Application of Stock Reduction Analysis to goliath grouper (*Epinephelus itajara*) off southeastern U.S.A, 1918 – 2009

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1. Introduction

Stock Reduction Analysis (SRA) is a removal method asking how large the stock (including recruitment levels) needs to have been in order to explain and sustain the historical catches (landings + discards) while producing the observed changes in relative abundance. This is the reason why the historical catch and abundance indices are the key inputs for SRA models in order to predict plausible recruitment and stock trajectories and the current stock status.

SRA is basically appropriate for data-poor fisheries. However, even in data-rich situations, Walters *et al.* (2006) stress the need to make the SRA methodology a core component of the assessment procedures owing to its capability to potentially challenge the more complex assessment models especially about historical recruitment changes.

This note is devoted to the application of the stochastic version of SRA, StochasticSRA (Walters *et al.* 2006), to the population of goliath grouper inhabiting the southeastern waters off the U.S.A. The objective is two-fold. First is to reconstruct the possible abundance and exploitation rate trajectories for this population in light of the estimated or assumed time series of commercial removals over 1918-2009. Second is to determine the current stock status and estimate the management parameters, i.e., the maximum sustainable yield (*MSY*) and the fishing mortality associated with *MSY* (F_{MSY}, expressed as exploitation rate, U_{MSY}) under the assumption that *MSY* is the reference point against which the status of goliath grouper could be judged.

2. Materials and methods

StochasticSRA (Walters *et al.*, 2006) was run for an age-structured population of goliath grouper (ages 1-37) inhabiting the U.S. southeastern waters. StochasticSRA is a Bayesian implementation of an age-structured SRA model that assumes that:

The numbers (*N*) over age (*a*) and year (*t*) change following the survival equation:

$$N_{a+1,t+1} = N_{a,t} S_{a,t} \left(1 - v_{a,t} U_t\right) \quad (1)$$

where $S_{a,t} = e^{-M_{a,t}}$ is the natural survival rate by age and year (*M* is natural mortality); $v_{a,t}$ is the relative vulnerability of fish to fishing by age and year; and U_t is the exploitation rate on fully vulnerable fish in year *t*. U is calculated by dividing the observed catch by the predicted total vulnerable biomass.

The recruitment is log-normally distributed; its rates $\mathrm{R_t} = \mathrm{N_{1,t}}$ are estimated from annual egg production $\mathrm{E_t} = \sum_a \mathrm{N_{a,t}} \mathrm{f_a}$ (where $\mathrm{f_a}$is the relative fecundity at age a) according to a Beverton-Holt Stock-Recruitment (SR) function of the form:

$$R_{t+1} = \frac{recK(R_0/E_0)E_t}{1+\frac{(recK-1)}{E_0}E_t} \tag{2}$$

Here, *E* = eggs; $recK$ is the Goodyear recruitment compensation ratio; E_0 is average annual egg production; and R_0 is the unfished population recruitment. R_0, $recK$, and E_0 are the SR leading parameters while the management quantities generated by the StochasticSRA runs are the maximum sustainable yield (*MSY*) and the corresponding exploitation rate, U_{MSY}.

With StochasticSRA, an age-structured population model projects the population abundance each year given the observed annual catch (in kg) removals, a tuning index, population life-history information, eventual fishery management policies, a SR function with a set of lognormal recruitment anomalies, an initial age structure, and a vulnerability schedule. To estimate the leading parameters of the SR relation, StochasticSRA first assumes uniform Bayesian priors for *MSY* and U_{MSY}, then randomly samples these parameters many times from priors in such a way that the pairs chosen do not lead the population to extinction over the course of the projection while supporting the observed annual catches and fitting a series of relative abundance. To account for anomalies, a very large number of simulations are made with anomaly sequences chosen from normal prior distributions. The resulting sample of possible historical stock trajectories is resampled using sampling-importance resampling (SIR), or a large sample is taken using MCMC. In practice, StochasticSRA uses SIR to create an approximate distribution from the prior distribution to use as the starting points for the MCMC simulation of the posterior distribution for *MSY* and U_{MSY}. During the sampling process, the choice of each combination of *MSY* and U_{MSY} values is affected by the likelihood that these values result in a fit to the abundance index time series. This way the relative distribution of the "accepted" *MSY* and U_{MSY} pairs describe the likelihood profiles of *MSY* and U_{MSY}, thereby representing the uncertainty associated with these management parameters. Additionally, StochasticSRA may produce realistic uncertainty (i.e., MCMC posterior distributions) in the SR parameters, current stock condition (B_{2009}/B_0) and harvest rate (U_{2009}/U_{MSY}), and in the stock and exploitation rate trajectories.

