Pacific Islands Fisheries Science Center

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For further information direct inquiries to

Chief, Scientific Information Services
Pacific Islands Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce
2570 Dole Street
Honolulu, Hawaii 96822-2396

Phone: 808-983-5386
Fax: 808-983-2902

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Stock Assessment Update of the Status of the Bottomfish Resources of American Samoa, the Commonwealth of the Northern Mariana Islands, and Guam, 2012

Jon Brodziak,[1] Joseph O'Malley,[2] Benjamin Richards,[1]
and Gerard DiNardo[1]

[1]Pacific Islands Fisheries Science Center
Fisheries Research and Monitoring Division
National Marine Fisheries Service, NOAA
2570 Dole Street, Honolulu, Hawaii 96822-2396

[2]Joint Institute for Marine and Atmospheric Research
University of Hawaii
1000 Pope Road, Marine Science Building 312, Honolulu, Hawaii 96822

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ABSTRACT

In this report, we update the status of bottomfish complexes in Guam, American Samoa, and the Commonwealth of the Northern Mariana Islands using the same production modeling as used in the previous stock assessment. A Bayesian statistical framework is applied to estimate parameters of a production 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 Deviance information criterion. The sensitivity of status determination results to catch data and model assumptions is also evaluated. Stock status determinations based on the base case model with the best fit to the CPUE data appear relatively robust. Overall, the American Samoa, the Commonwealth of the Northern Mariana Islands, and the Guam bottomfish complexes were not depleted and were not experiencing overfishing in 2010, the most recent year of the stock assessment estimates.

Stock projections for 2013 and 2014, which assumed that a hypothetical two-year TAC would be harvested from the American Samoa bottomfish complex, indicated that the TAC to produce a 25% (1 out of 4) chance of overfishing in 2013 was 95,000 pounds and the TAC to produce a 50% (1 out of 2) chance of overfishing was 124,000 pounds. Similarly, stock projections for the Commonwealth of the Northern Mariana Islands bottomfish complex indicated that the TAC to produce a 25% chance of overfishing in 2013 was 219,000 pounds and the TAC to produce a 50% chance of overfishing was 293,000 pounds and projections for the Guam bottomfish complex indicated that the TAC to produce a 25% chance of overfishing in 2013 was 65,000 pounds and the TAC to produce a 50% chance of overfishing was 81,000 pounds. Actual bottomfish landings in 2010 for American Samoa, the Commonwealth of the Northern Mariana Islands, and Guam were 9,509, 22,395, and 28,958 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 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 set of bottomfish management unit species (BMUS) identified within the FMP 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 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 (e.g., lethrinids and Lutjanus spp) are largely lacking compared to American Samoa CNMI, and Guam. 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 not to their shallow and deep components.

In this report, we update the status of bottomfish resources of American Samoa, CNMI, and Guam using a production model as was used in the previous stock assessment (Moffitt et al. 2007). The production model relies 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 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 Deviance information criterion (DIC). The sensitivity of status determinations to catch data and model assumptions is also evaluated. Status determinations resulting from the production model and stock projection results are compared and discussed.

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, 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.

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.

Guam

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 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). From 1982 to 2005, the fishing effort exerted on the shallow component was nearly double that spent on the deep component.

METHODS

Catch and 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. The current statistical expansion of fishery data, however, adjusts for this 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 each territory, catch data from the surveyed subset of fishing trips are expanded to estimate total catch for the territory.

We will estimate B_{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 biomass and harvest rates to MSY-level reference points. 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.

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 (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 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 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. 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 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 700 thousand, 1200 thousand, and 450 thousand pounds for American Samoa, CNMI, and Guam respectively, based on the previous stock assessment (Moffitt et al. 2007). In that assessment, these initial estimates of K were based on two assumptions. First, MSY was approximately 75 thousand, 172 thousand, and 55 thousand pounds for American Samoa, CNMI, and Guam 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 by Moffitt et al. (2006). The coefficient of variation of K was set to 20% for each island group to allow for a range of fitted carrying capacity estimates. Alternative mean values for K were evaluated using a goodness-of-fit criterion to select a best-fitting model for each island group (see Alternative Production Models below).

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 species in the bottomfish complexes. The central tendency of the intrinsic growth rate prior was approximated using the estimate of r≈0.46 from Moffitt et al. (2006). The values of c and d were chosen to produce a mean of $\mu_r = 0.46$ with a coefficient of variation of 50%. 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) 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 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 $p(Q) \propto Q^{-1}$. 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 $p(\tau^2)$ were chosen to be moderately informative inverse-gamma distributions with scale parameter λ>0 and shape parameter *k*>0:

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

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 $\text{MODE}[\sigma^2] = 1/12 \approx 0.083$ 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 $\text{MODE}[\tau^2] = 10/12 \approx 0.83$. The ratio of the modes of the observation error prior to the process error prior was $\text{MODE}[\tau^2]/\text{MODE}[\sigma^2] = 10$ 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. Alternative mean values for the initial ratio of biomass to carrying capacity were evaluated using a goodness-of-fit criterion to select a best-fitting model for each island group (see Alternative Production Models below).

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:

(11)

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

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 applied to set the initial conditions, perform the MCMC calculations, and summarize the MCMC results.

MCMC simulations were conducted in an identical manner for each of the alternative models described below. 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. This burn-in period removed any dependence of the MCMC samples on the initial conditions. Each chain was also thinned by 25 to remove autocorrelation. That is, every twenty-fifth sample was used for inference. As a result, there were 30,000 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 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 2008) and the CODA package (Plummer et al. 2006).

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.

The goodness of fit of the alternative production models to the observed data was evaluated using the Deviance information criterion (Spiegelhalter et al. 2002), a Bayesian analog of the Akaike information criterion. In particular, the production model with the minimum DIC value was judged to provide the best fit to the data with the caveat that DIC differences of less than two units of deviance indicated that there was no substantial difference between model fits and that differences of more than seven units were substantial (e.g., Spiegelhalter et al. 2002).

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)	(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)	(1700, 0.80)

Guam

A total of ten alternative pairs of prior means for (K, P[1]) were evaluated for Guam. These were:

	(300, 0.30)	(500, 0.30)	
	(300, 0.45)	(500, 0.45)	
(200, 0.63)	(300, 0.63)	(500, 0.63)	(600, 0.63)
	(300, 0.75)	(500, 0.75)	

For each island group, the alternative model assumptions bracketed the baseline prior assumptions for K and P[1] and 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 $\varepsilon_{T:}$

(12) $$\varepsilon_T = \ln\left(I_T\right) - \ln\left(QKP_T\right)$$

Non-random patterns in the residuals were an indication that the observed CPUE may not conform to one or more model assumptions

The relative goodness of fit to the observed CPUE and complexity of the alternative models was evaluated using the Deviance information criterion (DIC, Spiegelhalter et al. (2002)) statistic based on the Markov Chain Monte Carlo simulations. The DIC values for the alternative models were calculated as

(13) $$DIC = 2 \cdot \overline{D} - D\left(\hat{\theta}\right) = \overline{D} + p_D$$

where $\overline{D}$ was the posterior mean of the model deviance, $D\left(\hat{\theta}\right)$ was the value of deviance evaluated at the posterior mean of the stochastic variables in the model, and p_D was the effective degrees of freedom in the model. The production model with the minimum DIC value provided the best fit to the CPUE data accounting for model complexity. The difference between the DIC values of the j^{th} ranked model and the best fitting model (ΔDIC_j) was

(14) $$\Delta DIC_j = DIC_j - DIC_{MIN}$$

where DIC_j was the DIC of the j^{th} alternative model and DIC_{MIN} was the minimum DIC values of the best fitting model. As a rough guide, values of ΔDIC_j less than 2 indicate that the two models provide relatively similar fits to the CPUE data while ΔDIC_j values greater than 2 indicate a poorer fit to the CPUE data (Spiegelhalter et al. 2002).

RESULTS

Catch and CPUE Data

Fishery dependent catch data for assessing the bottomfish complexes were tabulated using the most recent and best available data. The processed data for American Samoa, CNMI, and Guam was finalized for use in the stock assessment update on 5-March-2012.

American Samoa

We compared estimates of American Samoa bottomfish catch from the previous 2007 assessment and the 2012 assessment update and found that they were generally similar with the exception of 2004-2005 (Figure 1). The annual bottomfish catch used in the current assessment update averaged roughly 25,000 lbs during 1986-2010 and ranged from 7,913 to 64,587 lbs with a coefficient of variation of about 55% (Table 2, Figure 2). Recent average yield (2008-2010 average) for American Samoa bottomfish was 30,593 lbs, or about 24% above the long-term average yield.

Estimates of American Samoa bottomfish CPUE (lbs/line hr) were calculated using the same approach as used in the 2007 assessment. New CPUE estimates for 2006-2010 were similar in magnitude to those from the previous 2007 assessment (Figure 3). Bottomfish CPUE fluctuated around its long-term average of 3.74 lbs/line hr during 1986-2010 (Table 2, Figure 4) and ranged from 2.44 to 6.53 lbs/line hr with a CV of 30%. Recent average CPUE was 3.16 lbs/line hr and this was about 16% below its long-term average.

Commonwealth of the Northern Mariana Islands

Estimates of CNMI bottomfish catch from the previous 2007 assessment and the 2012 assessment update were compared. We found that they were identical for the period 1983-2005 (Figure 5). The annual bottomfish catch used in the current assessment update averaged roughly 40,000 lbs during 1986-2010 and ranged from 7,092 to 71,256 lbs with a coefficient of variation of about 44% (Table 2, Figure 6). Recent average yield (2008-2010 average) for CNMI bottomfish was 35,214 lbs, or about 12% below the long-term average yield.

The estimates of CNMI bottomfish CPUE (lbs/trip) were calculated in the same manner as in the 2007 assessment. New CPUE estimates for 2006-2010 were similar in magnitude to those from the previous 2007 assessment (Figure 7). Bottomfish CPUE fluctuated around a long-term average of 98 lbs/trip during 1983-2005 (Table 2, Figure 8) and ranged from 43 to 181 lbs/trip with a CV of 40%. CPUE average from 2001 to 2010 was 88 lbs/trip and this was about 10% below its long-term average. CPUE data from 2006 through 2010 differed markedly from the 1983 to 2005 period, due to changes in the reporting method and sampling frame to collect the CPUE data. As a result this data was not included in the assessment model and projected CPUE estimates for this period were used instead.

Guam

We compared estimates of Guam bottomfish catch from the previous 2007 assessment and the 2012 assessment update. The estimates were generally similar with the exception of 1985 and 1987-1992 (Figure 9). The annual bottomfish catch used in the current assessment update averaged roughly 41,000 lbs during 1982-2010 and ranged from 19,322 to 66,666 lbs with a coefficient of variation of about 29% (Table 2, Figure 10). Recent average yield (2008-2010 average) for Guam bottomfish was 35,499 lbs, or about 13% below the long-term average yield.

Estimates of Guam bottomfish CPUE (lbs/line hr) were also calculated using the same approach as used in the 2007 assessment. New CPUE estimates for 2006-2010 were similar in magnitude to those from the previous 2007 assessment (Figure 11). Bottomfish CPUE fluctuated around its long-term average of 3.08 lbs/line hr during 1982-2010 (Table 2, Figure 12) and ranged from 1.32 to 11.66 lbs/line hr with a CV of 60%. Recent average CPUE was 2.92 lbs/line hr and this was about 5% below its long-term average.

Production Model Analyses

Bottomfish landings, CPUE, and fishing effort for American Samoa, the Commonwealth of the Northern Mariana Islands, and Guam were analyzed using a state-space formulation of the Schaefer production model. Alternative production models for each island group were ranked by their goodness of fit to the CPUE data as measured by DIC.

Model Selection

American Samoa

Model selection was conducted using the MCMC estimates of DIC for the alternative prior means for carrying capacity and the initial proportion of carrying capacity during 1986 in American Samoa (Table 3). The estimation results indicated that the effective degrees of freedom was between 9 and 10 parameters for each of the alternative production models. Results indicated that the minimum value of DIC equal to 104.759 was achieved for the model with the prior mean for carrying capacity equal to K = 700 thousand pounds and the prior mean for initial proportion of carrying capacity equal to P[1] = 0.80 (Tables 3 and 4). This result was similar to the 2007 assessment in which the model with prior means of K = 900 thousand pounds and P[1] = 0.80 provided the best fit based on a root mean-square error criterion. As a result, the production model with prior means for K = 700 thousand pounds and P[1] = 0.80 was selected as the base case model for the American Samoa assessment.

There were thirteen other models with alternative prior means for K and P[1] that provided similar fits to the CPUE data and that had DIC difference values of $\Delta DIC < 2$ (Table 4). Together, these fourteen models formed a set of credible models that bounded the uncertainty in model parameters and stock status. While there were some differences in mean estimates of K and P[1] over the set of credible models, the stock status indicators from the set of credible models were robust. In particular, under the base case model scenario, the stock status indicator of the ratio of mean exploitable biomass in 2010 to mean B_{MSY} was $B_{2010}/B_{MSY} = 1.59$ (Table 5), while this ratio varied from 1.51 to 1.60 over the set of credible models. Similarly, under the base case model scenario, the ratio of mean harvest rate in 2010 to mean H_{MSY} was $H_{2010}/H_{MSY} = 0.08$, while this ratio ranged from 0.08 to 0.10 over the set of credible models. Overall, the stock status results were robust to uncertainty about the prior assumptions about the expected value of carrying capacity and initial stock size in 1986 as a fraction of carrying capacity.

Commonwealth of the Northern Mariana Islands

Model selection was based on estimates of DIC for the alternative prior means for carrying capacity and the initial proportion of carrying capacity during 1983 in CNMI (Table 6). The estimation results indicated that the effective degrees of freedom was between 8.7 and 9.5 parameters for each of the alternative production models. Results indicated that the minimum value of DIC equal to 254.558 was achieved for the model with the prior mean for carrying capacity equal to K = 1400 thousand pounds and the prior mean for initial proportion of carrying capacity equal to P[1] = 0.45 (Tables 6 and 7). This result was similar to the 2007 assessment in which the model with prior means of K = 1400 thousand pounds and P[1] = 0.45 provided the best fit based on a root mean-square error criterion. As a result, the production model with prior means for K = 1400 thousand pounds and P[1] = 0.45 was selected as the base case model for the CNMI assessment.

There were five alternative models with prior means for K and P[1] that provided similar fits to the CPUE data and that had DIC difference values of $\Delta DIC < 2$ (Table 7). Together, these six models formed a set of credible models that bounded the uncertainty in model parameters and stock status. While there were some differences in mean estimates of K and P[1] over the set of credible models, the stock status indicators from the set of credible models were robust. In particular, under the base case model scenario, the stock status indicator of the ratio of mean exploitable biomass in 2010 to mean B_{MSY} was $B_{2010}/B_{MSY} = 1.78$ (Table 8), while this ratio varied from 1.77 to 1.81 over the set of credible models. Similarly, under the base case model scenario, the ratio of mean harvest rate in 2010 to mean H_{MSY} was $H_{2010}/H_{MSY} = 0.74$, while this ratio ranged from 0.09 to 1.17 over the set of credible models. Overall, the stock status results were robust to uncertainty about the prior assumptions about the expected value of carrying capacity and initial stock size in 1983 as a fraction of carrying capacity.

Guam

Model selection using the estimates of DIC for the alternative prior means for carrying capacity and the initial proportion of carrying capacity during 1982 in Guam (Table 9). The estimation results indicated that the effective degrees of freedom was between 9 and 11 parameters for each of the alternative production models. Results indicated that the minimum value of DIC equal to 111.396 was achieved for the model with the prior mean for carrying capacity equal to K = 300 thousand pounds and the prior mean for initial proportion of carrying capacity equal to P[1] = 0.75 (Tables 9 and 10). This result was identical to the 2007 assessment in which the model with prior means of K = 300 thousand pounds and P[1] = 0.75 provided the best fit based on a root mean-square error criterion. As a result, the production model with prior means for K = 300 thousand pounds and P[1] = 0.75 was selected as the base case model for the current Guam assessment.

Six alternative production models with prior means for K and P[1] provided similar fits to the CPUE data and that had DIC difference values of $\Delta DIC < 2$ (Table 10). Together, these seven models formed a set of credible models that bounded the uncertainty in model parameters and stock status. While there were some differences in mean estimates of K and P[1] over the set of credible models, the stock status indicators from the set of credible models were robust. In particular, under the base case model scenario, the stock status indicator of the ratio of mean exploitable biomass in 2010 to mean B_{MSY} was $B_{2010}/B_{MSY} = 1.59$ (Table 11), while this ratio varied from 1.52 to 1.64 over the set of credible models. Similarly, under the base case model scenario, the ratio of mean harvest rate in 2010 to mean H_{MSY} was $H_{2010}/H_{MSY} = 0.35$, while this ratio ranged from 0.33 to 0.40 over the set of credible models. Overall, the stock status results were robust to uncertainty about the prior assumptions about the expected value of carrying capacity and initial stock size in 1982 as a fraction of carrying capacity.

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: BMSY, HMSY, MSY, K, r, P[1], q, sigma2, and tau2. 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, with the exception of one test for the observation error variance tau2. 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.

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: BMSY, HMSY, MSY, K, r, P[1], q, sigma2, and tau2. 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 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.

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: BMSY, HMSY, MSY, K, r, P[1], q, sigma2, and tau2. 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, with the exception of one test for the catchability coefficient q and one test for the carrying capacity in the initial year P[1]. 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 (Figure 13). 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 (Figure 14). 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 (Figure 15). 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 (Figure 16). 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 (Figure 17). 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 (Figure 18). 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

American Samoa

Carrying capacity estimates from the set of credible models indicated that K ranged from 423 to 927 thousand pounds (Table 5). The posterior means for intrinsic growth rate suggested that estimates of r ranged from 0.35 to 0.67. Estimates of the initial ratio of biomass to carrying capacity in 1986 were between 0.67 and 0.82 over the set of credible models. The posterior means (±1 standard deviation) of K, r, and P[1] from the base case model were: K = 670.7 ± 132.3, r = 0.47 ± 0.12, and P[1] = 0.82 ± 0.14. Posterior mean estimates of biological reference points from the base case model were: BMSY = 335.4 ± 66.1, HMSY = 0.24 ± 0.06, and MSY = 76.2 ± 14.3. The posterior mean of MSY was 1.6 thousand pounds was higher than the input OLO estimate of MSY = 75.0 thousand pounds. Estimates of American Samoa bottomfish exploitable biomass have fluctuated around 600 thousand pounds since 1986 (Table 12, Figure 19). Biomass increased moderately in the 1990s and has declined slightly since then. Estimates of exploitation rate have fluctuated around 5% since the late-1980s, increased to about 10% in 2009, and declined to about 2% in 2010 (Table 12, Figure 20).

Estimates of relative biomass indicate that the biomass of the American Samoa bottomfish complex has been above BMSY during 1986-2010 (Table 12, Figure 21). Similarly, estimates of relative exploitation rate indicate that the annual harvest rate has been below HMSY since 1986 (Figure 22). Lower bounds of the 80% confidence intervals for relative biomass show that the annual probability of biomass being at or above BMSY was 90% or greater throughout the time period (Figure 21). Similarly, upper bounds of the 80% confidence intervals for relative exploitation rate indicate that the annual probability of harvest rate being at or below HMSY was 90% or greater (Figure 22).

The biomass status of the American Samoa bottomfish complex in 2010 was healthy, with a probability of p>0.99 that biomass was above BMSY based on the best-fitting model (Table 12, Figure 23). Similarly, the probability that the harvest rate in 2010 exceeded the overfishing threshold was p<0.01 (Table 12, Figure 24). Overall, the production model results suggest that the American Samoa bottomfish complex was not overfished and did not experience overfishing during 1986-2010 (Figure 25).

Commonwealth of the Northern Mariana Islands

Carrying capacity estimates from the set of credible models indicated that K ranged from 1040 to 1632 thousand pounds (Table 8). The posterior means for intrinsic growth rate suggested that estimates of r ranged from 0.45 to 0.64. Estimates of the initial ratio of biomass to carrying capacity in 1983 were between 0.45 and 0.61 over the set of credible models. The posterior means (±1 standard deviation) of K, r, and P[1] from the base case model were: K = 1367 ± 256.4, r = 0.52 ± 0.13, and P[1] = 0.46 ± 0.08. Posterior mean estimates of biological reference points from the base case model were: BMSY = 683.6 ± 128.2, HMSY = 0.26 ± 0.06, and MSY = 172.9 ± 32.2. The posterior mean of MSY was 0.9 thousand pounds higher than the input OLO estimate of MSY = 172 thousand pounds. Estimates of CNMI bottomfish exploitable biomass have fluctuated around 1200 thousand pounds since 1983 (Table 13, Figure 26). Biomass increased moderately from 1983 to 1988 and then declined through 1991. Biomass increased again from 1991 to 1999 and then fluctuated through 2010. Estimates of exploitation rate have fluctuated around 4% since 1983 (Table 13, Figure 27).

Estimates of relative biomass indicate that the biomass of the CNMI bottomfish complex was slightly below BMSY in 1983 and has likely been above BMSY during 1984-2010 (Table 13, Figure 28). Similarly, estimates of relative exploitation rate indicate that the annual harvest rate has been well below HMSY since 1983 (Figure 29). Lower bounds of the 80% confidence intervals for relative biomass show that, while there is some overlap, estimates of exploitable biomass remained well above BMSY throughout the period 1986 to 2010 (Figure 28).

The biomass status of the CNMI bottomfish complex in 2010 was healthy, with a 97% probability that biomass was above BMSY based on the best-fitting model (Table 13, Figure 30). Similarly, there was a less than 1% probability that the harvest rate in 2010 exceeded the overfishing threshold (Table 13, Figure 31). Overall, the production model results suggest that the CNMI bottomfish complex has was not overfished and did not experience overfishing during 1983-2010 (Figure 32).

Guam

Carrying capacity estimates from the set of credible models indicated that K ranged from 248 to 568 thousand pounds (Table 11). The posterior means for intrinsic growth rate suggested that estimates of r ranged from 0.43 to 0.83. Estimates of the initial ratio of biomass to carrying capacity in 1982 were between 0.52 and 0.78 over the set of credible models. The posterior means (±1 standard deviation) of K, r, and P[1] from the base case model were: K = 324.5 ± 48.06, r = 0.70 ± 0.12, and P[1] = 0.77 ± 0.14. Posterior mean estimates of biological reference points from the base case model were: BMSY = 162.2 ± 24.03, HMSY = 0.35 ± 0.06, and MSY = 55.9 ± 7.9. The posterior mean of MSY was 900 pounds greater than the input OLO estimate of MSY = 55.0 thousand pounds.

Estimates of Guam bottomfish exploitable biomass have fluctuated around 238 thousand pounds since 1982 (Table 14, Figure 33). Biomass decreased moderately from a high in 1984 to a low in 1997 and has risen slightly and leveled off since then. Estimates of exploitation rate increased from a low of about 6% throughout the late 1980s and 1990s until they reached a peak of about 34% in 2000 (Figure 34). After 2000, exploitation rates suddenly decreased and have fluctuated about 15% through 2010 (Table 14, Figure 34).

Estimates of relative biomass indicate that the biomass of the Guam bottomfish complex has likely been above BMSY during 1982-2010, except for 1997 when the relative biomass was 0.97 (Table 14, Figure 35). Estimates of relative exploitation rate indicate that the annual harvest rate has been below HMSY for all years since 1982, except for 2000 when it was at HMSY (Figure 36). Lower bounds of the 80% confidence intervals for relative biomass show that the annual probability of biomass being at or above BMSY was below 90% from 1988 through 2002 and in 2007 through 2009 (Figure 35). However, the upper bounds of the 80% confidence intervals for relative exploitation rate indicate that the annual probability of harvest rate being at or below HMSY was below 90% in 1989, 1992-1994, 1996, and 1999-2001 (Figure 36).

The biomass status of the Guam bottomfish complex in 2010 was healthy; with a probability of 0.99 that biomass was above BMSY based on the best-fitting model (Table 14, Figure 37). Similarly, the probability that the harvest rate in 2010 exceeded the overfishing threshold was 0.01 (Table 14, Figure 38). Overall, the production model results suggest that the Guam bottomfish complex was not overfished and did not experience overfishing, with the possible exception of 2000, during 1982-2010 (Figure 39).

Base Case Model Projection Results

American Samoa

Under the constant 2-year TAC projection scenarios we evaluated, projected probabilities of overfishing, relative biomasses, and probabilities of depletion of American Samoa bottomfish (Table 15, Figures 40 to 45) showed the distribution of outcomes that would likely occur if constant TACs were applied during 2013-2014. Results of the stochastic projections indicated that the TAC in 2013 that would produce a low risk of 25% chance of overfishing in 2013 (i.e., exceeding HMSY) was 95 thousand pounds, or about 47% higher than the largest estimated catch during 1986-2010 (Table 15). For comparison, the smallest TAC that would lead to a high risk of a 50% chance of overfishing was 124 thousand pounds. Total allowable commercial catches of American Samoa bottomfish in 2012 ranging from 60 to 124 thousand pounds corresponded to risks of overfishing ranging from 5% to 50%. Applying the TAC to achieve a low risk of overfishing in 2014 would lead to a 33% risk of over fishing in 2014 and a 2% chance of stock depletion (Table 15, Figures 42 and 44). Similarly, applying the TAC to achieve a high risk of overfishing in 2014 would lead to a 72% risk of over fishing in 2014 and a 4% chance of stock depletion (Table 15, Figures 42 and 44). Last, if the two-year TAC was set to equal the recent average yield during 2008-2010 of about 30 thousand pounds, then there would be a negligible chance of overfishing or stock depletion (Table 15, Figures 40, 42, and 44).

Commonwealth of the Northern Mariana Islands

Under the constant 2-year TAC projection scenarios evaluated, projected probabilities of overfishing, relative biomasses, and probabilities of depletion of CNMI bottomfish (Table 16, Figures 46 to 51) showed the distribution of outcomes that would likely occur if constant TACs were applied during 2013-2014. Results of the stochastic projections indicated that a 2013 TAC of 219 thousand pounds would produce a low risk (25% chance) of overfishing (Table 16). This estimate is 330% higher than the largest estimated catch of 66.4 thousand pounds during the period 1983-2010 (Table 16). For comparison, the smallest TAC that would lead to a high risk of a 50% chance of overfishing was 293 thousand pounds. Total allowable commercial catches of CNMI bottomfish in 2013 ranging from 130 to 293 thousand pounds corresponded to risks of overfishing ranging from 5% to 50%. Applying the TAC of 219 thousand pounds to achieve a low risk (25%) of overfishing in 2013 would lead to a 34% risk of overfishing in 2014 and a 4% chance of stock depletion (Table 16, Figures 48 and 50). Similarly, applying the TAC of 293 thousand pounds to achieve a high risk (50%) of overfishing in 2013 would lead to a 78% risk of overfishing in 2014 and a 6% chance of stock depletion (Table 16, Figures 48 and 50). Last, if the two-year TAC was set to equal the recent average yield during 2008-2010 of about 26 thousand pounds, then there would be a negligible chance of overfishing or stock depletion (Table 16, Figures 46, 48, and 50).

Guam

Under the constant 2-year TAC projection scenarios evaluated, projected probabilities of overfishing, relative biomasses, and probabilities of depletion of Guam bottomfish (Table 17, Figures 52 to 57) showed the distribution of outcomes that would likely occur if constant TACs were applied during 2013-2014. Results of the stochastic projections indicated that the TAC in 2013 that would produce a low risk of 25% chance of overfishing in 2013 (i.e., exceeding HMSY) was 65 thousand pounds, or about 2% less than the largest estimated catch during 1982-2010 (Table 17). For comparison, the smallest TAC that would lead to a high risk of a 50% chance of overfishing was 81 thousand pounds. Total allowable commercial catches of Guam bottomfish in 2013 ranging from 44 to 81 thousand pounds corresponded to risks of overfishing ranging from 5% to 50%. Applying the TAC to achieve a low risk of overfishing in 2013 would lead to a 35% risk of over fishing in 2014 and a 4% chance of stock depletion (Table 17, Figures 54 and 56). Similarly, applying the TAC to achieve a high risk of overfishing in 2013 would lead to a 77% risk of over fishing in 2014 and a 6% chance of stock depletion (Table 17, Figures 54 and 56). Last, if the two-year TAC was set to equal the recent average yield during 2008-

2010 of about 35 thousand pounds, then there would be a 2% chance of overfishing or stock depletion (Table 17).

Catch Sensitivity Analysis Results

American Samoa

The scenario that doubled the estimated catch of American Samoa bottomfish during 1986-2010 indicated that the projected TAC in 2013 to produce a specified probability of overfishing would decrease in comparison to the base case run. Results of stochastic projections under the catch doubling scenario indicated that the TAC in 2013 that would produce a low risk of 25% chance of overfishing in 2013 was about 77 thousand pounds, (Figure 58), or about 19% below the low risk TAC for the base case model. In comparison, the TAC that would lead to a high risk of a 50% chance of overfishing under the catch doubling scenario was 104 thousand pounds, or about 16% below the base case amount. Total allowable commercial catches of American Samoa bottomfish in 2013 ranging from 21 to 104 thousand pounds corresponded to risks of overfishing ranging from 5% to 50%. Applying the TAC to achieve a low risk of overfishing in 2014 would lead to a 26% risk of overfishing in 2014 and a 6% chance of stock depletion (Figures 59 and 60). Similarly, applying the TAC to achieve a high risk of overfishing in 2014 would lead to a 59% risk of over fishing in 2014 and an 8% chance of stock depletion (Figures 59 and 60). Further, if the two-year TAC was set to equal the recent average yield during 2008-2010 of about 30 thousand pounds, then there would be a less than 1% chance of overfishing in 2013 under the catch doubling scenario.

Similarly, the scenario that quadrupled the estimated catch of American Samoa bottomfish during 1986-2010 also indicated that the projected TAC in 2013 to produce a specified probability of overfishing would decrease in comparison to the base case model. Results of stochastic projections under the catch quadrupling scenario indicated that the TAC in 2013 that would produce a low risk of 25% chance of overfishing in 2013 was about 53 thousand pounds, (Figure 61), or about 44% below the low risk TAC for the base case model. The TAC that would lead to a high risk of a 50% chance of overfishing under the catch quadrupling scenario was 75 thousand pounds, or about 40% below the base case amount. Total allowable commercial catches of American Samoa bottomfish in 2013 ranging from 28 to 75 thousand pounds corresponded to risks of overfishing ranging from 5% to 50%. Applying the TAC to achieve a low risk of overfishing in 2014 would lead to a 22% risk of overfishing in 2014 and a 26% chance of stock depletion (Figures 62 and 63). In comparison, applying the TAC to achieve a high risk of overfishing in 2014 would lead to a 47% risk of over fishing in 2014 and a 31% chance of stock depletion (Figures 62 and 63). Further, if the two-year TAC was set to equal the recent average yield during 2008-2010 of about 30 thousand pounds, then there would be a 6% chance of overfishing in 2013 under the catch doubling scenario.

Commonwealth of the Northern Mariana Islands

The scenario that doubled the estimated catch of CNMI bottomfish during 1983-2010 indicated that the projected TAC in 2013 to produce a specified probability of overfishing would decrease in comparison to the base case run. Results of stochastic projections under the catch doubling scenario indicated that a 2013 TAC of 192 thousand pounds would produce a low risk (25% chance) of overfishing in 2013 (Figure 64). This is 14% below the low risk TAC of 219 thousand pounds in the base case model. In comparison, a 2013 TAC of 260 thousand pounds (13% below the base case amount) would lead to a high risk (50% chance) of overfishing under the catch doubling scenario. Total allowable commercial catches of CNMI bottomfish in 2013 ranging from 109 to 260 thousand pounds corresponded to risks of overfishing ranging from 5% to 50%. Applying the 192 thousand pound TAC to achieve a low risk (25%) of overfishing in 2013 would lead to a 28% risk of overfishing in 2014 and a 6% chance of stock depletion (Figures 65 and 66). Similarly, applying the 260 thousand pound TAC to achieve a high risk (50%) of overfishing in 2013 would lead to a 66% risk of over fishing in 2014 and a 9% chance of stock depletion (Figures 65 and 66). Further, if the two-year TAC was set equal to the recent average yield during 2008-2010 of about 26 thousand pounds, then there would be a less than 1% chance of overfishing in 2013 under the catch doubling scenario.

Similarly, the scenario that quadrupled the estimated catch of CNMI bottomfish during 1983-2010 also indicated that the projected TAC in 2013 to produce a specified probability of overfishing would decrease in comparison to the base case model. Results of stochastic projections under the catch quadrupling scenario indicated that a 2013 TAC of 123 thousand pounds would produce a low risk (25% chance) of overfishing in 2013, (Figure 67), or about 78% below the low risk TAC of 219 thousand pounds for the base case model. In comparison, a 2013 TAC of 180 thousand pounds would lead to a high risk (50% chance) of overfishing under the catch quadrupling scenario, or about 63% below the low risk TAC of 293 thousand pounds for the base case model. Total allowable commercial catches of CNMI bottomfish in 2013 ranging from 61 to 180 thousand pounds corresponded to risks of overfishing ranging from 5% to 50%. Applying the 123 thousand pound TAC to achieve a low risk (25%) of overfishing in 2013 would lead to a 22% risk of overfishing in 2014 and a 22% chance of stock depletion (Figures 68 and 69). Similarly, applying the 180 thousand pound TAC to achieve a high risk (50%) of overfishing in 2013 would lead to a 50% risk of over fishing in 2014 and a 27% chance of stock depletion (Figures 68 and 69). Further, if the two-year TAC were set to equal the recent average yield during 2008-2010 of about 26 thousand pounds, then there would be a 1% chance of overfishing in 2013 under the catch quadrupling scenario.

Guam

The scenario that doubled the estimated catch of Guam bottomfish during 1986-2010 indicated that the projected TAC in 2013 to produce a specified probability of overfishing would decrease slightly in comparison to the base case run. Results of stochastic projections under the catch doubling scenario indicated that the TAC in 2013 that would produce a low risk of 25% chance of overfishing in 2014 was about 63 thousand pounds (Figure 70), or about 3% below the low risk TAC for the base case model. In comparison, the TAC that would lead to a high risk of a 50% chance of overfishing under the catch doubling scenario was 84 thousand pounds, or about 4% above the low risk TAC for the base case model. Total allowable commercial catches of Guam bottomfish in 2013 ranging from 36 to 84 thousand pounds corresponded to risks of overfishing ranging from 5% to 50%. Applying the TAC to achieve a low risk of overfishing in 2013 would lead to a 24% risk of overfishing in 2014 and a 12% chance of stock depletion (Figures 71 and 72). Similarly, applying the TAC to achieve a high risk of overfishing in 2013 would lead to a 57% risk of overfishing in 2014 and a 17% chance of stock depletion (Figures 71 and 72). Further, if the two-year TAC was set to equal the recent average yield during 2008-2010 of about 35 thousand pounds, then there would be a 5% chance of overfishing in 2013 under the catch doubling scenario.

Similarly, the scenario that quadrupled the estimated catch of Guam bottomfish during 1986-2010 also indicated that the projected TAC in 2013 to produce a specified probability of overfishing would decrease in comparison to the base case model. Results of stochastic projections under the catch quadrupling scenario indicated that the TAC in 2013 that would produce a low risk of 25% chance of overfishing in 2014 was about 19 thousand pounds, (Figure 73), or about 71% below the low risk TAC for the base case model. The TAC that would lead to a high risk of a 50% chance of overfishing under the catch quadrupling scenario was 39 thousand pounds, or about 52% below the base case amount. Total allowable commercial catches of Guam bottomfish in 2013 ranging from 2 to 39 thousand pounds corresponded to risks of overfishing ranging from 5% to 50%. Applying the TAC to achieve a low risk of overfishing in 2013 would lead to a 26% risk of overfishing in 2014 and a 43% chance of stock depletion (Figure 74 and 75). In comparison, applying the TAC to achieve a high risk of overfishing in 2013 would lead to a 50% risk of over fishing in 2014 and a 47% chance of stock depletion (Figures 74 and 75). Further, if the two-year TAC was set to equal the recent average yield during 2008-2010 of about 35 thousand pounds, then there would be a 46% chance of overfishing in 2013 under the catch quadrupling scenario.

SUMMARY

American Samoa

Recent annual catch estimates of American Samoa bottomfish have averaged about 30.6 thousand pounds, which is less than one-half of the estimated long-term potential yield. Recent estimates of CPUE have averaged about 3.2 pounds per line-hour, which is about 15% below the long-term average CPUE during 1982-2010. Overall, the fishery trends in exploitable biomass and catch appear to be relatively stable (Figure 76) and the results in this update for American Samoa bottomfish are similar to those in the previous stock assessment (Moffitt et al. 2007).

Estimates of exploitable biomass of American Samoa bottomfish have averaged 596.7 thousand pounds during 1986-2010, or about 78% above B_{MSY}. The probability that the American Samoa bottomfish complex has been depleted is very low and estimated to be on the order of 1%. Estimates of the annual harvest rate of American Samoa bottomfish have averaged 5% during 1986-2010, or about 79% below H_{MSY}, the harvest rate to produce MSY. The probability that the bottomfish complex has experienced overfishing is also very low, on the order of 1% or less. Overall, the American Samoa bottomfish complex was not depleted and was not experiencing overfishing in 2010, the most recent year of the stock assessment estimates.

Stock projections, which assumed recent average fishing effort had continued in 2011 and 2012, indicated that the exploitable biomass would be maintained at about 70% above B_{MSY} and that there would be a negligible chance of overfishing. Stock projections for 2013 and 2014, which assumed that a two-year TAC would be harvested from the bottomfish complex, indicated that the TAC to produce a 25% (1 out of 4) chance of overfishing in 2013 was 95 thousand pounds and the TAC to produce a 50% (1 out of 2) chance of overfishing was 124 thousand pounds. Probabilities that the bottomfish complex would be depleted in 2014 with a TAC of 95 and 124 thousand pounds were 2% (1 out of 50) and 4% (1 out of 25), respectively.

The catch sensitivity analysis scenario that doubled the estimated catch during 1986-2010 indicated that the TAC to produce a 25% chance of overfishing in 2013 was 77 thousand pounds and the TAC to produce a 50% chance of overfishing was 104 thousand pounds. If the TAC were set to be double the estimate of recent average yield, or about 60 thousand pounds, then the probability of overfishing in 2013 would be about 12%. Similarly, the catch sensitivity analysis scenario that quadrupled the estimated catch during 1986-2010 indicated that the TAC to produce a 25% chance of overfishing in 2013 was 53 thousand pounds and the TAC to produce a 50% chance of overfishing was 75 thousand pounds. If the TAC were set to be quadruple the estimate of recent average yield, or about 120 thousand pounds, then the probability of overfishing in 2013 would be about 84%. Overall, the TAC to produce a specified probability of overfishing in 2013 would decrease under either of the catch sensitivity analysis scenarios.

Commonwealth of the Northern Mariana Islands

Recent annual catch estimates of CNMI bottomfish have averaged about 26 thousand pounds, which is less than 15% of the estimated long-term potential yield of 172.9 thousand pounds. Recent estimates of CPUE have averaged about 92 pounds per trip, which is about 6% below the long-term average CPUE of 97.8 pounds per trip during 1983-2010. Overall, the fishery trends in exploitable biomass and catch appear to be stable, with some fluctuations in the early 1990s (Figure 77) and the results in this update for the Commonwealth of the Northern Mariana Islands bottomfish are similar to those in the previous stock assessment (Moffitt et al. 2007).

Estimates of exploitable biomass of CNMI bottomfish have averaged 1183.6 thousand pounds during 1983-2010, or about 73% above B_{MSY}. The probability that the CNMI bottomfish complex has been depleted is very slim and estimated to be on the order of 3%. Estimates of the annual harvest rate of CNMI bottomfish have averaged 4% during

1983-2010, or about 85% below H_{MSY}, the harvest rate to produce MSY. The probability that the bottomfish complex has experienced overfishing is also very low, on the order of 1% or less. Overall, the CNMI bottomfish complex was not depleted and was not experiencing overfishing in 2010, the most recent year of the stock assessment estimates.

Stock projections, which assumed recent average fishing effort had continued in 2011 and 2012, indicated that the exploitable biomass would be maintained at about 70% above B_{MSY} and that there would be a negligible chance of overfishing. Stock projections for 2013 and 2014, which assumed that a two-year TAC would be harvested from the bottomfish complex, indicated that the TAC to produce a 25% (1 out of 4) chance of overfishing in 2013 was 219 thousand pounds and the TAC to produce a 50% (1 out of 2) chance of overfishing was 293 thousand pounds. Probabilities that the bottomfish complex would be depleted in 2014 with a TAC of 219 and 293 thousand pounds were 4% (1 out of 25) and 6% (1 out of 16), respectively.

The catch sensitivity analysis scenario that doubled the estimated catch during 1983-2010 indicated that the TAC to produce a 25% chance of overfishing in 2013 was 192 thousand pounds and the TAC to produce a 50% chance of overfishing was 260 thousand pounds. If the TAC were set to be double the estimate of recent average yield, or about 52 thousand pounds, then the probability of overfishing in 2013 would be about 6%. Similarly, the catch sensitivity analysis scenario that quadrupled the estimated catch during 1983-2010 indicated that the TAC to produce a 25% chance of overfishing in 2013 was 123 thousand pounds and the TAC to produce a 50% chance of overfishing was 180 thousand pounds. If the TAC were set to be quadruple the estimate of recent average yield, or about 105 thousand pounds, then the probability of overfishing in 2013 would be about 18%. Overall, the TAC to produce a specified probability of overfishing in 2013 would decrease under either of the catch sensitivity analysis scenarios.

Guam

Recent annual catch estimates of Guam bottomfish have averaged about 35 thousand pounds, which is over half (62%) of the estimated long-term potential yield. Recent estimates of CPUE have averaged about 2.9 pounds per line-hour, which is about 5% below the long-term average CPUE during 1982-2010. Overall, the fishery trends in exploitable biomass and catch appear to be stable (Figure 78) and the results in this update for Guam bottomfish are similar to those in the previous stock assessment (Moffitt et al. 2007).

