PACIFIC ISLANDS FISHERIES SCIENCE CENTER

Hawaiian Bottomfish Assessment Update for 2008

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ABSTRACT

The Hawaiian bottomfish assessment was updated through 2007. The updated assessment was conducted using re-audited bottomfish catch and effort data from commercial logbook records collected during 1948-2007. A standardized bottomfish catch-per-unit effort (CPUE) data set was constructed for the main Hawaiian Islands using the re-audited catch and effort data and a multiplicative log-linear estimation model. The standardized series included fishing year, month, and fishing area as predictors of bottomfish CPUE on directed fishing trips ($\geq$ 50% bottomfish catch by weight). Each of the predictors had a significant ($P<0.0001$) influence on observed CPUE by trip. For comparison, the CPUE filtering approach used in previous bottomfish assessments was also applied to the revised CPUE data set to obtain a status quo CPUE series. A Bayesian production model was used to estimate bottomfish biomass and harvest rate time series. This model was also used to conduct short-term projections of future catches and associated risks of overfishing. These projections explicitly included uncertainty in the posterior distribution of estimated bottomfish biomass in 2007 and population dynamics parameters. The production model was fit to catch and standardized CPUE data for each of the three Hawaiian fishing zones: the main Hawaiian Islands zone, the Mau zone, and the Hoomalu zone. The production model fitting incorporated uninformative priors for carrying capacity, process error, observation error, and catchability parameters and an informative prior for intrinsic growth rate. Results of the catch and CPUE analyses, production modeling, and projections are summarized below.

INTRODUCTION

The Hawaiian bottomfish complex is a U.S. fishery management unit comprised primarily of several species of snappers and jacks and a grouper inhabiting waters of the Hawaiian Archipelago (Table 1). The archipelagic management unit includes three fishing zones: the main Hawaiian Islands (MHI) zone, the Mau zone, and the Hoomalu zone. Most fishing currently takes place in the MHI zone. The assessed bottomfish complex includes a subset of seven species, the “Deep 7”, that are a particular focus of management (Table 1). The Hawaiian bottomfish fishery is a traditional deep-water fishery that targets these species primarily using deepwater handline gear. Hawaiian bottomfish were targeted by Hawaiians using deep handlines from canoes for hundreds of years before the advent of the modern fishery after World War II. The modern fishery employs similar deep handline gear, albeit with braided synthetic line, along with power reels to haul back gear, fish finders to locate schools of fish, and GPS units and other navigational aids to find fishing grounds. Although the efficiency of fishing vessels has improved through time (Moffitt et al., 2009), the Hawaiian bottomfish fishery still uses traditional deep handline capture methods for commercial and recreational harvest.

Previous Assessment

The previous assessment of the Hawaiian bottomfish complex was conducted in 2005 using fishery data through calendar year 2004 (Moffitt et al., 2006). This assessment included surplus production model analyses of bottomfish catch and catch-per-unit effort data for the three fishing zones (Fig. 1). In these analyses, bottomfish CPUE was assumed to be proportional to relative abundance in each zone. Catchability of bottomfish in the MHI zone was assumed to be time varying and increasing through the assessment time horizon. Observed CPUE in the MHI was adjusted by an estimated catchability multiplier in four time periods to account for changes in catchability. Predicted CPUE was fitted to observed CPUE using nonlinear least squares to estimate model parameters. Biological reference points to achieve maximum sustainable yield (MSY) were estimated for each fishing zone. Stock status of the MHI bottomfish was assessed for calendar years 1948-2004 while status of the Mau and Hoomalu zones was assessed for 1988-2004. The status of the Archipelagic management unit was assessed based on a weighted average of the stock status of the three zones, where the weights were the fraction of total bottomfish habitat by zone. Assessment results indicated that the Archipelagic management unit was not depleted but was experiencing overfishing in 2004. Fishing mortality for the Archipelagic bottomfish management unit was estimated to be 24% above the overfishing threshold. As a result, management measures were crafted to reduce fishing mortality on MHI bottomfish where overfishing was occurring; these included seasonal fishery closures and total allowable commercial catch limits. Analyses of bottomfish total allowable catch limits were conducted by the PIFSC in 2007-2008 to address the issue of overfishing on the Archipelagic management unit and the MHI bottomfish stock.

Previous Risk Analyses

Risk analyses for bottomfish were conducted to provide guidance on appropriate total allowable bottomfish catches in 2007 and again in 2008. In 2007, a deterministic projection analysis was conducted to estimate the magnitude of the reduction in the MHI fishing mortality and catch to cease overfishing on the Archipelagic management unit. It was expected that there might be a sufficient reduction in commercial landings (25%) assuming the seasonal bottomfish closure (WPFMC, 2007) was perfectly implemented with no seasonal shifts in fishing effort and catch. Because the assumption that fishing effort would not shift seemed unlikely, alternative 2007 catch levels in the MHI that would meet the target reduction in fishing mortality (F) were projected (Brodziak et al., 2007). Three alternative total allowable catch levels in 2007 (TAC_{2007}) for the Deep 7 bottomfish species in the main Hawaiian Islands were developed. These were: (1) TAC_{2007} set at 76% of reported 2004 Deep 7 landings; (2) TAC_{2007} set with F_{2007} at 76% of F_{2006} which was assumed to be equal to F_{2005}; (3) TAC_{2007} set with F at 76% of F_{2004}. Under each alternative it was assumed that bottomfish fishing mortality had remained constant in the Northwestern Hawaiian Islands (NWHI) since 2004. For each alternative, the basic input data were the estimated bottomfish stock status in 2004 from Moffitt et al. (2006).

Results of the deterministic TAC calculations for the Deep 7 bottomfish in 2007 ranged from TAC_{2007}=72 thousand pounds (klb) under alternative 3, to TAC_{2007}=110 klb under alternative 2, to TAC_{2007}=178 klb under alternative 1 (Brodziak et al., 2007). It is important to note that all of the alternative TACs in 2007 were calculated to just meet the overfishing threshold and did not provide any precautionary reductions to account for uncertainty in the input data, process dynamics, or assessment estimates. These considerations were incorporated into a subsequent stochastic TAC risk analysis in 2008.

In 2008, another assessment of the risk of overfishing the bottomfish complex in the Hawaiian Archipelago was conducted (Brodziak, 2008). The purpose of this analysis was to quantify the probabilities that overfishing would occur on the archipelagic bottomfish complex for a range of total allowable commercial catches of Deep 7 bottomfish species in the main Hawaiian Islands during the 2008 fishing year. This analysis was conditioned on the results of the 2005 stock assessment of the Hawaiian bottomfish complex (Moffitt et al., 2006) which provided estimates of bottomfish biomass and fishing mortality through 2004. Thus, one component of the assessment was to project the biomasses and fishing mortalities that likely occurred in 2005-2007 in order to compute probabilities of overfishing in 2008 under various TACs. This projection was accomplished by simulating the impacts of reported commercial catches during 2005-2007 using the biomass dynamics model from the most recent assessment (Moffitt et al., 2006) and by accounting for uncertainty in the estimates of key model parameters. In particular, the simulation analysis estimated the TACs for the Deep 7 bottomfish species that would produce risks of archipelagic overfishing in 2008 of 0%, 5%, 10%, ..., 100%, conditioned on the baseline model assumptions.

Results of the stochastic risk analyses (Brodziak, 2008) indicated that the largest TAC_{2008} that would produce approximately 0% chance of overfishing in 2008 (i.e., exceeding F_{TARGET}) was 24 thousand pounds (klb). In contrast, the smallest TAC that would lead to a roughly 100%

chance of overfishing was 273 klb. Total allowable commercial catches in 2008 ranging from 24 to 99 thousand pounds, corresponded to risks of archipelagic overfishing ranging from 0% to 50%. The TAC to achieve a low risk of overfishing (25%) in 2008 was estimated to be $TAC_{25\%}$ = 61 klb and the TAC to achieve a neutral risk of overfishing (50%) in 2008 was estimated to be $TAC_{50\%}$ = 99 klb. The probability of exceeding F_{TARGET} was a concave function of TAC_{2008} over most of the TACs examined. This indicated that risk of overfishing increased less than proportionally with increasing TAC_{2008} values. Sensitivity analyses showed that the estimates of overfishing risk were highly sensitive to the estimates of biomass in 2004, intrinsic growth rate, and the proportion of Deep 7 bottomfish in the catch. In contrast, estimates of overfishing risk were moderately sensitive to the estimate of carrying capacity, the assumed bottomfish catches in 2007, and the coefficients of variation of key model parameters.

Current Assessment

The current assessment was conducted in 2008 using fishery data through 2007 and provides an update of the previous Hawaiian bottomfish assessment through 2007. In this context, the updated assessment was constrained to using the same data sources as the preceding assessment and also was constrained to using a modeling approach that was similar or identical to that used in the preceding assessment. However, it is important to note that the updated assessment addressed two concerns about the 2005 bottomfish assessment. The first concern was that the bottomfish catch and effort data from the MHI during the early portion of the time series may have contained multi-day trips with larger catches than the single-day trips used to compute a standardized catch-per-unit effort time series. The presence of multi-day bottomfish trips in the 1950s and 1960s could skew the average MHI CPUE to higher values than were representative of the single-day trips used to calculate the standard CPUE time series. This would lead to an overestimate of bottomfish relative abundance in the 1950s-1960s when MHI CPUE was used as an abundance index in the surplus production model. Thus, an intensive effort was made to re-audit the MHI catch and effort data to eliminate multi-day trip records using criteria developed from interviews with long-time bottomfish fishermen. The second concern about the 2005 bottomfish assessment was that it employed a least-squares estimation approach that provided no direct measure of the variability of parameter estimates for conducting risk analyses. To address this concern, a Bayesian surplus production modeling approach was applied to estimate bottomfish biomass and fishing mortality rates in the current assessment, assuming similar model structure and assumptions.

Data for the updated assessment included re-audited bottomfish catch and effort data from Hawaii Division of Aquatic Resources (HDAR) records collected during 1948-2007. A revised bottomfish catch-per-unit effort data set was constructed using the re-audited catch and effort data. The CPUE filtering approach used in previous bottomfish assessments was applied to the revised CPUE data set to obtain the status quo CPUE series used in the previous assessment (Moffitt et al., 2006). A statistical log-linear model described by Gavaris (1980) was applied to develop a spatially standardized CPUE series for the main Hawaiian Islands. This series included fishing year, month, and fishing area as predictors of bottomfish CPUE on directed fishing trips (> 50% bottomfish catch by weight). Each of the predictors had a significant ($P<0.0001$) influence on observed CPUE by trip. A Bayesian production model was used to estimate bottomfish biomass and harvest rate time series (Brodziak, 2007). This model was also used to conduct short-term projections of future catches and associated risks of overfishing. These projections explicitly included uncertainty in the posterior distribution of estimated bottomfish biomass in 2007 and population dynamics parameters. The production model was fit to catch and standardized CPUE data for each of the three Hawaiian fishing zones: the main Hawaiian Islands zone, the Mau zone, and the Hoomalu zone. The production model fitting incorporated uninformative priors for carrying capacity, process error, observation error, and catchability parameters and an informative prior for intrinsic growth rate. The mean of the prior for intrinsic growth rate was equal to the estimate of the parameter used in the previous bottomfish assessment (Moffitt et al., 2006). Methods and results of the catch and CPUE analyses, production modeling analyses, and stochastic projection analyses for estimating 2009 TACs and associated probabilities of overfishing are described in detail below.

MATERIALS AND METHODS

In this section, the bottomfish fishery data, the CPUE standardization method and results, and the production model used to estimate biomass and fishing mortality for the Hawaiian bottomfish assessment update are described.

Fishing Year

In the previous assessment (Moffitt et al., 2006), the annual time period for reporting bottomfish catches (Table 2) was the calendar year from 1-January to 31-December. The time period for calculating CPUE in the MHI was from 1-July of the previous year through 30-June of the current year (the fishing year, FY) during 1948-1992. This time period was chosen because it corresponded to the time period used for renewal of commercial marine licenses (CML) for the State of Hawaii. In particular, one CML number was associated with one vessel permit during the FY, while on a calendar year basis the CML would change at the end of June halfway through each year. Beginning on 1-July-1993, the CML became permanent and did not change from fishing year to fishing year. This made it possible to track vessel permit numbers beginning in 1993. In the previous assessment, the calendar year was used as the time period for calculating CPUE from 1993 to 2005. This enabled the catches of individual vessels to be tallied across years in the hope of developing time series of individual vessel CPUE in the MHI. In the Mau and Hoomalu fishing zones, CPUE used in the previous assessment was calculated on a fishing year basis.

In the current assessment, the annual time period for reporting bottomfish catch and CPUE is the fishing year from 1-July of the previous year through 30-June of the current year. There were two primary reasons for making the change to fishing year. First, the fishing year corresponds to the annual biological cycle of the deepwater snapper and grouper bottomfish complex in which spawning occurs in late spring to early summer. Thus, estimates of annual production biomass starting in July coincided with the settlement of juvenile bottomfish through mid-summer. Second, the commercial fishery catch of bottomfish is typically highest during the winter months when there is strong market demand for snapper during New Years and other holidays. The use of calendar year split the primary bottomfish season into two separate years. In contrast, the use of fishing year included the primary bottomfish season in one annual assessment time period. In addition, the use of fishing year might make it possible to track individual fishing vessel catches and CPUE prior to 1993 using annual records of the CML associated with individual vessel permit numbers. Overall, the treatment of MHI CPUE in the current assessment differs slightly from the use of CPUE from a mixture of fishing year and calendar year in the previous assessment.

Fishery Catch

Fishery catch data for the updated assessment included commercial bottomfish catch and effort data extracted from a total of 4,066,464 HDAR logbook catch records submitted by commercial fishers during fishing years 1949-2007 (M. Quach, PIFSC, pers. comm. 14-July-2008). Bottomfish catch data by trip were assigned to the three fishing zones based on the reported HDAR fishing area in the logbook (Fig. 1). Some bottomfish catch trip records had an unknown area and these small catches were apportioned to the three areas based on the annual catch proportion by area. As in the previous bottomfish assessment (Moffitt et al., 2006), the bottomfish catch used in the assessment update consisted of all reported bottomfish landings (Table 2 and Fig. 2) excluding the catches of kahala (*Seriola dumerili*) and taape (*Lutjanus kasmira*). Catches by trip were assigned to fishing year (the fishing year extends from July 1st of the previous year to June 30th of the current year). The fishing year corresponds to the fiscal year basis on which commercial fishing licenses are allocated by the state of Hawaii and also includes the entire winter season, when bottomfish catches typically are highest, in a single fishing year. Estimates of recreational bottomfish catch were not included in the current assessment, similar to the previous assessment. Overall, the total commercial bottomfish catch used in the assessment included fishing year catches from the MHI during 1949-2007 and the fishing year catches from the Mau and Hoomalu zones during 1988-2007 when fishery CPUE data were available from these two zones.

Standardized Commercial Fishery Catch-Per-Unit Effort

Bottomfish catch per trip was calculated in the MHI for directed deep handline trips for which information was reported on fishing date, commercial marine license, area fished, and fishing gear code during FY 1948-2007. In particular, logbook catch records were audited to remove records that were missing either fishing date, CML number, or fishing area as well as records that did not have a fishing gear code equal to deep handline fishing gear. This led to a total of n=214,981 directed commercial bottomfish trips using deep handline gear with a total catch of roughly 33.2 million pounds.

In an independent review of the previous Hawaiian bottomfish assessment, it was reported that there were a few logbook trip records for the main Hawaiian Islands fishing zone that exceeded 5,000 pounds of bottomfish catch per trip in the 1950s and 1960s. Such trips were expected to represent multiday trips in the MHI by larger vessels, and not the single-day trip that was representative of the primary fishing fleet operating in the MHI during FY 1948-2007. Since there were no screening procedures to eliminate possible multi-days trips from the data set used for calculating MHI CPUE in the previous assessment, there was a concern that the status quo CPUE series might overestimate the long-term decline in commercial fishery CPUE. This, in turn, would be expected to lead to an overestimate of the decline of relative bottomfish biomass in the MHI.

To address the concern about the possible inclusion of multi-day trips in the CPUE standardization, several interviews with long-term bottomfish fishermen were conducted by the PIFSC to gather information on the historic operation of the fishery. In August 2008, the results of these interviews were reviewed at a CPUE standardization workshop that included participants from the PIFSC, HDAR, and the Western Pacific Regional Fishery Management Council (Moffitt et al., 2009). The workshop was also convened to address the issue of changes in bottomfish fishing technology through time and to address the issues of what data were appropriate and what qualifying criteria for including a trip in the bottomfish CPUE analyses were appropriate, e.g., include a trip only if the ratio of bottomfish catch weight to total catch weight was greater than 90%, as in Moffitt et al. (2006).

The CPUE standardization workshop participants agreed to a number of points regarding the treatment of CPUE data from the MHI for the current assessment update (Moffitt et al. 2009). The workshop participants agreed that the exclusion of catch data for kahala, a species with decreased market demand since the mid-1980s due to possible ciguatera poisoning, and for taape, an introduced species, was appropriate and should be continued in the assessment update. The workshop also agreed that consideration of different trip qualifying criteria would be appropriate. In particular, there was a consensus that trips landing over 1,500 pounds per day would not be appropriate for single-day trip operations. The workshop participants also agreed that it would be useful to consider less restrictive qualifying criteria to increase the spatial coverage of the fishing operations used to compute standardized CPUE. Workshop participants also agreed that changes in the fishery catchability coefficient (Fig. 3) corresponding to major changes in technology and fleet dynamics should continue to be used in future assessments. Workshop participants also thought it would be useful to investigate the effects of vessel characteristics, oceanographic conditions, and socioeconomic factors on bottomfish CPUE in a medium to long-term research effort.

Based on the CPUE workshop recommendations, bottomfish CPUE time series for the main Hawaiian Islands were calculated using a standardization approach that included the spatial effect of fishing area as well as the status quo approach from Moffitt et al. (2006) for comparison. For each fishing year in 1949-2007, the status quo CPUE in the MHI was calculated using the selection algorithm from Moffitt et al. (2006) with the additional trip qualifying criterion that trips reporting over 1,500 pounds of bottomfish catch were not included in the CPUE analysis of single-day trips. Another trip qualifying criterion for the status quo approach was that bottomfish comprise at least 90% of the total trip catch by weight. Further, qualifying trips had to have annual catches that were 30% or more of the annual median of the top ten ranked Maui Nui fishing area catches by CML. The value of status quo CPUE in each year was the arithmetic average of the CPUE values for qualifying trips. On average, the status quo CPUE time series was based on 25% of the total deep handline catch of

MHI bottomfish during 1949-2007 (Fig. 4). Similarly, the status quo CPUE time series was based on 10% of the total deep handline trips that captured MHI bottomfish, on average, during 1949-2007 (Fig. 5). Applying the status quo CPUE approach to the re-audited HDAR data produced a similar trend to that observed in the status quo CPUE series from the previous assessment (Spearman R=0.83, P<0.001). Overall, the status quo CPUE from the current and the previous assessments were significantly positively correlated.

For the current assessment, bottomfish CPUE time series in the Mau and Hoomalu zones during 1988-2004 were taken from the previous assessment (Moffitt et al., 2006) and CPUE values during 2005-2007 were updated using the same approach as in the previous assessment (Fig. 7). Overall, the CPUE series from the Mau and Hoomalu zones were negatively correlated (Spearman R=-0.32, P=0.17) during 1988-2007 but this association was not significant.

For the current assessment, bottomfish CPUE for the main Hawaiian Islands was standardized using a multiplicative loglinear model (e.g., a special case of a generalized linear model, GLM) applied to the re-audited HDAR data. This enabled us to evaluate the statistical significance of the available predictors and to calculate the standardized CPUE from the estimated year coefficients of the fitted GLM. The format of the HDAR logbook has changed since 2000 to include more detailed information on fishing operations, including line hours fished for deep handline fishing, but these detailed data were not recorded throughout most of the logbook time series from 1949 to 2007. However, two potential predictors of bottomfish CPUE were consistently recorded in the HDAR data during 1949-2007; these were area fished and month fished for each trip. In the context of CPUE standardization, each of these factors could have an effect on bottomfish CPUE that varied on an annual basis due to changes in the fishery and distribution of fish. The area factor represented potential differences in the spatial distribution of bottomfish and their catchability. The month factor represented potential differences in the seasonal distribution of bottomfish and associated catchability. Overall, the goal of the standardization analysis was to remove the impact of the spatial and seasonal factors on the annual relative abundance of bottomfish, as indexed by the year effect estimated in the GLM.

The HDAR logbook reporting areas were used to develop a set of area strata for the directed bottomfish fishery in the MHI. In particular, the logbook CPUE data were constrained to be single-day trips (bottomfish catch less than 1,500 lbs) using deep handline gear. There were a large number of individual HDAR reporting areas in the nearshore (< 3 miles) and offshore (> 3 miles) around the main Hawaiian Islands (Fig. 8). To avoid estimating area effect coefficients for each of these areas, many of which had little or no reported bottomfish catch, we tabulated the reported bottomfish catch by area during 1949-2007 to discern the key bottomfish areas. In this case, the key 3-digit areas were those areas that accounted for at least 1% of the total bottomfish handline catch during 1949-2007 (Fig. 8, red shading 3-digit areas). The remaining three digit areas were grouped by island region to define an aggregate area for estimating the spatial effect of area on CPUE in the GLM. In particular, the six aggregate areas were (Fig. 8): Other Offshore (light tan shading), Other Kauai (lavender shading), Other Oahu (light orange shading), Other Maui, Molokai, and Lanai (light green shading), and Other Hawaii (pink shading). Overall, there were twenty six key areas and six aggregate areas used to estimate the spatial effect in the GLM.

Potential seasonal effects on bottomfish CPUE in the MHI were accounted for by considering each month as a factor level. In this case, the significance of the seasonal effect was assessed using the analysis of deviance explained by the month effect in the GLM.

The selection of a qualifying percentage of bottomfish catch by weight per trip was revisited for the GLM analyses of MHI CPUE as suggested by the CPUE Standardization Workshop. Roughly one-half of the deep handline trips that landed some bottomfish during 1949-2007 also landed some other non-bottomfish species. This suggested that a ratio of at least 50% bottomfish catch weight per trip would be a reasonable cutoff to define a fishing trip that had probably targeted bottomfish for a substantial fraction, if not a majority, of the fishing time expended. The annual distribution of bottomfish catch ratio for deep handline gear (Fig. 9) also indicated that the median trip caught a high percentage of bottomfish, fluctuating around 80% during the 1950s-1980s and increasing to nearly 100% in the 1990s. This implied that the use of a 50% bottomfish ratio would provide better coverage of the fishery than a 90% cutoff. As a result, a 50% bottomfish ratio per trip was chosen as the qualifying criterion for the GLM analyses to standardize CPUE. This choice implied that, on average, roughly 85% of the annual bottomfish catch (Fig. 4) and 73% of deep handline trips (Fig. 5) were used in the CPUE standardization analysis. GLM sensitivity analyses were conducted for a bottomfish ratio of 90% and for all deep handline trips that caught at least 1 pound of bottomfish.

A statistical approach described by Gavaris (1980) was applied to develop a spatially standardized CPUE series for the main Hawaiian Islands. The multiplicative loglinear model to standardize bottomfish catch rate per trip (CPUE) in the MHI had three explanatory variables. These were fishing year (Y), fishing area (A), and fishing month (M). These were the only factors that were available for the entire time series of HDAR logbook data besides the CML, which changed each fishing year until 1993, the fishing gear, and the catch by species. For an individual deep handline trip, the multiplicative model took the form

$$(1) \qquad CPUE_{ijk} = U_R \cdot \prod_i Y_i^{X_{y,i}} \prod_j A_j^{X_{a,j}} \prod_k M_k^{X_{m,k}} \cdot \exp\left(\varepsilon_{ijk}\right)$$

where U_R was the reference mean catch for a particular combination of year, area, and month, Y_i were the year effect coefficients with indicator variable $X_{y,i} = 1$ if the trip occurred in year i and $X_{y,i} = 0$ otherwise, A_k were the area effect coefficients with indicator variable $X_{a,j} = 1$ if the trip occurred in area j and $X_{a,j} = 0$ otherwise, M_k were the month effect coefficients with indicator variable $X_{m,k} = 1$ if the trip occurred in month k and $X_{m,k} = 0$ otherwise, and the iid normal error term ε_{ijk}. In this case, the multiplicative model predicts CPUE for an individual trip as a mean catch rate times a proportional effect for year (interpreted as a relative abundance index for bottomfish), area, and month along with a multiplicative lognormally-distributed error term. The properties of this loglinear model are well established. In particular, if the catch rate is lognormally distributed then the estimator of catch rate determined by this model is the minimum variance unbiased estimator. The linear form of the model is typically used for estimation purposes

$$(2) \qquad \ln\left(CPUE_{ijk}\right) = U_R + \sum_i X_{y,i} \ln\left(Y_i\right) + \sum_j X_{a,j} \ln\left(A_j\right) + \sum_k X_{m,k} \ln\left(M_k\right) + \varepsilon_{ijk}$$

In this case, maximum likelihood estimates (θ) were calculated from the normal equations to solve this linear regression model

(3) $$\theta = \left(X^T X\right)^{-1} X^T y$$

using SAS Proc GLM (SAS, 1990), where θ is the vector of log-transformed parameter estimates, X is the design matrix of indicator variable values and y is the vector of log-transformed CPUE observations. Alternatively, model parameters could be estimated using iteratively reweighted least squares, as in a GLM. The estimated parameters within each factor were linearly dependent and treatment contrasts were used with the reference cell year equal to1980 (the start of the standard catchability time period, see Fig. 3), the area equal to 331 (i.e., Penguin Bank), and the month equal to December. The choice of the reference cell was arbitrary and it did not affect the parameter estimates.

Back-transformed year coefficients with bias adjustment to account for the natural logarithmic transformation (Gavaris, 1980; eqn 7 with $g_m(t)=\exp(t)$) were used to compute the mean standardized CPUE in each year t as

(4) $$CPUE(t) = U_R \cdot \exp\left(\ln(Y_t) + 0.5\left(\sigma^2 - Var\left[\ln(Y_t)\right]\right)\right)$$

where σ^2 was the residual variance from the regression and $Var[\ln(Y_t)]$ was the variance of the log-scale year coefficient. The variance of CPUE(t) was computed from the associated expression for the unbiased estimator of variance (Gavaris, 1980; eqn 8 with $g_m(t)=\exp(t)$)

(5)

$$Var\left[CPUE(t)\right] = U_R^2 \cdot \exp\left(2\ln\left(Y_t\right)\right)\left\{\exp\left(0.5\left(\sigma^2 - Var\left[\ln\left(Y_t\right)\right]\right)\right)^2 - \exp\left(\sigma^2 - 2\cdot Var\left[\ln\left(Y_t\right)\right]\right)\right\}$$

Bottomfish catches were log-transformed for the standardization analysis. The resulting log-scale catch rate distribution appeared to be approximately normal (Fig. 10) although a hypothesis test would reject that assumption due to the large number of CPUE observations. The individual 3-digit areas used in the spatial standardization included the individual HDAR reporting areas that accounted for at least 1% of the total bottomfish catch reported during 1949-2007 fishing years along with the six aggregate areas (Fig. 5).

The fit of the GLM was highly significant ($P<0.0001$), in part due to the large number of CPUE observations ($n\approx141{,}000$) included in the analysis (Appendix, Table A1). A diagnostic plot of residuals versus fitted CPUE did not indicate substantial model misspecification (Fig. A1) although the upper bound of 1500 pounds per trip was apparent. In particular, the CPUE residuals and fitted values were not correlated (Spearman rank correlation $R=0.001$, $P=0.59$). A diagnostic plot to assess whether the variance of CPUE changed as a function of the fitted value suggested there was a moderate increase in variance with increasing CPUE (Fig. A2). In comparison, the multiplicative lognormal error assumption of the GLM implied that variance in CPUE would be expected to increase in proportion to mean CPUE. A diagnostic plot to assess whether the three explanatory variables reduced the observed variability in CPUE suggested that some of the variability was being explained by the combination of the year, area, and month effects (Fig. A3) but that there was a substantial amount of unexplained variation. Nonetheless, a linear regression of observed log-scale CPUE on fitted values was highly significant (P<0.001) with an estimated slope coefficient of B_1=1.000 (±0.006 SE) for fitted values. Overall, the GLM explained approximately 18% of the observed variation in the CPUE data. A Q-Q plot of the standardized CPUE residuals suggested that there was a moderate departure from normality (Fig. A4) and this was likely due to the tendency for variability in CPUE to increase slightly more than in proportion with mean CPUE. Last, a histogram of the standardized CPUE residuals from the fitted GLM suggested that the residuals were approximately normal (Fig. A5), although there was a moderate negative skew in the residual distribution. Overall, the GLM appeared to fit the CPUE data reasonably well, although there was some evidence of heteroscedastcity and non-normality of the residuals.

Standardized mean annual catch rates for MHI bottomfish exhibited a decreasing trend since the 1960s (Fig. 11). The standardized CPUE was significantly positively correlated with the status quo CPUE (Spearman R=0.75, P<0.001) but exhibited much less interannual variation (Fig. 11). The estimated area coefficients and associated mean CPUE values by fishing area indicated that there was substantial heterogeneity in the spatial pattern of bottomfish CPUE in the main Hawaiian Islands (Fig. 12). The estimated month coefficients and associated standardized CPUE values suggested that there were moderate but statistically significant seasonal differences in bottomfish CPUE in the main Hawaiian Islands (Fig. 13).

The GLM sensitivity analysis with a bottomfish ratio of 90% had a similar declining CPUE trend as the baseline model. However, the 90% ratio GLM provided a poorer overall fit to the selected data (R^2=0.135) and exhibited a slightly higher residual variance. Similarly, the GLM sensitivity analysis using all deep handline trips that caught at least 1 pound of bottomfish had a similar qualitative trend in CPUE but had a poorer fit (R^2=0.166) and had a higher residual variance than the baseline GLM.

Assessment Model

In the previous assessment of the Hawaiian bottomfish complex, the status of the multispecies complex in each fishing zone was assessed using a Schaefer surplus production model (Moffitt et al., 2006). The previous assessment assumed that the intrinsic growth rate of Hawaiian bottomfish was equal across zones and a single intrinsic growth rate was estimated for all zones in the surplus production models. The previous assessment also assumed that the relative amount of bottomfish habitat in each zone was proportional to the linear extent of its 100-fathom contour. In this case, the carrying capacity of the MHI was a freely estimated parameter while the carrying capacities of the Mau and Hoomalu zones were set based on the ratio of MHI habitat to Mau or Hoomalu habitat multiplied by the carrying capacity estimate for the MHI. Overall, the bottomfish surplus production model for the previous assessment included linkages between the intrinsic growth rates and carrying capacities estimated for each fishing zone. These linkages were maintained in the current assessment.

Status determination of the Archipelagic bottomfish management unit in the previous assessment was based on the habitat-weighted average of the model results by fishing zone.

That is, the status of the complex was assessed for the entire Hawaiian Archipelago as specified in the Fishery Management Plan. This status determination was based on the assumption that there was sufficient interchange among adult and larval fishes of the three zones to treat them as a single management unit. Status determination criteria in the current assessment were calculated in the same manner as in the previous assessment.

In the previous assessment, the estimation procedure was nonlinear least squares with no assumptions regarding the error structure for fitting parameters. As a result, no estimates of parameter uncertainty were available to quantify the risks associated with alternative fishery management actions. In the current assessment, a Bayesian statistical framework was applied to directly estimate production model parameters and parameter uncertainty for risk analyses.

Production Model

The Schaefer production model for bottomfish was formulated as a Bayesian state space model with explicit process and observation error terms (see, for example, Meyer and Millar, 1999). The unobserved biomass states were estimated from the observed relative abundance indices (CPUE) and catches based on an observation error likelihood function and prior distributions for each model parameter (θ). In this case, the observation error likelihood measured the discrepancy between observed and model predictions of CPUE.

The process dynamics were based on a quadratic surplus production model with an annual time step. In this model, biomass in year T (B_T) depends on the previous biomass, catch (C_{T-1}), the intrinsic growth rate parameter (R), and the carrying capacity parameter (K), for years $T = 2,\ldots, N$.

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

The values of biomass and harvest rate that maximize surplus production were relevant for fishery management under the Magnuson Fishery Conservation and Management Act as reauthorized in 1996. For the Schaefer model, the biomass that maximizes surplus production (B_{MSY}) was

(7) $$B_{MSY} = \frac{K}{2}$$

The corresponding harvest rate that maximizes surplus production (H_{MSY}) was

(8) $$H_{MSY} = \frac{R}{2}$$

and the maximum surplus production (MSY) was

$$MSY = \frac{R \cdot K}{4} \tag{9}$$

The biomass dynamics were reparameterized in terms of the proportion of carrying capacity ($P = B/K$) to improve the efficiency of the Markov Chain Monte Carlo sampling algorithm. Based on this parameterization, the process dynamics became

$$P_T = P_{T-1} + R \cdot P_{T-1}\left(1 - P_{T-1}\right) - \frac{C_{T-1}}{K} \tag{10}$$

Annual fluctuations in life history parameters, trophic interactions, environmental conditions and other factors were expected to change the process dynamics through an annual process error term. In this context, the process error represented the joint effect of a large number of random multiplicative events which combined to form a multiplicative lognormal random variable under the Central Limit Theorem. Given this, the process error terms were 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.

State equations described how the stochastic process dynamics related the unobserved biomass states to the observed catches and the model parameters. Given the lognormal process error assumption, the state equations for the initial time period $T = 1$ and subsequent periods $T > 1$ of the Schaefer model were

$$\begin{aligned} P_1 &= \eta_1 \\ P_T &= \left(P_{T-1} + R \cdot P_{T-1}\left(1 - P_{T-1}\right) - \frac{C_{T-1}}{K}\right) \cdot \eta_T \end{aligned} \tag{11}$$

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

Changes in Catchability

In the previous assessment, trends in relative abundance were based solely on fishery catch-per-unit-effort (CPUE) data. To address the fact that fishing technology used to locate and capture bottomfish has improved over time (e.g., Moffitt et al., 2009), it was assumed that the fishery catchability coefficient Q increased in each of four successive time periods with catchability being constant in each period (Fig. 3). In the previous assessment, the relative catchabilities of the four periods were set based on limited field observations, anecdotal knowledge, and subjective judgment. The fishery catchability coefficient for the standard time period (Q_{STD}) during 1980-1991 was a freely estimated parameter in the production and the other values were set based on their relative catchabilities (c). The relative catchabilities during 1949-1967, 1968-1979, 1980-1991, and 1992-2007 were c=0.7, c=0.8, c=1, and c=1.2, respectively, and the resulting catchability coefficients were calculated as $Q=c \cdot Q_{STD}$. Thus, the current assessment applied the same approach to dealing with long-term improvements in fishing technology as was used in the previous assessment.

Likelihood Model

The likelihood model related the observed standardized fishery CPUE to the exploitable bottomfish biomass. It was assumed that the CPUE index (*I*) was proportional to biomass with catchability coefficient *Q*

(12) $$I_T = QB_T = QKP_T$$

The CPUE values were observed with sampling error and it was assumed that the observation errors were lognormally distributed. In particular, the observation errors were $\nu_T = e^{V_T}$ where the V_T were iid normal random variables with zero mean and variance τ^2. Given these assumptions, the observation equations for the state space model in years $T = 1,\ldots, N$ were

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

This equation specified the likelihood function $p(I_T|\theta)$ for each period.

Prior Distributions

Under the Bayesian paradigm, prior distributions were employed to quantify existing knowledge (or the lack thereof) of the likely value of model parameters and the unobserved biomass states. In this context, the model parameters were the carrying capacity parameter, intrinsic growth rate parameter, catchability parameter, the process and observation error variance parameters, and the initial biomass as a proportion of carrying capacity parameters. Unobserved biomass states were estimated from the proportion of carrying capacity, conditioned on the previous proportion, and the catchability parameter.

Prior for Carrying Capacity

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

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

The mean parameter was set to be 2 million pounds based on the numerical scale of biomass estimates in Moffitt et al. (2006).The variance parameter was set to be 100 million pounds to allow for a wide range of probable carrying capacity values. In effect, this was an uninformative prior for *K*. The values of carrying capacity for the Mau and Hoomalu zones were set based on the estimate of *K* and the relative habitat weights for the three bottomfish management zones ($W_{MHI} = 0.447$, $W_{Mau} = 0.124$, $W_{Hoomalu} = 0.429$) as in the previous assessment (Moffitt et al., 2006). Thus, the carrying capacities of the Mau and Hoomalu zones calculated as a fraction of the habitat weighted carrying capacity of the main Hawaiian Islands were 0.277*K* and 0.960*K*, respectively.

Prior for Intrinsic Growth Rate

The prior distribution for intrinsic growth rate *p*(*R*) was a beta distribution with parameters *c* and *d*:

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

This choice constrained the intrinsic growth rate parameter to be within the interval $[0, 1]$. The mean of the prior for R was set to be μ_R=0.46. This choice was based on the estimate from Moffitt et al. (2006) of *R* = 0.46. This range was consistent with the fact that the bottomfish complex included snappers with relatively high values of natural mortality ($M > 0.25$) and moderate values of Brody growth coefficients (Martinez-Andrade, 2003).Values of the beta distribution parameters were set to *c* = 7.67 and *d* =9 to set the coefficient of variation (CV) of R to be 26%. The sensitivity of model results to the choice of the informative prior distribution for *R* was examined below.

Prior for Catchability

The prior for the inverse of catchability $p(Q^{-1})$ was chosen to be a diffuse gamma distribution with scale parameter λ and shape parameter *k*. This prior was used to approximate an improper prior for catchability $p(Q) = Q^{-1}$ (see Meyer and Millar, 1999). In particular the prior for the inverse of Q was

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

The scale and shape parameters were set to be λ = *k* = 0.001. This choice of parameters implied that 1/*Q* had a mean of 1 and a variance of 1000. As a result, the prior for catchability was an inverse gamma distribution that was approximately proportional to 1/Q, e.g., $p(Q) \propto Q^{-1}$. Since 1/*Q* is unbounded at *Q* = 0, an additional numerical constraint that *Q* lie within the interval [0.0001, 10] was imposed.

Priors for Error Variances

Priors for the process error variance $p(\sigma^2)$ and observation error variance $p(\tau^2)$ were also chosen to be inverse-gamma distributions, a natural choice for dispersion priors (Congdon, 2001). For the process error variance prior, the scale parameter was set to $\lambda = 4$ and the shape parameter was $k = 0.01$. This choice of parameters produced an 80% confidence interval of approximately [0.04, 0.08] for σ. Similarly, for the observation error variance prior, the scale parameter was set to $\lambda = 2$ and the shape parameter was $k = 0.01$. This choice of parameters gave an 80% confidence interval of approximately [0.05, 0.14] for τ. The ratio of the observation error prior mean to the process error prior mean was $E[\tau]/E[\sigma] = 0.0707/0.05 \approx 1.41$. Thus, the observation error variance was assumed to be about 40% greater than the process error variance. The sensitivity of model results to this assumption was examined below.