Two base-run scenarios were considered. For each scenario, the input fishery data consisted of estimated commercial landings (1918-1990) and an arbitrary time-invariant amount of 2,000 kg assumed to be due to release mortality over 1991-2009. The model-estimated vulnerable biomass was tuned with the abundance index of juvenile goliath grouper (1975-2009) obtained using the ENP creel survey (Cass-Calay, 2010). The analysis also required some unverifiable assumptions and a variety of life history information about variability of recruitment and growth, vulnerability to the fishery, variability and magnitude of the current (i.e., 2009) stock biomass and exploitation rate, variance associated with the abundance index, and uncertainty about management parameters (Table 4.1). The growth parameters are those that were developed during the DW using the von Bertlanffy growth function (L_∞ = 222 cm *TL*; *K* = 0.094*year^{-1}; and a_0 = -0.68 years), with an average coefficient of variation (*cv*) for mean length at age of 0.11 and a theoretical weight at 100 cm of 19.3 kg. The length at maturity was 127.5 cm *TL* [i.e., the mean of the lower and upper bounds of the length range (120 – 135 cm *TL*) within which female goliath groupers first mature; Bullock *et al.*, 1992]. The standard deviation (*SD*) for recruitment anomalies was the value used by Porch *et al.* (2006), i.e., 0.98 fish; no autocorrelation among recruitment estimates was considered. Relative vulnerability at age (selectivity) corresponded to values also developed by Porch *et al.* (2006) using a logistic function for the Everglades National Park (ENP) angler creel survey data. Here, however, fish of ages 9-36 were assumed to be equally and fully vulnerable to the fishery. In the absence of information about the absolute values and variability of the current stock biomass and exploitation rate, these parameters were initialized with guesses of 50,000 kg (*SD* = 5,000,000 kg) and 0.05 (*SD* = 0.05). Natural survival rate (and hence, natural mortality) was treated as age-independent and was sampled for each simulation trial from a uniform prior distribution with *S* ranging between 0.8 and 0.95; this range includes the overall natural survival rate of 0.89*year^{-1} (i.e., M = 0.12*year^{-1}) that was estimated during the DW. Given that goliath grouper has apparently experienced severe historical depletion, simulation trials for *MSY* and U_{MSY} ranged from 13,740 kg to 80,000 kg and from 0.02 to 0.25, respectively. The lower and upper bounds of *MSY* corresponded to 10% and about 58% of the observed maximum historical catch of about 137,401 kg, respectively. The SIR sampling routine was allowed to execute 100,000 trials from priors of various parameters and the model runs were conducted assuming a variance of recruitment index of 0.5. Forward-projection of population biomass was performed over 2010-2019 assuming a future, constant total allowable catch of 10,000 kg. While the previous StochasticSRA configuration relates to the primary base-run scenario (henceforth called scenario 1), the second one (scenario 2) was only different in that it used the default *SD* of 0.5 for recruitment anomalies, with an upper bound of 68,700 kg for *MSY* and the variance of abundance index equal to 1.

In practice, MCMC convergence with StochasticSRA is determined by manual settings of "parameter" and "anomaly" steps, aimed to bound the maximum sizes of random parameter changes tested by the MCMC sampling procedure – and of course, of the *MSY* and U_{MSY} ranges; it is usually most rapid when the acceptance rate is around 20% (Carl Walters, UBC, personal communication). The defaults of these steps are 0.2 and 0.1, respectively. Setting lower steps and providing too wide ranges to *MSY* and U_{MSY} typically cause higher acceptance rates for the defaults (> 40%) but slower movement over the parameter space – accepting too many tiny moves - and conversely for higher steps. For this analysis, the default for "anomaly" step was kept; however, the "parameter" step and the previous bounds of *MSY* and U_{MSY} were set at values in such a way to ensure acceptance rates of 20 – 40%.

