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May 2008

Administrative Report H-08-03

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BACKGROUND

An assessment of the risk of overfishing the bottomfish complex in the Hawaiian Archipelago was conducted. 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 (TACs) of Deep-7 bottomfish species (Table 1) in the main Hawaiian Islands (MHI) during the 2008 fishing year. This analysis was conditioned on the results of the most recent stock assessment of the Hawaiian bottomfish complex conducted in 2005 (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 by 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 (Table 1) that would produce risks of archipelagic overfishing in 2008 of 0%, 5%, 10%, ..., 100%, conditioned on the baseline model assumptions. Sensitivity analyses were also conducted to show the likely effects of changing model parameters or assumptions.

MATERIALS AND METHODS TO ESTIMATE THE RISK OF OVERFISHING

Information on parameter values for the simulation model (Table 1) was collected from the 2005 bottomfish assessment (Moffitt et al., 2006) and from an updated analysis of bottomfish TAC alternatives for 2007 (Brodziak et al., 2007). The 2005 assessment indicated that the archipelagic bottomfish complex was experiencing overfishing in 2004. In particular, fishing mortality on the MHI bottomfish complex was more than two times F_{MSY}, i.e., $F_{2004} = 2.11*F_{\mathrm{MSY}}$ (Moffitt et al., 2006). It was estimated that a reduction of 24% in the fishing mortality rate in 2004 for the MHI bottomfish was needed to eliminate overfishing on the archipelagic stock. As a result, the target fishing mortality to cease overfishing of MHI bottomfish was set at $F_{\mathrm{TARGET}} = 0.76*F_{2004} = 0.41$ (Table 1). TACs that produced fishing mortalities in excess of F_{TARGET} would be expected to lead to overfishing of the archipelagic bottomfish complex, all else being equal.

The bottomfish risk assessment model was designed to produce estimates of the probability of overfishing in 2008 that were consistent with the stock status determination from the most recent assessment. In this context, the 2005 stock assessment provided the best available information on stock status of MHI bottomfish through 2004 (Fig. 1). Given an estimate of MHI bottomfish stock biomass at the beginning of 2004 and estimates of MHI commercial catch (in weight) in 2005–2007, the biomass dynamics model from the assessment was applied to simulate trajectories of biomass and fishing mortality that would have occurred during 2005–2007 (Figs. 1 and 2) under the assumption that there was no change in the status of the bottomfish complex outside the MHI. This simulation produced a distribution of initial MHI bottomfish stock condition at the beginning of 2008 based on the point estimate of relative MHI biomass in 2004 which was

(1.1) $$\frac{B_{2004}}{B_{MSY}} = 0.42$$

The distribution of projected biomass at the beginning of 2008 depended on the variability (uncertainty) in three key model parameters: the 2004 estimate of bottomfish biomass (B_{2004}), the annual intrinsic growth rate (R_T), and the proportion of the Deep-7 bottomfish species in the total bottomfish catch ($P_{\mathrm{DEEP7},\, T}$). In the rest of this section, descriptions of the model structure, uncertainty in parameter estimates, input catch data for the baseline scenario, feasibility constraints, simulation algorithm, baseline case, and sensitivity analyses are provided.

Model Structure

The bottomfish biomass dynamics model described the annual change in MHI bottomfish biomass from year T (B_T) to year $T + 1$ depending on intrinsic growth rate, carrying capacity (K), and catch (C_T) as

(1.2) $$B_{T+1} = B_T + R_T B_T \left(1 - \frac{B_T}{K}\right) - C_T$$

This production model was consistent with the 2004 stock status determination from Moffitt et al., (2006) and was used to project MHI bottomfish biomass from 2004 through 2009 conditioned on estimated catches and parameter estimate uncertainty.

Parameter Uncertainty

Uncertainty in estimates of the biomass in 2004, the annual intrinsic growth rate from the 2005 assessment, and the proportion of Deep-7 bottomfish from the analysis of MHI bottomfish TAC alternatives for 2007 (Brodziak et al., 2007) was incorporated into the simulation model. Because standard errors of the estimators of B_{2004} and R_T were not available in Moffitt et al., (2006), the coefficients of variation (CV = standard deviation/mean) of the estimates of B_{2004} and R_T were assigned values based on analogy with a recent production model analysis of MHI bottomfish (Brodziak, 2007) and through feedback and review comments from the Western Pacific Regional Fishery Management Council's Scientific and Statistical Committee (SSC). The most likely MHI bottomfish production model reported in Brodziak (2007) estimated the CVs of B_{2004} and R_T to be roughly 10% while the SSC recommended using higher CVs of 25% or greater. In the baseline model, the CV of the estimator of B_{2004} was assumed to be 25% and the CV of R_T was assumed to be 10%. Sensitivity analyses were conducted for higher CVs for both variables. The CV of the proportion of Deep-7 bottomfish was assumed to be 2% based on the observed CV during 2002–2005 (Brodziak et al., 2007).

In each simulated trajectory for the risk analyses, estimation uncertainty for MHI bottomfish biomass in 2004 was modeled as an independent and identically distributed (iid) normal random variable with mean equal to the point estimate (μ_B) from Moffitt et al., (2006) and standard deviation (σ_B) corresponding to a CV of 25%. In particular, the probability density function for B_{2004}, denoted as $p(B)$, was

$$(1.3) \qquad p(B) = \left(2\pi\sigma_B^2\right)^{-0.5} \exp\left(\frac{-\left(B-\mu_B\right)^2}{2\sigma_B^2}\right)$$

Similarly, process uncertainty in the annual intrinsic growth rate was modeled as an iid normal random variable with mean equal to the point estimate from the 2005 assessment (μ_R = 0.455) and a CV of 25% (σ_R = 0.114). Last, process uncertainty in the proportion of Deep-7 species in the catch was modeled as an iid normal random variable with mean equal to the observed proportion during 2002–2005 (μ_P = 0.658) with a CV of 2% (σ_P = 0.013). Correlation among these three random variables was assumed to be negligible.

Catch Data

Annual commercial catches of MHI bottomfish during 2004–2007 were required inputs for the simulation analyses. In this context, commercial catch refers to all bottomfish management unit species and not just the Deep-7 species. Catch in 2004 was taken from Moffitt et al., (2006); C_{2004} = 366.358 thousand pounds (klb). Catch in 2005 was taken from Brodziak et al., (2007) with C_{2005} = 335.905 thousand pounds. Catch in 2006 was estimated from fishermen reported catches of Deep-7 MHI bottomfish (193.643 klb, pers. comm. M. Quach PIFSC, 11-Feb-2008) and the simulated proportion of Deep-7 species; mean C_{2006} = 193.643/ $P_{\mathrm{DEEP7,\,2006}} \approx$ 294.290 klb. Catch in 2007 was assumed to be equal to the Deep-7 total allowable catch set for fishing year 2007 (177.838 klb) and the simulated proportion of Deep-7 species; mean C_{2007} = 177.838/ $P_{\mathrm{DEEP7,\,2007}} \approx$ 270.271 klb. In this case, it was assumed that the 2007 TAC was completely harvested. This assumption was based on the fact that the total of fishermen reported catches during calendar year 2007 was 177.707 klb of MHI Deep-7 bottomfish (pers. comm. M. Quach PIFSC, 11-Feb-2008) which was approximately equal to the 2007 TAC. Sensitivity analyses were conducted to evaluate the effect of this assumption.

Feasibility Constraints

Based on the estimates of MHI bottomfish catches during 2005–2007, deterministic projections of biomass production and stock biomass from the point estimates in 2004 exhibited decreasing trends (Fig. 1). These trends resulted from catch exceeding biomass production during 2004–2007. For the stochastic simulations, this implied that some simulated trajectories could result in stock biomass too small to produce the estimated catch (as projected using equation 1.2) in one or more years during 2005–2007. Since the estimated catches were based on observed data, simulated biomass trajectories that could not produce the observed catches in one or more years during 2005–2007 were not feasible. This situation could have occurred, for example, if the initial simulated biomass in 2004 was lower than the point estimate from the 2005 assessment and the simulated annual intrinsic growth rates were also lower than expected, leading to a more rapid decline in biomass than expected (Fig. 2). Given these possibilities, biomass trajectories for which simulated biomass in 2005–2007 was less than 1.0 thousand pounds were defined to be infeasible; all other trajectories were feasible. The infeasible trajectories were excluded from the risk assessment since they could not have occurred. As a result, the probability of overfishing in 2008 for each TAC value was conditioned on the set of feasible trajectories where conditional probability for a set of simulations was defined as

$$p\left(F_{2008} > F_{TARGET} \mid feasible\right) = \frac{p\left(F_{2008} > F_{TARGET}\ and\ feasible\right)}{p\left(feasible\right)} \tag{1.4}$$

Simulation Algorithm

The simulation algorithm had three elements: the input data, the output results, and the pseudo-code algorithm. The pseudo-code algorithm had eight steps (Table 2). The inputs were: the number of TACs to evaluate, the minimum TAC, the maximum TAC, the number of simulations to compute the probability of overfishing, the multiplier of B_{2004} to set the mean μ_B, the CV of B_{2004}, the multiplier of R to set the mean μ_R, the CV of R, the catch in 2007, the proportion of Deep-7 species catch, and the CV of the proportion of Deep-7 species catch.

The outputs were: F_{MSY}, F_{TARGET}, probability that F_{2007} exceeds F_{TARGET} at a given assumed 2008 TAC value, the probability that a simulation is infeasible at this TAC, the mean relative biomasses in 2007–2009 at this TAC, the probability that F_{2008} exceeds F_{MSY} at the TAC, the probability that F_{2008} exceeds F_{MSY} and is feasible at this TAC, the conditional probability that F_{2008} exceeds F_{MSY} given feasible at this TAC, the probability that F_{2008} exceeds F_{TARGET} at the TAC, the probability that F_{2008} exceeds F_{TARGET} and is feasible at this TAC, and the conditional probability that F_{2008} exceeds F_{TARGET} given it is feasible at this TAC. A plot was produced of the conditional probabilities that F_{2008} exceeds F_{MSY} and F_{TARGET}, given feasibility, as a function of the TAC.