Priors for Proportions of Carrying Capacity

Prior distributions for the time series of biomass in proportion to carrying capacity, $p(P_T)$, were determined by the lognormal distributions and the process dynamics. The prior mean for the initial proportion of carrying capacity in the main Hawaiian Islands in 1949 ($P_{MHI,1}$) was set to be 0.6 based on the minimum root-mean square error of the fit to the MHI CPUE over alternative values of $P_{MHI,1}$ from 0.1 to 1.0 (Fig. A.6). Prior means for the initial proportions of carrying capacity in the Mau and Hoomalu zones in 1988 were set to 0.8.

Posterior Distribution

The posterior distribution was numerically sampled to make inferences about model parameters. From Bayes' theorem, the posterior distribution given catch and CPUE data D, $p(\theta|D)$, was proportional to the product of the priors and the likelihood of the CPUE data.

$$p(\theta \mid D) \propto p(K)\,p(R)\,p(M)\,p(Q)\,p(\sigma^2)\,p(\tau^2)\prod_{T=1}^{N} p(P_T)\prod_{T=1}^{N} p(I_T \mid \theta) \quad (17)$$

There was no analytic solution to determine parameter estimates from the posterior distribution in (17).

Under the Bayesian paradigm, parameter estimation for nonlinear models like the bottomfish production model is typically based on simulating a large number of independent samples from the posterior distribution. In this case, Markov Chain Monte Carlo (MCMC) simulation (Gilks et al., 1996) was applied to numerically generate a sequence of samples from the posterior distribution. The WINBUGS software (Lunn et al., 2000; Spiegelhalter et al., 2003) was used to program the model, set the initial conditions, perform the MCMC calculations, and summarize the production model results (Appendix, Table A2). The baseline production model used the standardized CPUE in the MHI along with Mau and Hoomalu CPUE series to estimate model parameters.

MCMC simulations were conducted in an identical manner for the baseline model and sensitivity analyses described below. Two chains of 210,000 samples from the posterior distribution were simulated in each model run. The first 60,000 samples of each chain were excluded from the estimation process. This burn-in period removed dependence of the MCMC samples on the initial conditions. Next, each chain was thinned by 3 to remove autocorrelation, e.g., every third sample from the posterior distribution was used for inference. As a result, 100,000 samples from the posterior distribution were used to summarize model results. Convergence of the MCMC chains to the posterior distribution was checked using the Brooks-Gelman-Rubin (BGR) convergence diagnostic (Brooks and Gelman, 1998). This diagnostic assessed convergence by comparing the variance ratio (V) of within- to between-chain variability and was monitored for key model parameters (intrinsic growth rate, carrying capacity, catchability, initial proportion of carrying capacity) and the root-mean squared error (RMSE). Values of the variance ratio V that were close to unity and no greater than 1.2 indicated convergence was likely to have occurred (Gelman et al., 1995).

Model residuals were used to measure the goodness of fit of the production model. Residuals for the CPUE series were the log-scale observation errors ε_T.

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

Non-random patterns in the residuals indicated that the observed CPUE did not conform to one or more model assumptions. The RMSE of the CPUE fit provided another diagnostic of the model goodness of fit with lower RMSE indicating a better fit.

Production model results included the status of the entire Archipelagic management unit as well as the individual fishing zones relative to MSY reference points. Time series of the relative harvest rate (for example, in 2007 the relative harvest rate is the ratio H_{2007}/H_{MSY}) and relative biomass (e.g., the ratio B_{2007}/B_{MSY}) were calculated for the Archipelagic unit and individual zones using the mean values from the joint posterior distribution of model parameters.

Sensitivity Analyses

The sensitivity of model biomass estimates to the CPUE index was evaluated by fitting the production model using the status quo CPUE as the relative abundance index for the MHI with all other input data and assumptions remaining the same. This sensitivity analysis addressed the question of whether model results were sensitive to the use of the status quo CPUE series instead of the standardized CPUE series.

The sensitivity of model results to the prior mean for intrinsic growth rate was also evaluated by fitting the model using different prior means for R. In this case, the prior mean for R ranged from 0.25 to 0.75 in increments of 0.05. This sensitivity analysis addressed whether the choice of a prior mean for R=0.46 had a strong influence on model results.

Similarly, the sensitivity of model results to the prior mean for carrying capacity was also evaluated by fitting the model using different prior means for K. For this analysis, the prior mean for K ranged from 1500 to 2500 klbs in increments of 100 klbs. This sensitivity analysis addressed whether the choice of a prior mean for K=2000 had a strong influence on model results.

Sensitivity analyses to the prior means for the observation and process error terms were conducted by fitting the model using different prior means for τ^2 and σ^2. For the observation error variance, the prior mean for τ^2 was multiplied by 10, 100, 1000, and 10000, and the production model was fit in each of the four cases with all other inputs and assumptions remaining the same. Similarly, for the process error variance, the prior mean for σ^2 was multiplied by 10, 100, 1000, and 10000, and the production model was fit in each case with all other inputs and assumptions constant. These analyses addressed the question of whether the choice of the prior mean for the observation or process error had a strong influence on model results.

Projections for 2008-2010

Bottomfish biomass, catch, and relative biomass were projected for fishing years 2008-2010 under alternative fishing mortality and catch assumptions for the main Hawaiian Islands. In these projections, status quo fishing mortality rates were assumed for the Mau and Hoomalu zones in 2008. With the exception of the F_{MSY} projection, fishing mortality rates for the Hoomalu and Mau zones in fishing years 2009-2010 were also set equal to the mean of the 2007 harvest rate estimate. These status quo rates were $H_{SQ,Mau}$=0.03, and $H_{SQ,Hoomalu}$=0.07. In comparison, the mean estimate of H_{MSY} for both zones was H_{MSY}=0.29. In the MHI the bottomfish catch in fishing year 2008 was estimated using an estimate of the total Deep 7 bottomfish catch in FY 2008, which was $C_{DEEP7,\ 2008}$ = 192,614 lbs, and the average ratio of Deep 7 to total bottomfish catch in 2005-2007, which was $R_{DEEP7,2005\text{-}2007}$ = 0.723 (Table A3). The resulting estimate of total MHI bottomfish catch in 2008 was C_{2008} = 266,409 lbs. This 2008 catch was used to estimate the MHI fishing mortality rate in fishing year 2008 in each of the alternative projections.

Three sets of projections were conducted using alternative fishing mortality or catch assumptions for the MHI. The first projection was the F_{MSY} scenario which provided an estimate of the upper bound of catch for each of the zones. In the F_{MSY} scenario, harvest rates in the MHI, Mau, and Hoomalu zones were set equal to F_{MSY} in 2009-2010.

The second projection was the status quo fishing mortality scenario. In this projection, fishing mortality rates during 2009-2010 in the main Hawaiian Island, Mau zone, and Hoomalu zone were set equal to the estimate of the mean harvest rate in 2008.

The third projection was the constant total allowable catch for the main Hawaiian Islands scenario in fishing year 2009-2010. For this scenario, the set of median catches of MHI bottomfish in 2009 that would produce probabilities of overfishing in the MHI ranging from

0% to 100% by 5% intervals were calculated. These TACs were then applied to the MHI in 2009-2010 while status quo fishing mortality rates were assumed in the Mau and Hoomalu zones.

RESULTS

In this section, production model results are described. These include: model diagnostics, biomass and fishing mortality estimates to assess stock status, sensitivity analyses, and projection analyses.

Model Diagnostics

Model residual diagnostics indicated that the Bayesian production model provided a good fit to the bottomfish CPUE time series from the MHI (Fig. 14), the Mau zone (Fig. 15) and the Hoomalu zone (Fig. 16). The BGR convergence diagnostic indicated that the MCMC chains had converged after the burn-in period for all the monitored parameters including: MHI carrying capacity V=1.08; initial proportion of carrying capacity for MHI V=0.98, for Mau V=1.01, and for Hoomalu V=1.00; catchability for MHI V=1.01, for Mau V=1.00, and for Hoomalu V=1.01; and for intrinsic growth rate V=1.04. Overall, the residual and convergence diagnostics indicated that there were no problems with convergence of the baseline model.

Stock Status

Bottomfish biomass and harvest rate estimates and MSY-based reference points from the production model were summarized for the Archipelago and the MHI, Mau, and Hoomalu zones (Tables 3, 4, and 5 and Table A4). Estimates of biological reference points for bottomfish were similar to the estimates from the previous assessment (Moffitt et al., 2006). Relative biomass and harvest rate estimates for the Archipelagic bottomfish stock indicated that the stock was not overfished (B_{2007}/B_{MSY}=1.13, Fig. 17) and was not currently experiencing overfishing (H_{2007}/H_{MSY}=0.62). In fishing year 2007, there was a 97% probability that Archipelagic biomass exceeded B_{MSY} and a 0% chance that the harvest rate exceeded H_{MSY}. Biomass of the Archipelagic stock declined from roughly 150% of B_{MSY} in the late-1980s to slightly above B_{MSY} in recent years. Harvest rates for the Archipelagic stock declined from roughly 90%-100% of H_{MSY} in the late-1980s to range from 60%-80% of H_{MSY} since 2000.

Results for the Hoomalu zone bottomfish stock indicated that the stock was not overfished (B_{2007}/B_{MSY}=1.54, Table 3 and Fig. 18) and was not currently experiencing overfishing (H_{2007}/H_{MSY}=0.25, Table 4 and Fig. 18). In fishing year 2007, there was a 99.9% probability that Hoomalu biomass exceeded B_{MSY} and a 0% chance that the harvest rate exceeded H_{MSY}. Biomass in the Hoomalu zone declined from about 200% of B_{MSY} in the late-1980s to range from 120% to 150% of B_{MSY} since 2000. Relative harvest rates in the Hoomalu zone fluctuated from 10% to 50% of H_{MSY} since 1988.

Similarly, results for the Mau zone bottomfish stock indicated that the stock was not overfished (B_{2007}/B_{MSY}=1.55, Table 3 and Fig. 19) and was not currently experiencing overfishing (H_{2007}/H_{MSY}=0.12, Table 4 and Fig. 19). In fishing year 2007, there was a 99.9% probability that Mau biomass exceeded B_{MSY} and a 0% chance that the harvest rate exceeded H_{MSY}. Biomass in the Mau zone declined from 180% of B_{MSY} in the late 1980s to about 120% of B_{MSY} in the late 1990s and has increased to 150%-160% of BMSY since 2000. Harvest rates in the Mau zone exceeded H_{MSY} in 1991 but have since declined to range from roughly 10% to 60% of H_{MSY} since 2000.

In contrast, results for the main Hawaiian Islands bottomfish stock indicated that the stock was depleted (B_{2007}/B_{MSY}=0.62, Table 3 and Fig. 20) and was currently experiencing overfishing (H_{2007}/H_{MSY}=1.11, Table 4 and Fig. 20). In fishing year 2007, there was a 0% probability that MHI biomass exceeded B_{MSY} and an 87% chance that the harvest rate exceeded H_{MSY}. Bottomfish biomass exhibited a long-term decline from high values in the 1960s-1970s to relatively low values since the mid-1990s (Fig. 21). Biomass in the MHI zone declined from roughly B_{MSY} in the late-1980s to about 60% of B_{MSY} since 2000. Harvest rates were relatively low in the 1960s to mid-1970s, increased to peak in 1989, and have declined gradually since then (Fig. 22). Harvest rates in the MHI declined from roughly 200% of H_{MSY} in the late-1980s to range from 94% to 140% of H_{MSY} since 2000.

Sensitivity Analyses

The sensitivity analysis on the effect of using the status quo MHI CPUE series indicated that using the status quo CPUE series instead of the standardized CPUE series would have decreased estimates of relative biomass and increased estimates of relative harvest rate across zones (Table 6). In particular, the status quo CPUE indicated a much more abrupt decline in bottomfish biomass over time (Fig. 11) decreasing from an average of 462 lbs/trip in the 1950s and 1960s to roughly 181 lbs/trip in the 2000s (-61%). In comparison, the standardized CPUE declined from an average of 304 lbs/trip in the 1950s-1960s to an average of 170 lbs/trip since 2000 (-44%). As a result, the Archipelagic bottomfish stock would be estimated to be approaching an overfished condition in 2007 and would be estimated to have been experiencing overfishing since 1988 (Table 6, Fig. 23) if relative abundance was assumed to be proportional to status quo CPUE.

The sensitivity analysis on the effect of using different prior means for the intrinsic growth rate parameter showed that changing the mean R would not have much of an effect on estimates of relative biomass in the MHI (Fig. 24). In comparison to the mean R=0.46 used in the assessment, changing the mean value from R=0.25 (-46%) to R=0.75 (+63%) did not alter the trend in relative biomass. Overall, assessment results did not appear to be sensitive to the prior mean for intrinsic growth rate.

The sensitivity analysis to examine the effect of using different prior means for carrying capacity in the MHI indicated that there was no practical impact for the range of K investigated (Fig. 25). This suggested that there was sufficient information in the CPUE and fishery catch trends to estimate K. Overall, the assessment results were not sensitive to the prior mean for carrying capacity.

The sensitivity analysis on the effect of increasing the mean of the prior for the observation error variance suggested that a 10-fold increase in observation error would have no practical effect (Fig. 26) while an increase of 100-fold in the observation error variance would have a moderate effect on relative MHI biomass. Increases on the order of 1000-fold or more would have an important effect on the estimated trends in relative biomass and in particular, would produce a sharply increasing trend in recent years. Overall, the assessment results appeared to be sensitive to increases of 1000-fold or more in the mean of the observation error variance prior.

The sensitivity analysis on the effect of increasing the process error variance indicated that increasing the process error variance would tend to increase the relative MHI biomass (Fig. 27). A 10-fold increase in the process error mean produced a nearly identical trend in relative biomass as estimated in the assessment and a 100-fold increase produced a similar trend. Increases in process error on the order of 1000-fold to 10000-fold increased the relative biomass in the MHI but did not affect the estimated trend. Overall, results were moderately sensitive to the mean of the prior for process error variance.

Projections

Under the F_{MSY} scenario, projected bottomfish catches, probabilities of overfishing, and relative biomasses (Table 7) showed the probable distribution of outcomes if fishing mortality was set equal to the overfishing threshold in 2009-2010. In this case, fishing mortality was set to the overfishing threshold in each fishing zone. The resulting yields in 2009-2010 were higher in the Mau and Hoomalu zones because the current fishing mortality in these zones was much lower than F_{MSY} (Table 4). Relative biomass of the Archipelagic stock would be projected to decrease by 2010 under this scenario but would still exceed B_{MSY}. In comparison, relative biomass in the MHI would be projected to increase moderately by 2010 but would still remain below the estimate of B_{MSY}.

Under the status quo fishing effort scenario, projected bottomfish catches, probabilities of overfishing, and relative biomasses (Table 8) indicated the probable distribution of outcomes if fishing effort and mortality rates in the Hoomalu and Mau zones remained at fishing year 2007 levels in 2009-2010 while fishing mortality in the MHI in 2009-2010 was equal to the value in 2008 as estimated from the MHI catch in 2008. The status quo results led to a 0% probability of overfishing the Archipelagic stock in 2009-2010 (Table 8). The catch biomasses in the Hoomalu zone were projected to increase slightly (Fig. 28) under the status quo scenario while catch in the Mau zone would remain relatively constant (Fig. 29). The MHI catch biomass was projected to increase in 2009-2010 (Fig. 30) following a decrease in 2008. Stock biomasses in the Hoomalu and Mau zones were projected to increase moderately in 2009-2010 (Figs. 31 and 32). Similarly, biomass in the MHI was projected to increase under the F_{2008} fishing mortality scenario (Fig. 33) although the probability that MHI biomass exceeded B_{MSY} in 2010 would be relatively low (2%).

Under the constant TAC scenarios, projected probabilities of overfishing, relative biomasses, and probabilities of depletion of MHI bottomfish (Table 9) showed the distribution of outcomes that would likely occur if constant TACs were applied in the MHI during 2009-2010. The probability of overfishing the MHI bottomfish stock as a function of the Deep 7 bottomfish TAC in 2009 showed that there was a range of Deep 7 bottomfish TAC values that would produce a less than 50% chance of overfishing in the MHI (Fig. 34). Results of the stochastic projections indicated that the largest Deep 7 TAC_{2009} that would produce approximately 0% chance of overfishing in 2009 (i.e., exceeding F_{MSY}) was 172 thousand pounds. For comparison, the smallest Deep 7 TAC that would lead to a roughly 100% chance of overfishing the Archipelagic stock was 343 klb. Total allowable commercial catches of Deep 7 bottomfish in 2009 ranging from 172 to 249 thousand pounds corresponded to risks of Archipelagic overfishing ranging from 0% to 50%. The Deep 7 TAC to achieve a low risk of overfishing (25%) in 2009 was estimated to be $TAC_{25\%}$ = 227 klb and the Deep 7 TAC to achieve a neutral risk of overfishing (50%) in 2008 was estimated to be $TAC_{50\%}$ = 249 klb. Sensitivity analyses of a similar projection model suggested that the estimates of overfishing risk would be sensitive to the estimates of biomass, intrinsic growth rate, and the proportion of Deep 7 bottomfish in the catch (Brodziak, 2008). In contrast, estimates of overfishing risk were unlikely to be sensitive to the estimate of carrying capacity, the assumed bottomfish catches in 2007, and the coefficients of variation of these model parameters.

SUMMARY

Assessment results indicated that the Archipelagic bottomfish management unit was not overfished during 1988-2007 but had experienced overfishing in 1989 when the record bottomfish catch of roughly 1.144 million pounds was harvested. Archipelagic biomass in 2007 was estimated to be about 13% above B_{MSY} with a harvest rate of roughly 60% of F_{MSY}. Thus, the Archipelagic stock was not overfished and was not experiencing overfishing in 2007.

Results for bottomfish in the Hoomalu and Mau fishing zones were generally similar. Bottomfish biomass in both zones ranged from roughly 120% to 200% of B_{MSY} since 1988. Current biomass in both zones was estimated to be about 150% of B_{MSY} in 2007. Harvest rates in the Hoomalu zone ranged from 12% to 49% of F_{MSY} since 1988. In comparison, harvest rates in the Mau zone were more variable and ranged from 12% to 102% of F_{MSY} during 1988-2007. The 2007 harvest rate in the Hoomalu zone was estimated to be about 25% of F_{MSY} while in the Mau zone, the current harvest rate was 12% of F_{MSY}. Thus, both Hoomalu and Mau zone bottomfish stocks were not overfished and not experiencing overfishing in 2007.

For the main Hawaiian Islands bottomfish, assessment results indicated a long-term decline in exploitable biomass from high levels in the 1950s-1960s to relatively low levels since the 1990s. In the late 1980s, bottomfish biomass in the MHI was roughly at B_{MSY}. Since then, biomass has declined and has fluctuated around 60% of B_{MSY} since the mid-1990s. Current MHI biomass was estimated to be 62% of B_{MSY} in 2007. Bottomfish harvest rates in the MHI were relatively low in the 1960s at roughly 50% of F_{MSY}. MHI harvest rates increased in the late-1970s and peaked at roughly 200% of F_{MSY} in the late-1980s. Since then, MHI bottomfish harvest rates have declined and have ranged from 94% to 140% of F_{MSY} since 2000. The current MHI harvest rate was 111% of F_{MSY} in 2007. Thus, the MHI bottomfish stock was overfished and was experiencing overfishing in 2007.

Projection results indicated that it was highly unlikely that the Archipelagic management unit would be overfished or experience overfishing at current levels of fishing effort. Similarly, bottomfish biomass in the Hoomalu and Mau zones would be likely to remain above B_{MSY} in 2009-2010 at current levels of fishing effort. Projection results for the main Hawaiian Islands indicated that a range of total allowable catches of Deep 7 bottomfish in the MHI of roughly 172 klb to 249 klb in 2009 would produce probabilities of overfishing in the MHI ranging from 0% to 50%. Applying a TAC from this range in both 2009 and 2010 would be projected to lead to a probability of 10% or less that MHI bottomfish would be considered to be overfished in 2010.

The primary difference between the results of the current and previous bottomfish assessments was the use of the standardized CPUE to index the relative abundance of bottomfish in the main Hawaiian Islands. In this case, the standardized CPUE index was developed using a larger fraction of directed bottomfish catches (85%) than the CPUE calculations in the previous assessment (25%). The standardized CPUE index also incorporated a larger subset of deep handline fishing trips (73%) than the previous approach (10%). Thus, the standardized CPUE index was based on a fuller coverage of the directed bottomfish fishery in the MHI.

In the future, assessments of individual bottomfish species will likely be considered. However, such attempts to assess individual bottomfish species will be constrained by the amount and quality of fishery data. If fishery-dependent and fishery-independent data collection systems for Hawaiian bottomfish were augmented, age- or length-structured assessment models could be more readily applied to assess individual bottomfish species. In this context, one priority would be to sample the recreational fishery to estimate total recreational catch as well as catch at length by species. Collection of bottomfish length composition and length-weight data from the Honolulu fish auction could provide valuable information on commercial fishery catches and some auction sampling was conducted in 2008. Such fishery-dependent data could be used to evaluate the catch at age by species given sufficient age-length keys and ongoing sampling effort. Last, the development of a consistent fishery-independent survey in the main Hawaiian Islands and Northwestern Hawaiian Islands would greatly enhance the capacity to assess and to effectively manage the bottomfish resources.

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REFERENCES

Brodziak, J.
2007. An investigation of alternative production models to assess the Hawaiian bottomfish complex. Pacific Islands Fish. Sci. Cent., Natl. Mar. Fish. Ser., NOAA, Honolulu, HI 96822-2326. Pacific Islands Fish. Sci. Cent. Admin. Rep. H-07-01, 71 p.

Brodziak, J.
2008. An Assessment of the Risk of Archipelagic Overfishing for Alternative Total Allowable Catches of Deep-7 Bottomfish in the Main Hawaiian Islands Pacific Islands Fish. Sci. Cent., Natl. Mar. Fish. Serv., NOAA, Honolulu, HI 96822-2396. Pacific Islands Fish. Sci. Cent. Admin. Rep. H-08-03, 31 p.

Brodziak, J., R. Moffitt, and G. DiNardo.
2007. Main Hawaiian Islands Total Allowable Catch Alternatives. Pacific Islands Fish. Sci. Cent., Natl. Mar. Fish. Ser., NOAA, Honolulu, HI 96822-2326. Pacific Islands Fish. Sci. Cent. Internal Rep. IR-07-010, 6 p.

Brooks, S. P., and A. Gelman.
1998. Alternative methods for monitoring convergence of iterative simulations. Journal of Computational and Graphical Statistics, 7:434–455.

Congdon, P.
2001. Bayesian statistical modeling. Wiley, New York, 531 p.

Gavaris, S.
1980. Use of a multiplicative model to estimate catch rate and effort from commercial data. Can. J. Fish. Aquat. Sci. 37:2272-2275.

Gelman, A., J. Carlin, H. Stern, and D. Rubin.
1995. Bayesian data analysis. Chapman and Hall, New York, NY, 526 p.

Gilks, W. R., S. Richardson, and D. J. Spiegelhalter. [Eds.]
1996. Markov Chain Monte Carlo in Practice. Chapman and Hall, London. 486 p.

Lunn, D.J., A. Thomas, N. Best, and D. Spiegelhalter.
2000. WinBUGS -- a Bayesian modelling framework: concepts, structure, and extensibility. Statistics and Computing, 10:325--337.

Martinez-Andrade, F.
2003. A comparison of life histories and ecological aspects among snappers (Pisces: Lutjanidae). Ph.D. Dissertation, Louisiana State Univ. 194 p.

Meyer, R., and R. Millar.
1999. BUGS in Bayesian stock assessments. Can. J. Fish. Aquat. Sci. 56:1078–1086.

Moffitt, R., D. Kobyashi, and G. DiNardo.
2006. Status of the Hawaiian bottomfish stocks, 2004. Pacific Islands Fish. Sci. Cent., Natl. Mar. Fish. Ser., NOAA, Honolulu, HI 96822-2326. Pacific Islands Fish. Sci. Cent. Admin. Rep. H-06-01, 45 p.

Moffitt, R., G. DiNardo, J. Brodziak, K. Kawamoto, M. Quach, M. Pan, K. Brookins, C. Tam, and M. Mitsuyatsu.
2009. CPUE standardization workshop proceedings August 4-6, 2008. Pacific Islands Fish. Sci. Cent., Natl. Mar. Fish. Ser., NOAA, Honolulu, HI 96822-2326. Pacific Islands Fish. Sci. Cent. Internal Rep.

SAS Institute Inc. [SAS].
1990. SAS/STAT User's Guide, Version 6, 4th Ed, Volume 2. SAS Institute Inc., Cary, NC, 846 p.

Searle, S.
1987. Linear models for unbalanced data. John Wiley & Sons, New York, NY, 535 p.

Spiegelhalter, D., A. Thomas, N. Best, and D. Lunn.
2003. WinBUGS User Manual. Available at: http://www.mrc.bsu.carn.ac.uk/bugs/winbugs/manual14.pdf

Western Pacific Fishery Management Council [WPFMC].
2007. Main Hawaiian Islands Bottomfish Seasonal Closure Announcement. Available at: http://www.wpcouncil.org/index.htm\

Table 1.--List of Hawaiian bottomfish species used for reporting fishery catch and CPUE and those included in production model analyses in the current bottomfish assessment update and in the previous stock assessment (Moffitt et al., 2006).

Common name	Local name	Scientific name	Deep 7 species	Species included in assessment
Pink snapper	Opakapaka	*Pristipomoides filamentosus*	X	X
Longtail snapper	Onaga	*Etelis coruscans*	X	X
Squirrelfish snapper	Ehu	*Etelis carbunculus*	X	X
Sea bass	Hapuupuu	*Epinephelus quernus*	X	X
Grey jobfish	Uku	*Aprion virescens*		X
Snapper	Gindai	*Pristipomoides zonatus*	X	X
Snapper	Kalekale	*Pristipomoides seiboldii*	X	X
Blue stripe snapper	Taape	*Lutjanus kasmira*		
Yellowtail snapper	Yellowtail kalekale	*Pristipomoides auricilla*		X
Silver jaw jobfish	Lehi	*Aphareus rutilans*	X	X
Amberjack	Kahala	*Seriola dumerili*		
Thick lipped trevally	Butaguchi	*Pseudocaranx dentex*		X
Giant trevally	White ulua	*Caranx ignobilis*		X
Black jack	Black ulua	*Caranx lugubris*		X
Armorhead		*Pseudopentaceros wheeleri*		

Table 2.--Total Hawaiian bottomfish catch used in the assessment update by zone and fishing year and fishery zone. As in the previous assessment, fishery catches in the Mau and Hoomalu zones prior to 1988 are not used in the assessment update because there are no CPUE data available for these zones prior to 1988 and the initial proportion of carrying capacity in 1988 was an estimated parameter for the Mau and Hoomalu zones.

Fishing Year	Main Hawaiian Islands Bottomfish Catch Used in this Assessment (000 lbs)	Mau Zone Bottomfish Catch Used in this Assessment (000 lbs)	Hoomalu Zone Bottomfish Catch Used in this Assessment (000 lbs)	Total Catch by Fishing Year during 1988-2007 (000 lbs)
1949	512.812			
1950	431.817			
1951	416.819			
1952	389.113			
1953	375.470			
1954	370.070			
1955	318.004			
1956	382.184			
1957	434.718			
1958	312.884			
1959	293.832			
1960	226.944			
1961	189.962			
1962	237.813			
1963	299.509			
1964	307.018			
1965	317.130			
1966	249.043			
1967	328.351			
1968	273.108			
1969	264.002			
1970	233.280			
1971	203.334			
1972	303.987			
1973	233.679			
1974	326.603			
1975	324.690			
1976	366.530			
1977	363.726			
1978	436.206			
1979	400.264			
1980	343.842			
1981	450.492			
1982	464.614			
1983	579.104			
1984	555.910			
1985	619.434			
1986	621.324			
1987	725.632			
1988	804.011	32.897	194.618	1031.526
1989	964.785	77.349	101.816	1143.950
1990	647.051	90.941	119.346	857.338
1991	497.024	195.536	205.428	897.988
1992	493.009	79.843	196.154	769.006
1993	348.334	60.781	237.251	646.365
1994	407.289	115.097	288.539	810.925
1995	458.570	162.243	252.011	872.824
1996	368.267	135.961	173.606	677.834
1997	397.395	146.442	199.328	743.166
1998	381.278	63.616	249.348	694.242
1999	313.286	47.047	314.988	675.322
2000	419.407	57.963	250.293	727.662
2001	348.517	53.195	226.287	627.999
2002	294.996	76.305	154.183	525.484
2003	302.622	125.516	144.175	572.313
2004	279.466	95.415	142.609	517.490
2005	336.920	81.741	170.777	589.438
2006	258.497	103.217	124.158	485.872
2007	309.522	22.929	168.229	500.680
Average 1988-2007	431.512	91.202	195.657	718.371

Table 3.--Production model estimates of bottomfish biomass and relative biomass (B/B_{MSY}) status by fishery zone, 1988-2007.

Bottomfish Biomass and Status Estimates, 1988-2007

Year	Mean MHI Biomass (klb)	Mean Mau Biomass (klb)	Mean Hoomalu Biomass (klb)	Mean Relative MHI Biomass	Mean Relative Mau Biomass	Mean Relative Hoomalu Biomass	Mean Relative Archipelagic Biomass
1988	1622	698	3152	1.02	1.59	2.07	1.54
1989	1579	801	3121	0.99	1.82	2.05	1.55
1990	1276	763	2819	0.80	1.74	1.85	1.37
1991	1232	678	2773	0.78	1.54	1.82	1.32
1992	1029	541	2680	0.65	1.23	1.76	1.20
1993	972	568	2844	0.61	1.29	1.87	1.23
1994	1018	624	2599	0.64	1.42	1.71	1.19
1995	1044	608	2416	0.66	1.38	1.59	1.15
1996	914	562	2340	0.58	1.28	1.54	1.08
1997	961	568	2361	0.61	1.29	1.55	1.10
1998	905	533	2253	0.57	1.21	1.48	1.04
1999	953	568	2263	0.60	1.29	1.49	1.07
2000	1053	602	2358	0.66	1.37	1.55	1.13
2001	1010	642	2184	0.64	1.46	1.43	1.08
2002	970	712	1858	0.61	1.62	1.22	1.00
2003	938	739	1988	0.59	1.68	1.31	1.03
2004	911	701	1906	0.57	1.59	1.25	0.99
2005	1019	711	1965	0.64	1.62	1.29	1.04
2006	962	716	2006	0.61	1.63	1.32	1.04
2007	982	682	2344	0.62	1.55	1.54	1.13

Table 4.--Production model estimates of bottomfish biomass and relative harvest rate (H/H_{MSY}) status by fishery zone, 1988-2007.

Bottomfish Harvest Rate and Status Estimates, 1988-2007

Year	Mean MHI Harvest Rate	Mean Mau Harvest Rate	Mean Hoomalu Harvest Rate	Mean Relative MHI Harvest Rate	Mean Relative Mau Harvest Rate	Mean Relative Hoomalu Harvest Rate	Mean Relative Archipelagic Harvest Rate
1988	50%	5%	6%	1.74	0.17	0.22	0.89
1989	62%	10%	3%	2.15	0.34	0.12	1.05
1990	51%	12%	4%	1.78	0.42	0.15	0.91
1991	41%	29%	7%	1.42	1.02	0.26	0.87
1992	48%	15%	7%	1.68	0.52	0.26	0.93
1993	36%	11%	8%	1.26	0.38	0.29	0.74
1994	40%	19%	11%	1.41	0.65	0.39	0.88
1995	44%	27%	11%	1.54	0.95	0.37	0.97
1996	41%	25%	8%	1.42	0.86	0.26	0.85
1997	42%	26%	9%	1.45	0.92	0.30	0.89
1998	43%	12%	11%	1.48	0.43	0.39	0.88
1999	33%	8%	14%	1.16	0.29	0.49	0.76
2000	40%	10%	11%	1.40	0.34	0.38	0.83
2001	35%	8%	10%	1.21	0.30	0.37	0.74
2002	31%	11%	8%	1.07	0.38	0.29	0.65
2003	33%	17%	7%	1.13	0.60	0.26	0.69
2004	31%	14%	8%	1.08	0.48	0.27	0.66
2005	33%	12%	9%	1.16	0.41	0.31	0.70
2006	27%	15%	6%	0.94	0.51	0.22	0.58
2007	32%	3%	7%	1.11	0.12	0.25	0.62

Table 5.--Production model estimates of bottomfish maximum sustainable yield (MSY) reference points by fishery zone, 1988-2007, including the posterior mean biomass (thousands of pounds) to produce MSY (B_{MSY}) and its 80% credibility interval ([P_{10}, P_{90}]), the posterior mean harvest rate to produce MSY (H_{MSY}) and its 80% credibility interval, and the annual instantaneous fishing mortality rate to produce MSY (F_{MSY}) and its 80% credibility interval.

	B_{MSY}		
Fishery Zone	P_{10}	Mean	P_{90}
Main Hawaiian Islands	1451	1588	1729
Mau Zone	402	440	479
Hoomalu Zone	1392	1524	1659

	H_{MSY}		
Fishery Zone	P_{10}	Mean	P_{90}
Main Hawaiian Islands, Mau Zone, Hoomalu Zone	25%	29%	33%

	F_{MSY}		
Fishery Zone	P_{10}	Mean	P_{90}
Main Hawaiian Islands, Mau Zone, Hoomalu Zone	0.29	0.34	0.39

Table 6.--Sensitivity analysis using the status quo MHI CPUE to assess bottomfish relative biomass (B/B_{MSY}) and relative harvest rate (H/H_{MSY}) status by fishery zone, 1988-2007.

Sensitivity Analysis Using Status Quo MHI CPUE

Year	Mean Relative MHI Biomass	Mean Relative Mau Biomass	Mean Relative Hoomalu Biomass	Mean Relative Archipelagic Biomass	Mean Relative MHI Harvest Rate	Mean Relative Mau Harvest Rate	Mean Relative Hoomalu Harvest Rate	Mean Relative Archipelagic Harvest Rate
1988	1.05	1.09	1.11	1.08	2.54	0.36	0.63	1.45
1989	1.29	1.63	1.07	1.24	2.46	0.59	0.35	1.32
1990	1.09	1.54	0.96	1.09	1.97	0.72	0.45	1.17
1991	0.82	1.21	0.95	0.92	1.99	1.95	0.79	1.47
1992	0.68	0.90	0.91	0.81	2.39	1.08	0.78	1.54
1993	0.62	0.97	0.96	0.81	1.86	0.76	0.90	1.31
1994	0.67	1.14	0.88	0.82	2.00	1.21	1.19	1.56
1995	0.79	1.10	0.81	0.84	1.93	1.78	1.14	1.57
1996	0.60	1.03	0.78	0.73	2.03	1.59	0.82	1.45
1997	0.57	1.14	0.79	0.74	2.29	1.58	0.93	1.61
1998	0.56	1.01	0.76	0.70	2.24	0.78	1.20	1.61
1999	0.57	1.01	0.76	0.71	1.82	0.57	1.51	1.53
2000	0.64	0.97	0.78	0.74	2.16	0.73	1.18	1.56
2001	0.53	1.06	0.72	0.68	2.19	0.61	1.16	1.55
2002	0.57	1.33	0.60	0.68	1.72	0.69	0.93	1.25
2003	0.54	1.45	0.65	0.70	1.84	1.05	0.82	1.30
2004	0.50	1.38	0.62	0.66	1.86	0.84	0.84	1.29
2005	0.54	1.44	0.65	0.70	2.05	0.69	0.97	1.42
2006	0.50	1.43	0.66	0.68	1.70	0.88	0.69	1.17
2007	0.54	1.30	0.78	0.74	1.89	0.21	0.80	1.21

Table 7.--Projected bottomfish catches, probabilities of overfishing, and relative biomasses under the $F=F_{MSY}$ alternative in fishing years 2009-2010 in the main Hawaiian Islands, Mau zone, and Hoomalu zone.

F=FMSY Projection for 2009-2010

Bottomfish Management Unit	Median Potential Bottomfish Catch at FMSY in FY 2009 (klb)	Median Potential Deep 7 Bottomfish Catch at FMSY in FY 2009 (klb)	Pr(Overfishing in 2009)	Mean Relative Biomass (B/BMSY) at Start of 2009	Pr(Biomass exceeds BMSY at Start of 2009)	Median Potential Bottomfish Catch at FMSY in FY 2010 (klb)	Median Potential Deep 7 Bottomfish Catch at FMSY in FY 2010 (klb)	Pr(Overfishing in 2010)	Mean Relative Biomass (B/BMSY) at Start of 2010	Pr(Biomass exceeds BMSY at Start of 2010)
Archipelago			1.00	1.28	1.00			1.00	1.11	1.00
MHI	343.6	248.4	1.00	0.76	0.00	368.1	266.1	1.00	0.81	0.00
Mau	226.1	163.5	1.00	1.78	1.00	174.1	125.9	1.00	1.38	1.00
Hoomalu	738.3	533.8	1.00	1.68	1.00	590.6	427.0	1.00	1.35	1.00

Table 8.--Projected bottomfish catches, probabilities of overfishing, and relative biomasses under the $F=F_{STATUS\ QUO}$ alternative in fishing years 2009-2010 in the main Hawaiian Islands, Mau zone, and Hoomalu zone.

F=F2008 Status Quo Projection for 2009-2010

Bottomfish Management Unit	Median Potential Bottomfish Catch at F2008 in FY 2009 (klb)	Median Potential Deep 7 Bottomfish Catch at F2008 in FY 2009 (klb)	Pr(Overfishing in 2009)	Mean Relative Biomass (B/BMSY) at Start of 2009	Pr(Biomass exceeds BMSY at Start of 2009)	Median Potential Bottomfish Catch at F2008 in FY 2010 (klb)	Median Potential Deep 7 Bottomfish Catch at F2008 in FY 2010 (klb)	Pr(Overfishing in 2010)	Mean Relative Biomass (B/BMSY) at Start of 2010	Pr(Biomass exceeds BMSY at Start of 2010)
Archipelago			0	1.28	1.00			0.00	1.33	1.00
MHI	301.3	217.8	0	0.76	0.00	333.1	240.8	0.01	0.84	0.02
Mau	26.6	19.2	0	1.78	1.00	27.3	19.7	0.00	1.83	1.00
Hoomalu	185.5	134.1	0	1.68	1.00	188.9	136.6	0.00	1.71	1.00

Table 9.--Projected TACs, probabilities of overfishing, relative biomasses, and probabilities of depletion of MHI bottomfish under the constant MHI TAC alternative in fishing years 2009-2010.