Three million MCMC trials were conducted and yielded approximately one million accepted samples. Preliminarily, the last 250,000 accepted samples were used for these analyses (i.e., the burn-in period was set to 750,000 samples). Burn-in appears to be on the order of 80,000 samples from inspection of the trace plots, so additional samples could be gained from the runs using a shorter burn-in period. Autocorrelation among the samples (using the R package 'boa') was not assessed initially for these preliminary analyses, but is significant out to lags of around 1,000 samples for most of the variables in the MCMC output. If further analyses are planned, more trials should be run, a shorter burn-in period to gain more samples should be used, and thinning the samples at a rate of 1,000 to reduce autocorrelation would be advisable.

3. Results and discussion

StochasticSRA primarily serves to derive likely estimates of important management parameters, namely *MSY* and U_{MSY}, owing to the persistence of population exploitation over time. The estimated trends in and distribution of vulnerable biomass and ENP index of abundance are contrasted to help estimate the likely values of the aforementioned parameters. The fit of the StochasticSRA model fairly matches the observed ENP index to the trends in estimated vulnerable biomass except for some of the most recent extreme values (Figure 5.1a) when the variation in recruitment anomalies was set higher (i.e., to 0.98). The fit to the ENP index was not as good when the variation in recruitment anomalies set to 0.5 (Figure 5.1b).

Figure 5.1 depicts the population biomass resulting from the most likely parameter combinations found during the MCMC search. Overall, goliath grouper biomass declined over 1918 – 1990, but generally stabilized across the 1950s – 1970s probably because of the lack of contrast in landings. The biomass trends since 1975 were largely driven by those in the ENP index: biomass dropped to historical lower levels by the end of the 1980s, and rebounded abruptly since then. The modal estimates of biomass (small black dots in Figure 5.1) were similar for both run scenarios except prior to the 1940s (when the runs with scenario 2 yielded optimistic estimates – Figure 5.1b), but the magnitude of the best estimates of vulnerable biomass was sensitive to the hypothesis made about the SD for the recruitment anomalies (Figure 5.1a). In fact, runs with scenario 1 resulted in optimistic best biomass estimates except prior to 1945.

Regarding estimated exploitation rates (Figures 5.2 and 5.3), they were low and stable until the mid-1930s (0.03 – .05); increased since then until 1950 (0.05 – 0.20) with a peak in the mid-1940s; varied without trends during the 1950s – mid-1970s at moderate levels for runs with scenario 1 (0.06 – 0.35). Annual exploitation rates reached their peak in scenario one in 1988 (Figure 5.2a), but scenario two did not show a pronounced trend up to 1988 (Figure 5.3b). Allowance of small and constant amount of goliath grouper released dead (i.e., allowing for a release mortality of 5%) after 1990 resulted in very low exploitation rates (0 to less than 0.01 according to run scenarios).

Estimates of the posterior distributions from MCMC simulations of the management parameters are in Figures 5.4 and 5.5. The preliminary estimates and most likely stock condition are summarized in Table 4.2. In general, MSY and U_{MSY} were well estimated and were robust whatever the hypothesis made on recruitment variability. In contrast, the current stock condition reflected in the biomass ratio B_{2009}/B_{1918} is sensitive to such hypotheses. This is because of the differences in biomass estimates and trajectories alluded to previously especially in early years (Figures 5.1). Specifically, use of $SD = 0.98$ for recruitment anomalies led to a more optimistic view of the current goliath grouper stock. Finally, noticeable is how, relative to the initial goliath grouper stock level, the stock biomass had decreased to very low levels in 1990 (Figures 5.1a and b; B_{1990}/B_{1918} ratio in Table 4.2). However, upon the establishment of a moratorium on harvest to allow the population time to rebuild, the stock appears to be recovering as reflected in B_{2009}/B_{1918} ratio that is approaching one (Table 4.2).

All in all, it is worth keeping in mind that SRA is a removal method. Its outcomes largely depend on the completeness and reliability of historical catches from all fishery sectors. The current results may therefore have been particularly impeded by lack of harvest estimates for the recreational fishery. The analyses also suggest that goliath grouper in the southeastern waters of the U.S. are highly vulnerable to overexploitation, and that variations in recruitment probably would play a large role in the population's rate of recovery.

4. Tables

Table	Description
4.1	Input parameters used to run the stochastic stock reduction analysis (StochasticSRA) for goliath grouper population inhabiting the southeastern waters of U.S.A. All lengths are in centimeters; all weights are in kilograms. **Parameter values in parentheses are specific to the second run scenario (see text).**
4.2	Preliminary estimates for management parameters and indicators of goliath grouper stock condition off the southeastern U.S.A. from stock-reduction analyses.