Baseline Model

The baseline model consisted of the following input data and assumptions: the number of TACs to evaluate was 301, the minimum TAC was 0 pounds, the maximum TAC was 300 klb, the number of simulations to compute the probability of overfishing was 20,000, the multiplier of the point estimate of B_{2004} to set the mean μ_B was 1, the CV of B_{2004} was 25%, the multiplier of R to set the mean μ_R was 1, the CV of R was 25%, the catch in 2007 was equal to the TAC of 177.838 klb, the proportion of Deep-7 species catch was 0.658, and the CV of the proportion of Deep-7 species catch was 2%.

Sensitivity Analyses

Sensitivity analyses were used to quantify the impacts of changes in the input data used in the baseline model. The sensitivity analyses were conducted by changing the value of one input variable at a time with all else remaining unchanged. In most cases, the changes were equivalent to multiplying the input variable by 3/2 (50% increase) or conversely by 2/3 (33% decrease). The sensitivity analyses adjusted the following input variables by amounts indicated in parentheses: B_{2004} (+50% and –33%), CV of B_{2004} (+100%), R (+50% and –33%), CV of R

(+100%), TAC_{2007} (+50% and –33%), proportion of Deep-7 species (+25% and –25%), and CV of proportion of Deep-7 species (+100%). Two additional sensitivity analyses were conducted by modifying the baseline model to include annual variation in carrying capacity. In this case, process variability in K was modeled as a normal random variable with mean equal to the point estimate from the 2005 assessment with a CV of 10%. The two sensitivity analyses for K were: K (+50% and –33%) and CV of K (+100%). For each of the sensitivity analyses, the value of the estimated TAC in 2008 that produced a 25% chance of archipelagic overfishing (low risk of exceeding F_{TARGET}), denoted as $TAC_{25\%}$, was used to measure the effect of a directional change in the input variable. An approximate elasticity (percent change in $TAC_{25\%}$ from a 1% change in input variable) was also calculated to assess the relative importance of the input variables on the estimate of the low risk TAC.

RESULTS

Baseline Model

Results of the baseline risk assessment model (Table 3, Fig. 3) 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. In comparison, selecting a low risk (25%) of overfishing would set TAC_{2008} = 61 klb while choosing a neutral risk (50%) of overfishing would set TAC_{2008} = 99 klb. The probability of exceeding F_{TARGET} was a concave function of TAC_{2008} over most of the TACs examined (Fig. 3). This indicated that risk of overfishing increased less than proportionally with increasing TAC_{2008} values. Last, the probability that fishing mortality exceeded F_{MSY} in the MHI during 2008 (Fig. 3) was generally higher than that of exceeding F_{TARGET} for the Hawaiian Archipelago because F_{TARGET} was greater than F_{MSY}. In this case, the value of F_{TARGET} was based on an average of the low fishing mortality rates for bottomfish in the Mau and Ho'omalu Zones and the high fishing mortality rate for MHI bottomfish (Moffitt et al., 2006).

Sensitivity Analyses: Biomass Estimate in 2004

Increasing the estimated value of B_{2004} by 50% generally decreased the probability of overfishing in 2008 relative to the baseline case (Fig. 4.1). Under this scenario, the low risk TAC was $TAC_{25\%}$ = 153 klb and the neutral risk TAC was $TAC_{50\%}$ = 222 klb. The risk assessment model was highly sensitive to the B_{2004} parameter and had an approximate elasticity of 3.0 for the low risk TAC, implying a threefold increase in the output TAC per unit change of input B_{2004}.

Decreasing the estimated value of B_{2004} by 33% generally increased the probability of overfishing in 2008 relative to the baseline case (Fig. 4.2). The low risk and neutral risk TACs were 35 and 48 klb, respectively. Decreasing B_{2004} by 33% led to a 43% decrease in TAC_{2008} for the low risk TAC indicating an approximate elasticity of 1.3.

Increasing the coefficient of variation of the simulated value of B_{2004} by 100% generally decreased the probability of overfishing in 2008 relative to the baseline (Fig. 4.3). Under the high CV scenario, the low risk TAC was $TAC_{25\%}$ = 92 klb with an approximate elasticity of 0.3 while the neutral risk TAC was 158 klb. Assuming a higher CV led to a set of TACs for a given risk of overfishing (Table 4) that was consistent with the SSC's suggestion that the CV of the estimate of B_{2004} was likely 25% or more.

Sensitivity Analyses: Intrinsic Growth Rate

When the estimated value of R was increased by 50%, the probability of overfishing in 2008 decreased relative to the baseline case (Fig. 5.1). Under this scenario, the low risk TAC was $TAC_{25\%}$ = 213 klb and the neutral risk TAC was $TAC_{50\%}$ = 324 klb. The risk assessment model was highly sensitive to the R parameter with an approximate elasticity of 5.0 for the low risk TAC, or roughly a fivefold increase in the output TAC per unit change of the intrinsic growth rate.

Decreasing the estimated value of R by 33% generally increased the probability of overfishing in 2008 relative to the baseline (Fig. 5.2). The low risk and neutral risk TACs were 22 and 34 klb, respectively. Decreasing R by 33% led to a 64% decrease in TAC_{2008} for the low risk TAC indicating an approximate elasticity of 1.9.

When the coefficient of variation of the simulated value of R was increased by 100%, the probability of overfishing in 2008 did not change relative to the baseline (Fig. 5.3). Under the high CV scenario, the low risk TAC was $TAC_{25\%}$ = 61 klb with an approximate elasticity of 0.0 while the neutral risk TAC was 100 klb.

Sensitivity Analyses: Total Allowable Catch in 2007

Increasing the assumed value of the total catch of Deep-7 bottomfish in 2007 by 50% to TAC_{2007} = 266.757 klb did not appreciably change the probability of overfishing in 2008 relative to the baseline (Fig. 6.1). In this case, the low risk TAC was $TAC_{25\%}$ = 62 klb and the neutral risk TAC was $TAC_{50\%}$ = 91 klb. Model results were not sensitive to the TAC_{2007} parameter and had an approximate elasticity of 0.0 for the low risk TAC.

When the assumed value of the total catch of Deep-7 bottomfish in 2007 was decreased by 33%, the probability of overfishing in 2008 was similar to the baseline (Fig. 6.2). The low risk TAC was $TAC_{25\%}$ = 61 klb, and the neutral risk TAC was $TAC_{50\%}$ = 104 klb. The risk assessment model was not sensitive to the R parameter with an approximate elasticity of 0.0 for the low risk TAC.

Sensitivity Analyses: Proportion of Deep-7 Bottomfish

When the value of P_{Deep7} was increased by 25%, the probability of overfishing in 2008 decreased relative to the baseline (Fig. 7.1). In this case, the low risk TAC was $TAC_{25\%}$ = 82 klb and the neutral risk TAC was $TAC_{50\%}$ = 136 klb. The risk assessment model was moderately sensitive to the P_{Deep7} parameter with an approximate elasticity of 1.4 for the low risk TAC.

Decreasing the value of P_{Deep7} by 25% increased the probability of overfishing in 2008 relative to the baseline (Fig. 7.2). The low risk and neutral risk TACs were 42 and 63 klb, respectively. Decreasing P_{Deep7} by 25% led to a 31% decrease in TAC_{2008} for the low risk TAC with an approximate elasticity of 1.2.

When the coefficient of variation of the simulated value of P_{Deep7} was increased by 100%, the probability of overfishing in 2008 did not change relative to the baseline (Fig. 7.3). Under the high CV scenario, the low risk TAC was $TAC_{25\%}$ = 61 klb with an approximate elasticity of 0.0 and the neutral risk TAC was 97 klb.

Sensitivity Analyses: Carrying Capacity

Increasing the estimated value of *K* by 50% generally decreased the probability of overfishing in 2008 relative to the baseline (Fig. 8.1). Under the increased carrying capacity scenario, the low risk TAC was $TAC_{25\%}$ = 71 klb and the neutral risk TAC was $TAC_{50\%}$ = 119 klb. The results were not sensitive to the K parameter with an approximate elasticity of 0.3 for the low risk TAC.

Decreasing the estimated value of *K* by 33% increased the probability of overfishing in 2008 relative to the baseline (Fig. 8.2). The low risk and neutral risk TACs were 47 and 72 klb, respectively. Decreasing *K* by 33% led to a 23% decrease in TAC_{2008} for the low risk TAC indicating an approximate elasticity of 0.7.

When the coefficient of variation of the simulated value of *K* was increased by 100%, the probability of overfishing in 2008 did not appreciably change relative to the baseline (Fig. 8.3). Under the high CV scenario, the low risk TAC was $TAC_{25\%}$ = 58 klb with an approximate elasticity of 0.0 and the neutral risk TAC was 94 klb.

SUMMARY

Total allowable commercial catches in 2008 ranging from 24 to 99 klb correspond to risks of archipelagic overfishing ranging from 0% to 50% (Table 3 and Fig. 3). 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.

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 TAC in 2007, and the coefficients of variation of key model parameters (B_{2004}, R, P_{deep7}, and K).

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Table 1.--Glossary of terms used in the simulation model to estimate total allowable bottomfish catches and the associated probabilities of overfishing in 2008.