Constant MHI TAC Projections for 2009-2010

Main Hawaiian Islands Bottomfish Annual Total Allowable Catch (klb)	Main Hawaiian Islands Deep 7 Bottomfish Annual Total Allowable Catch Equivalent (klb)	Probability of Overfishing Bottomfish in the Hawaiian Archipelago in FY 2009	Probability of Overfishing Bottomfish in the Main Hawaiian Islands in FY 2009	Probability of Overfishing Bottomfish in the Main Hawaiian Islands in FY 2010	Mean Relative Biomass (B/BMSY) in the MHI at Start of FY 2010	Probability That Bottomfish in the Main Hawaiian Islands Are Depleted (B<0.7*BMSY) in FY 2010
238	172	0.000	0.00	0.00	0.88	0.02
274	198	0.000	0.05	0.02	0.85	0.04
288	208	0.000	0.10	0.04	0.84	0.05
299	216	0.000	0.15	0.07	0.84	0.05
307	222	0.000	0.20	0.10	0.83	0.06
314	227	0.000	0.25	0.13	0.83	0.07
321	232	0.000	0.30	0.17	0.82	0.07
327	236	0.000	0.35	0.21	0.82	0.08
333	241	0.000	0.40	0.25	0.82	0.09
338	244	0.000	0.45	0.29	0.81	0.09
344	249	0.000	0.50	0.34	0.81	0.10
350	253	0.000	0.55	0.39	0.80	0.11
356	257	0.000	0.60	0.44	0.80	0.12
362	262	0.000	0.65	0.50	0.80	0.13
368	266	0.000	0.70	0.55	0.79	0.14
375	271	0.000	0.75	0.61	0.79	0.15
383	277	0.000	0.80	0.68	0.78	0.16
392	283	0.000	0.85	0.75	0.78	0.18
405	293	0.000	0.90	0.83	0.77	0.21
423	306	0.001	0.95	0.91	0.76	0.25
475	343	0.007	1.00	0.99	0.73	0.38

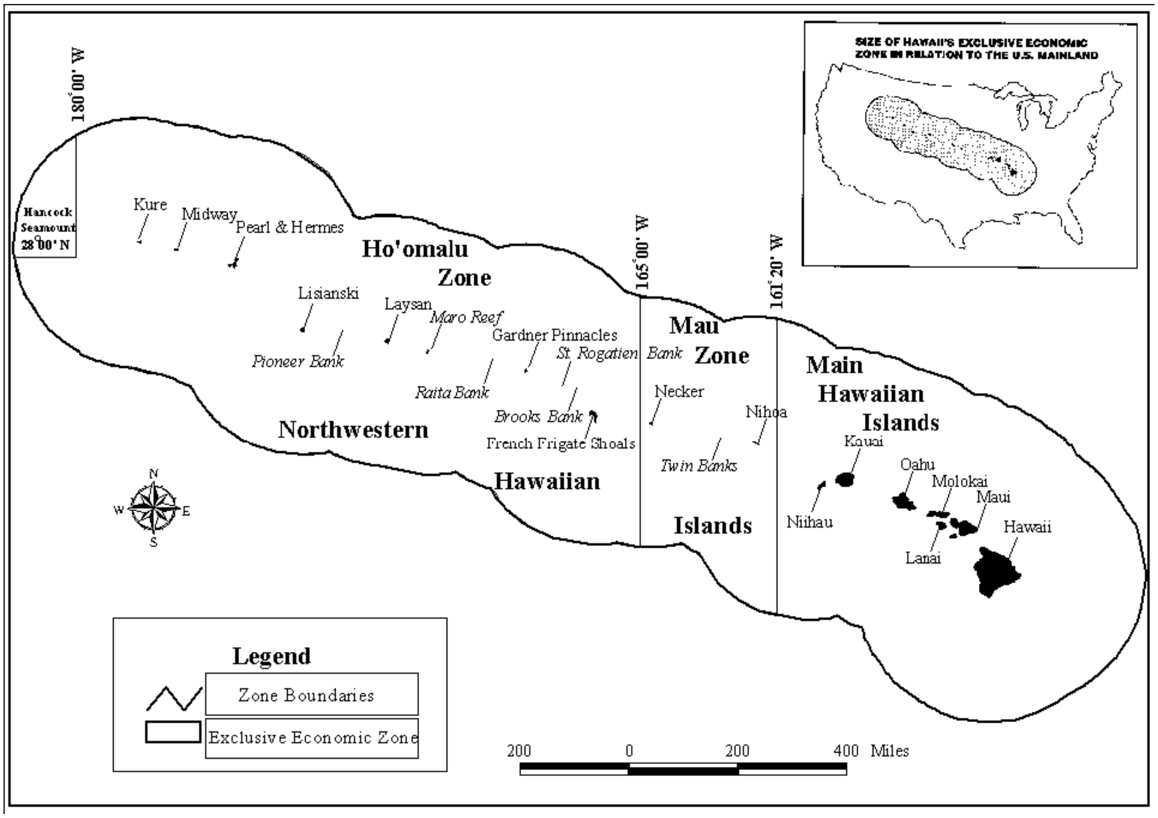


Figure 1.--Location of the three Hawaiian bottomfish fishing zones: MHI, the Mau zone, and the Hoomalu zone.

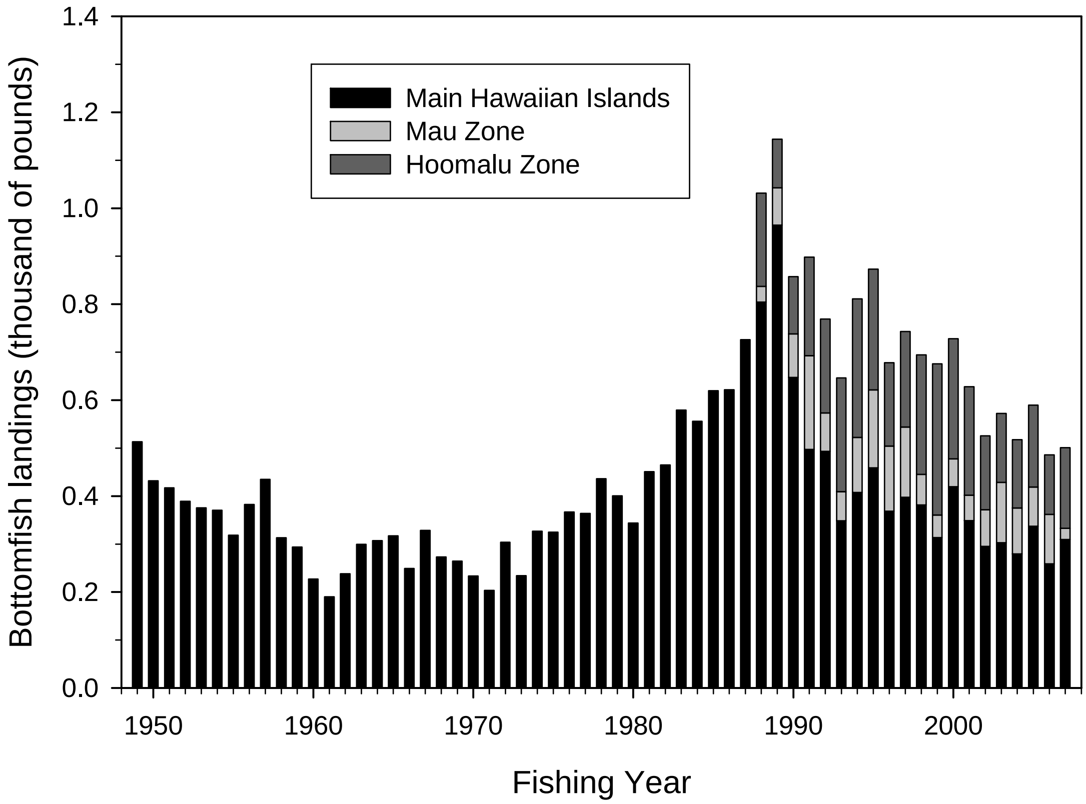


Figure 2.--Total Hawaiian bottomfish catch used in the assessment update by zone and fishing year (e.g., fishing 1949 corresponds to July 1st 1948 to June 30th 1949) and fishery zone. As in the previous assessment, fishery catches in the Mau and Hoomalu zones prior to 1988 were not used in the assessment update because there were no CPUE data available to provide relative abundance indices for these zones prior to 1988.

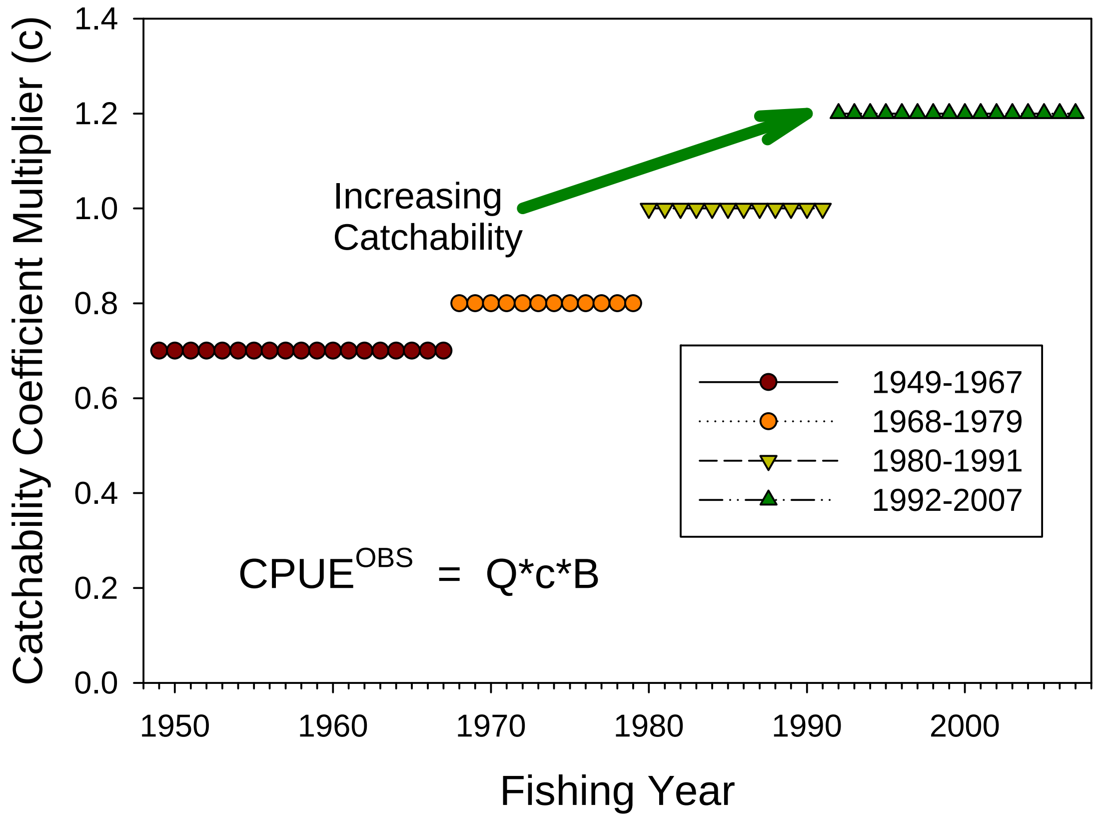


Figure 3.--Bottomfish CPUE adjustment coefficients to account for increases in Hawaiian bottomfish fishing technology during 1949-2007 adapted from Moffitt et al. (2006). Observed CPUE input to the assessment model was the product of the catchability parameter (Q) for the standard time period (1980-1991) times the technology coefficient (c) times the model estimate of fishable biomass (B).

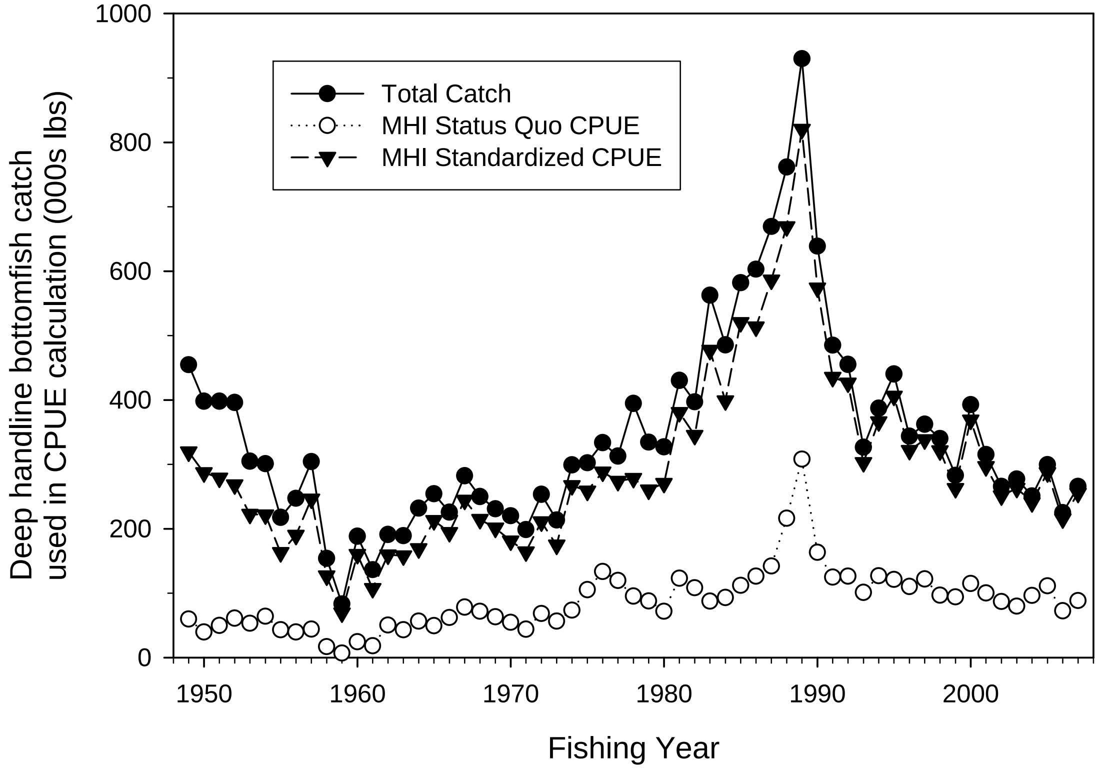


Figure 4.--Total bottomfish catch on deep handline trips by fishing year used for status quo and GLM standardization approaches to compute CPUE for the bottomfish fishery in the main Hawaiian Islands along with total bottomfish catch on all deep handline trips.

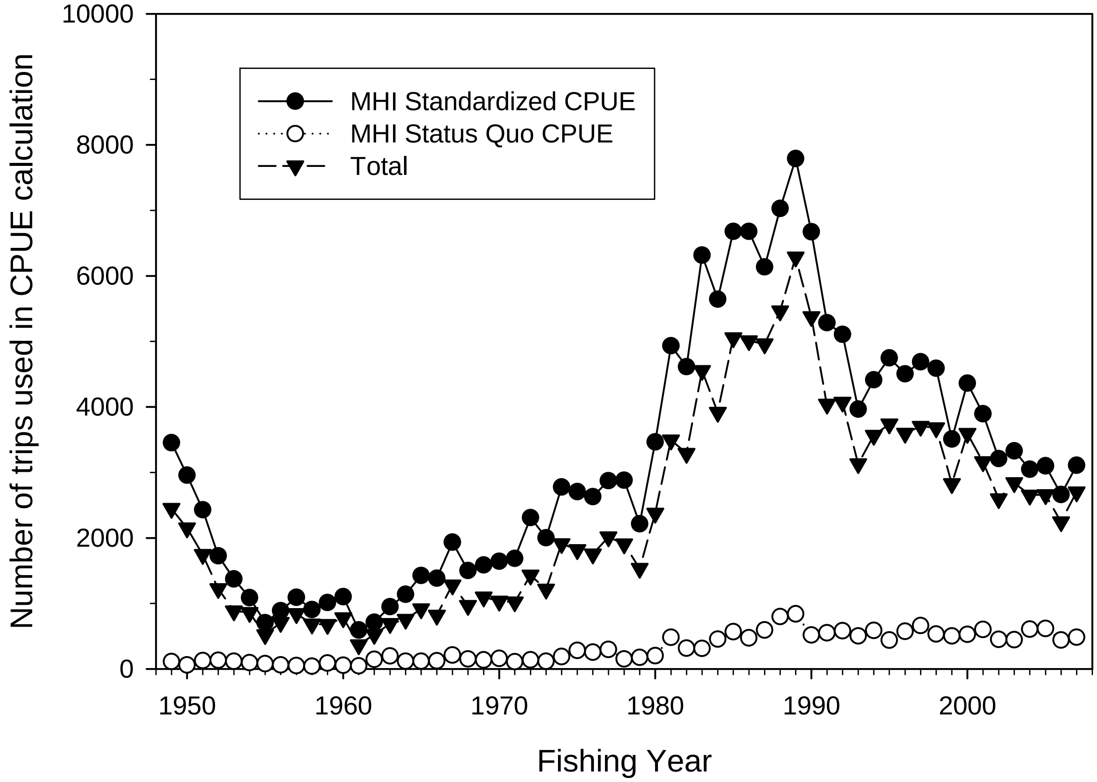


Figure 5.--Total bottomfish deep handline trips by fishing year used for status quo and GLM standardization approaches to compute CPUE for the bottomfish fishery in the main Hawaiian Islands along with total bottomfish deep handline trips in the MHI.

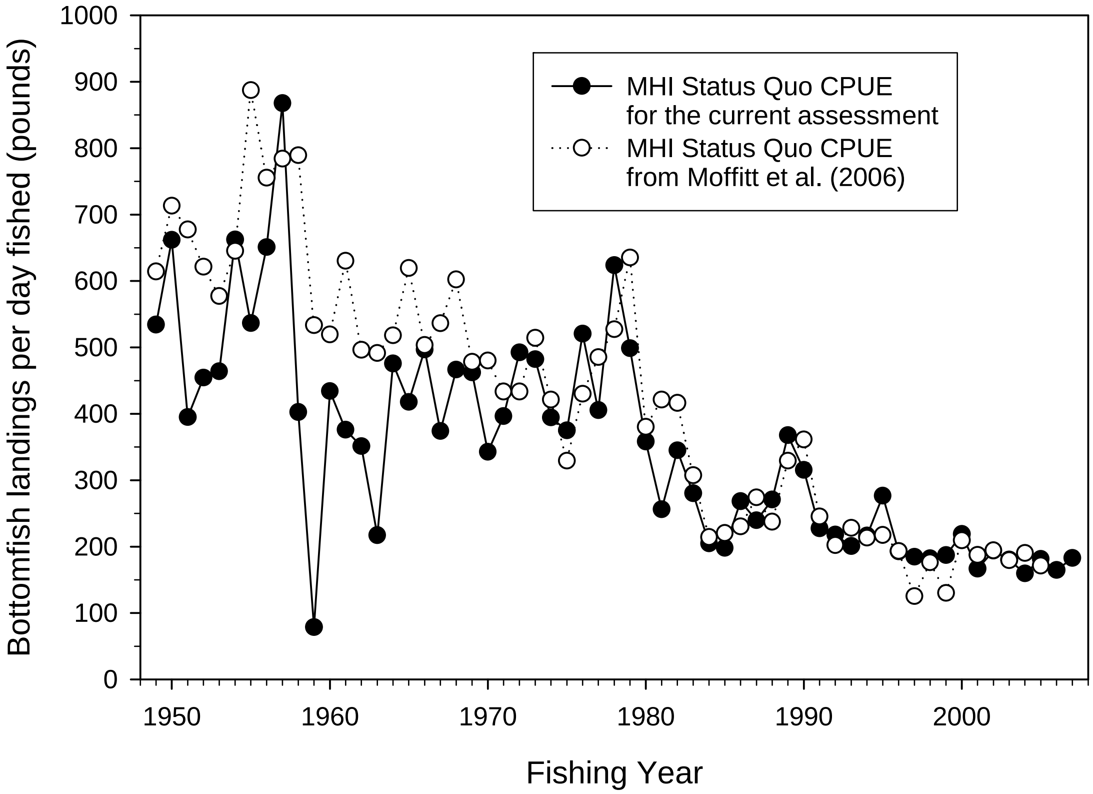


Figure 6.--Comparison of trends in status quo bottomfish CPUE in the MHI as calculated in this assessment and in the previous assessment. The status quo CPUE for the MHI is calculated using re-audited HDAR logbook data and the same approach as in Moffitt et al. (2006) except that a single-day trip qualifying criterion of no more than 1,500 pounds of bottomfish is applied.

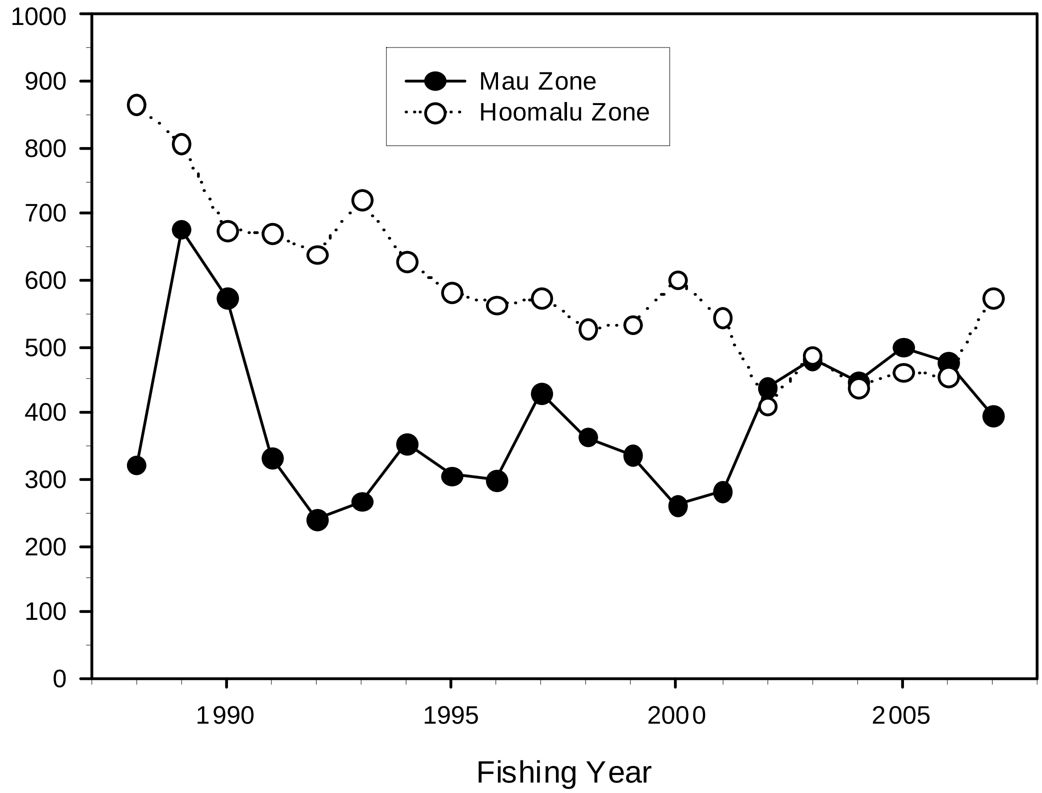


Figure 7.--Trends in bottomfish CPUE (pounds per day fished) by fishing year in the Mau and Hoomalu zones. The CPUE for the Mau and Hoomalu zones during 1988-2004 were taken from the previous assessment (Moffitt et al., 2006) and CPUE in 2005-2007 were calculated using the same approach as in the previous assessment.

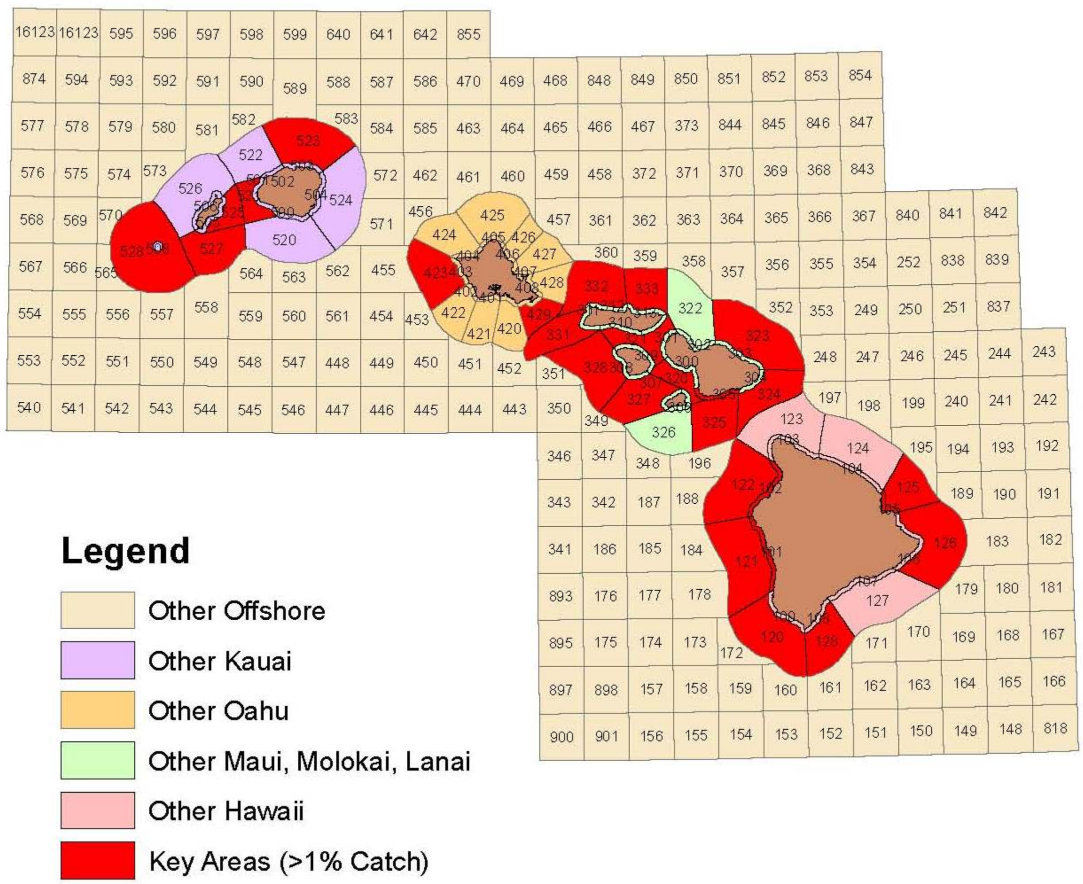


Figure 8.--HDAR fishery reporting areas used for the area effect in the GLM approach to standardize bottomfish CPUE in the main Hawaiian Islands bottomfish fishery.

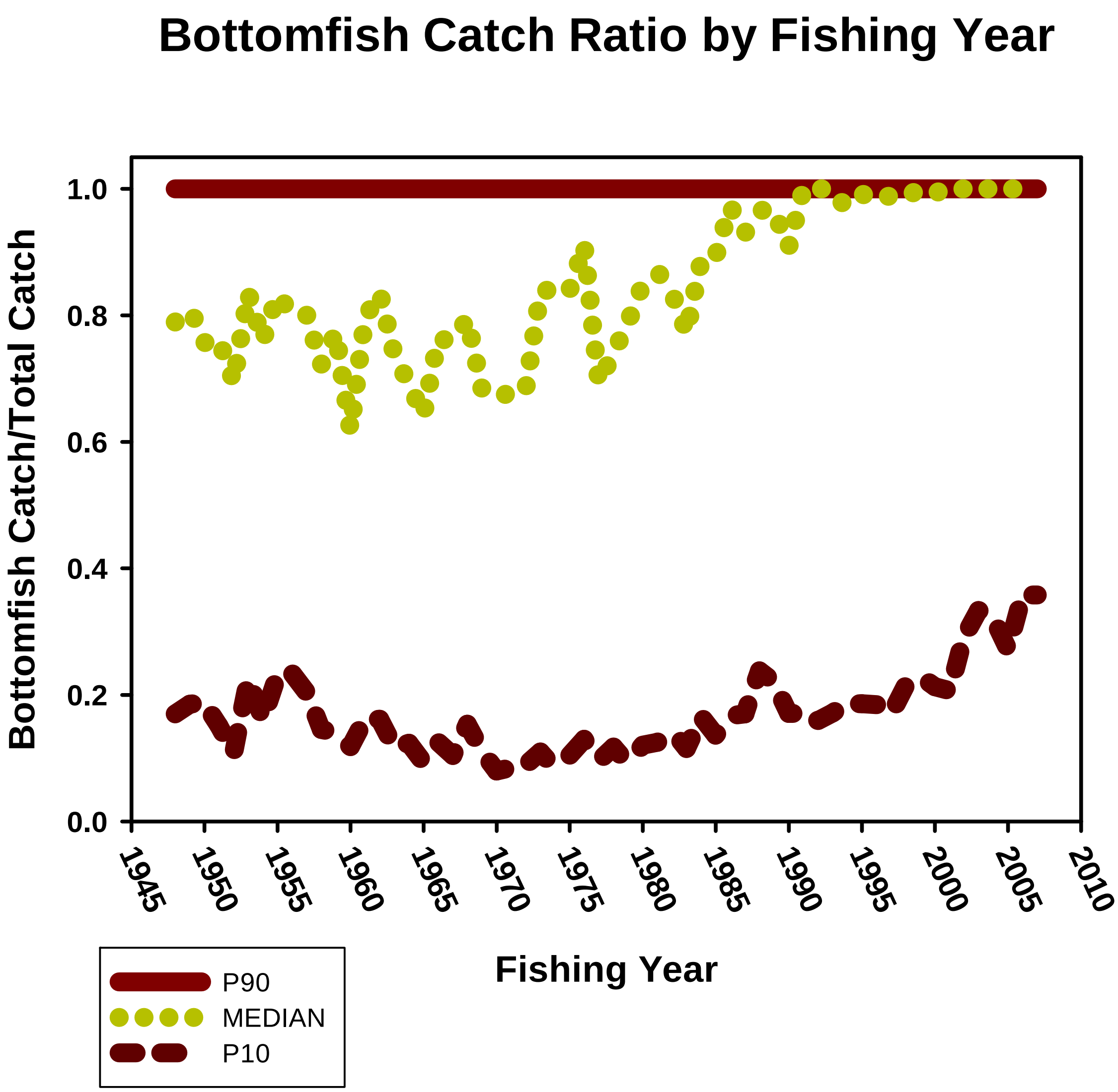


Figure 9.--Annual percentiles of the ratio of bottomfish catch (Table 2) to total catch weight per trip for fishing trips reporting deep handline gear in the main Hawaiian Islands during 1949-2007 including the 90th percentile (p90), the median and the 10th percentile (p10).

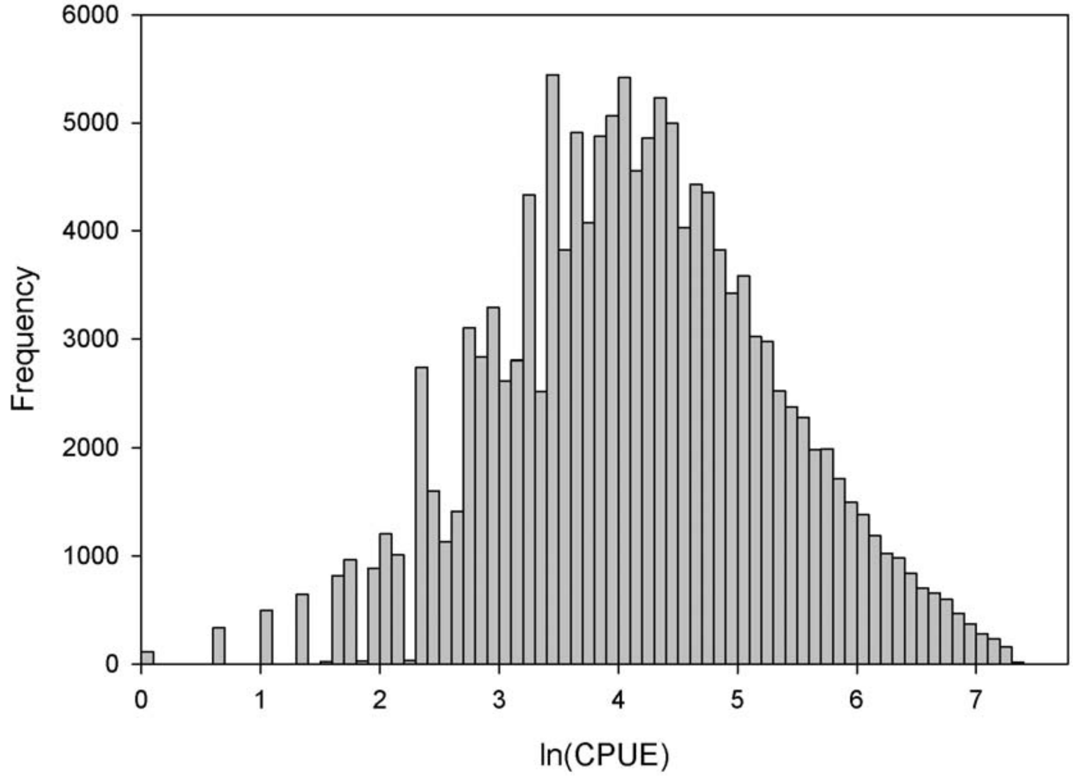


Figure 10.--Histogram of natural log-transformed bottomfish catch rates for directed deep handline trips from the main Hawaiian Islands during fishing years 1949-2007.

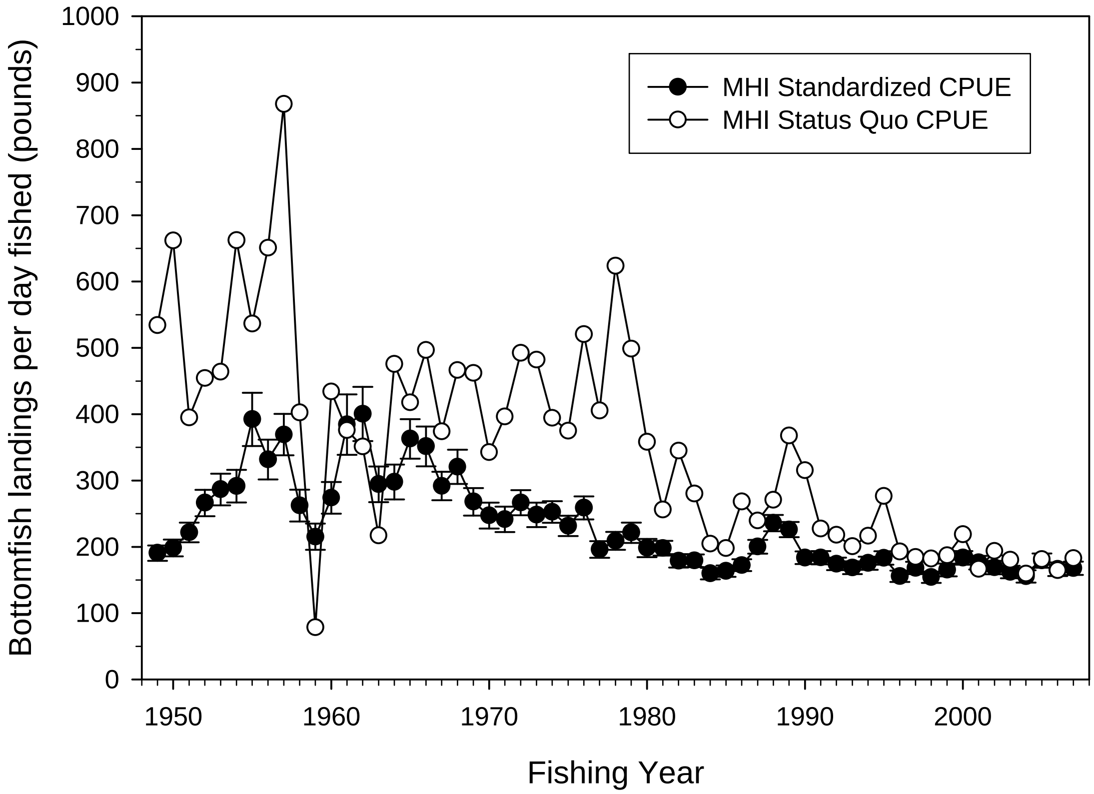


Figure 11.--Annual trends in mean standardized bottomfish CPUE in the main Hawaiian Islands (solid circle) and 95% confidence interval as estimated by the log-linear model along with the status quo CPUE (open circle) for comparison.

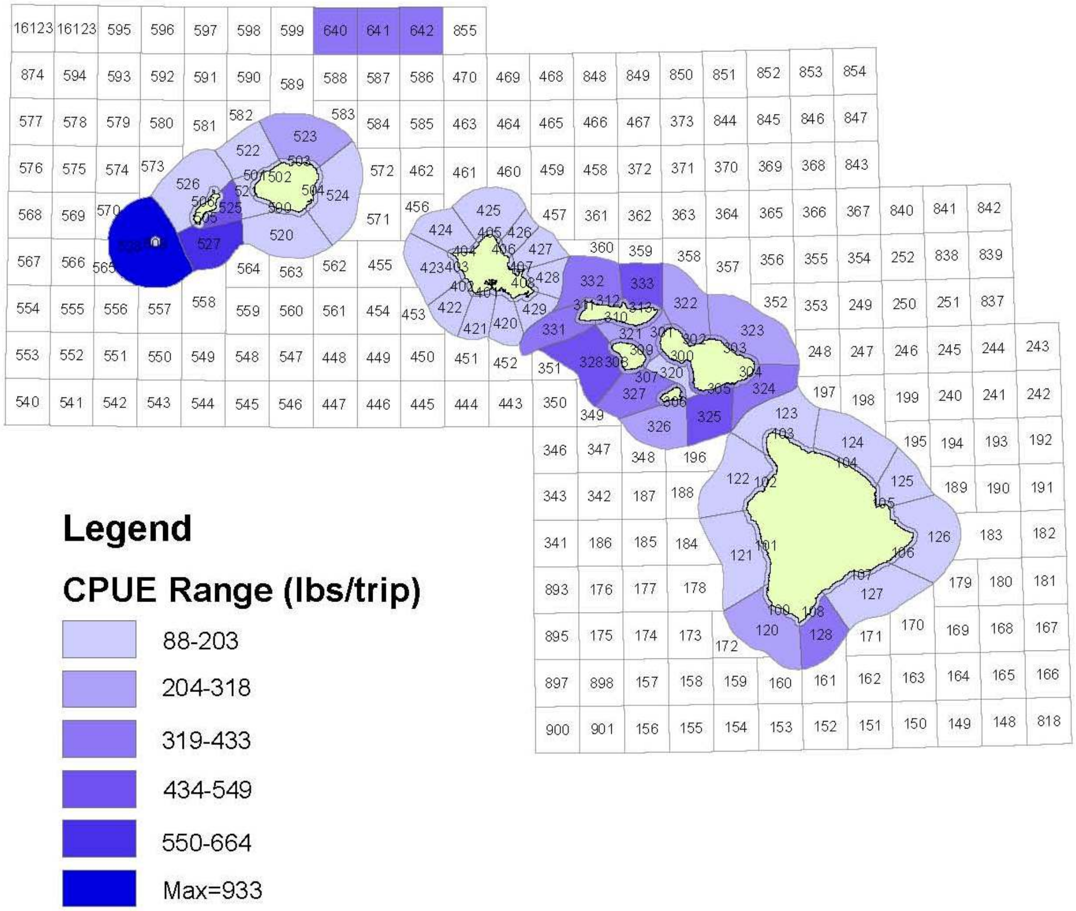


Figure 12.--Estimated mean CPUE by fishing area for the directed main Hawaiian Islands bottomfish fishery.