Table 4.1. Input parameters used to run the stochastic stock reduction analysis (StochasticSRA) for goliath grouper population inhabiting the southeastern waters of U.S.A. All lengths are in centimeters; all weights are in kilograms. **Parameter values in parentheses are specific to the second run scenario (see text).**

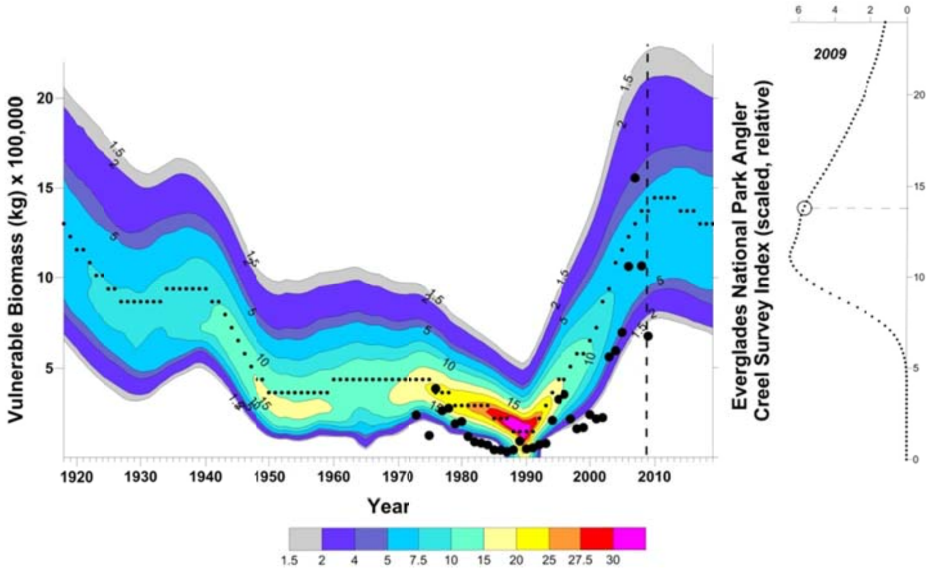
Parameters	Values	Source
Recruitment: standard deviation (SD)	0.98 (0.5)	Porch et al. (2006)
Recruitment: autocorrelation	0	
VB growth: K (year^{-1})	0.094	Data Workshop (DW)
VB growth: L_∞	222	DW
VB growth: a_0	-0.68	DW
VB growth: CV length at age	0.11	DW
Weight at 100 cm	19.267	DW
Length at maturity	127.5	Bullock et al. (1992)
Bhat (2009)	50,000	
SD of Bhat (2009)	5,000,000	
Uhat (2009)	0.05	
SD of Uhat (2009)	0.05	
Future TAC	10,000	
Future U	0	
MSY: minimum	13,740	
MSY: maximum	80,000 (68,700)	
U: minimum	0.02	
U: maximum	0.25 (0.2)	
Natural survival: minimum (year^{-1})	0.8	
Natural survival: maximum (year^{-1})	0.95	
Variability of abundance index	0.5 (1)	

Table 4.2. Preliminary estimates for management parameters and indicators of goliath grouper stock condition off the southeastern U.S.A. from stock-reduction analyses.