MHI	the Main Hawaiian Islands
B_T	the biomass of MHI bottomfish at the beginning of year T
F_T	the fishing mortality rate on MHI bottomfish in year T in instantaneous units
F_{TARGET}	the target fishing mortality to cease archipelagic overfishing in 2004 where $F_{\text{TARGET}} = 0.76\ F_{2004}$
H_T	the fraction of the biomass of MHI bottomfish harvested in year T where $F_T = -\log(1 - H_T)$
C_T	the total catch (in weight, same units as stock biomass) of MHI bottomfish harvested in year T where $C_T = H_T \cdot B_T$
R_T	the simulated intrinsic growth rate of MHI bottomfish in year T with expected value $E[R_T] = 0.455$ from Moffitt et al., (2006)
K	estimated carrying capacity of MHI bottomfish from Moffitt et al., (2006) where $K = 3186.215$ klb
$P_{\text{DEEP7},\,T}$	the fraction of Deep-7 bottomfish biomass in the total MHI bottomfish catch in year T where the Deep-7 bottomfish species are: (1) Opakapaka (*Pristipomoides filamentosus*) (2) Kalekale (*Pristipomoides sieboldii*) (3) Lehi (*Aphareus rutilans*) (4) Gindai (*Pristipomoides zonatus*) (5) Onaga (*Etelis coruscans*) (6) Ehu (*Etelis carbunculus*) (7) Hapuupuu (*Epinephelus quernus*).
MSY	the maximum sustainable yield of MHI bottomfish
B_{MSY}	the biomass of MHI bottomfish that produces MSY
F_{MSY}	the fishing mortality rate that produces MSY when biomass is B_{MSY}
TAC_Y	the total allowable commercial catch of Deep-7 bottomfish in year Y

Table 2.--Simulation algorithm for the risk assessment model to estimate probabilities of overfishing in 2008 for a range of total allowable catches of Deep-7 bottomfish species.

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1. Read input data
2. Initialization
    - 2.1. Initialize parameter values from 2005 assessment
    - 2.2. Initialize derived variables
    - 2.3. Initialize to summarize simulated biomass (B), fishing mortality (F), catch (C), growth rate (R), and derived outputs
    - 2.4. Compute mesh for TAC loop
3. TAC loop
    - 3.1. Set value of 2008 TAC, TAC_{2008}
    - 3.2. Simulation loop
        - 3.2.1. Initialize feasible array
        - 3.2.2. Initialize B, F, C, and R for time=1 (year=2004)
        - 3.2.3. Compute B, F, C, and R for time=2 (year=2005) using C_{2005}
        - 3.2.4. Compute B, F, C, and R for time=3 (year=2006) using C_{2006}
        - 3.2.5. Compute B, F, C, and R for time=4 (year=2007) using TAC_{2007}/ P_{DEEP7}
        - 3.2.6. Compute B, F, C, and R for time=5 (year=2008) using TAC_{2008}
        - 3.2.7. Compute B for time=6 (year=2009)
        - 3.2.8. End of Simulation Loop
    - 3.3. End of TAC loop
4. Identify feasible simulations
5. Count realized F values that exceed F_{TARGET} and F_{MSY}
6. Compute mean relative biomasses (B/B_{MSY}) in 2007-2009
7. Compute probabilities that F exceeds F_{TARGET} and F_{MSY}
8. Output results

Table 3.--Simulation results for the baseline model to assess the risk of archipelagic overfishing in 2008 including probabilities of archipelagic overfishing in 2008 ($p[F_{2008} > F_{TARGET}]$) and associated total allowable catches (TAC_{2008}) of Deep-7 bottomfish in the MHI (klb) along with the associated relative biomasses (B_{2009}/B_{MSY}) of all bottomfish management unit species at the beginning of 2009.

$p(F_{2008} > F_{TARGET})$ %	TAC_{2008}	B_{2009}/B_{MSY}
0	24	0.38
5	32	0.38
10	40	0.37
15	46	0.37
20	54	0.36
25	61	0.35
30	68	0.35
35	75	0.34
40	82	0.33
45	90	0.32
50	99	0.31
55	106	0.31
60	114	0.30
65	124	0.30
70	132	0.28
75	143	0.27
80	156	0.26
85	168	0.25
90	187	0.24
95	212	0.21
100	273	0.16

Table 4.--Results for the sensitivity analysis of the effects of a 100% increase in the assumed coefficient of variation for the estimate of biomass in 2004 including probabilities of archipelagic overfishing in 2008 ($p[F_{2008} > F_{\mathrm{TARGET}}]$) and associated total allowable catches (TAC_{2008}) of Deep-7 bottomfish in the MHI (thousands of pounds) along with the associated relative biomasses ($B_{2009}/B_{\mathrm{MSY}}$) of all bottomfish management unit species at the beginning of 2009.

$p(F_{2008} > F_{\mathrm{TARGET}})$ %	TAC_{2008}	$B_{2009}/B_{\mathrm{MSY}}$
0	25	0.59
5	39	0.59
10	53	0.58
15	67	0.56
20	81	0.55
25	93	0.53
30	107	0.52
35	119	0.51
40	132	0.49
45	147	0.48
50	158	0.47
55	173	0.46
60	187	0.45
65	202	0.43
70	216	0.42
75	233	0.40
80	250	0.38
85	268	0.37
90	296	0.35
95	333	0.32
100	404	0.27

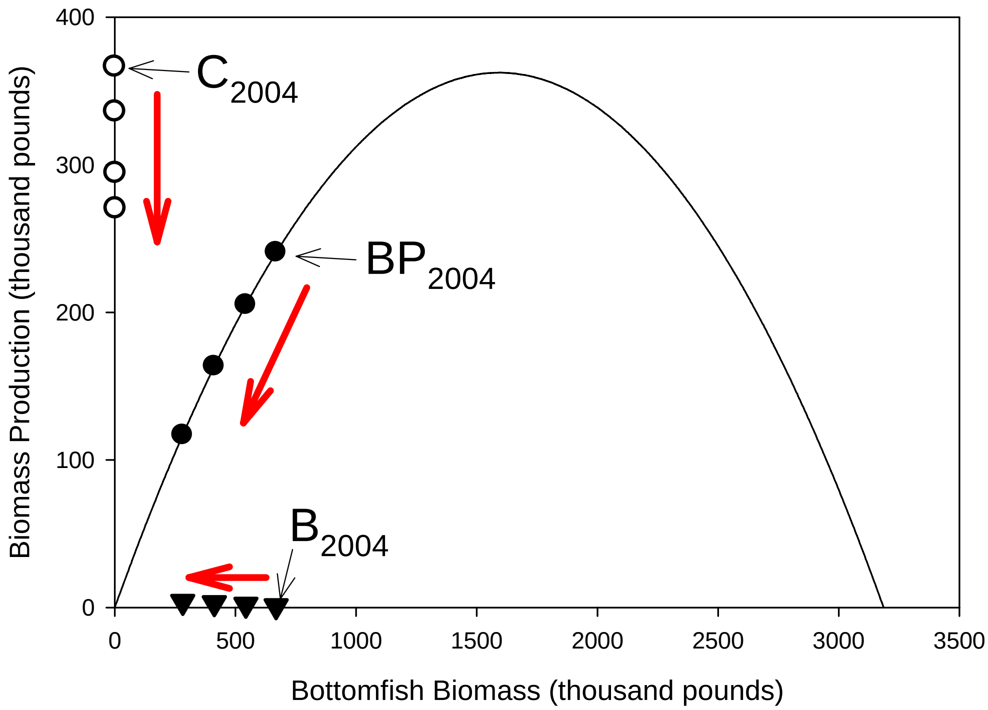

Figure 1.--Trends in MHI bottomfish catch (C, open circles), biomass production (BP, solid circles), and stock biomass (B, solid triangles) based on a deterministic projection from the point estimate of estimated biomass in 2004 (Moffitt et al., 2006) and estimated catches in 2005–2007.