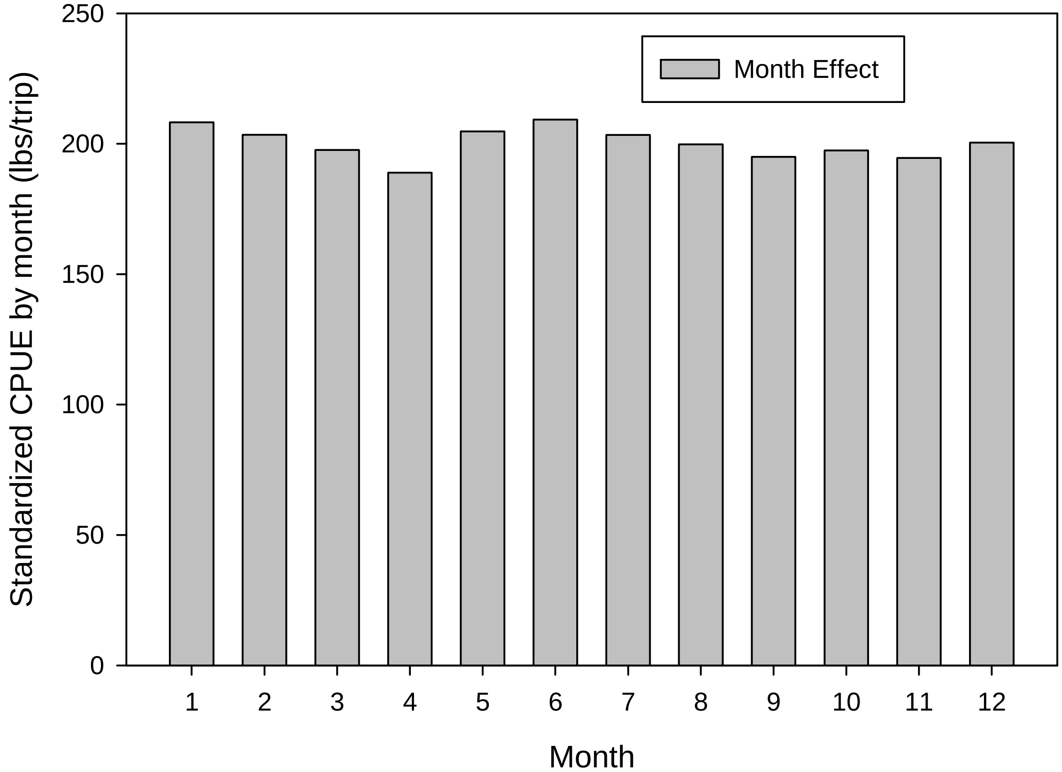
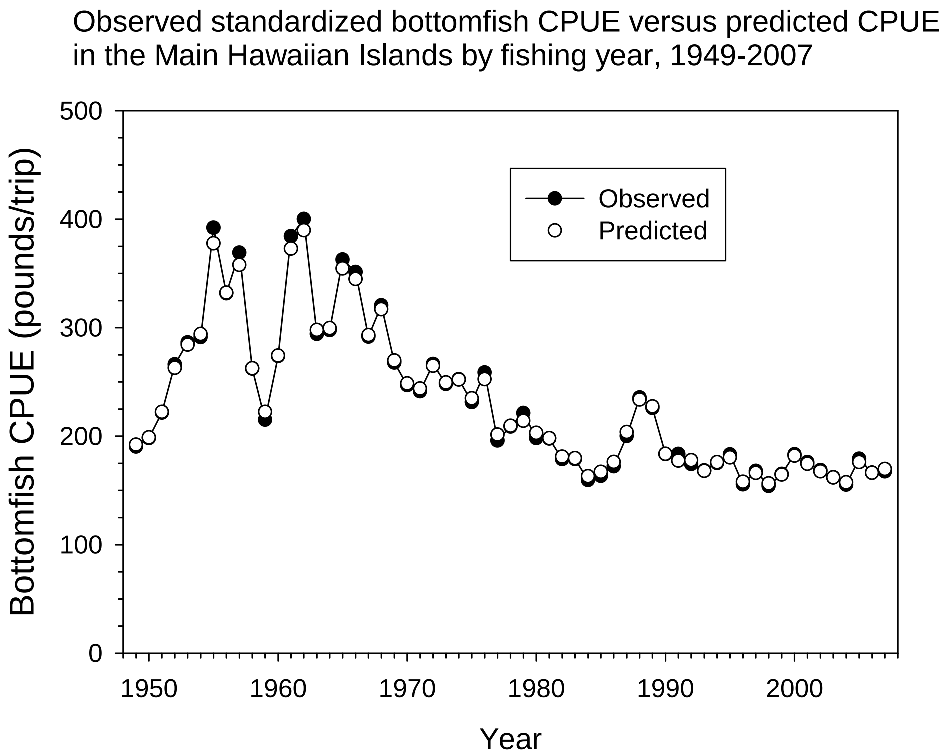


Figure 13.--Estimated standardized CPUE by month for the spatial CPUE standardization approach applied to the main Hawaiian Islands bottomfish fishery where January is month 1, February is month 2, ..., and December is month 12.



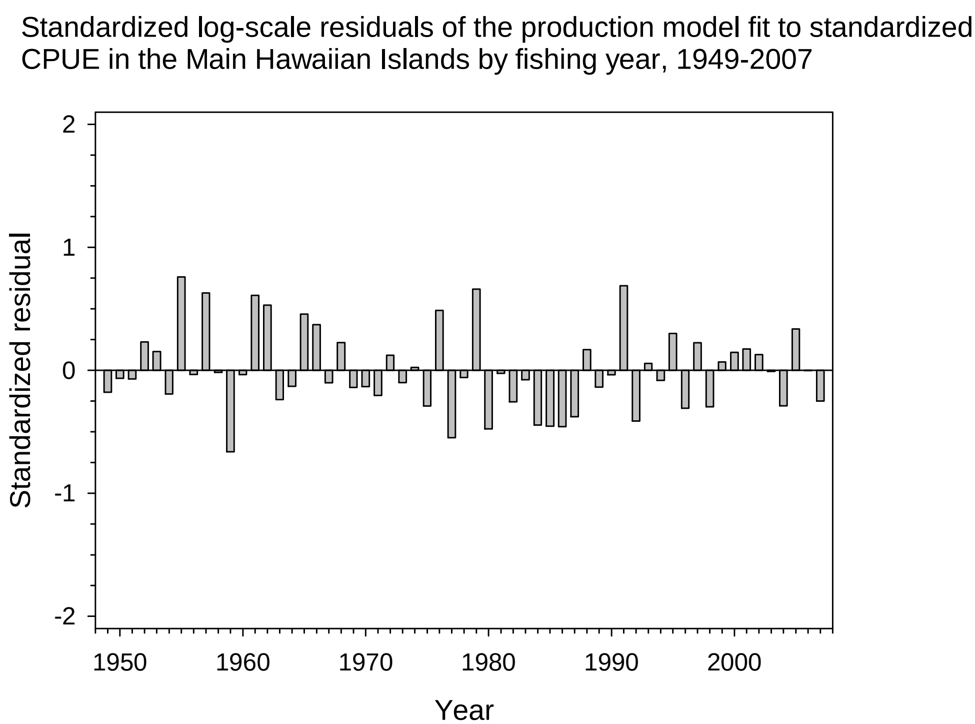
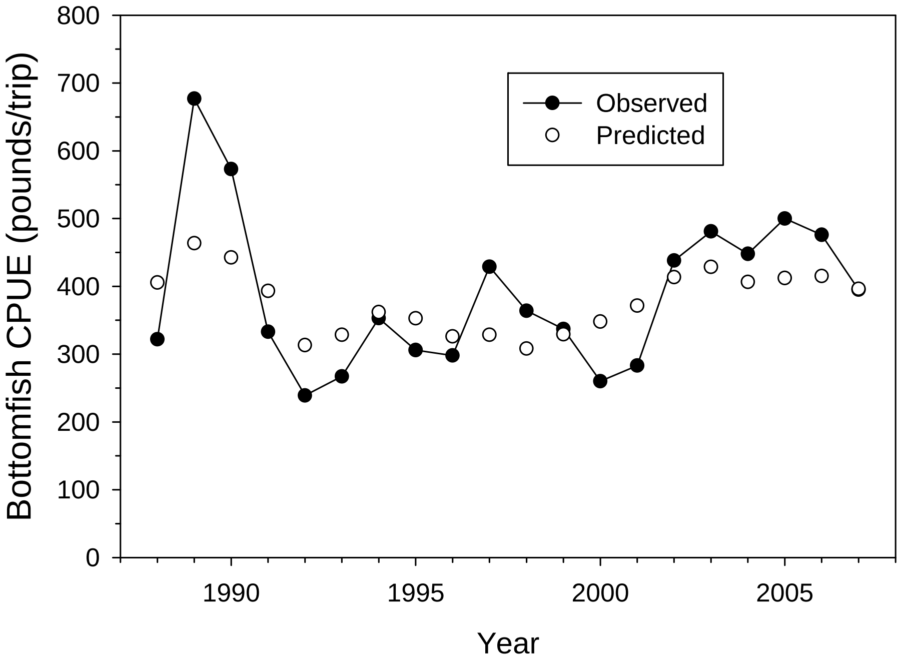


Figure 14.--Production model fit to the observed standardized bottomfish CPUE for the main Hawaiian Islands along with standardized log-scale CPUE residuals.

Observed standardized bottomfish CPUE versus predicted CPUE
in the Mau zone by fishing year, 1988-2007



Standardized log-scale residuals of the model fit to standardized CPUE
in the Mau zone by fishing year, 1988-2007

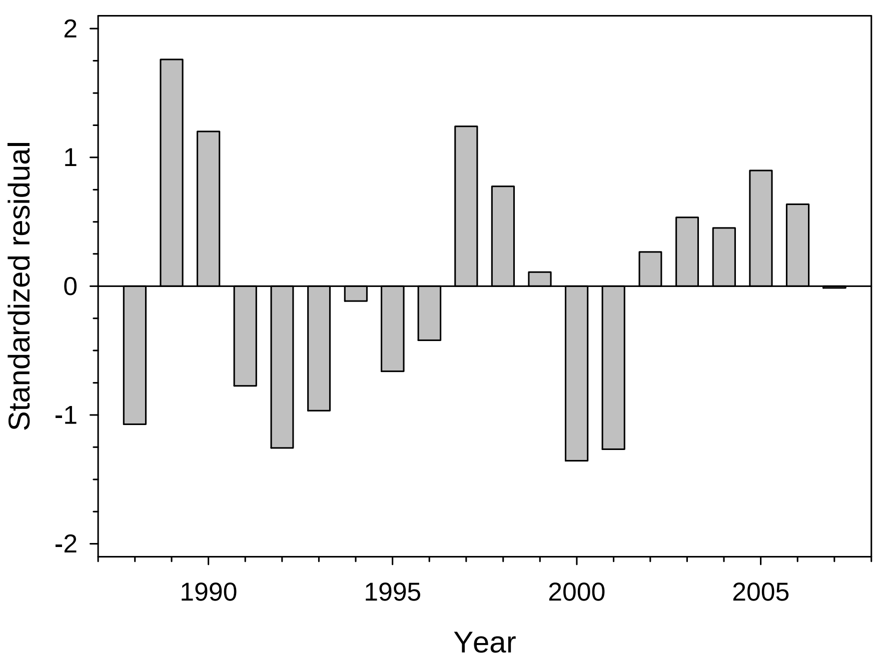
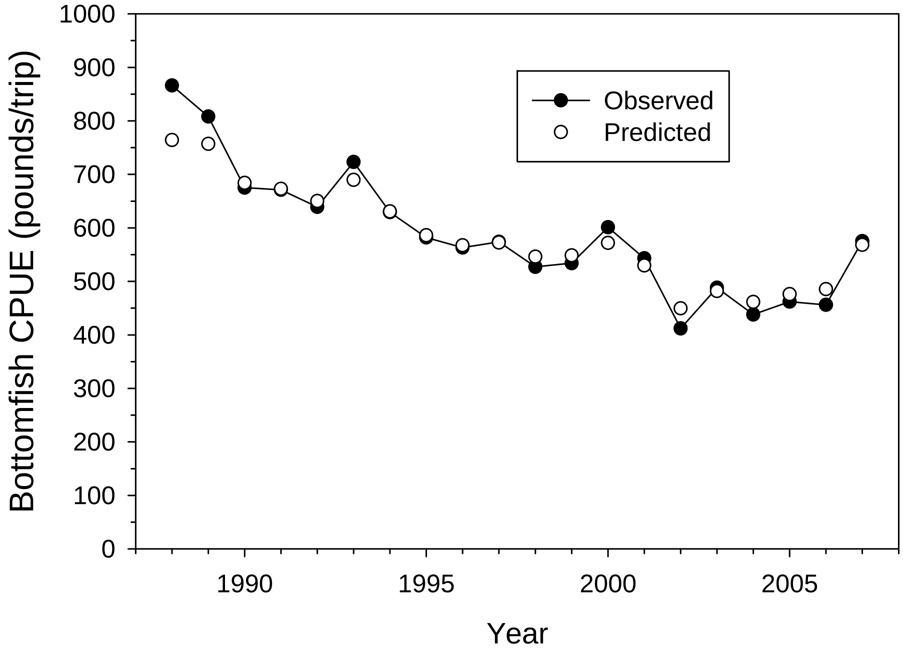
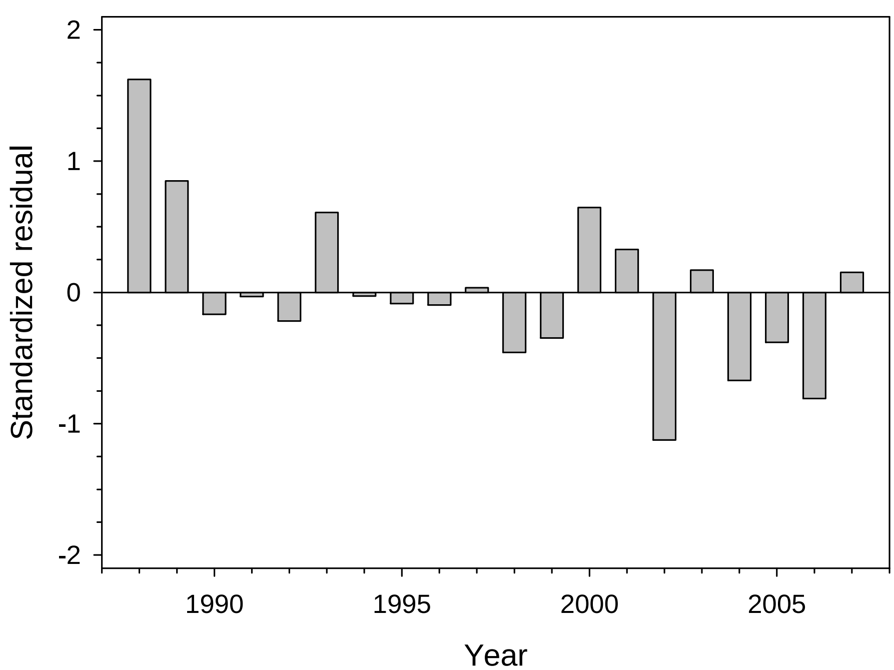


Figure 15.--Production model fit to the observed standardized bottomfish CPUE for the Mau zone along with standardized log-scale CPUE residuals.

Observed standardized bottomfish CPUE versus predicted CPUE
in the Hoomalu zone by fishing year, 1988-2007



Standardized log-scale residuals of the production model fit to
standardized CPUE in the Hoomalu zone by fishing year, 1988-2007



v

Figure 16.--Production model fit to the observed standardized bottomfish CPUE for the Hoomalu zone along with standardized log-scale CPUE residuals.

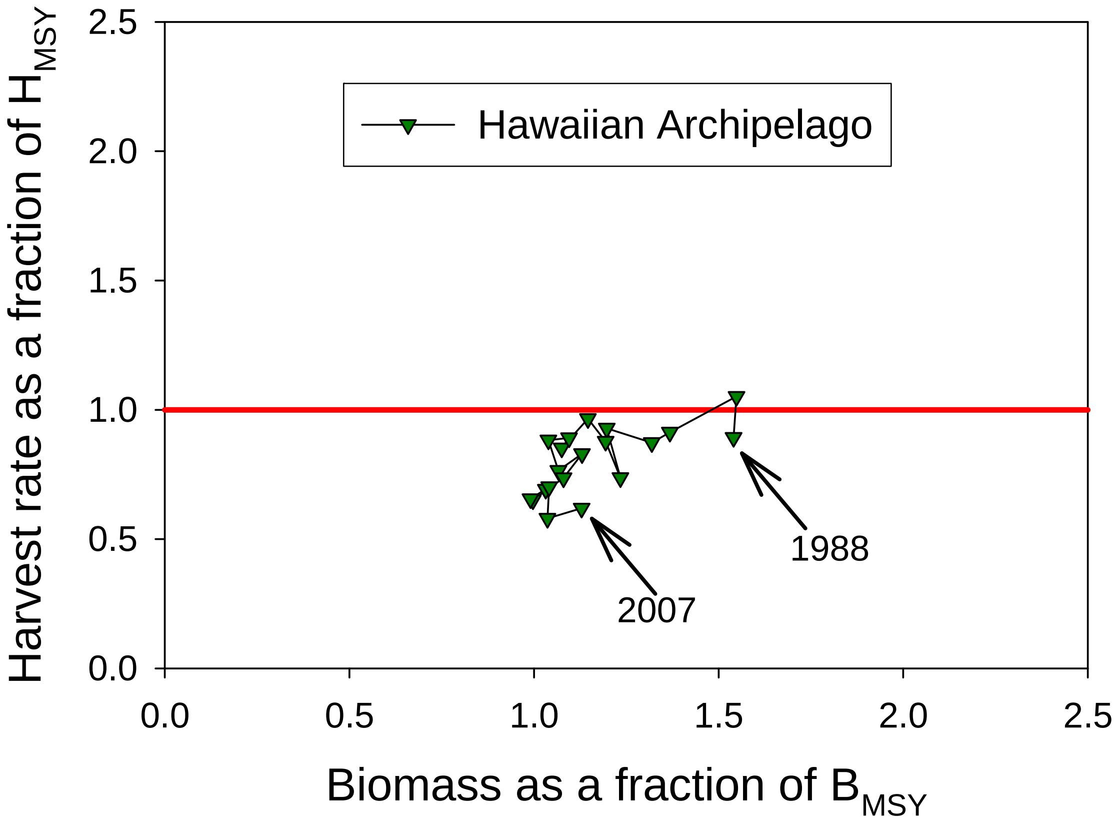


Figure 17.--Stock status of the Archipelagic bottomfish stock during 1988-2007. The stock was experiencing overfishing in a fishing year if the harvest rate fraction exceeded 1. The stock was overfished in a fishing year if the biomass fraction was less than 0.7.

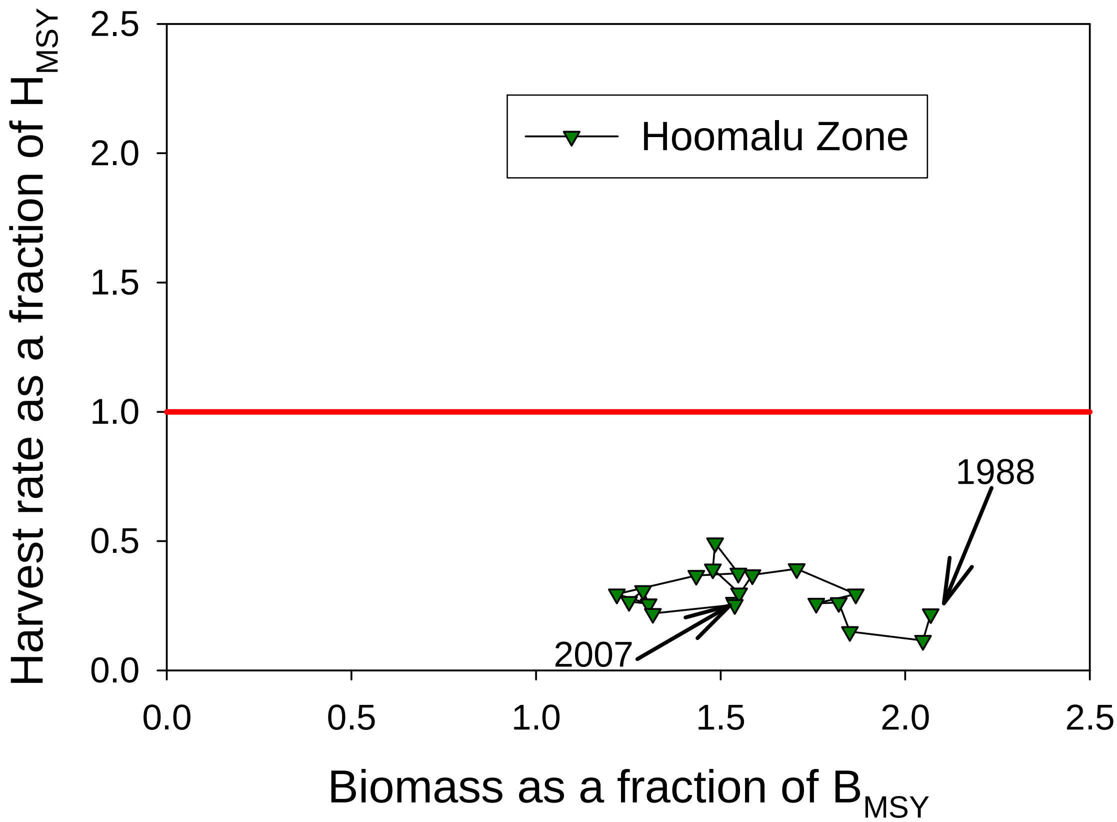


Figure 18.--Stock status of the Hoomalu zone bottomfish stock during 1988-2007. The stock was experiencing overfishing in a fishing year if the harvest rate fraction exceeded 1. The stock was overfished in a fishing year if the biomass fraction was less than 0.7.

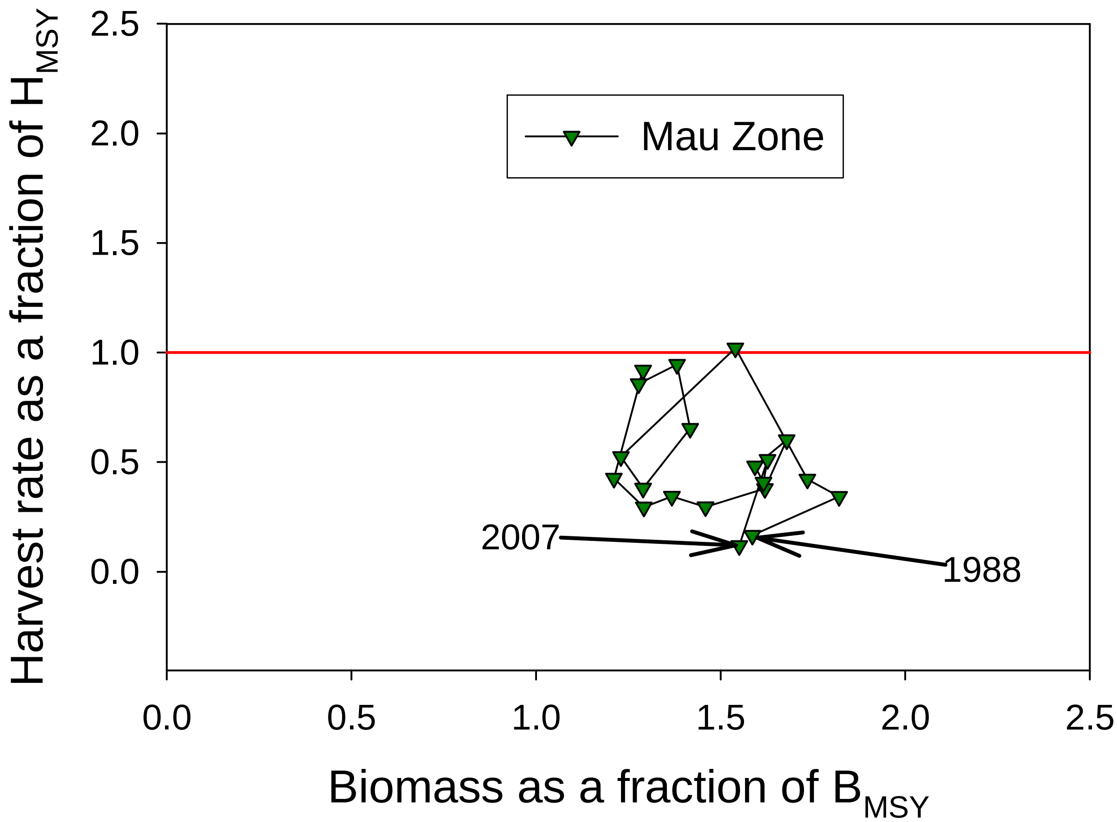


Figure 19.--Stock status of the Mau zone bottomfish stock during 1988-2007. The stock was experiencing overfishing in a fishing year if the harvest rate fraction exceeded 1. The stock was overfished in a fishing year if the biomass fraction was less than 0.7.

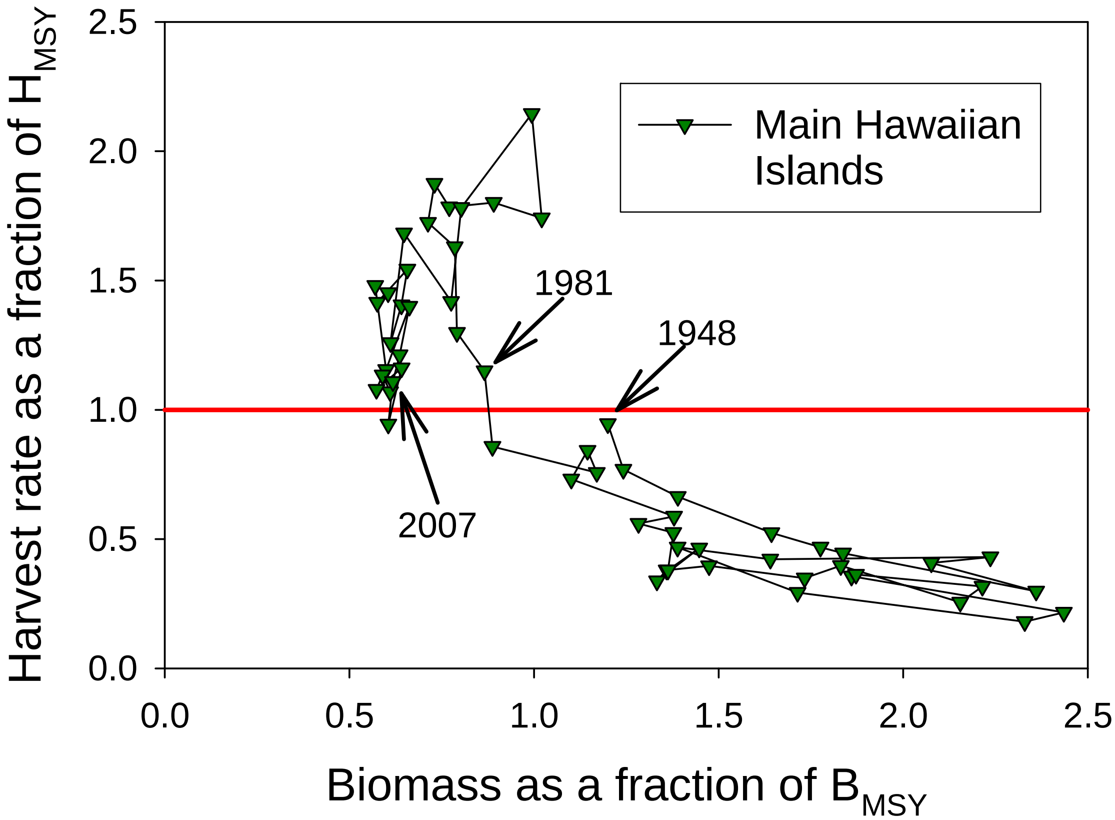


Figure 20.--Stock status of the main Hawaiian Islands bottomfish stock during 1949-2007. The stock was experiencing overfishing in a fishing year if the harvest rate fraction exceeded 1. The stock was overfished in a fishing year if the biomass fraction was less than 0.7.

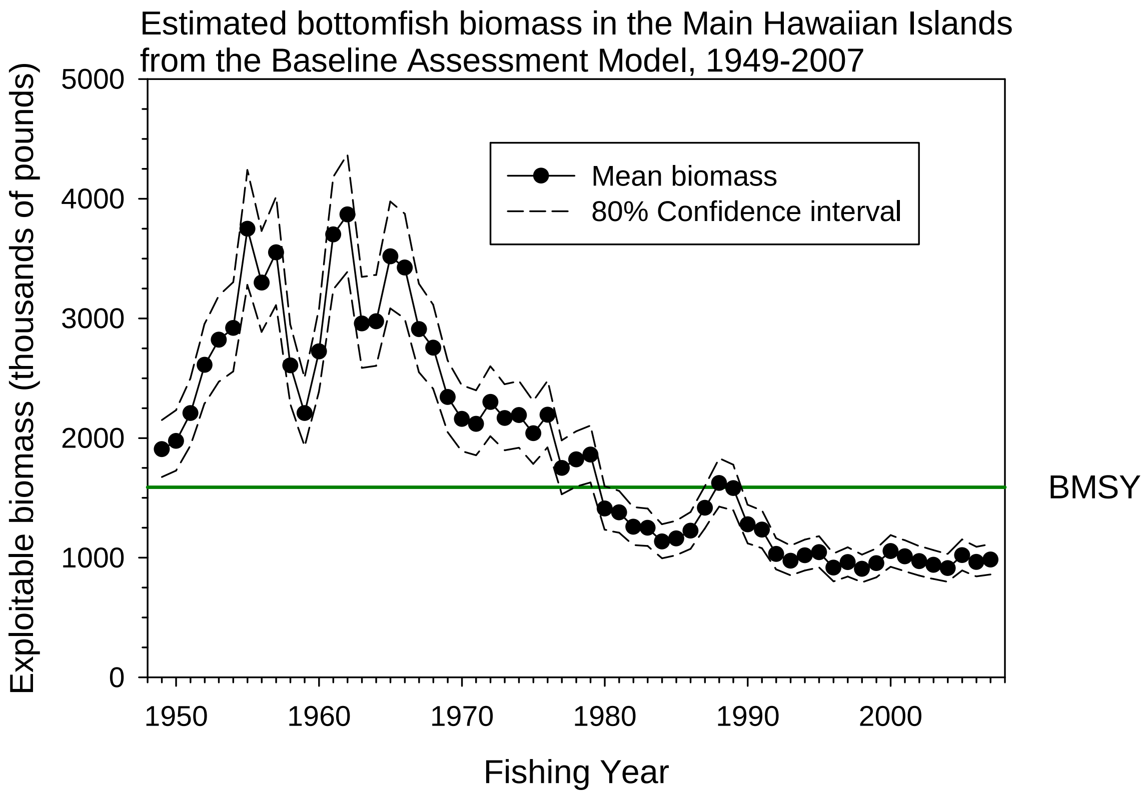


Figure 21.--Mean bottomfish biomass in the main Hawaiian Islands and 80% confidence interval from the baseline assessment model, 1949-2007.

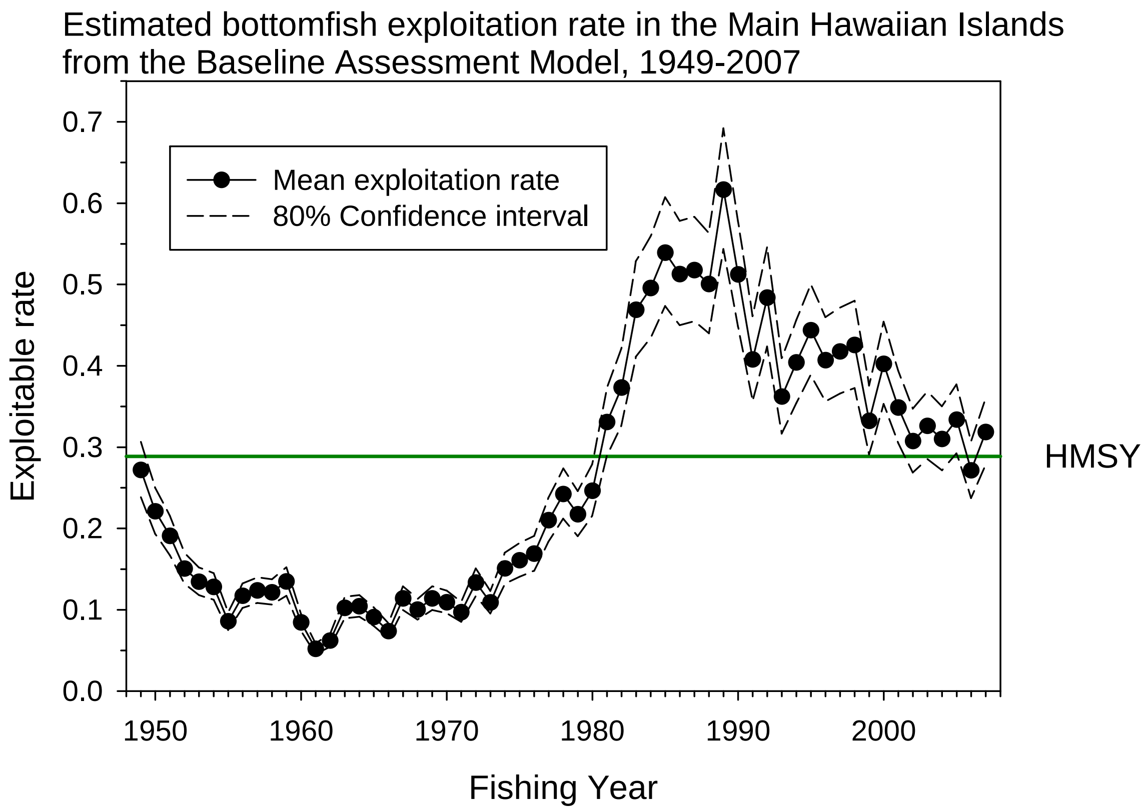


Figure 22.--Mean exploitation rate for bottomfish in the main Hawaiian Islands and 80% confidence interval from the baseline assessment model, 1949-2007.

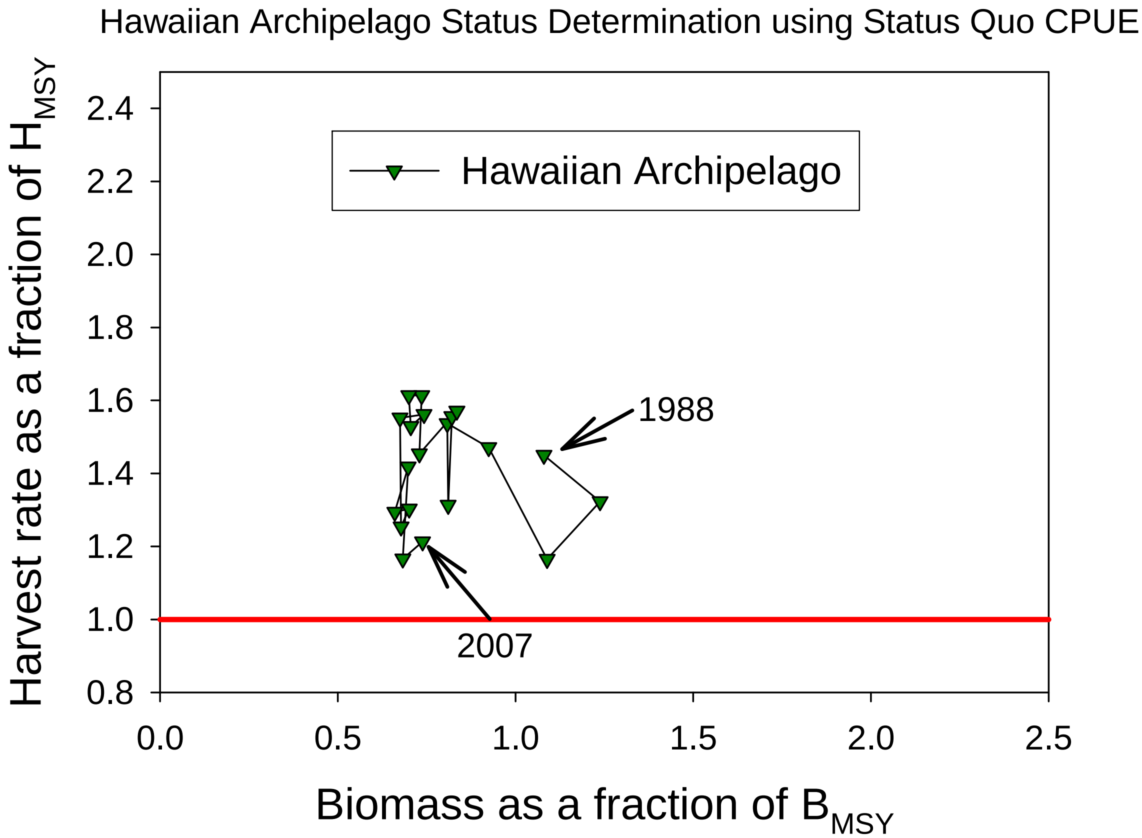


Figure 23.--Sensitivity analysis of stock status of the Archipelagic bottomfish stock during 1988-2007 if status quo main Hawaiian Islands CPUE was used to fit the model instead of standardized CPUE. The stock was experiencing overfishing in a fishing year if the harvest rate fraction exceeded 1. The stock was overfished in a fishing year if the biomass fraction was less than 0.7.