Estimates of exploitable biomass of Guam bottomfish have averaged 238.71 thousand pounds during 1982-2010, or about 47% above B_{MSY}. The probability that the Guam bottomfish complex has been depleted is very small and estimated to be on the order of 2%. Estimates of the annual harvest rate of Guam bottomfish have averaged 19% during 1982-2010, or about 46% below H_{MSY}, the harvest rate to produce MSY. The probability that the bottomfish complex has experienced overfishing is also low, on the order of 8% or less. However, there was a 49% probability that overfishing occurred in 2000. Overall, the

Guam bottomfish complex was not depleted and was not experiencing overfishing in 2010, the most recent year of the stock assessment estimates.

Stock projections, which assumed recent average fishing effort had continued in 2011 and 2012, indicated that the exploitable biomass would be maintained at about 58% above B_{MSY} and that there would be a negligible chance of overfishing. Stock projections for 2013 and 2014, which assumed that a two-year TAC would be harvested from the bottomfish complex, indicated that the TAC to produce a 25% (1 out of 4) chance of overfishing in 2013 was 65 thousand pounds and the TAC to produce a 50% (1 out of 2) chance of overfishing was 81 thousand pounds. Probabilities that the bottomfish complex would be depleted in 2014 with a TAC of 65 and 81 thousand pounds were 4% (1 out of 50) and 6% (1 out of 25), respectively.

The catch sensitivity analysis scenario that doubled the estimated catch during 1982-2010 indicated that the TAC to produce a 25% chance of overfishing in 2013 was 63 thousand pounds and the TAC to produce a 50% chance of overfishing was 84 thousand pounds. If the TAC were set to be double the estimate of recent average yield, or about 70 thousand pounds, then the probability of overfishing in 2013 would be about 33%. Similarly, the catch sensitivity analysis scenario that quadrupled the estimated catch during 1982-2010 indicated that the TAC to produce a 25% chance of overfishing in 2013 was 19 thousand pounds and the TAC to produce a 50% chance of overfishing was 39 thousand pounds. If the TAC were set to be quadruple the estimate of recent average yield, or about 105 thousand pounds, then the probability of overfishing in 2013 would be about 86%. Overall, the TAC to produce a specified probability of overfishing in 2013 wouldn't decrease under the double catch sensitivity analysis scenario, an indication of an underexploited stock. However, the quadruple catch sensitivity analysis scenario suggests that if the actual catch was four times greater than the reported catch then there would be high probability of overfishing and stock depletion.

DISCUSSION

Stock status determinations based on models with the best 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, using 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 statistically significant, however, and depends on the judgment that the set of alternative models adequately approximates the dynamics of each bottomfish complex.

There are three 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 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, or misidentification of species. If the fishery removals are inaccurate then the production model results will reflect this problem. In this context, the catch sensitivity analyses provide some guidance on the likely magnitude of changes in stock status if fishery removals are underestimated.

Third, 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. If the relative abundance index is inaccurate then the trends from the production model will reflect this problem.

Overall, it would be useful to continue to improve the bottomfish fishery catch reporting systems of the three island groups to account for these potential problems. 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 a biosampling program. This ongoing data collection program will provide additional information on the average size of fish in the catch, which should eventually support more sophisticated assessment methods for individual species.

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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. Annual estimates of catch and CPUE of BMUS bottomfish species in American Samoa, the Commonwealth of the Northern Mariana Islands (CNMI), and Guam used in the 2012 stock assessment update along with average values during 1982-2010, 2001-2010, and 2008-2010.

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	3.40
1991	13010	2.64	7092	47	39596	2.00
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
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	2.90	42070		37316	1.93
2009	47458	3.62	41176		40222	3.17
2010	9509	2.96	22395		28958	3.65
Average						
1982-2010	24740	3.74	40152	98	40614	3.08
2001-2010	24630	3.50	45926	88	36710	3.28
2008-2010	30593	3.16	35214		35499	2.92

Table 3. Alternative production models for American Samoa bottomfish and their goodness of fit to the CPUE data based on the Deviance information criterion value.

Prior Mean for Carrying Capacity (K)	Prior Mean for Initial Proportion of Carrying Capacity (P[1])	Posterior Mean of Deviance	Value of Deviance at Posterior Mean of Stochastic Nodes	Effective Degrees of Freedom	Deviance Information Criterion
400	0.40	99.305	89.626	9.678	108.983
400	0.63	96.210	86.875	9.335	105.545
400	0.80	95.713	86.529	9.184	104.897
500	0.40	99.160	89.418	9.741	108.901
500	0.63	96.032	86.619	9.413	105.446
500	0.80	95.537	86.22	9.318	104.855
600	0.40	99.017	89.199	9.817	108.834
600	0.63	96.071	86.593	9.478	105.548
600	0.80	95.470	86.118	9.352	104.822
700	0.40	98.832	89.01	9.822	108.653
700	0.63	96.047	86.569	9.478	105.525
700	0.80	95.413	86.066	9.346	104.759
800	0.40	98.691	88.888	9.803	108.494
800	0.63	96.028	86.563	9.464	105.492
800	0.80	95.446	86.096	9.35	104.796
900	0.40	98.481	88.709	9.773	108.254
900	0.63	96.040	86.563	9.476	105.516
900	0.80	95.434	86.082	9.351	104.785
1000	0.40	98.233	88.508	9.725	107.958
1000	0.63	96.041	86.613	9.428	105.469
1000	0.80	95.483	86.157	9.326	104.809

Table 4. DIC difference values ΔDIC for alternative production models for American Samoa bottomfish relative to the best-fitting model with mean K=700 and mean P[1]=0.80.

	Prior Mean for P[1]		
Prior Mean for Carrying Capacity (K)	0.40	0.63	0.80
400	4.224	0.786	0.138
500	4.142	0.687	0.096
600	4.075	0.789	0.063
700	3.894	0.766	0
800	3.735	0.733	0.037
900	3.495	0.757	0.026
1000	3.199	0.71	0.05

Table 5. Alternative production models for American Samoa bottomfish ranked by DIC value 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), ratio of mean biomass in 2010 to BMSY B2010/BMSY, ratio of mean harvest rate in 2010 to HMSY H2010/HMSY, and DIC difference (ΔDIC) from the best-fitting model.

Prior Mean for Carrying Capacity K	Prior Mean for Initial Proportion of Carrying Capacity P[1]	K	q	r	P[1]	sigma2	tau2	B2010/BMSY	H2010/HMSY	ΔDIC
700	0.80	670.40	0.01	0.47	0.82	0.06	0.18	1.59	0.08	0
900	0.80	839.00	0.01	0.39	0.82	0.06	0.18	1.59	0.08	0.03
800	0.80	754.50	0.01	0.42	0.82	0.06	0.18	1.59	0.08	0.04
1000	0.80	927.00	0.005	0.35	0.82	0.06	0.18	1.60	0.08	0.05
600	0.80	586.00	0.01	0.53	0.82	0.06	0.18	1.59	0.09	0.06
500	0.80	505.50	0.01	0.59	0.81	0.06	0.18	1.57	0.09	0.10
400	0.80	423.10	0.01	0.67	0.81	0.06	0.18	1.56	0.09	0.14
500	0.63	504.30	0.01	0.60	0.68	0.06	0.19	1.54	0.09	0.69
1000	0.63	927.00	0.01	0.35	0.67	0.06	0.18	1.51	0.09	0.71
800	0.63	754.30	0.01	0.42	0.68	0.06	0.18	1.53	0.09	0.73
900	0.63	839.70	0.01	0.38	0.68	0.06	0.18	1.52	0.09	0.76
700	0.63	670.40	0.01	0.47	0.68	0.06	0.18	1.54	0.09	0.77
400	0.63	423.10	0.01	0.67	0.68	0.06	0.19	1.54	0.10	0.79
600	0.63	587.00	0.01	0.53	0.68	0.06	0.18	1.54	0.09	0.79

Table 6. Alternative production models for the Commonwealth of the Northern Mariana Islands bottomfish and their goodness of fit to the CPUE data based on the Deviance information criterion value.

Prior Mean for Carrying Capacity (K)	Prior Mean for Initial Proportion of Carrying Capacity (P[1])	Posterior Mean of Deviance	Value of Deviance at Posterior Mean of Stochastic Nodes	Effective Degrees of Freedom	Deviance Information Criterion
1000	0.45	245.515	236.419	9.096	254.61
1000	0.63	246.566	237.82	8.746	255.312
1000	0.80	245.515	236.419	9.096	254.61
1400	0.45	245.222	235.887	9.335	254.558
1400	0.63	246.131	237.154	8.977	255.108
1400	0.80	247.557	238.852	8.706	256.263
1700	0.45	245.183	235.753	9.430	254.613
1700	0.63	246.047	236.965	9.082	255.129
1700	0.80	247.363	238.484	8.879	256.242

Table 7. DIC difference values ΔDIC for alternative production models the Commonwealth of the Northern Mariana Islands bottomfish relative to the best-fitting model with mean K=700 and mean P[1]=0.80.

	Prior Mean for P[1]		
Prior Mean for Carrying Capacity (K)	0.45	0.63	0.80
1000	0.052	0.754	1.98
1400	0	0.55	1.705
1700	0.055	0.571	1.684

Table 8. Alternative production models for the Commonwealth of the Northern Mariana Islands bottomfish ranked by DIC value 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), ratio of mean biomass in 2010 to BMSY B2010/BMSY, ratio of harvest rate in 2010 to HMSY H2010/HMSY, and DIC difference (ΔDIC) from the best-fitting model.

Prior Mean for Carrying Capacity K	Prior Mean for Initial Proportion of Carrying Capacity P[1]	K	q	r	P[1]	sigma2	tau2	B2010/BMSY	H2010/HMSY	ΔDIC
1400	0.45	1365	0.09	0.52	0.46	0.09	0.22	1.78	0.07	0.00
1000	0.45	1040	0.11	0.64	0.45	0.09	0.23	1.77	0.14	0.05
1700	0.45	1613	0.07	0.45	0.46	0.09	0.22	1.79	0.09	0.06
1400	0.63	1378	0.08	0.51	0.60	0.08	0.23	1.80	0.09	0.55
1700	0.63	1632	0.07	0.45	0.61	0.08	0.23	1.81	0.17	0.57
1000	0.63	1046	0.11	0.63	0.60	0.08	0.23	1.77	0.08	0.75

Table 9. Alternative production models for Guam bottomfish and their goodness of fit to the CPUE data based on the Deviance information criterion value.

Prior Mean for Carrying Capacity (K)	Prior Mean for Initial Proportion of Carrying Capacity (P[1])	Posterior Mean of Deviance	Value of Deviance at Posterior Mean of Stochastic Nodes	Effective Degrees of Freedom	Deviance Information Criterion
200	0.63	102.00	92.60	9.40	111.401
300	0.30	106.36	96.21	10.15	116.507
300	0.45	103.26	93.27	9.99	113.247
300	0.63	101.86	92.02	9.84	111.692
300	0.75	101.63	91.87	9.76	111.396
500	0.30	106.01	95.84	10.17	116.174
500	0.45	103.56	93.37	10.18	113.741
500	0.63	102.15	92.02	10.13	112.285
500	0.75	101.82	91.75	10.07	111.886
600	0.63	102.31	92.16	10.15	112.465

Table 10. DIC difference values ΔDIC for alternative production models for Guam bottomfish relative to the best-fitting model with mean K=700 and mean P[1]=0.80.

	Prior Mean for P[1]			
Prior Mean for Carrying Capacity (K)	0.30	0.45	0.63	0.75
200			0.005	
300	5.111	1.851	0.296	0.000
500	4.778	2.345	0.889	0.490
600			1.069	

Table 11. Alternative production models for Guam bottomfish ranked by DIC value 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), ratio of mean biomass in 2010 to BMSY B2010/BMSY, ratio of mean harvest rate in 2010 to HMSY H2010/HMSY, and DIC difference (ΔDIC) from the best-fitting model.

Prior Mean for Carrying Capacity K	Prior Mean for Initial Proportion of Carrying Capacity P[1]	K	q	r	P[1]	sigma2	tau2	B2010/BMSY	H2010/HMSY	ΔDIC
300	0.75	324.80	0.01	0.70	0.77	0.07	0.22	1.59	0.35	0
200	0.63	248.30	0.02	0.83	0.66	0.07	0.22	1.52	0.40	0.01
300	0.63	323.10	0.01	0.70	0.67	0.07	0.22	1.58	0.36	0.30
500	0.75	485.40	0.01	0.50	0.78	0.07	0.22	1.64	0.33	0.49
500	0.63	483.60	0.01	0.50	0.68	0.07	0.22	1.59	0.34	0.89
600	0.63	568.50	0.01	0.43	0.68	0.07	0.22	1.59	0.34	1.07
300	0.45	321.80	0.01	0.71	0.52	0.08	0.23	1.52	0.37	1.85

Table 12. American Samoa base case production model mean estimates of exploitable biomass, relative biomass, the probability of being overfished, harvest rate, relative harvest rate and the probability of overfishing, 1986-2010 and 2011-2013 estimates from projection model.

Year	Exploitable Biomass (B, units are 1000 lbs)	Mean Relative Biomass (B/BMSY)	Probability of Being Overfished (B<0.7*BMSY)	Harvest Rate (H)	Relative Harvest Rate (H/HMSY)	Probability of Overfishing (H>HMSY)
1986	547.2	1.63	0.00	0.13	0.56	0.02
1987	558.7	1.66	0.00	0.04	0.17	0.00
1988	673.7	2.01	0.00	0.06	0.25	0.00
1989	621.6	1.85	0.00	0.06	0.26	0.00
1990	572.5	1.71	0.00	0.02	0.10	0.00
1991	532.8	1.59	0.00	0.03	0.12	0.00
1992	525.5	1.57	0.00	0.02	0.09	0.00
1993	567.9	1.70	0.00	0.03	0.13	0.00
1994	601.7	1.79	0.00	0.06	0.27	0.00
1995	654.2	1.95	0.00	0.05	0.21	0.00
1996	722.1	2.15	0.00	0.05	0.21	0.00
1997	655.4	1.95	0.00	0.05	0.24	0.00
1998	639.4	1.90	0.00	0.02	0.09	0.00
1999	645.4	1.92	0.00	0.03	0.12	0.00
2000	675.1	2.01	0.00	0.03	0.14	0.00
2001	674.4	2.01	0.00	0.06	0.27	0.00
2002	588.9	1.75	0.00	0.06	0.28	0.00
2003	652.6	1.94	0.00	0.03	0.14	0.00
2004	629.9	1.88	0.00	0.03	0.13	0.00
2005	568.5	1.70	0.00	0.03	0.14	0.00
2006	528	1.58	0.01	0.02	0.07	0.00
2007	526.2	1.57	0.00	0.05	0.20	0.00
2008	539.8	1.61	0.00	0.07	0.32	0.00
2009	558.3	1.67	0.00	0.09	0.42	0.01
2010	533.2	1.59	0.01	0.02	0.09	0.00
2011	578.3	1.73	0.01	0.06	0.30	0.00
2012	569.8	1.70	0.01	0.06	0.30	0.00
2013	565.3	1.69				
Average 1986-2010	596.7	1.78	0.00	0.05	0.21	0.00

Table 13. CNMI base case production model mean estimates of exploitable biomass, relative biomass, the probability of being overfished, harvest rate, relative harvest rate and the probability of overfishing, 1983-2010 and 2011-2013 estimates from projection model.

Year	Exploitable Biomass (B, units are 1000 lbs)	Mean Relative Biomass (B/BMSY)	Probability of Being Overfished (B<0.7*BMSY)	Harvest Rate (H)	Relative Harvest Rate (H/HMSY)	Probability of Overfishing (H>HMSY)
1983	628.7	0.92	0.08	0.05	0.19	0.00
1984	882.6	1.29	0.02	0.05	0.21	0.00
1985	1164.0	1.70	0.00	0.04	0.16	0.00
1983	1293.0	1.89	0.00	0.03	0.10	0.00
1987	1510.0	2.21	0.00	0.04	0.15	0.00
1988	1517.0	2.22	0.00	0.04	0.14	0.00
1989	1138.0	1.66	0.01	0.02	0.10	0.00
1990	1056.0	1.55	0.01	0.01	0.06	0.00
1991	925.4	1.36	0.03	0.01	0.03	0.00
1992	971.0	1.42	0.02	0.01	0.05	0.00
1993	1083.0	1.59	0.01	0.02	0.08	0.00
1994	1126.0	1.65	0.01	0.03	0.10	0.00
1995	1240.0	1.81	0.00	0.03	0.13	0.00
1996	1373.0	2.01	0.00	0.05	0.21	0.00
1997	1446.0	2.11	0.00	0.05	0.20	0.00
1998	1473.0	2.15	0.00	0.05	0.18	0.00
1999	1423.0	2.08	0.00	0.04	0.18	0.00
2000	1074.0	1.57	0.01	0.05	0.19	0.00
2001	1083.0	1.58	0.01	0.07	0.30	0.00
2002	1169.0	1.71	0.01	0.05	0.18	0.00
2003	1180.0	1.73	0.00	0.04	0.16	0.00
2004	1217.0	1.78	0.00	0.05	0.20	0.00
2005	1137.0	1.66	0.01	0.07	0.28	0.00
2006	1173.0	1.71	0.02	0.03	0.12	0.00
2007	1214.0	1.78	0.02	0.04	0.16	0.00
2008	1217.0	1.78	0.03	0.04	0.17	0.00
2009	1212.0	1.77	0.03	0.04	0.17	0.00
2010	1216.0	1.78	0.03	0.02	0.09	0.00
2011	959.0	1.49	0.08	0.04	0.30	0.00
2012	991.7	1.55	0.09	0.04	0.30	0.00
2013	1013.0	1.58				
Average 1983-2012	1183.6	1.73	0.01	0.04	0.15	0.00

Table 14. Guam base case production model mean estimates of exploitable biomass, relative biomass, the probability of being overfished, harvest rate, relative harvest rate and the probability of overfishing, 1982-2010 and 2011-2013 estimates from projections.

Year	Exploitable Biomass (B, units are 1000 lbs)	Mean Relative Biomass (B/BMSY)	Probability of Being Overfished (B<0.7*BMSY)	Harvest Rate (H)	Relative Harvest Rate (H/HMSY)	Probability of Overfishing (H>HMSY)
1982	249.7	1.538	0.00	0.11	0.32	0.00
1983	281.1	1.728	0.00	0.16	0.45	0.00
1984	361.2	2.219	0.00	0.06	0.17	0.00
1985	278.8	1.713	0.00	0.19	0.56	0.02
1986	265.6	1.63	0.00	0.08	0.24	0.00
1987	281.2	1.731	0.00	0.11	0.33	0.00
1988	249.9	1.538	0.00	0.20	0.59	0.03
1989	233	1.433	0.01	0.27	0.80	0.18
1990	225.6	1.386	0.01	0.21	0.60	0.04
1991	210.5	1.294	0.02	0.21	0.60	0.04
1992	217.3	1.338	0.01	0.25	0.74	0.13
1993	220.9	1.359	0.01	0.28	0.81	0.21
1994	205	1.26	0.02	0.27	0.77	0.17
1995	187.9	1.155	0.05	0.24	0.70	0.11
1996	182.9	1.125	0.06	0.33	0.96	0.39
1997	158.1	0.9718	0.16	0.22	0.63	0.07
1998	174.7	1.076	0.08	0.24	0.70	0.10
1999	193	1.189	0.03	0.30	0.88	0.29
2000	203.1	1.251	0.02	0.36	1.04	0.49
2001	216.4	1.329	0.01	0.28	0.81	0.20
2002	225.9	1.386	0.01	0.12	0.34	0.00
2003	271.7	1.671	0.00	0.18	0.51	0.02
2004	258.3	1.586	0.00	0.16	0.45	0.01
2005	284.9	1.751	0.00	0.14	0.41	0.00
2006	269.4	1.656	0.00	0.16	0.45	0.01
2007	233.7	1.437	0.01	0.13	0.38	0.00
2008	231	1.421	0.01	0.18	0.51	0.01
2009	250.3	1.539	0.00	0.18	0.51	0.02
2010	259.2	1.594	0.00	0.12	0.36	0.00
2011	263.1	1.62	0.01	0.16	0.47	0.00
2012	249.9	1.544	0.02	0.16	0.47	0.00
2013	245.5	1.519				
Average 1982-2010	238.71	1.47	0.02	0.19	0.57	0.08

Table 15. American Samoa probability of overfishing in 2013 at different levels of total allowable catch in 2013 and 2014 and the associated probability of overfishing in 2014, the relative biomass in 2013, and probability of depletion in 2014.

Probability of Overfishing Bottomfish in American Samoa in 2013	Total Allowable Commercial Catch (1000 pounds) of American Samoa Bottomfish in 2013 and 2014	Probability of Overfishing Bottomfish in American Samoa in Fishing Year 2014	Ratio of Bottomfish Exploitable Biomass in 2013 to BMSY in American Samoa	Probability That American Samoa Bottomfish Biomass in 2014 Is Less Than the Minimum Stock Size Threshold (0.7*BMSY)
0	33	0.00	1.64	0.01
0.05	60	0.05	1.56	0.01
0.10	73	0.12	1.52	0.02
0.15	81	0.18	1.49	0.02
0.20	89	0.26	1.47	0.02
0.25	95	0.33	1.45	0.02
0.30	101	0.41	1.43	0.03
0.35	107	0.49	1.41	0.03
0.40	112	0.56	1.40	0.03
0.45	118	0.64	1.38	0.04
0.50	124	0.72	1.36	0.04
0.55	130	0.78	1.34	0.04
0.60	136	0.84	1.32	0.05
0.65	142	0.89	1.30	0.05
0.70	149	0.94	1.28	0.06
0.75	156	0.96	1.26	0.06
0.80	166	0.99	1.23	0.07
0.85	177	1.00	1.19	0.08
0.90	192	1.00	1.15	0.10
0.95	217	1.00	1.07	0.15
1.00	300	1.00	0.82	0.36

Table 16. CNMI probability of overfishing in 2013 at different levels of total allowable catch in 2013 and 2014 and the associated probability of overfishing in 2014, the relative biomass in 2013, and probability of depletion in 2014.

Probability of Overfishing Bottomfish in CNMI in 2013	Total Allowable Commercial Catch (1000 pounds) of CNMI Bottomfish in 2013 and 2014	Probability of Overfishing Bottomfish in CNMI in Fishing Year 2014	Ratio of Bottomfish Exploitable Biomass in 2013 to BMSY in CNMI	Probability That CNMI Bottomfish Biomass in 2014 Is Less Than the Minimum Stock Size Threshold (0.7*BMSY)
0	40	0.00	1.76	0.01
0.05	130	0.05	1.57	0.02
0.10	162	0.11	1.52	0.03
0.15	183	0.17	1.49	0.03
0.20	203	0.26	1.46	0.03
0.25	219	0.34	1.44	0.04
0.30	234	0.43	1.41	0.04
0.35	249	0.52	1.39	0.05
0.40	264	0.61	1.37	0.05
0.45	279	0.7	1.35	0.06
0.50	293	0.78	1.33	0.06
0.55	308	0.85	1.30	0.07
0.60	324	0.91	1.28	0.07
0.65	340	0.95	1.25	0.08
0.70	359	0.98	1.23	0.09
0.75	379	0.99	1.20	0.10
0.80	402	1.00	1.16	0.11
0.85	431	-	1.12	0.14
0.90	471	-	1.06	0.17
0.95	> 501	-	-	-
1.00	> 501	-	-	-

Table 17. Guam probability of overfishing in 2013 at different levels of total allowable catch in 2013 and 2014 and the associated probability of overfishing in 2014, the relative biomass in 2013, and probability of depletion in 2014.

Probability of Overfishing Bottomfish in Guam in 2013	Total Allowable Commercial Catch (1000 pounds) of Guam Bottomfish in 2013 and 2014	Probability of Overfishing Bottomfish in Guam in Fishing Year 2014	Ratio of Bottomfish Exploitable Biomass in 2013 to BMSY in Guam	Probability That Guam Bottomfish Biomass in 2014 Is Less Than the Minimum Stock Size Threshold (0.7*BMSY)
0	22	0.00	1.55	0.01
0.05	44	0.05	1.41	0.02
0.10	51	0.11	1.37	0.02
0.15	56	0.17	1.34	0.03
0.20	61	0.26	1.31	0.03
0.25	65	0.35	1.28	0.04
0.30	68	0.43	1.26	0.04
0.35	71	0.51	1.24	0.05
0.40	75	0.62	1.22	0.05
0.45	78	0.70	1.20	0.06
0.50	81	0.77	1.18	0.06
0.55	85	0.85	1.16	0.07
0.60	88	0.89	1.14	0.08
0.65	92	0.94	1.11	0.09
0.70	97	0.97	1.08	0.10
0.75	101	0.99	1.06	0.11
0.80	107	1.00	1.02	0.14
0.85	114	1.00	0.97	0.16
0.90	123	1.00	0.92	0.21
0.95	138	1.00	0.82	0.30
1.00	191	1.00	0.50	0.74

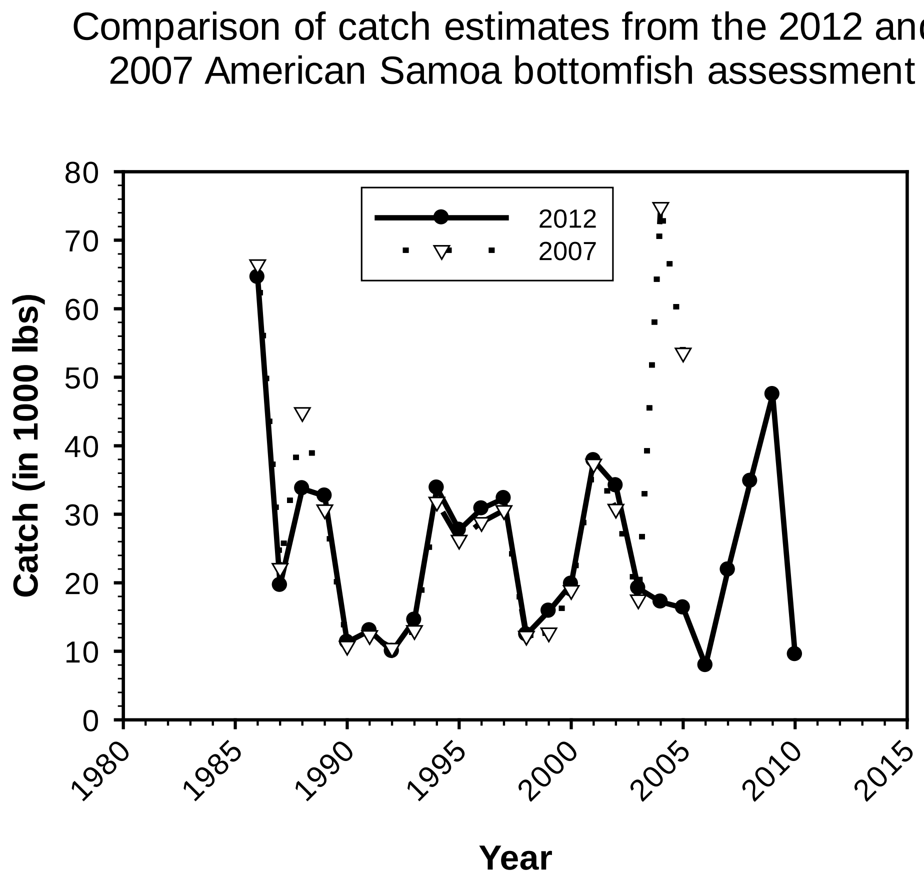

Figure 1. Comparison of catch estimates from the 2012 update and the 2007 American Samoa bottomfish assessment.

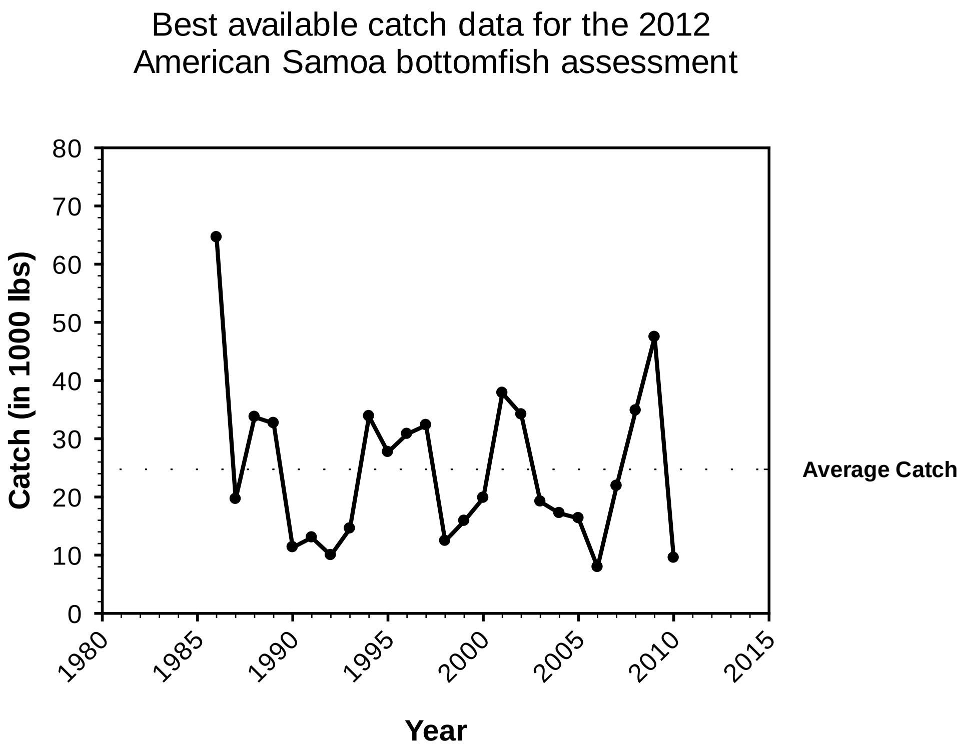

Figure 2. Best available catch data for the 2012 American Samoa bottomfish assessment update.

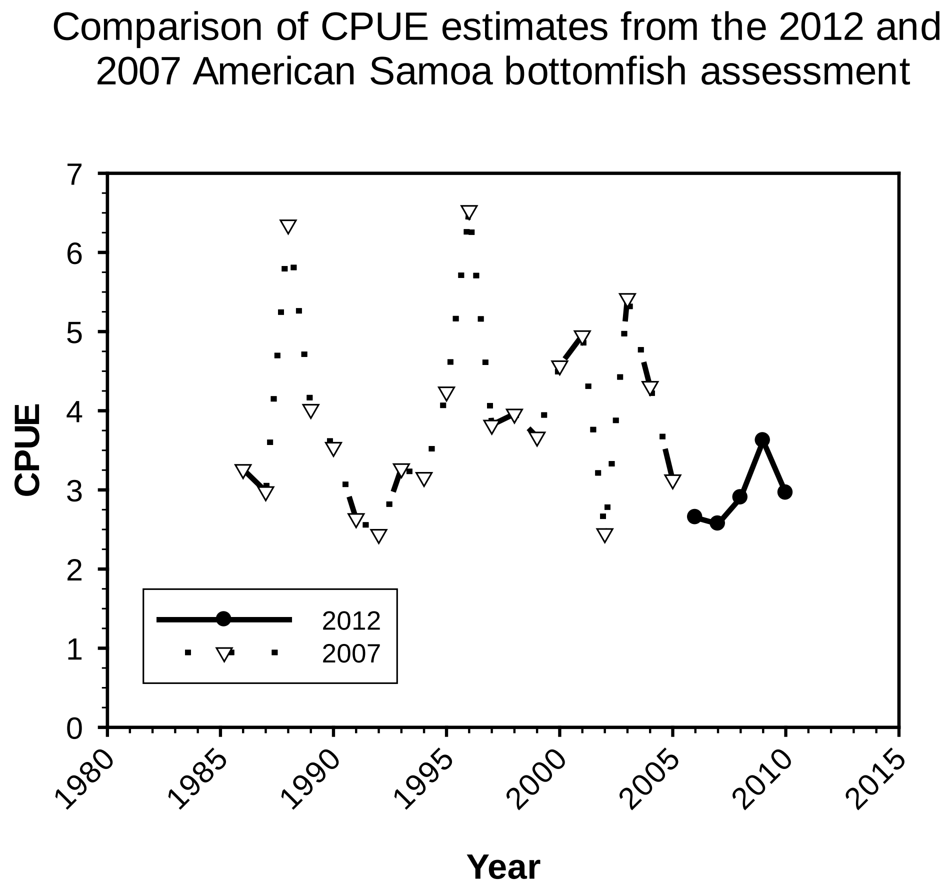

Figure 3. Comparison of CPUE estimates from the 2012 update and the 2007 American Samoa bottomfish assessment.

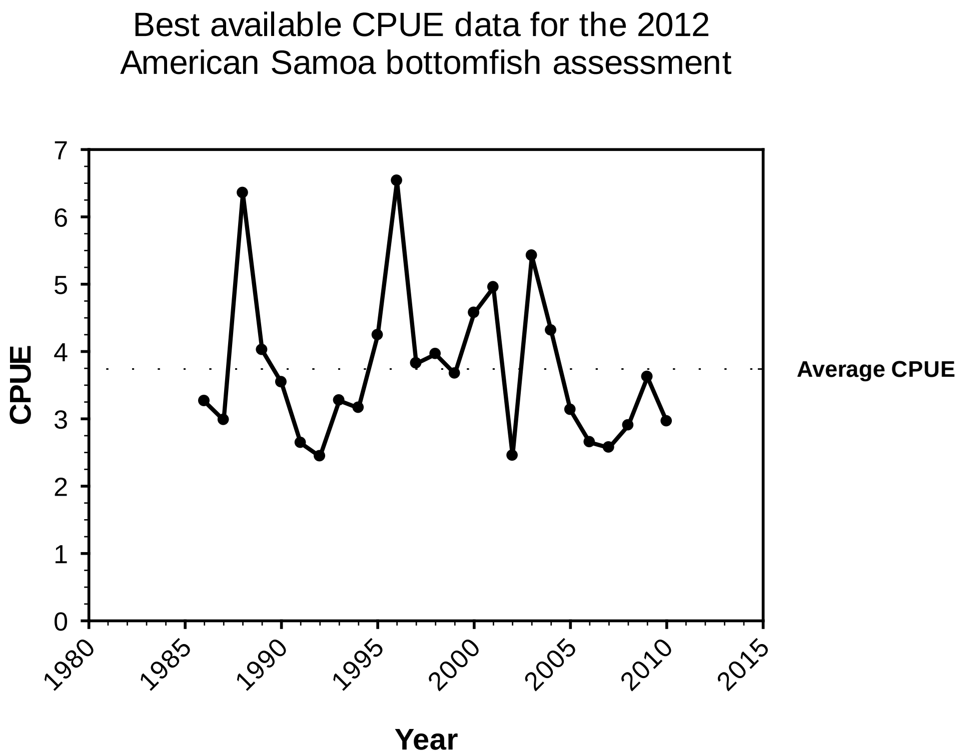

Figure 4. Best available CPUE data for the 2012 American Samoa bottomfish assessment update.

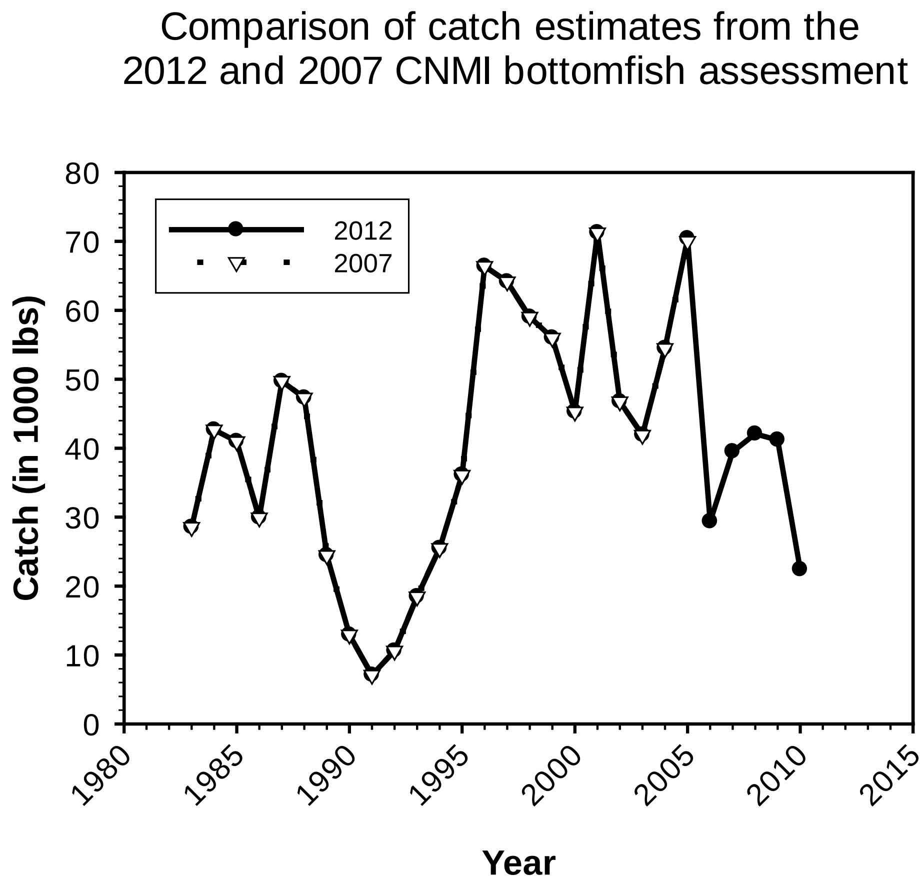

Figure 5. Comparison of catch estimates from the 2012 update and the 2007 CNMI bottomfish assessment.

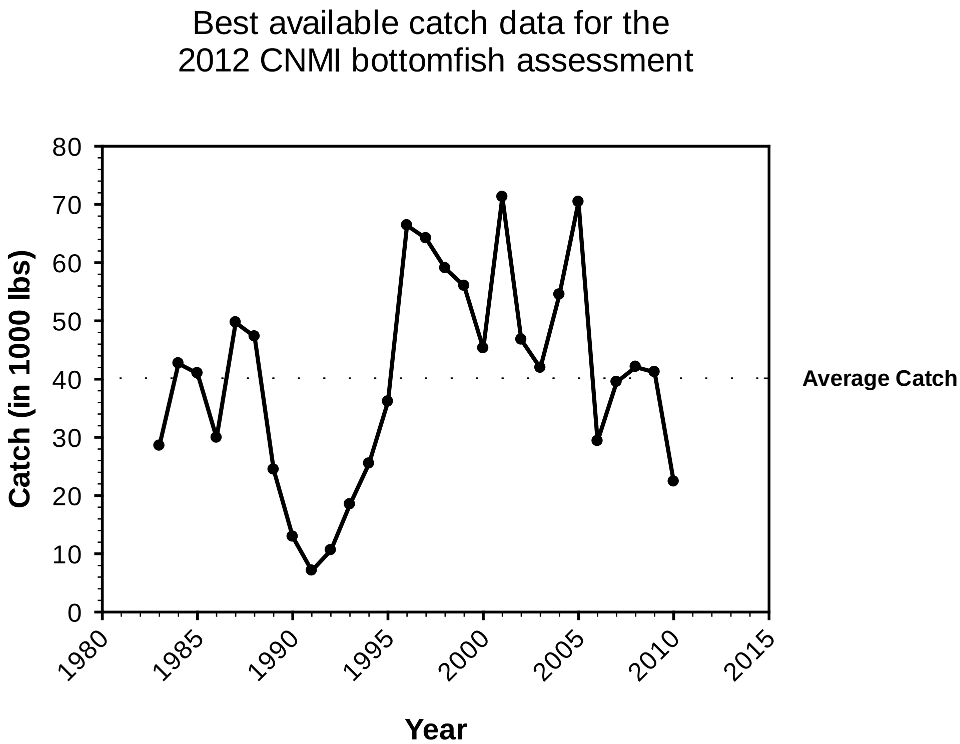

Figure 6. Best available catch data for the 2012 CNMI bottomfish assessment update.

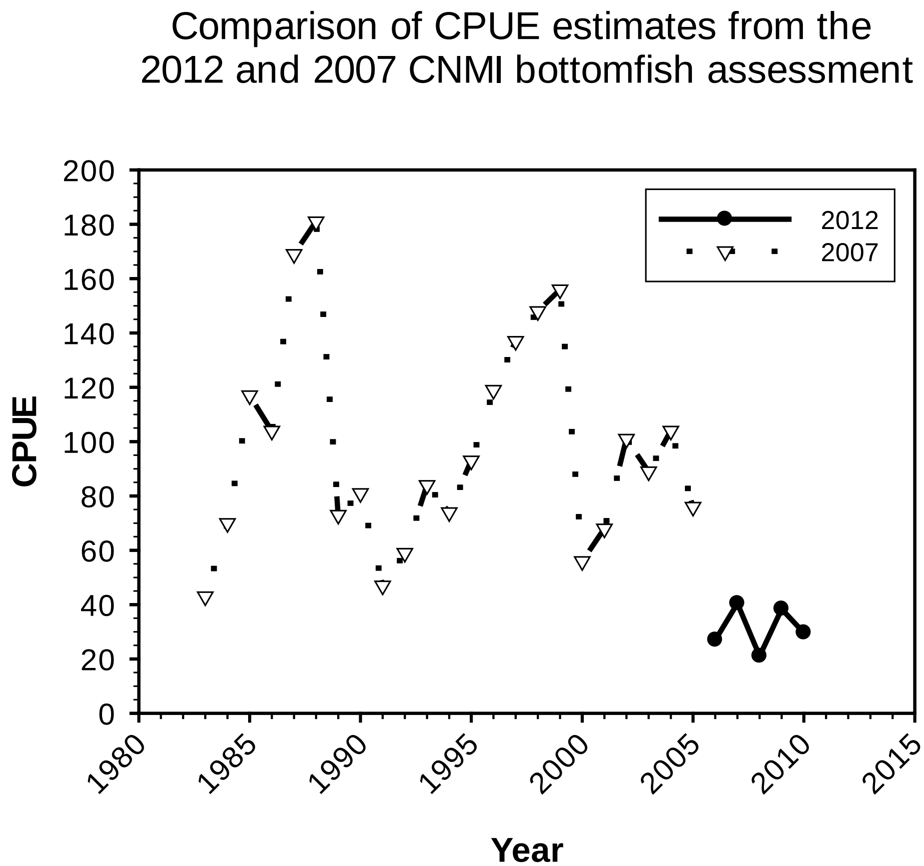

Figure 7. Comparison of CPUE estimates from the 2012 update and the 2007 CNMI bottomfish assessment.