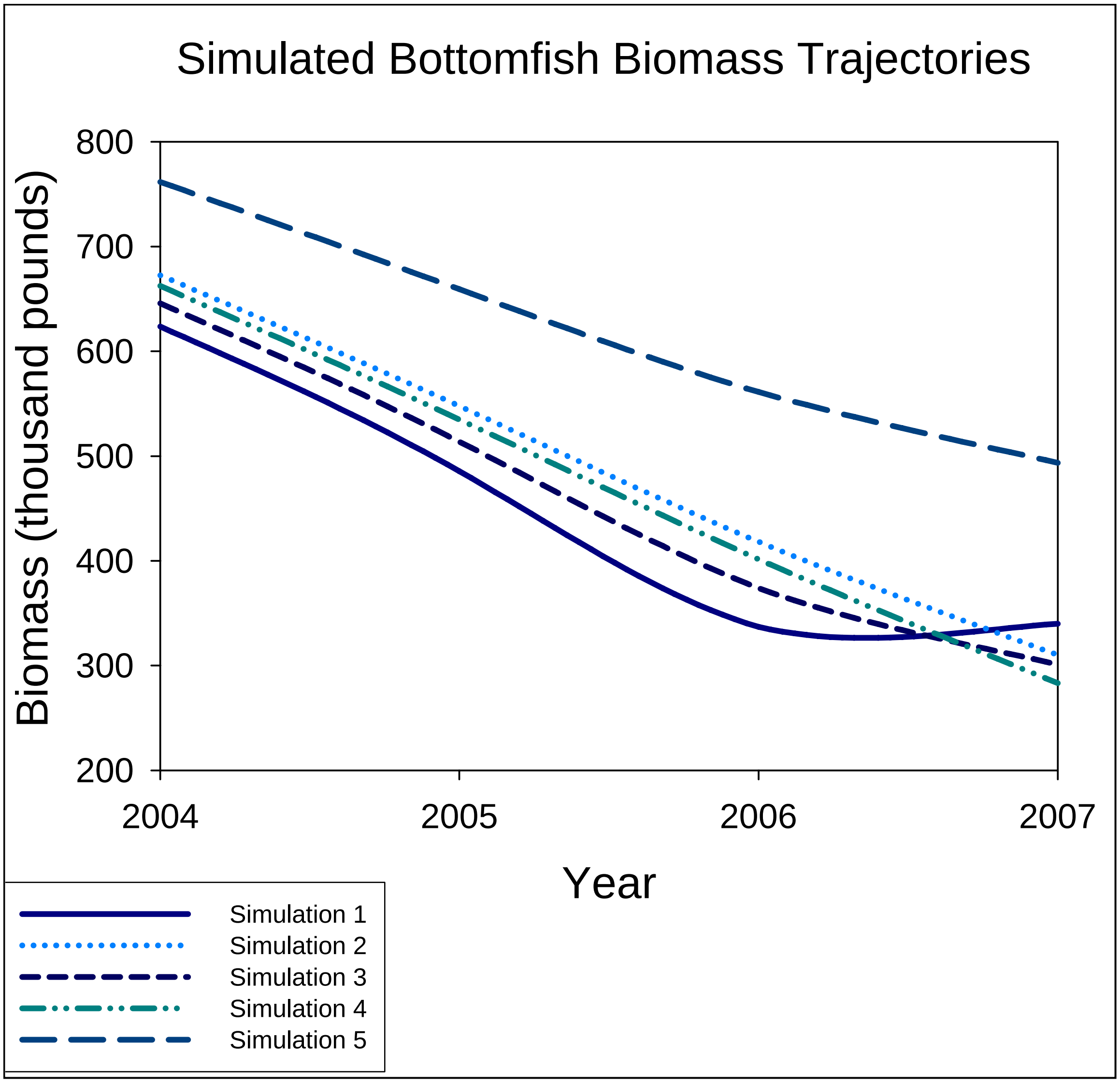

Figure 2.--Simulated trajectories of MHI bottomfish biomass for estimating the risk of archipelagic overfishing in 2008.

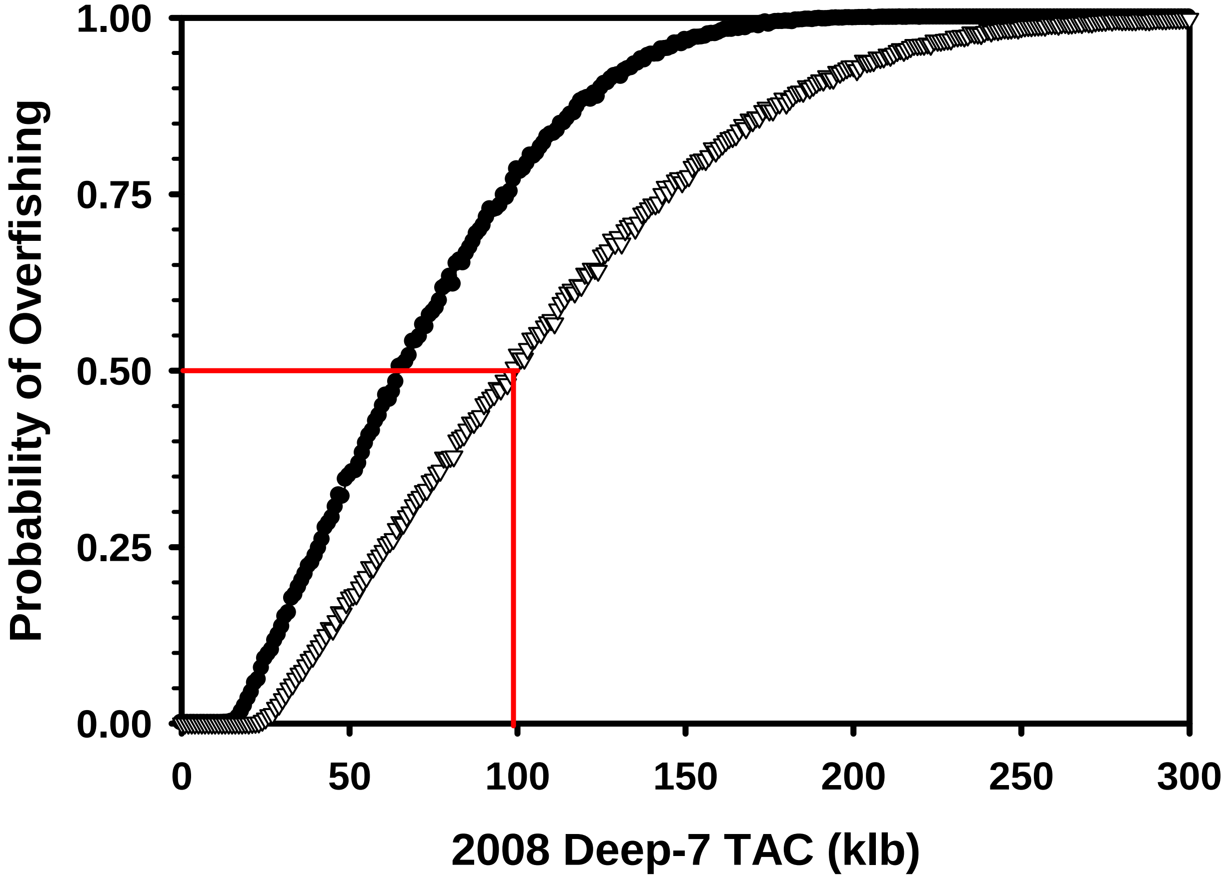

Figure 3.--Results of the baseline model including the probability of archipelagic overfishing (open triangle, $P_r[F_{2008} > F_{\text{TARGET}} \mid_{\text{FEASIBLE}}]$) and the probability of overfishing in the MHI (solid circle, $P_r[F_{2008} > F_{\text{MSY}}|_{\text{FEASIBLE}}]$) as a function of the total allowable commercial catch of Deep-7 bottomfish species in the MHI in 2008.

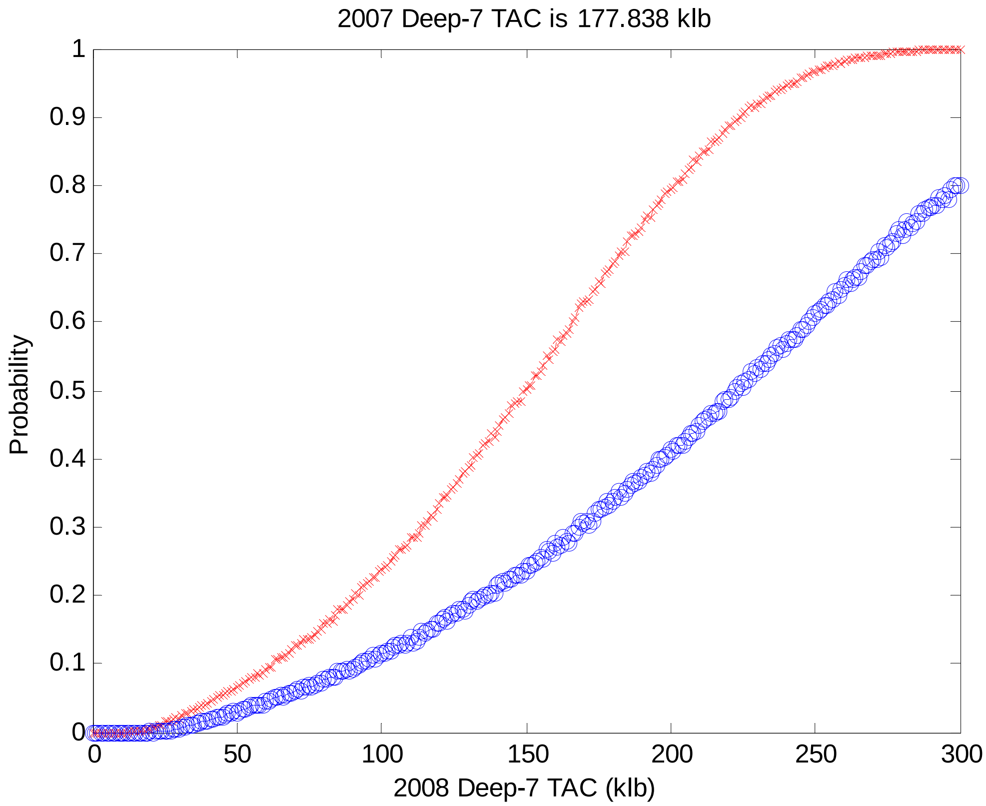

Figure 4.1.--Results of the sensitivity analysis to show the effect of increasing the estimate of biomass in 2004 by 50% including the probability of archipelagic overfishing (open circle, $P_r[F_{2008} > F_{\mathrm{TARGET}\,|\,\mathrm{FEASIBLE}}]$) and the probability of overfishing in the MHI (cross, $P_r[F_{2008} > F_{\mathrm{MSY}\,|\,\mathrm{FEASIBLE}}]$) as a function of the total allowable commercial catch of Deep-7 bottomfish species in the MHI in 2008.