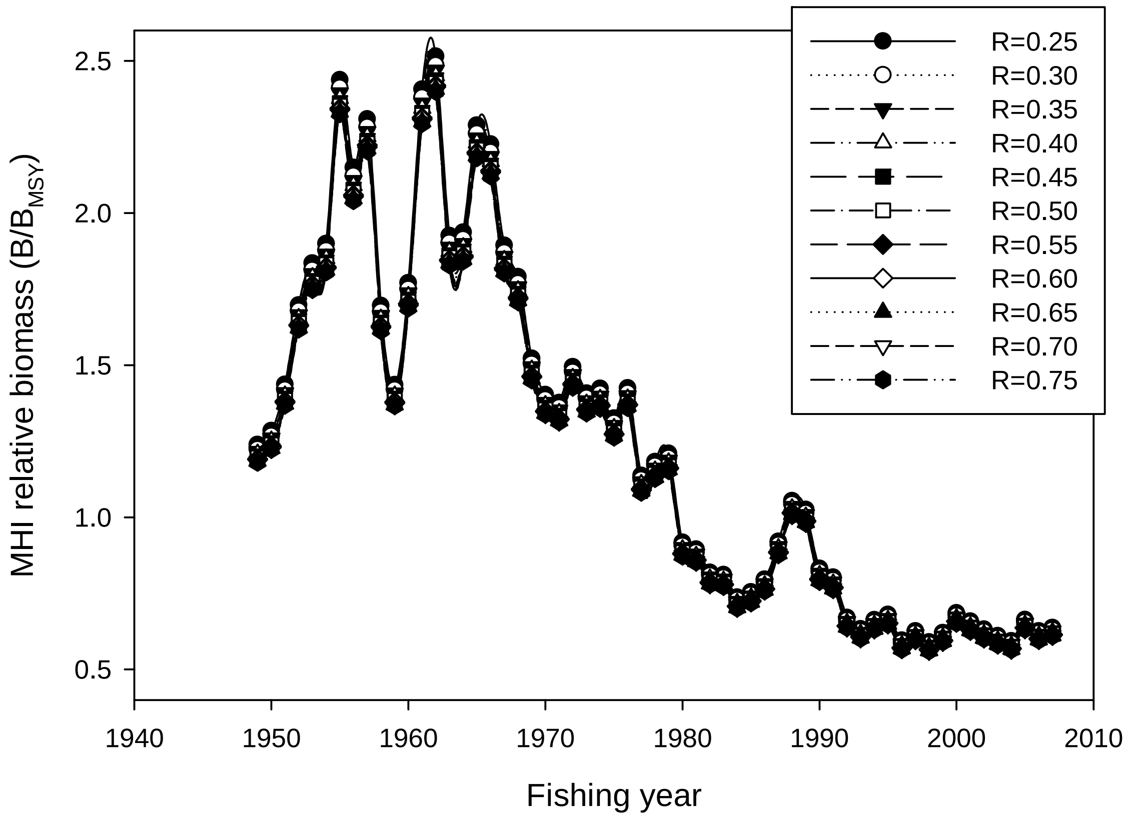


Figure 24.--Sensitivity analysis of relative bottomfish biomass estimates for the main Hawaiian Islands to assumed values of prior means for the intrinsic growth rate parameter from R=0.25 to 0.75. The mean prior value of R used in the baseline model was R=0.46.

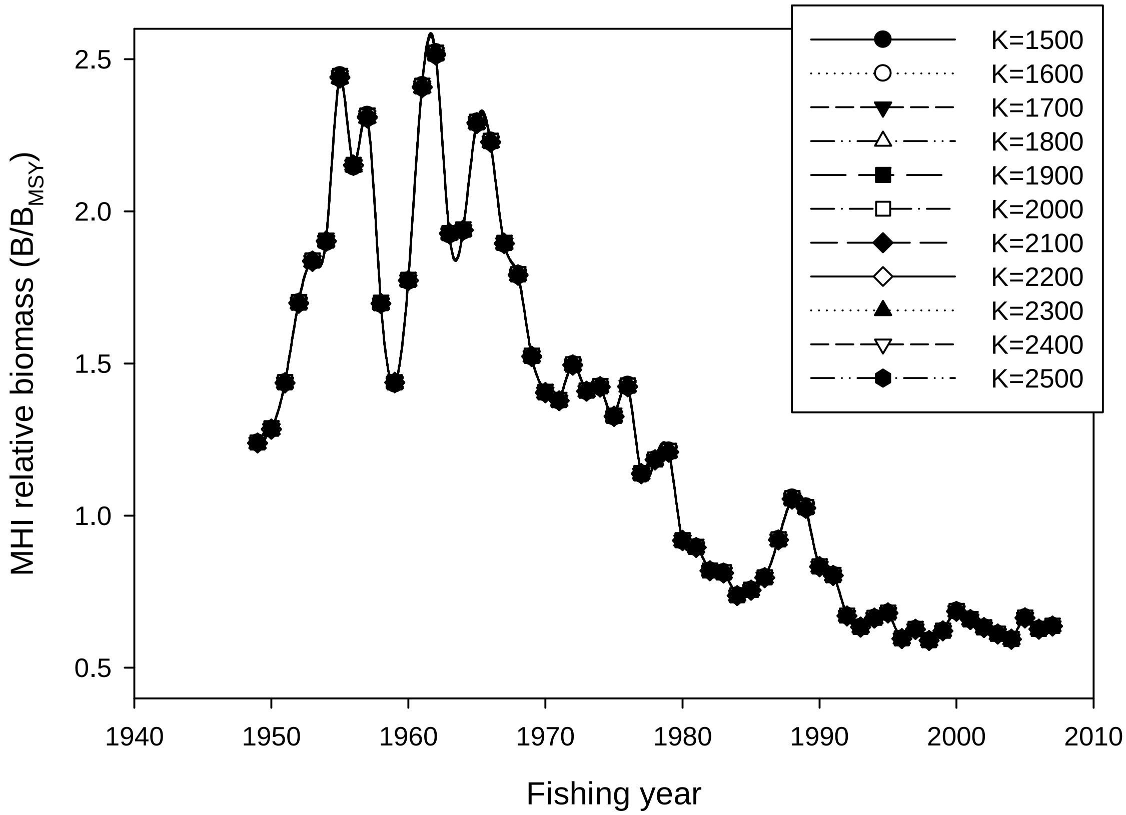


Figure 25.--Sensitivity analysis of relative bottomfish biomass estimates for the main Hawaiian Islands to assumed values of prior means for the MHI carrying capacity parameter from K=1500 to 2500 klbs. The mean prior value of K used in the baseline model was K=2000 klbs.

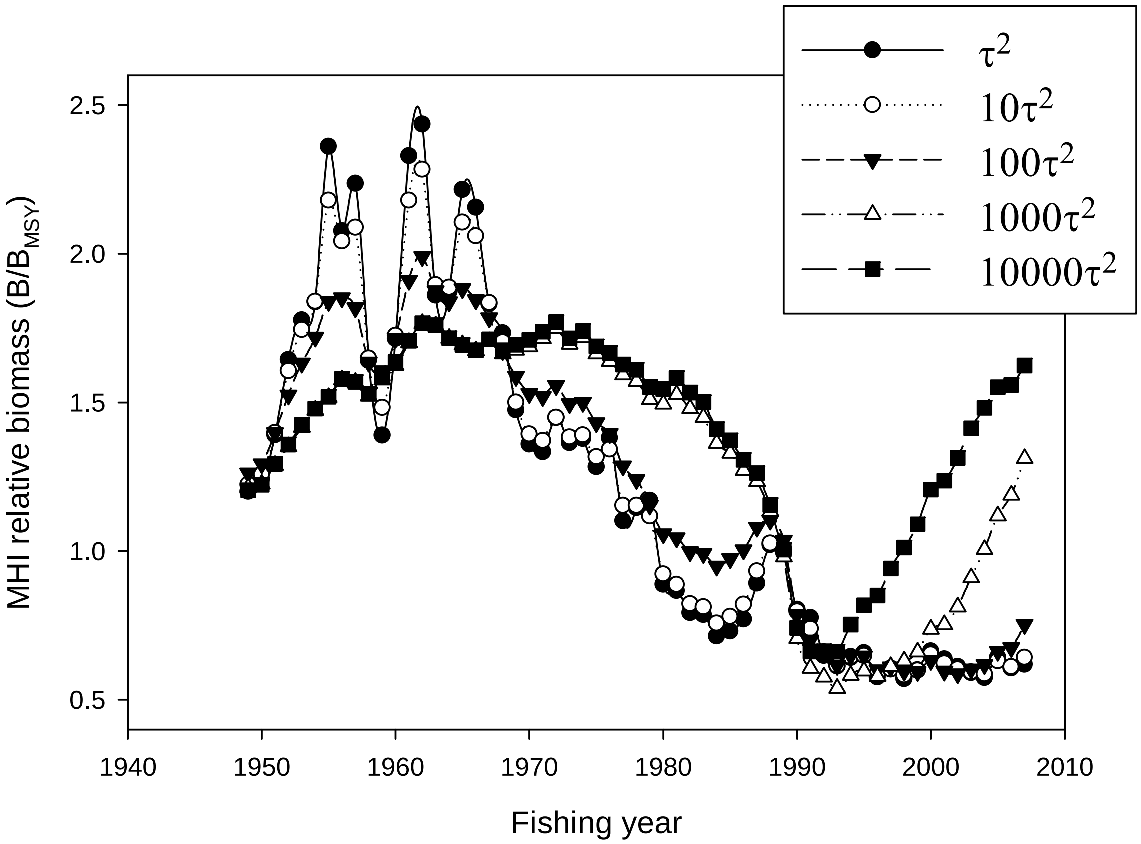


Figure 26.--Sensitivity analysis of relative bottomfish biomass estimates for the main Hawaiian Islands to assumed values of prior means of the observation error variance parameter (τ^2) by fishing zone for values $10\tau^2$., $100\tau^2$, $1000\tau^2$, and 10000 τ^2.

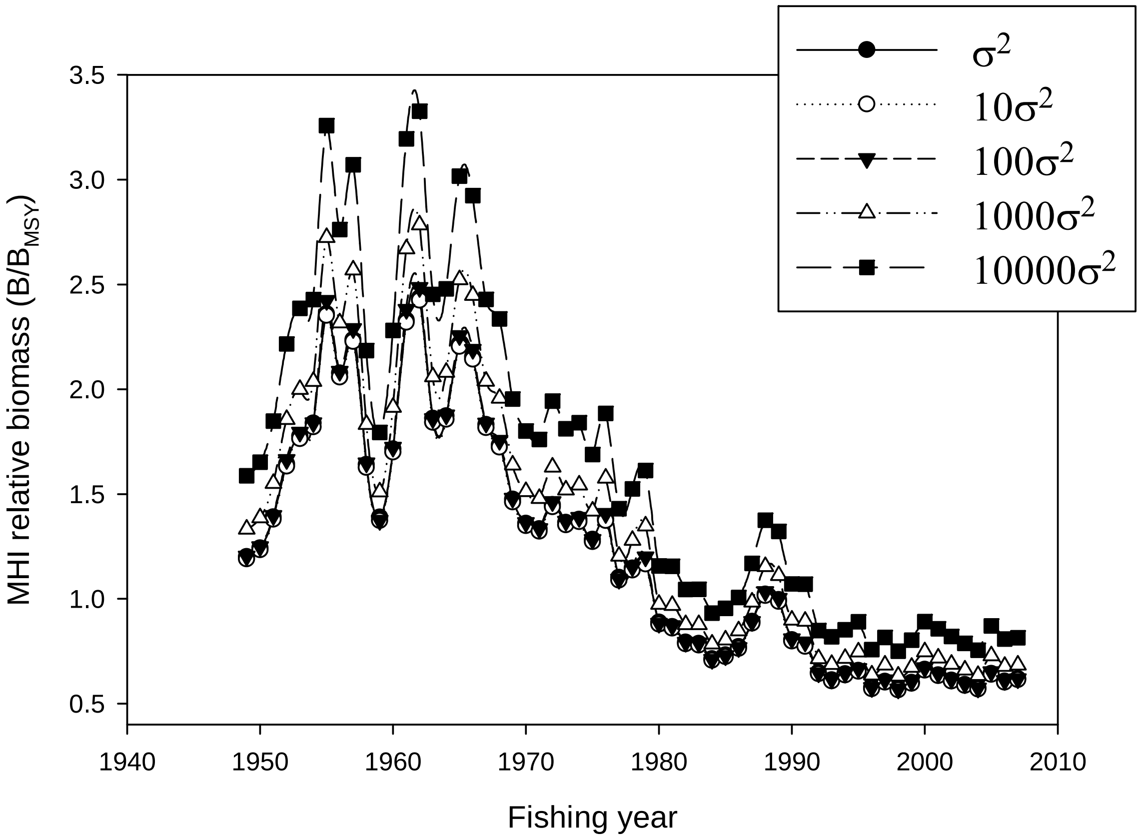


Figure 27.--Sensitivity analysis of relative bottomfish biomass estimates for the main Hawaiian Islands to assumed values of prior means of the process error variance parameter (σ^2) by fishing zone for values 10 σ^2., 100 σ^2 , 1000 σ^2, and 10000 σ^2.

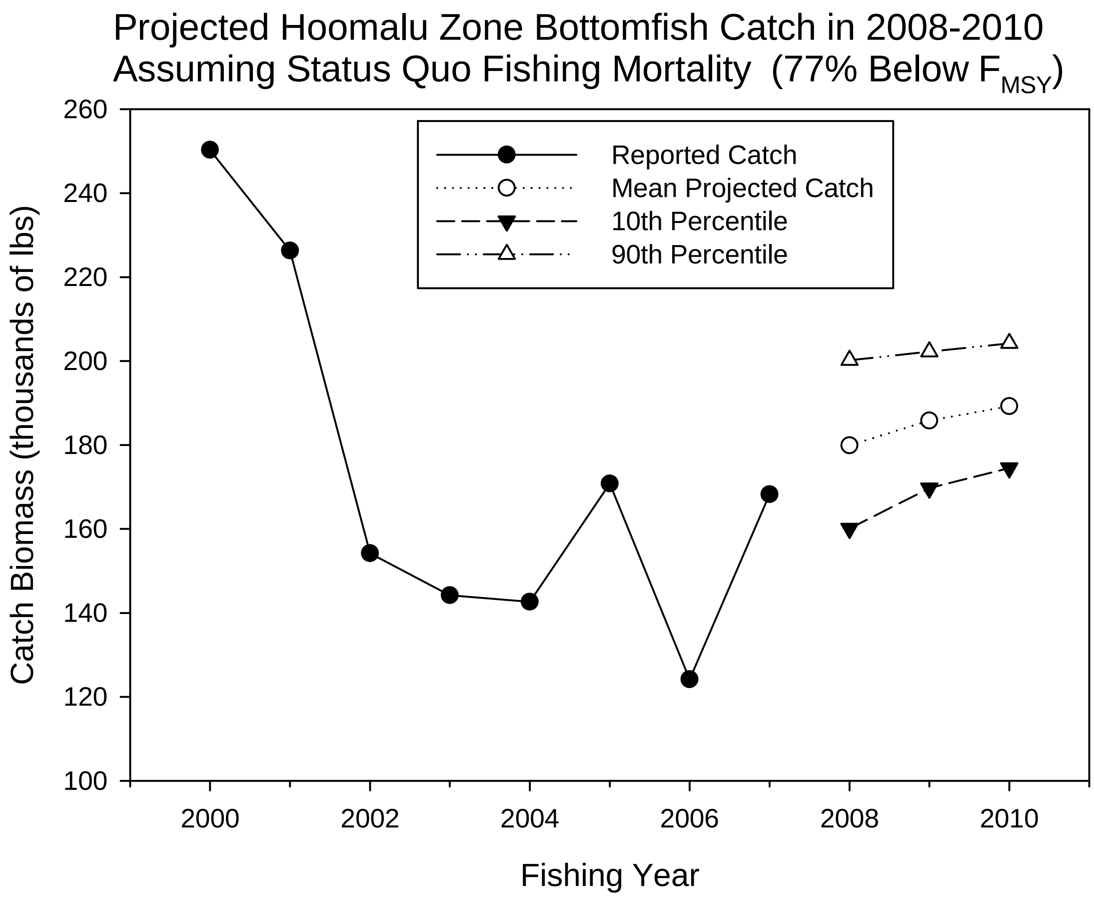


Figure 28.--Projected bottomfish catch biomass in the Hoomalu zone during 2008-2010 assuming status quo fishing effort and mortality.

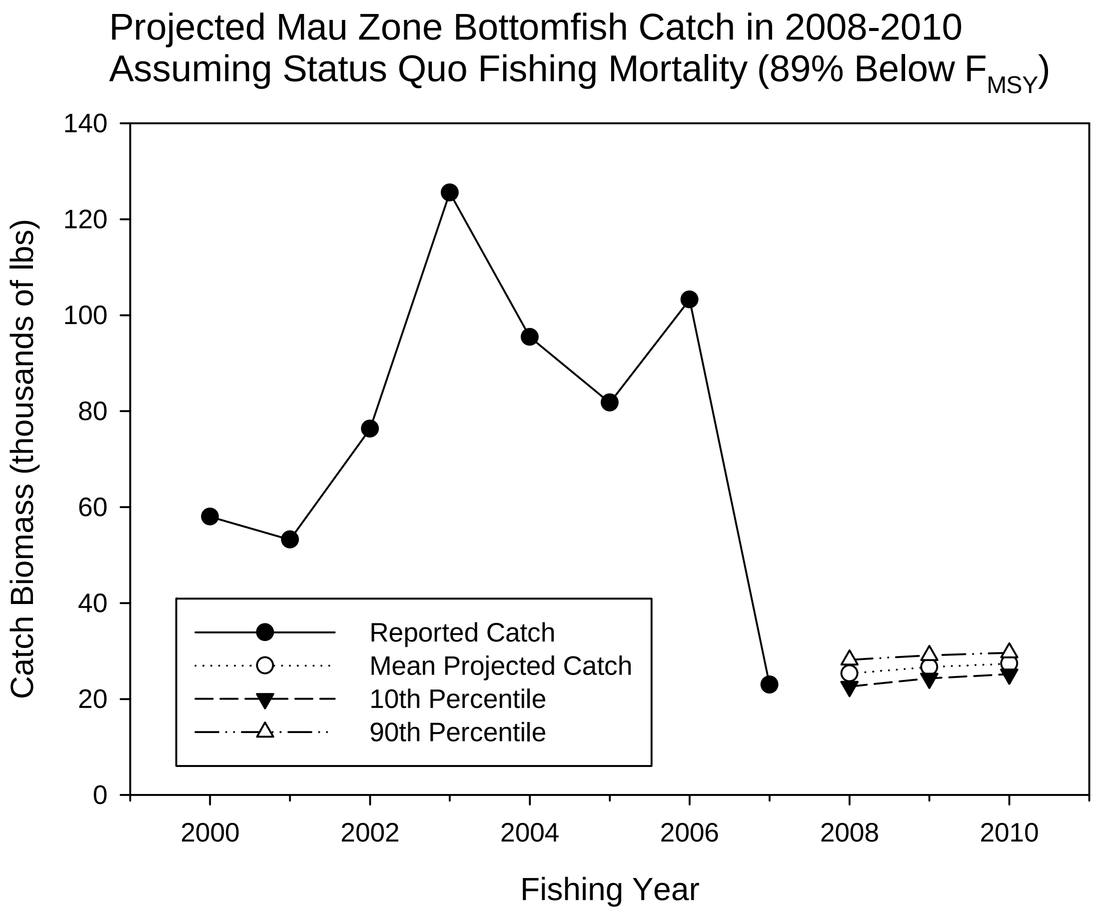


Figure 29.--Projected bottomfish catch biomass in the Mau zone during 2008-2010 assuming status quo fishing effort and mortality.

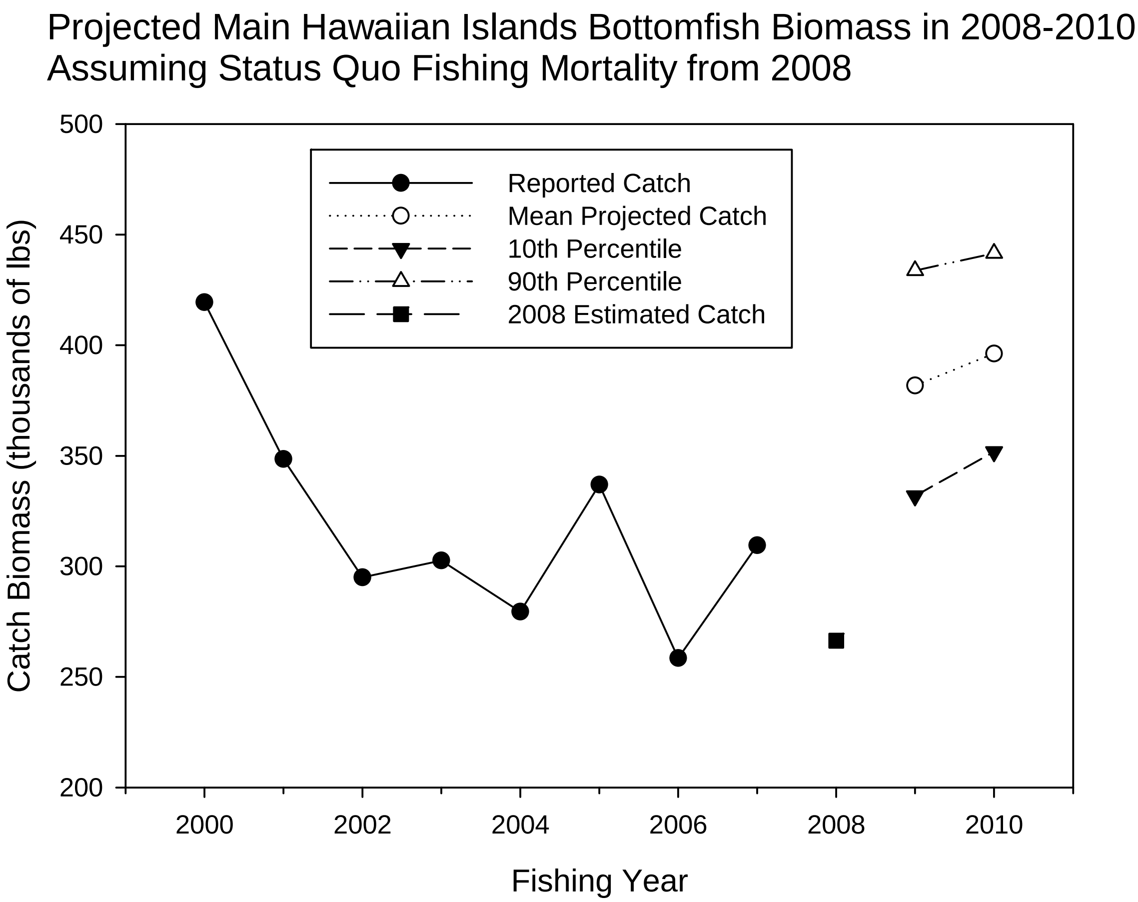


Figure 30.--Projected bottomfish catch biomass in the main Hawaiian Islands during 2009-2010 assuming status quo fishing effort and mortality.

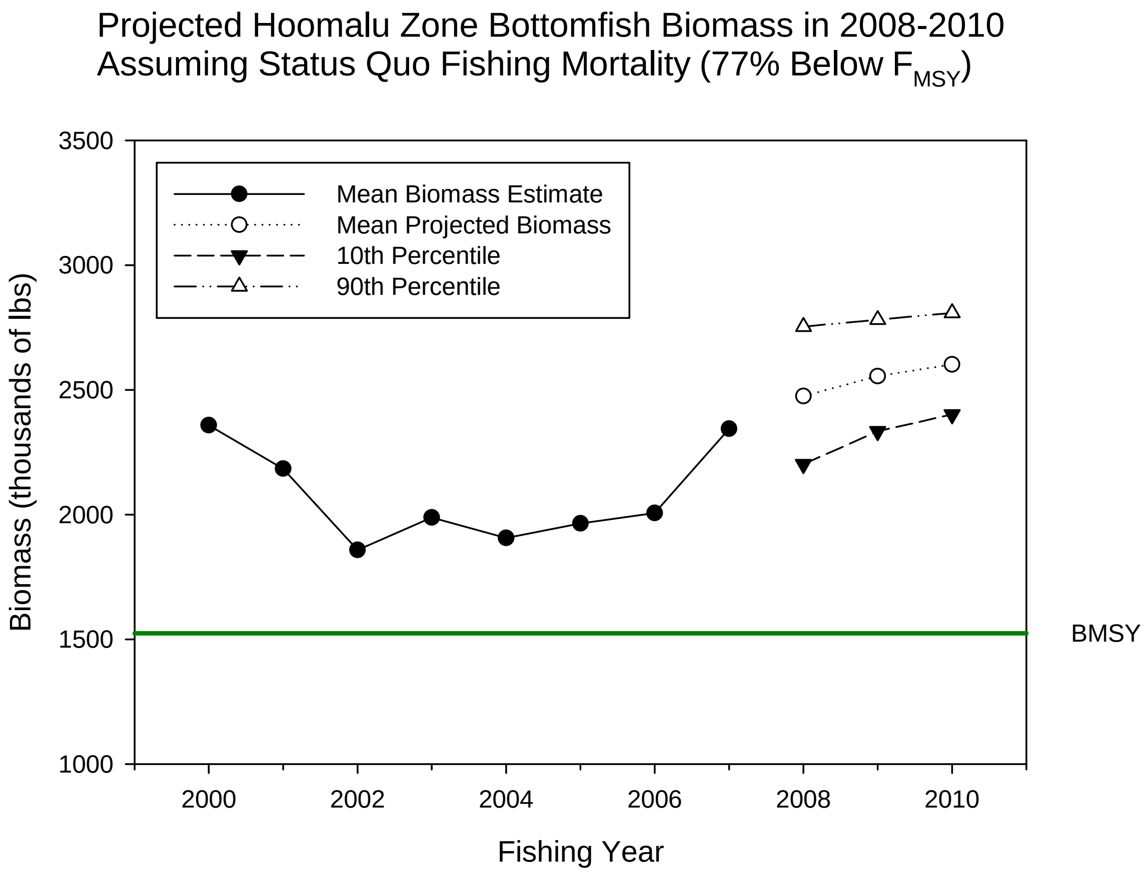


Figure 31.--Projected bottomfish biomass in the Hoomalu zone during 2008-2010 assuming status quo fishing effort and mortality.

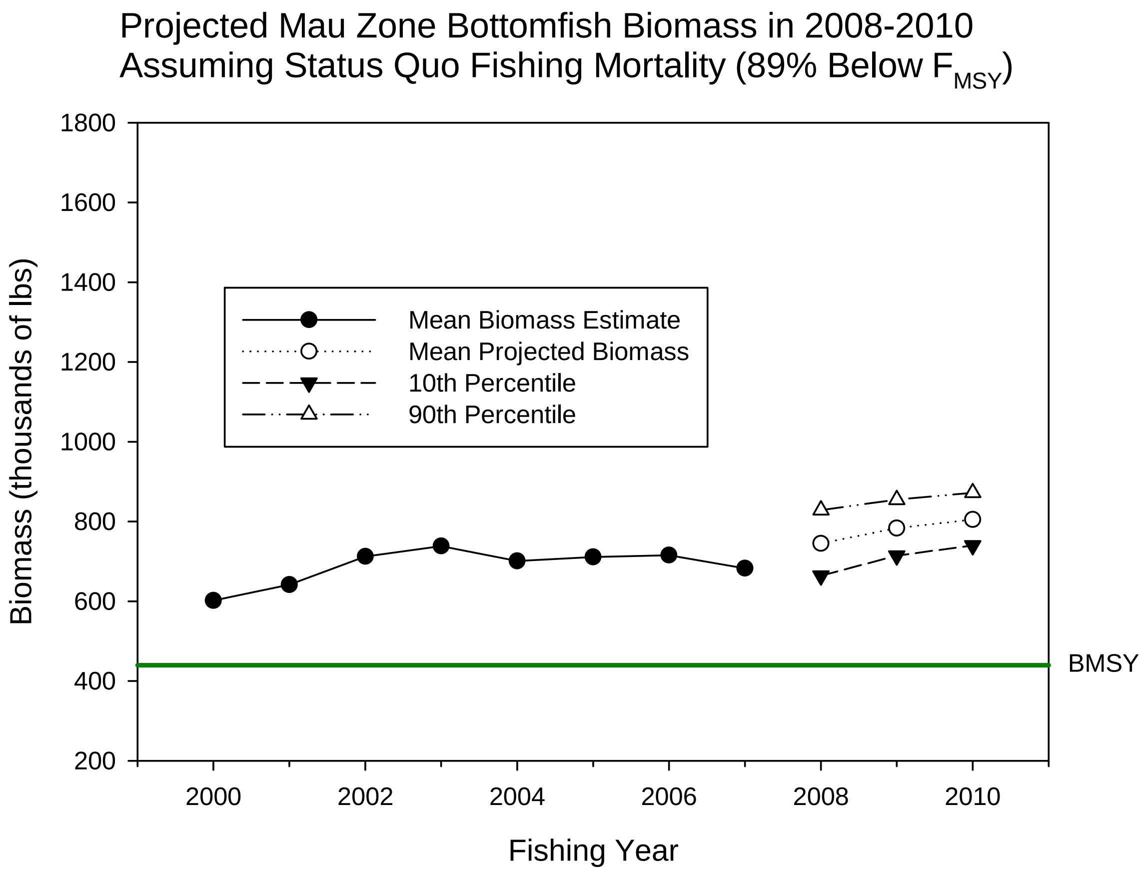


Figure 32.--Projected bottomfish biomass in the Mau zone during 2008-2010 assuming status quo fishing effort and mortality.

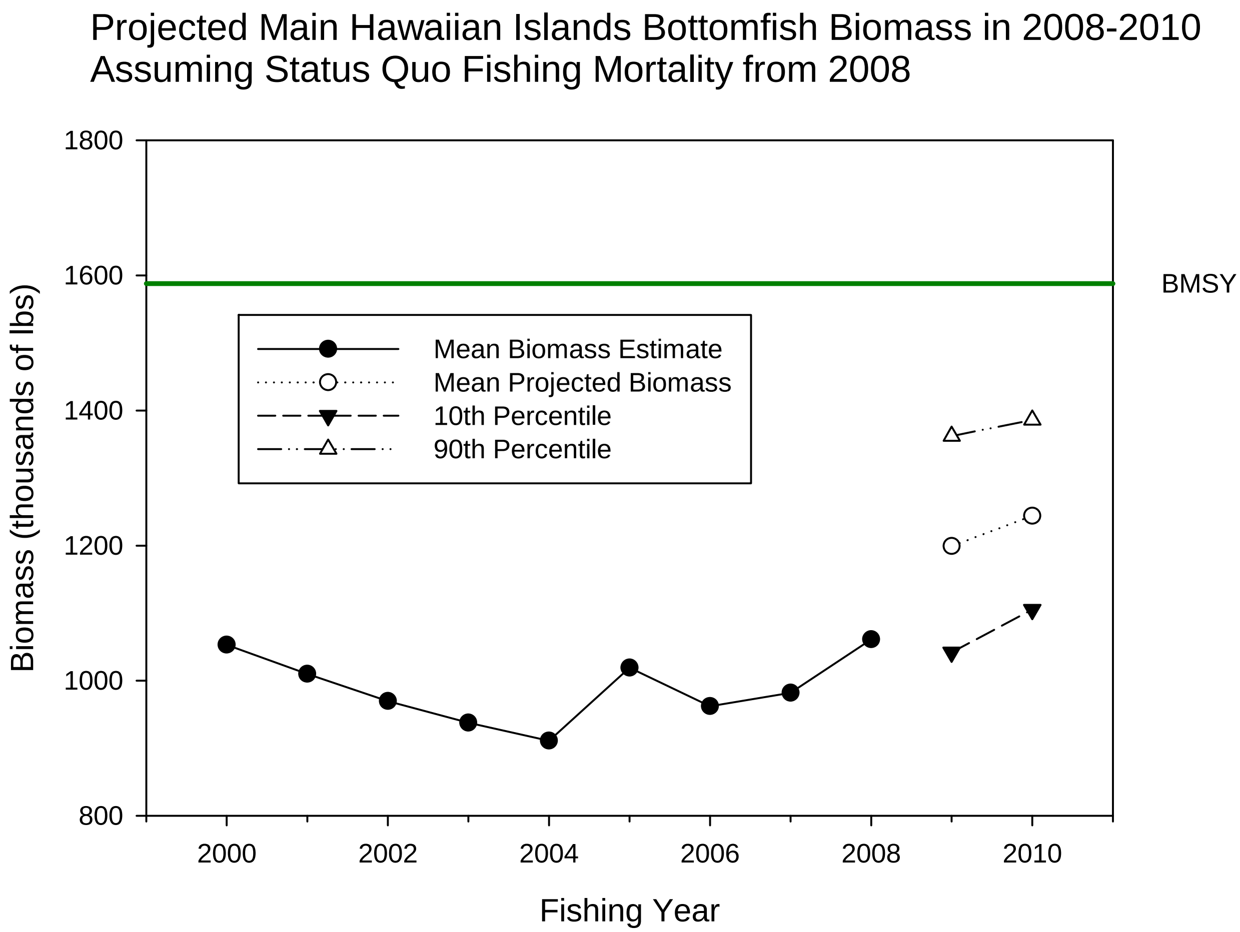


Figure 33.--Projected bottomfish biomass in the main Hawaiian Islands during 2009-2010 assuming status quo fishing effort and mortality.

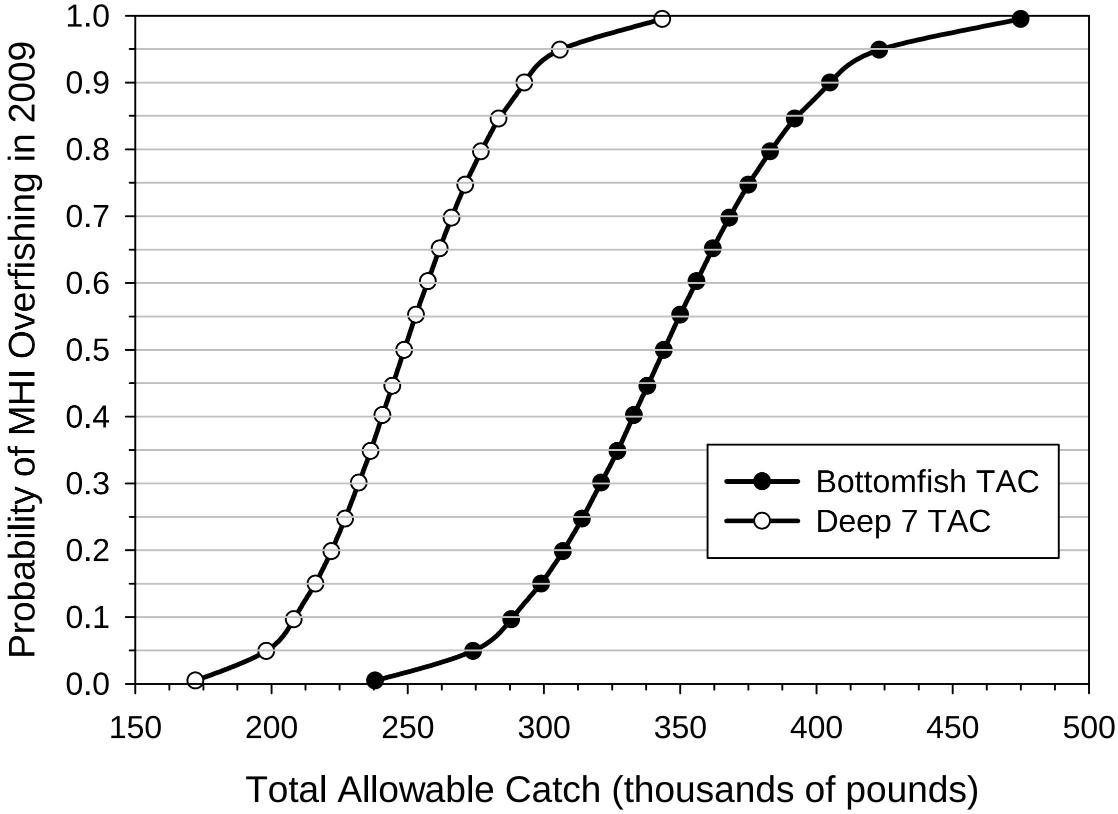


Figure 34.--Risk of overfishing the main Hawaiian Islands bottomfish stock complex in 2009 as a function of the total allowable catch (TAC) in 2009 of bottomfish or the deep 7 bottomfish species.

Appendix.

Table A1.--Results of the multiplicative loglinear model (Gavaris, 1980) used to standardize bottomfish CPUE for the main Hawaiian Islands. The CPUE predictors included fishing year (fishyear), month, and fishing area (garea) as predictors of bottomfish CPUE on directed fishing trips (defined as trips that had at least 50% bottomfish catch by weight). Estimates of log-scale parameter factor level along with their standard errors and P-values were listed for each predictor. Inferences about the significance of predictors was judged using the Type III sums of squares which are appropriate for unbalanced data sets (e.g., Searle, 1987) which do not contain the same number of observations in each cell.

```
              Bottomfish directed CPUE standardization, 1949-2007             1
                       log(bfish) = fishyear, area, month
                                        12:19 Monday, September 22, 2008

                                  The GLM Procedure

                               Class Level Information

Class        Levels  Values

fishyear         59  1949 1950 1951 1952 1953 1954 1955 1956 1957 1958 1959 1960
                     1961 1962 1963 1964 1965 1966 1967 1968 1969 1970 1971 1972
                     1973 1974 1975 1976 1977 1978 1979 1981 1982 1983 1984 1985
                     1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997
                     1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 91980

garea            32  101 102 105 120 121 122 125 126 128 305 320 321 323 324 325
                     327 328 332 333 423 429 521 523 525 527 528 1000 3000 4000
                     5000 6000 9331

month            12  1 2 3 4 5 6 7 8 9 10 11 12

                        Number of observations    141123
```

Table A1.--continued.

Bottomfish directed CPUE standardization, 1949-2007 2
log(bfish) = fishyear, area, month
12:19 Monday, September 22, 2008

The GLM Procedure

Dependent Variable: logbfish

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	100	33308.4659	333.0847	300.34	<.0001
Error	141022	156396.8501	1.1090		
Corrected Total	141122	189705.3160			

R-Square	Coeff Var	Root MSE	logbfish Mean
0.175580	25.29915	1.053102	4.162599

Source	DF	Type I SS	Mean Square	F Value	Pr > F
fishyear	58	6884.13761	118.69203	107.02	<.0001
garea	31	26325.00996	849.19387	765.71	<.0001
month	11	99.31834	9.02894	8.14	<.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
fishyear	58	5550.80400	95.70352	86.30	<.0001
garea	31	26243.88126	846.57681	763.35	<.0001
month	11	99.31834	9.02894	8.14	<.0001

Parameter		Estimate		Standard Error	t Value	Pr > |t|
Intercept		4.721213986	B	0.02396156	197.03	<.0001
fishyear	1949	-0.040312401	B	0.03056248	-1.32	0.1872
fishyear	1950	0.000001308	B	0.03169828	0.00	1.0000
fishyear	1951	0.112011992	B	0.03343181	3.35	0.0008
fishyear	1952	0.294633125	B	0.03729274	7.90	<.0001
fishyear	1953	0.368273500	B	0.04164092	8.84	<.0001
fishyear	1954	0.385474478	B	0.04215206	9.14	<.0001
fishyear	1955	0.683201259	B	0.05120106	13.34	<.0001
fishyear	1956	0.515491905	B	0.04531814	11.37	<.0001
fishyear	1957	0.622372072	B	0.04246508	14.66	<.0001
fishyear	1958	0.280701852	B	0.04584210	6.12	<.0001
fishyear	1959	0.082593782	B	0.04628571	1.78	0.0744
fishyear	1960	0.323732640	B	0.04368901	7.41	<.0001
fishyear	1961	0.663261680	B	0.05936434	11.17	<.0001
fishyear	1962	0.703328701	B	0.05114267	13.75	<.0001
fishyear	1963	0.395829033	B	0.04570463	8.66	<.0001
fishyear	1964	0.407243969	B	0.04409104	9.24	<.0001
fishyear	1965	0.604452587	B	0.04108083	14.71	<.0001

Table A1.--continued.