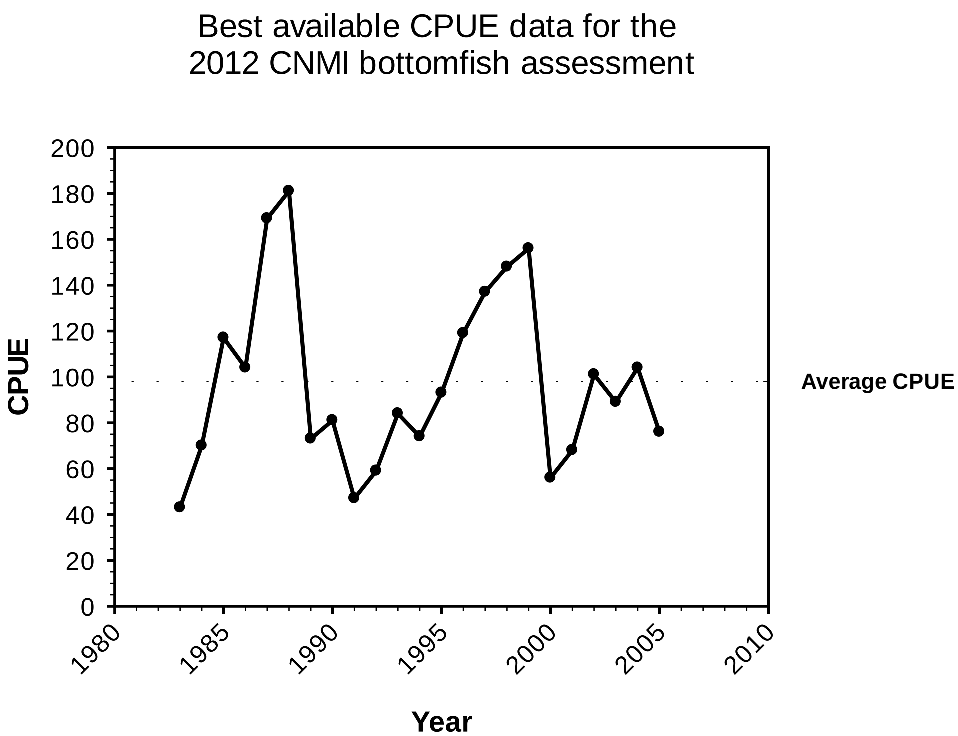

Figure 8. Best available CPUE data for the 2012 CNMI bottomfish assessment update.

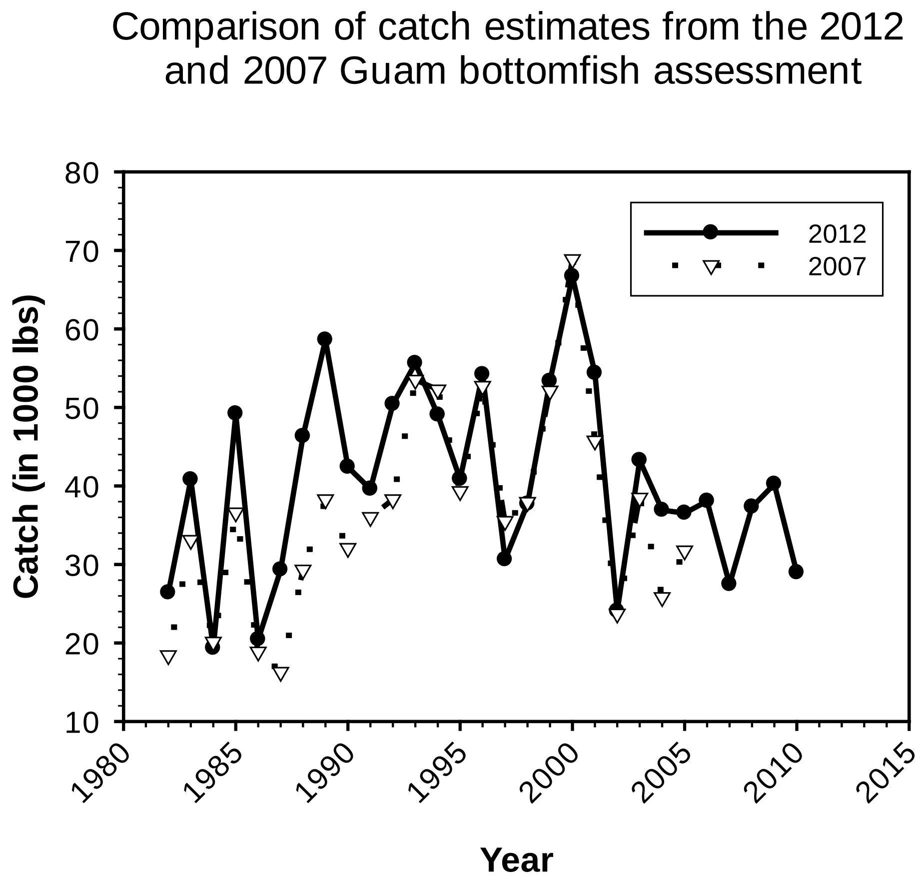

Figure 9. Comparison of catch estimates from the 2012 update and the 2007 Guam bottomfish assessment.

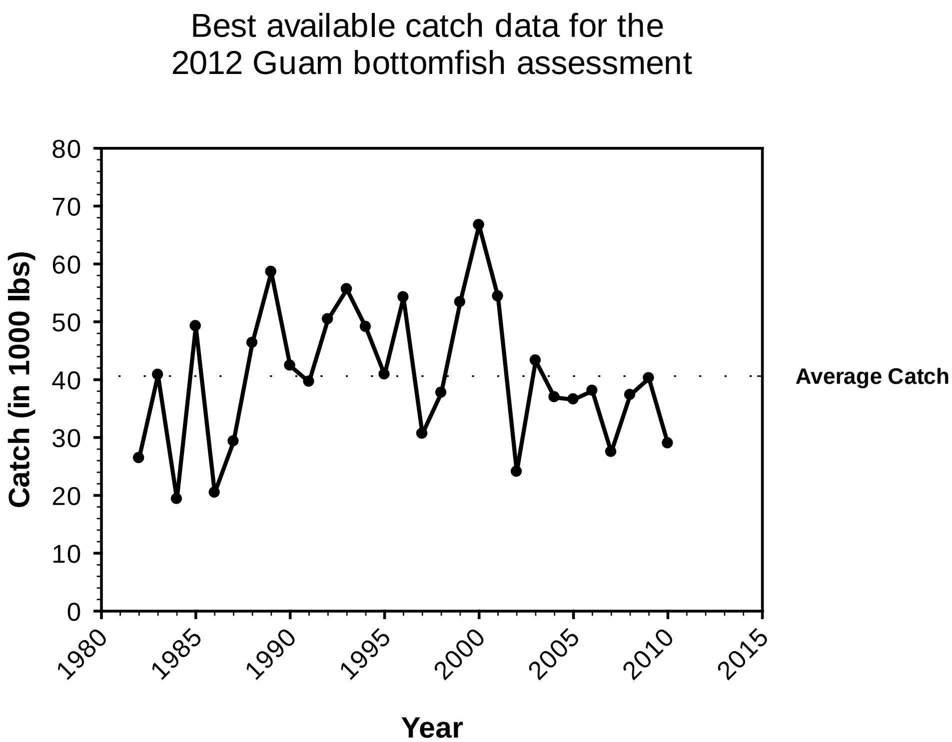

Figure 10. Best available catch data for the 2012 Guam bottomfish assessment update.

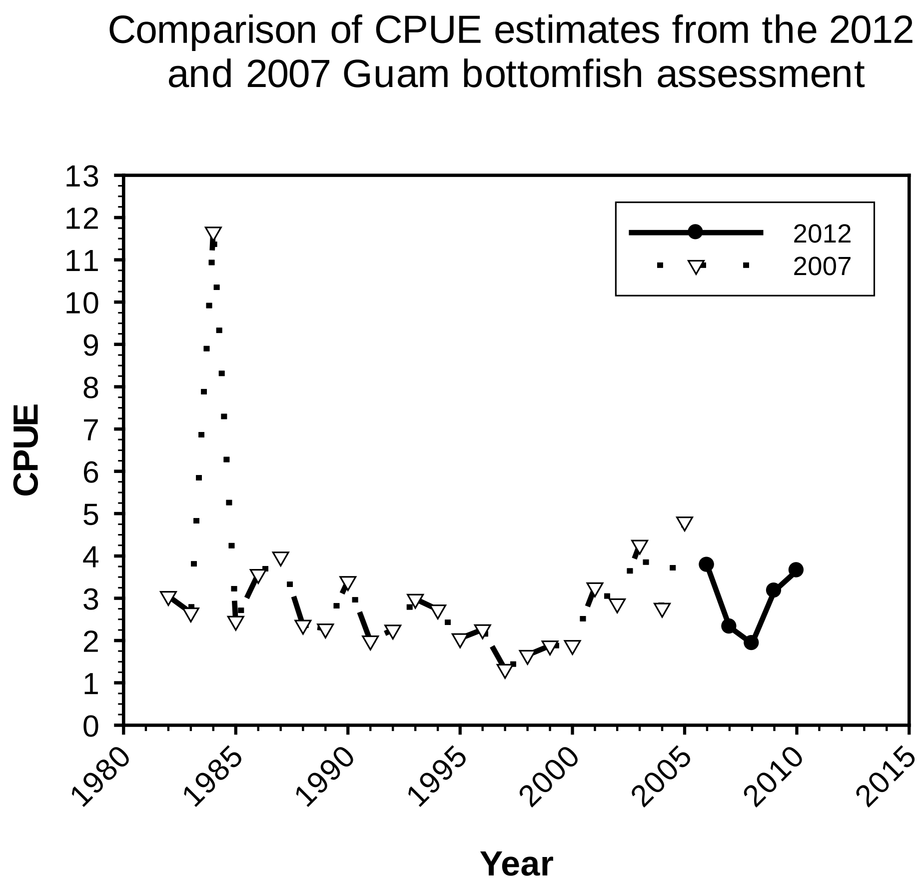

Figure 11. Comparison of CPUE estimates from the 2012 update and the 2007 Guam bottomfish assessment.

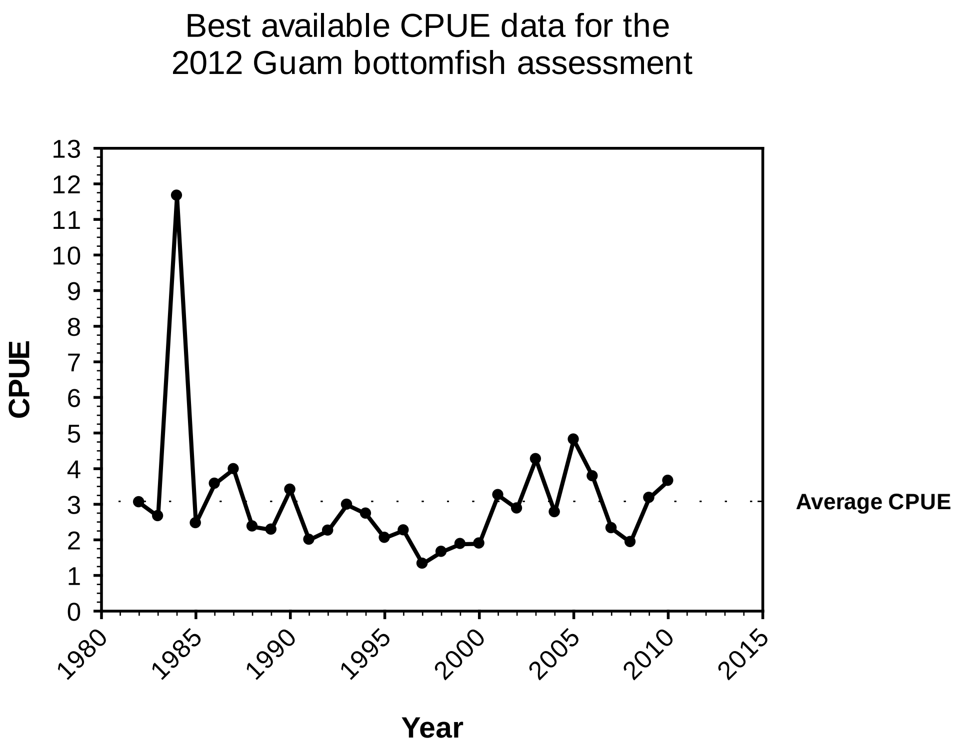

Figure 12. Best available CPUE data for the 2012 Guam bottomfish assessment update.

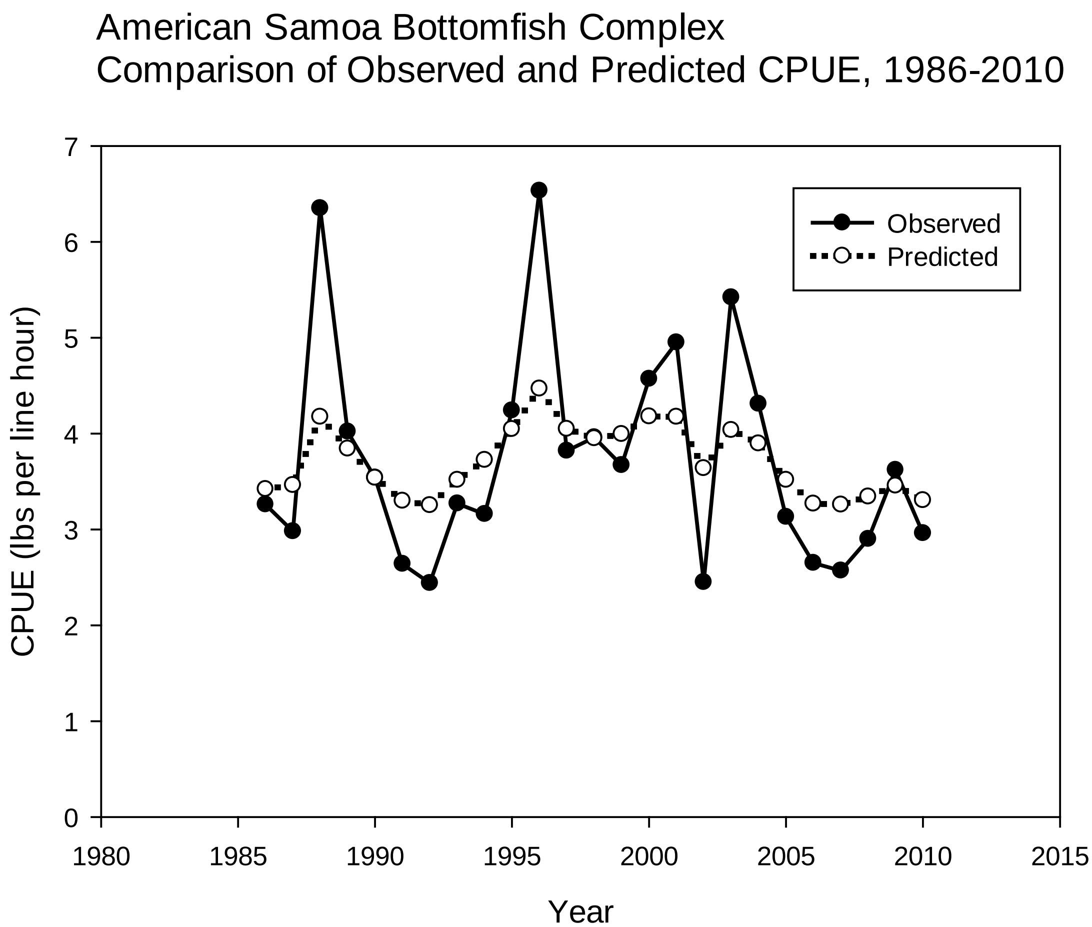

Figure 13. American Samoa bottomfish complex: Comparison of observed and predicted CPUE, 1986-2010.

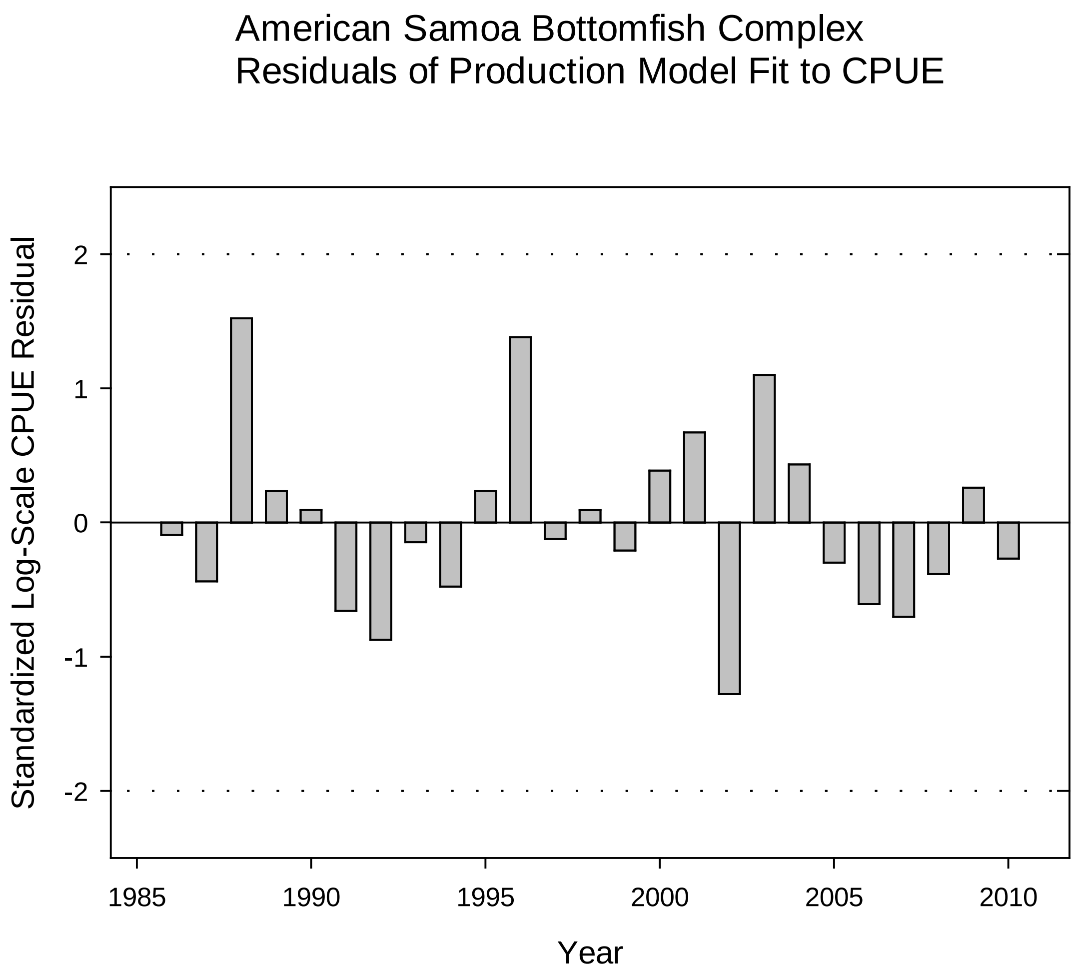

Figure 14. American Samoa bottomfish complex: Residuals of production model fit to CPUE.

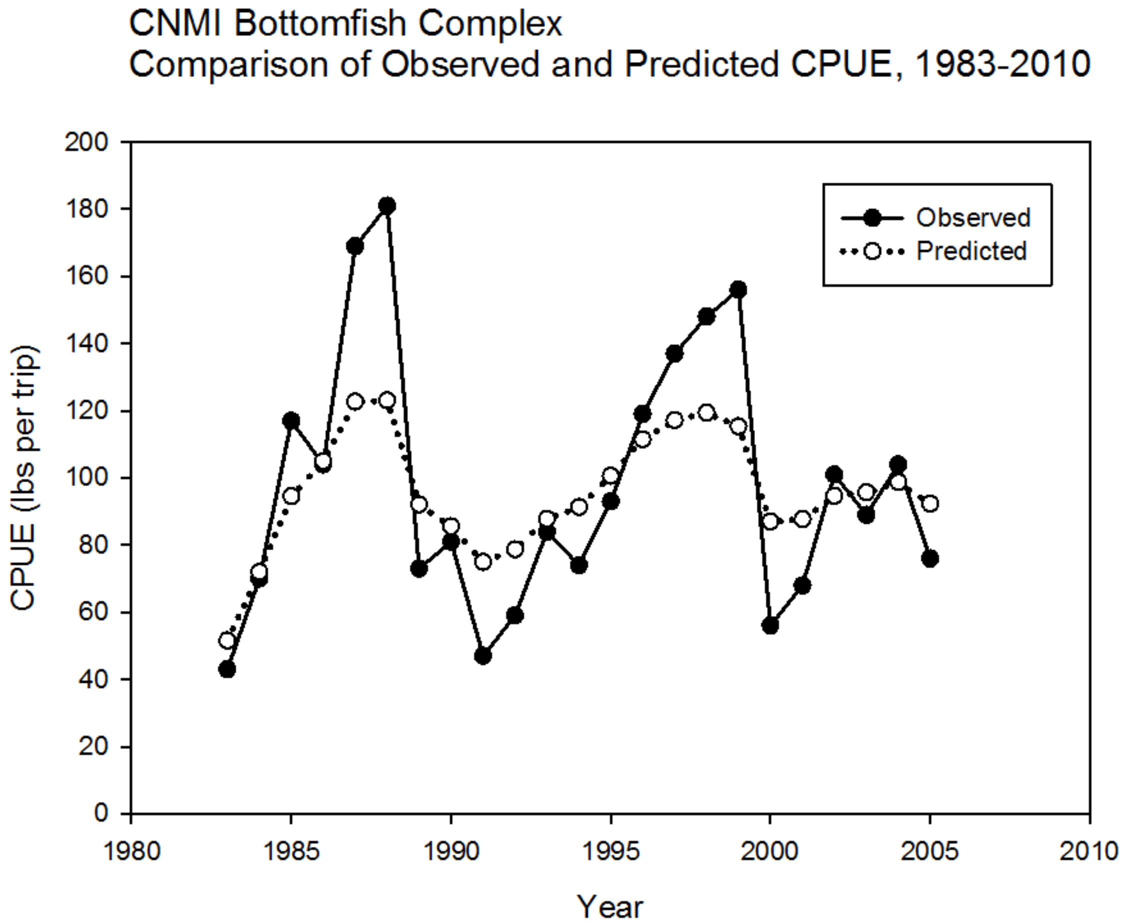

Figure 15. CNMI bottomfish complex: Comparison of observed and predicted CPUE, 1986-2010.

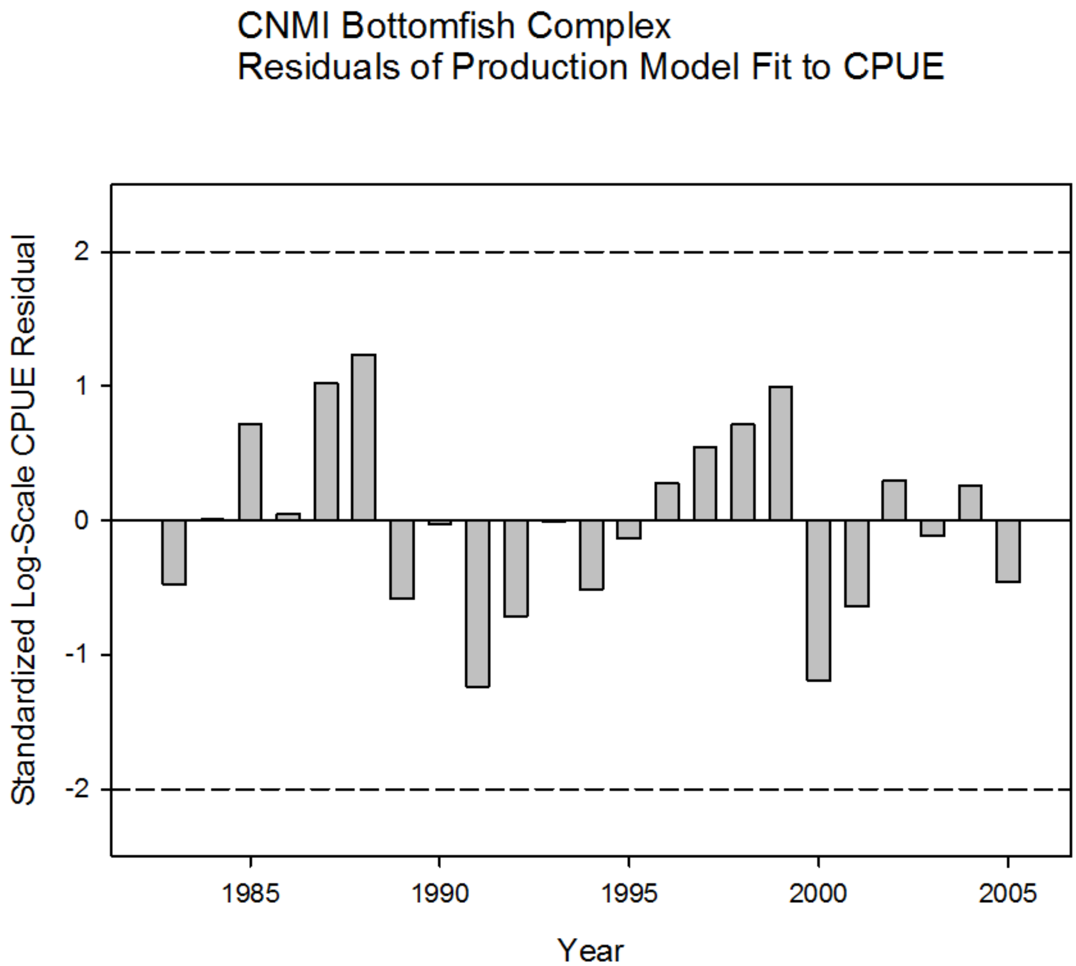

Figure 16. CNMI bottomfish complex: Residuals of production model fit to CPUE.

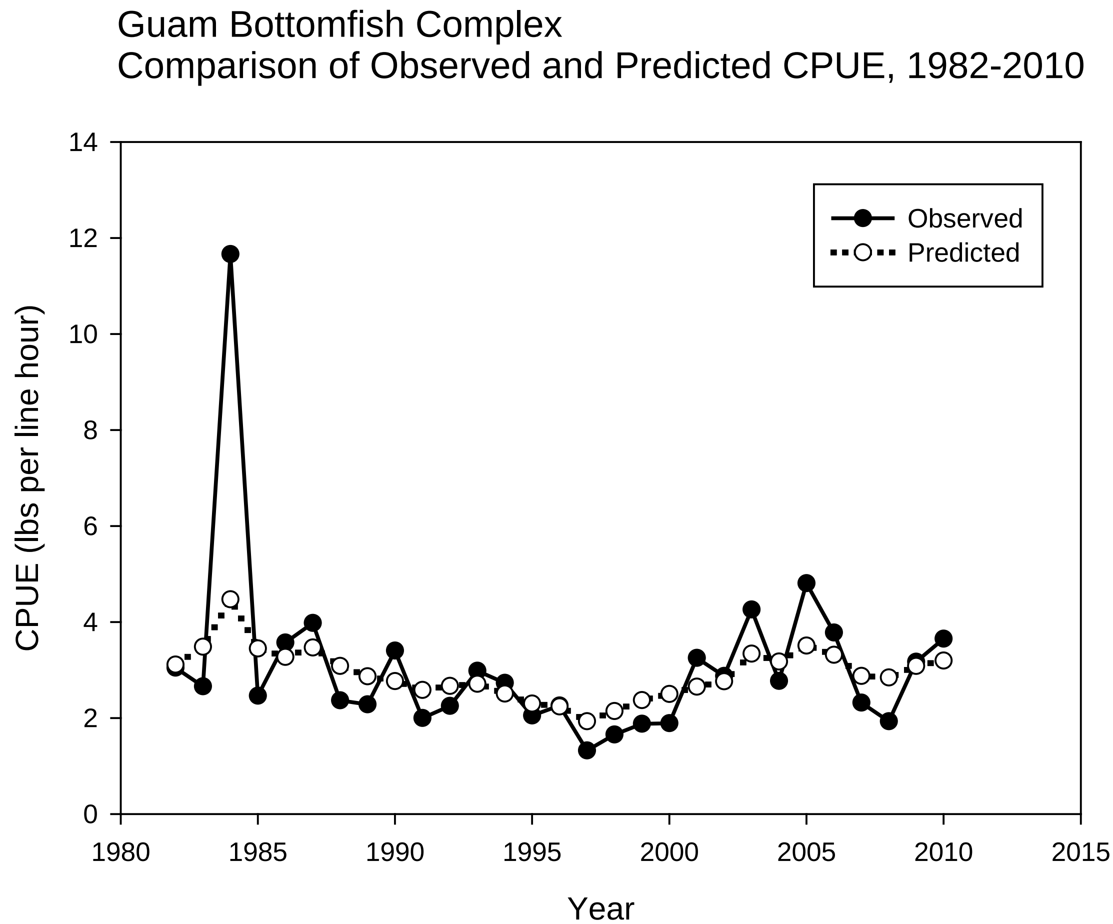

Figure 17. Guam bottomfish complex: Comparison of observed and predicted CPUE, 1986-2010.

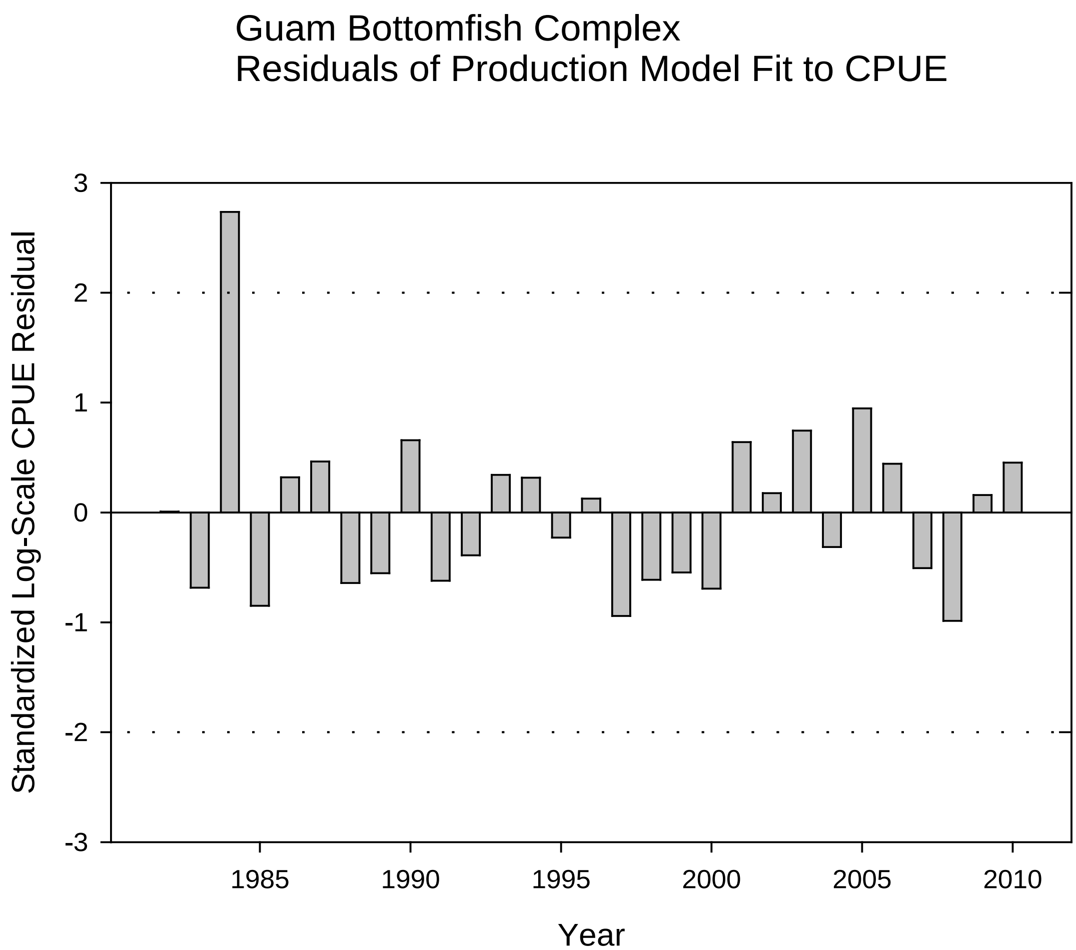

Figure 18. Guam bottomfish complex: Residuals of production model fit to CPUE.

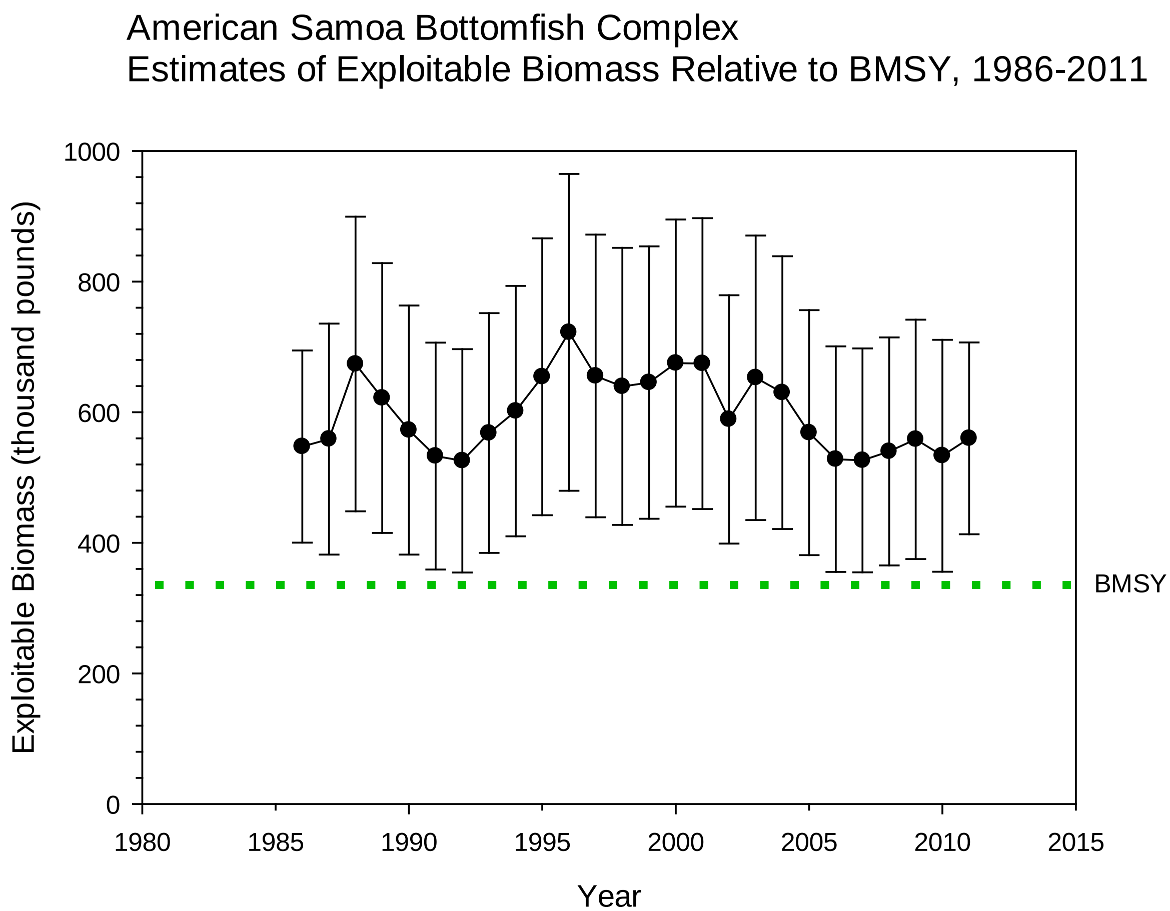

Figure 19. American Samoa bottomfish complex: Estimates of exploitable biomass relative to BMSY, 1986-2011.

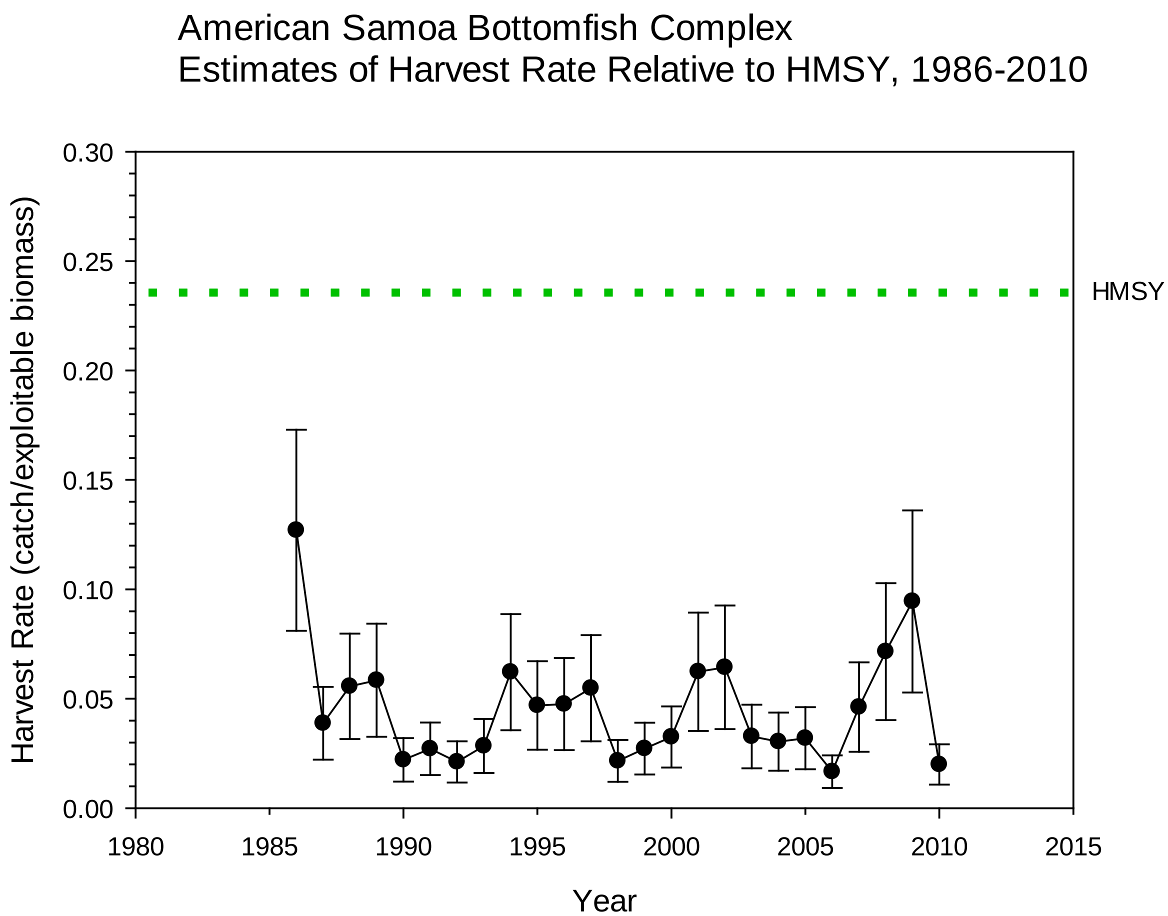

Figure 20. American Samoa bottomfish complex: Estimates of harvest rate relative to HMSY, 1986-2010.

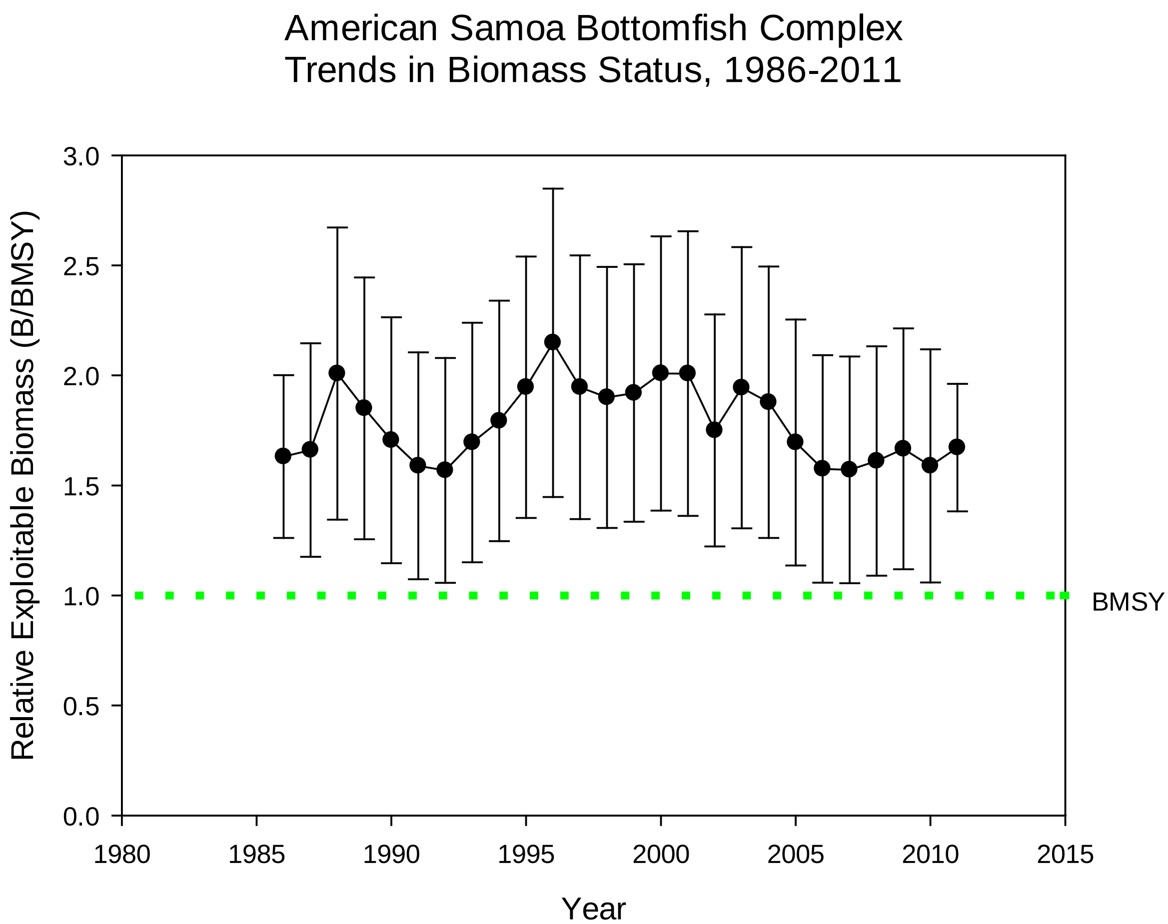

Figure 21. American Samoa bottomfish complex: Trends in biomass status, 1986-2011.

