	r	P[1]	sigma2	tau2	p(B>BMSY)	p(F>FMSY)	RMSE	N*log(MSE)	Δj	Relative Likelihood	Akaike Weight
900, 800	906	0.005	0.48	0.80	0.004	0.067	1.00	0.00	0.270	-62.9	0.0	1	0.11
800, 800	808	0.005	0.48	0.80	0.004	0.067	1.00	0.00	0.270	-62.9	0.0	0.99	0.11
700, 800	711	0.006	0.48	0.80	0.004	0.067	1.00	0.01	0.270	-62.9	0.0	0.98	0.11
600, 800	615	0.007	0.48	0.80	0.004	0.068	1.00	0.04	0.270	-62.8	0.2	0.92	0.10
500, 800	522	0.009	0.48	0.80	0.004	0.000	0.99	0.10	0.271	-62.7	0.3	0.87	0.10
400, 800	440	0.011	0.48	0.80	0.004	0.069	0.98	0.23	0.273	-62.4	0.6	0.75	0.08
600, 626	610	0.008	0.46	0.64	0.004	0.072	0.99	0.09	0.278	-61.4	1.6	0.46	0.05
700, 626	707	0.007	0.47	0.64	0.004	0.072	1.00	0.04	0.279	-61.3	1.6	0.45	0.05
800, 626	807	0.006	0.47	0.64	0.004	0.072	1.00	0.02	0.279	-61.3	1.6	0.45	0.05
500, 626	517	0.010	0.45	0.65	0.004	0.072	0.97	0.19	0.279	-61.3	1.6	0.44	0.05
900, 626	905	0.005	0.47	0.64	0.004	0.072	1.00	0.01	0.279	-61.3	1.6	0.44	0.05
400, 626	432	0.013	0.45	0.64	0.004	0.072	0.91	0.37	0.279	-61.2	1.7	0.42	0.05
400, 400	431	0.024	0.32	0.41	0.008	0.077	0.21	0.88	0.288	-59.8	3.1	0.21	0.02
500, 400	498	0.019	0.30	0.41	0.005	0.078	0.28	0.82	0.288	-59.7	3.2	0.20	0.02
600, 400	578	0.016	0.29	0.41	0.005	0.078	0.35	0.76	0.289	-59.7	3.3	0.19	0.02
700, 400	682	0.012	0.31	0.42	0.005	0.083	0.55	0.57	0.297	-58.3	4.7	0.10	0.01
800, 400	788	0.009	0.35	0.42	0.006	0.087	0.69	0.40	0.304	-57.1	5.8	0.06	0.01
900, 400	895	0.007	0.38	0.43	0.006	0.091	0.80	0.26	0.310	-56.3	6.7	0.04	0.00

Table 3.3.--Alternative production models for CNMI bottomfish ranked by root mean-squared error (RMSE) along with posterior mean values of carrying capacity (K), catchability (q), intrinsic growth rate (r), ratio of initial biomass to carrying capacity (P[1]), process error variance (sigma2), observation error variance (tau2), probability that biomass in 2005 exceeds B_{MSY} (p(B>BMSY)), probability that harvest rate in 2005 exceeds H_{MSY} (p(H>HMSY)), CPUE-based AIC difference (Δ_j) from the best-fitting model, relative likelihood, and Akaike weight.

Alternative CNMI Models Ranked by RMSE: Prior Means for K and P[1]	K	q	R	P[1]	sigma2	tau2	p(B>BMSY)	p(F>FMSY)	RMSE	N*log(MSE)	Δj	Relative Likelihood	Akaike Weight
1400, 450	1416	0.076	0.57	0.45	0.023	0.094	1.00	0.00	0.292	-59.0	0.0	1	0.48
1700, 450	1713	0.062	0.57	0.45	0.021	0.096	1.00	0.00	0.298	-58.1	1.0	0.61	0.29
1000, 450	1027	0.108	0.57	0.45	0.021	0.099	1.00	0.06	0.303	-57.3	1.7	0.42	0.20
1700, 626	1713	0.059	0.54	0.62	0.008	0.117	1.00	0.00	0.349	-50.6	8.5	0.01	0.01
1400, 626	1417	0.072	0.54	0.61	0.008	0.117	1.00	0.00	0.349	-50.5	8.6	0.01	0.01
1000, 626	1027	0.103	0.54	0.61	0.008	0.121	1.00	0.00	0.355	-49.7	9.3	0.01	0.00
1700, 800	1713	0.057	0.52	0.78	0.006	0.126	1.00	0.00	0.365	-48.3	10.7	0.00	0.00
1400, 800	1417	0.070	0.52	0.78	0.006	0.128	1.00	0.00	0.368	-48.0	11.1	0.00	0.00
1000, 800	1028	0.100	0.52	0.78	0.006	0.131	1.00	0.00	0.374	-47.3	11.8	0.00	0.00

Table 4.--Mean estimates of relative biomass ($B_{status} = B_{year}/B_{MSY}$) and fishing mortality ($F_{status} = F_{year}/F_{MSY}$) trends for the islands of Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands from the best-fitting surplus production model. Bottomfish are considered to be overfished in years when $B_{status} < 0.7$ and are experiencing overfishing when $F_{status} > 1$.

	Guam		American Samoa		Commonwealth of the Northern Mariana Islands	
Year	Bstatus	Fstatus	Bstatus	Fstatus	Bstatus	Fstatus
1982	1.52	0.24				
1983	1.65	0.39			0.89	0.17
1984	1.70	0.23			1.23	0.18
1985	1.71	0.42			1.63	0.14
1986	1.65	0.23	1.61	0.41	1.75	0.09
1987	1.70	0.19	1.63	0.14	2.12	0.13
1988	1.72	0.34	1.77	0.26	2.21	0.12
1989	1.66	0.45	1.74	0.18	1.70	0.08
1990	1.60	0.40	1.73	0.06	1.71	0.04
1991	1.57	0.45	1.75	0.07	1.57	0.03
1992	1.54	0.49	1.77	0.06	1.64	0.04
1993	1.52	0.70	1.82	0.07	1.78	0.06
1994	1.42	0.73	1.86	0.17	1.76	0.08
1995	1.34	0.59	1.88	0.14	1.87	0.10
1996	1.35	0.78	1.93	0.15	2.00	0.18
1997	1.28	0.56	1.89	0.16	2.07	0.17
1998	1.33	0.57	1.87	0.07	2.11	0.15
1999	1.38	0.76	1.89	0.07	2.12	0.14
2000	1.35	1.02	1.93	0.10	1.62	0.16
2001	1.26	0.73	1.92	0.20	1.67	0.23
2002	1.29	0.37	1.84	0.17	1.80	0.14
2003	1.44	0.54	1.88	0.09	1.79	0.12
2004	1.46	0.36	1.89	0.40	1.86	0.16
2005	1.56	0.41	1.75	0.31	1.73	0.22

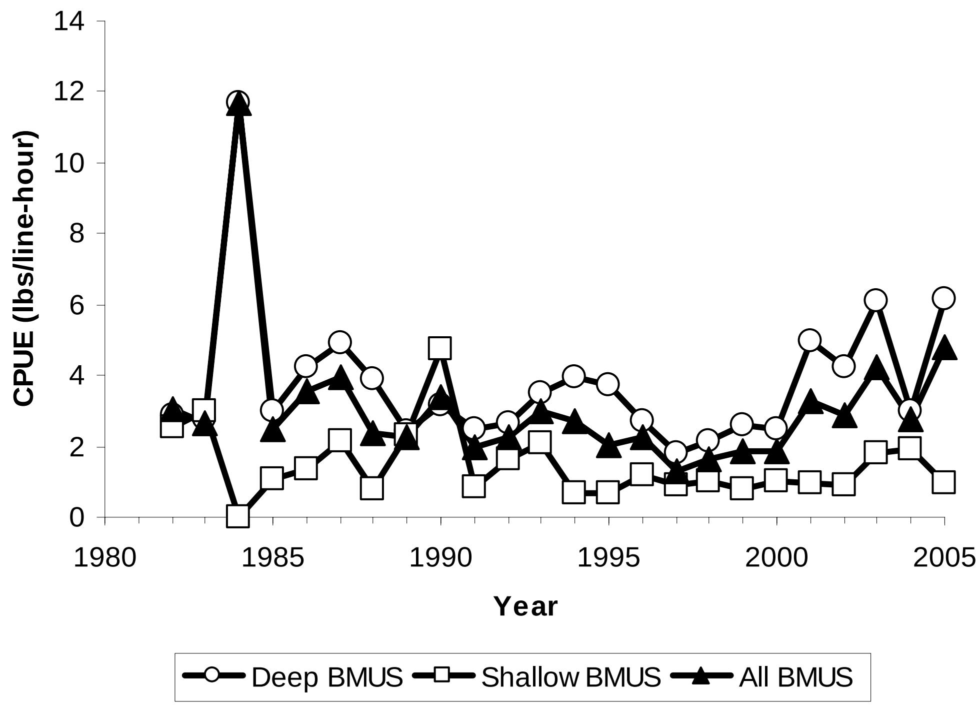


Figure 1.1.--Commercial catch-per-unit effort of Guam bottomfish complex during 1982-2005.