The GLM Procedure

Dependent Variable: logbfish

Parameter		Estimate		Standard Error	t Value	Pr > |t|
fishyear	1966	0.572696922	B	0.04280716	13.38	<.0001
fishyear	1967	0.386446453	B	0.03669147	10.53	<.0001
fishyear	1968	0.481069688	B	0.04031231	11.93	<.0001
fishyear	1969	0.301167251	B	0.03860226	7.80	<.0001
fishyear	1970	0.220276025	B	0.03937677	5.59	<.0001
fishyear	1971	0.197326482	B	0.03952253	4.99	<.0001
fishyear	1972	0.296050329	B	0.03535004	8.37	<.0001
fishyear	1973	0.224969475	B	0.03717966	6.05	<.0001
fishyear	1974	0.241788471	B	0.03241352	7.46	<.0001
fishyear	1975	0.154955574	B	0.03285501	4.72	<.0001
fishyear	1976	0.266222004	B	0.03322212	8.01	<.0001
fishyear	1977	-0.011470396	B	0.03196104	-0.36	0.7197
fishyear	1978	0.052504268	B	0.03244660	1.62	0.1056
fishyear	1979	0.109998194	B	0.03458804	3.18	0.0015
fishyear	1981	-0.001729916	B	0.02804660	-0.06	0.9508
fishyear	1982	-0.103224912	B	0.02841338	-3.63	0.0003
fishyear	1983	-0.102117053	B	0.02673888	-3.82	0.0001
fishyear	1984	-0.217175984	B	0.02750504	-7.90	<.0001
fishyear	1985	-0.193410087	B	0.02632161	-7.35	<.0001
fishyear	1986	-0.140542397	B	0.02633684	-5.34	<.0001
fishyear	1987	0.009187137	B	0.02634475	0.35	0.7273
fishyear	1988	0.172509603	B	0.02594805	6.65	<.0001
fishyear	1989	0.130704923	B	0.02543734	5.14	<.0001
fishyear	1990	-0.077829378	B	0.02605490	-2.99	0.0028
fishyear	1991	-0.077223417	B	0.02731937	-2.83	0.0047
fishyear	1992	-0.129073171	B	0.02727384	-4.73	<.0001
fishyear	1993	-0.163120179	B	0.02872986	-5.68	<.0001
fishyear	1994	-0.123346948	B	0.02796375	-4.41	<.0001
fishyear	1995	-0.079349172	B	0.02772992	-2.86	0.0042
fishyear	1996	-0.242271411	B	0.02793067	-8.67	<.0001
fishyear	1997	-0.165683338	B	0.02776633	-5.97	<.0001
fishyear	1998	-0.251648126	B	0.02781503	-9.05	<.0001
fishyear	1999	-0.182509575	B	0.02937734	-6.21	<.0001
fishyear	2000	-0.078669349	B	0.02793479	-2.82	0.0049
fishyear	2001	-0.118673073	B	0.02867416	-4.14	<.0001
fishyear	2002	-0.161782953	B	0.02999149	-5.39	<.0001
fishyear	2003	-0.202209728	B	0.02937616	-6.88	<.0001
fishyear	2004	-0.244808567	B	0.02982776	-8.21	<.0001
fishyear	2005	-0.101512305	B	0.02983524	-3.40	0.0007
fishyear	2006	-0.176096393	B	0.03109526	-5.66	<.0001
fishyear	2007	-0.168124788	B	0.02970689	-5.66	<.0001
fishyear	91980	0.000000000	B	.	.	.
garea	101	-0.974282250	B	0.02049550	-47.54	<.0001
garea	102	-0.894392706	B	0.02123207	-42.12	<.0001
garea	105	-1.372208164	B	0.01808404	-75.88	<.0001
garea	120	-0.464481003	B	0.02999957	-15.48	<.0001
garea	121	-0.935436701	B	0.01565290	-59.76	<.0001

Table A1.--continued.

```
          Bottomfish directed CPUE standardization, 1949-2007             4
                     log(bfish) = fishyear, area, month
                                            12:19 Monday, September 22, 2008

                                The GLM Procedure

Dependent Variable: logbfish
```

Parameter		Estimate		Standard Error	t Value	Pr > |t|
garea	122	-0.801311706	B	0.01307570	-61.28	<.0001
garea	125	-1.139865966	B	0.01812828	-62.88	<.0001
garea	126	-1.005327470	B	0.02116473	-47.50	<.0001
garea	128	0.194495262	B	0.04386945	4.43	<.0001
garea	305	0.150410225	B	0.03101746	4.85	<.0001
garea	320	-0.637359395	B	0.01145319	-55.65	<.0001
garea	321	-0.370246381	B	0.01619020	-22.87	<.0001
garea	323	-0.327256054	B	0.02653792	-12.33	<.0001
garea	324	0.131016949	B	0.02933380	4.47	<.0001
garea	325	0.321392382	B	0.02974878	10.80	<.0001
garea	327	0.065727983	B	0.01889979	3.48	0.0005
garea	328	0.353773485	B	0.01866461	18.95	<.0001
garea	332	0.121565082	B	0.04347714	2.80	0.0052
garea	333	0.320841166	B	0.03978457	8.06	<.0001
garea	423	-0.686846311	B	0.02151546	-31.92	<.0001
garea	429	-1.024662815	B	0.02382235	-43.01	<.0001
garea	521	-0.576986493	B	0.03546451	-16.27	<.0001
garea	523	-0.476038630	B	0.03073719	-15.49	<.0001
garea	525	0.454329896	B	0.04129522	11.00	<.0001
garea	527	0.650410241	B	0.06056900	10.74	<.0001
garea	528	0.989596210	B	0.04678633	21.15	<.0001
garea	1000	-0.717895280	B	0.01563849	-45.91	<.0001
garea	3000	-0.410445640	B	0.01320285	-31.09	<.0001
garea	4000	-0.918167951	B	0.01316849	-69.72	<.0001
garea	5000	-0.657986570	B	0.01356081	-48.52	<.0001
garea	6000	0.014392663	B	0.03576605	0.40	0.6874
garea	9331	0.000000000	B	.	.	.
month	1	0.038091677	B	0.01116962	3.41	0.0006
month	2	0.014676044	B	0.01168437	1.26	0.2091
month	3	-0.013873985	B	0.01222211	-1.14	0.2563
month	4	-0.059030186	B	0.01356812	-4.35	<.0001
month	5	0.020992007	B	0.01340970	1.57	0.1175
month	6	0.043253451	B	0.01411368	3.06	0.0022
month	7	0.014489902	B	0.01438072	1.01	0.3137
month	8	-0.003327236	B	0.01324220	-0.25	0.8016
month	9	-0.027394116	B	0.01207241	-2.27	0.0233
month	10	-0.015012321	B	0.01182470	-1.27	0.2042
month	11	-0.029830086	B	0.01163992	-2.56	0.0104
month	12	0.000000000	B	.	.	.

Table A2.--WINBUGS source code used to fit baseline assessment model for bottomfish using standardized MHI CPUE during 1949-2007 and to determine TACs that produce probabilities of overfishing the MHI in 2009 of 0%, 5%, …, 100%.

Hawaiian Bottomfish Archipelagic Assessment 2008
Bayesian State-Space Implementation
of Schaefer Production Model
Fishing Year 1949-2007
PROJECTION MODEL bfish_baseline_TAC_grid
MHI C2008 Estimate=266.409
FIND TAC TO SET P(MHI 2009 Overfishing)=0.05, …, 1.00

```
##########################################################################################
# Jon Brodziak, PIFSC, September 2008
# Catch units are thousands of pounds
# CPUE units are thousands of pounds per trip
# This program analyzes MHI catch & cpue data for 1949-2007
# This program analyzes Mau and Hoomalu catch & cpue data for 1988-2007
# This program uses CPUE calculated with GLM standardization approach.
# This program assumes 4 periods for MHI catchability based on interviews similar to AR H0601
# This program assumes a common intrinsic growth rate across regions, r
# This program estimates carrying capacity for MHI only
# This program assumes carrying capacities for Mau and Hoomalu are proportional to habitat
##########################################################################################

model bfish_baseline_TAC_test
{

# Prior distributions
####################################################

# Diffuse normal prior for carrying capacity parameter, K
#(1)###################################################
K_MHI ~ dnorm(2000,0.00001)
K_Mau <- 0.277*K_MHI
K_Hoomalu <- 0.960*K_MHI

# Beta prior for intrinsic growth rate parameter, r
# with mean=0.46 and CV=26%
#(2)###################################################
 r ~ dbeta(7.67,9)

# Gamma priors for CPUE catchability coefficients
# within interval (0.0001,10), q
#(3)###################################################
iq_MHI ~ dgamma(0.001,0.001)I(0.1,10000)
q_MHI <- 1/iq_MHI
iq_Mau ~ dgamma(0.001,0.001)I(0.1,10000)
q_Mau <- 1/iq_Mau
iq_Hoomalu ~ dgamma(0.001,0.001)I(0.1,10000)
q_Hoomalu <- 1/iq_Hoomalu

# Gamma prior for process error variances, sigma2
#(4)###################################################
isigma2_MHI ~ dgamma(a0_MHI,b0_MHI)
sigma2_MHI <- 1/isigma2_MHI
isigma2_Mau ~ dgamma(a0_Mau,b0_Mau)
sigma2_Mau <- 1/isigma2_Mau
isigma2_Hoomalu ~ dgamma(a0_Hoomalu,b0_Hoomalu)
sigma2_Hoomalu <- 1/isigma2_Hoomalu
```

Table A2.--continued.

```
# Gamma priors for observation error variances, tau2
#(5)######################################################
itau2_MHI   ~ dgamma(c0_MHI,d0_MHI)
tau2_MHI   <- 1/itau2_MHI
itau2_Mau   ~ dgamma(c0_Mau,d0_Mau)
tau2_Mau   <- 1/itau2_Mau
itau2_Hoomalu   ~ dgamma(c0_Hoomalu,d0_Hoomalu)
tau2_Hoomalu   <- 1/itau2_Hoomalu

# Lognormal priors for time series of proportions of K, P
#(6)######################################################
# MHI time series starts in 1949 and ends in 2007, n=59
# Start at 60% of K
Pmean_MHI[1] <- -0.511
P_MHI[1] ~ dlnorm(Pmean_MHI[1],isigma2_MHI) I(0.001,10)

# Process dynamics
for (i in 2:N_MHI) {
  Pmean_MHI[i] <- log(max(P_MHI[i-1] + r*P_MHI[i-1]*(1-P_MHI[i-1]) - Catch_MHI[i-1]/K_MHI,0.001))
   P_MHI[i]  ~ dlnorm(Pmean_MHI[i],isigma2_MHI)I(0.001,10)
   }

# Mau time series starts in 1988 and ends in 2007, n=20, P[1]=0.8
Pmean_Mau[1] <- -0.223
P_Mau[1] ~ dlnorm(Pmean_Mau[1],isigma2_Mau) I(0.001,10)

# Process dynamics
for (i in 2:N_Mau) {
  Pmean_Mau[i] <- log(max(P_Mau[i-1] + r*P_Mau[i-1]*(1-P_Mau[i-1]) - Catch_Mau[i-1]/K_Mau,0.001))
   P_Mau[i]  ~ dlnorm(Pmean_Mau[i],isigma2_Mau)I(0.001,10)
   }

# Hoomalu time series starts in 1988 and ends in 2007, n=20, P[1]=0.8
Pmean_Hoomalu[1] <- -0.223
P_Hoomalu[1] ~ dlnorm(Pmean_Hoomalu[1],isigma2_Hoomalu) I(0.001,10)

# Process dynamics
for (i in 2:N_Hoomalu) {
  Pmean_Hoomalu[i] <- log(max(P_Hoomalu[i-1] + r*P_Hoomalu[i-1]*(1-P_Hoomalu[i-1]) - Catch_Hoomalu[i-
1]/K_Hoomalu,0.001))
   P_Hoomalu[i]  ~ dlnorm(Pmean_Hoomalu[i],isigma2_Hoomalu)I(0.001,10)
   }

# Lognormal likelihood for observed CPUE indices
#(7)######################################################
# MHI CPUE LIKELIHOOD 1949-2007 P_MHI[1:59], 4 Periods for Q
# Period 1: 1949--1967 relative Q=0.7
for (i in 1:19) {
    CPUEmean_MHI[i] <- log(0.7*q_MHI*K_MHI*P_MHI[i])
    CPUE_MHI[i] ~ dlnorm(CPUEmean_MHI[i],itau2_MHI)
    RESID_MHI[i] <- log(CPUE_MHI[i]) - log(0.7*q_MHI*K_MHI*P_MHI[i])
           }
# Period 2: 1968--1979 relative Q=0.8
for (i in 20:31) {
    CPUEmean_MHI[i] <- log(0.8*q_MHI*K_MHI*P_MHI[i])
    CPUE_MHI[i] ~ dlnorm(CPUEmean_MHI[i],itau2_MHI)
    RESID_MHI[i] <- log(CPUE_MHI[i]) - log(0.8*q_MHI*K_MHI*P_MHI[i])
           }
           # Period 3: 1980--1991 relative Q=1
for (i in 32:43) {
    CPUEmean_MHI[i] <- log(q_MHI*K_MHI*P_MHI[i])
    CPUE_MHI[i] ~ dlnorm(CPUEmean_MHI[i],itau2_MHI)
    RESID_MHI[i] <- log(CPUE_MHI[i]) - log(q_MHI*K_MHI*P_MHI[i])
           }
           # Period 4: 1992--2007 relative Q=1.2
for (i in 44:59) {
    CPUEmean_MHI[i] <- log(1.2*q_MHI*K_MHI*P_MHI[i])
```

Table A2.--continued.

```
    CPUE_MHI[i] ~ dlnorm(CPUEmean_MHI[i],itau2_MHI)
    RESID_MHI[i] <- log(CPUE_MHI[i]) - log(1.2*q_MHI*K_MHI*P_MHI[i])
             }
# Compute RMSE for MHI CPUE
RSS_MHI <- inprod(RESID_MHI[], RESID_MHI[])
RMSE_MHI <- sqrt(RSS_MHI/N_MHI)
AIC_MHI <- N_MHI*log(RSS_MHI/N_MHI)+2*NPAR_MHI
AICC_MHI <- AIC_MHI+2*NPAR_MHI*(NPAR_MHI+1)/(N_MHI-NPAR_MHI-1)

# Mau CPUE LIKELIHOOD 1988-2007 P_Mau[1:20], qMultiplier=1
for (i in 1:N_Mau) {
    CPUEmean_Mau[i] <- log(q_Mau*K_Mau*P_Mau[i])
    CPUE_Mau[i] ~ dlnorm(CPUEmean_Mau[i],itau2_Mau)
    RESID_Mau[i] <- log(CPUE_Mau[i]) - log(q_Mau*K_Mau*P_Mau[i])
             }
# Compute RMSE for Mau CPUE
RSS_Mau <- inprod(RESID_Mau[], RESID_Mau[])
RMSE_Mau <- sqrt(RSS_Mau/N_Mau)

# Hoomalu CPUE LIKELIHOOD 1988-2007 P_Hoomalu[1:20], qMultiplier=1
for (i in 1:N_Hoomalu) {
    CPUEmean_Hoomalu[i] <- log(q_Hoomalu*K_Hoomalu*P_Hoomalu[i])
    CPUE_Hoomalu[i] ~ dlnorm(CPUEmean_Hoomalu[i],itau2_Hoomalu)
    RESID_Hoomalu[i] <- log(CPUE_Hoomalu[i]) - log(q_Hoomalu*K_Hoomalu*P_Hoomalu[i])
             }
# Compute RMSE for Hoomalu CPUE
RSS_Hoomalu <- inprod(RESID_Hoomalu[], RESID_Hoomalu[])
RMSE_Hoomalu <- sqrt(RSS_Hoomalu/N_Hoomalu)

# Use total likelihood for overall AIC calculation
N_TOT <- N_MHI+N_Mau+N_Hoomalu
AIC_TOT<-
N_MHI*log(RSS_MHI/N_MHI)+N_Mau*log(RSS_Mau/N_Mau)+N_Hoomalu*log(RSS_Hoomalu/N_Hoomalu)+2*NPAR_TOT
AICC_TOT <- AIC_TOT+2*NPAR_TOT*(NPAR_TOT+1)/(N_TOT-NPAR_TOT-1)

# Compute exploitation rate and biomass time series
#(8)######################################################
# MHI 1949-2007 P_MHI[1:59]
for (i in 1:N_MHI) {
    B_MHI[i] <- P_MHI[i]*K_MHI
    H_MHI[i] <- Catch_MHI[i]/B_MHI[i]
   }

# Mau 1988-2007 P_Mau[1:20]
for (i in 1:N_Mau) {
    B_Mau[i] <- P_Mau[i]*K_Mau
    H_Mau[i] <- Catch_Mau[i]/B_Mau[i]
   }

# Hoomalu 1988-2007 P_Hoomalu[1:20]
for (i in 1:N_Hoomalu) {
    B_Hoomalu[i] <- P_Hoomalu[i]*K_Hoomalu
    H_Hoomalu[i] <- Catch_Hoomalu[i]/B_Hoomalu[i]
   }

# Compute reference points
#(9)######################################################
# MHI Reference points
BMSP_MHI <- K_MHI/2
PMSP_MHI <- BMSP_MHI/K_MHI
MSP_MHI <- r*K_MHI/4
HMSP_MHI <- r/2
INDEXMSP_MHI <- q_MHI*BMSP_MHI
# MHI 1949-2007 BSTATUS_MHI and HSTATUS_MHI
for (i in 1:N_MHI) {
    BSTATUS_MHI[i] <- B_MHI[i]/BMSP_MHI
```

Table A2.--continued.

```
    HSTATUS_MHI[i] <- H_MHI[i]/HMSP_MHI
   }

# Mau Reference points
BMSP_Mau <- K_Mau/2
PMSP_Mau <- BMSP_Mau/K_Mau
MSP_Mau <- r*K_Mau/4
HMSP_Mau <- r/2
INDEXMSP_Mau <- q_Mau*BMSP_Mau
# Mau 1988-2007 BSTATUS_Mau and HSTATUS_Mau
for (i in 1:N_Mau) {
    BSTATUS_Mau[i] <- B_Mau[i]/BMSP_Mau
    HSTATUS_Mau[i] <- H_Mau[i]/HMSP_Mau
   }

# Hoomalu Reference points
BMSP_Hoomalu <- K_Hoomalu/2
PMSP_Hoomalu <- BMSP_Hoomalu/K_Hoomalu
MSP_Hoomalu <- r*K_Hoomalu/4
HMSP_Hoomalu <- r/2
INDEXMSP_Hoomalu <- q_Hoomalu*BMSP_Hoomalu
# Hoomalu 1988-2004 BSTATUS_Hoomalu and HSTATUS_Hoomalu
for (i in 1:N_Hoomalu) {
    BSTATUS_Hoomalu[i] <- B_Hoomalu[i]/BMSP_Hoomalu
    HSTATUS_Hoomalu[i] <- H_Hoomalu[i]/HMSP_Hoomalu
   }

# Archipelago Reference points
BMSP_Archipelago <- BMSP_MHI + BMSP_Mau + BMSP_Hoomalu
MSP_Archipelago <- MSP_MHI + MSP_Mau + MSP_Hoomalu
HMSP_Archipelago <- r/2
K_Archipelago <- K_MHI + K_Mau + K_Hoomalu
# Archipelago 1988-2007 BSTATUS_Archipelago and HSTATUS_Archipelago
for (i in 1:N_Mau) {
    BSTATUS_Archipelago[i] <-
weight_MHI*BSTATUS_MHI[i+39]+weight_Mau*BSTATUS_Mau[i]+weight_Hoomalu*BSTATUS_Hoomalu[i]
    HSTATUS_Archipelago[i] <-
weight_MHI*HSTATUS_MHI[i+39]+weight_Mau*HSTATUS_Mau[i]+weight_Hoomalu*HSTATUS_Hoomalu[i]
   }

# Compute probabilities of overfishing and overfished in 2007
pH_MHI07<- step(HSTATUS_MHI[N_MHI] - 1.0)
pH_Mau07 <- step(HSTATUS_Mau[N_Mau] - 1.0)
pH_Hoomalu07 <- step(HSTATUS_Hoomalu[N_Hoomalu] - 1.0)
pH_Archipelago07 <- step(HSTATUS_Archipelago[N_Mau] - 1.0)
pB_MHI07 <- step(BSTATUS_MHI[N_MHI] - 1.0)
pB_Mau07 <- step(BSTATUS_Mau[N_Mau] - 1.0)
pB_Hoomalu07 <- step(BSTATUS_Hoomalu[N_Hoomalu] - 1.0)
pB_Archipelago07 <- step(BSTATUS_Archipelago[N_Mau] - 1.0)
pB70_MHI07 <- step(BSTATUS_MHI[N_MHI] - 0.7)

# F-Based Projections with MHI Catch Estimate for FY 2008
#(11)############################################################
P_P_MHI[1] <- max(P_MHI[N_MHI]+r*P_MHI[N_MHI]*(1-P_MHI[N_MHI])-Catch_MHI[N_MHI]/K_MHI,0.001)
P_P_Mau[1] <-  max(P_Mau[N_Mau]+r*P_Mau[N_Mau]*(1-P_Mau[N_Mau])-Catch_Mau[N_Mau]/K_Mau,0.001)
P_P_Hoomalu[1] <-  max(P_Hoomalu[N_Hoomalu]+r*P_Hoomalu[N_Hoomalu]*(1-P_Hoomalu[N_Hoomalu])-
Catch_Hoomalu[N_Hoomalu]/K_Hoomalu,0.001)

# Use estimate of C2008 for MHI projection
  P_B_MHI[1] <- P_P_MHI[1]*K_MHI
  P_B_Mau[1] <- P_P_Mau[1]*K_Mau
  P_B_Hoomalu[1] <- P_P_Hoomalu[1]*K_Hoomalu

  P_C_MHI[1] <-  C2008_MHI
  P_C_Mau[1] <-  P_B_Mau[1]*HPROJ_Mau[1]
  P_C_Hoomalu[1] <-  P_B_Hoomalu[1]*HPROJ_Hoomalu[1]
```

Table A2.--continued.

```
   P_H2008_MHI <- C2008_MHI/P_B_MHI[1]
   P_HSTAT_MHI[1] <- P_H2008_MHI/HMSP_MHI
   P_HSTAT_Mau[1] <- HPROJ_Mau[1]/HMSP_Mau
   P_HSTAT_Hoomalu[1] <- HPROJ_Hoomalu[1]/HMSP_Hoomalu
   P_HSTAT_Archipelago[1] <-
weight_MHI*P_HSTAT_MHI[1]+weight_Mau*P_HSTAT_Mau[1]+weight_Hoomalu*P_HSTAT_Hoomalu[1]

   pH_MHI[1] <- step(P_HSTAT_MHI[1] - 1.0)
   pH_Mau[1] <- step(P_HSTAT_Mau[1] - 1.0)
   pH_Hoomalu[1] <- step(P_HSTAT_Hoomalu[1] - 1.0)
   pH_Archipelago[1] <- step(P_HSTAT_Archipelago[1] - 1.0)

   P_BSTAT_MHI[1] <- P_B_MHI[1]/BMSP_MHI
   P_BSTAT_Mau[1] <- P_B_Mau[1]/BMSP_Mau
   P_BSTAT_Hoomalu[1] <- P_B_Hoomalu[1]/BMSP_Hoomalu
   P_BSTAT_Archipelago[1] <-
weight_MHI*P_BSTAT_MHI[1]+weight_Mau*P_BSTAT_Mau[1]+weight_Hoomalu*P_BSTAT_Hoomalu[1]

   pB_MHI[1] <- step(P_BSTAT_MHI[1] - 1.0)
   pB_Mau[1] <- step(P_BSTAT_Mau[1] - 1.0)
   pB_Hoomalu[1] <- step(P_BSTAT_Hoomalu[1] - 1.0)
   pB_Archipelago[1] <- step(P_BSTAT_Archipelago[1] - 1.0)
   pB70_MHI[1] <- step(P_BSTAT_MHI[1] - 0.7)

   P_P_MHI[2]  <- P_P_MHI[1]*(1.0+r*(1.0-P_P_MHI[1])-P_H2008_MHI)
   P_P_Mau[2]  <- P_P_Mau[1]*(1.0+r*(1.0-P_P_Mau[1])-HPROJ_Mau[1])
   P_P_Hoomalu[2]  <- P_P_Hoomalu[1]*(1.0+r*(1.0-P_P_Hoomalu[1])-HPROJ_Hoomalu[1])

# F Status Quo 2007 Based Projections for 2009 and Beyond
# Grid of TAC in 2009 from 50 to 550 by 5
for (j in 1:NTAC)
  {
   P_B2009_MHI[j] <- P_P_MHI[2]*K_MHI

   P_C2009_MHI[j] <-  TAC_MHI[2]+j-1

   P_H_MHI[j] <- P_C2009_MHI[j]/P_B2009_MHI[j]

   P_HSTAT2009_MHI[j] <- P_H_MHI[j]/HMSP_MHI

   pH2009_MHI[j] <- step(P_HSTAT2009_MHI[j] - 1.0)


  }

# END OF CODE
###############################################################
}
```

Table A3.--Ratio of Deep 7 bottomfish catch to total bottomfish catch in the main Hawaiian Islands by fishing year, 1949-2007 along with recent average ratios.

MHI Deep 7 Ratio by Fishing Year, 1949-2007

Fishing Year	MHI FY BMUS Catch (lbs) Less Taape and Kahala = Catch Used in the Assessment	MHI Deep 7 Catch (lbs)	Ratio Deep 7 to Catch Used in Assessment
1949	512812	354117	0.691
1950	431817	302676	0.701
1951	416819	320154	0.768
1952	389113	299094	0.769
1953	375470	256895	0.684
1954	370070	273287	0.738
1955	318004	223141	0.702
1956	382184	276124	0.722
1957	434718	317814	0.731
1958	312884	211031	0.674
1959	293832	204004	0.694
1960	226944	163861	0.722
1961	189962	129041	0.679
1962	237813	167839	0.706
1963	299509	210809	0.704
1964	307018	201581	0.657
1965	317130	223807	0.706
1966	249043	181868	0.730
1967	328351	231315	0.704
1968	273108	195039	0.714
1969	264002	177495	0.672
1970	233280	158195	0.678
1971	203334	135189	0.665
1972	303987	228375	0.751
1973	233679	169273	0.724
1974	326603	225767	0.691
1975	324690	222114	0.684
1976	366530	258852	0.706
1977	363726	274882	0.756
1978	436206	306376	0.702
1979	400264	273846	0.684
1980	343842	244278	0.710
1981	450492	308296	0.684
1982	464614	329436	0.709
1983	579104	409948	0.708
1984	555910	341576	0.614
1985	619434	485057	0.783
1986	621324	512075	0.824
1987	725632	579170	0.798
1988	804011	566724	0.705
1989	964785	559538	0.580
1990	647051	455802	0.704
1991	497024	324897	0.654
1992	493009	361617	0.733
1993	348334	254050	0.729
1994	407289	307305	0.755
1995	458570	356485	0.777
1996	368267	288231	0.783
1997	397395	299683	0.754
1998	381278	296755	0.778
1999	313286	214803	0.686
2000	419407	309747	0.739
2001	348517	260267	0.747
2002	294996	215492	0.730
2003	302622	244322	0.807
2004	279466	205129	0.734
2005	336920	245737	0.729
2006	258497	186731	0.722
2007	309522	221576	0.716

Recent Averages of MHI Deep 7 Ratio

Time Period (Fishing Year)	Average MHI Deep 7 Ratio	Standard Error of Mean	Standard Deviation
2000-2007	0.741	0.0101	0.0286
2001-2007	0.741	0.0117	0.0308
2002-2007	0.740	0.0137	0.0337
2003-2007	0.742	0.0167	0.0373
2004-2007	0.725	0.0040	0.0080
2005-2007	0.723	0.0039	0.0068
2006-2007	0.719	0.0033	0.0046
2007	0.716		
1949-2007	0.717	0.0057	0.0439

Table A4.--Distributions of parameter estimates for the baseline bottomfish assessment model fit using standardized MHI CPUE during 1949-2007.

Variable	Mean	Standard Deviation	MCMC Error	Percentile 2.5%	Percentile 10%	Median	Percentile 90%	Percentile 97.5%
BMSP_Hoomalu	1524	104	2.81	1327	1392	1521	1659	1734
BMSP_MHI	1588	108.4	2.927	1383	1451	1585	1729	1806
BMSP_Mau	439.9	30.02	0.8109	383	401.8	439	478.8	500.3
BSTATUS_Archipelago[1]	1.541	0.0923	4.77E-04	1.361	1.422	1.54	1.659	1.724
BSTATUS_Archipelago[2]	1.549	0.09	5.40E-04	1.378	1.435	1.547	1.664	1.731
BSTATUS_Archipelago[3]	1.368	0.07683	4.99E-04	1.219	1.271	1.367	1.466	1.523
BSTATUS_Archipelago[4]	1.319	0.07521	5.03E-04	1.171	1.224	1.318	1.414	1.468
BSTATUS_Archipelago[5]	1.197	0.07192	4.77E-04	1.054	1.105	1.197	1.288	1.339
BSTATUS_Archipelago[6]	1.234	0.07612	4.92E-04	1.087	1.139	1.233	1.332	1.387
BSTATUS_Archipelago[7]	1.194	0.07075	4.77E-04	1.054	1.105	1.194	1.284	1.335
BSTATUS_Archipelago[8]	1.146	0.06789	4.65E-04	1.012	1.06	1.145	1.232	1.28
BSTATUS_Archipelago[9]	1.075	0.06653	4.58E-04	0.9457	0.9908	1.074	1.159	1.208
BSTATUS_Archipelago[10]	1.095	0.0689	4.94E-04	0.9634	1.009	1.094	1.184	1.234
BSTATUS_Archipelago[11]	1.039	0.06851	4.90E-04	0.9085	0.9542	1.037	1.128	1.18
BSTATUS_Archipelago[12]	1.066	0.06698	4.80E-04	0.9362	0.9816	1.064	1.152	1.2
BSTATUS_Archipelago[13]	1.13	0.06848	4.76E-04	0.996	1.044	1.129	1.217	1.267
BSTATUS_Archipelago[14]	1.08	0.0653	4.75E-04	0.9533	0.9979	1.08	1.164	1.21
BSTATUS_Archipelago[15]	0.997	0.06681	4.97E-04	0.8775	0.9167	0.9923	1.084	1.145
BSTATUS_Archipelago[16]	1.032	0.06494	4.87E-04	0.9122	0.9526	1.029	1.115	1.171
BSTATUS_Archipelago[17]	0.9908	0.06738	4.97E-04	0.8715	0.911	0.9859	1.077	1.144
BSTATUS_Archipelago[18]	1.041	0.06898	5.07E-04	0.9179	0.9583	1.036	1.129	1.195
BSTATUS_Archipelago[19]	1.037	0.06974	5.00E-04	0.9134	0.9533	1.032	1.128	1.192
BSTATUS_Archipelago[20]	1.129	0.06871	4.58E-04	0.9972	1.043	1.127	1.217	1.268
BSTATUS_Hoomalu[1]	2.069	0.2038	0.001087	1.677	1.804	2.067	2.331	2.473
BSTATUS_Hoomalu[2]	2.048	0.1907	0.001157	1.685	1.806	2.045	2.292	2.432
BSTATUS_Hoomalu[3]	1.85	0.164	0.001143	1.529	1.645	1.849	2.057	2.179
BSTATUS_Hoomalu[4]	1.82	0.1644	0.001196	1.497	1.614	1.82	2.027	2.147
BSTATUS_Hoomalu[5]	1.759	0.1591	0.001148	1.443	1.557	1.759	1.959	2.072
BSTATUS_Hoomalu[6]	1.866	0.1691	0.001188	1.538	1.656	1.863	2.083	2.207
BSTATUS_Hoomalu[7]	1.706	0.1551	0.001104	1.4	1.511	1.706	1.902	2.015
BSTATUS_Hoomalu[8]	1.586	0.1483	0.001088	1.297	1.399	1.585	1.773	1.881
BSTATUS_Hoomalu[9]	1.536	0.1466	0.001088	1.252	1.352	1.534	1.722	1.831
BSTATUS_Hoomalu[10]	1.55	0.149	0.001152	1.263	1.363	1.548	1.739	1.849
BSTATUS_Hoomalu[11]	1.479	0.1492	0.001142	1.195	1.294	1.474	1.671	1.786
BSTATUS_Hoomalu[12]	1.485	0.1451	0.001109	1.206	1.304	1.482	1.671	1.779
BSTATUS_Hoomalu[13]	1.548	0.1463	0.001079	1.263	1.364	1.546	1.733	1.841
BSTATUS_Hoomalu[14]	1.434	0.1388	0.001084	1.165	1.26	1.431	1.611	1.713
BSTATUS_Hoomalu[15]	1.219	0.144	0.001121	0.9687	1.049	1.207	1.406	1.547
BSTATUS_Hoomalu[16]	1.305	0.1392	0.001126	1.05	1.137	1.298	1.483	1.609
BSTATUS_Hoomalu[17]	1.252	0.1466	0.001179	0.9969	1.081	1.239	1.437	1.595
BSTATUS_Hoomalu[18]	1.29	0.1477	0.001186	1.031	1.117	1.279	1.478	1.633
BSTATUS_Hoomalu[19]	1.317	0.1513	0.001171	1.051	1.138	1.304	1.511	1.662
BSTATUS_Hoomalu[20]	1.539	0.1497	0.001135	1.252	1.352	1.535	1.73	1.845
BSTATUS_MHI[1]	1.2	0.08271	7.87E-04	1.047	1.097	1.196	1.306	1.373
BSTATUS_MHI[2]	1.242	0.08904	8.65E-04	1.077	1.131	1.239	1.357	1.428
BSTATUS_MHI[3]	1.39	0.09963	9.70E-04	1.205	1.266	1.386	1.518	1.598
BSTATUS_MHI[4]	1.643	0.1187	0.001124	1.422	1.495	1.639	1.797	1.889
BSTATUS_MHI[5]	1.776	0.1282	0.001198	1.538	1.617	1.771	1.94	2.043
BSTATUS_MHI[6]	1.837	0.1302	0.001223	1.595	1.676	1.832	2.006	2.108
BSTATUS_MHI[7]	2.36	0.1733	0.001592	2.032	2.142	2.355	2.582	2.716
BSTATUS_MHI[8]	2.076	0.1462	0.001406	1.804	1.894	2.07	2.264	2.379
BSTATUS_MHI[9]	2.236	0.1644	0.001523	1.925	2.031	2.232	2.446	2.573
BSTATUS_MHI[10]	1.64	0.1178	0.001123	1.423	1.494	1.635	1.792	1.886
BSTATUS_MHI[11]	1.389	0.1009	9.63E-04	1.205	1.265	1.384	1.52	1.602
BSTATUS_MHI[12]	1.714	0.1222	0.001161	1.488	1.562	1.709	1.872	1.968
BSTATUS_MHI[13]	2.329	0.1682	0.001597	2.011	2.118	2.325	2.545	2.673
BSTATUS_MHI[14]	2.435	0.1773	0.001582	2.101	2.214	2.43	2.662	2.799
BSTATUS_MHI[15]	1.86	0.1327	0.001294	1.614	1.696	1.854	2.032	2.138
BSTATUS_MHI[16]	1.872	0.133	0.001286	1.624	1.707	1.866	2.044	2.149
BSTATUS_MHI[17]	2.215	0.1595	0.001493	1.916	2.015	2.21	2.42	2.544

Table A4.--continued.