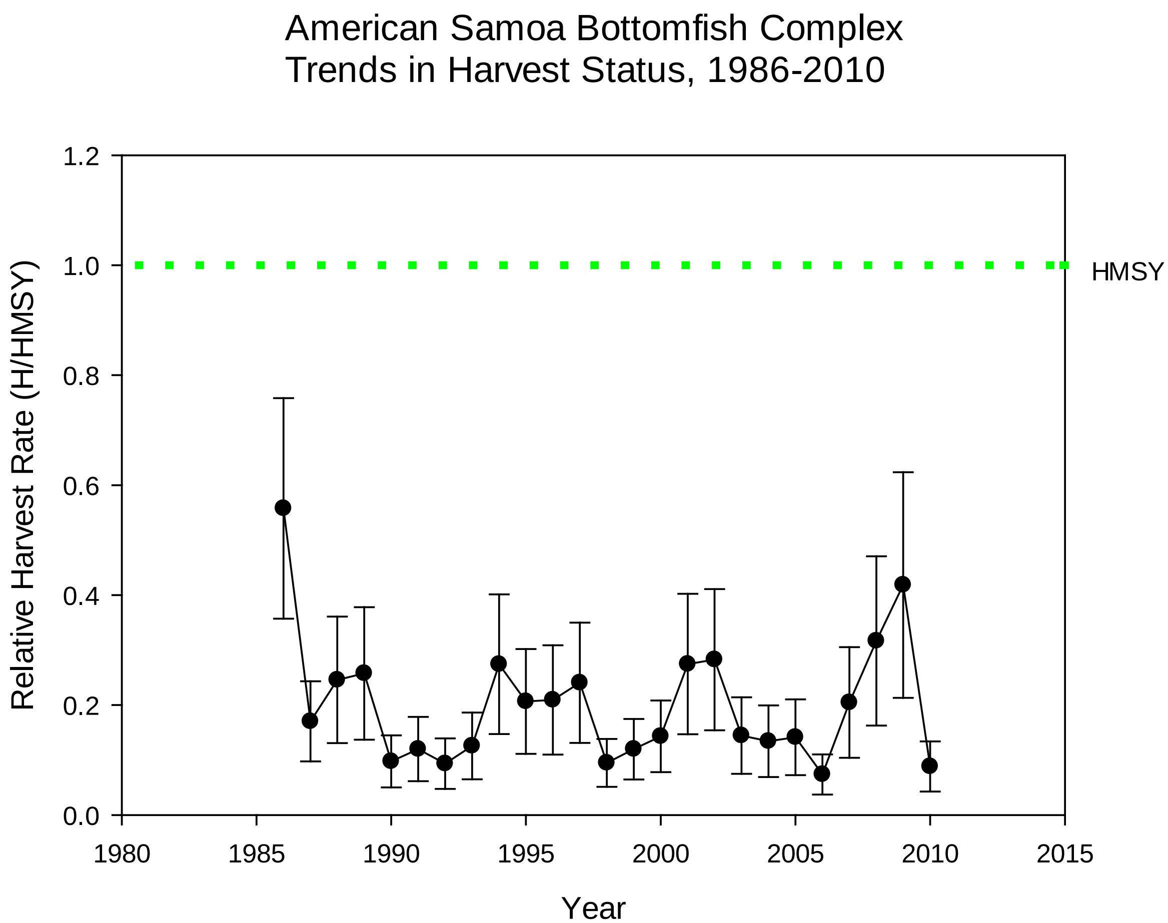

Figure 22. American Samoa bottomfish complex: Trends in harvest status, 1986-2010.

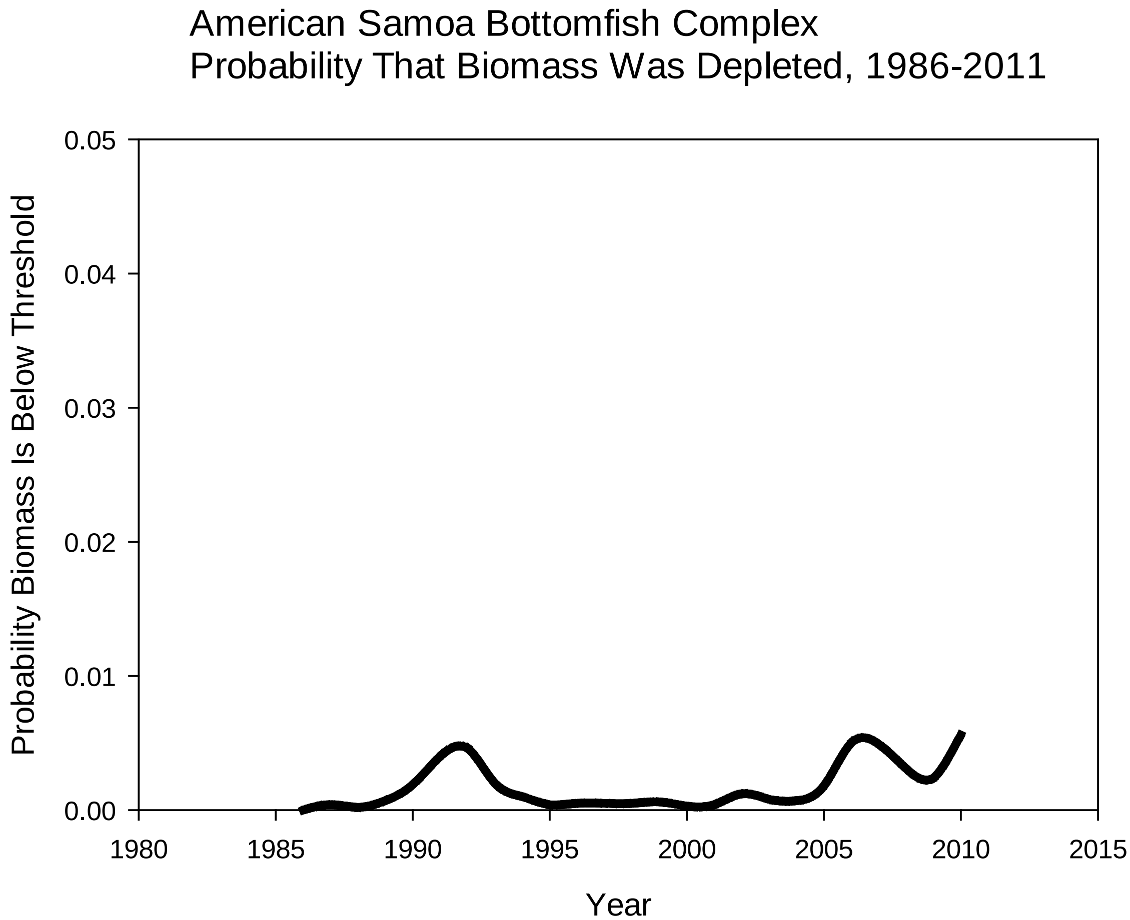

Figure 23. American Samoa bottomfish complex: Probability that biomass was depleted, 1986-2011.

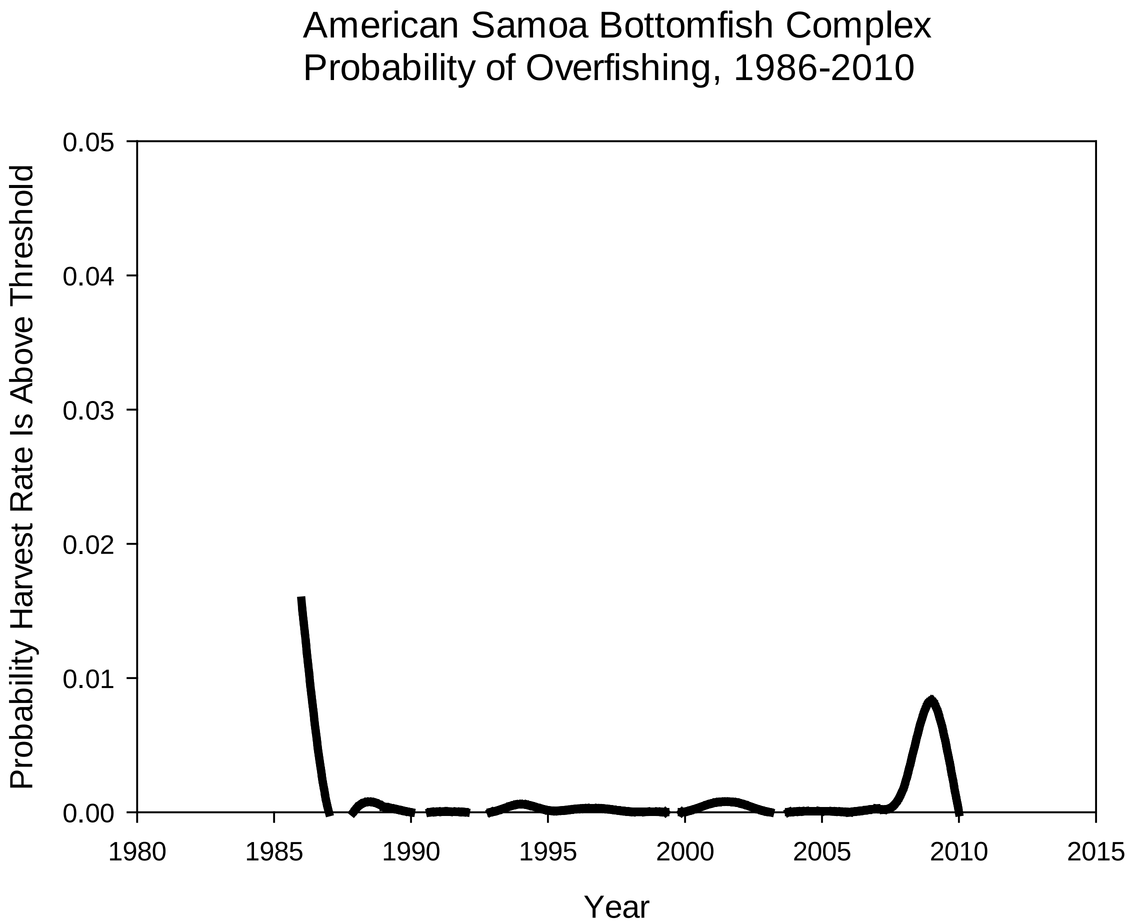

Figure 24. American Samoa bottomfish complex: Probability of overfishing, 1986-2010.

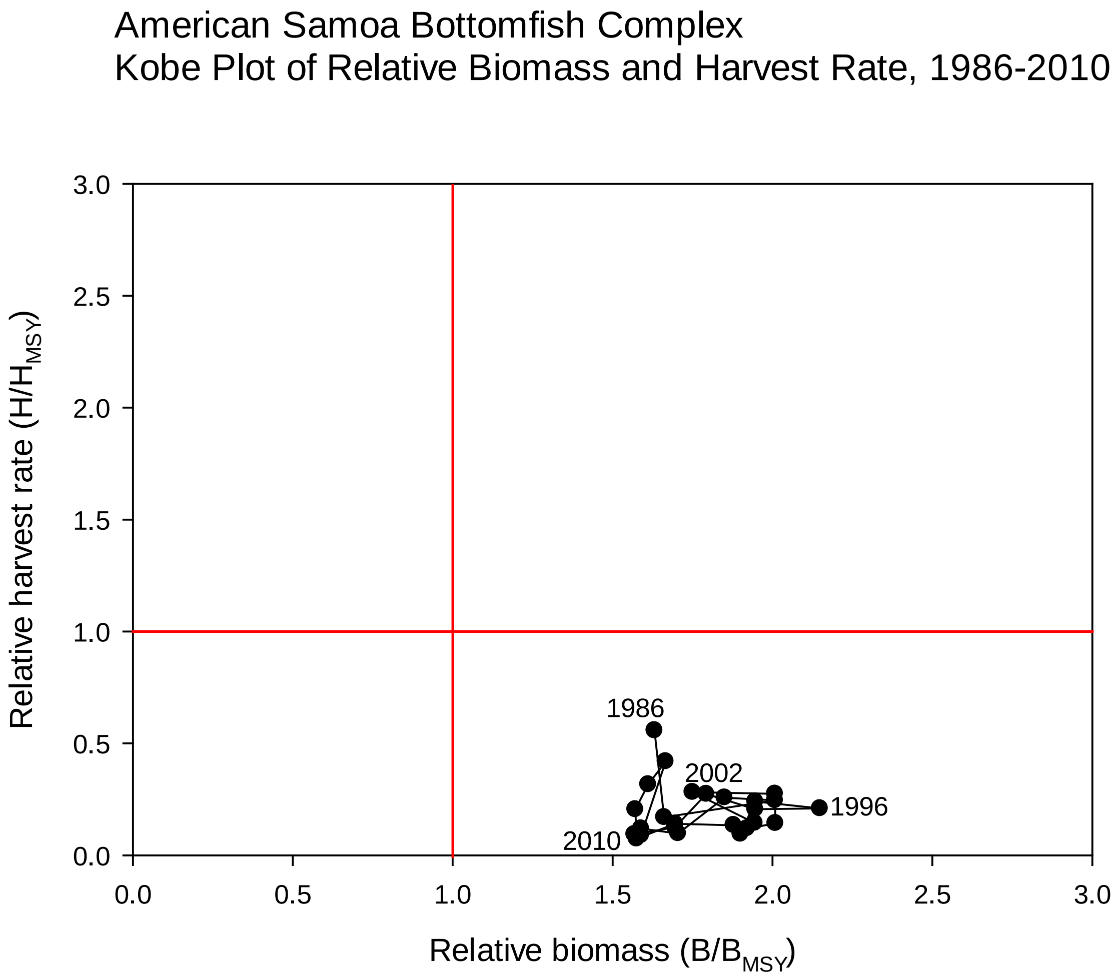

Figure 25. American Samoa bottomfish complex: Kobe plot of relative biomass and harvest rate, 1986-2010.

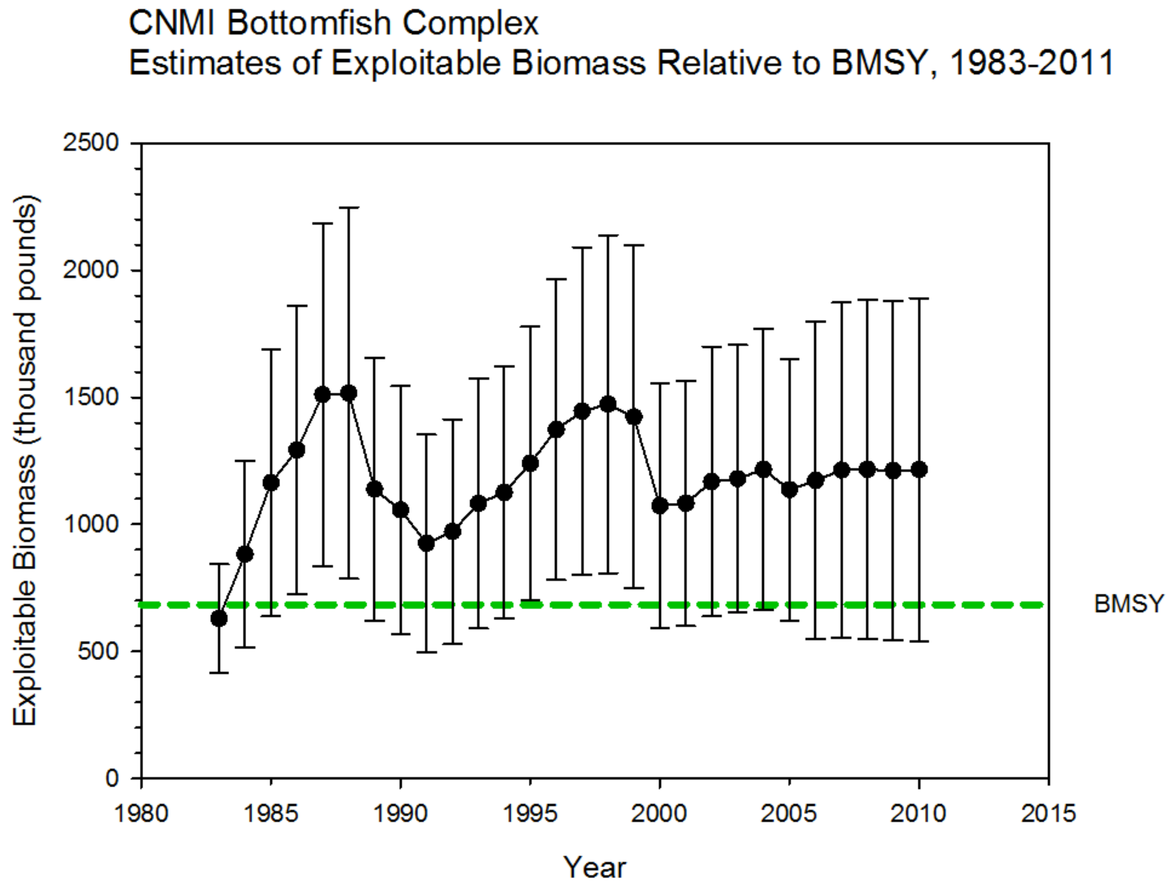

Figure 26. CNMI bottomfish complex: Estimates of exploitable biomass relative to BMSY, 1983-2011.

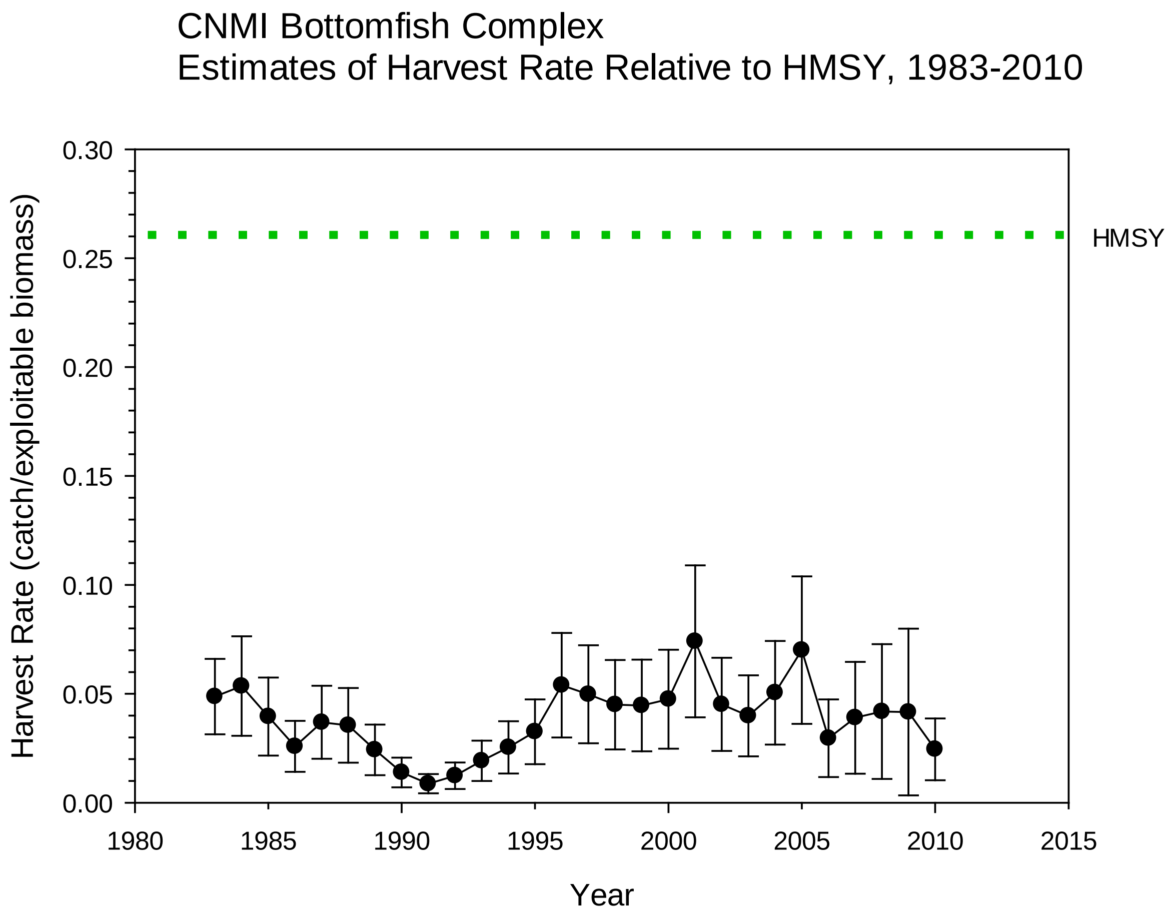

Figure 27. CNMI bottomfish complex: Estimates of harvest rate relative to HMSY, 1983-2010.

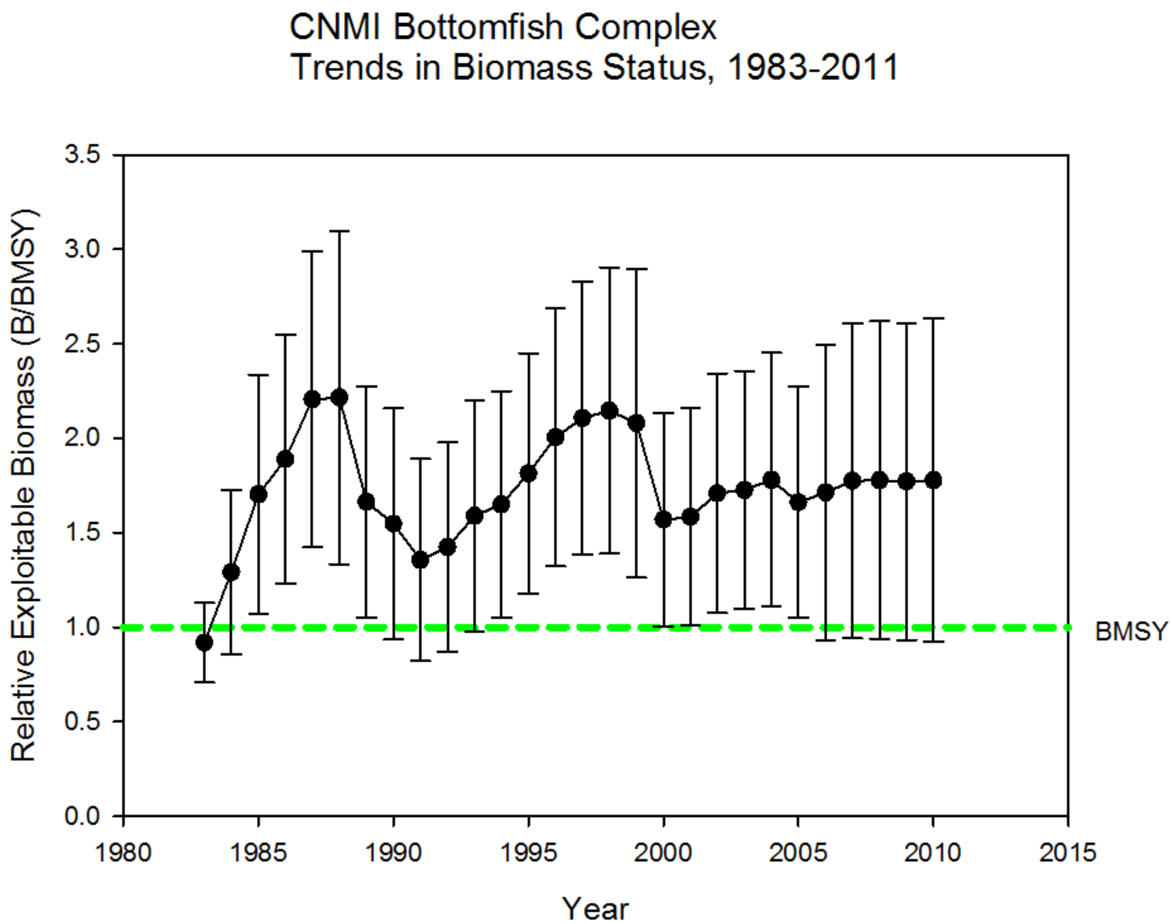

Figure 28. CNMI bottomfish complex: Trends in biomass status, 1983-2011.

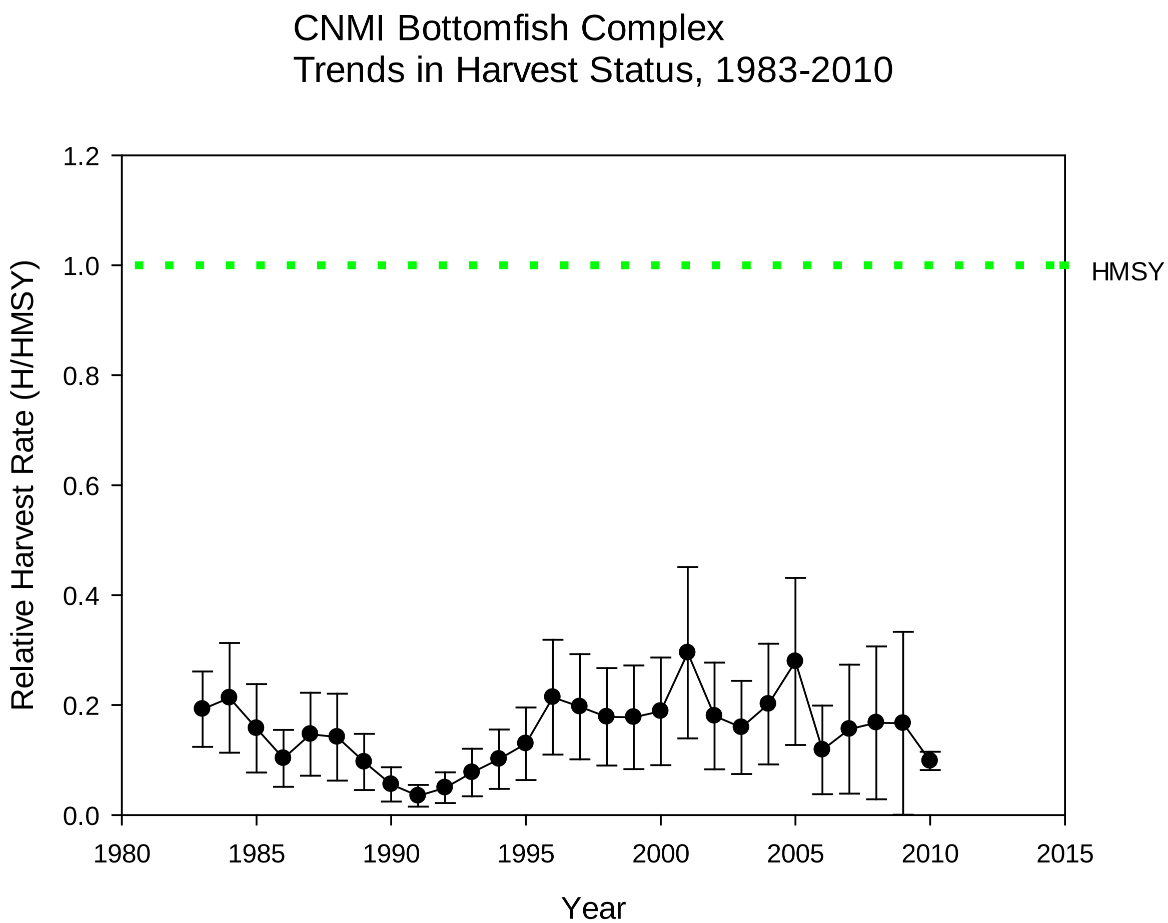

Figure 29. CNMI bottomfish complex: Trends in harvest status, 1983-2010.

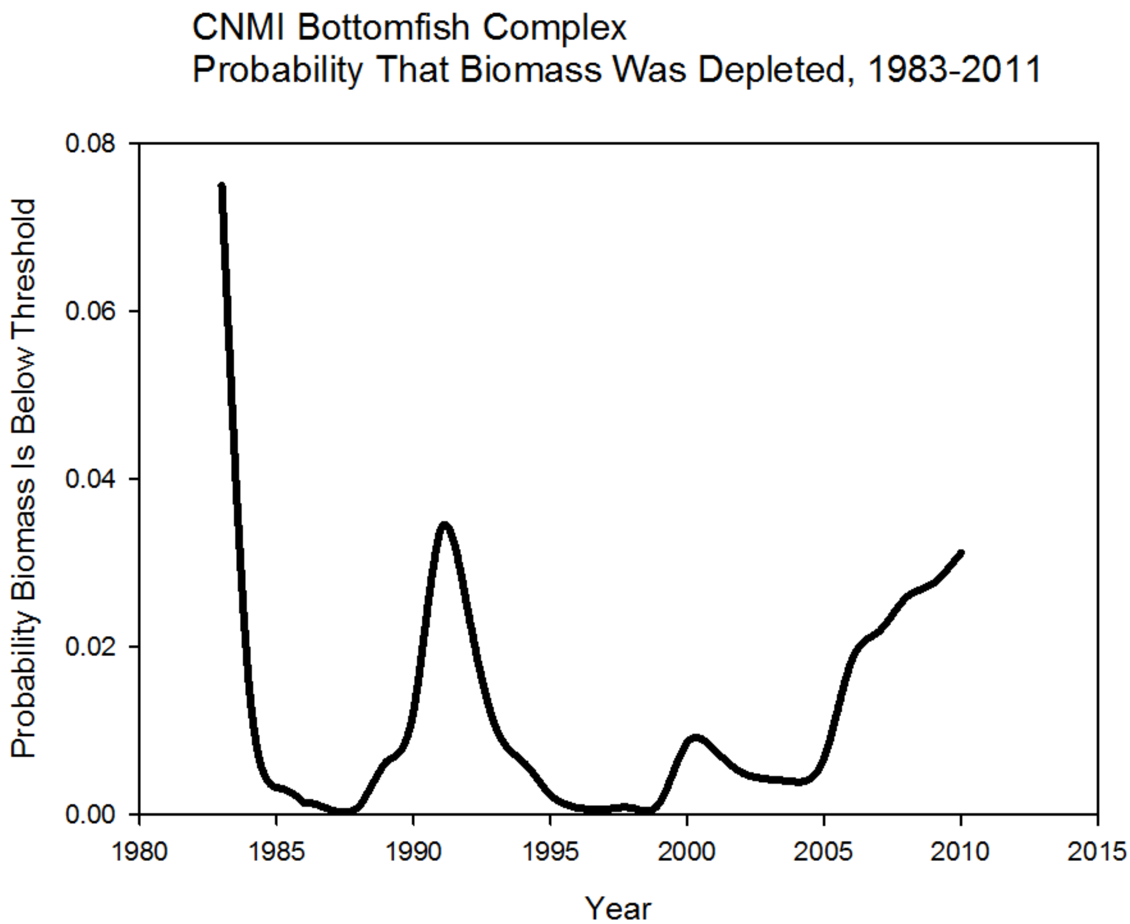

Figure 30. CNMI bottomfish complex: Probability that biomass was depleted, 1983-2011.

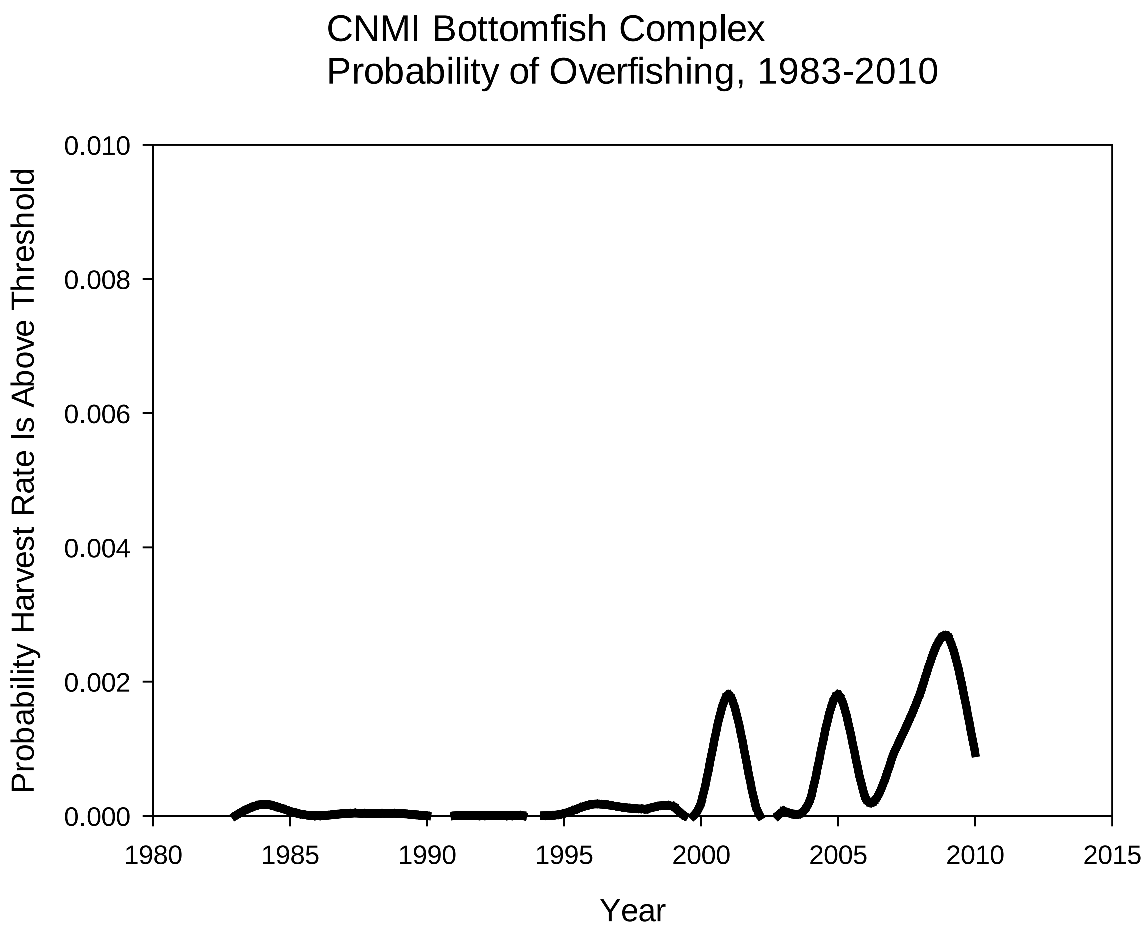

Figure 31. CNMI bottomfish complex: Probability of overfishing, 1983-2010.

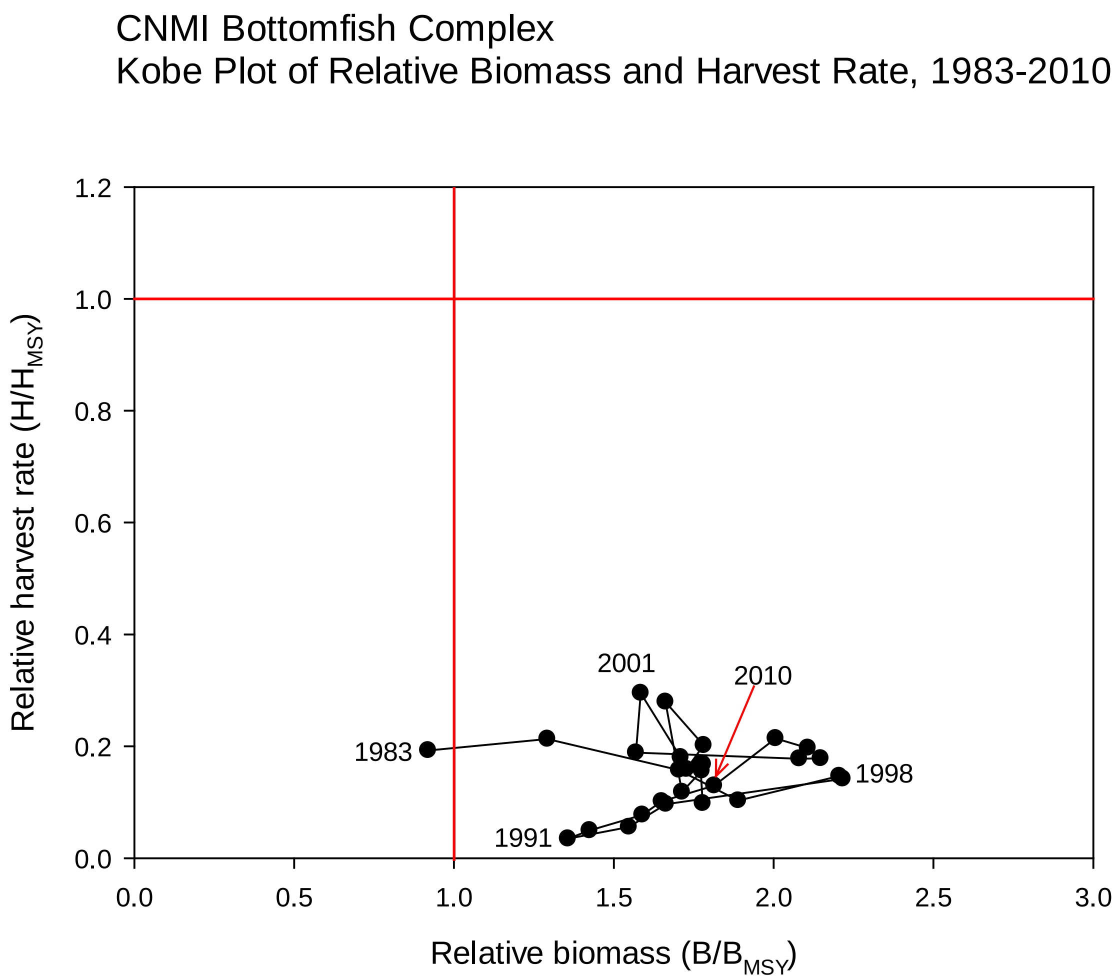

Figure 32. CNMI bottomfish complex: Kobe plot of relative biomass and harvest rate, 1983-2010.

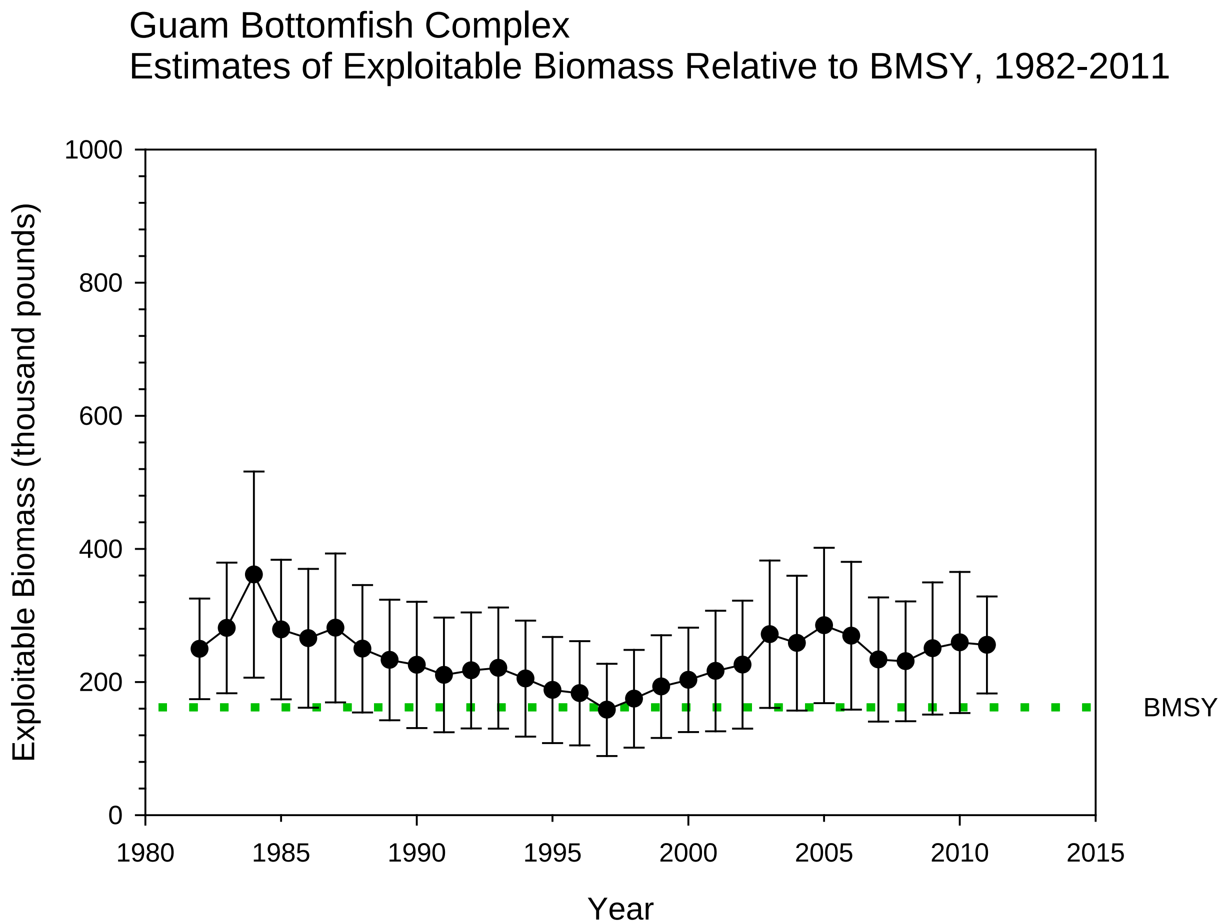

Figure 33. Guam bottomfish complex: Estimates of exploitable biomass relative to BMSY, 1982-2011.