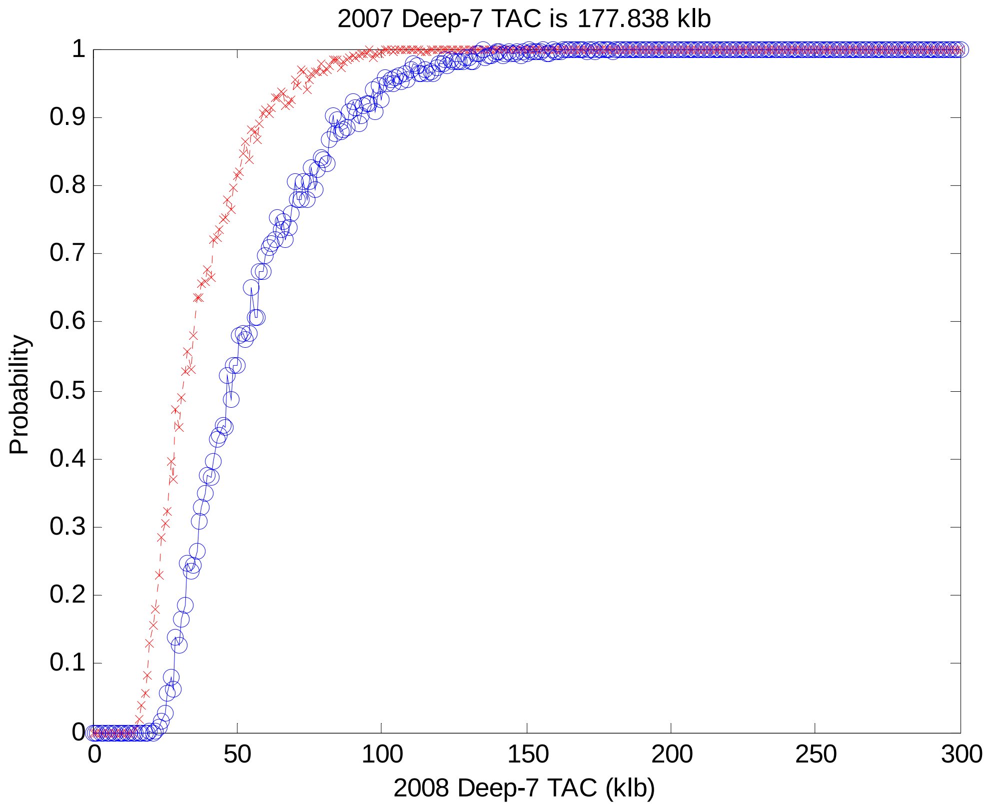

Figure 4.2.--Results of the sensitivity analysis to show the effect of decreasing the estimate of biomass in 2004 by 33% including the probability of archipelagic overfishing (open circle, $P_r[F_{2008} > F_{\mathrm{MSY\,|\,FEASIBLE}}]$) and the probability of overfishing in the MHI (cross, $P_r[F_{2008} > F_{\mathrm{MSY\,|\,FEASIBLE}}]$) as a function of the total allowable commercial catch of Deep-7 bottomfish species in the MHI in 2008.

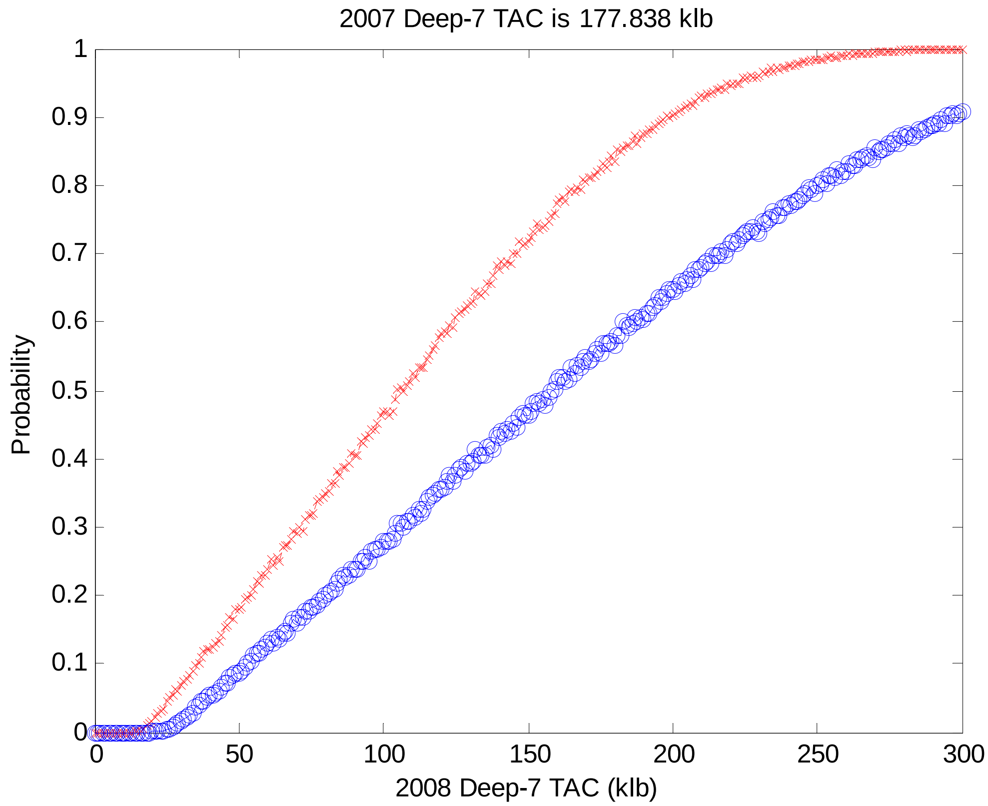

Figure 4.3.--Results of the sensitivity analysis to show the effect of increasing the CV of biomass in 2004 by 100% including the probability of archipelagic overfishing (open circle, $P_r[F_{2008} > F_{\text{TARGET}\,|\,\text{FEASIBLE}}]$) and the probability of overfishing in the MHI (cross, $P_r[F_{2008} > F_{\text{MSY}\,|\,\text{FEASIBLE}}]$) as a function of the total allowable commercial catch of Deep-7 bottomfish species in the MHI in 2008.

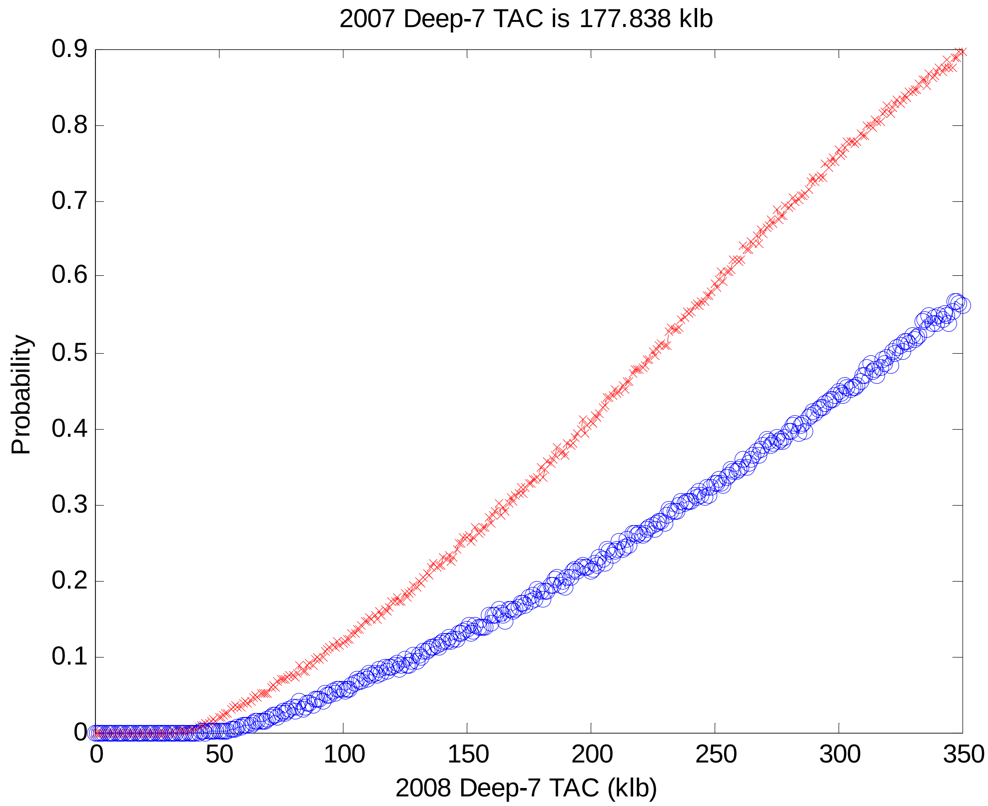

Figure 5.1.--Results of the sensitivity analysis to show the effect of increasing the annual intrinsic growth rate by 50% including the probability of archipelagic overfishing (open circle, $P_r[F_{2008} > F_{\text{TARGET}\,|\,\text{FEASIBLE}}]$) and the probability of overfishing in the MHI (cross, $P_r[F_{2008} > F_{\text{MSY}\,|\,\text{FEASIBLE}}]$) as a function of the total allowable commercial catch of Deep-7 bottomfish species in the MHI in 2008.