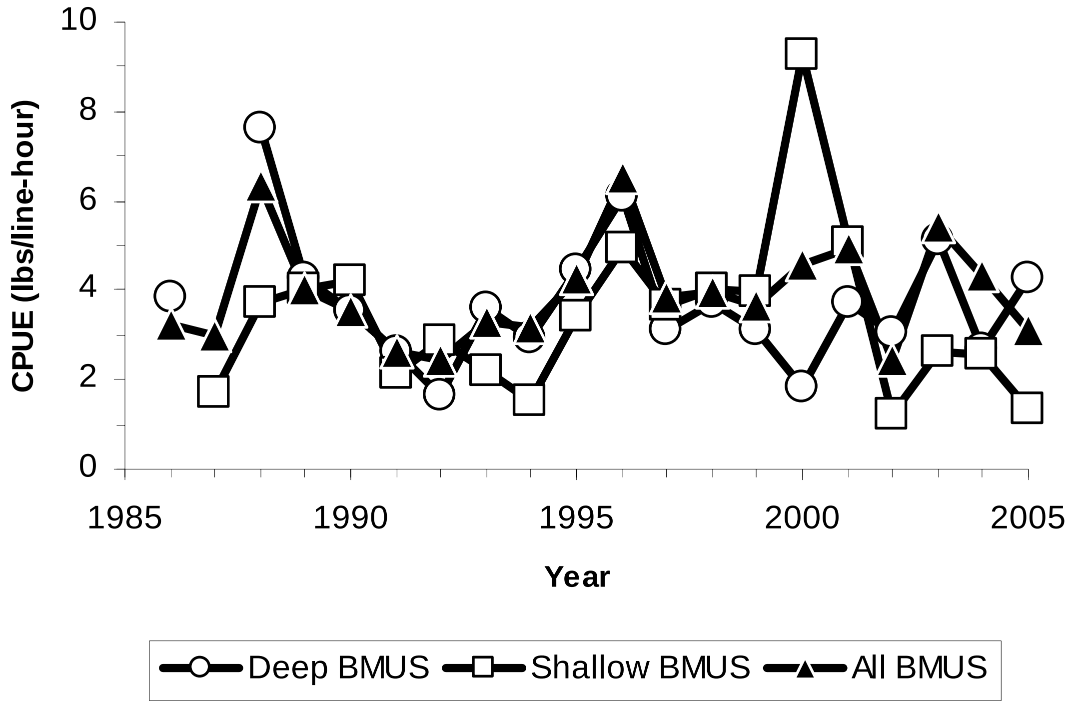


Figure 1.2.--Commercial catch-per-unit effort of American Samoa bottomfish complex during 1986-2005.

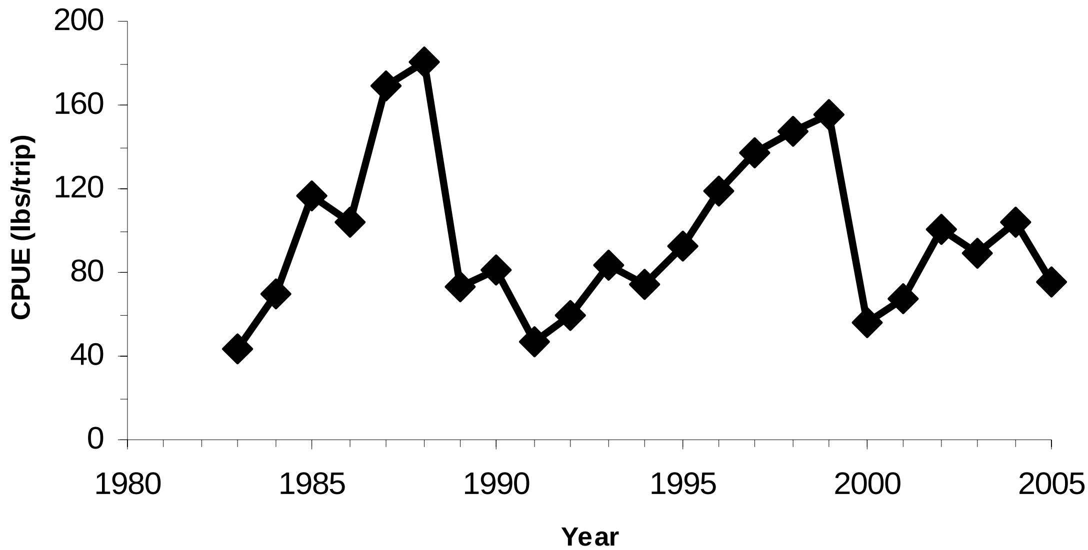


Figure 1.3.--Commercial catch-per-unit effort of Commonwealth of the Northern Mariana Islands bottomfish (nominal bottomfish species) during 1983-2005.

Figure 2.1.--Empirical distributions of Guam bottomfish (BMUS species only) catch, effort, and CPUE for all areas, deep, and shallow water depth zones by year. Symbols indicate the quintile of each annual value.

(a). Total Guam Bottomfish Catch, Effort and CPUE, 1982-2005.

	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
Guam Bottomfish Catch Total	◉	◑	◉	○	◉	◉	◑	◐	◑	○	◐	●	●	◐	●	○	○	●	●	◐	◉	◐	◑	◑
Guam Bottomfish Effort Total	◉	○	◉	○	◉	◉	◑	○	◑	◐	◐	◐	◐	◐	●	●	●	●	●	○	◑	◑	◑	◉
Guam Bottomfish CPUE Total	◐	○	●	○	●	●	◑	◑	◐	◉	◑	◐	○	◑	◑	◉	◉	◉	◉	◐	◐	●	○	●

Legend

● Highest	◐ 2nd Highest	○ Middle	◑ 2nd Lowest	◉ Lowest

(b). Deepwater Guam Bottomfish Catch, Effort and CPUE, 1982-2005.

	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
Guam Bottomfish Catch Deepwater	◑	◐	◉	○	◉	◉	◑	◐	○	○	○	●	●	◑	●	◉	◑	●	●	◐	◉	◐	◑	◐
Guam Bottomfish Effort Deepwater	◑	●	◉	◐	◉	◉	◑	●	○	◐	◐	◐	◐	◑	●	○	○	●	●	◑	◉	◉	○	◑
Guam Bottomfish CPUE Deepwater	◑	◑	●	○	◐	●	◐	◉	○	◉	◑	○	◐	◐	◑	◉	◉	◑	◉	●	◐	●	○	●

Legend

● Highest	◐ 2nd Highest	○ Middle	◑ 2nd Lowest	◉ Lowest

(c). Shallow Guam Bottomfish Catch, Effort and CPUE, 1982-2005

	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
Guam Bottomfish Catch Shallow	◉	◉	◉	○	◑	◉	○	◑	◑	○	◐	●	◐	●	●	●	◐	◐	●	◐	◑	○	◑	◉
Guam Bottomfish Effort Shallow	◉	◉		○	◑	◉	○	◑	◉	◐	○	○	●	●	◐	●	◐	●	●	◐	○	◑	◉	◑
Guam Bottomfish CPUE Shallow	●	●		○	○	●	◉	●	●	◉	◐	◐	◉	◉	○	◑	○	◉	○	◑	◑	◐	◐	◑

Legend

● Highest	◐ 2nd Highest	○ Middle	◑ 2nd Lowest	◉ Lowest

Figure 2.2.--Empirical distributions of American Samoa bottomfish (BMUS species only) catch, effort, and CPUE for all areas, deep, and shallow water depth zones by year. Symbols indicate the quintile of each annual value.

(a). Total American Samoa Bottomfish Catch, Effort and CPUE, 1986-2005.

	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
Amercian Samoa Bottomfish Catch All Areas	●	○	●	◐	◉	◉	◉	◑	◐	○	○	○	◉	◑	◑	◐	◐	◑	●	●
Amercian Samoa Bottomfish CPUE All Areas	◑	◉	●	◐	○	◉	◉	◑	◑	◐	●	○	○	○	◐	●	◉	●	◐	◑
Amercian Samoa Bottomfish Effort All Areas	●	○	○	◐	◉	○	◑	◑	◐	○	◑	◐	◉	◉	◑	◐	●	◉	●	●

Legend

● Highest	◐ 2nd Highest	○ Middle	◑ 2nd Lowest	◉ Lowest

(b). Deep water American Samoa Bottomfish Catch, Effort and CPUE, 1986-2005.