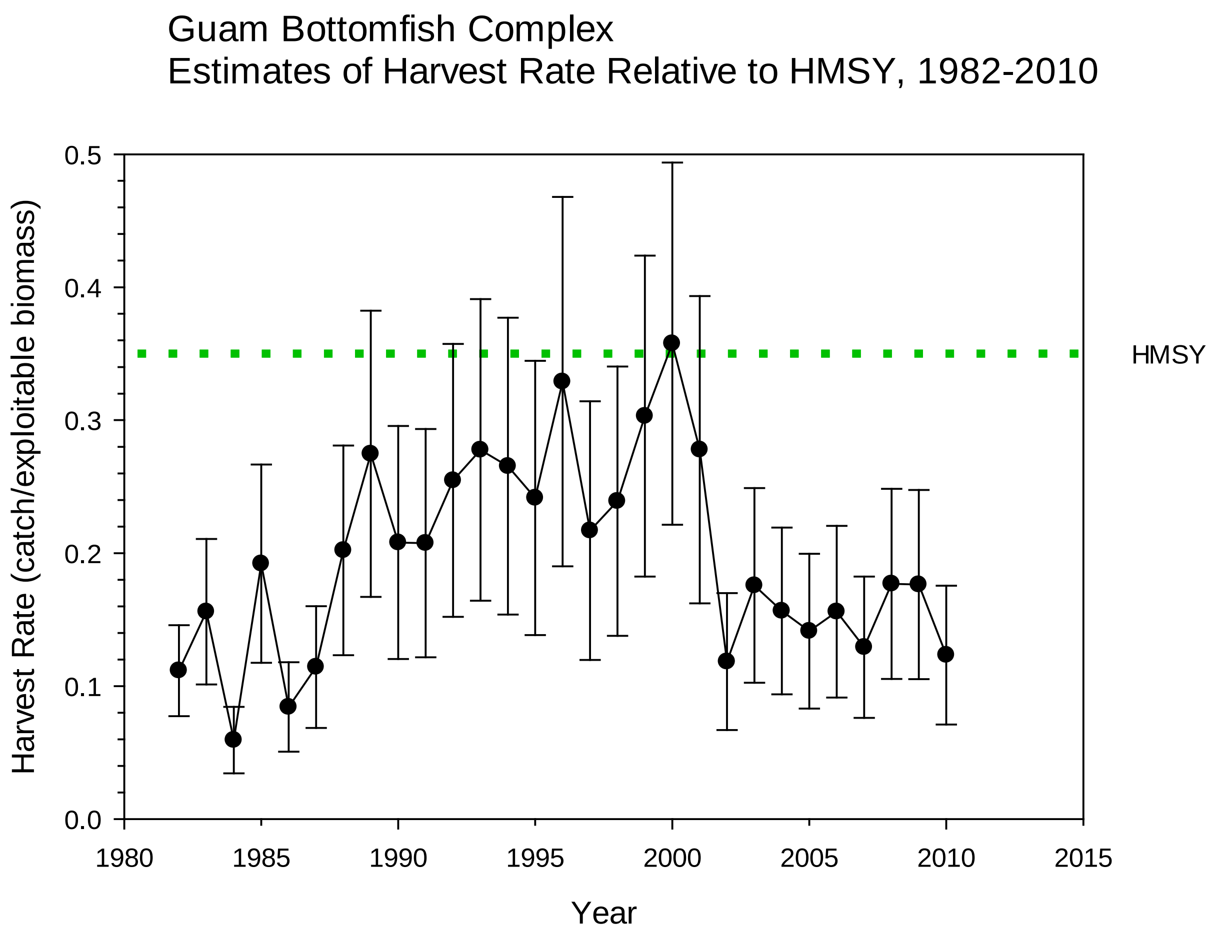

Figure 34. Guam bottomfish complex: Estimates of harvest rate relative to HMSY, 1982-2010.

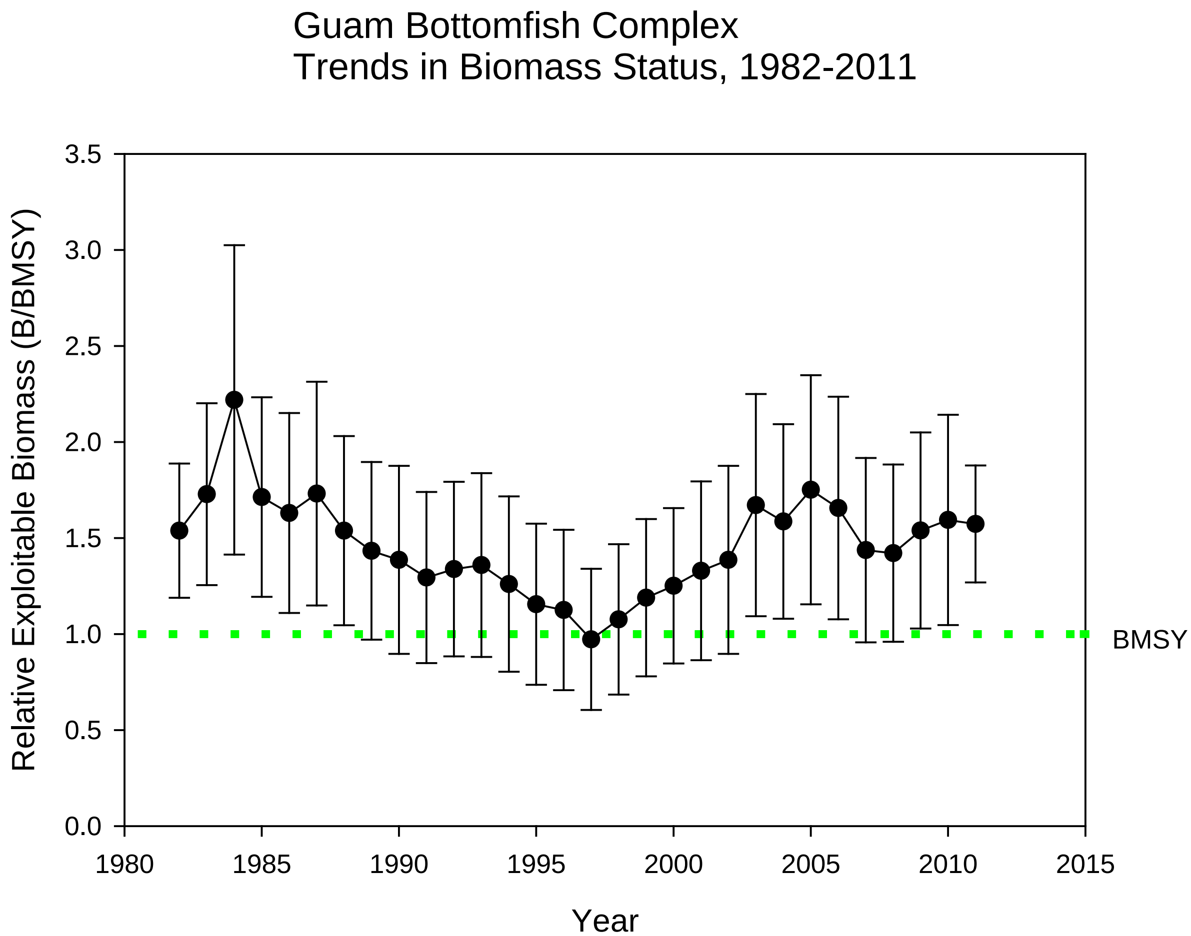

Figure 35. Guam bottomfish complex: Trends in biomass status, 1982-2011.

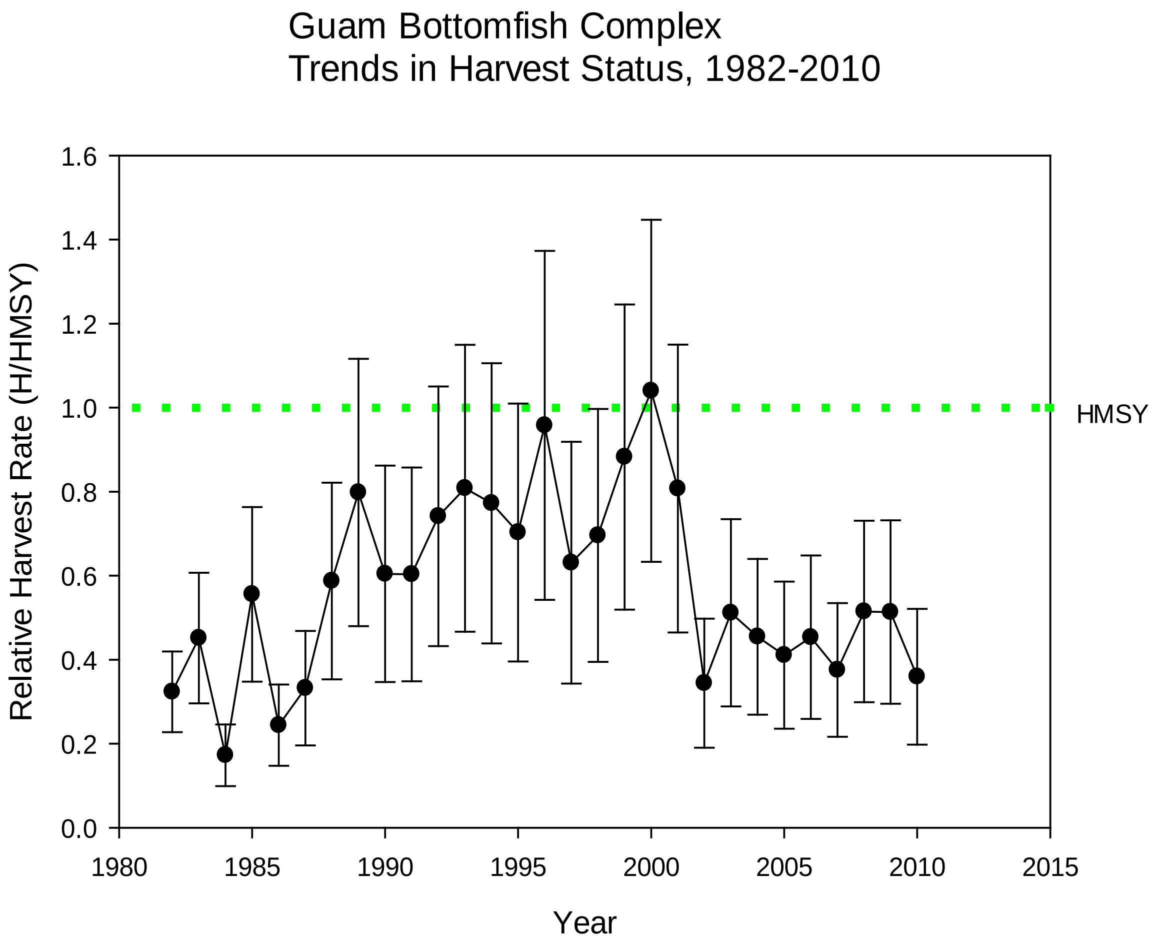

Figure 36. Guam bottomfish complex: Trends in harvest status, 1982-2010.

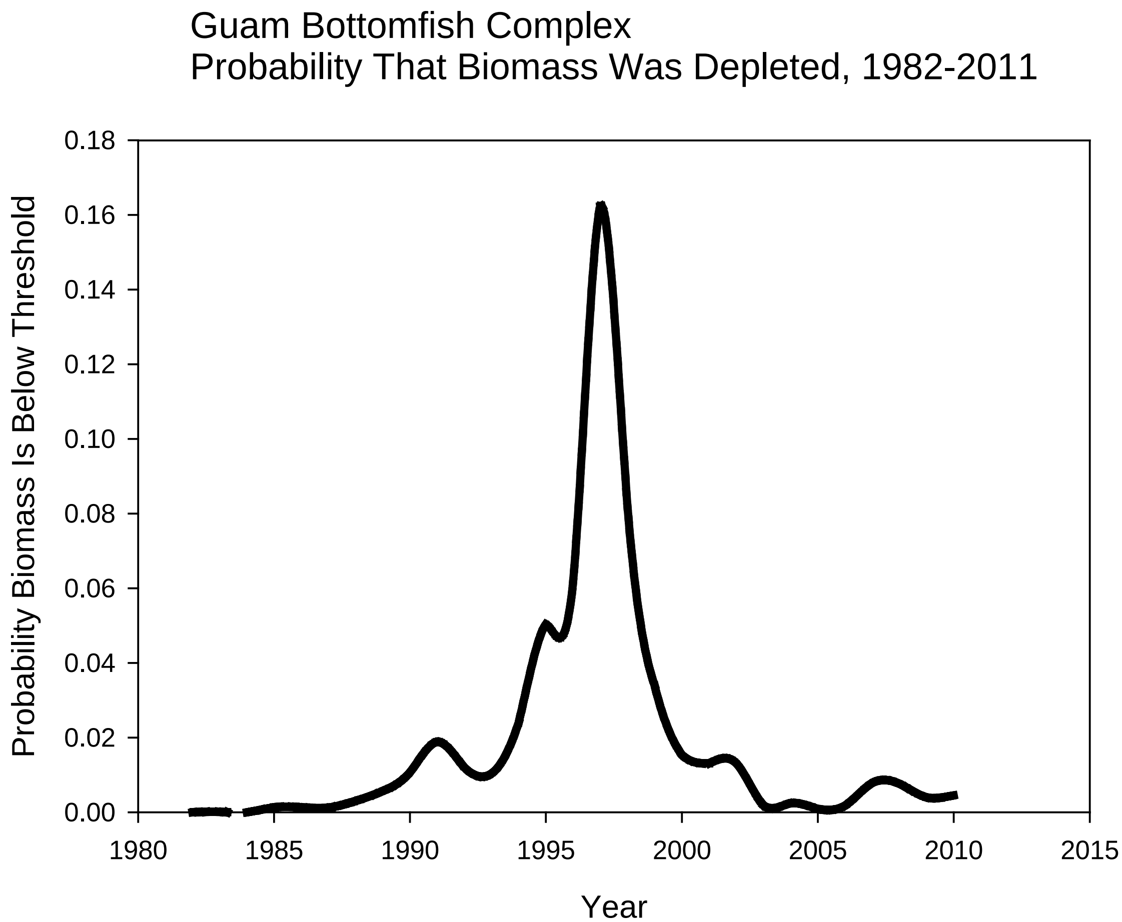

Figure 37. Guam bottomfish complex: Probability that biomass was depleted, 1982-2011.

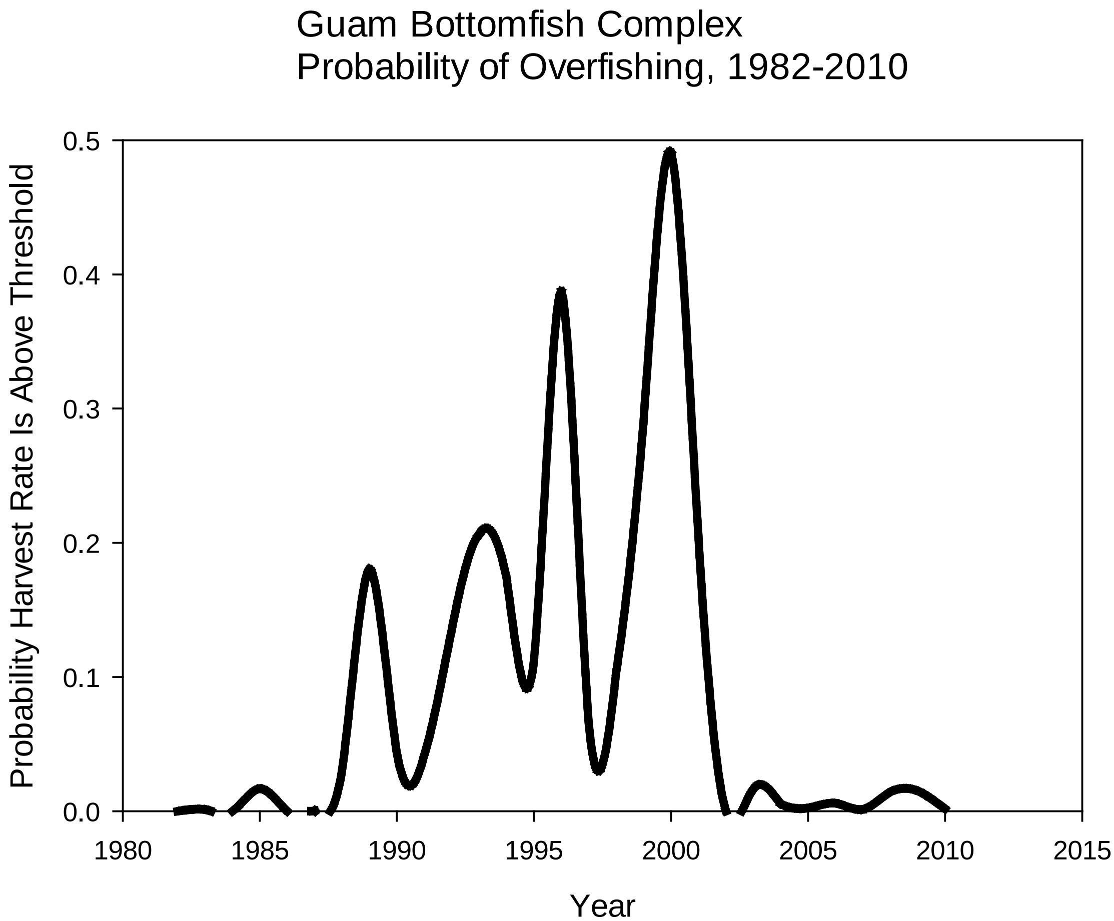

Figure 38. Guam bottomfish complex: Probability of overfishing, 1982-2010.

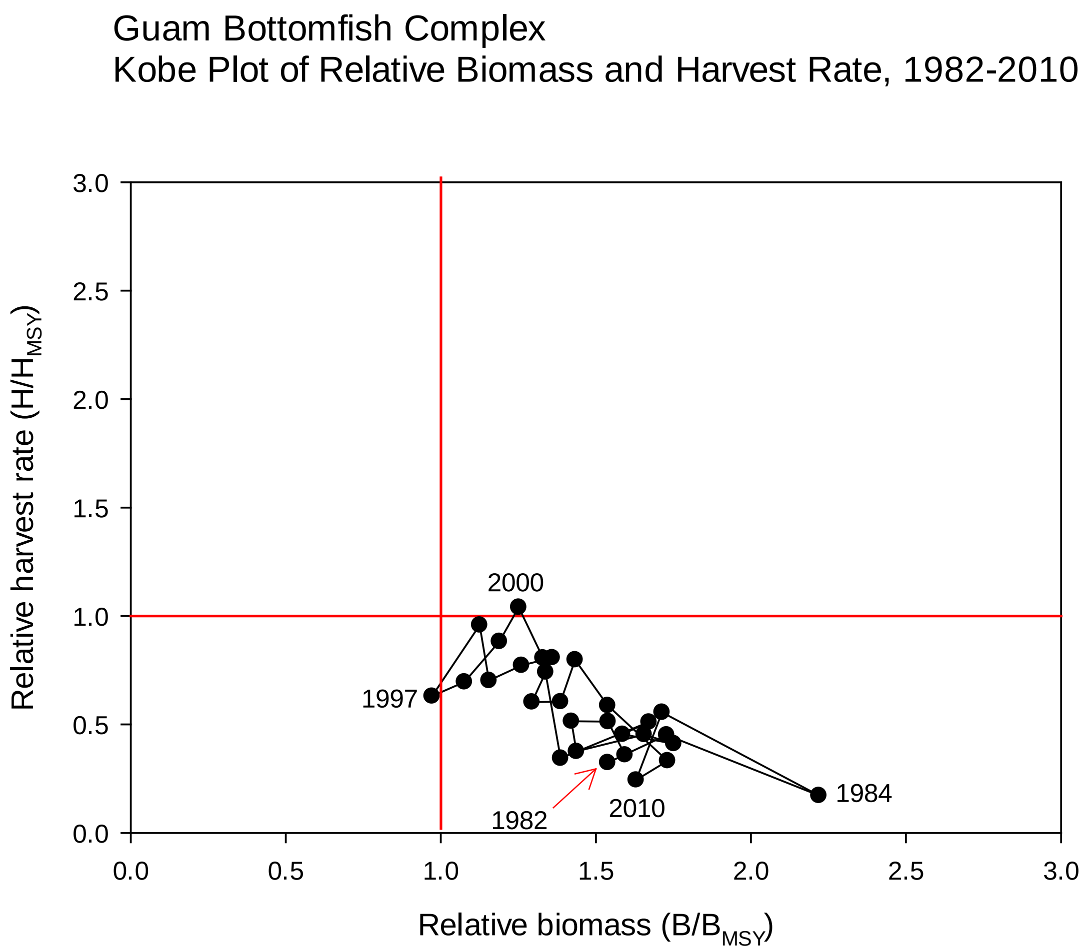

Figure 39. Guam bottomfish complex: Kobe plot of relative biomass and harvest rate, 1982-2010.

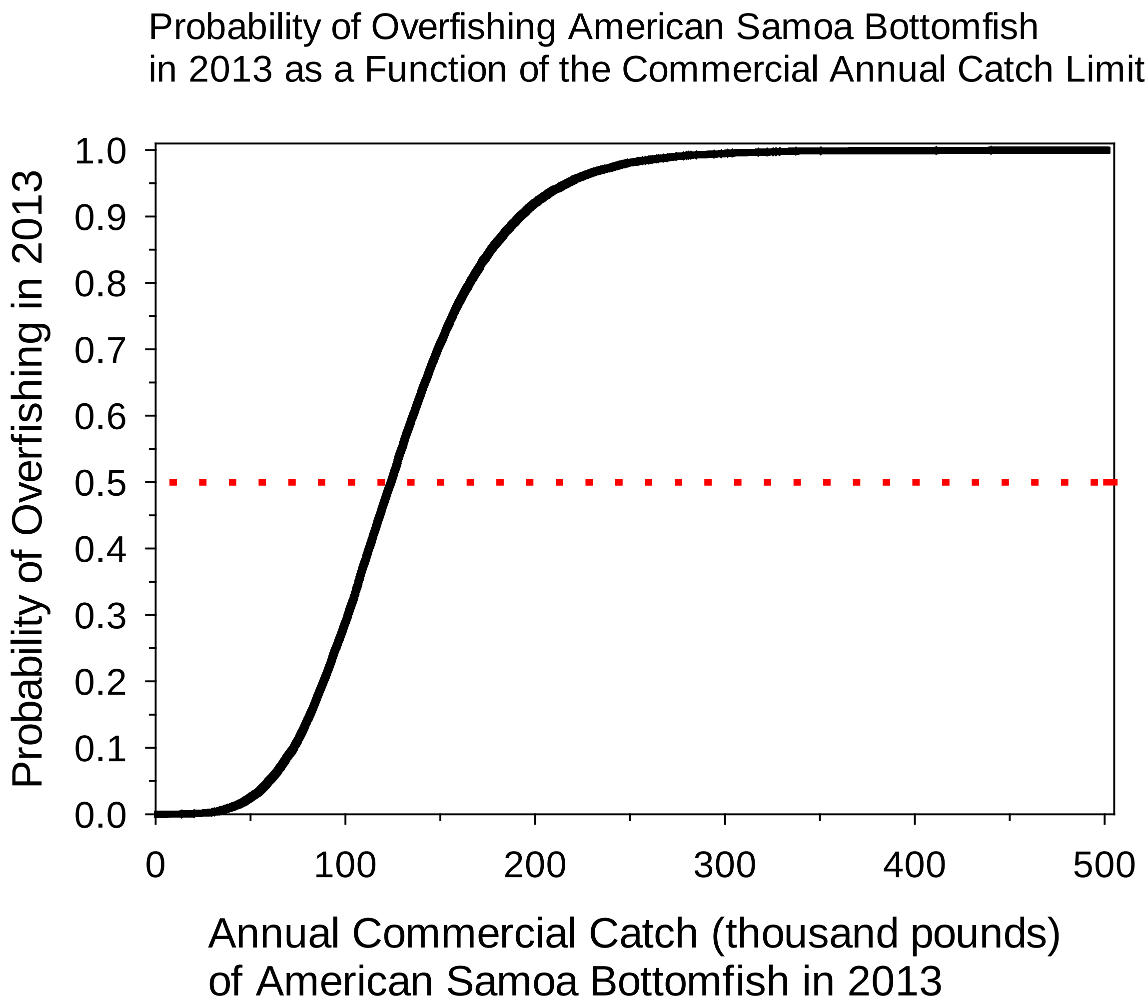

Figure 40. Probability of overfishing American Samoa bottomfish in 2013 as a function of the commercial annual catch limit.

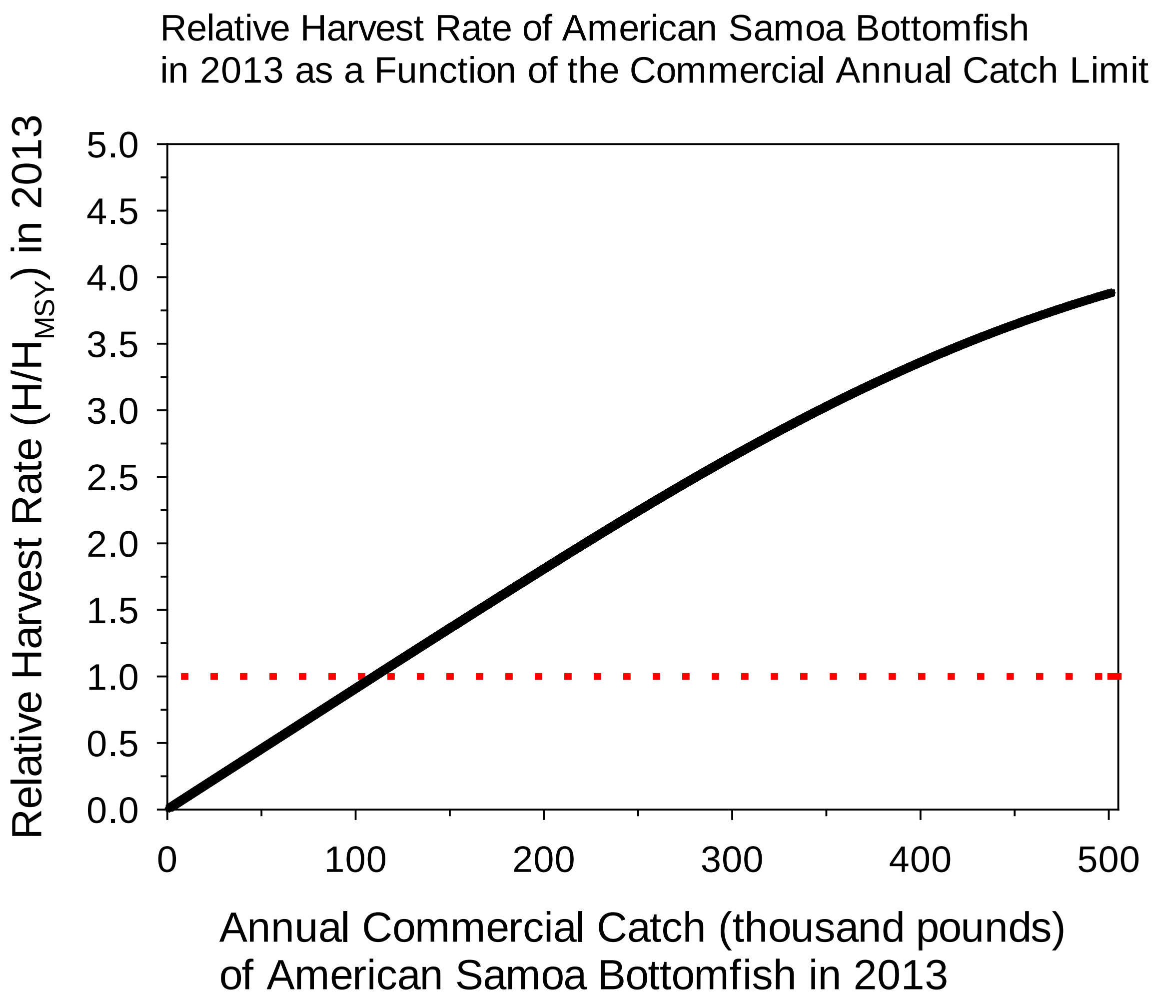

Figure 41. Relative harvest rate of American Samoa bottomfish in 2013 as a function of the commercial annual catch limit.

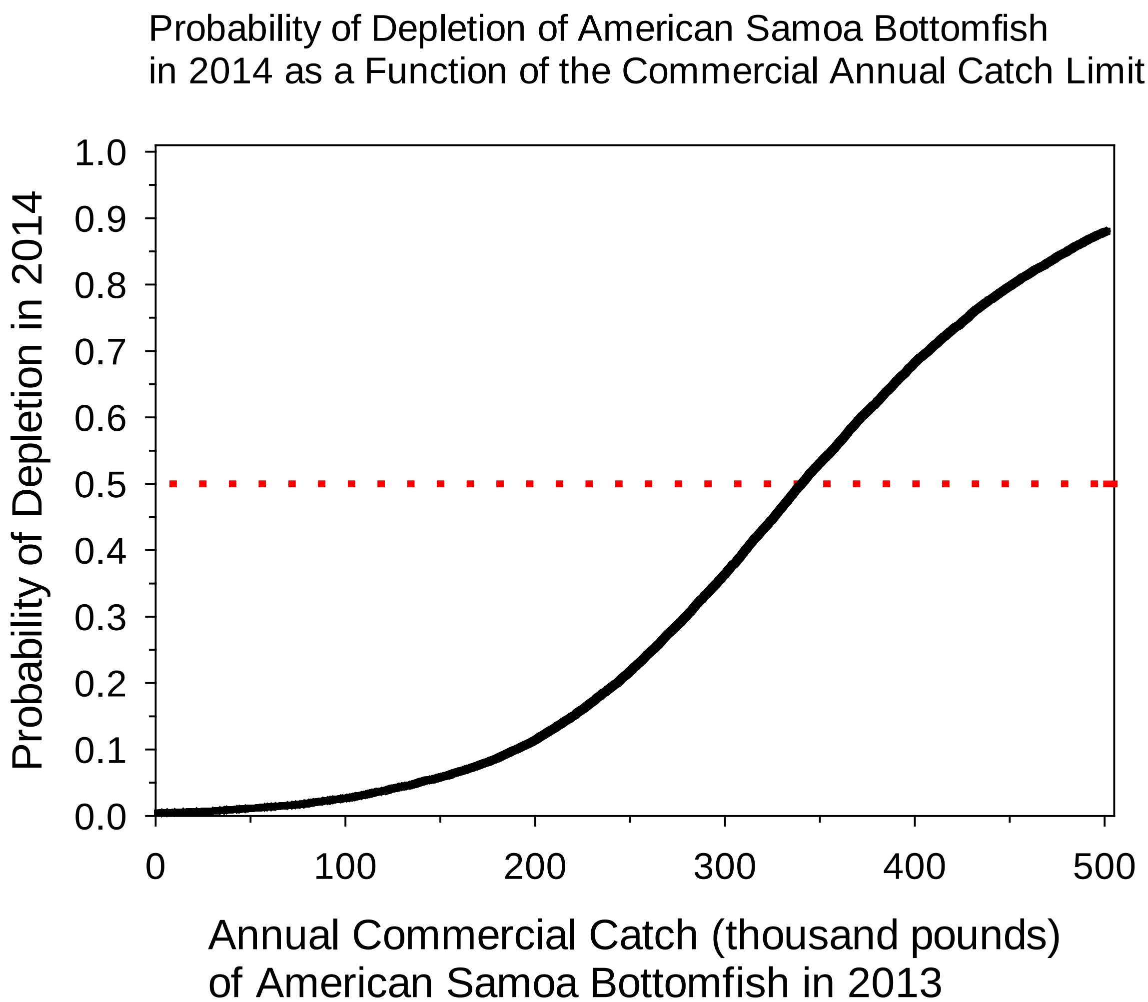

Figure 42. Probability of depletion of American Samoa bottomfish in 2014 as a function of the commercial annual catch limit.

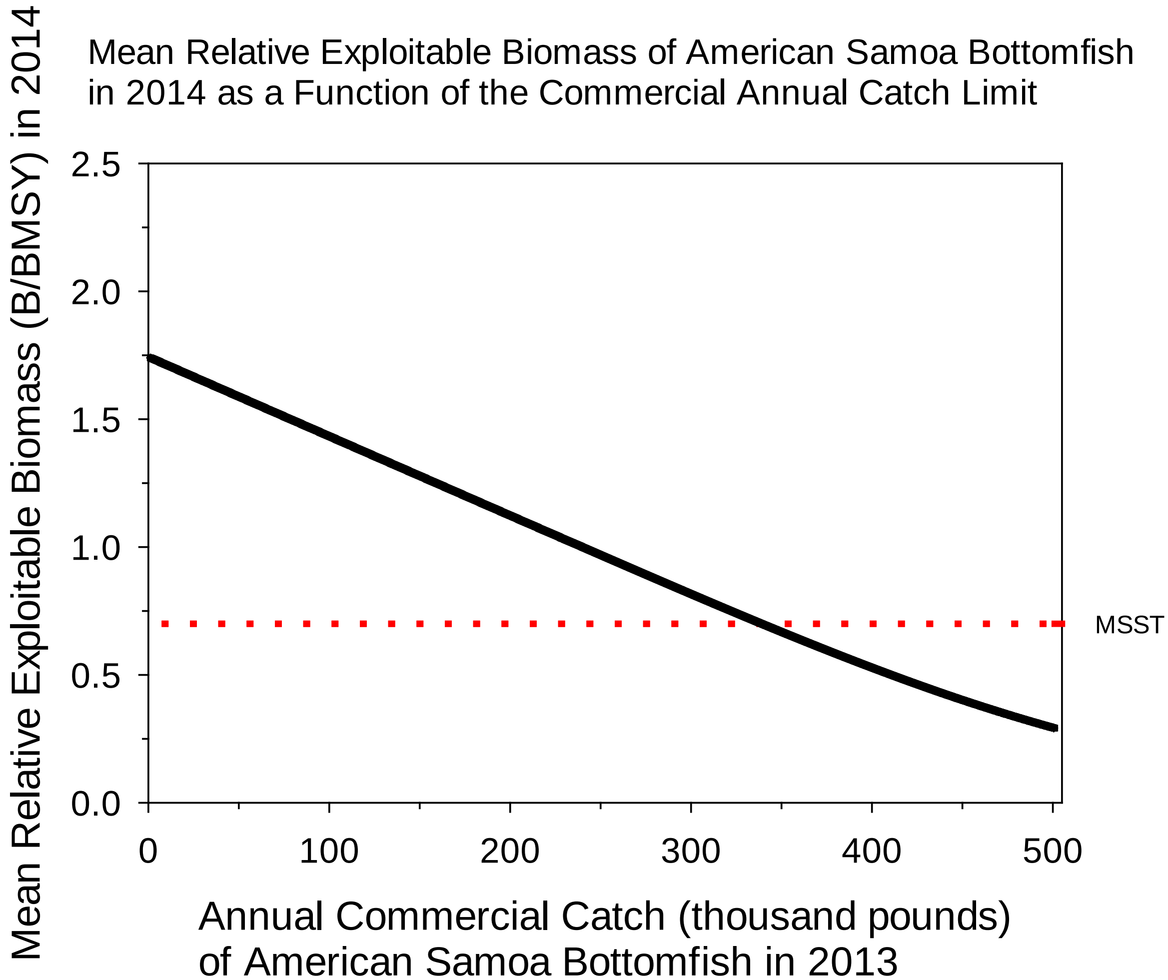

Figure 43. Mean relative exploitable biomass of American Samoa bottomfish in 2014 as a function of the commercial annual catch limit.

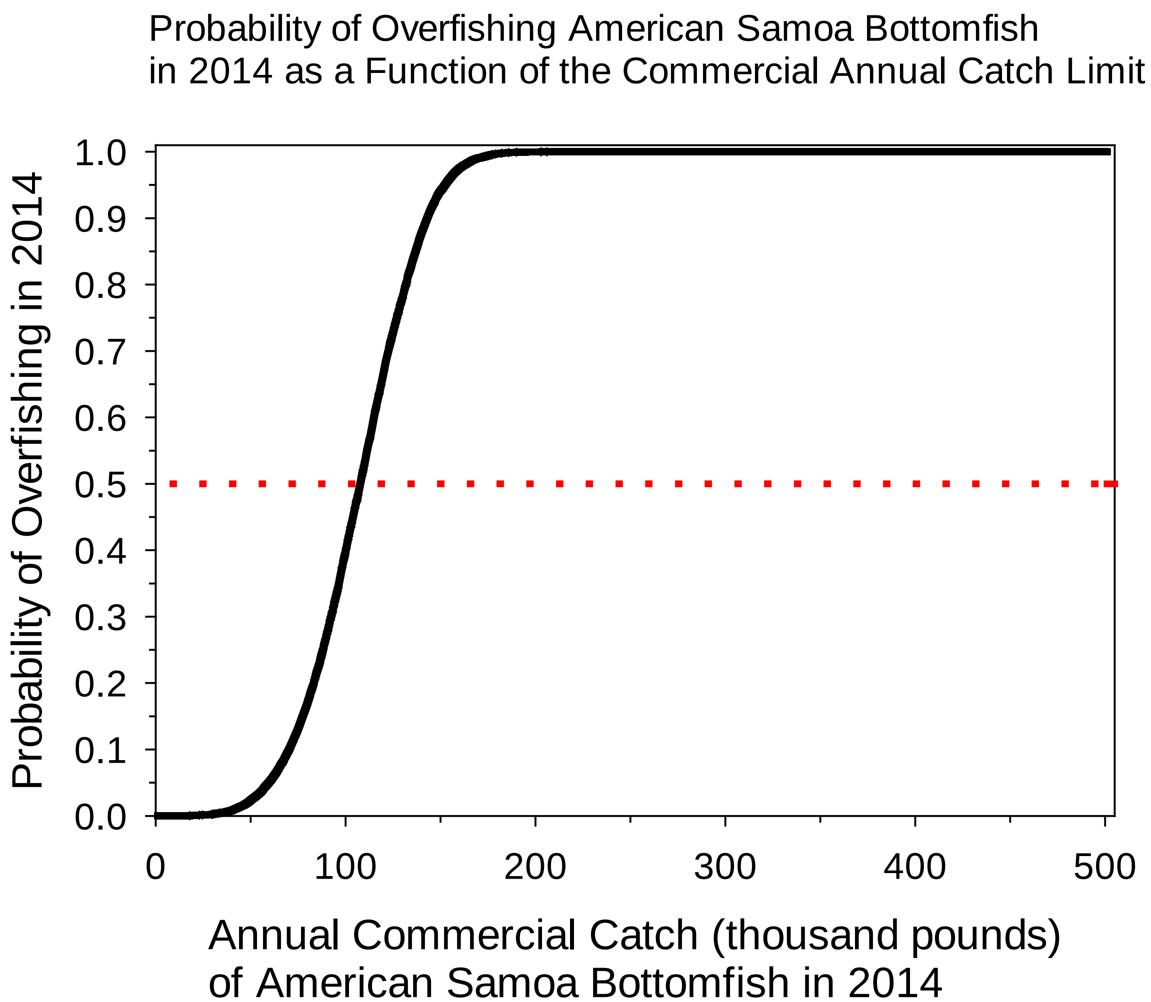

Figure 44. Probability of overfishing American Samoa bottomfish in 2014 as a function of the commercial annual catch limit.

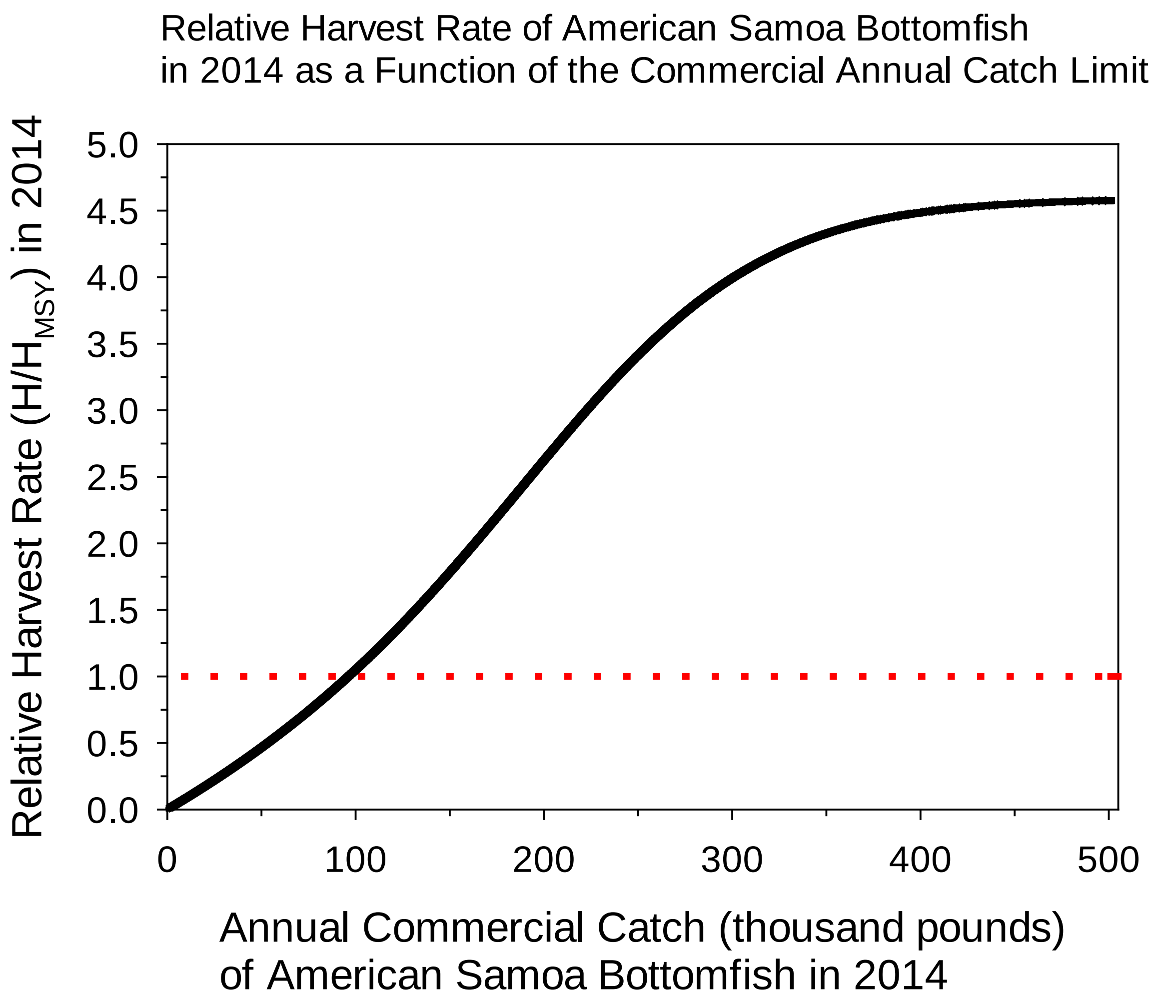

Figure 45. Relative harvest rate of American Samoa bottomfish in 2014 as a function of the commercial annual catch limit.