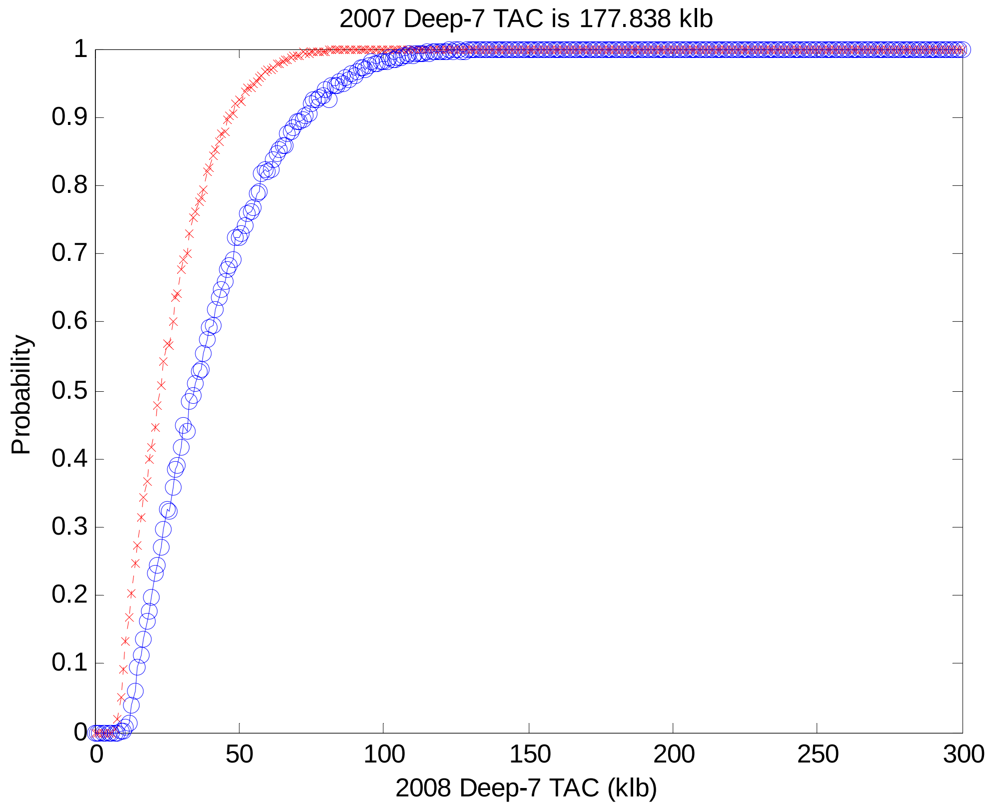

Figure 5.2.--Results of the sensitivity analysis to show the effect of decreasing the annual intrinsic growth rate by 33% including the probability of archipelagic overfishing (open circle, $P_r[F_{2008} > F_{\text{TARGET | FEASIBLE}}]$) and the probability of overfishing in the MHI (cross, $P_r[F_{2008} > F_{\text{MSY | FEASIBLE}}]$) as a function of the total allowable commercial catch of Deep-7 bottomfish species in the MHI in 2008.

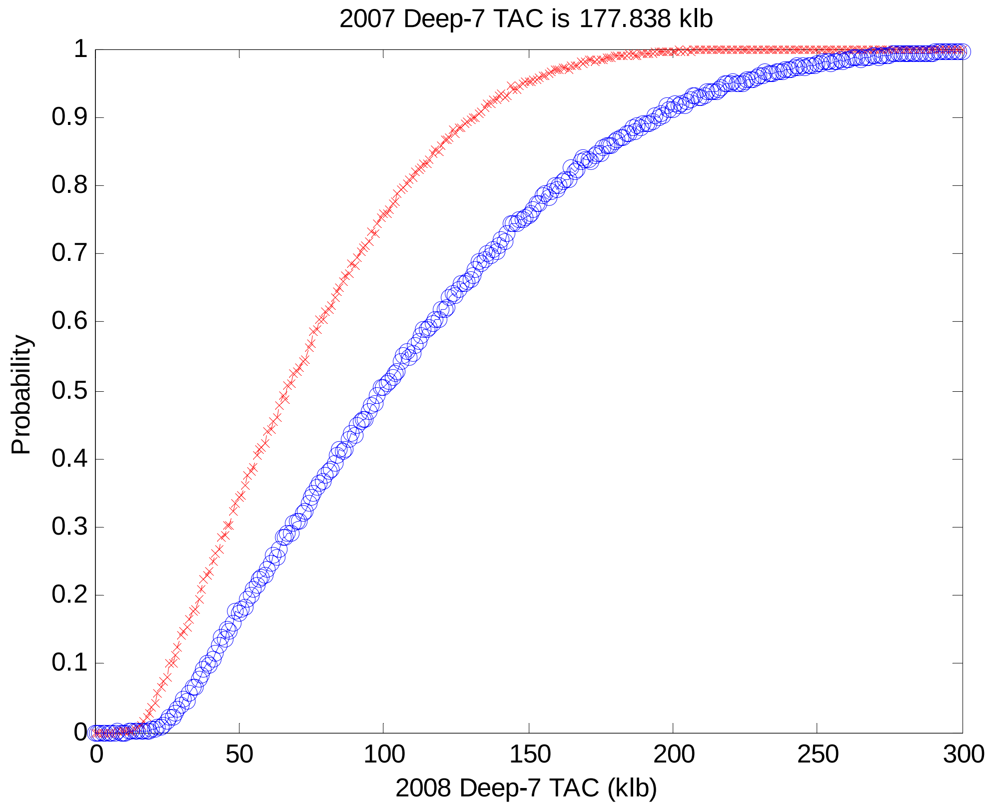

Figure 5.3.--Results of the sensitivity analysis to show the effect of increasing the CV of annual intrinsic growth rate by 100% including the probability of archipelagic overfishing (open circle, $P_r[F_{2008} > F_{\mathrm{TARGET\,|\,FEASIBLE}}]$) and the probability of overfishing in the MHI (cross, $P_r[F_{2008} > F_{\mathrm{MSY\,|\,FEASIBLE}}]$) as a function of the total allowable commercial catch of Deep-7 bottomfish species in the MHI in 2008.

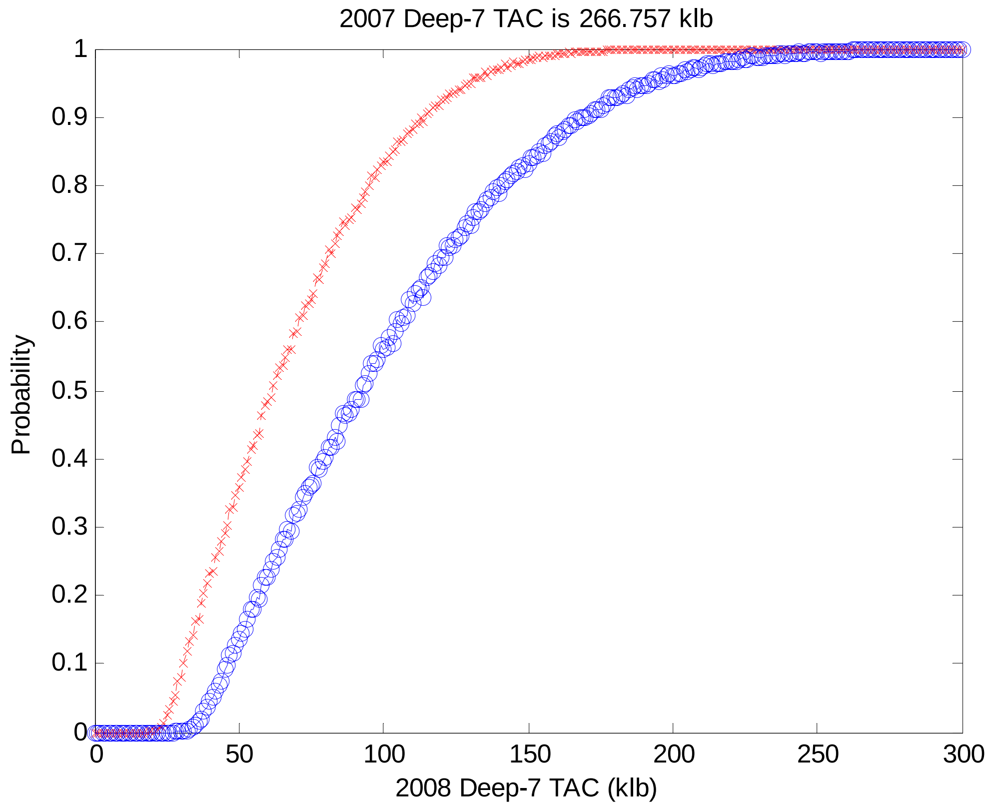

Figure 6.1.--Results of the sensitivity analysis to show the effect of increasing the 2007 TAC of Deep-7 bottomfish species by 50% including the probability of archipelagic overfishing (open circle, $P_r[F_{2008} > F_{TARGET \mid FEASIBLE}]$) and the probability of overfishing in the MHI (cross, $P_r[F_{2008} > F_{MSY \mid FEASIBLE}]$) as a function of the total allowable commercial catch of Deep-7 bottomfish species in the MHI in 2008.

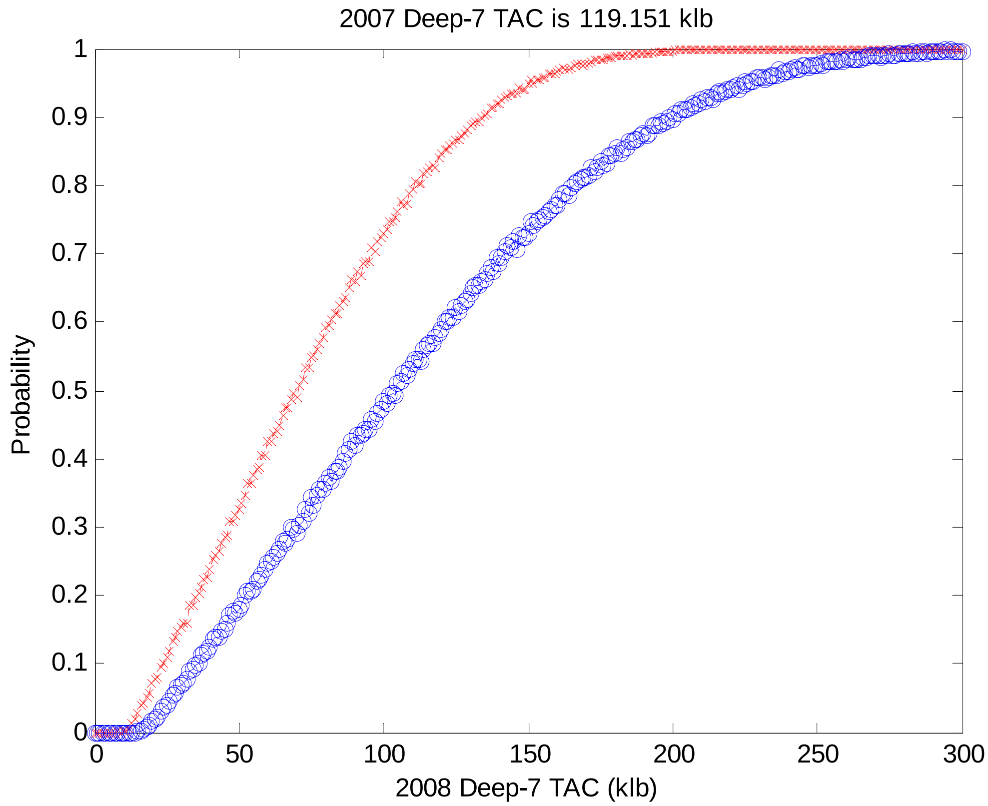

Figure 6.2.--Results of the sensitivity analysis to show the effect of decreasing the 2007 TAC of Deep-7 bottomfish species by 33% including the probability of archipelagic overfishing (open circle, $P_r[F_{2008} > F_{\text{TARGET} \mid \text{FEASIBLE}}]$) and the probability of overfishing in the MHI (cross, $P_r[F_{2008} > F_{\text{MSY} \mid \text{FEASIBLE}}]$) as a function of the total allowable commercial catch of Deep-7 bottomfish species in the MHI in 2008.