	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
Amercian Samoa Bottomfish Catch Deep	●	○	●	○	◉	◉	◉	◑	◐	◐	○	◐	◑	◑	◉	◐	○	◑	●	●
Amercian Samoa Bottomfish CPUE Deep	◐		●	◐	○	◉	◉	○	◑	●	●	◑	◐	◑	◉	◐	◑	●	◉	◐
Amercian Samoa Bottomfish Effort Deep	●		○	○	◉	◉	◑	◉	◐	◐	◑	●	◑	○	◑	◐	◐	◉	●	●

Legend

● Highest	◐ 2nd Highest	○ Middle	◑ 2nd Lowest	◉ Lowest

(c). Shallow water American Samoa Bottomfish Catch, Effort and CPUE, 1986-2005

	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
Amercian Samoa Bottomfish Catch Shallow	●	◑	●	◐	◑	◑	◉	◉	◐	○	○	○	◉	◉	○	◐	◐	◑	●	●
Amercian Samoa Bottomfish CPUE Shallow		◉	◐	◐	●	◑	○	◑	◉	○	●	○	◐	◐	●	●	◉	◑	◑	◉
Amercian Samoa Bottomfish Effort Shallow		◐	◐	◐	◉	○	◑	◑	●	○	◑	○	◉	◉	◉	◐	●	◑	●	●

Legend

● Highest	◐ 2^{nd} Highest	○ Middle	◑ 2nd Lowest	◉ Lowest

Figure 2.3.--Empirical distributions of Commonwealth of the Northern Mariana Islands bottomfish (nominal bottomfish species) catch, effort, and CPUE for all areas by year. Symbols indicate the quintile of each annual value.

(a). Total CNMI Bottomfish Catch, Effort and CPUE, 1983-2005.

	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05
CNMI Bottomfish Catch All Areas	◑	○	○	◑	◐	◐	⊙	⊙	⊙	⊙	⊙	◑	◑	●	●	●	◐	○	●	○	○	◐	●
CNMI Bottomfish CPUE All Areas	⊙	◑	◐	◐	●	●	◑	○	⊙	⊙	○	◑	○	◐	●	●	●	⊙	⊙	○	○	◐	◑
CNMI Bottomfish Effort All Areas	●	●	○	◑	◑	⊙	◑	⊙	⊙	⊙	⊙	◑	○	◐	◐	○	○	●	●	○	◐	◐	●

Legend

● Highest ◐ 2nd Highest ○ Middle ◑ 2nd Lowest ⊙ Lowest

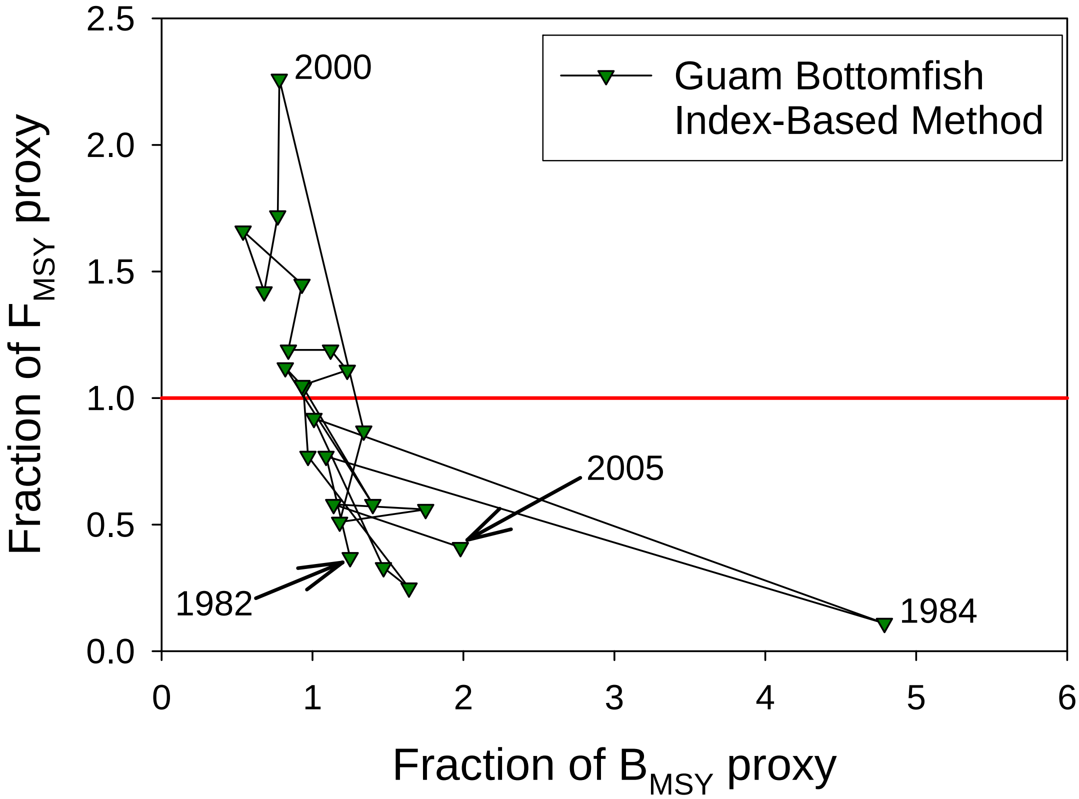


Figure 3.1.--Estimates of the relative biomass and harvest rate status for Guam bottomfish, 1982-2005 using the index-based assessment method.

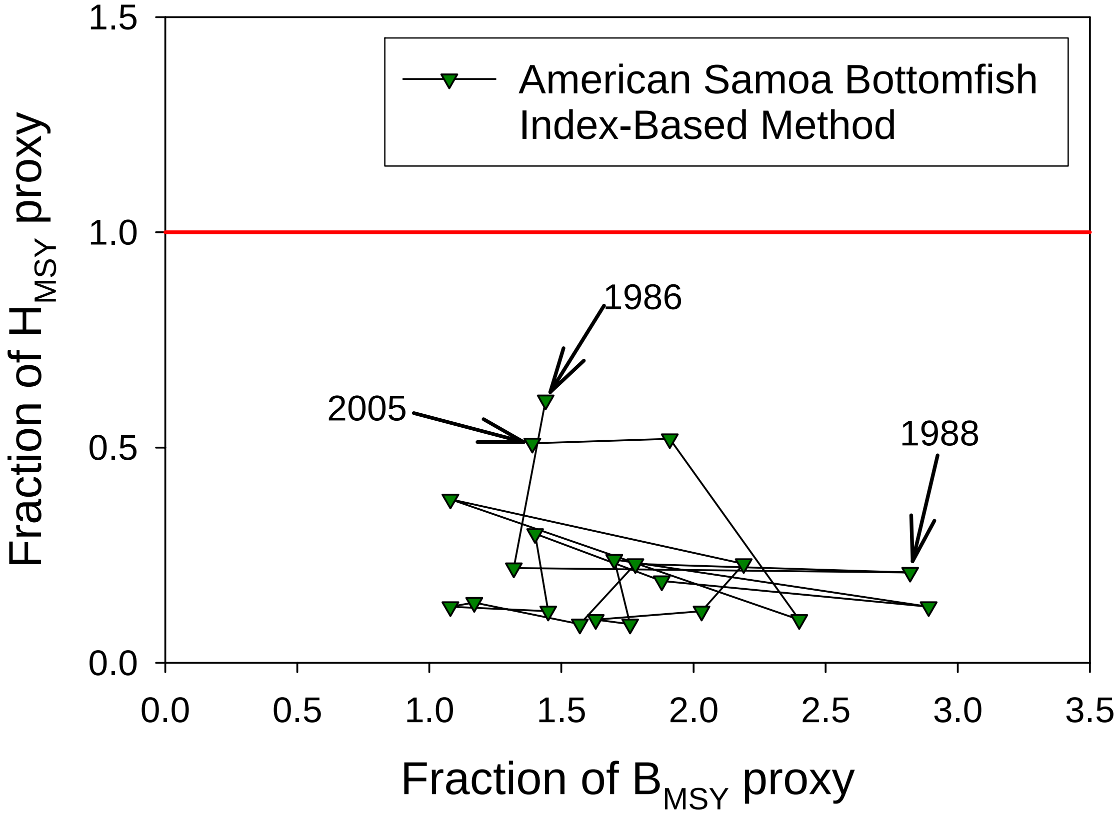


Figure 3.2.--Estimates of the relative biomass and harvest rate status for American Samoa bottomfish, 1986-2005 using the index-based assessment method.