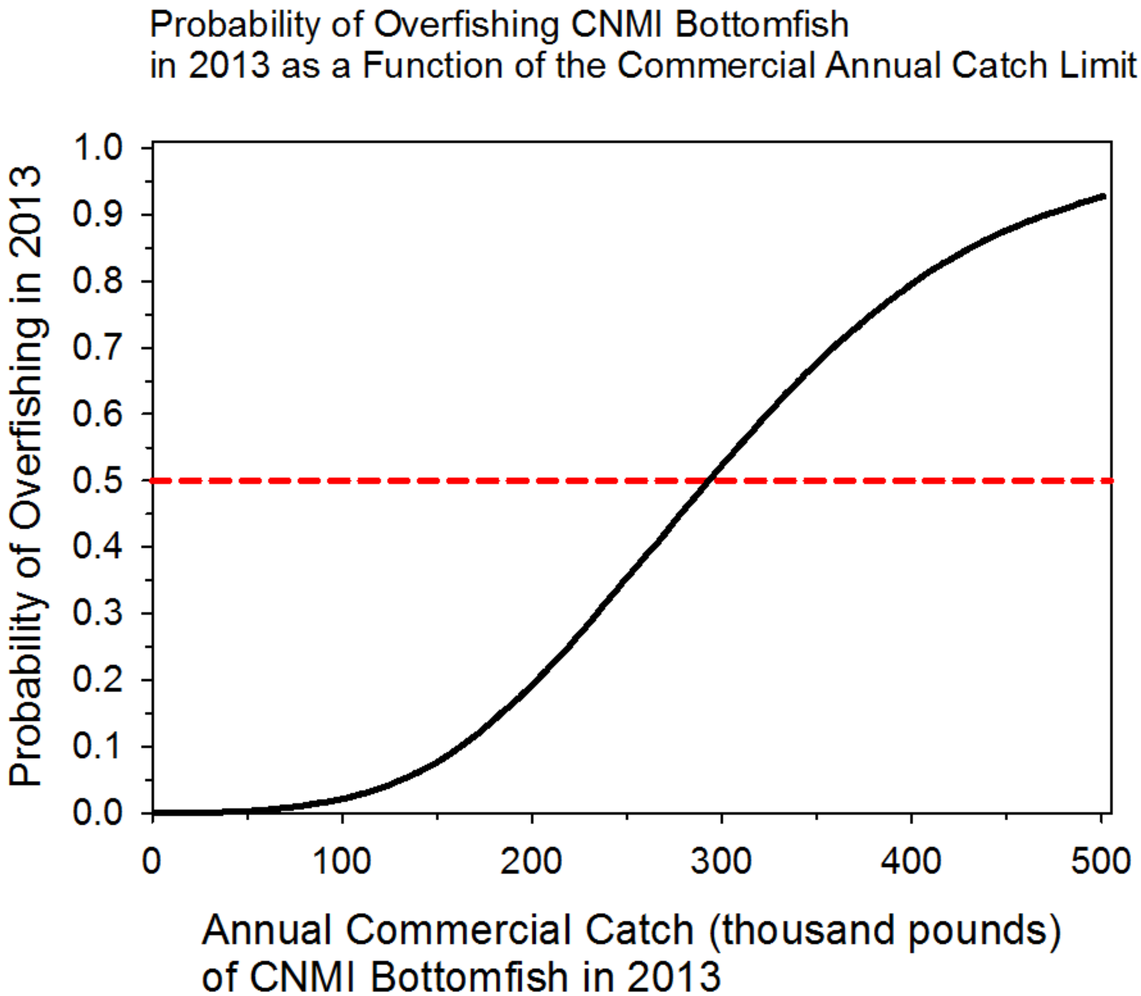

Figure 46. Probability of overfishing CNMI bottomfish in 2013 as a function of the commercial annual catch limit.

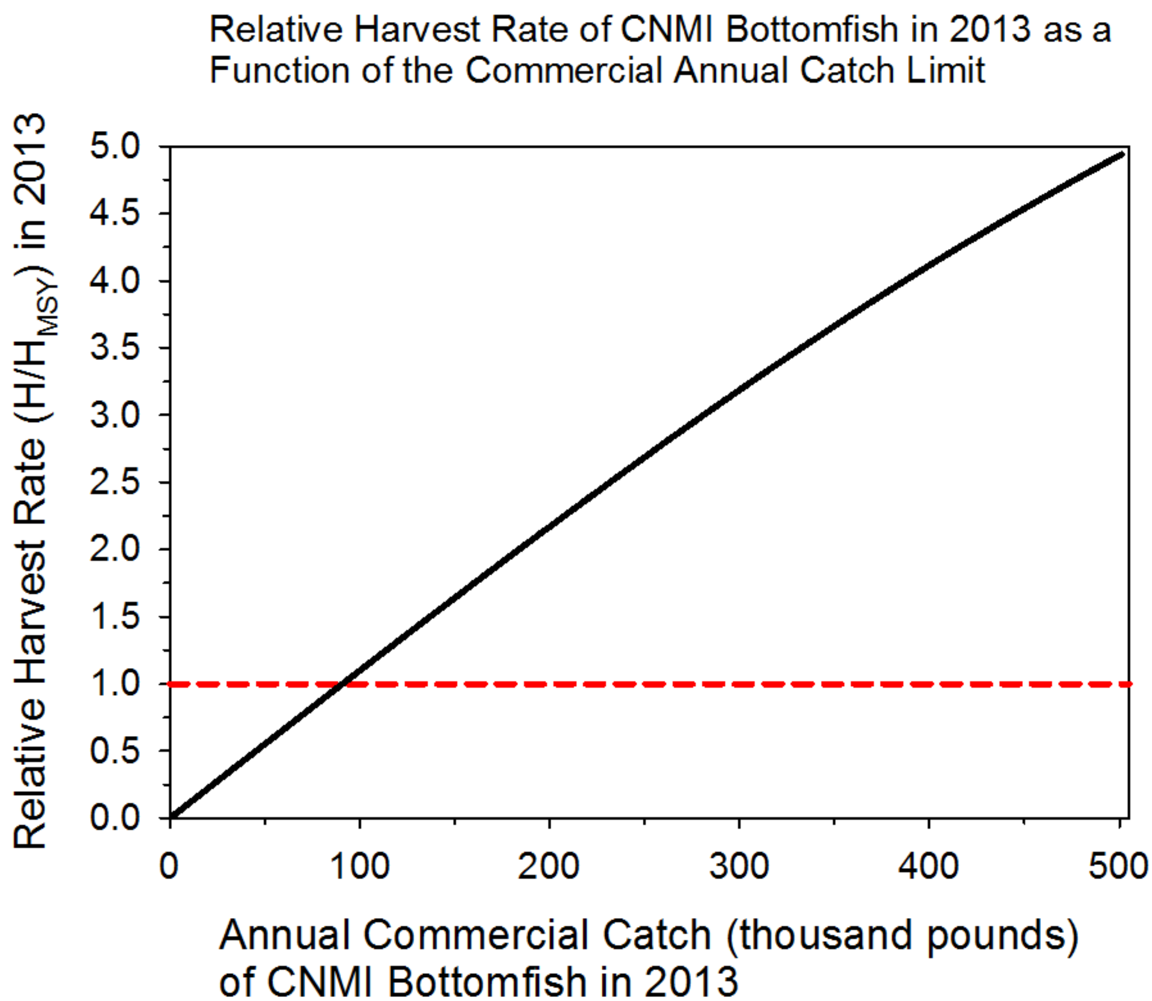

Figure 47. Relative harvest rate of CNMI bottomfish in 2013 as a function of the commercial annual catch limit.

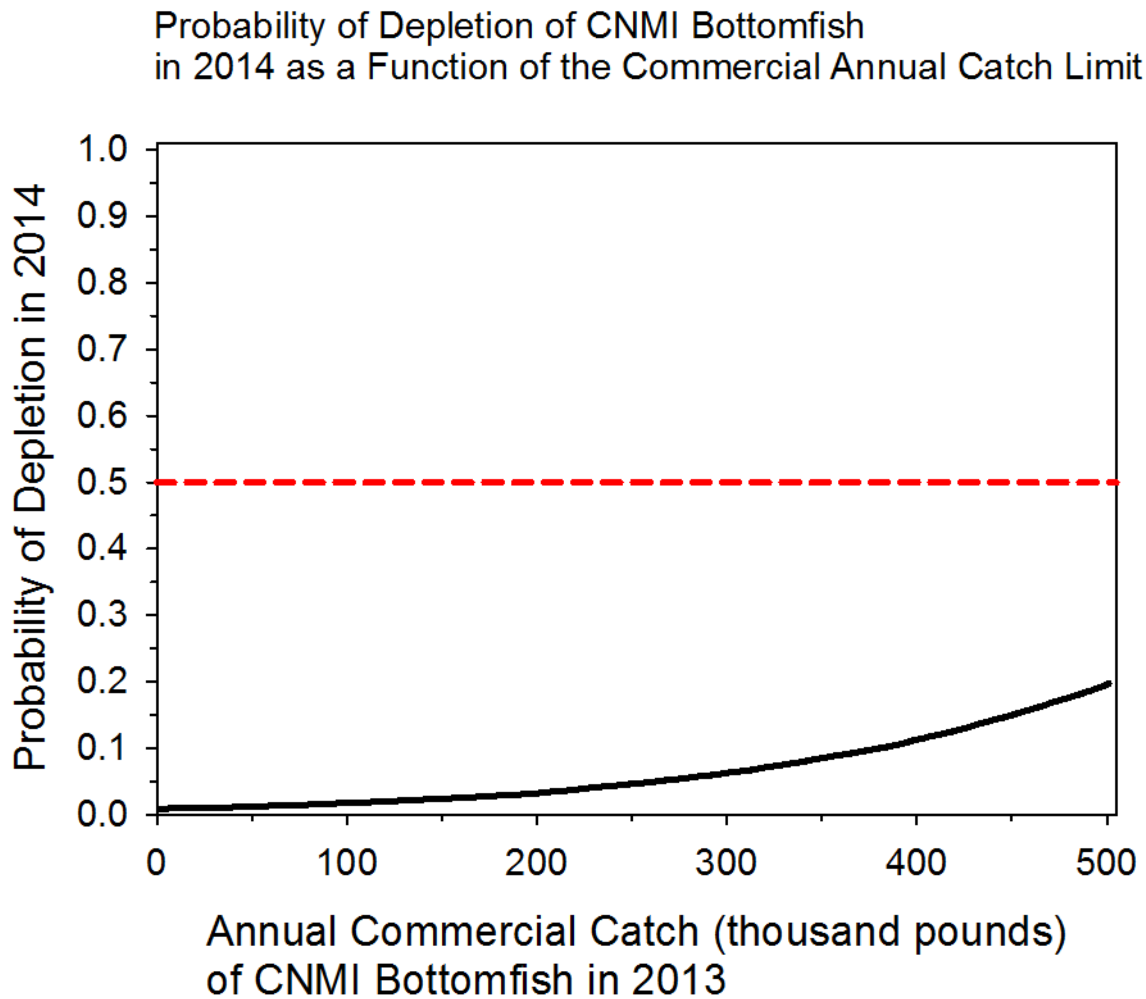

Figure 48. Probability of depletion of CNMI bottomfish in 2014 as a function of the commercial annual catch limit.

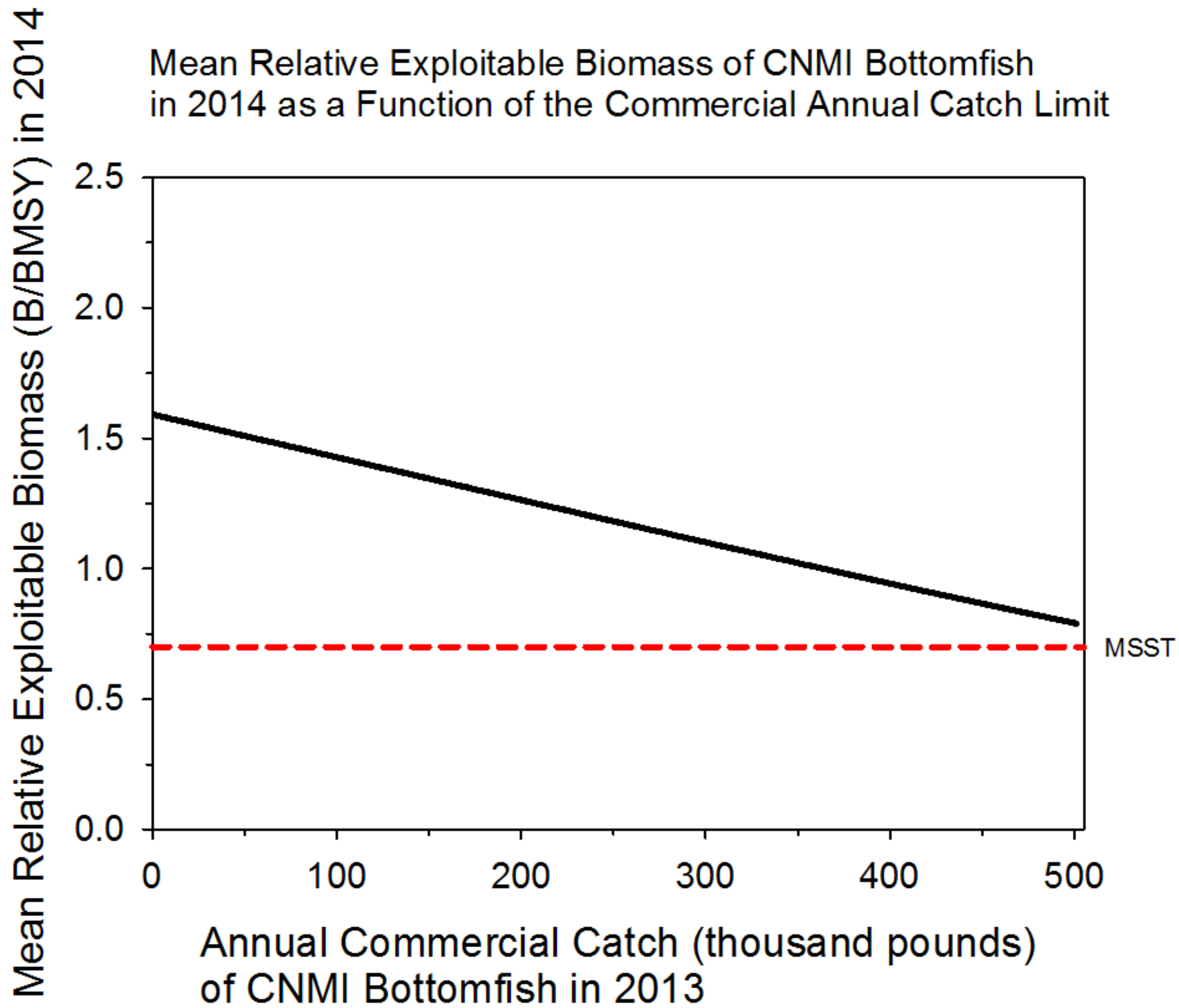

Figure 49. Mean relative exploitable biomass of CNMI bottomfish in 2014 as a function of the commercial annual catch limit.

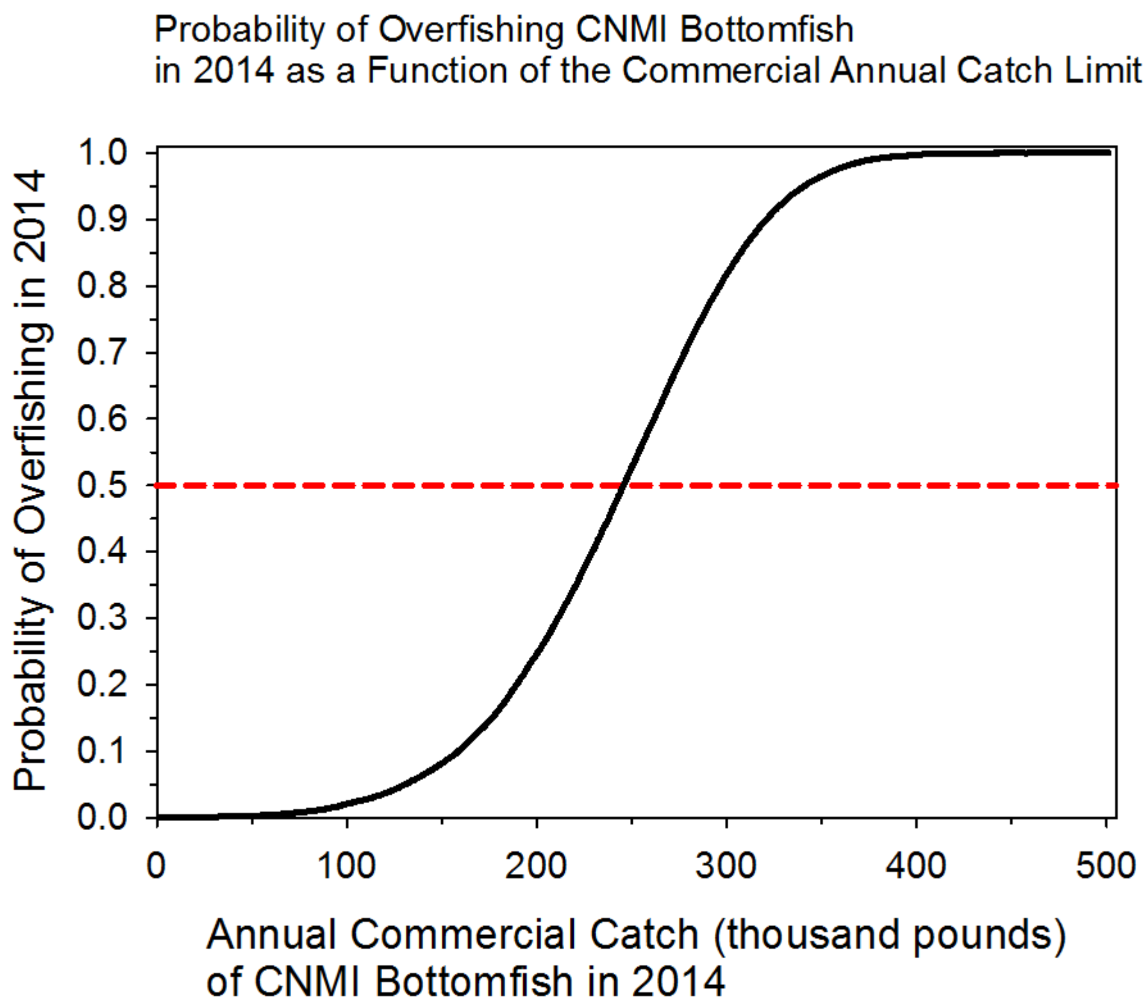

Figure 50. Probability of overfishing CNMI bottomfish in 2014 as a function of the commercial annual catch limit.

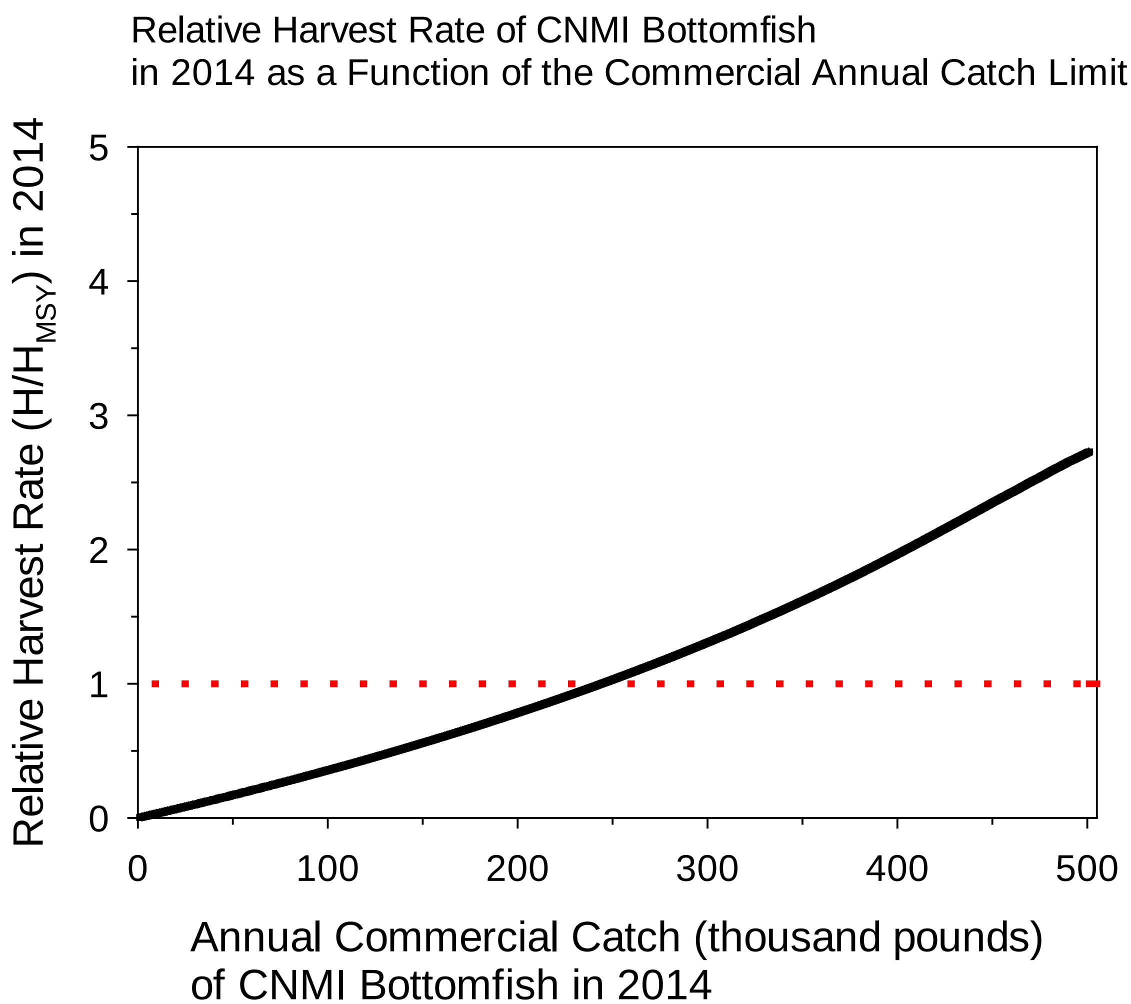

Figure 51. Relative harvest rate of CNMI bottomfish in 2014 as a function of the commercial annual catch limit.

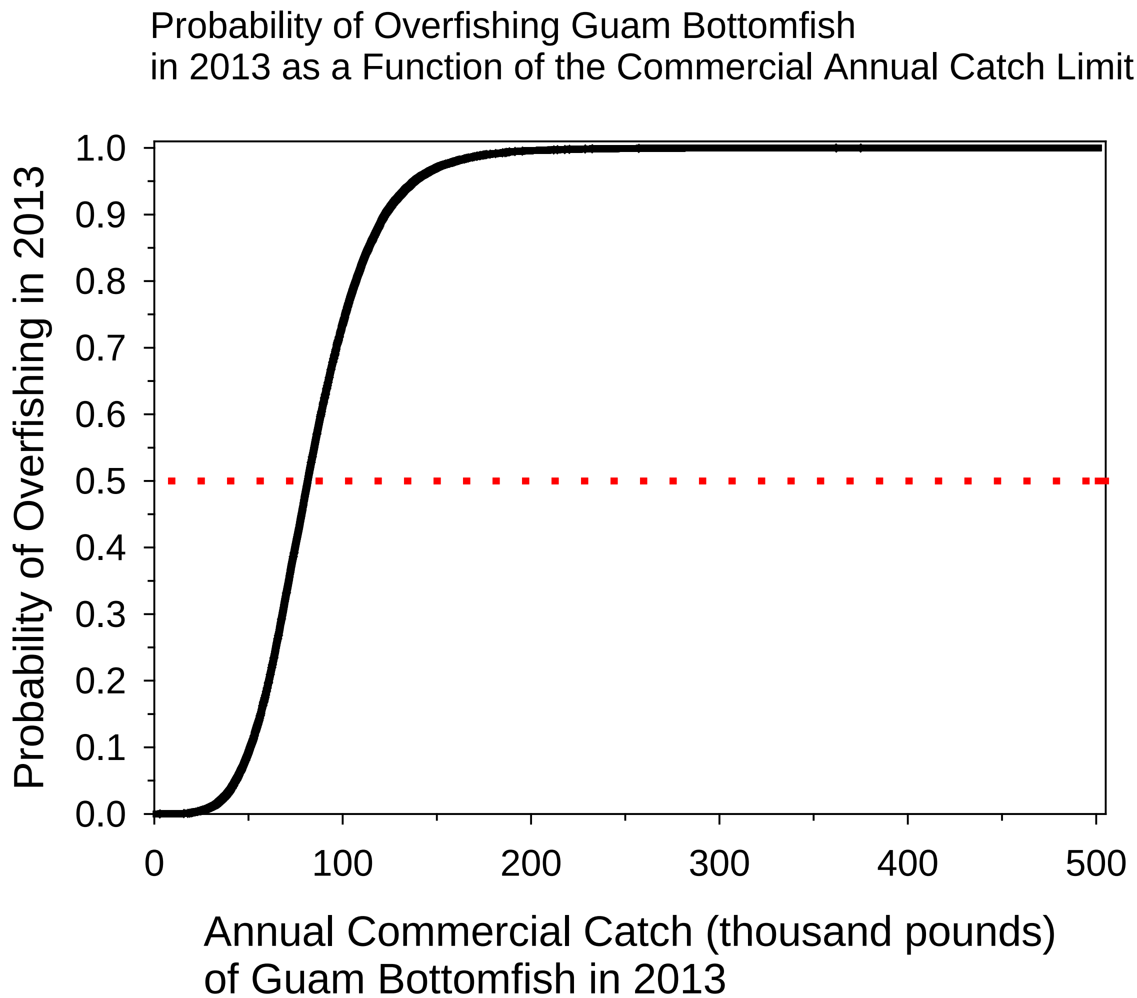

Figure 52. Probability of overfishing Guam bottomfish in 2013 as a function of the commercial annual catch limit.

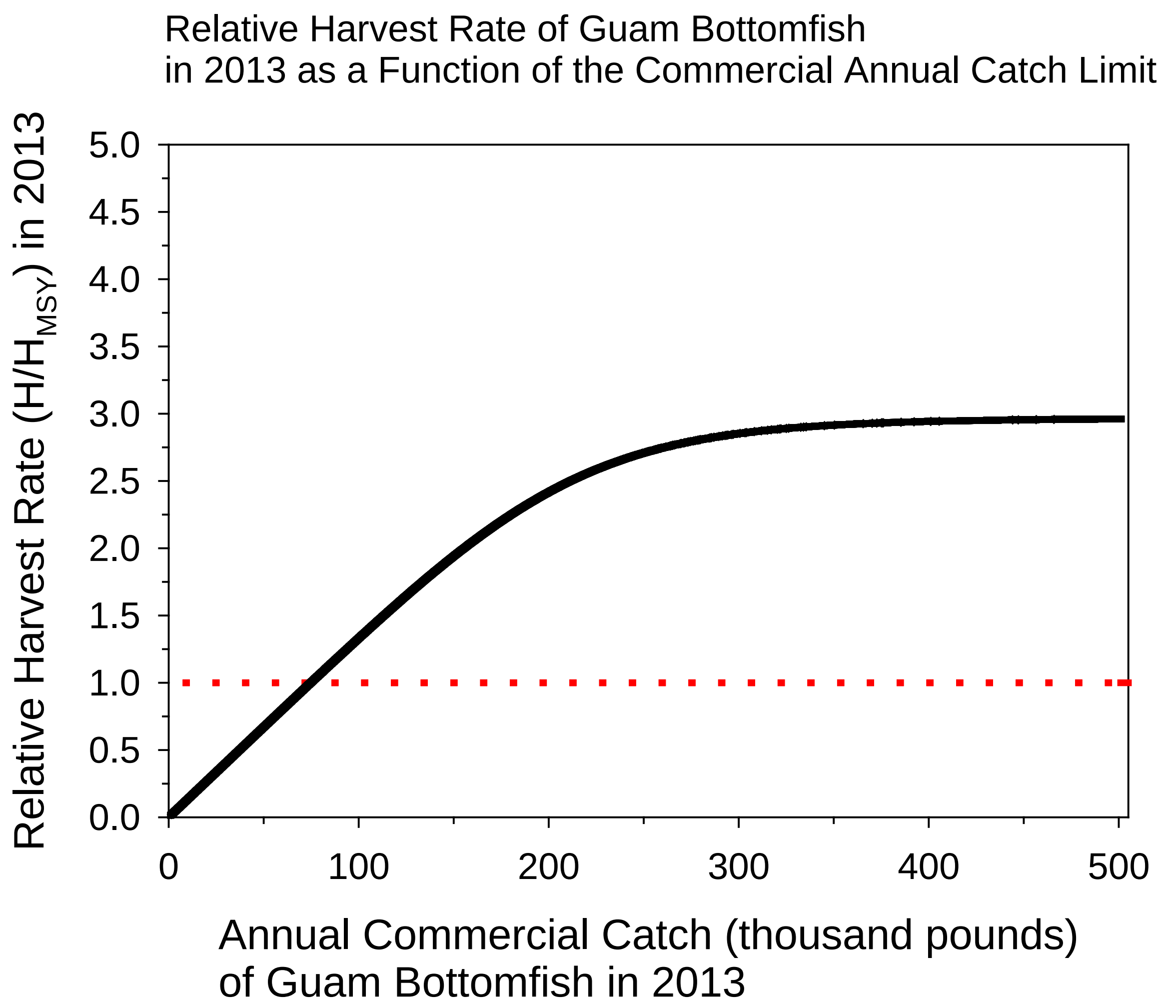

Figure 53. Relative harvest rate of Guam bottomfish in 2013 as a function of the commercial annual catch limit.

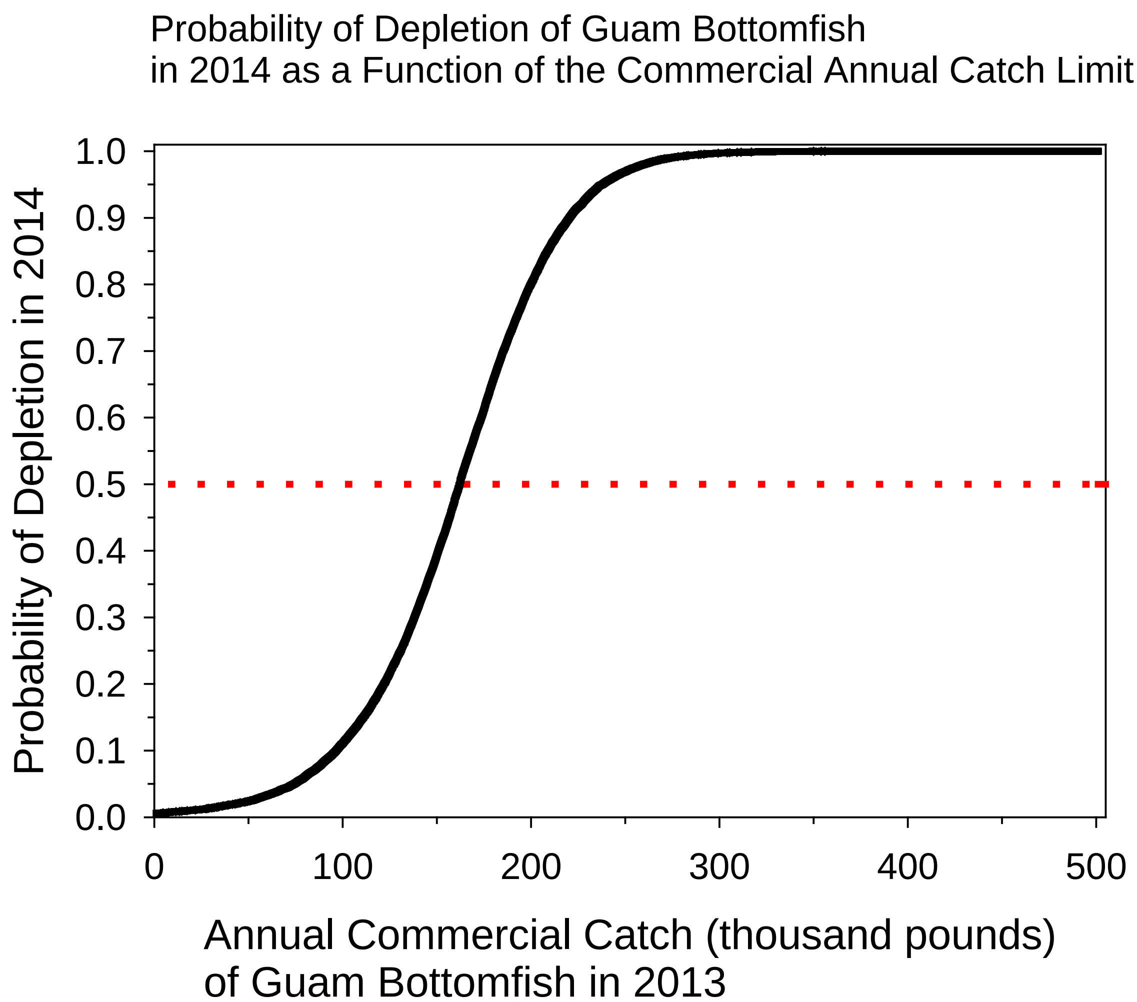

Figure 54. Probability of depletion of Guam bottomfish in 2014 as a function of the commercial annual catch limit.

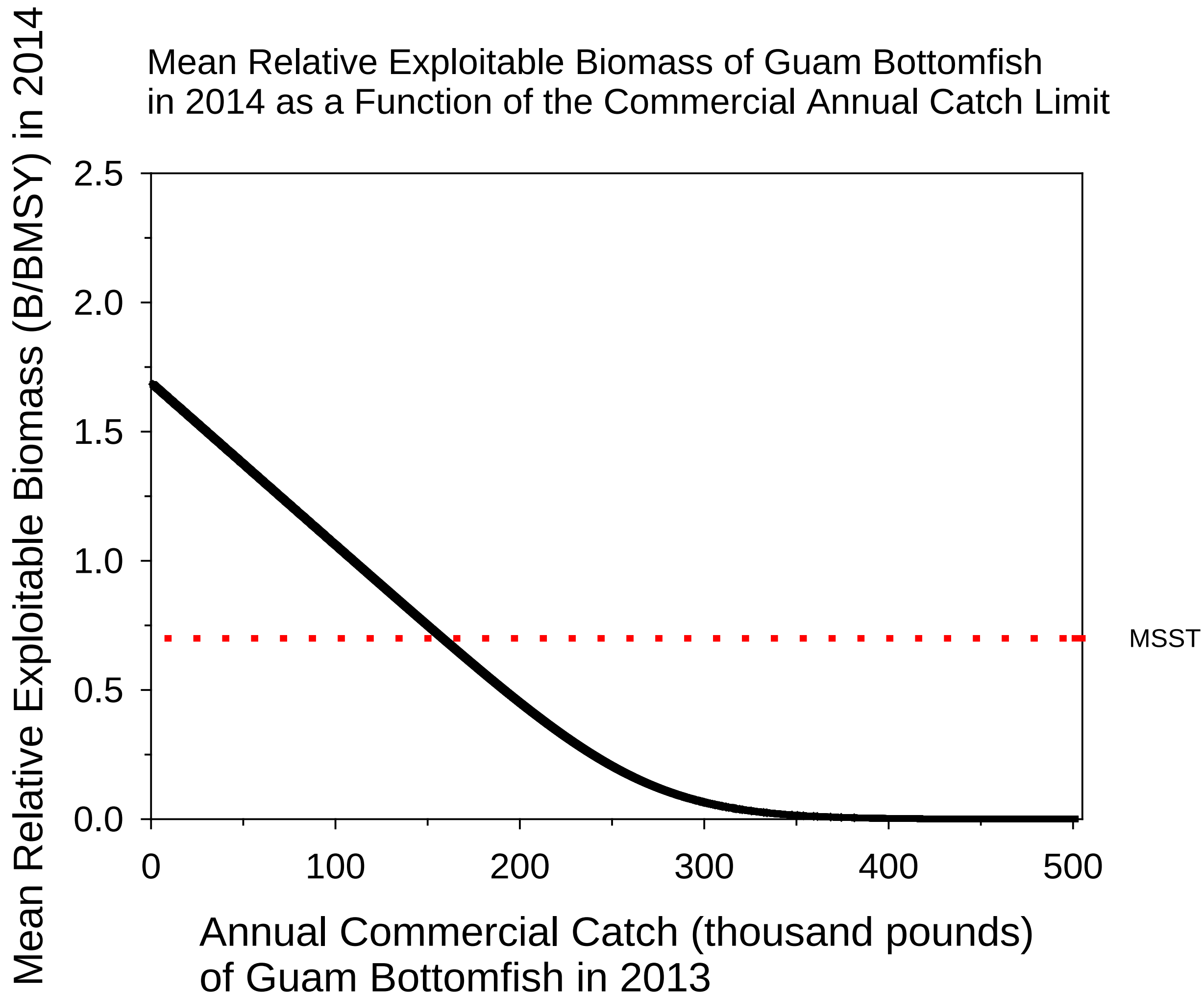

Figure 55. Mean relative exploitable biomass of Guam bottomfish in 2014 as a function of the commercial annual catch limit.

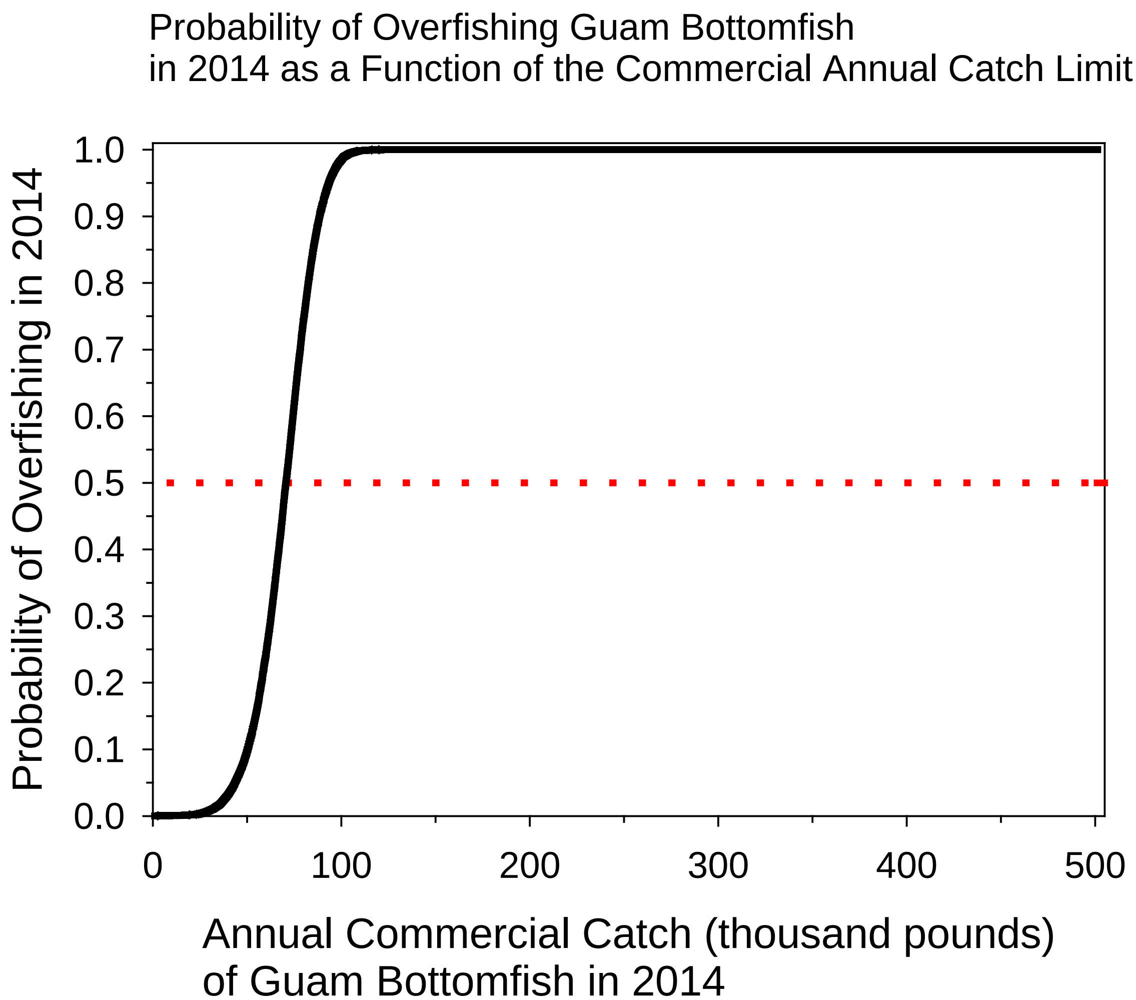

Figure 56. Probability of overfishing Guam bottomfish in 2014 as a function of the commercial annual catch limit.