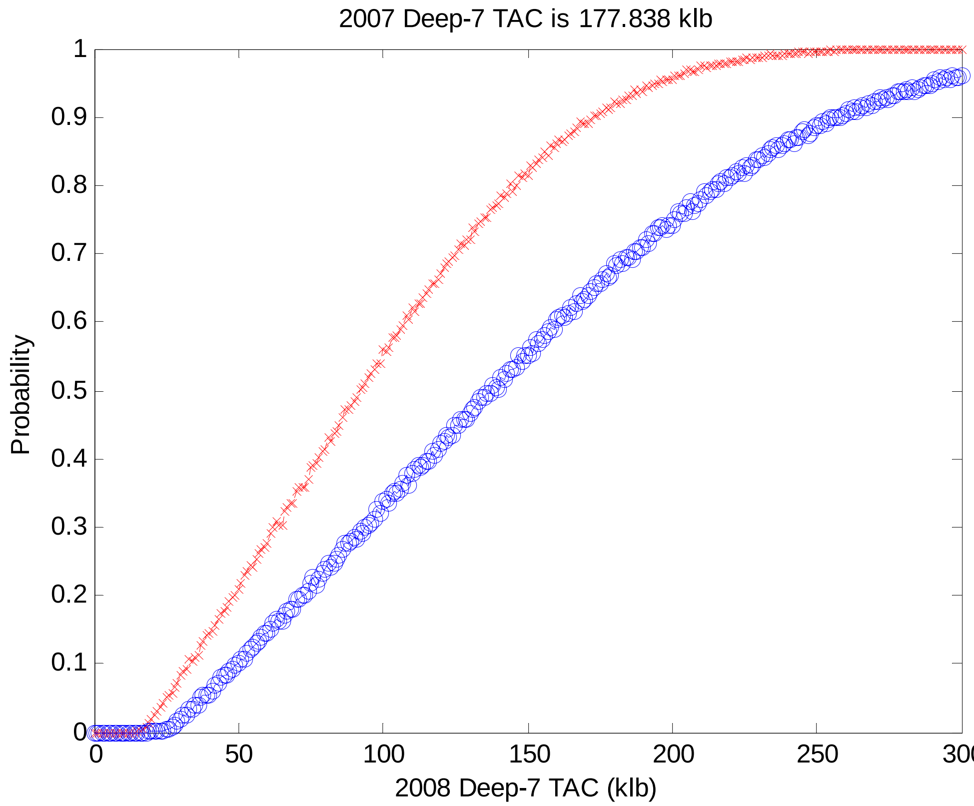

Figure 7.1.--Results of the sensitivity analysis to show the effect of increasing the simulated proportion of Deep-7 bottomfish species by 25% including the probability of archipelagic overfishing (open circle, $P_r[F_{2008} > F_{\mathrm{TARGET\,|\,FEASIBLE}}]$) and the probability of overfishing in the MHI (cross, $P_r[F_{2008} > F_{\mathrm{MSY\,|\,FEASIBLE}}]$) as a function of the total allowable commercial catch of Deep-7 bottomfish species in the MHI in 2008.

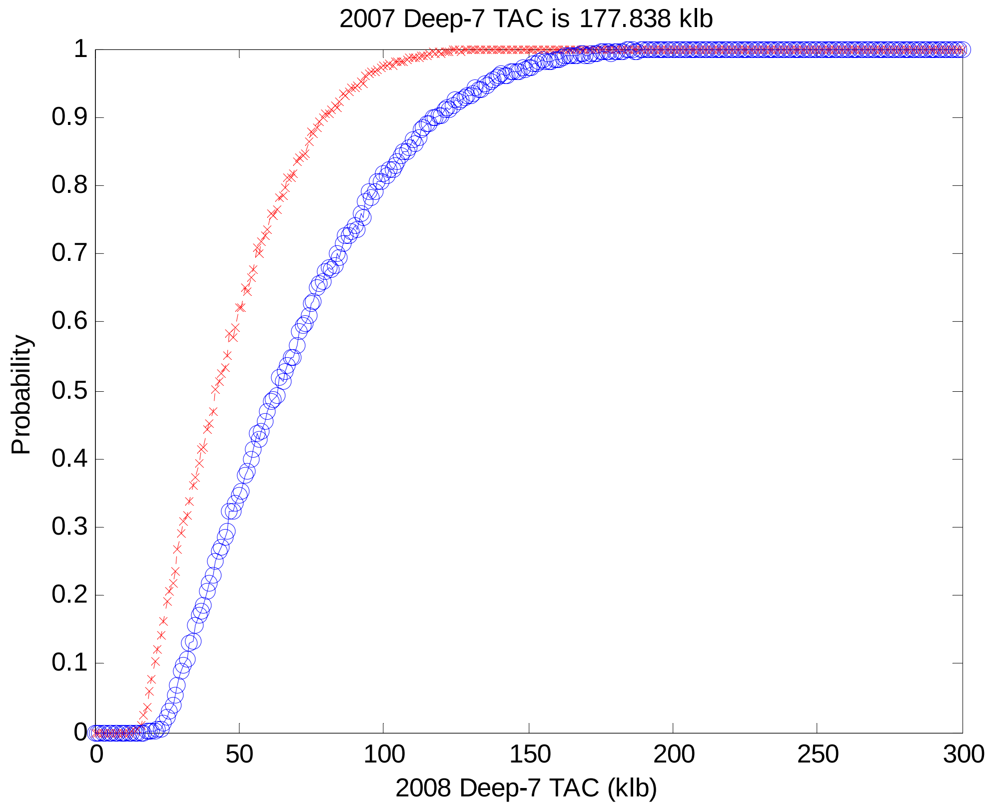

Figure 7.2.--Results of the sensitivity analysis to show the effect of decreasing the simulated proportion of Deep-7 bottomfish species by 25% including the probability of archipelagic overfishing (open circle, $P_r(F_{2008} > F_{\text{TARGET | FEASIBLE}})$) and the probability of overfishing in the MHI (cross, $P_r(F_{2008} > F_{\text{MSY | FEASIBLE}})$) as a function of the total allowable commercial catch of Deep-7 bottomfish species in the MHI in 2008.

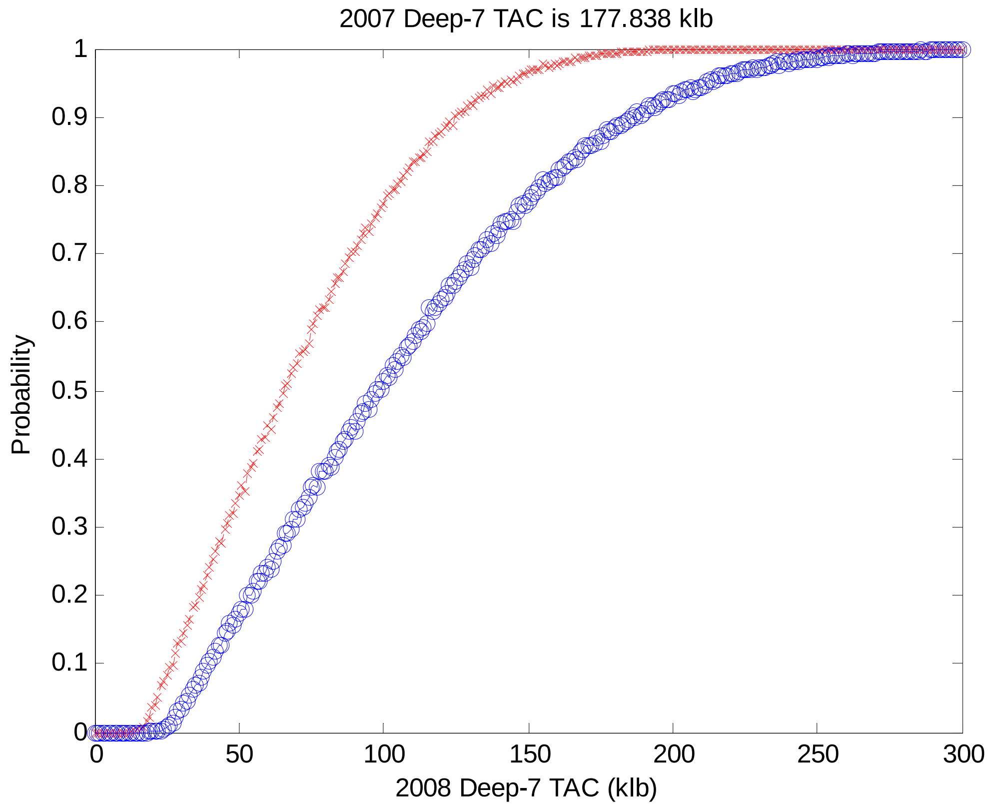

Figure 7.3.--Results of the sensitivity analysis to show the effect of increasing the CV of the simulated proportion of Deep-7 bottomfish species by 100% including the probability of archipelagic overfishing (open circle, $P_r(F_{2008} > F_{\mathrm{TARGET\,|\,FEASIBLE}})$) and the probability of overfishing in the MHI (cross, $P_r(F_{2008} > F_{\mathrm{MSY\,|\,FEASIBLE}})$) as a function of the total allowable commercial catch of Deep-7 bottomfish species in the MHI in 2008.