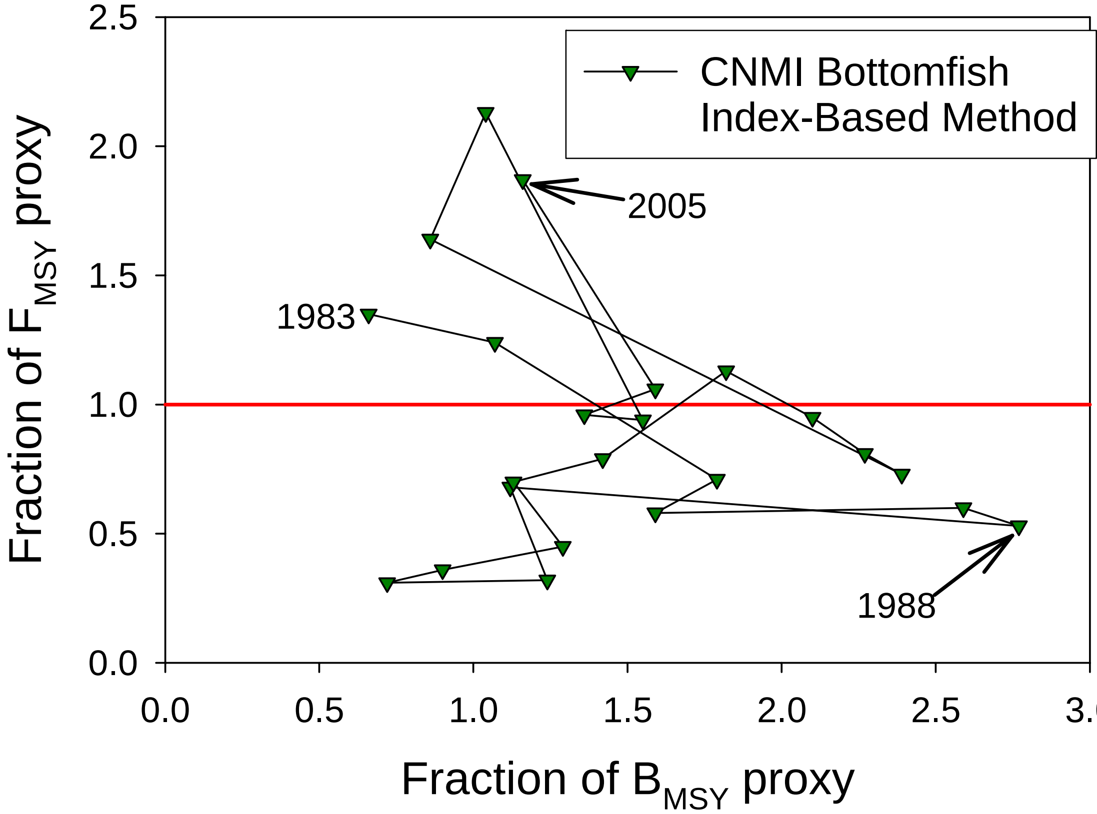


Figure 3.3.--Estimates of the relative biomass and harvest rate status for the Commonwealth of the Northern Mariana Islands bottomfish, 1983-2005 using the index-based assessment method applied to all reported bottomfish landings.

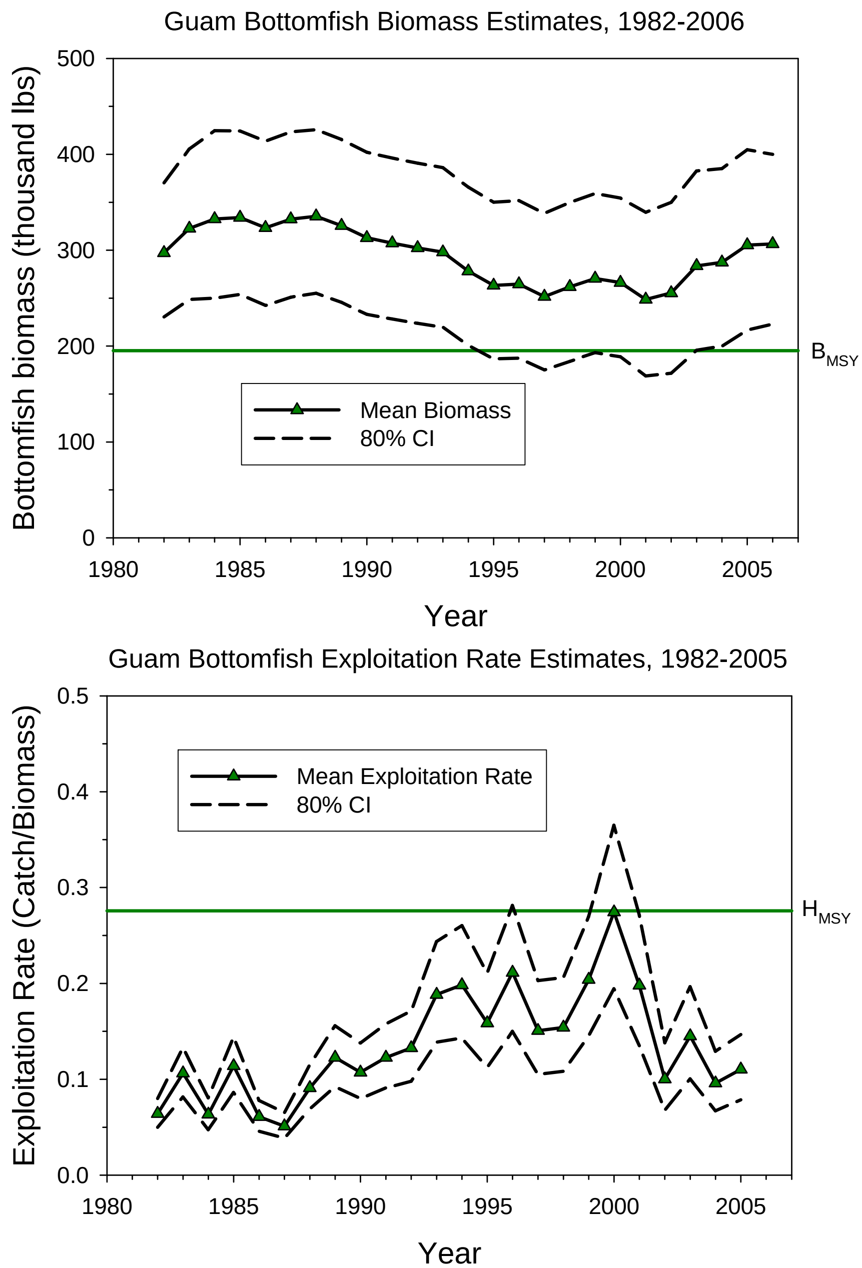
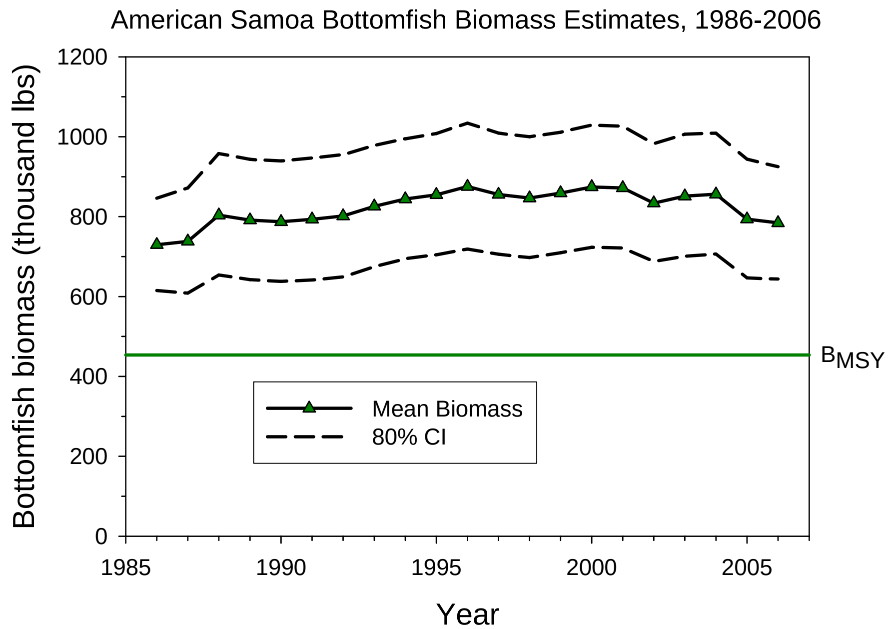


Figure 4.1.--Estimates of annual bottomfish biomass and exploitation rate from the best-fitting production model for Guam, 1982-2005.