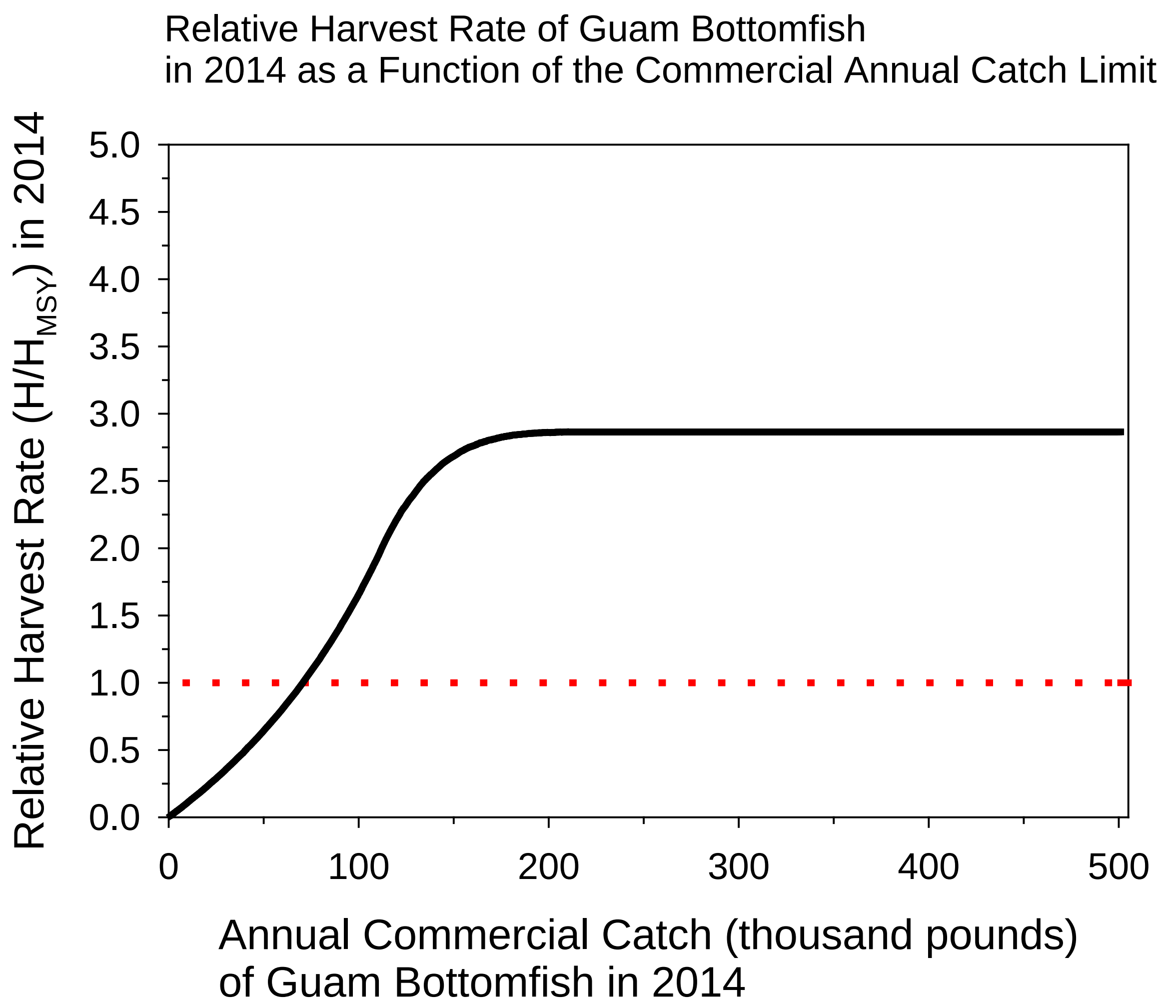

Figure 57. Relative harvest rate of Guam bottomfish in 2014 as a function of the commercial annual catch limit.

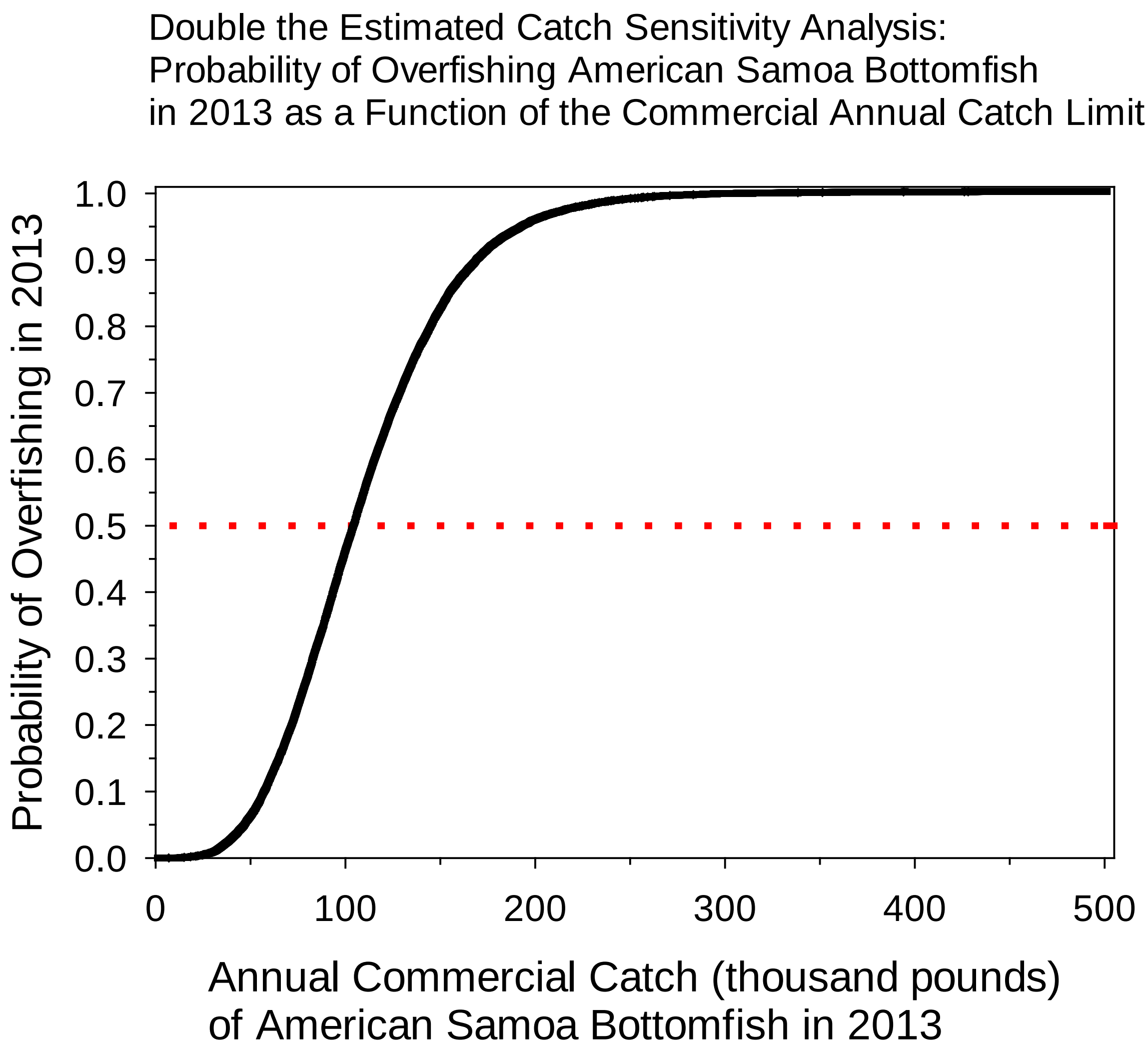

Figure 58. Double the estimated catch sensitivity analysis: Probability of overfishing American Samoa bottomfish in 2013 as a function of the commercial annual catch limit.

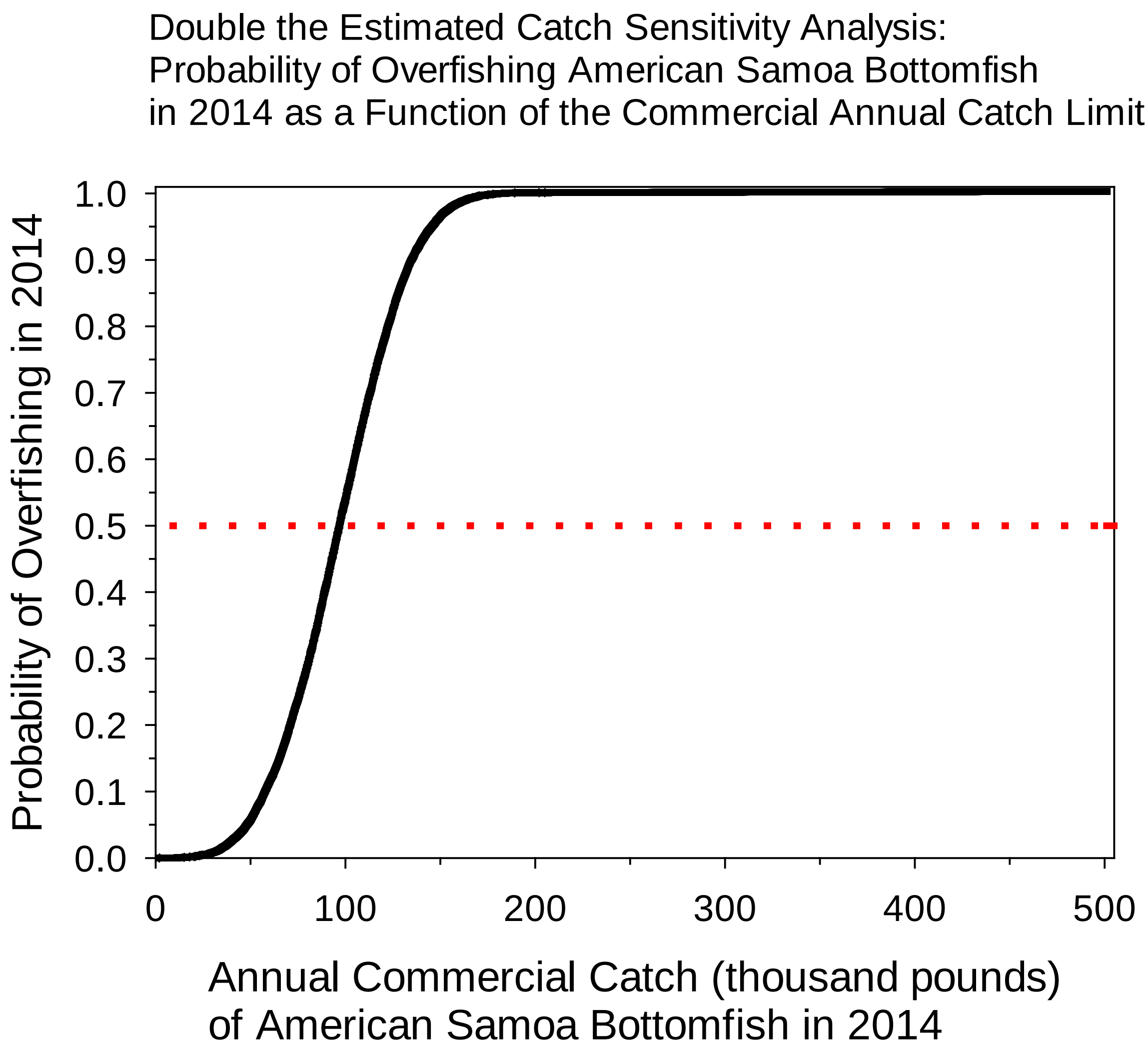

Figure 59. Double the estimated catch sensitivity analysis: Probability of overfishing American Samoa bottomfish in 2014 as a function of the commercial annual catch limit.

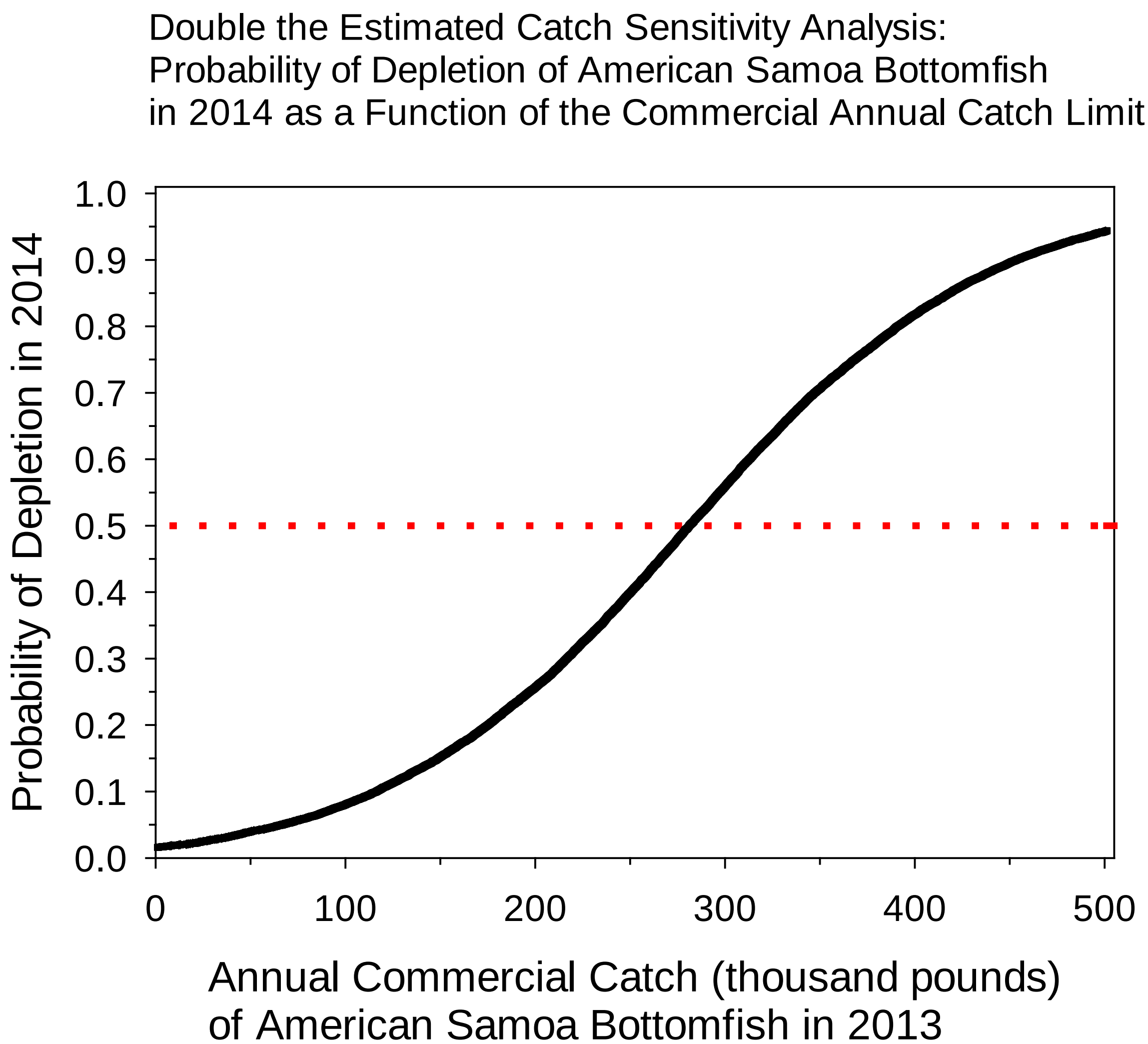

Figure 60. Double the estimated catch sensitivity analysis: Probability of depletion of American Samoa bottomfish in 2014 as a function of the commercial annual catch limit.

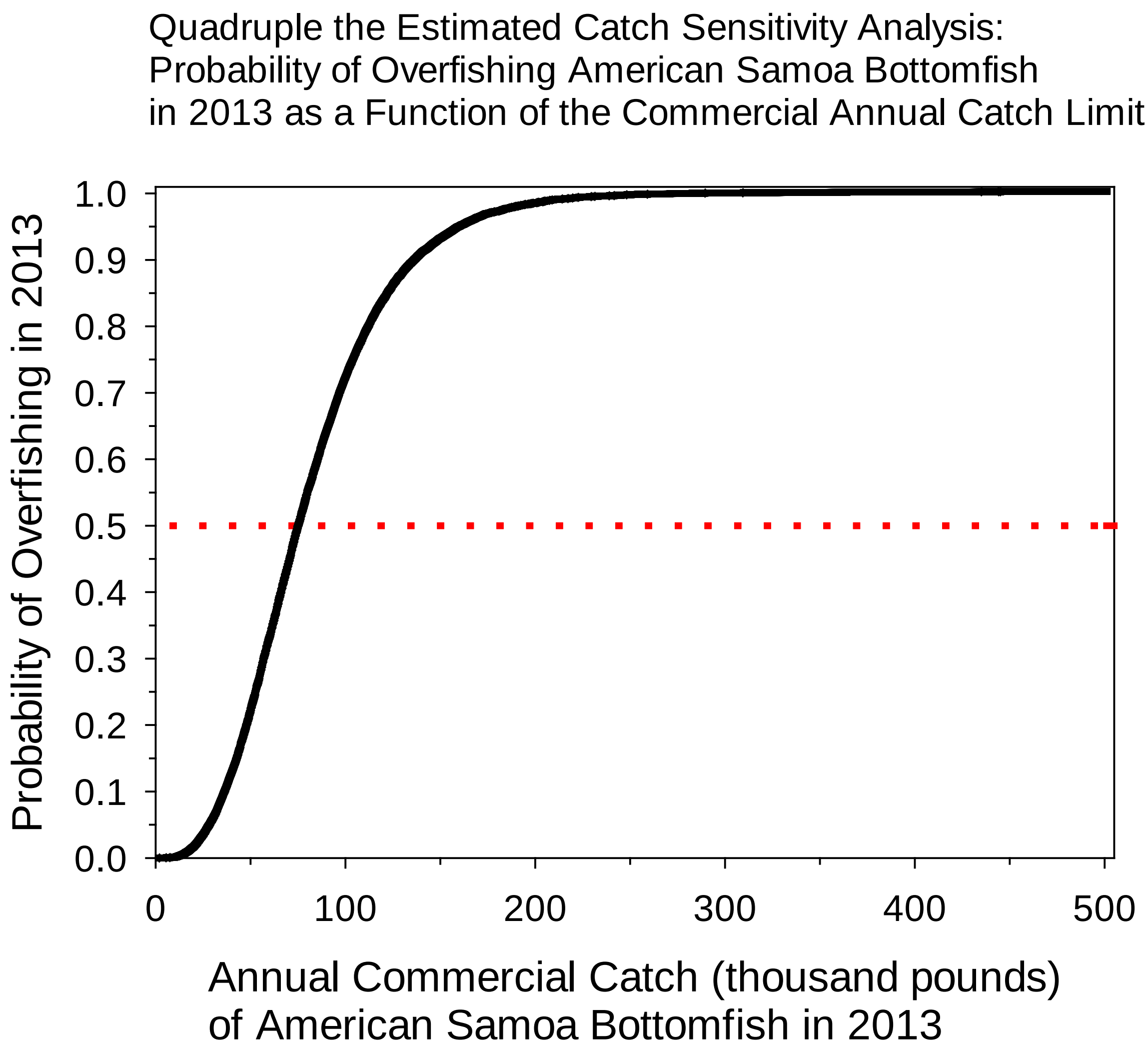

Figure 61. Quadruple the estimated catch sensitivity analysis: Probability of overfishing American Samoa bottomfish in 2013 as a function of the commercial annual catch limit.

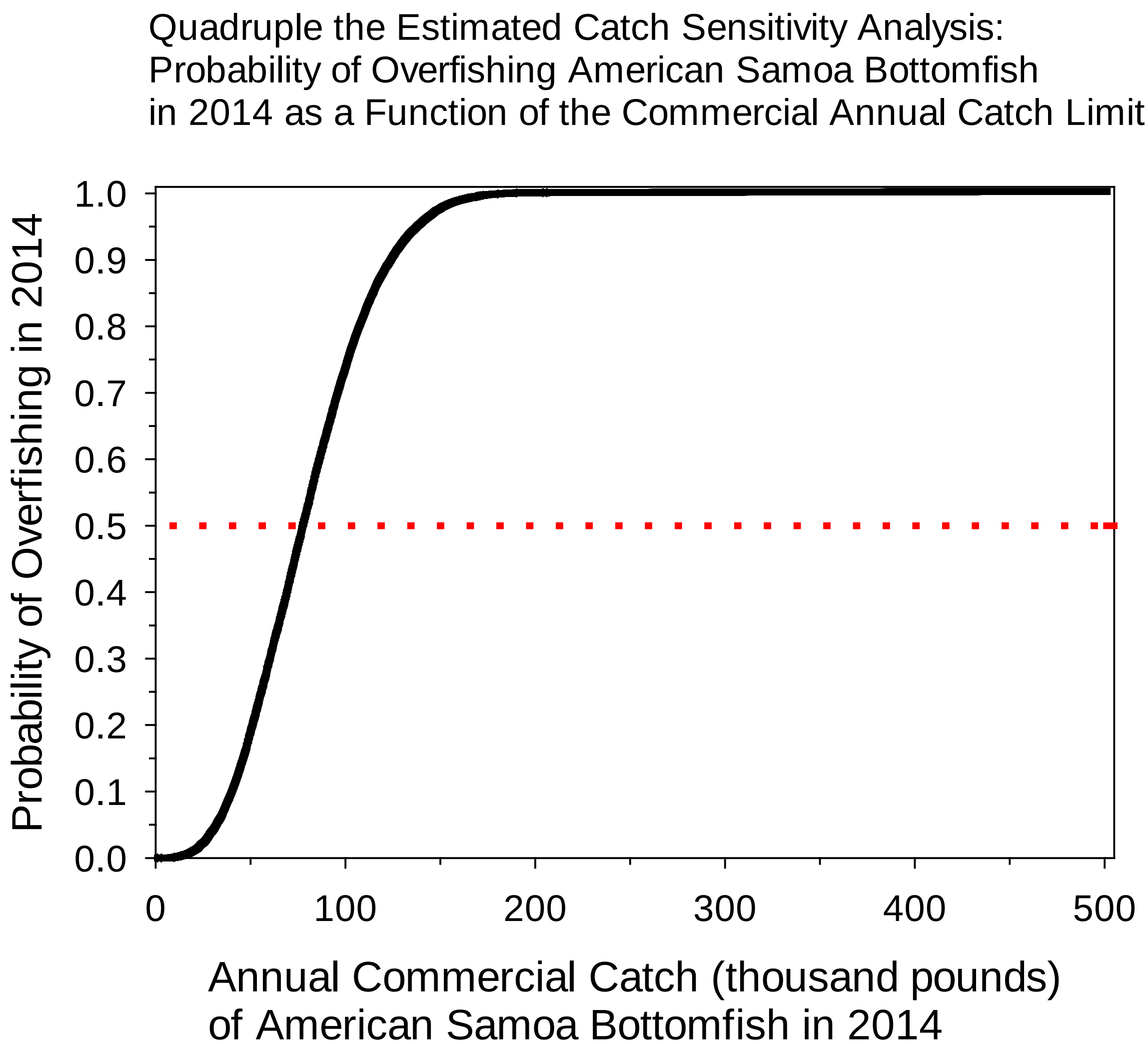

Figure 62. Quadruple the estimated catch sensitivity analysis: Probability of overfishing American Samoa bottomfish in 2014 as a function of the commercial annual catch limit.

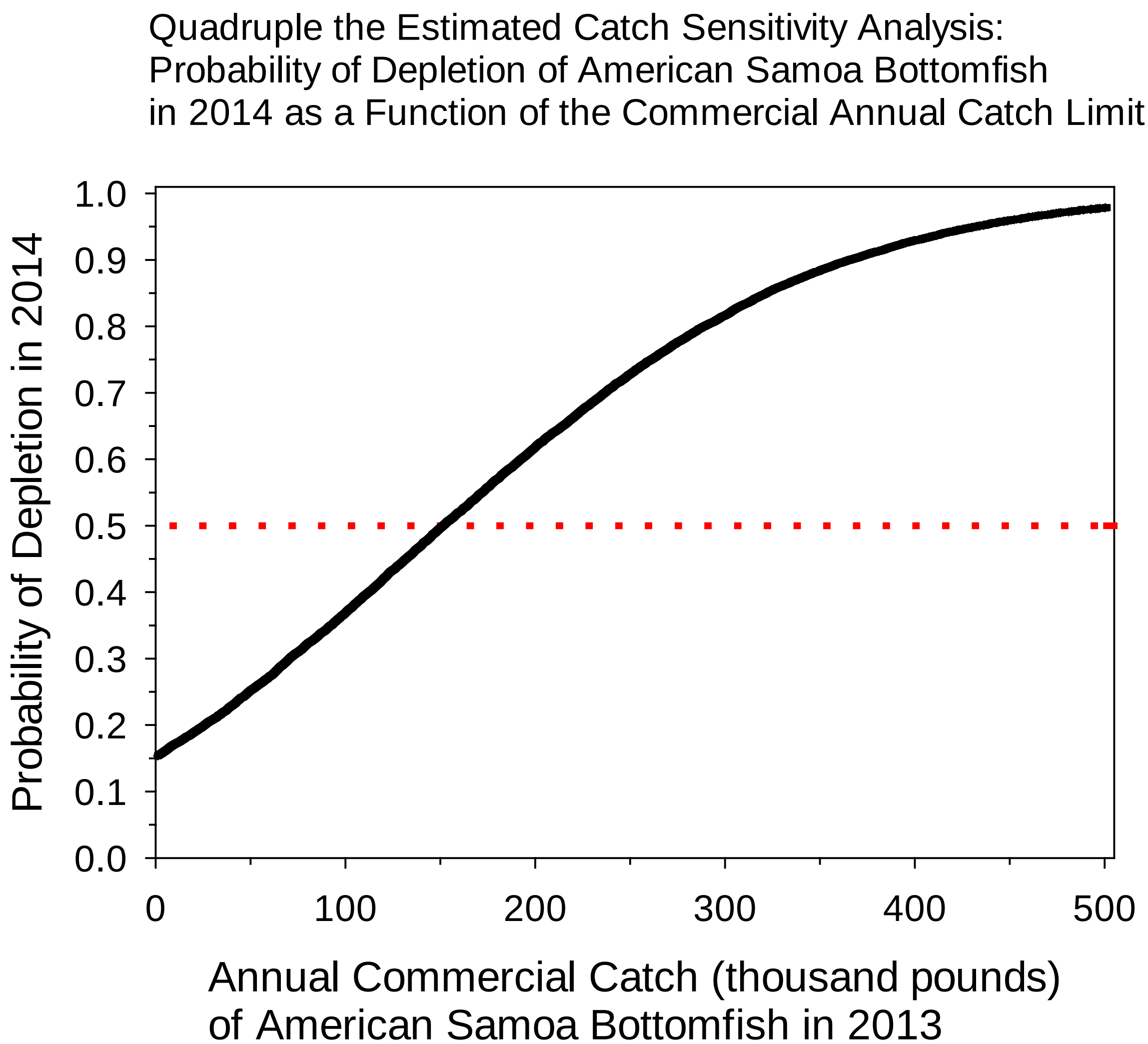

Figure 63. Quadruple the estimated catch sensitivity analysis: Probability of depletion of American Samoa bottomfish in 2014 as a function of the commercial annual catch limit.

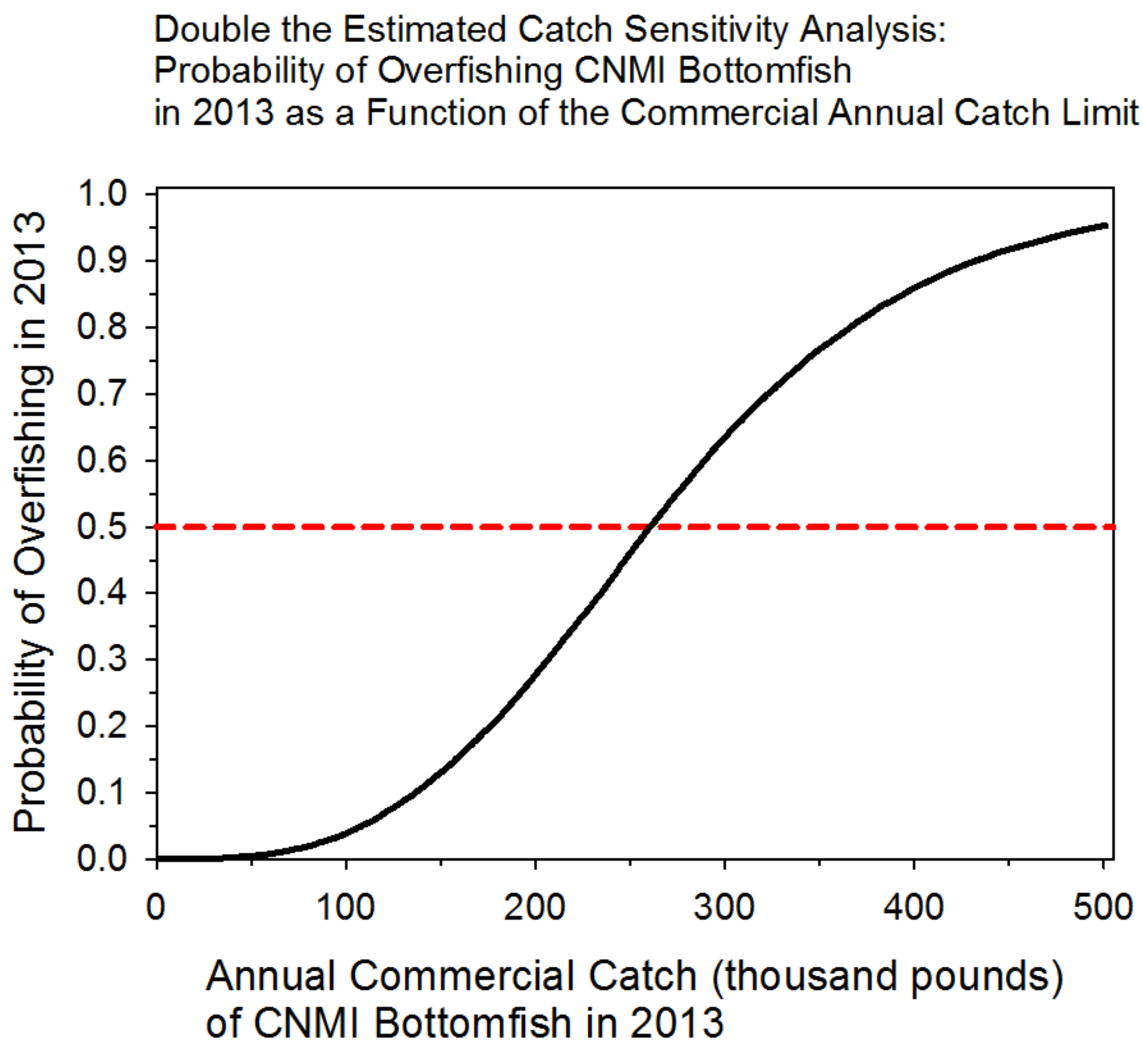

Figure 64. Double the estimated catch sensitivity analysis: Probability of overfishing CNMI bottomfish in 2013 as a function of the commercial annual catch limit.

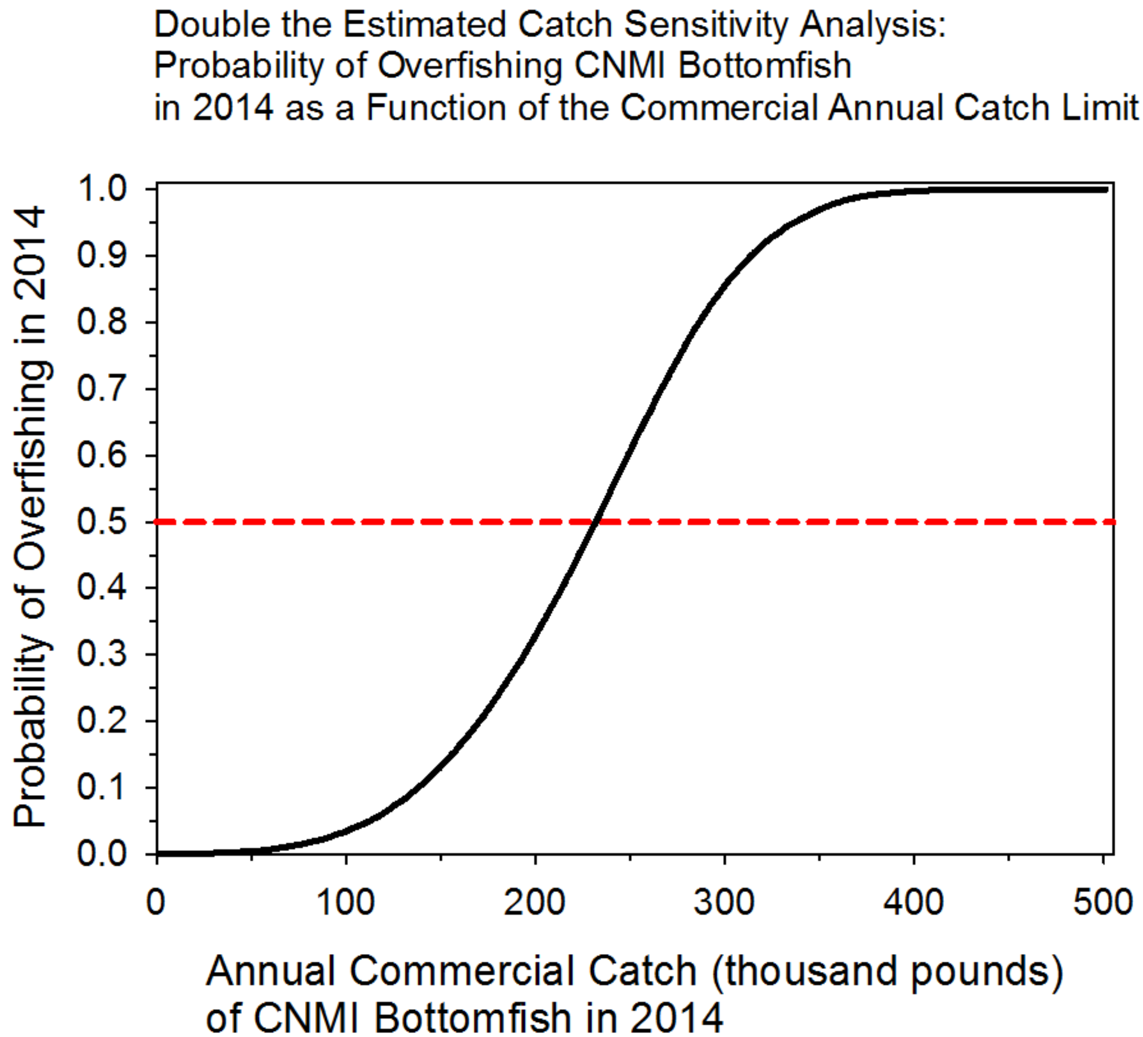

Figure 65. Double the estimated catch sensitivity analysis: Probability of overfishing CNMI bottomfish in 2014 as a function of the commercial annual catch limit.

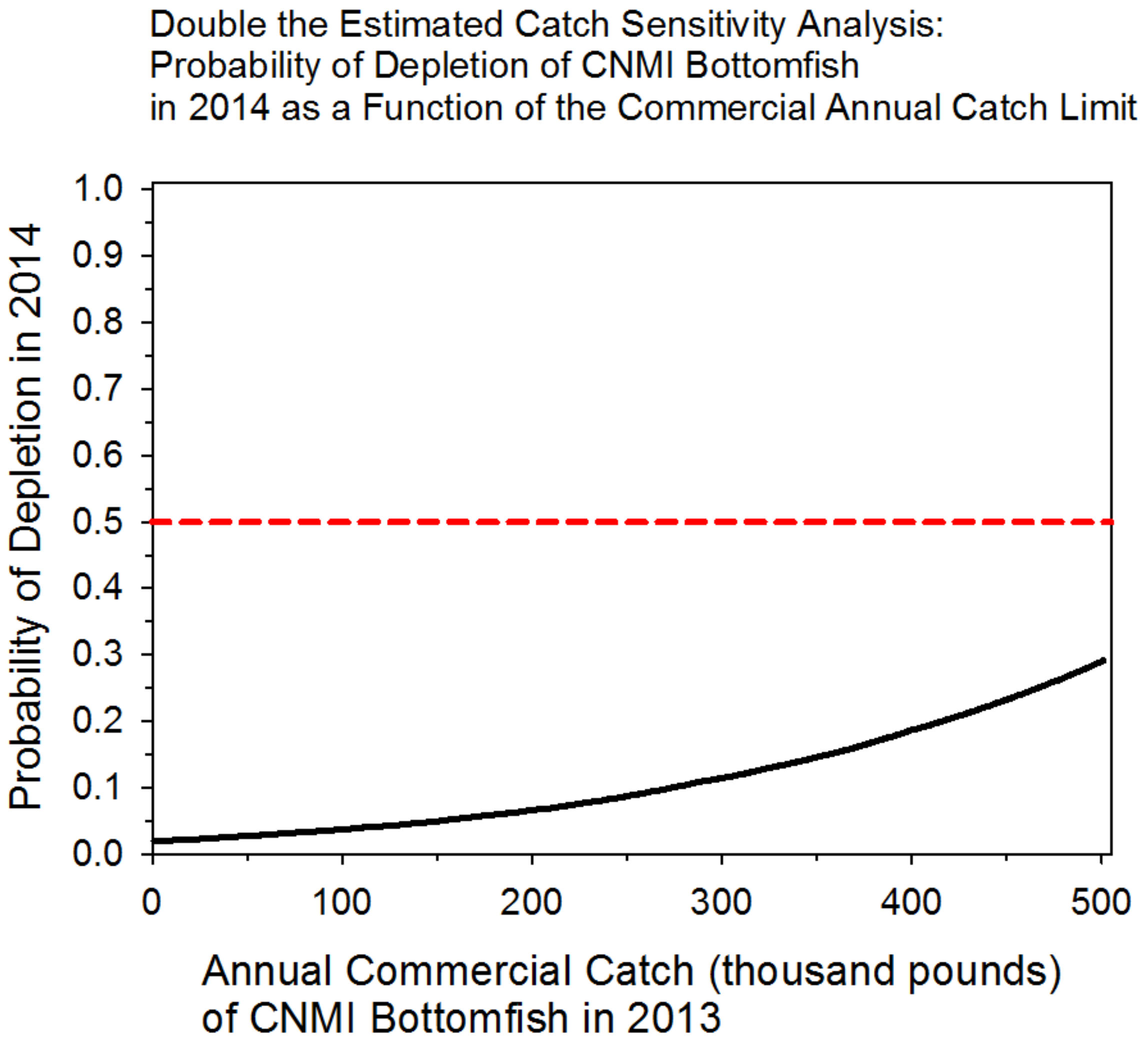

Figure 66. Double the estimated catch sensitivity analysis: Probability of depletion of CNMI bottomfish in 2014 as a function of the commercial annual catch limit.

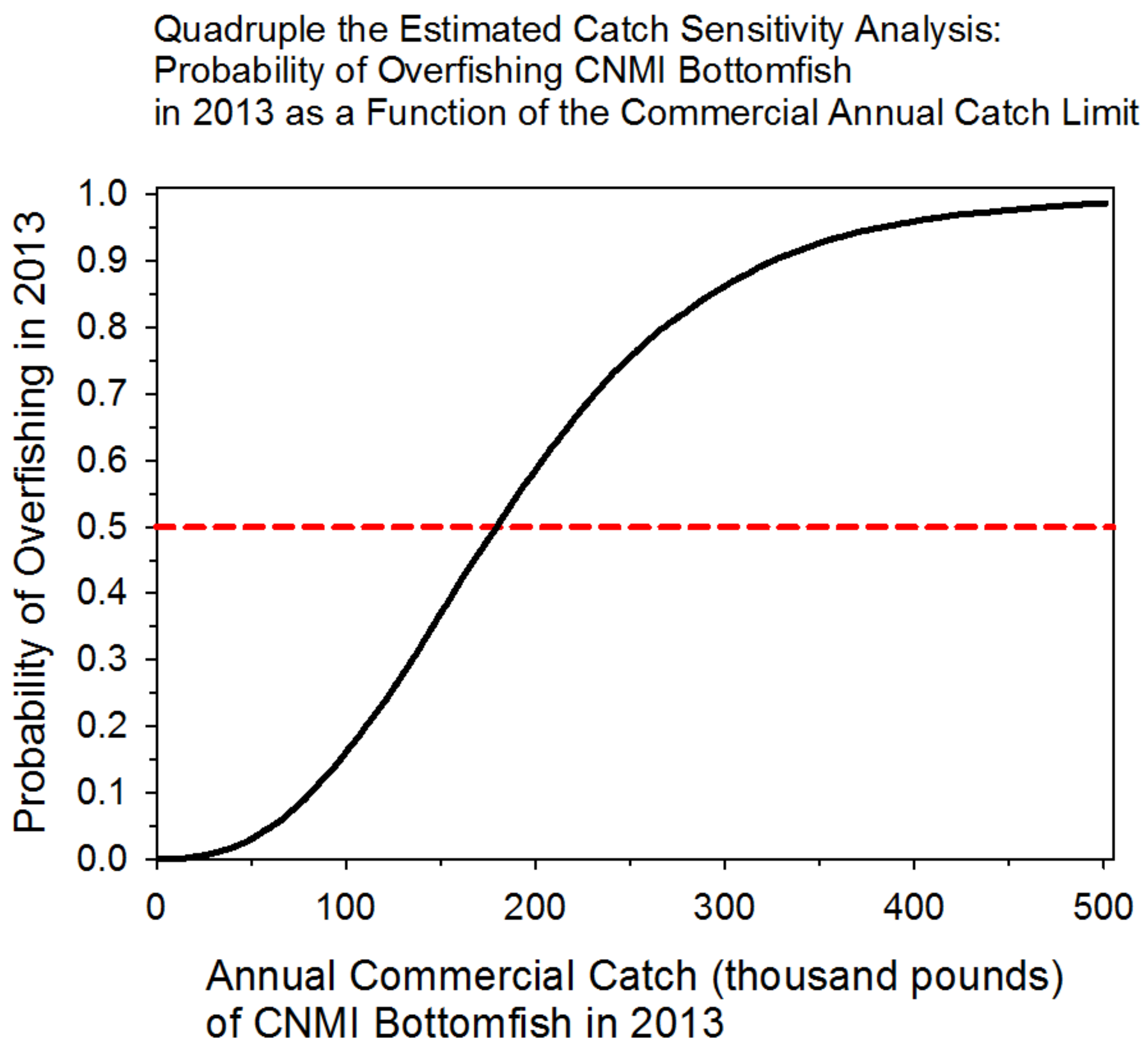

Figure 67. Quadruple the estimated catch sensitivity analysis: Probability of overfishing CNMI bottomfish in 2013 as a function of the commercial annual catch limit.