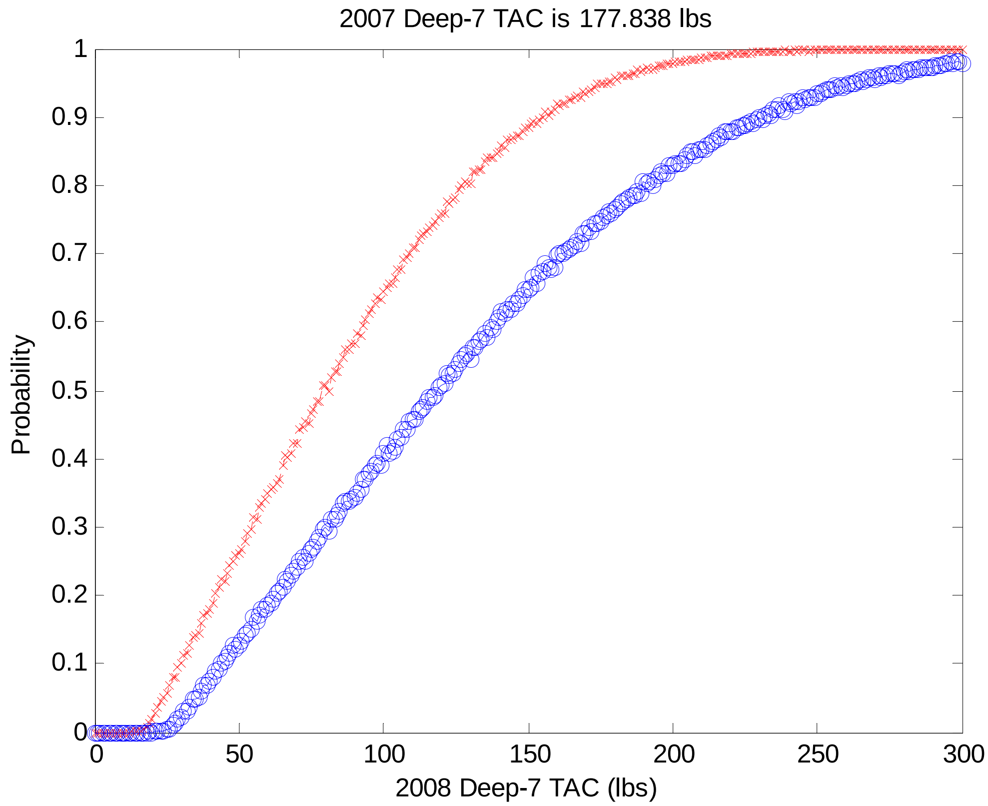

Figure 8.1.--Results of the sensitivity analysis to show the effect of increasing the estimate of carrying capacity by 50% including the probability of archipelagic overfishing (open circle, $P_r(F_{2008} > F_{\mathrm{TARGET\,|\,FEASIBLE}})$) and the probability of overfishing in the MHI (cross, $P_r(F_{2008} > F_{\mathrm{MSY\,|\,FEASIBLE}})$) as a function of the total allowable commercial catch of Deep-7 bottomfish species in the MHI in 2008.

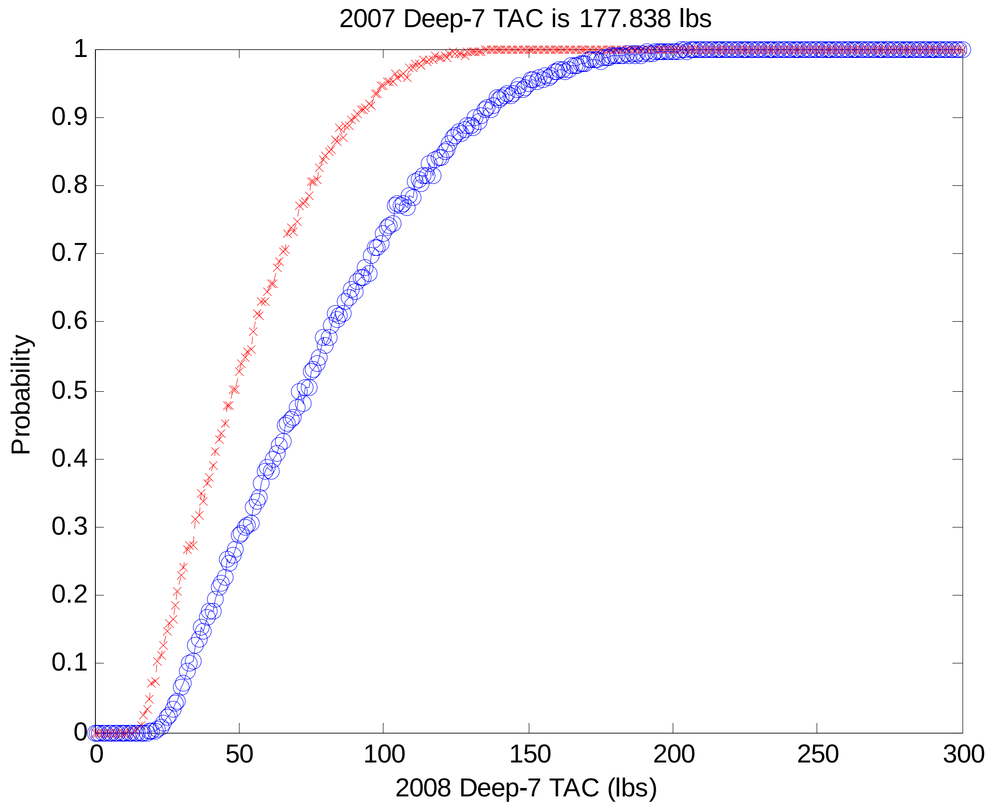

Figure 8.2.--Results of the sensitivity analysis to show the effect of decreasing the estimate of carrying capacity by 33% including the probability of archipelagic overfishing (open circle, $P_r(F_{2008} > F_{\text{TARGET | FEASIBLE}})$) and the probability of overfishing in the MHI (cross, $P_r(F_{2008} > F_{\text{MSY | FEASIBLE}})$) as a function of the total allowable commercial catch of Deep-7 bottomfish species in the MHI in 2008.

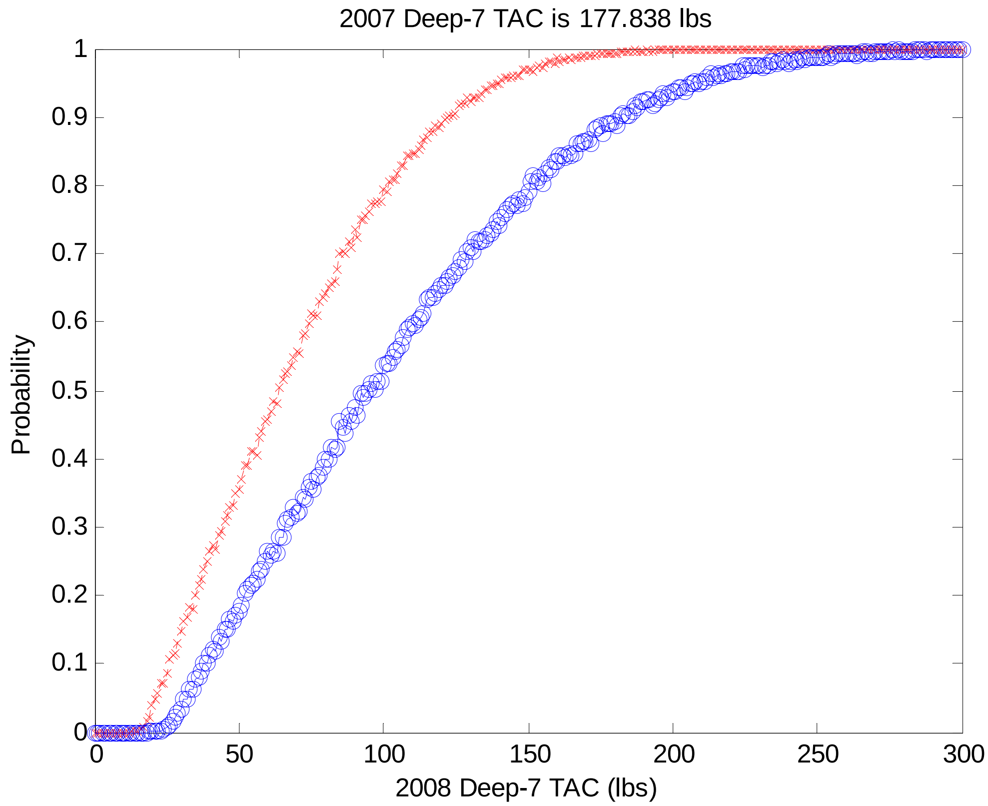

Figure 8.3.--Results of the sensitivity analysis to show the effect of increasing the CV of simulated carrying capacity by 100% including the probability of archipelagic overfishing (open circle, $P_r(F_{2008} > F_{\mathrm{TARGET}\,|\,\mathrm{FEASIBLE}})$) and the probability of overfishing in the MHI (cross, $P_r(F_{2008} > F_{\mathrm{MSY}\,|\,\mathrm{FEASIBLE}})$) as a function of the total allowable commercial catch of Deep-7 bottomfish species in the MHI in 2008.