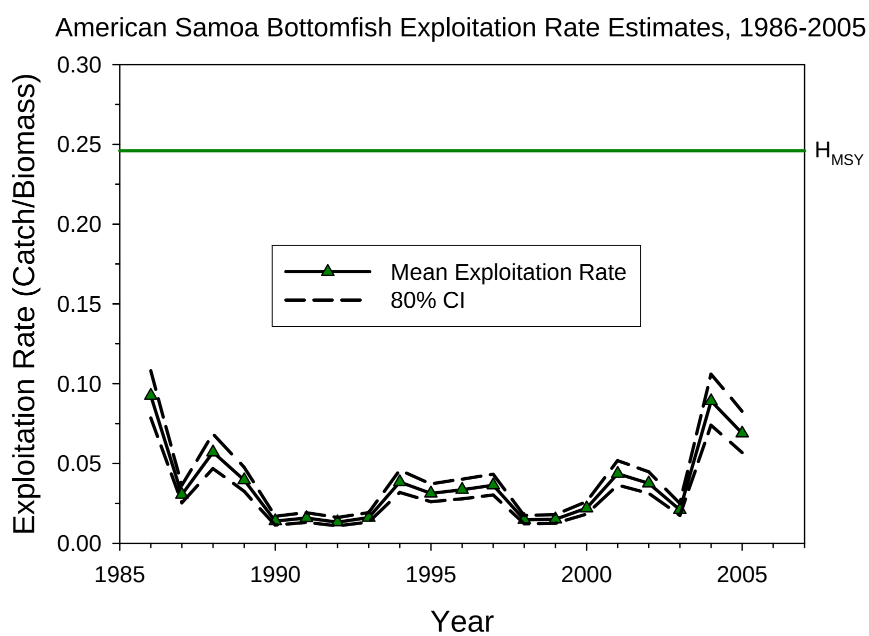
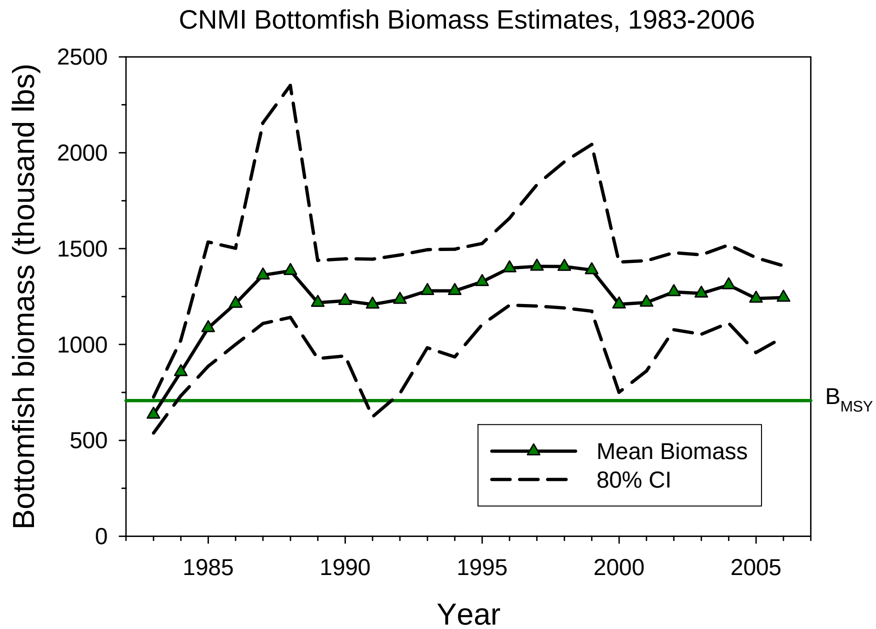


Figure 4.2.--Estimates of annual bottomfish biomass and exploitation rate from the best-fitting production model for American Samoa, 1986-2005.



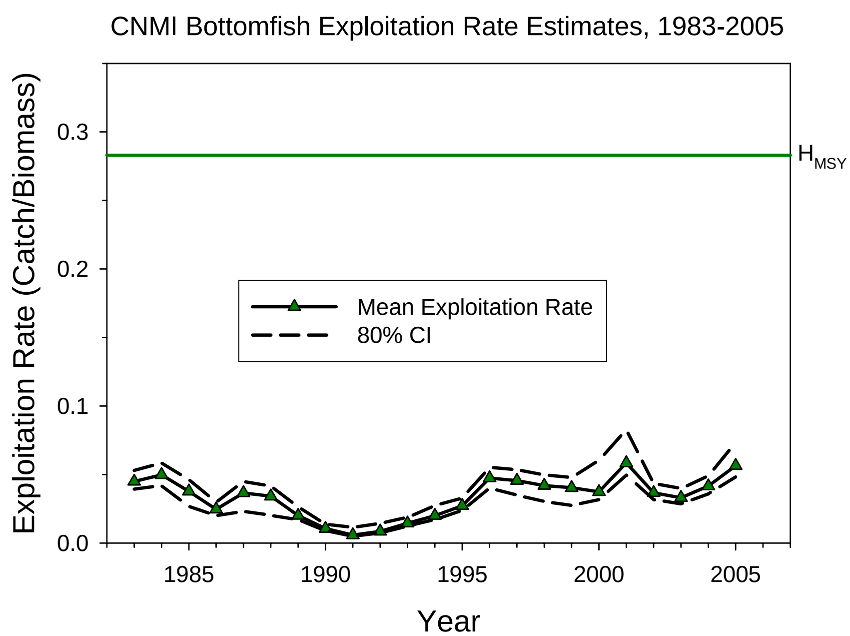


Figure 4.3.--Estimates of annual bottomfish biomass and exploitation rate from the best-fitting production model for the Commonwealth of the Northern Mariana Islands, 1983-2005.

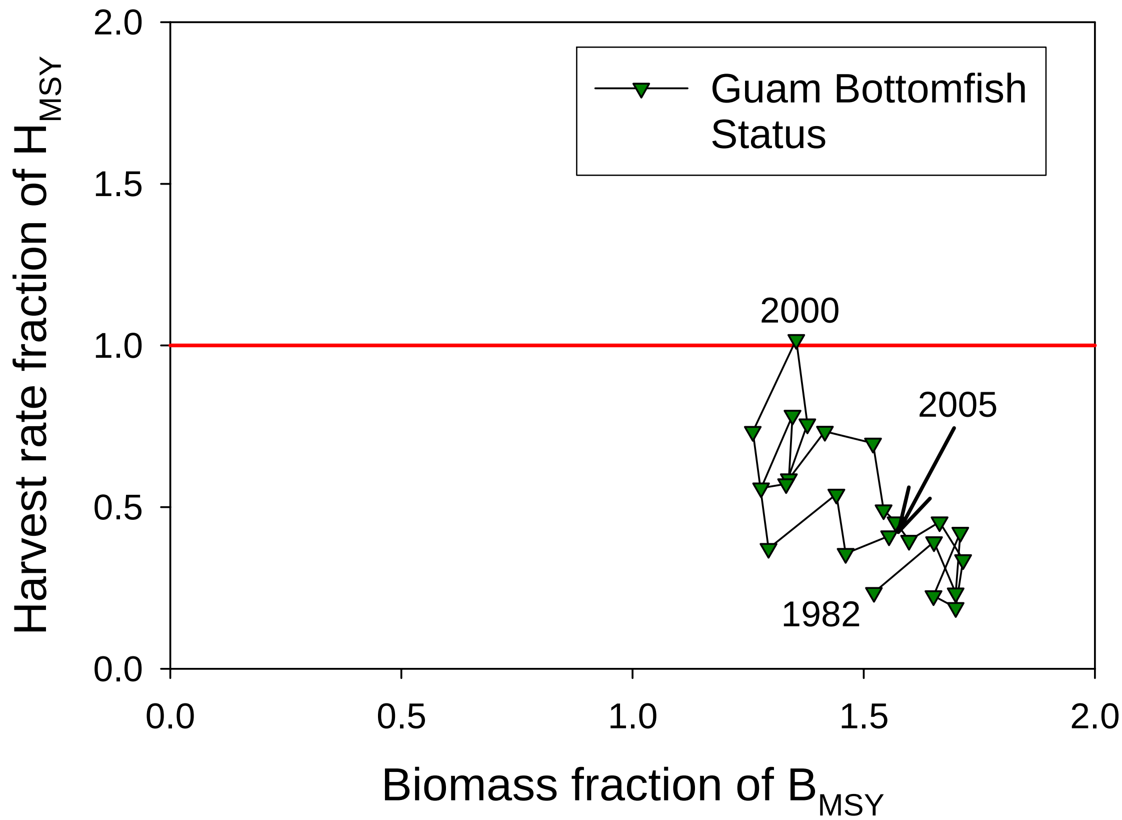


Figure 5.1.--Estimates of relative biomass and relative exploitation rate from the best-fitting production model for Guam, 1982-2005.