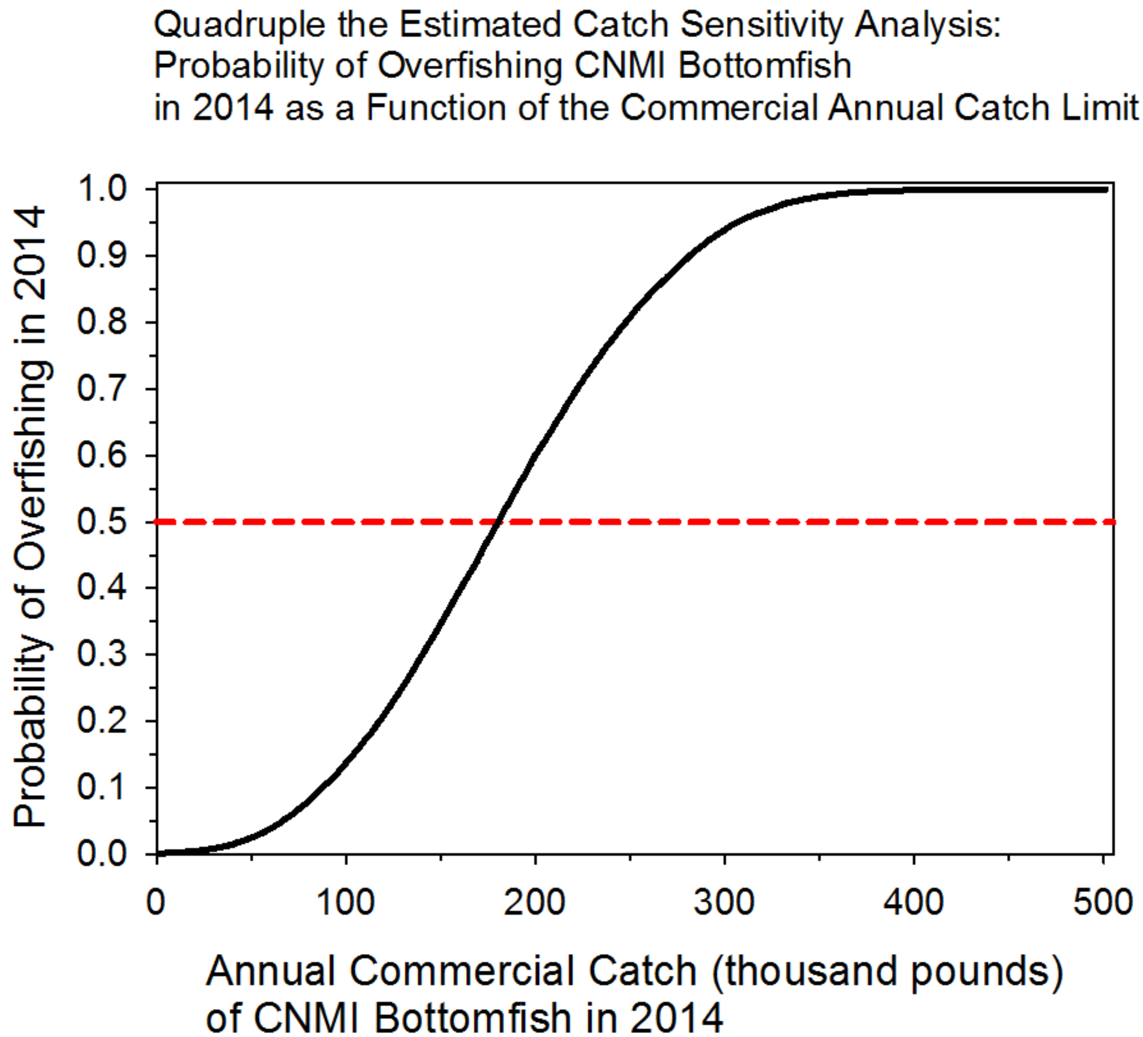

Figure 68. Quadruple the estimated catch sensitivity analysis: Probability of overfishing CNMI bottomfish in 2014 as a function of the commercial annual catch limit.

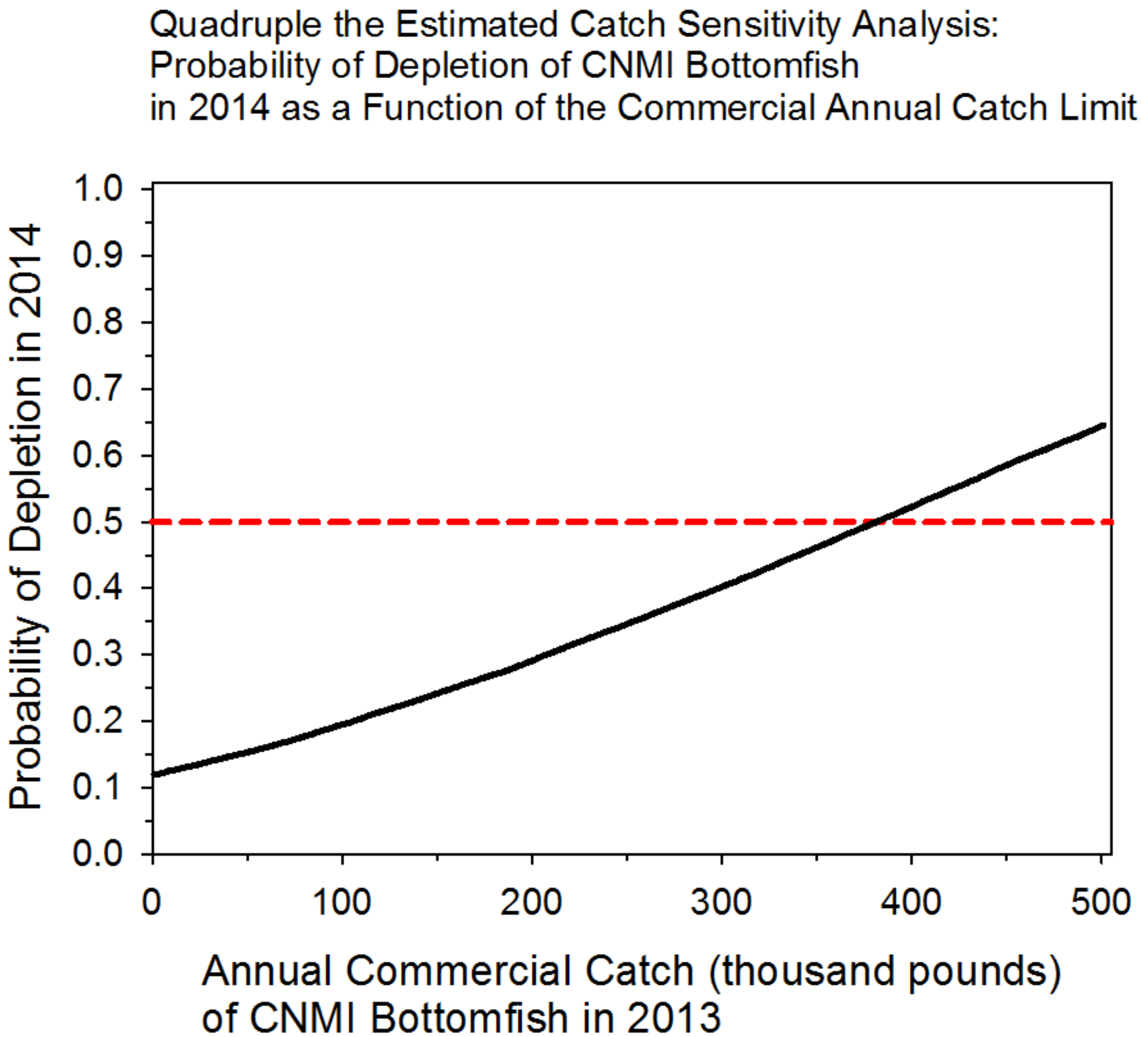

Figure 69. Quadruple the estimated catch sensitivity analysis: Probability of depletion of CNMI bottomfish in 2014 as a function of the commercial annual catch limit.

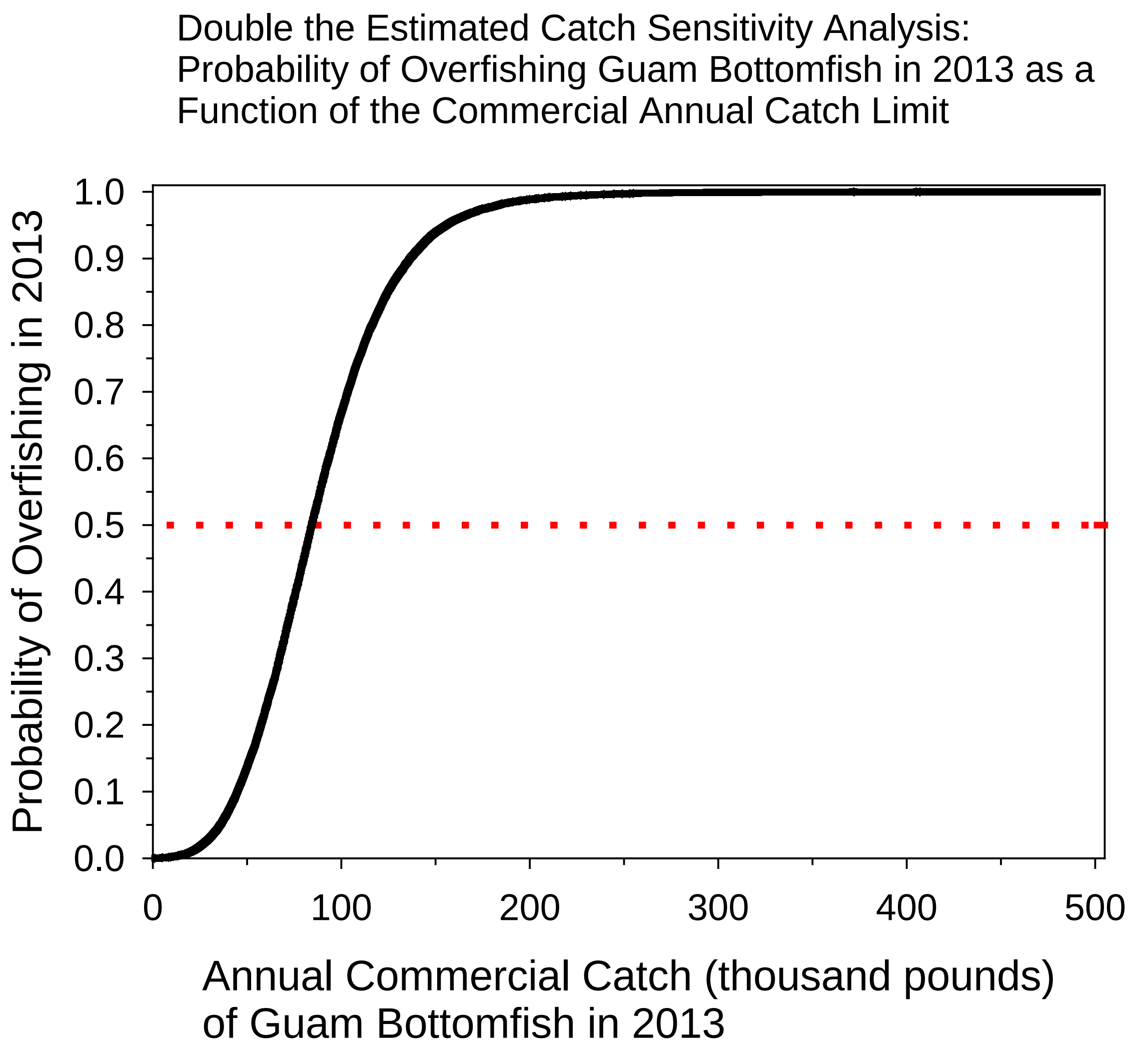

Figure 70. Double the estimated catch sensitivity analysis: Probability of overfishing Guam bottomfish in 2013 as a function of the commercial annual catch limit.

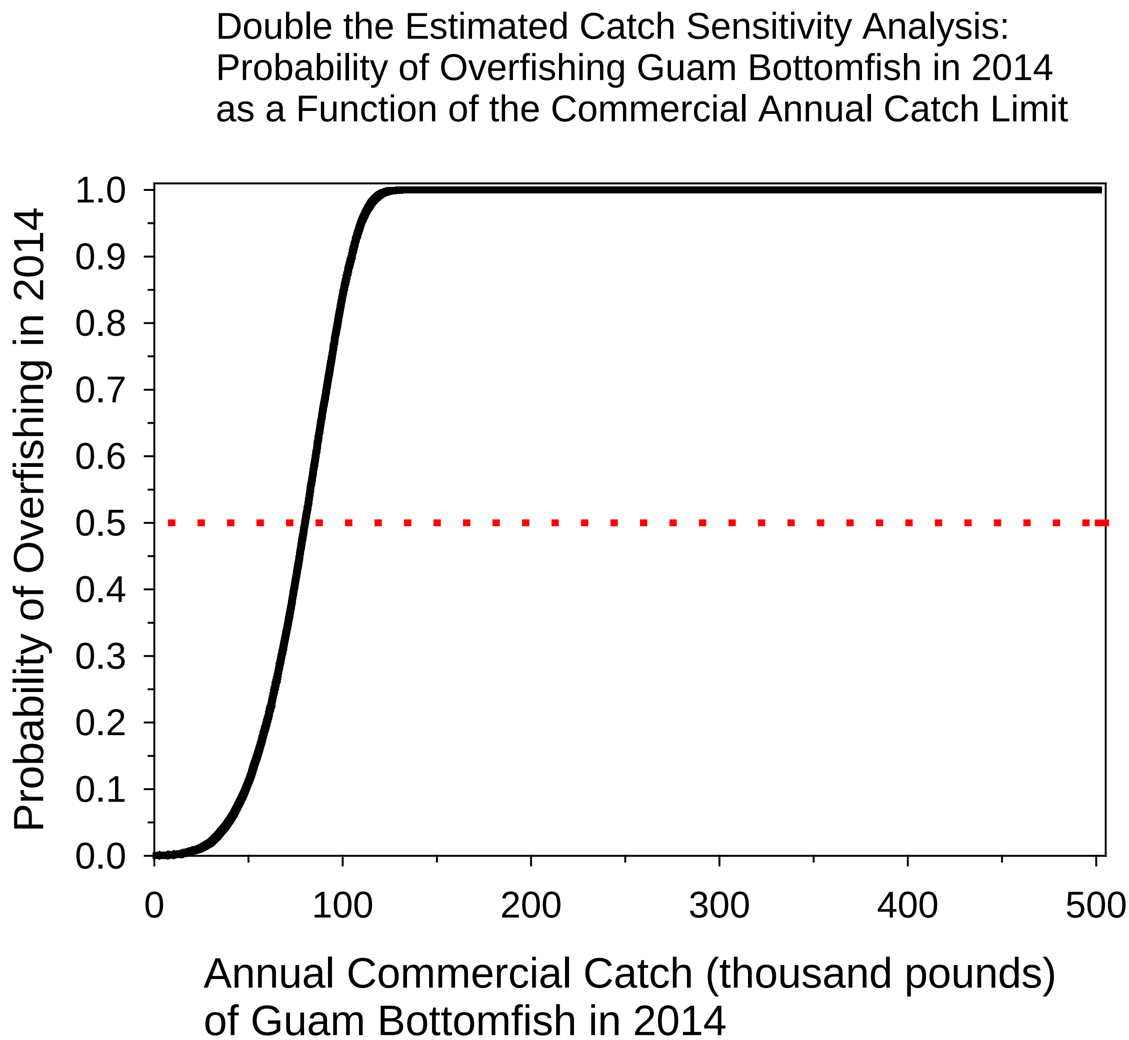

Figure 71. Double the estimated catch sensitivity analysis: Probability of overfishing Guam bottomfish in 2014 as a function of the commercial annual catch limit.

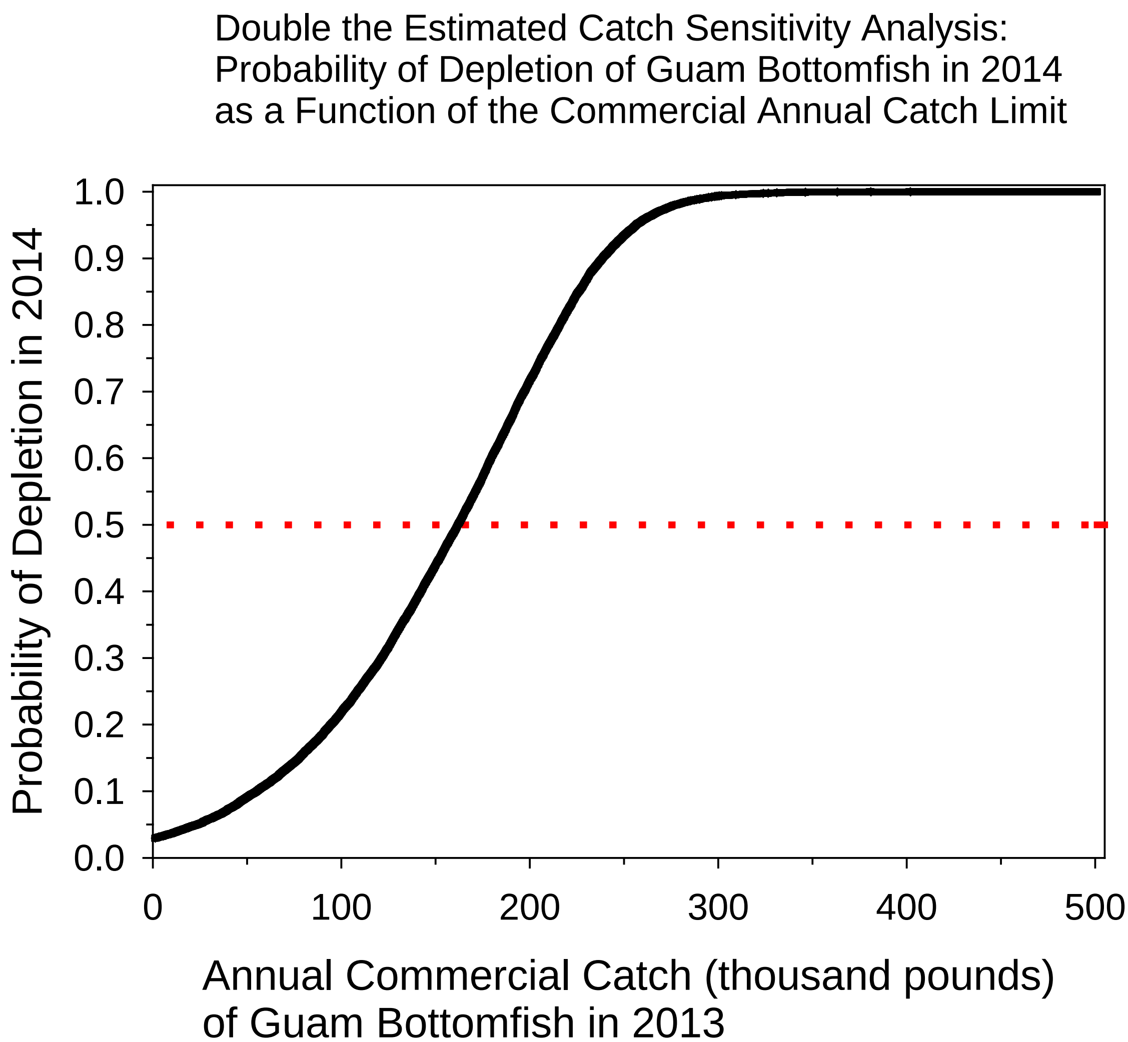

Figure 72. Double the estimated catch sensitivity analysis: Probability of depletion of Guam bottomfish in 2014 as a function of the commercial annual catch limit.

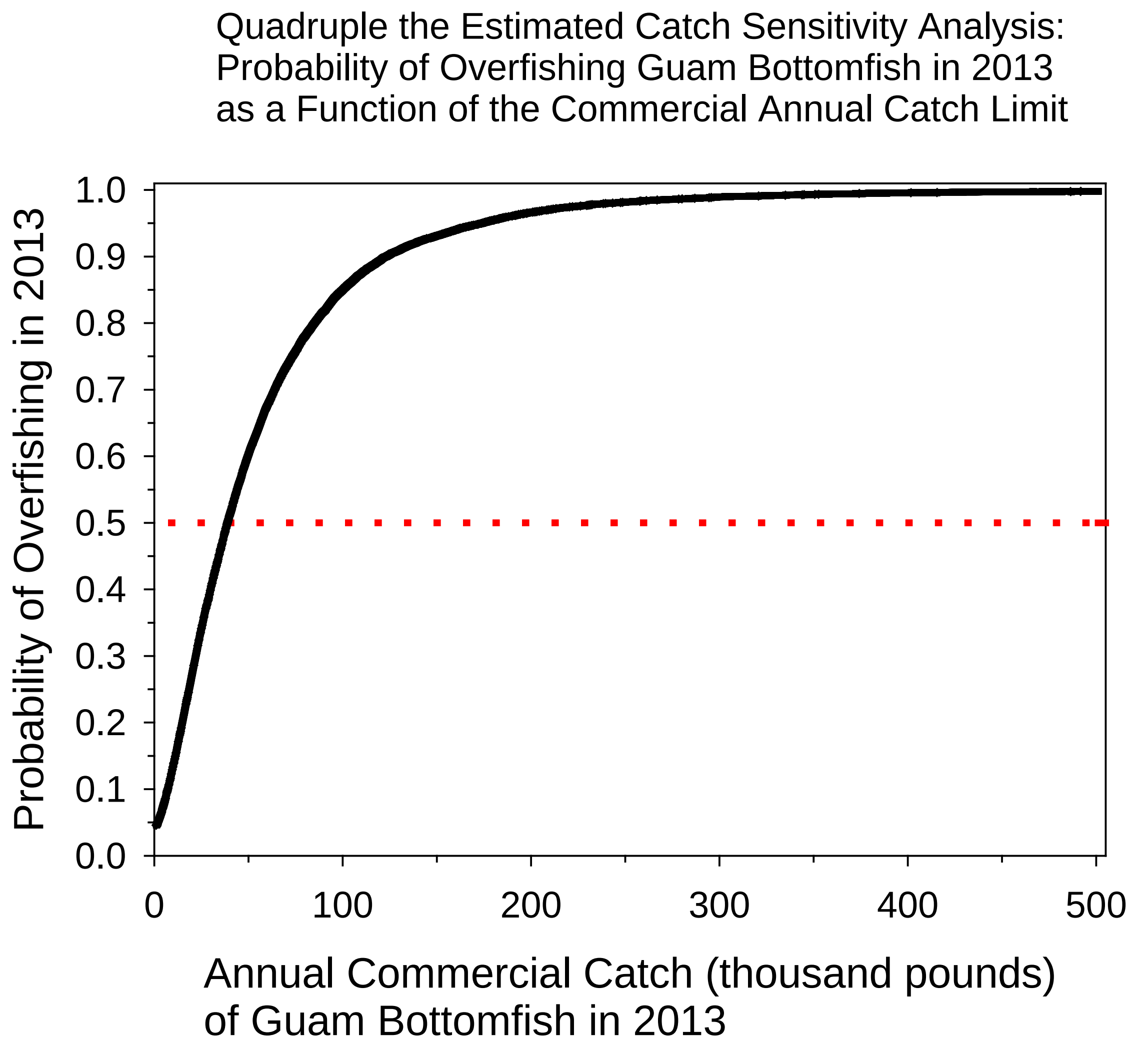

Figure 73. Quadruple the estimated catch sensitivity analysis: Probability of overfishing Guam bottomfish in 2013 as a function of the commercial annual catch limit.

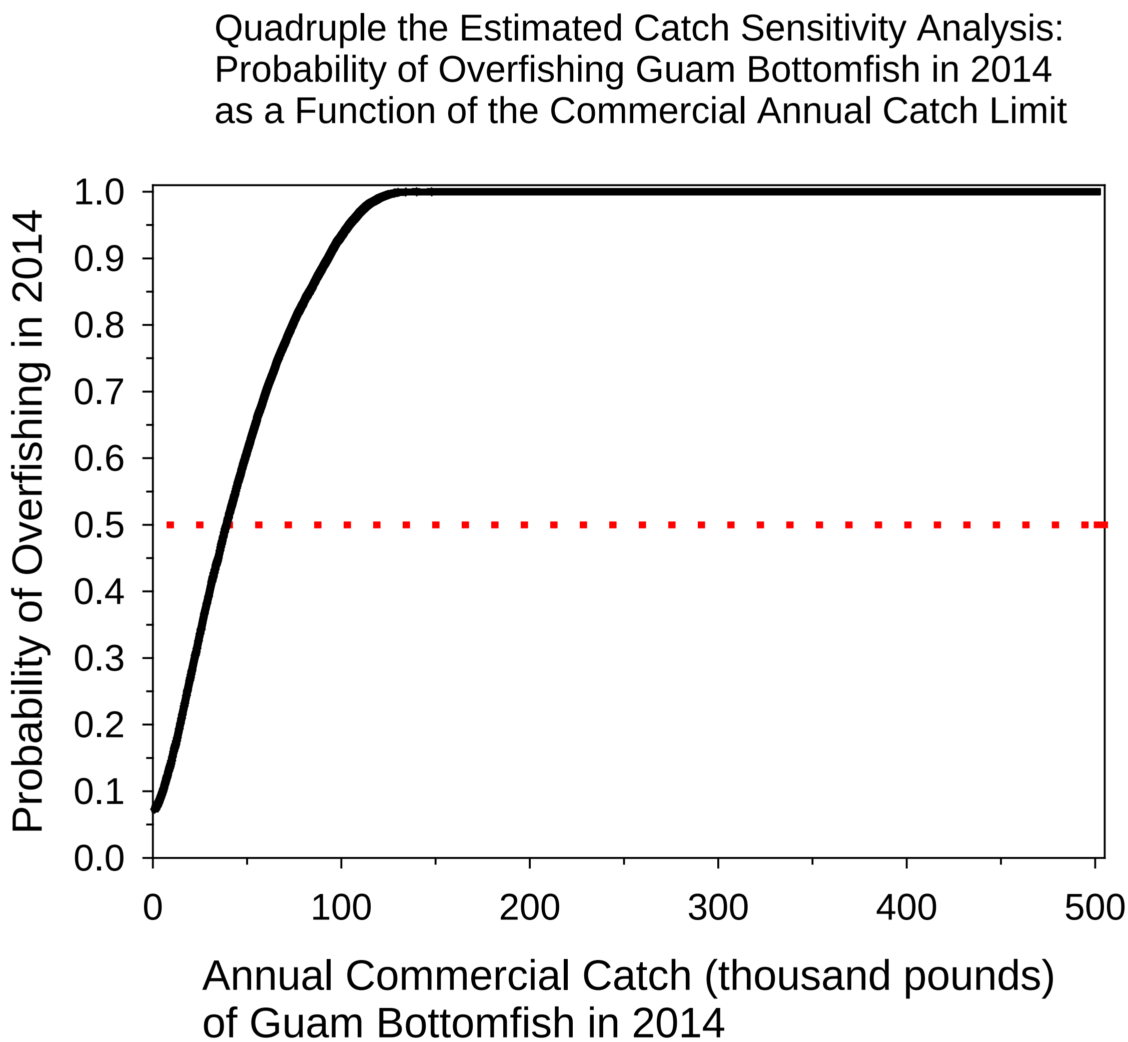

Figure 74. Quadruple the estimated catch sensitivity analysis: Probability of overfishing Guam bottomfish in 2014 as a function of the commercial annual catch limit.

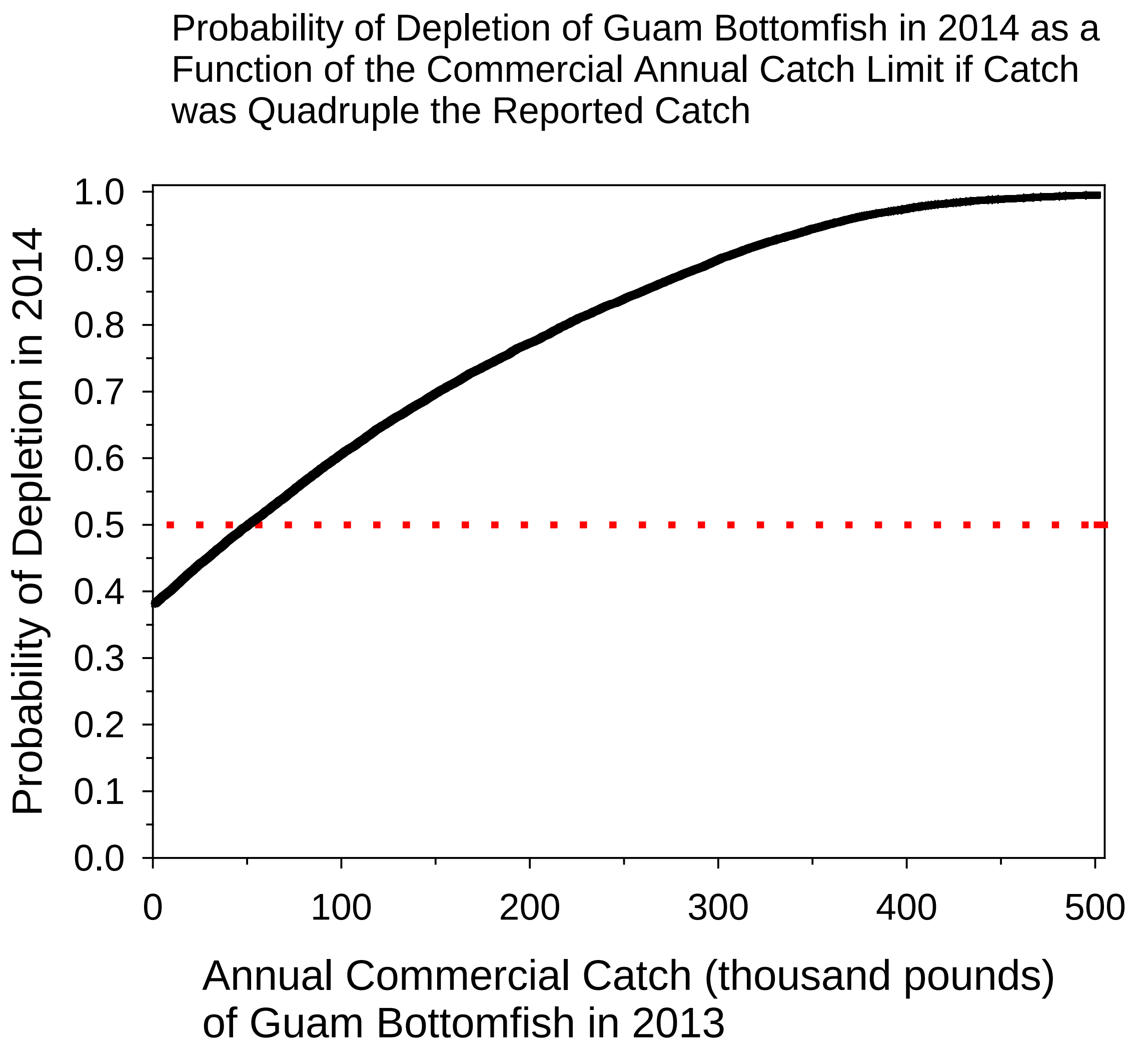

Figure 75. Quadruple the estimated catch sensitivity analysis: Probability of depletion of Guam bottomfish in 2014 as a function of the commercial annual catch limit.

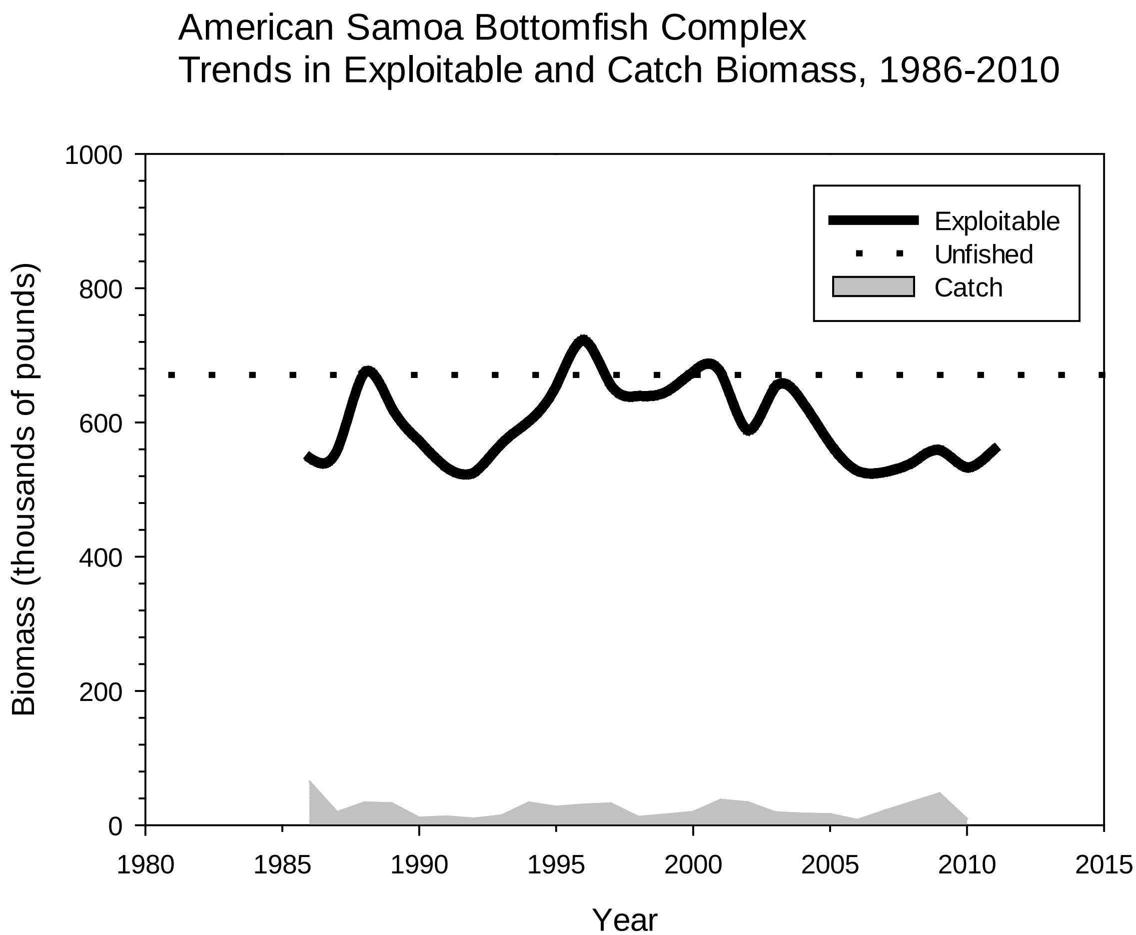

Figure 76. American Samoa bottomfish complex: Trends in exploitable and catch biomass, 1986-2010.

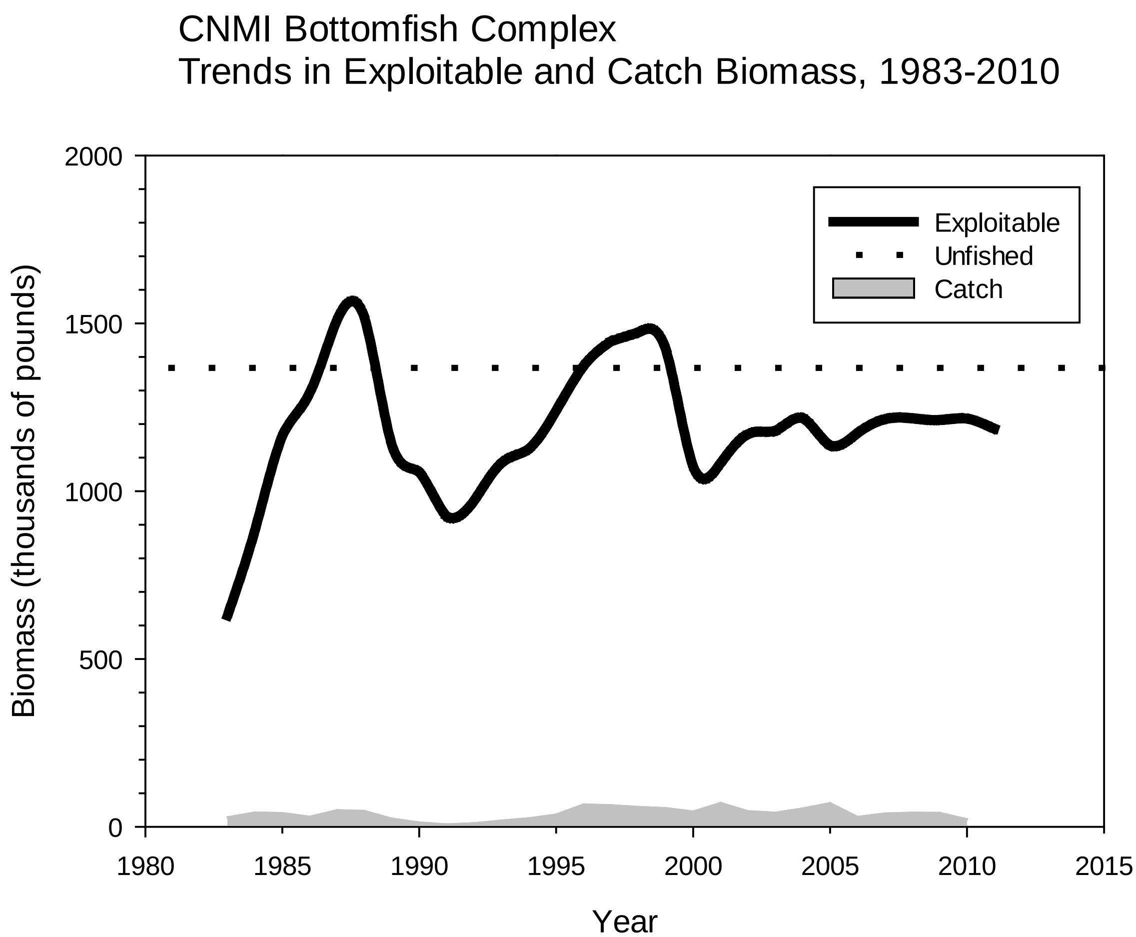

Figure 77. CNMI bottomfish complex: Trends in exploitable and catch biomass, 1983-2010.

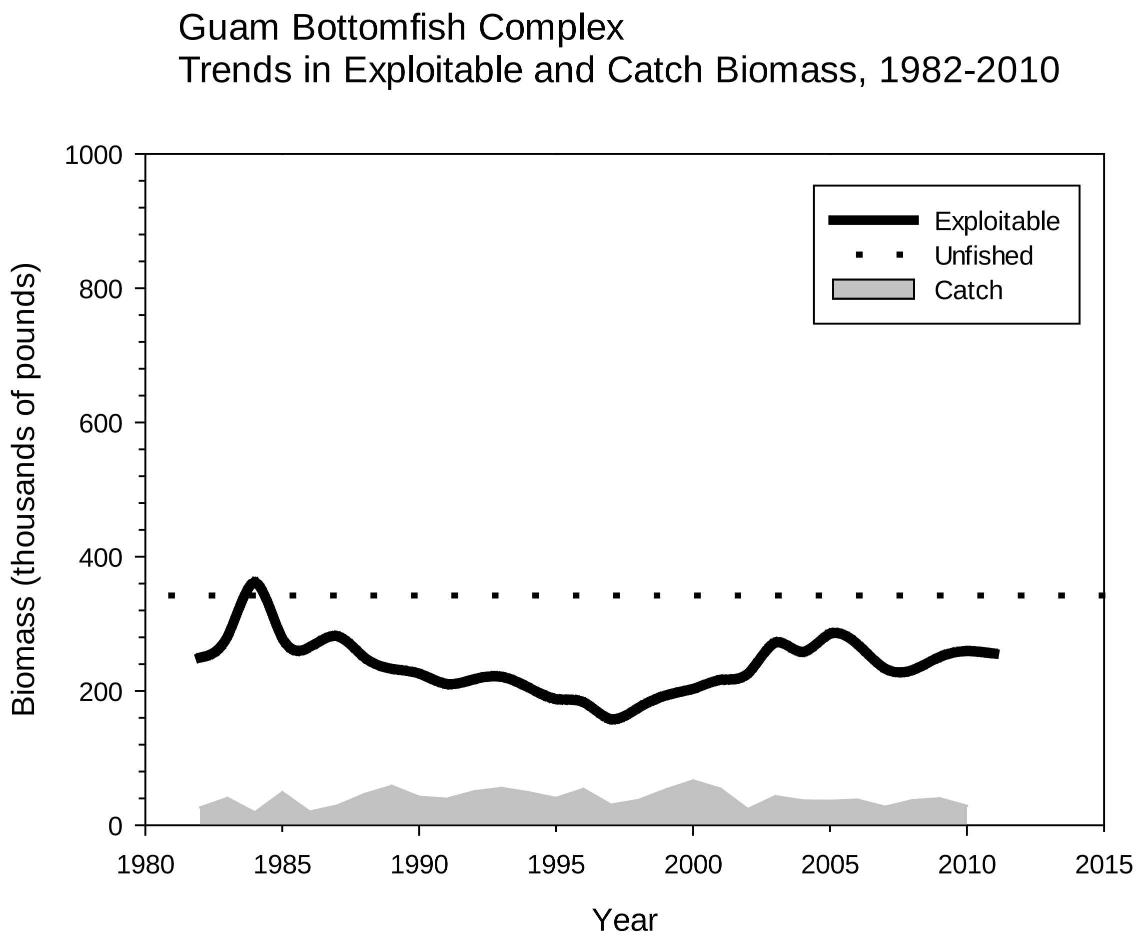

Figure 78. Guam bottomfish complex: Trends in exploitable and catch biomass, 1982-2010.