Variable	Mean	Standard Deviation	MCMC Error	Percentile 2.5%	Percentile 10%	Median	Percentile 90%	Percentile 97.5%
BSTATUS_MHI[18]	2.155	0.1562	0.001455	1.862	1.959	2.15	2.355	2.477
BSTATUS_MHI[19]	1.831	0.1311	0.001236	1.589	1.669	1.826	1.999	2.105
BSTATUS_MHI[20]	1.733	0.1259	0.001168	1.496	1.577	1.728	1.895	1.993
BSTATUS_MHI[21]	1.474	0.1066	0.001033	1.277	1.342	1.47	1.611	1.698
BSTATUS_MHI[22]	1.359	0.09824	9.62E-04	1.177	1.237	1.355	1.485	1.563
BSTATUS_MHI[23]	1.333	0.09637	9.30E-04	1.155	1.213	1.329	1.457	1.533
BSTATUS_MHI[24]	1.448	0.1049	9.95E-04	1.253	1.317	1.444	1.583	1.666
BSTATUS_MHI[25]	1.363	0.09889	9.34E-04	1.181	1.241	1.36	1.491	1.569
BSTATUS_MHI[26]	1.378	0.09973	9.52E-04	1.194	1.255	1.374	1.507	1.586
BSTATUS_MHI[27]	1.283	0.09304	9.06E-04	1.112	1.168	1.279	1.404	1.477
BSTATUS_MHI[28]	1.38	0.1013	9.47E-04	1.19	1.254	1.377	1.511	1.59
BSTATUS_MHI[29]	1.101	0.07983	7.63E-04	0.9537	1.002	1.097	1.203	1.268
BSTATUS_MHI[30]	1.145	0.0825	7.96E-04	0.9931	1.043	1.142	1.252	1.317
BSTATUS_MHI[31]	1.17	0.08681	8.21E-04	1.008	1.062	1.168	1.282	1.35
BSTATUS_MHI[32]	0.8875	0.06413	6.27E-04	0.7692	0.8083	0.8845	0.9703	1.021
BSTATUS_MHI[33]	0.8664	0.06218	6.02E-04	0.7514	0.7891	0.8639	0.9468	0.9952
BSTATUS_MHI[34]	0.7918	0.05642	5.52E-04	0.6873	0.7223	0.7894	0.865	0.9103
BSTATUS_MHI[35]	0.7857	0.05545	5.41E-04	0.6832	0.7168	0.7834	0.8573	0.9013
BSTATUS_MHI[36]	0.7132	0.0502	4.88E-04	0.6209	0.6515	0.7107	0.778	0.819
BSTATUS_MHI[37]	0.7306	0.05107	4.91E-04	0.637	0.6676	0.7282	0.7966	0.8379
BSTATUS_MHI[38]	0.7705	0.05407	5.24E-04	0.6714	0.7035	0.768	0.8405	0.8843
BSTATUS_MHI[39]	0.8913	0.06182	5.91E-04	0.7774	0.815	0.8885	0.9709	1.022
BSTATUS_MHI[40]	1.021	0.07154	6.78E-04	0.8901	0.9327	1.019	1.114	1.171
BSTATUS_MHI[41]	0.9944	0.0677	6.38E-04	0.8694	0.9105	0.9918	1.082	1.135
BSTATUS_MHI[42]	0.8034	0.05673	5.52E-04	0.6988	0.7329	0.8009	0.8767	0.9219
BSTATUS_MHI[43]	0.7757	0.05684	5.54E-04	0.6694	0.7047	0.7738	0.8488	0.8934
BSTATUS_MHI[44]	0.648	0.04591	4.43E-04	0.5631	0.5911	0.646	0.7073	0.7443
BSTATUS_MHI[45]	0.6119	0.04412	4.40E-04	0.5305	0.5573	0.61	0.6686	0.7045
BSTATUS_MHI[46]	0.6411	0.04586	4.39E-04	0.5564	0.5842	0.6393	0.7005	0.7363
BSTATUS_MHI[47]	0.6574	0.04682	4.50E-04	0.5709	0.5993	0.6557	0.7176	0.7548
BSTATUS_MHI[48]	0.5757	0.04108	4.06E-04	0.5005	0.5249	0.5737	0.6288	0.6613
BSTATUS_MHI[49]	0.6053	0.04328	4.21E-04	0.5251	0.5515	0.6035	0.6611	0.6956
BSTATUS_MHI[50]	0.57	0.04053	4.00E-04	0.4954	0.5198	0.5681	0.6221	0.6548
BSTATUS_MHI[51]	0.5998	0.04318	4.24E-04	0.5195	0.5461	0.5983	0.6554	0.6897
BSTATUS_MHI[52]	0.6629	0.04732	4.71E-04	0.5745	0.6041	0.6612	0.7239	0.761
BSTATUS_MHI[53]	0.636	0.04586	4.46E-04	0.551	0.5791	0.6342	0.6946	0.7318
BSTATUS_MHI[54]	0.6106	0.04425	4.37E-04	0.5288	0.5557	0.6089	0.6676	0.7028
BSTATUS_MHI[55]	0.5904	0.04236	4.14E-04	0.5115	0.538	0.5888	0.6451	0.6786
BSTATUS_MHI[56]	0.5737	0.04129	4.10E-04	0.4975	0.5227	0.5719	0.6269	0.6603
BSTATUS_MHI[57]	0.6419	0.04623	4.46E-04	0.5556	0.5841	0.6402	0.7012	0.7382
BSTATUS_MHI[58]	0.6058	0.04382	4.23E-04	0.5243	0.5515	0.6041	0.6622	0.6969
BSTATUS_MHI[59]	0.6183	0.04548	4.26E-04	0.5338	0.5617	0.6164	0.677	0.713
BSTATUS_Mau[1]	1.586	0.1119	5.49E-04	1.333	1.454	1.591	1.714	1.798
BSTATUS_Mau[2]	1.821	0.2253	0.001664	1.54	1.619	1.772	2.064	2.5
BSTATUS_Mau[3]	1.735	0.1862	0.001228	1.463	1.55	1.706	1.945	2.246
BSTATUS_Mau[4]	1.54	0.137	7.65E-04	1.24	1.362	1.549	1.702	1.791
BSTATUS_Mau[5]	1.23	0.1384	9.80E-04	0.9139	1.042	1.245	1.391	1.466
BSTATUS_Mau[6]	1.29	0.1436	9.43E-04	0.9754	1.098	1.302	1.462	1.544
BSTATUS_Mau[7]	1.418	0.1383	8.36E-04	1.131	1.24	1.424	1.588	1.679
BSTATUS_Mau[8]	1.382	0.1328	8.17E-04	1.106	1.212	1.387	1.545	1.633
BSTATUS_Mau[9]	1.278	0.1229	7.56E-04	1.036	1.123	1.279	1.431	1.523
BSTATUS_Mau[10]	1.29	0.1575	0.00111	1.028	1.113	1.275	1.478	1.676
BSTATUS_Mau[11]	1.211	0.1469	0.001019	0.9442	1.034	1.203	1.392	1.535
BSTATUS_Mau[12]	1.292	0.1423	9.21E-04	1.013	1.112	1.292	1.471	1.574
BSTATUS_Mau[13]	1.368	0.1641	0.001161	1.016	1.149	1.378	1.567	1.664
BSTATUS_Mau[14]	1.459	0.1645	0.001127	1.097	1.241	1.472	1.656	1.751
BSTATUS_Mau[15]	1.62	0.149	9.20E-04	1.325	1.434	1.621	1.802	1.92
BSTATUS_Mau[16]	1.679	0.1563	9.62E-04	1.399	1.497	1.669	1.869	2.03
BSTATUS_Mau[17]	1.593	0.1509	9.14E-04	1.33	1.42	1.579	1.78	1.941
BSTATUS_Mau[18]	1.616	0.1727	0.001143	1.341	1.429	1.593	1.829	2.049

Table A4.--continued.

Variable	Mean	Standard Deviation	MCMC Error	Percentile 2.5%	Percentile 10%	Median	Percentile 90%	Percentile 97.5%
BSTATUS_Mau[19]	1.627	0.1606	9.91E-04	1.357	1.446	1.61	1.825	2.007
BSTATUS_Mau[20]	1.551	0.1375	6.63E-04	1.293	1.386	1.546	1.723	1.845
B_Hoomalu[1]	3152	367.9	5.46	2460	2689	3141	3628	3904
B_Hoomalu[2]	3121	350.4	5.464	2476	2682	3106	3576	3847
B_Hoomalu[3]	2819	305.5	4.906	2253	2439	2806	3215	3460
B_Hoomalu[4]	2773	301.8	4.771	2212	2398	2761	3165	3398
B_Hoomalu[5]	2680	294	4.696	2134	2313	2668	3060	3282
B_Hoomalu[6]	2844	308.9	4.751	2279	2461	2830	3245	3490
B_Hoomalu[7]	2599	283.7	4.454	2075	2246	2588	2966	3188
B_Hoomalu[8]	2416	269.1	4.158	1920	2082	2405	2765	2973
B_Hoomalu[9]	2340	263.1	4.023	1854	2013	2328	2681	2887
B_Hoomalu[10]	2361	264.3	3.97	1874	2032	2349	2704	2909
B_Hoomalu[11]	2253	261.6	3.82	1774	1928	2241	2592	2801
B_Hoomalu[12]	2263	256.8	3.803	1789	1943	2252	2597	2794
B_Hoomalu[13]	2358	261	3.895	1874	2032	2348	2695	2901
B_Hoomalu[14]	2184	245.1	3.609	1733	1879	2174	2502	2693
B_Hoomalu[15]	1858	243	3.258	1436	1565	1838	2176	2395
B_Hoomalu[16]	1988	237.2	3.259	1563	1697	1975	2295	2498
B_Hoomalu[17]	1906	245.9	3.259	1481	1613	1886	2226	2460
B_Hoomalu[18]	1965	248.4	3.307	1534	1668	1945	2289	2523
B_Hoomalu[19]	2006	256	3.447	1557	1698	1985	2341	2573
B_Hoomalu[20]	2344	262.3	3.804	1863	2017	2333	2685	2891
B_MHI[1]	1905	187.4	4.037	1565	1673	1895	2150	2302
B_MHI[2]	1973	198.1	4.238	1616	1728	1962	2232	2393
B_MHI[3]	2207	221.9	4.745	1807	1933	2194	2497	2677
B_MHI[4]	2610	261.8	5.542	2136	2288	2595	2952	3164
B_MHI[5]	2820	283	5.993	2312	2471	2803	3189	3419
B_MHI[6]	2918	293.6	6.289	2391	2556	2901	3302	3540
B_MHI[7]	3747	378.3	7.909	3063	3280	3728	4239	4546
B_MHI[8]	3297	331.8	7.147	2697	2887	3277	3731	4.00E+03
B_MHI[9]	3550	356.7	7.397	2903	3109	3533	4015	4304
B_MHI[10]	2605	263.3	5.617	2131	2281	2589	2949	3166
B_MHI[11]	2206	226	4.811	1802	1929	2193	2502	2690
B_MHI[12]	2722	273	5.834	2230	2385	2706	3077	3302
B_MHI[13]	3699	370.2	7.844	3027	3241	3680	4181	4483
B_MHI[14]	3867	387.5	8.081	3164	3390	3847	4369	4688
B_MHI[15]	2955	299.8	6.473	2415	2585	2937	3346	3587
B_MHI[16]	2973	299.3	6.416	2435	2603	2956	3362	3608
B_MHI[17]	3517	352.7	7.458	2880	3084	3497	3977	4264
B_MHI[18]	3422	344.9	7.272	2797	2995	3403	3872	4150
B_MHI[19]	2908	292.8	6.229	2380	2549	2891	3289	3530
B_MHI[20]	2752	276.5	5.827	2253	2411	2737	3113	3336
B_MHI[21]	2341	236.6	5.04	1916	2049	2328	2649	2843
B_MHI[22]	2158	217.3	4.657	1766	1890	2146	2440	2621
B_MHI[23]	2117	213.8	4.569	1733	1853	2105	2396	2569
B_MHI[24]	2299	230.3	4.82	1884	2015	2287	2599	2787
B_MHI[25]	2165	218.4	4.619	1771	1897	2152	2450	2629
B_MHI[26]	2189	219.4	4.651	1791	1918	2177	2475	2654
B_MHI[27]	2038	206.5	4.412	1668	1784	2026	2308	2477
B_MHI[28]	2192	220	4.574	1796	1921	2179	2479	2660
B_MHI[29]	1748	177.5	3.777	1430	1530	1737	1979	2126
B_MHI[30]	1819	182.5	3.874	1490	1593	1808	2057	2204
B_MHI[31]	1859	187.3	3.896	1520	1628	1849	2103	2255
B_MHI[32]	1409	142.9	3.047	1153	1234	1401	1596	1714
B_MHI[33]	1376	137.8	2.94	1128	1206	1368	1556	1668
B_MHI[34]	1257	125.9	2.709	1031	1103	1250	1421	1526
B_MHI[35]	1248	123.3	2.641	1025	1096	1240	1409	1510
B_MHI[36]	1133	112.4	2.417	930.5	994.2	1126	1279	1372
B_MHI[37]	1160	114.2	2.453	956	1020	1154	1308	1405
B_MHI[38]	1224	120.9	2.591	1007	1074	1217	1381	1481

Table A4.--continued.

Variable	Mean	Standard Deviation	MCMC Error	Percentile 2.5%	Percentile 10%	Median	Percentile 90%	Percentile 97.5%
B_MHI[39]	1415	138.2	2.966	1167	1244	1407	1596	1708
B_MHI[40]	1622	158.4	3.37	1337	1427	1612	1829	1959
B_MHI[41]	1579	150.3	3.199	1309	1394	1570	1775	1899
B_MHI[42]	1276	127.2	2.736	1047	1119	1268	1442	1547
B_MHI[43]	1232	124.4	2.627	1007	1078	1225	1394	1495
B_MHI[44]	1029	102.9	2.218	843.7	901.9	1023	1163	1248
B_MHI[45]	971.9	98.28	2.105	795.7	850.8	966.1	1100	1181
B_MHI[46]	1018	101.6	2.153	835.5	892.9	1012	1151	1234
B_MHI[47]	1044	103.5	2.203	857	916.8	1037	1179	1263
B_MHI[48]	914.3	92.08	1.975	748.7	801	909	1034	1110
B_MHI[49]	961.2	95.77	2.041	788.2	842.8	956	1086	1164
B_MHI[50]	905.2	90.78	1.953	742.1	794	899.9	1024	1098
B_MHI[51]	952.6	96.01	2.051	780.3	834.3	946.9	1077	1158
B_MHI[52]	1053	104.6	2.239	864	923.4	1047	1188	1275
B_MHI[53]	1010	101.6	2.156	826.3	884.9	1004	1143	1226
B_MHI[54]	969.7	97.82	2.081	794.1	849.6	963.9	1097	1178
B_MHI[55]	937.6	94.1	2.013	768.8	821.3	932.6	1061	1137
B_MHI[56]	911.1	91.84	1.971	745.1	798.1	905.8	1031	1107
B_MHI[57]	1019	101.8	2.161	836.5	893.5	1014	1152	1235
B_MHI[58]	962.1	97.09	2.061	787.8	842.7	956.5	1089	1168
B_MHI[59]	981.8	99.55	2.087	803.2	858.9	975.7	1112	1193
B_Mau[1]	697.5	69.33	1.345	560.3	612.1	697	784.5	836.3
B_Mau[2]	800.5	110.6	1.495	643.9	688.7	781.8	927.1	1102
B_Mau[3]	763.1	95.8	1.417	612.9	658.2	750.7	878.3	1.00E+03
B_Mau[4]	677.5	76.52	1.299	525.3	581	677.4	774.2	829
B_Mau[5]	541.3	74.93	1.238	388.2	444.6	543	635	686.5
B_Mau[6]	567.8	75.87	1.189	415.2	470	568.9	663.4	715
B_Mau[7]	623.8	73.77	1.159	481.5	530.8	623.1	717.6	772.5
B_Mau[8]	608	71.85	1.157	469.8	517.2	606.9	699.5	753.2
B_Mau[9]	562.4	68.24	1.141	436.3	477.2	559.8	650.2	704.1
B_Mau[10]	567.8	80.58	1.182	432.6	473.5	560.2	669.6	753.4
B_Mau[11]	532.8	76.2	1.144	397.8	440.2	528	630.5	698.5
B_Mau[12]	568.4	74.33	1.118	430.2	475.4	565.9	663.4	722.5
B_Mau[13]	601.5	82.64	1.17	433.8	494.9	602.9	704.9	761.2
B_Mau[14]	641.5	83.55	1.207	469.7	533.9	643.5	745.9	801.6
B_Mau[15]	712.4	79.6	1.25	563.5	614.4	709.3	813.6	878.2
B_Mau[16]	738.5	84.1	1.338	590.7	638.3	732.3	845.3	923.3
B_Mau[17]	700.6	83.24	1.388	556.8	601.5	693.9	807.7	886.1
B_Mau[18]	710.9	90.94	1.415	561.6	606.2	700.7	826.8	923.3
B_Mau[19]	715.6	86.48	1.387	568.7	614.1	707.5	826.4	911.3
B_Mau[20]	682.4	77.97	1.34	542.2	587.6	677.8	782.8	850.2
HMSP_Hoomalu	0.2885	0.02886	5.82E-04	0.233	0.2518	0.2883	0.3255	0.346
HMSP_MHI	0.2885	0.02886	5.82E-04	0.233	0.2518	0.2883	0.3255	0.346
HMSP_Mau	0.2885	0.02886	5.82E-04	0.233	0.2518	0.2883	0.3255	0.346
HSTATUS_Archipelago[1]	0.8925	0.0712	3.32E-04	0.7634	0.8048	0.8888	0.9849	1.043
HSTATUS_Archipelago[2]	1.051	0.08291	4.02E-04	0.9003	0.9484	1.046	1.159	1.226
HSTATUS_Archipelago[3]	0.9128	0.07296	3.60E-04	0.7795	0.8227	0.9087	1.008	1.067
HSTATUS_Archipelago[4]	0.8726	0.07061	3.73E-04	0.7459	0.7862	0.8681	0.9641	1.023
HSTATUS_Archipelago[5]	0.9284	0.07497	3.77E-04	0.7931	0.8361	0.9243	1.026	1.087
HSTATUS_Archipelago[6]	0.7366	0.06044	3.10E-04	0.6287	0.663	0.733	0.8154	0.866
HSTATUS_Archipelago[7]	0.8776	0.07241	4.01E-04	0.7495	0.7894	0.8727	0.972	1.033
HSTATUS_Archipelago[8]	0.9652	0.0793	4.42E-04	0.8237	0.8689	0.96	1.068	1.136
HSTATUS_Archipelago[9]	0.8515	0.07065	3.83E-04	0.7252	0.7653	0.8471	0.9432	1.003
HSTATUS_Archipelago[10]	0.8913	0.07527	4.24E-04	0.7576	0.7994	0.8863	0.9898	1.052
HSTATUS_Archipelago[11]	0.8825	0.07404	4.14E-04	0.7499	0.7925	0.8776	0.9792	1.041
HSTATUS_Archipelago[12]	0.7644	0.06572	3.98E-04	0.6481	0.6847	0.7597	0.8499	0.9062
HSTATUS_Archipelago[13]	0.8294	0.06946	3.79E-04	0.7055	0.7447	0.825	0.9197	0.9787
HSTATUS_Archipelago[14]	0.7358	0.06189	3.48E-04	0.6258	0.6604	0.7317	0.8165	0.8688
HSTATUS_Archipelago[15]	0.6513	0.0549	3.17E-04	0.5532	0.5843	0.6479	0.7229	0.7689
HSTATUS_Archipelago[16]	0.6918	0.05804	3.19E-04	0.5888	0.6211	0.688	0.7671	0.8165

Table A4.--continued.

Variable	Mean	Standard Deviation	MCMC Error	Percentile 2.5%	Percentile 10%	Median	Percentile 90%	Percentile 97.5%
HSTATUS_Archipelago[17]	0.6556	0.05513	3.07E-04	0.5568	0.5883	0.6522	0.7273	0.7733
HSTATUS_Archipelago[18]	0.702	0.05892	3.35E-04	0.5973	0.6302	0.6983	0.7784	0.8282
HSTATUS_Archipelago[19]	0.5797	0.04874	2.69E-04	0.4927	0.5202	0.5765	0.643	0.6838
HSTATUS_Archipelago[20]	0.6191	0.05354	2.73E-04	0.5233	0.5537	0.6156	0.6887	0.7339
HSTATUS_Hoomalu[1]	0.2185	0.02976	2.12E-04	0.1687	0.1829	0.2156	0.2579	0.284
HSTATUS_Hoomalu[2]	0.1154	0.01553	1.22E-04	0.08973	0.09709	0.1138	0.1355	0.1501
HSTATUS_Hoomalu[3]	0.1496	0.01964	1.69E-04	0.1177	0.1268	0.1473	0.1749	0.1942
HSTATUS_Hoomalu[4]	0.2618	0.03497	3.08E-04	0.205	0.2214	0.2578	0.3067	0.3419
HSTATUS_Hoomalu[5]	0.2587	0.03459	3.03E-04	0.2028	0.2189	0.2545	0.3035	0.3376
HSTATUS_Hoomalu[6]	0.2949	0.03987	3.41E-04	0.23	0.2488	0.2903	0.3466	0.3856
HSTATUS_Hoomalu[7]	0.3924	0.05289	4.58E-04	0.3065	0.3313	0.3863	0.4608	0.5126
HSTATUS_Hoomalu[8]	0.3689	0.05064	4.48E-04	0.2866	0.3102	0.3632	0.4343	0.484
HSTATUS_Hoomalu[9]	0.2626	0.03659	3.24E-04	0.2031	0.22	0.2585	0.31	0.3455
HSTATUS_Hoomalu[10]	0.2988	0.04195	3.79E-04	0.2303	0.2499	0.2942	0.3531	0.3938
HSTATUS_Hoomalu[11]	0.392	0.05587	5.03E-04	0.2996	0.3268	0.3861	0.4642	0.5176
HSTATUS_Hoomalu[12]	0.4927	0.06938	6.22E-04	0.379	0.4114	0.4852	0.5823	0.6497
HSTATUS_Hoomalu[13]	0.3757	0.05296	4.62E-04	0.2899	0.3144	0.3695	0.444	0.4965
HSTATUS_Hoomalu[14]	0.3668	0.05216	4.71E-04	0.2817	0.3063	0.3611	0.4341	0.4854
HSTATUS_Hoomalu[15]	0.2949	0.04501	4.04E-04	0.2158	0.2414	0.2913	0.3527	0.3931
HSTATUS_Hoomalu[16]	0.2571	0.03804	3.48E-04	0.1928	0.2127	0.2535	0.3063	0.342
HSTATUS_Hoomalu[17]	0.2658	0.0405	3.71E-04	0.1937	0.218	0.2625	0.3173	0.355
HSTATUS_Hoomalu[18]	0.3085	0.04666	4.27E-04	0.2264	0.2536	0.3045	0.368	0.4119
HSTATUS_Hoomalu[19]	0.2198	0.03323	3.00E-04	0.1614	0.1805	0.2172	0.2621	0.2932
HSTATUS_Hoomalu[20]	0.2541	0.0361	3.21E-04	0.1949	0.212	0.2501	0.3004	0.336
HSTATUS_MHI[1]	0.9454	0.07811	3.74E-04	0.803	0.8484	0.9417	1.047	1.109
HSTATUS_MHI[2]	0.7691	0.06514	3.20E-04	0.6507	0.6884	0.7661	0.8536	0.9067
HSTATUS_MHI[3]	0.6636	0.05618	2.71E-04	0.5611	0.5941	0.6606	0.7369	0.7812
HSTATUS_MHI[4]	0.5239	0.0445	2.15E-04	0.4434	0.4689	0.5215	0.5816	0.6177
HSTATUS_MHI[5]	0.4679	0.03955	1.90E-04	0.3956	0.4192	0.4659	0.5192	0.5513
HSTATUS_MHI[6]	0.4456	0.03729	1.73E-04	0.3778	0.3993	0.4437	0.4941	0.5244
HSTATUS_MHI[7]	0.2982	0.02553	1.22E-04	0.2525	0.2668	0.2966	0.3315	0.3529
HSTATUS_MHI[8]	0.4073	0.03376	1.62E-04	0.3462	0.3654	0.4057	0.4511	0.4786
HSTATUS_MHI[9]	0.4303	0.03704	1.74E-04	0.3636	0.3848	0.4281	0.4785	0.5096
HSTATUS_MHI[10]	0.4221	0.03565	1.67E-04	0.3569	0.3781	0.4204	0.4685	0.4971
HSTATUS_MHI[11]	0.4681	0.04012	1.97E-04	0.3946	0.4182	0.4662	0.5201	0.5524
HSTATUS_MHI[12]	0.293	0.02473	1.19E-04	0.2481	0.2623	0.2918	0.325	0.3451
HSTATUS_MHI[13]	0.1804	0.01527	7.41E-05	0.1531	0.1616	0.1796	0.2003	0.2129
HSTATUS_MHI[14]	0.2161	0.01841	8.46E-05	0.1831	0.1934	0.2151	0.2402	0.2553
HSTATUS_MHI[15]	0.3562	0.02993	1.46E-04	0.3013	0.3192	0.3547	0.3951	0.4191
HSTATUS_MHI[16]	0.3629	0.03047	1.45E-04	0.3073	0.3252	0.3614	0.4025	0.4271
HSTATUS_MHI[17]	0.3168	0.02681	1.27E-04	0.2686	0.2837	0.3154	0.3517	0.3739
HSTATUS_MHI[18]	0.2557	0.02177	1.03E-04	0.2164	0.2289	0.2546	0.2839	0.3022
HSTATUS_MHI[19]	0.3967	0.03345	1.60E-04	0.3357	0.3553	0.395	0.4402	0.4671
HSTATUS_MHI[20]	0.3487	0.02986	1.41E-04	0.2948	0.3118	0.3471	0.3877	0.4118
HSTATUS_MHI[21]	0.3963	0.03368	1.65E-04	0.3347	0.3548	0.3947	0.4397	0.4672
HSTATUS_MHI[22]	0.3798	0.0325	1.59E-04	0.3206	0.3396	0.3782	0.422	0.4482
HSTATUS_MHI[23]	0.3375	0.02887	1.41E-04	0.285	0.3019	0.3361	0.375	0.3985
HSTATUS_MHI[24]	0.4646	0.03972	1.91E-04	0.3925	0.4158	0.4625	0.5162	0.5492
HSTATUS_MHI[25]	0.3793	0.03249	1.52E-04	0.3203	0.3391	0.3775	0.4215	0.4479
HSTATUS_MHI[26]	0.5243	0.04482	2.20E-04	0.4427	0.4688	0.5221	0.5824	0.6191
HSTATUS_MHI[27]	0.5598	0.04789	2.37E-04	0.4725	0.5004	0.5574	0.6217	0.6613
HSTATUS_MHI[28]	0.5876	0.05049	2.38E-04	0.4961	0.5256	0.5848	0.6532	0.6944
HSTATUS_MHI[29]	0.7313	0.06262	3.03E-04	0.6166	0.6539	0.7281	0.8122	0.8626
HSTATUS_MHI[30]	0.8428	0.07164	3.43E-04	0.7127	0.7542	0.8393	0.9354	0.9937
HSTATUS_MHI[31]	0.7568	0.06505	3.07E-04	0.6395	0.6766	0.7532	0.8418	0.8937
HSTATUS_MHI[32]	0.8572	0.07292	3.62E-04	0.7242	0.7671	0.8535	0.9522	1.01
HSTATUS_MHI[33]	1.15	0.09668	4.71E-04	0.9747	1.031	1.146	1.276	1.353
HSTATUS_MHI[34]	1.298	0.1088	5.42E-04	1.099	1.164	1.293	1.439	1.529
HSTATUS_MHI[35]	1.63	0.1353	6.50E-04	1.384	1.463	1.623	1.807	1.916
HSTATUS_MHI[36]	1.724	0.1429	6.87E-04	1.461	1.547	1.717	1.909	2.024

Table A4.--continued.

Variable	Mean	Standard Deviation	MCMC Error	Percentile 2.5%	Percentile 10%	Median	Percentile 90%	Percentile 97.5%
HSTATUS_MHI[37]	1.875	0.1544	7.38E-04	1.592	1.684	1.867	2.076	2.2
HSTATUS_MHI[38]	1.784	0.1475	7.05E-04	1.513	1.601	1.777	1.974	2.095
HSTATUS_MHI[39]	1.801	0.1475	7.14E-04	1.53	1.619	1.794	1.991	2.113
HSTATUS_MHI[40]	1.741	0.1428	6.76E-04	1.479	1.564	1.734	1.926	2.042
HSTATUS_MHI[41]	2.145	0.1721	8.24E-04	1.831	1.932	2.136	2.368	2.506
HSTATUS_MHI[42]	1.781	0.1462	7.22E-04	1.513	1.6	1.774	1.971	2.089
HSTATUS_MHI[43]	1.418	0.1197	5.98E-04	1.2	1.27	1.412	1.573	1.671
HSTATUS_MHI[44]	1.683	0.1399	6.70E-04	1.426	1.509	1.677	1.864	1.975
HSTATUS_MHI[45]	1.259	0.1056	5.24E-04	1.066	1.129	1.254	1.397	1.48
HSTATUS_MHI[46]	1.405	0.1174	5.67E-04	1.191	1.26	1.399	1.557	1.652
HSTATUS_MHI[47]	1.543	0.128	6.18E-04	1.31	1.384	1.537	1.709	1.814
HSTATUS_MHI[48]	1.415	0.1184	5.85E-04	1.197	1.269	1.409	1.568	1.664
HSTATUS_MHI[49]	1.452	0.121	5.91E-04	1.232	1.303	1.447	1.609	1.707
HSTATUS_MHI[50]	1.48	0.1234	6.06E-04	1.254	1.327	1.474	1.64	1.738
HSTATUS_MHI[51]	1.155	0.09694	4.81E-04	0.9784	1.036	1.151	1.281	1.36
HSTATUS_MHI[52]	1.4	0.1168	5.87E-04	1.186	1.255	1.394	1.551	1.646
HSTATUS_MHI[53]	1.212	0.1017	5.01E-04	1.027	1.087	1.207	1.344	1.426
HSTATUS_MHI[54]	1.069	0.09	4.47E-04	0.9051	0.9577	1.064	1.186	1.26
HSTATUS_MHI[55]	1.134	0.09542	4.64E-04	0.9595	1.016	1.129	1.258	1.336
HSTATUS_MHI[56]	1.078	0.09104	4.51E-04	0.9107	0.9647	1.074	1.196	1.269
HSTATUS_MHI[57]	1.161	0.0974	4.76E-04	0.9843	1.041	1.157	1.288	1.367
HSTATUS_MHI[58]	0.9441	0.08001	3.86E-04	0.798	0.8452	0.9402	1.048	1.113
HSTATUS_MHI[59]	1.108	0.09783	4.61E-04	0.9305	0.9873	1.103	1.235	1.316
HSTATUS_Mau[1]	0.166	0.01789	1.22E-04	0.1364	0.1454	0.1642	0.1886	0.2064
HSTATUS_Mau[2]	0.343	0.04773	3.72E-04	0.2376	0.2846	0.3437	0.401	0.4365
HSTATUS_Mau[3]	0.4221	0.05694	4.25E-04	0.308	0.3534	0.4204	0.4933	0.5405
HSTATUS_Mau[4]	1.02	0.1336	9.61E-04	0.8059	0.8674	1.004	1.193	1.326
HSTATUS_Mau[5]	0.5249	0.08184	6.12E-04	0.4015	0.4341	0.5122	0.6317	0.7181
HSTATUS_Mau[6]	0.3807	0.05934	4.44E-04	0.2887	0.3136	0.3723	0.4581	0.5193
HSTATUS_Mau[7]	0.6538	0.09399	7.16E-04	0.5019	0.5447	0.6428	0.7771	0.8673
HSTATUS_Mau[8]	0.9453	0.134	0.001024	0.7273	0.7894	0.9296	1.121	1.249
HSTATUS_Mau[9]	0.857	0.1232	9.45E-04	0.6554	0.7129	0.843	1.018	1.135
HSTATUS_Mau[10]	0.9191	0.1489	0.001172	0.6577	0.7428	0.9063	1.112	1.248
HSTATUS_Mau[11]	0.426	0.07228	5.69E-04	0.3081	0.342	0.4178	0.5201	0.5921
HSTATUS_Mau[12]	0.2946	0.04821	3.78E-04	0.2183	0.2394	0.2883	0.3579	0.4063
HSTATUS_Mau[13]	0.3437	0.05876	4.64E-04	0.2536	0.2773	0.3351	0.4217	0.4811
HSTATUS_Mau[14]	0.2951	0.04812	3.77E-04	0.2216	0.2408	0.288	0.3582	0.4079
HSTATUS_Mau[15]	0.3791	0.05407	4.29E-04	0.2926	0.3173	0.3724	0.4497	0.5044
HSTATUS_Mau[16]	0.6014	0.08305	6.46E-04	0.4609	0.5051	0.5928	0.7084	0.7893
HSTATUS_Mau[17]	0.4821	0.06638	5.01E-04	0.3678	0.4048	0.476	0.5668	0.6314
HSTATUS_Mau[18]	0.4078	0.05875	4.47E-04	0.3012	0.3379	0.4037	0.4822	0.5368
HSTATUS_Mau[19]	0.5109	0.07145	5.35E-04	0.3861	0.4266	0.5049	0.6022	0.669
HSTATUS_Mau[20]	0.1188	0.01604	1.12E-04	0.09231	0.1002	0.1171	0.1395	0.1551
H_Hoomalu[1]	0.06259	0.007446	1.10E-04	0.04986	0.05364	0.06195	0.07239	0.07912
H_Hoomalu[2]	0.03304	0.003752	5.81E-05	0.02647	0.02847	0.03278	0.03796	0.04112
H_Hoomalu[3]	0.04284	0.004694	7.49E-05	0.03449	0.03713	0.04253	0.04893	0.05298
H_Hoomalu[4]	0.07496	0.008264	1.30E-04	0.06046	0.06491	0.0744	0.08566	0.09288
H_Hoomalu[5]	0.07409	0.008247	1.30E-04	0.05976	0.06411	0.07351	0.08479	0.09193
H_Hoomalu[6]	0.08443	0.009249	1.41E-04	0.06798	0.07311	0.08384	0.0964	0.1041
H_Hoomalu[7]	0.1123	0.01242	1.94E-04	0.09051	0.09729	0.1115	0.1284	0.1391
H_Hoomalu[8]	0.1056	0.01191	1.83E-04	0.08478	0.09113	0.1048	0.1211	0.1313
H_Hoomalu[9]	0.07515	0.008563	1.30E-04	0.06014	0.06475	0.07457	0.08626	0.09363
H_Hoomalu[10]	0.0855	0.009692	1.45E-04	0.06853	0.07372	0.08485	0.09808	0.1064
H_Hoomalu[11]	0.1122	0.01317	1.92E-04	0.08902	0.0962	0.1113	0.1293	0.1406
H_Hoomalu[12]	0.141	0.01619	2.39E-04	0.1127	0.1213	0.1399	0.1621	0.176
H_Hoomalu[13]	0.1075	0.01204	1.78E-04	0.08628	0.09287	0.1066	0.1232	0.1336
H_Hoomalu[14]	0.1049	0.01193	1.75E-04	0.08401	0.09044	0.1041	0.1204	0.1306
H_Hoomalu[15]	0.08441	0.01095	1.49E-04	0.06438	0.07086	0.0839	0.09855	0.1074
H_Hoomalu[16]	0.07356	0.008794	1.22E-04	0.05773	0.06282	0.07301	0.08497	0.09224
H_Hoomalu[17]	0.07604	0.009677	1.31E-04	0.05797	0.06407	0.0756	0.08842	0.09628

Table A4.--continued.

Variable	Mean	Standard Deviation	MCMC Error	Percentile 2.5%	Percentile 10%	Median	Percentile 90%	Percentile 97.5%
H_Hoomalu[18]	0.08826	0.01103	1.50E-04	0.0677	0.07462	0.08778	0.1024	0.1113
H_Hoomalu[19]	0.06291	0.007974	1.09E-04	0.04826	0.05305	0.06254	0.07313	0.07972
H_Hoomalu[20]	0.07269	0.008234	1.19E-04	0.0582	0.06266	0.07211	0.08339	0.09032
H_MHI[1]	0.2718	0.02666	5.73E-04	0.2228	0.2385	0.2706	0.3065	0.3278
H_MHI[2]	0.2211	0.02212	4.71E-04	0.1805	0.1935	0.2201	0.2499	0.2672
H_MHI[3]	0.1908	0.01911	4.07E-04	0.1557	0.167	0.19	0.2156	0.2306
H_MHI[4]	0.1506	0.01507	3.17E-04	0.123	0.1318	0.15	0.1701	0.1822
H_MHI[5]	0.1345	0.01344	2.83E-04	0.1098	0.1177	0.134	0.152	0.1624
H_MHI[6]	0.1281	0.01283	2.74E-04	0.1045	0.1121	0.1276	0.1448	0.1548
H_MHI[7]	0.08573	0.00865	1.80E-04	0.06996	0.07501	0.0853	0.09695	0.1038
H_MHI[8]	0.1171	0.01175	2.52E-04	0.09556	0.1024	0.1166	0.1324	0.1417
H_MHI[9]	0.1237	0.01242	2.56E-04	0.101	0.1083	0.123	0.1398	0.1498
H_MHI[10]	0.1213	0.01221	2.60E-04	0.09882	0.1061	0.1208	0.1372	0.1468
H_MHI[11]	0.1346	0.0137	2.91E-04	0.1092	0.1174	0.134	0.1523	0.1631
H_MHI[12]	0.08422	0.008409	1.79E-04	0.06872	0.07376	0.08388	0.09514	0.1018
H_MHI[13]	0.05187	0.005186	1.09E-04	0.04237	0.04543	0.05162	0.05861	0.06276
H_MHI[14]	0.06212	0.006217	1.29E-04	0.05073	0.05443	0.06182	0.07016	0.07515
H_MHI[15]	0.1024	0.01034	2.22E-04	0.08349	0.08951	0.102	0.1158	0.124
H_MHI[16]	0.1043	0.01046	2.23E-04	0.08509	0.09131	0.1039	0.118	0.1261
H_MHI[17]	0.09107	0.009112	1.91E-04	0.07438	0.07974	0.09069	0.1028	0.1101
H_MHI[18]	0.07352	0.007395	1.55E-04	0.06001	0.06432	0.07319	0.08316	0.08904
H_MHI[19]	0.114	0.01144	2.42E-04	0.09302	0.09983	0.1136	0.1288	0.138
H_MHI[20]	0.1002	0.01005	2.11E-04	0.08187	0.08774	0.09979	0.1133	0.1212
H_MHI[21]	0.1139	0.01146	2.43E-04	0.09285	0.09965	0.1134	0.1289	0.1378
H_MHI[22]	0.1092	0.01095	2.34E-04	0.089	0.09559	0.1087	0.1234	0.1321
H_MHI[23]	0.09703	0.009768	2.08E-04	0.07914	0.08486	0.09661	0.1097	0.1173
H_MHI[24]	0.1335	0.01332	2.78E-04	0.1091	0.117	0.1329	0.1509	0.1614
H_MHI[25]	0.109	0.01095	2.31E-04	0.08887	0.09538	0.1086	0.1232	0.1319
H_MHI[26]	0.1507	0.01506	3.18E-04	0.1231	0.1319	0.1501	0.1703	0.1823
H_MHI[27]	0.1609	0.01622	3.46E-04	0.1311	0.1407	0.1603	0.182	0.1947
H_MHI[28]	0.1689	0.01689	3.49E-04	0.1378	0.1479	0.1682	0.1908	0.2041
H_MHI[29]	0.2102	0.02123	4.51E-04	0.1711	0.1838	0.2093	0.2378	0.2544
H_MHI[30]	0.2423	0.0242	5.12E-04	0.1979	0.212	0.2413	0.2737	0.2928
H_MHI[31]	0.2175	0.0219	4.52E-04	0.1775	0.1903	0.2165	0.2459	0.2633
H_MHI[32]	0.2464	0.02488	5.29E-04	0.2006	0.2154	0.2455	0.2787	0.2983
H_MHI[33]	0.3307	0.03296	7.01E-04	0.2701	0.2896	0.3292	0.3734	0.3992
H_MHI[34]	0.3732	0.03719	7.98E-04	0.3044	0.327	0.3716	0.4214	0.4506
H_MHI[35]	0.4687	0.0461	9.84E-04	0.3836	0.4111	0.4669	0.5285	0.5649
H_MHI[36]	0.4956	0.04889	0.001049	0.4051	0.4345	0.4937	0.5592	0.5975
H_MHI[37]	0.539	0.05269	0.001129	0.441	0.4735	0.537	0.6074	0.648
H_MHI[38]	0.5127	0.05037	0.001077	0.4194	0.4498	0.5106	0.5783	0.6172
H_MHI[39]	0.5176	0.05027	0.001076	0.4248	0.4547	0.5157	0.5831	0.6218
H_MHI[40]	0.5004	0.0486	0.001031	0.4105	0.4397	0.4987	0.5633	0.6015
H_MHI[41]	0.6166	0.05833	0.001239	0.5082	0.5435	0.6146	0.6921	0.7369
H_MHI[42]	0.5122	0.05078	0.001088	0.4182	0.4486	0.5102	0.5781	0.618
H_MHI[43]	0.4076	0.04108	8.62E-04	0.3325	0.3566	0.4057	0.461	0.4936
H_MHI[44]	0.4838	0.04813	0.001035	0.3951	0.4238	0.4817	0.5466	0.5843
H_MHI[45]	0.3621	0.03643	7.77E-04	0.295	0.3167	0.3606	0.4094	0.4378
H_MHI[46]	0.404	0.04014	8.47E-04	0.33	0.354	0.4023	0.4562	0.4875
H_MHI[47]	0.4436	0.04378	9.28E-04	0.363	0.3889	0.442	0.5002	0.5351
H_MHI[48]	0.4069	0.04076	8.71E-04	0.3318	0.3561	0.4051	0.4597	0.4919
H_MHI[49]	0.4175	0.04145	8.80E-04	0.3414	0.366	0.4157	0.4715	0.5042
H_MHI[50]	0.4254	0.04245	9.11E-04	0.3474	0.3725	0.4237	0.4802	0.5138
H_MHI[51]	0.3322	0.03333	7.09E-04	0.2706	0.2908	0.3309	0.3755	0.4015
H_MHI[52]	0.4023	0.03986	8.49E-04	0.329	0.353	0.4006	0.4542	0.4854
H_MHI[53]	0.3485	0.03494	7.38E-04	0.2844	0.305	0.347	0.3939	0.4218
H_MHI[54]	0.3073	0.03086	6.54E-04	0.2504	0.2689	0.306	0.3472	0.3715
H_MHI[55]	0.326	0.03259	6.94E-04	0.2662	0.2853	0.3245	0.3685	0.3936
H_MHI[56]	0.3099	0.0311	6.65E-04	0.2524	0.2712	0.3085	0.3502	0.3751
H_MHI[57]	0.3338	0.03325	7.02E-04	0.2728	0.2925	0.3324	0.3771	0.4028

Table A4.--continued.