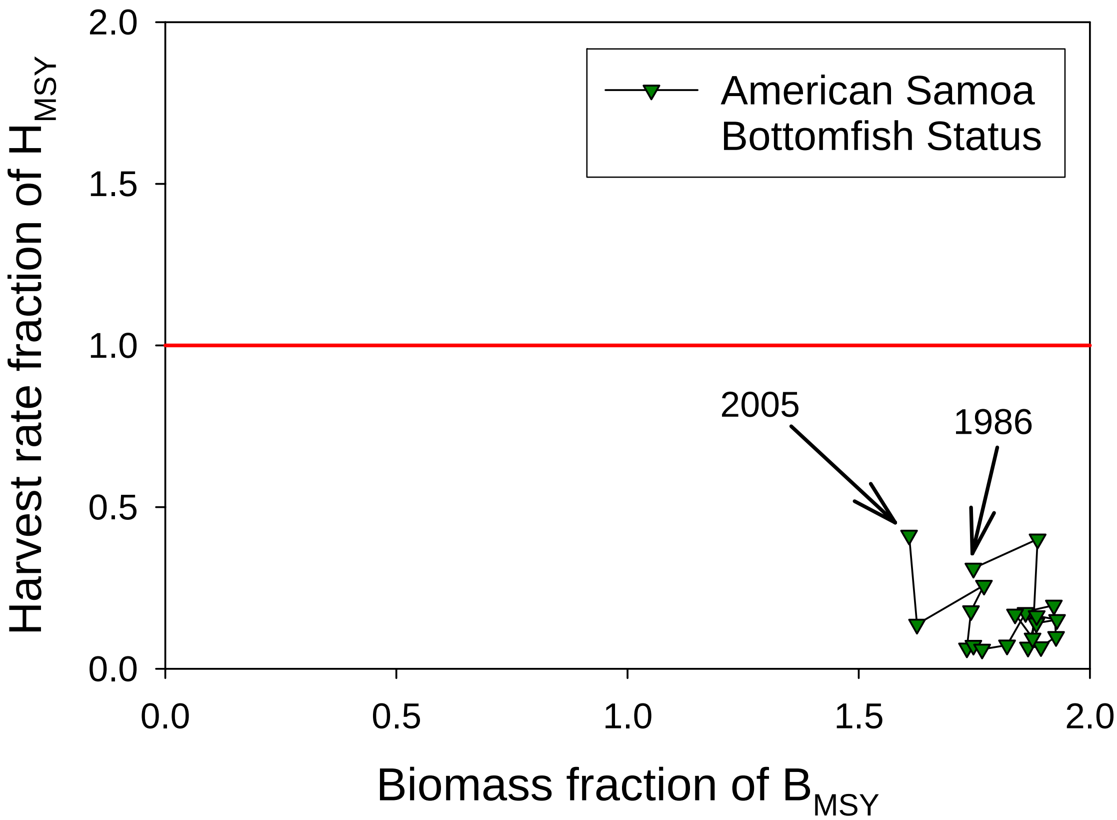


Figure 5.2.--Estimates of relative biomass and relative exploitation rate from the best-fitting production model for American Samoa, 1986-2005.

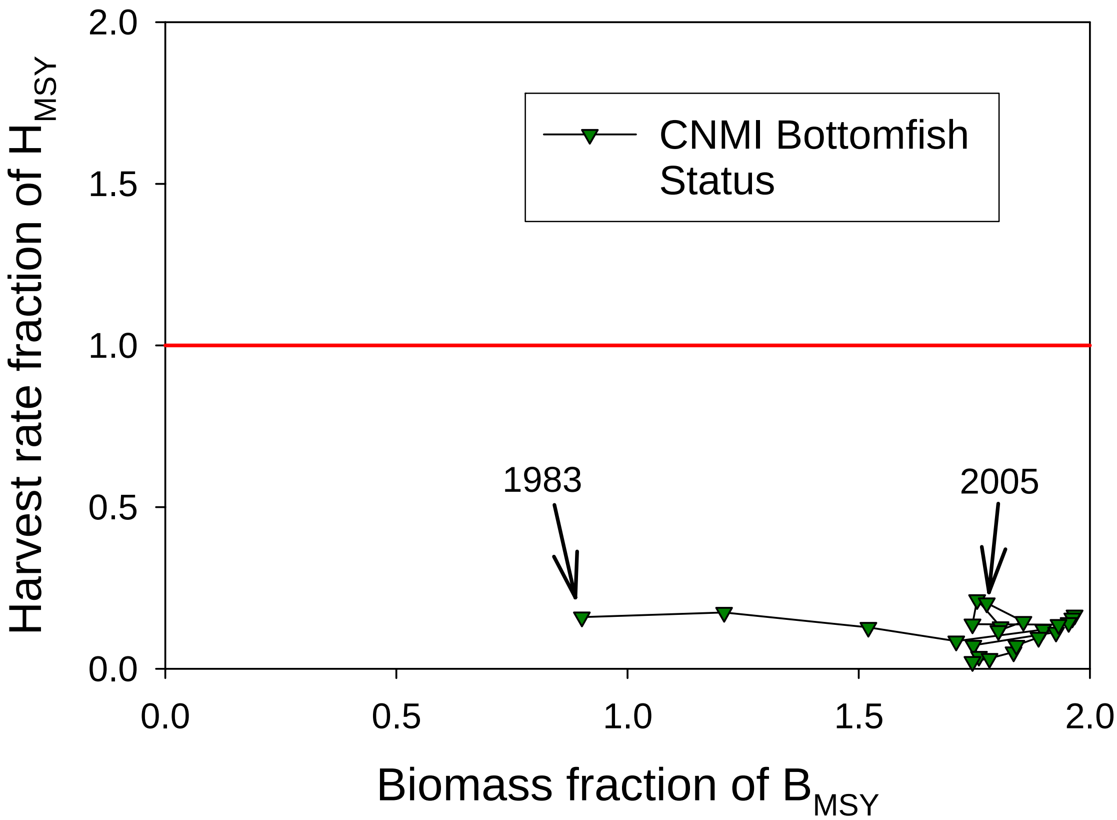


Figure 5.3.--Estimates of relative biomass and relative exploitation rate from the best-fitting production model for the Commonwealth of the Northern Mariana Islands, 1983-2005.

Appendix

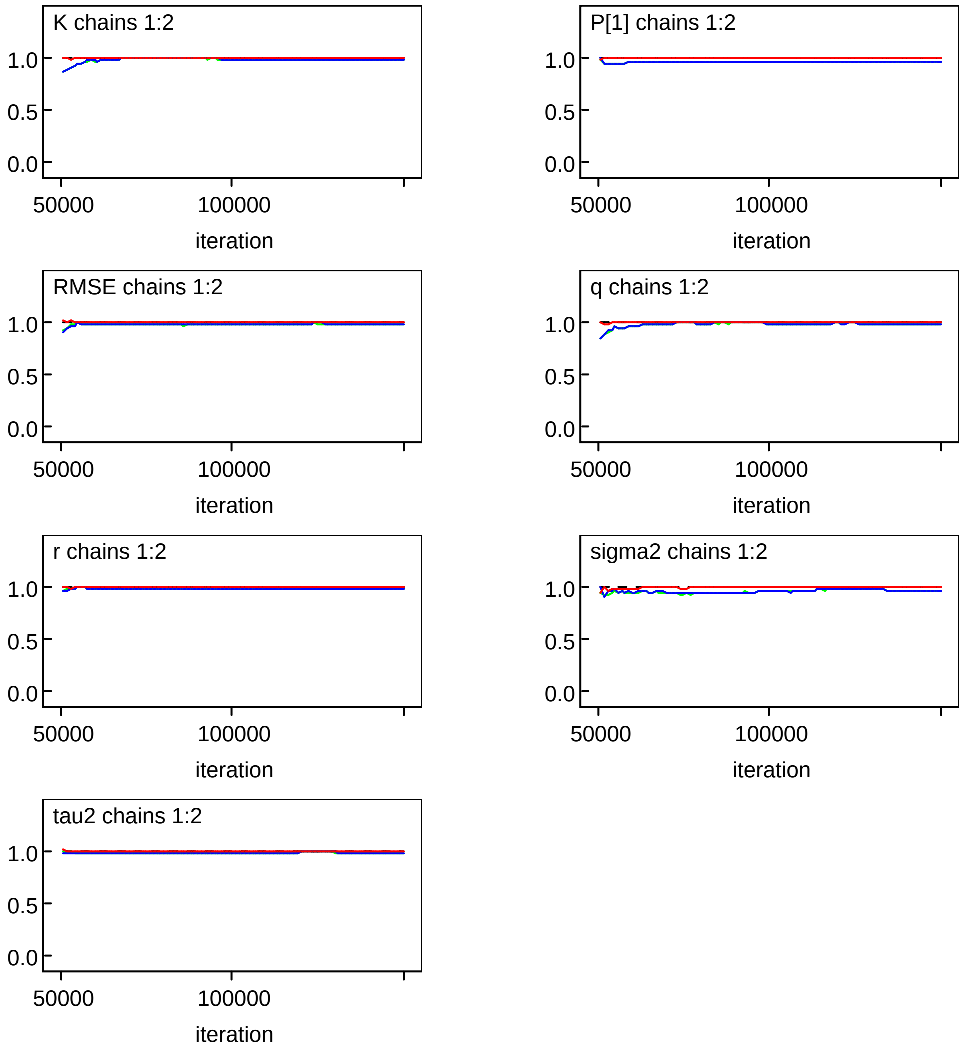


Figure A.1.1.--Plots showing the convergence of the Brooks, Gelman, and Rubin diagnostic for parameters of the best fitting production model for Guam.

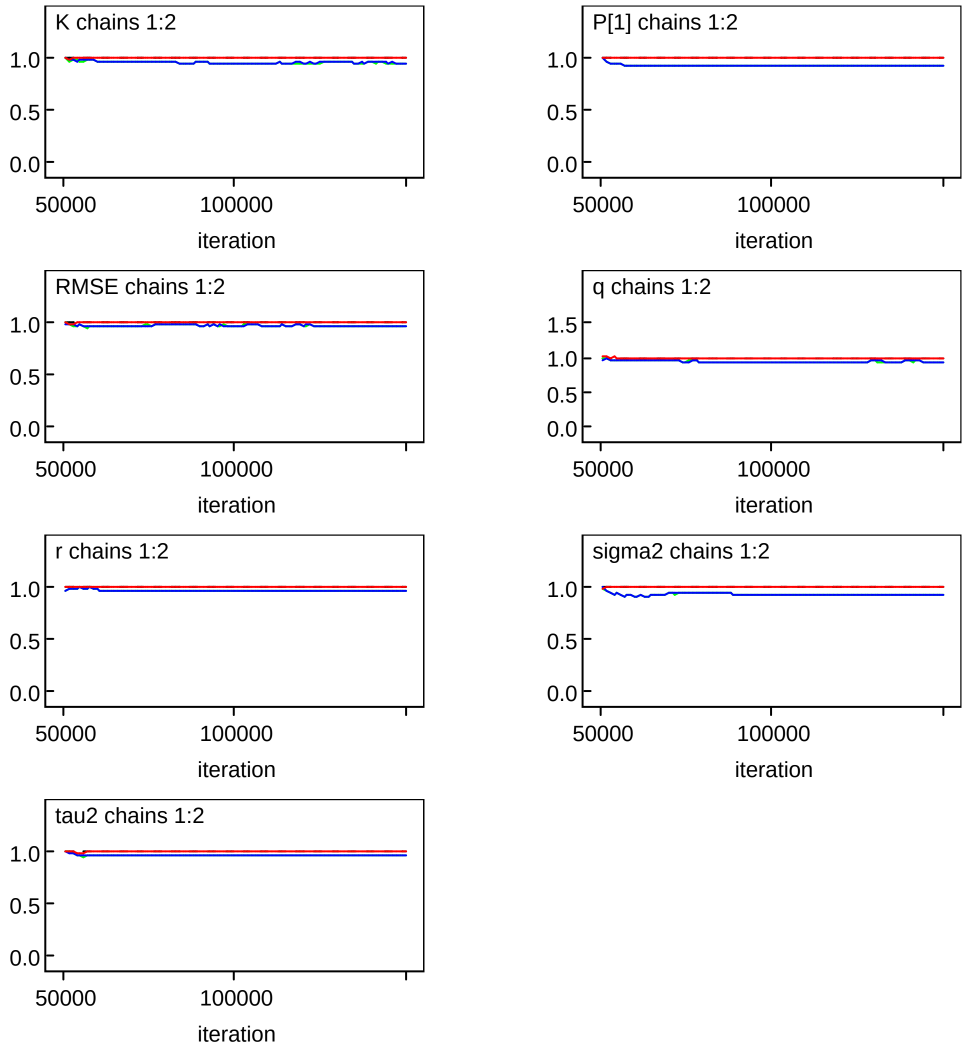


Figure A.1.2.--Plots showing the convergence of the Brooks, Gelman, and Rubin diagnostic for parameters of the best fitting production model for American Samoa.

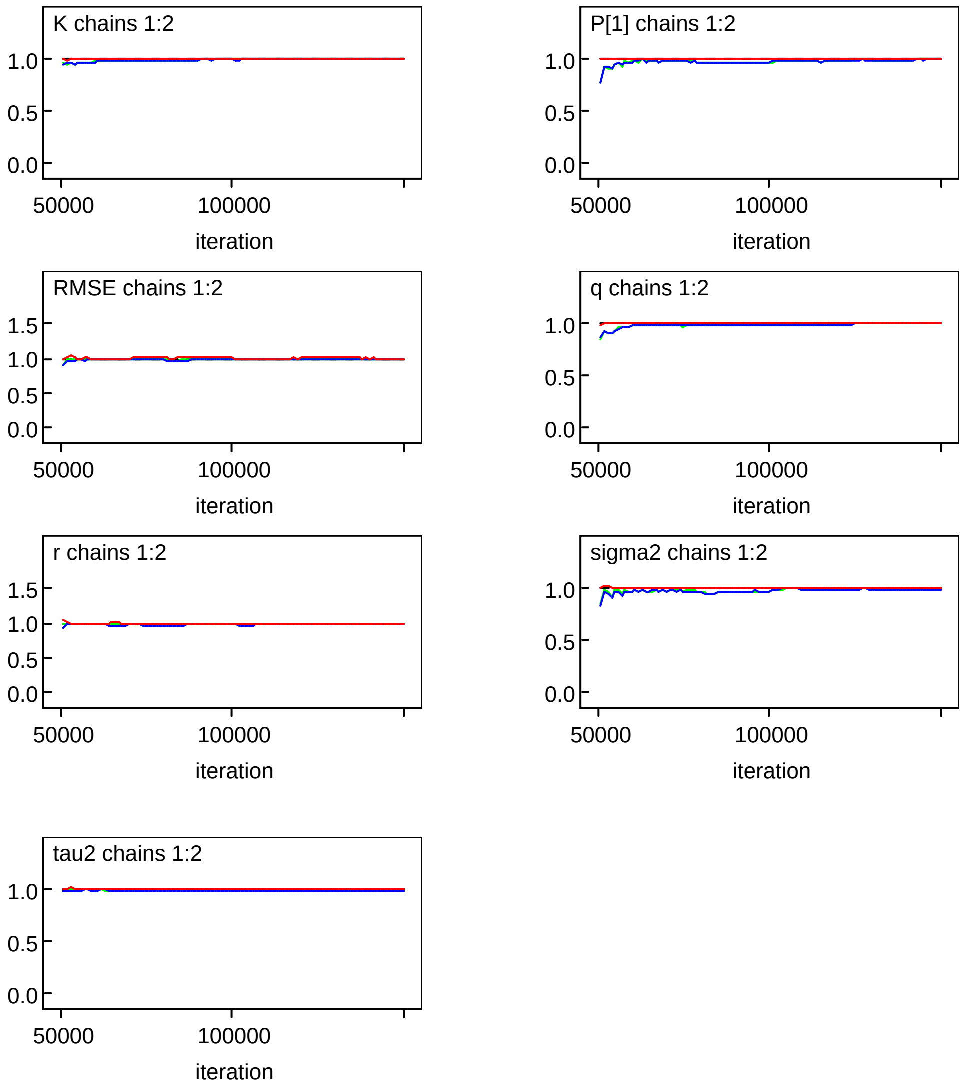


Figure A.1.3.--Plots showing the convergence of the Brooks, Gelman, and Rubin diagnostic for parameters of the best fitting production model for the Commonwealth of the Northern Mariana Islands.