Variable	Mean	Standard Deviation	MCMC Error	Percentile 2.5%	Percentile 10%	Median	Percentile 90%	Percentile 97.5%
H_MHI[58]	0.2714	0.02729	5.77E-04	0.2213	0.2374	0.2703	0.3067	0.3281
H_MHI[59]	0.3185	0.03213	6.71E-04	0.2595	0.2783	0.3172	0.3604	0.3854
H_Mau[1]	0.04764	0.004928	9.26E-05	0.03934	0.04194	0.0472	0.05374	0.05871
H_Mau[2]	0.09824	0.01194	1.77E-04	0.07018	0.08344	0.09894	0.1123	0.1201
H_Mau[3]	0.1209	0.01409	2.21E-04	0.0909	0.1035	0.1211	0.1382	0.1484
H_Mau[4]	0.2924	0.03454	5.66E-04	0.2359	0.2526	0.2886	0.3366	0.3722
H_Mau[5]	0.1505	0.02256	3.52E-04	0.1163	0.1257	0.147	0.1796	0.2057
H_Mau[6]	0.1091	0.01557	2.32E-04	0.08501	0.09162	0.1068	0.1293	0.1464
H_Mau[7]	0.1872	0.02294	3.50E-04	0.149	0.1604	0.1847	0.2169	0.239
H_Mau[8]	0.2707	0.03311	5.19E-04	0.2154	0.2319	0.2673	0.3137	0.3454
H_Mau[9]	0.2454	0.03031	4.99E-04	0.1931	0.2091	0.2429	0.2849	0.3116
H_Mau[10]	0.2629	0.03619	5.46E-04	0.1944	0.2187	0.2614	0.3092	0.3385
H_Mau[11]	0.1218	0.01748	2.64E-04	0.09107	0.1009	0.1205	0.1445	0.1599
H_Mau[12]	0.08423	0.01131	1.67E-04	0.06512	0.07092	0.08313	0.09896	0.1094
H_Mau[13]	0.09832	0.01457	1.97E-04	0.07615	0.08223	0.09614	0.1171	0.1336
H_Mau[14]	0.08443	0.01186	1.63E-04	0.06636	0.07131	0.08267	0.09964	0.1132
H_Mau[15]	0.1085	0.01229	1.90E-04	0.08689	0.09378	0.1076	0.1242	0.1354
H_Mau[16]	0.1721	0.0193	3.10E-04	0.136	0.1485	0.1714	0.1966	0.2125
H_Mau[17]	0.1381	0.01607	2.72E-04	0.1077	0.1181	0.1375	0.1586	0.1714
H_Mau[18]	0.1168	0.0143	2.31E-04	0.08854	0.09886	0.1167	0.1348	0.1456
H_Mau[19]	0.1463	0.01717	2.82E-04	0.1133	0.1249	0.1459	0.1681	0.1815
H_Mau[20]	0.03404	0.003881	6.68E-05	0.02697	0.02929	0.03383	0.03902	0.04229
K_Archipelago	7104	484.8	13.1	6186	6490	7090	7734	8081
K_Hoomalu	3049	208.1	5.621	2655	2785	3043	3319	3468
K_MHI	3176	216.7	5.855	2765	2901	3170	3457	3613
K_Mau	879.7	60.03	1.622	766	803.6	878	957.7	1001
MSP_Hoomalu	437.8	32.03	0.2463	373.4	396.6	438.3	478.1	499.4
MSP_MHI	456	33.37	0.2565	388.9	413.1	456.6	498.1	520.2
MSP_Mau	126.3	9.243	0.07106	107.7	114.4	126.5	138	144.1
RESID_Hoomalu[1]	0.1255	0.1031	5.85E-04	-0.03012	0.01193	0.1076	0.266	0.3823
RESID_Hoomalu[2]	0.06573	0.08431	4.39E-04	-0.06968	-0.02821	0.0541	0.1755	0.2721
RESID_Hoomalu[3]	-0.01292	0.06334	2.52E-04	-0.1374	-0.09168	-0.01345	0.06599	0.1159
RESID_Hoomalu[4]	-0.002422	0.06195	2.32E-04	-0.1251	-0.07998	-0.002405	0.0751	0.1214
RESID_Hoomalu[5]	-0.01688	0.061	2.11E-04	-0.1387	-0.09346	-0.01661	0.05909	0.1041
RESID_Hoomalu[6]	0.04716	0.06783	2.76E-04	-0.07667	-0.03417	0.04297	0.135	0.1937
RESID_Hoomalu[7]	-0.002189	0.06132	2.06E-04	-0.1226	-0.07829	-0.002829	0.07481	0.1215
RESID_Hoomalu[8]	-0.00653	0.06066	1.96E-04	-0.1281	-0.08226	-0.006553	0.06899	0.1137
RESID_Hoomalu[9]	-0.00743	0.06073	1.91E-04	-0.1295	-0.08394	-0.006713	0.06803	0.1115
RESID_Hoomalu[10]	0.002742	0.06039	1.98E-04	-0.1191	-0.07329	0.003228	0.07793	0.1215
RESID_Hoomalu[11]	-0.03534	0.06281	2.15E-04	-0.1665	-0.116	-0.03269	0.04132	0.08239
RESID_Hoomalu[12]	-0.02688	0.06053	1.89E-04	-0.1503	-0.1043	-0.0252	0.04801	0.08906
RESID_Hoomalu[13]	0.04998	0.06521	2.37E-04	-0.07166	-0.02969	0.04698	0.1342	0.1868
RESID_Hoomalu[14]	0.0253	0.06152	2.01E-04	-0.09545	-0.05063	0.0243	0.103	0.1488
RESID_Hoomalu[15]	-0.08691	0.07524	3.44E-04	-0.2574	-0.1866	-0.07912	0.001159	0.04051
RESID_Hoomalu[16]	0.01316	0.06527	2.76E-04	-0.1268	-0.06844	0.01547	0.09198	0.1352
RESID_Hoomalu[17]	-0.05186	0.07344	3.58E-04	-0.225	-0.1457	-0.04438	0.03261	0.07239
RESID_Hoomalu[18]	-0.0294	0.0714	3.30E-04	-0.196	-0.1203	-0.02266	0.05296	0.09333
RESID_Hoomalu[19]	-0.06251	0.07294	3.20E-04	-0.2296	-0.1579	-0.05505	0.02231	0.06209
RESID_Hoomalu[20]	0.01184	0.06438	2.21E-04	-0.1178	-0.06829	0.01173	0.0923	0.1391
RESID_MHI[1]	-0.008822	0.0478	1.47E-04	-0.1054	-0.06922	-0.00832	0.05097	0.08401
RESID_MHI[2]	-0.003239	0.04785	1.49E-04	-0.09875	-0.06405	-0.00297	0.0568	0.09084
RESID_MHI[3]	-0.003486	0.04805	1.65E-04	-0.09958	-0.06416	-0.003331	0.05688	0.09077
RESID_MHI[4]	0.01141	0.0487	1.60E-04	-0.08322	-0.04927	0.01078	0.07295	0.1091
RESID_MHI[5]	0.007518	0.04875	1.52E-04	-0.08829	-0.05343	0.007106	0.06881	0.1051
RESID_MHI[6]	-0.009536	0.04821	1.55E-04	-0.1063	-0.07027	-0.009157	0.05067	0.0852
RESID_MHI[7]	0.03768	0.05171	1.69E-04	-0.05855	-0.02543	0.03537	0.1039	0.1466
RESID_MHI[8]	-0.001677	0.04873	1.68E-04	-0.09812	-0.06296	-0.001749	0.05985	0.09477
RESID_MHI[9]	0.03119	0.05141	1.72E-04	-0.06515	-0.03193	0.02919	0.0968	0.1392
RESID_MHI[10]	-8.59E-04	0.049	1.59E-04	-0.09871	-0.06194	-8.46E-04	0.06052	0.09664
RESID_MHI[11]	-0.03288	0.05002	1.70E-04	-0.1372	-0.0966	-0.03107	0.02833	0.06042

Table A4.--continued.

Variable	Mean	Standard Deviation	MCMC Error	Percentile 2.5%	Percentile 10%	Median	Percentile 90%	Percentile 97.5%
RESID_MHI[12]	-0.00175	0.04834	1.58E-04	-0.09828	-0.06246	-0.001555	0.05881	0.09378
RESID_MHI[13]	0.03021	0.05042	1.68E-04	-0.0647	-0.03205	0.02841	0.0943	0.1354
RESID_MHI[14]	0.02631	0.0514	1.73E-04	-0.07001	-0.03666	0.02433	0.09197	0.134
RESID_MHI[15]	-0.0118	0.04941	1.74E-04	-0.1125	-0.07417	-0.01105	0.04966	0.08445
RESID_MHI[16]	-0.006451	0.04847	1.61E-04	-0.1043	-0.06726	-0.006113	0.05434	0.08783
RESID_MHI[17]	0.02265	0.04984	1.64E-04	-0.07192	-0.03905	0.02129	0.08602	0.1249
RESID_MHI[18]	0.0184	0.05026	1.54E-04	-0.07784	-0.04403	0.01716	0.08198	0.1216
RESID_MHI[19]	-0.005027	0.0489	1.55E-04	-0.1028	-0.06626	-0.004719	0.0561	0.09128
RESID_MHI[20]	0.01117	0.04939	1.54E-04	-0.08519	-0.05048	0.0107	0.07349	0.111
RESID_MHI[21]	-0.006907	0.04861	1.55E-04	-0.105	-0.06815	-0.006464	0.05371	0.08823
RESID_MHI[22]	-0.006557	0.04864	1.52E-04	-0.1038	-0.06799	-0.006058	0.05403	0.08854
RESID_MHI[23]	-0.01015	0.04868	1.48E-04	-0.1078	-0.07152	-0.009696	0.05075	0.08469
RESID_MHI[24]	0.006027	0.04868	1.61E-04	-0.08985	-0.05482	0.005796	0.06722	0.103
RESID_MHI[25]	-0.004995	0.04863	1.52E-04	-0.103	-0.06598	-0.00455	0.05567	0.09047
RESID_MHI[26]	0.001148	0.04866	1.61E-04	-0.09594	-0.05992	0.001382	0.06221	0.09682
RESID_MHI[27]	-0.01438	0.04861	1.56E-04	-0.1127	-0.07606	-0.01364	0.04617	0.07957
RESID_MHI[28]	0.02414	0.04934	1.60E-04	-0.07071	-0.03715	0.02318	0.08674	0.1254
RESID_MHI[29]	-0.02716	0.04887	1.49E-04	-0.1269	-0.08944	-0.02566	0.03315	0.06583
RESID_MHI[30]	-0.002888	0.04796	1.52E-04	-0.09887	-0.06331	-0.002682	0.05723	0.09108
RESID_MHI[31]	0.03279	0.05004	1.69E-04	-0.06171	-0.02858	0.03105	0.09666	0.1366
RESID_MHI[32]	-0.02367	0.04825	1.57E-04	-0.1226	-0.08486	-0.02263	0.03613	0.06829
RESID_MHI[33]	-0.00124	0.04732	1.49E-04	-0.0959	-0.06097	-8.44E-04	0.05812	0.0917
RESID_MHI[34]	-0.0127	0.04694	1.43E-04	-0.1081	-0.07214	-0.0118	0.0458	0.0778
RESID_MHI[35]	-0.003829	0.04633	1.51E-04	-0.09724	-0.06275	-0.003266	0.05412	0.08657
RESID_MHI[36]	-0.02213	0.04677	1.45E-04	-0.1185	-0.08154	-0.02083	0.03603	0.0665
RESID_MHI[37]	-0.02254	0.04641	1.43E-04	-0.1183	-0.08188	-0.02116	0.03496	0.06522
RESID_MHI[38]	-0.02275	0.04647	1.41E-04	-0.1192	-0.08236	-0.02115	0.03469	0.06459
RESID_MHI[39]	-0.01871	0.04566	1.51E-04	-0.1122	-0.07683	-0.01768	0.03804	0.06822
RESID_MHI[40]	0.008278	0.04579	1.56E-04	-0.08216	-0.04941	0.008317	0.06614	0.09882
RESID_MHI[41]	-0.006765	0.04461	1.79E-04	-0.09607	-0.06332	-0.00647	0.04938	0.08065
RESID_MHI[42]	-0.001821	0.04572	1.44E-04	-0.09258	-0.05964	-0.001673	0.05581	0.08826
RESID_MHI[43]	0.03406	0.04818	1.66E-04	-0.05725	-0.0258	0.03263	0.0958	0.1336
RESID_MHI[44]	-0.02045	0.0463	1.48E-04	-0.1148	-0.07925	-0.01966	0.03741	0.06853
RESID_MHI[45]	0.002771	0.04691	1.43E-04	-0.09075	-0.05629	0.002842	0.06173	0.09499
RESID_MHI[46]	-0.004063	0.04663	1.49E-04	-0.09744	-0.0629	-0.003822	0.05449	0.08731
RESID_MHI[47]	0.01484	0.0466	1.50E-04	-0.07617	-0.04342	0.0143	0.07399	0.1086
RESID_MHI[48]	-0.0153	0.04666	1.52E-04	-0.1093	-0.07446	-0.01457	0.0432	0.07536
RESID_MHI[49]	0.01111	0.04664	1.54E-04	-0.08097	-0.04738	0.01109	0.06998	0.1042
RESID_MHI[50]	-0.01471	0.0465	1.52E-04	-0.1094	-0.07392	-0.01387	0.04338	0.07493
RESID_MHI[51]	0.003345	0.04682	1.49E-04	-0.08933	-0.0554	0.003383	0.06213	0.09613
RESID_MHI[52]	0.007217	0.04667	1.56E-04	-0.08436	-0.05133	0.006924	0.06614	0.1007
RESID_MHI[53]	0.00863	0.04717	1.59E-04	-0.08312	-0.05034	0.008057	0.06851	0.1032
RESID_MHI[54]	0.006319	0.04728	1.62E-04	-0.08665	-0.05312	0.00586	0.06594	0.1016
RESID_MHI[55]	-4.71E-04	0.04709	1.57E-04	-0.09415	-0.0595	-3.37E-04	0.05866	0.09282
RESID_MHI[56]	-0.01434	0.04737	1.56E-04	-0.1106	-0.07416	-0.01367	0.04465	0.07735
RESID_MHI[57]	0.01662	0.04726	1.48E-04	-0.07507	-0.04245	0.01602	0.07636	0.112
RESID_MHI[58]	-1.43E-04	0.04733	1.49E-04	-0.09456	-0.05965	-4.14E-05	0.05929	0.09363
RESID_MHI[59]	-0.01241	0.05051	1.57E-04	-0.1151	-0.07598	-0.01164	0.05013	0.08597
RESID_Mau[1]	-0.2306	0.09181	5.11E-04	-0.4097	-0.3451	-0.2321	-0.114	-0.04124
RESID_Mau[2]	0.3785	0.1174	8.06E-04	0.07386	0.2273	0.3943	0.5088	0.5665
RESID_Mau[3]	0.2583	0.1021	6.13E-04	0.01777	0.1253	0.2677	0.3778	0.4357
RESID_Mau[4]	-0.1664	0.08995	4.53E-04	-0.3342	-0.2774	-0.1702	-0.04913	0.02288
RESID_Mau[5]	-0.2702	0.1113	7.46E-04	-0.4587	-0.3989	-0.2827	-0.1195	-0.006903
RESID_Mau[6]	-0.2078	0.1051	6.12E-04	-0.3911	-0.3325	-0.2177	-0.06496	0.02874
RESID_Mau[7]	-0.02493	0.08652	3.63E-04	-0.1902	-0.1323	-0.0268	0.08531	0.1533
RESID_Mau[8]	-0.1421	0.08541	3.77E-04	-0.3032	-0.2481	-0.145	-0.03133	0.03532
RESID_Mau[9]	-0.09026	0.08059	3.11E-04	-0.2498	-0.192	-0.09027	0.01201	0.0681
RESID_Mau[10]	0.2668	0.09958	5.76E-04	0.03356	0.1387	0.2752	0.3844	0.4424
RESID_Mau[11]	0.1666	0.09763	5.33E-04	-0.03676	0.0392	0.1703	0.2869	0.3516
RESID_Mau[12]	0.02332	0.08736	3.51E-04	-0.1477	-0.08621	0.02251	0.1341	0.1975

Table A4.--continued.

Variable	Mean	Standard Deviation	MCMC Error	Percentile 2.5%	Percentile 10%	Median	Percentile 90%	Percentile 97.5%
RESID_Mau[13]	-0.2915	0.1082	6.71E-04	-0.4755	-0.4169	-0.3029	-0.1489	-0.03168
RESID_Mau[14]	-0.2722	0.1043	6.30E-04	-0.4513	-0.3933	-0.283	-0.1348	-0.02298
RESID_Mau[15]	0.05723	0.08102	3.24E-04	-0.1019	-0.0452	0.05681	0.1596	0.2179
RESID_Mau[16]	0.115	0.0856	4.03E-04	-0.06011	0.004729	0.1175	0.2214	0.2773
RESID_Mau[17]	0.09712	0.08932	4.36E-04	-0.08763	-0.01828	0.1002	0.2081	0.2645
RESID_Mau[18]	0.1933	0.09977	5.65E-04	-0.02591	0.06048	0.2009	0.313	0.3725
RESID_Mau[19]	0.1368	0.09455	4.80E-04	-0.05949	0.01341	0.1406	0.254	0.3121
RESID_Mau[20]	-0.002929	0.08989	3.35E-04	-0.1852	-0.1174	-0.001491	0.1099	0.1712
RMSE_Hoomalu	0.07737	0.02981	1.83E-04	0.03734	0.04635	0.07124	0.1159	0.1574
RMSE_MHI	0.04961	0.01063	4.50E-05	0.03228	0.03705	0.04839	0.0636	0.0738
RMSE_Mau	0.2151	0.04188	3.33E-04	0.08357	0.1649	0.225	0.2526	0.268
pB_Archipelago	0.9724	0.1638	9.53E-04	0	1	1	1	1
pB_Hoomalu	0.9998	0.01414	5.94E-05	1	1	1	1	1
pB_MHI	0	0	2.24E-13	0	0	0	0	0
pB_Mau	0.9999	0.01183	4.20E-05	1	1	1	1	1
pH_Archipelago	1.00E-05	0.003162	1.00E-05	0	0	0	0	0
pH_Hoomalu	0	0	2.24E-13	0	0	0	0	0
pH_MHI	0.8722	0.3339	0.001267	0	0	1	1	1
pH_Mau	0	0	2.24E-13	0	0	0	0	0
q_Hoomalu	0.2451	0.02397	4.14E-04	0.2035	0.2162	0.2433	0.2762	0.2972
q_MHI	0.1452	0.01277	3.07E-04	0.1214	0.1293	0.1448	0.1618	0.1716
q_Mau	0.5875	0.06183	0.001125	0.4786	0.5119	0.5832	0.6683	0.7207
r	0.577	0.05771	0.001164	0.4661	0.5036	0.5765	0.6509	0.6919
sigma2_Hoomalu	0.01268	0.005544	2.60E-05	0.003806	0.006414	0.01196	0.01976	0.02567
sigma2_MHI	0.02395	0.005135	4.31E-05	0.01573	0.01798	0.02333	0.03073	0.03571
sigma2_Mau	0.006231	0.008022	6.61E-05	0.001261	0.001698	0.00354	0.01327	0.03202
tau2_Hoomalu	0.007161	0.006123	3.65E-05	0.001761	0.00249	0.005336	0.01371	0.02443
tau2_MHI	0.002816	0.001238	5.02E-06	0.0012	0.001541	0.002555	0.004404	0.005927
tau2_Mau	0.0446	0.0202	1.11E-04	0.006804	0.02161	0.04276	0.06944	0.09059

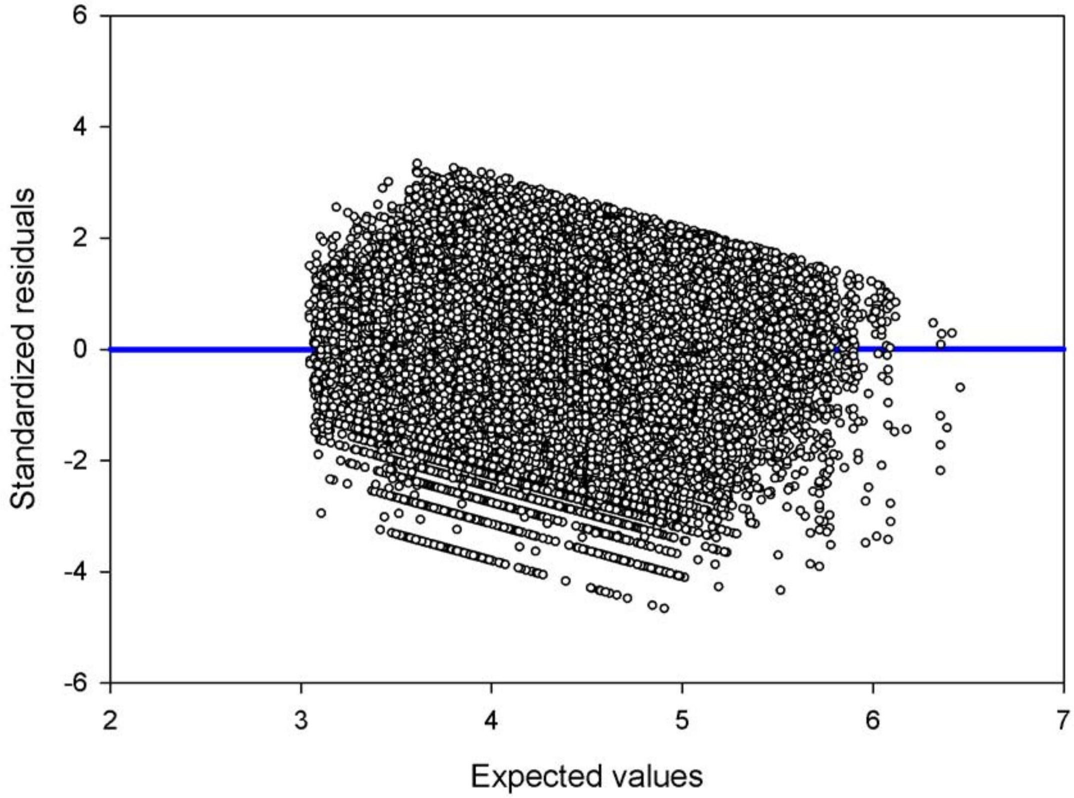


Figure A1.--Residual plot of standardized CPUE residual as a function of fitted CPUE values to evaluate whether model misspecification was occurring.

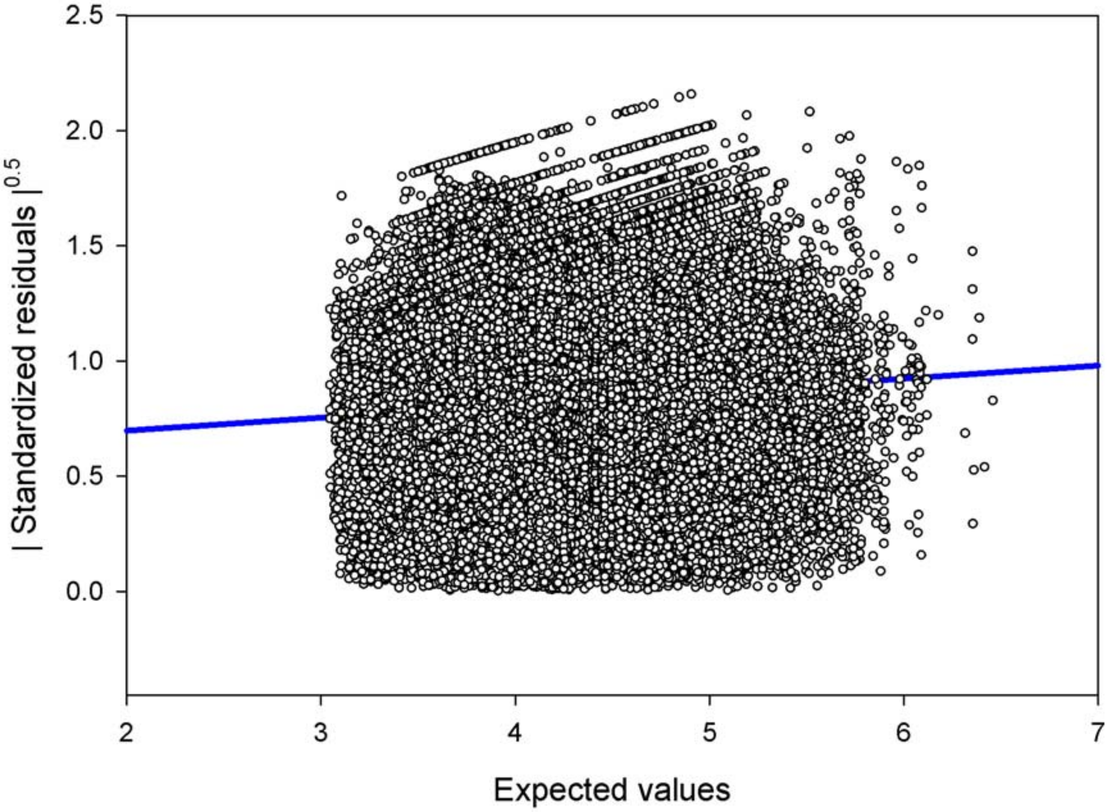


Figure A2.--Residual plot of the square root of the absolute value of standardized CPUE residuals as a function of fitted CPUE values to evaluate whether variance changed with fitted value.

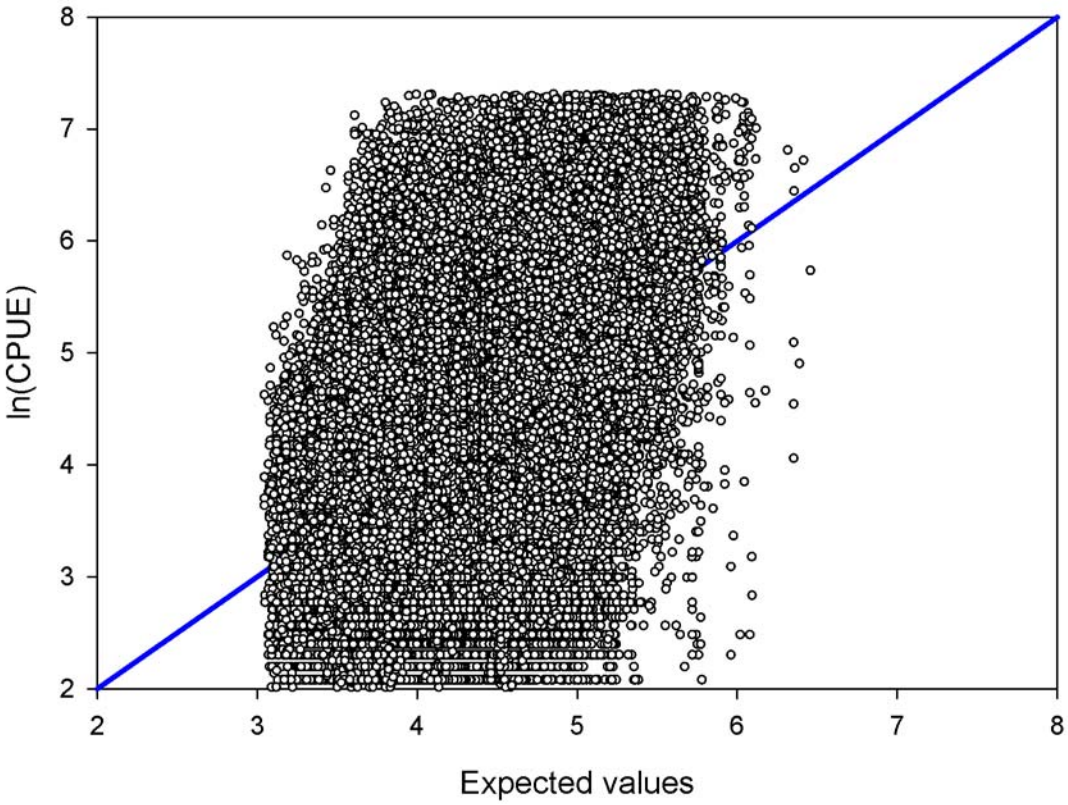


Figure A3.--Diagnostic plot of observed log-scale CPUE as a function of the fitted value along with the estimated regression slope for observed CPUE as a function of the predicted value.

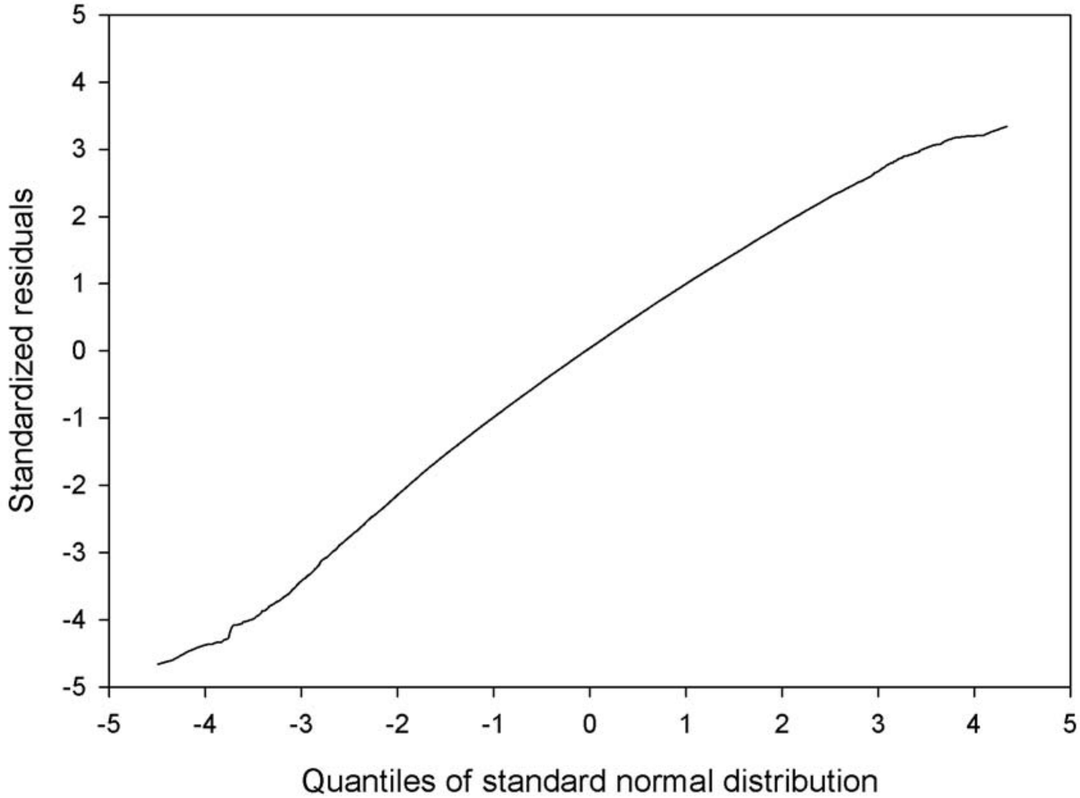


Figure A4.--A Q-Q plot of CPUE residuals versus the standard normal distribution.

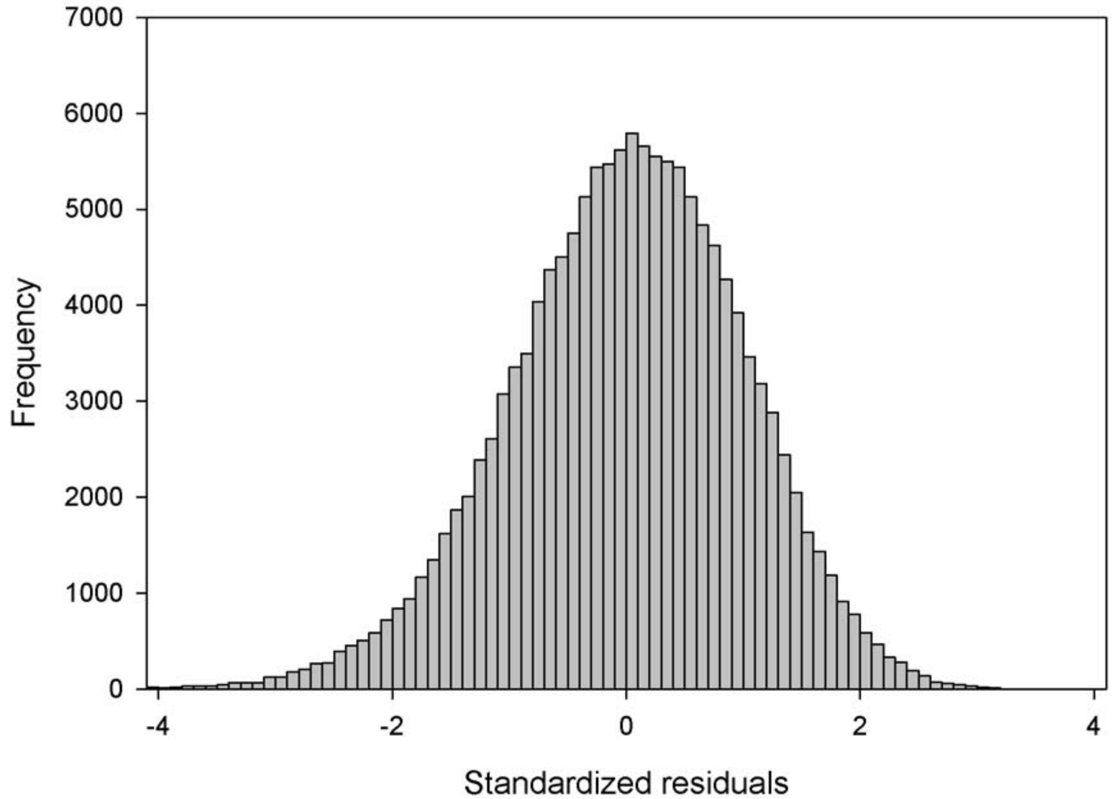
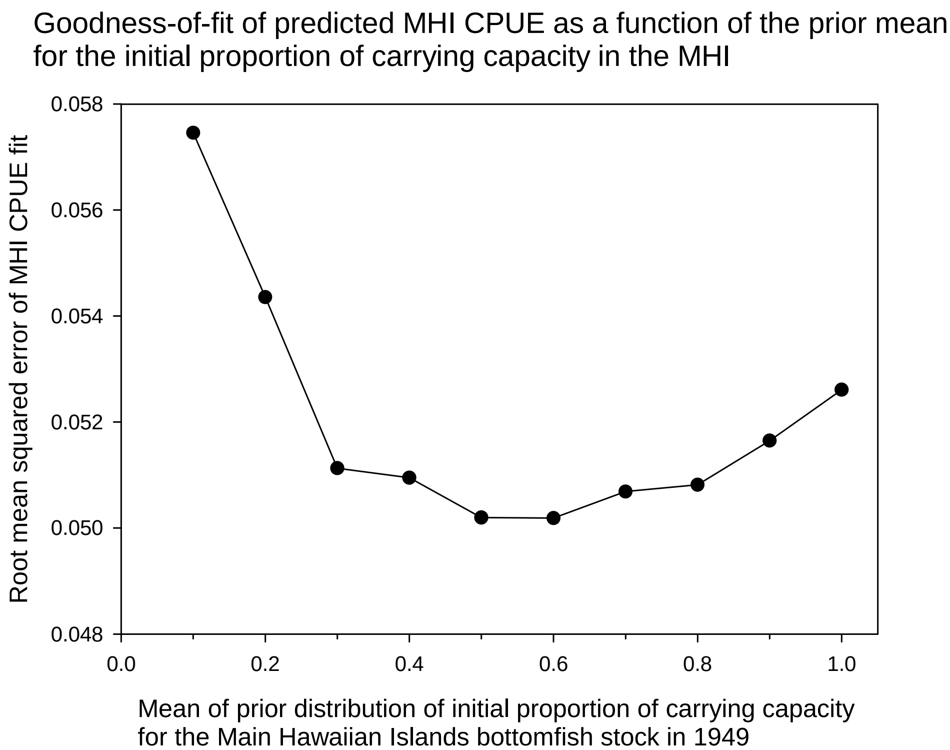


Figure A5.--Histogram of standardized CPUE residuals from the fitted GLM.



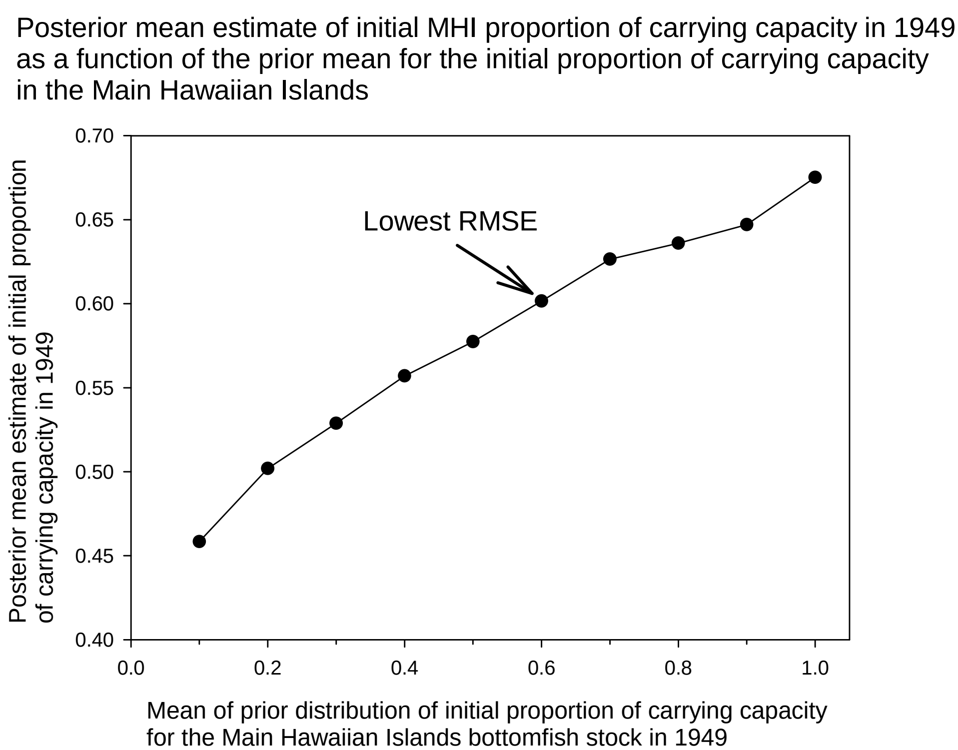


Figure A6.--Goodness-of-fit of alternative values for the mean of the prior distribution of the initial proportion of carrying capacity in the main Hawaiian Islands in 1949.