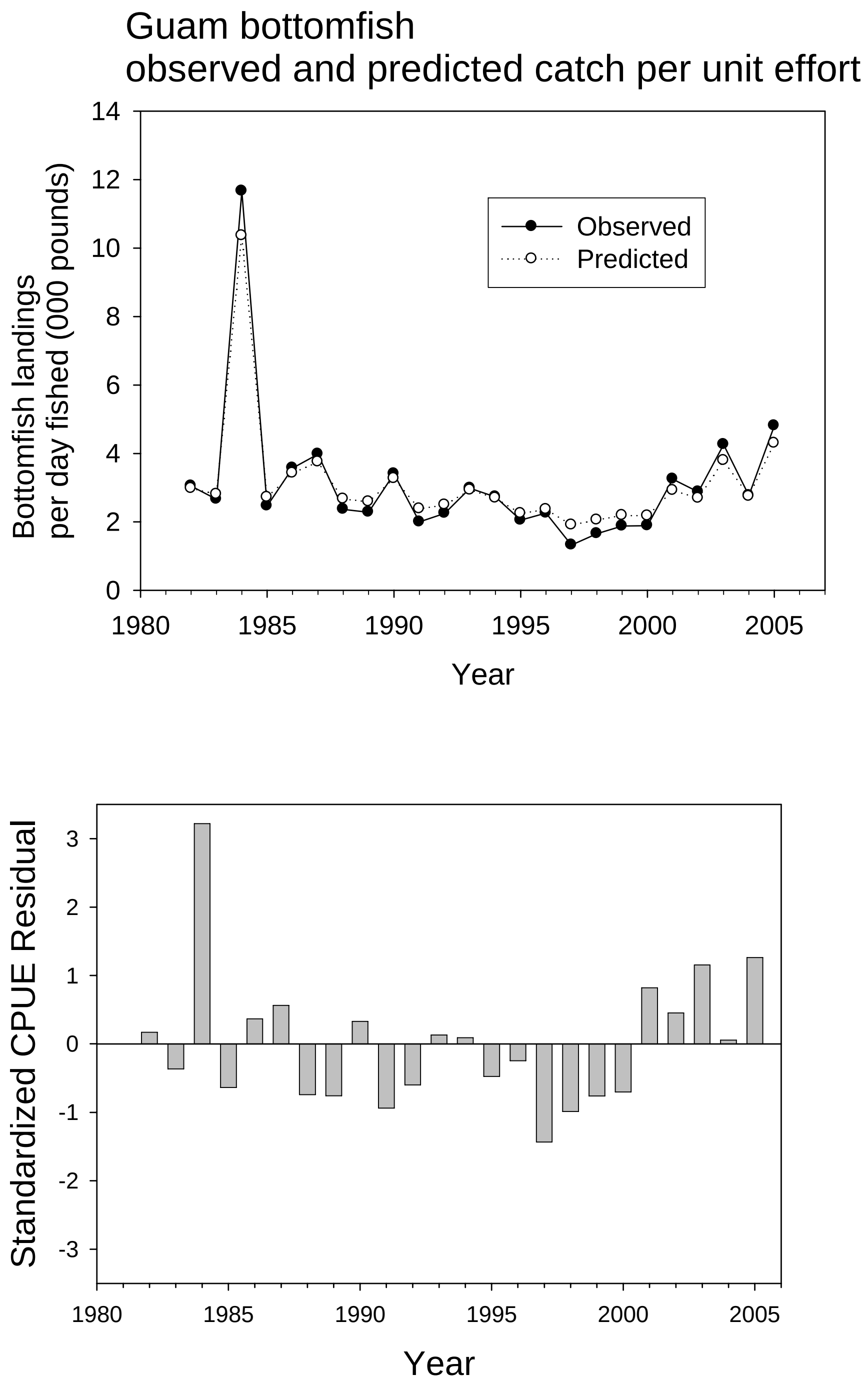
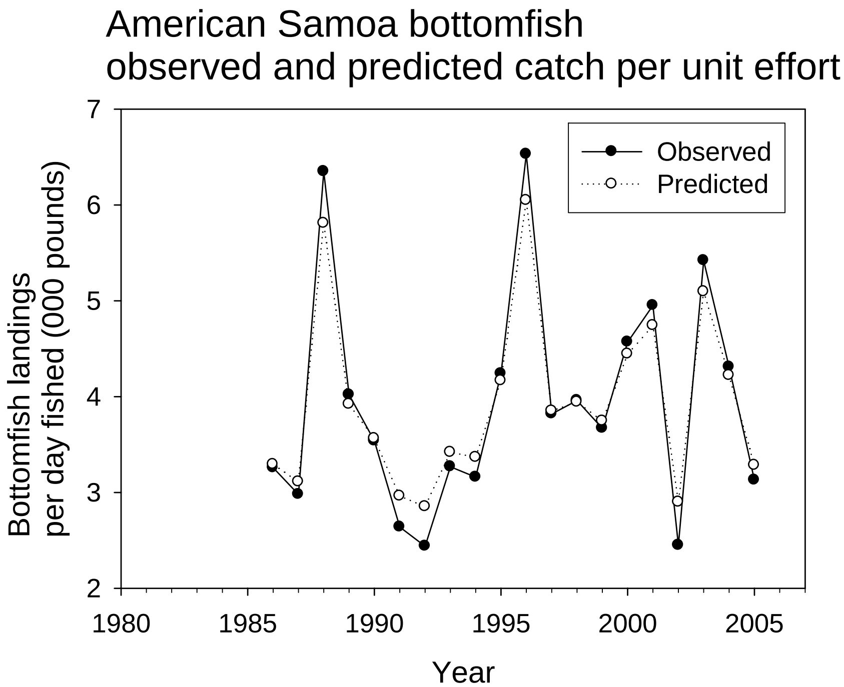


Figure A.2.1.--Observed and predicted CPUE for Guam bottomfish along with standardized residuals of the CPUE fit from the best fitting production model.



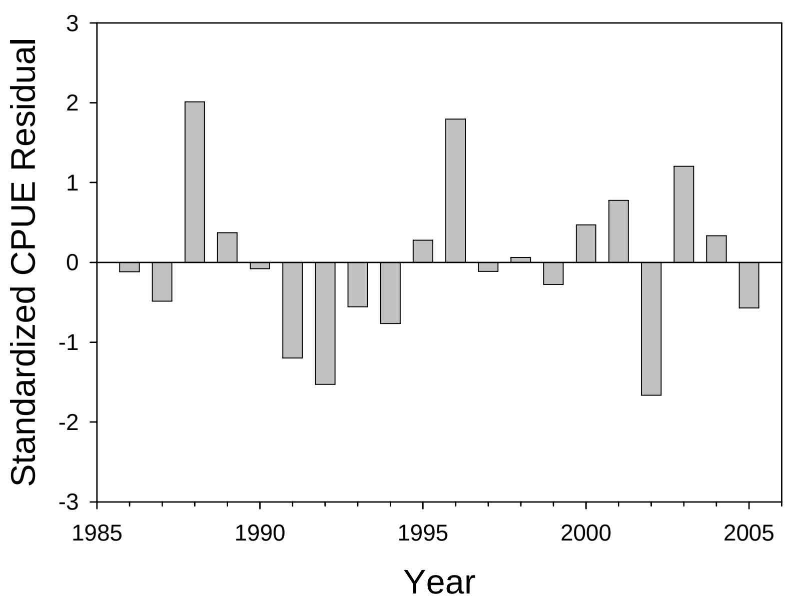


Figure A.2.2.--Observed and predicted CPUE for American Samoa bottomfish along with standardized residuals of the CPUE fit from the best fitting production model.

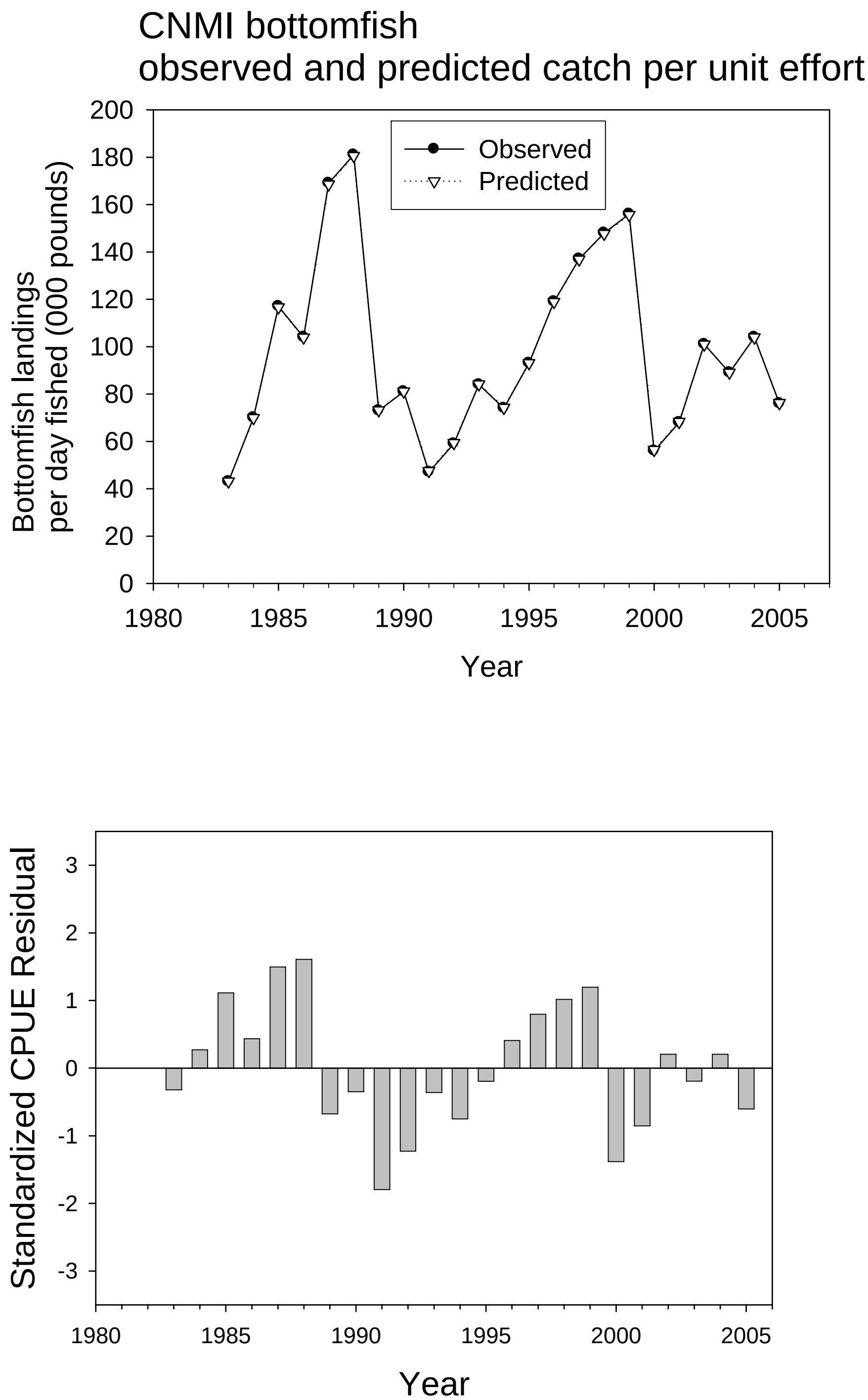


Figure A.2.3.--Observed and predicted CPUE for the Commonwealth of the Northern Mariana Islands bottomfish along with standardized residuals of the CPUE fit from the best fitting production model.