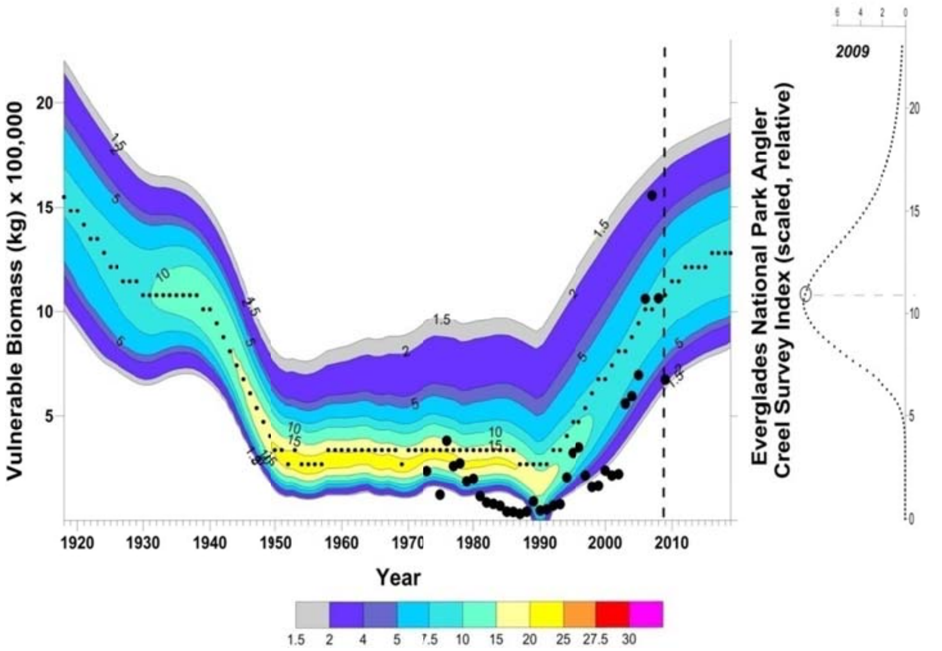
	Run-1 (SD = 0.98)	Run-2 (SD = 0.5)
Parameter estimate		
• U_{MSY}	0.147	0.087
• MSY (kg)	0.057×10^6	0.049×10^6
Biomass (kg)		
• 1918	1.299×10^6	1.214×10^6
• 1990	0.072×10^6	0.067×10^6
• 2009	1.082×10^6	1.011×10^6
Biomass and exploitation ratios		
• U_{2009}/U_{MSY}	0.0	0.0
• B_{1990}/B_{1918}	0.06	0.09
• B_{2009}/B_{1918}	0.83	0.65

5. Figures

Figure	Description
5.1	Temporal trajectories (median vulnerable biomass; small black dots) and distributions of estimated vulnerable biomass from StochasticSRA runs for goliath grouper off the southeastern U.S.A, 1918 – 2009, with the 1975-2009 ENP index of abundance (large black dots) superimposed. a). first run scenario (SD for recruitment anomalies = 0.98); b.) second run scenario (SD for recruitment anomalies = 0.5).
5.2	Annual estimates for exploitation rate (U = C/B) and calculated fishing mortality rates (from estimates of U) for goliath grouper off the southeastern U.S.A, 1918 – 2009, obtained from Stochastic SRA runs, with scenarios assuming the standard deviations for recruitment anomalies of 0.98.
5.3	Annual estimates for exploitation rate (U = C/B) and calculated fishing mortality rates (from estimates of U) for goliath grouper off the southeastern U.S.A, 1918 – 2009, obtained from Stochastic SRA runs, with scenarios assuming the standard deviations for recruitment anomalies of 0.5.
5.4	Stock Reduction Analysis of goliath grouper commercial landings. Results are the model configuration with the standard deviation for recruitment anomalies set to 0.98. Sample distribution estimates for MSY and U_{MSY} from last 250,000 of 1 million accepted chains out of 2.65 million MCMC trials. Data were binned and contoured. Bounds on MSY were based upon historical commercial landings, and ranged from 13,740 to 80,000 kg, and on U_{MSY} from 0.02 to 0.25. Separate plots of frequencies from MCMC runs for MSY, U_{MSY}, U_{2009}/U_{MSY}, log(RecK), and steepness (calculated from RecK) are also presented.
5.5	Stock Reduction Analysis of goliath grouper commercial landings. Results are the model configuration with standard deviation for recruitment anomalies set to 0.05. Sample distribution estimates for MSY and U_{MSY} from last 250,000 of 1 million accepted chains out of 2.65 million MCMC trials. Data were binned and contoured. Bounds on MSY were based upon historical commercial landings, and ranged from 13,740 to 80,000 kg, and on U_{MSY} from 0.02 to 0.25. Separate plots of frequencies from MCMC runs for MSY, U_{MSY}, U_{2009}/U_{MSY}, log(RecK), and steepness (calculated from RecK) are also presented.



a. Vulnerable biomass by year, 1918-2009 plus projected years. Recruitment standard deviation set to 0.98 based on a meta-analysis of data in Myers et al. (1999) by Porch et al. (2006).



b. Vulnerable biomass by year, 1918-2009 plus projected years. Recruitment standard deviation set to 0.50 for a sensitivity run.

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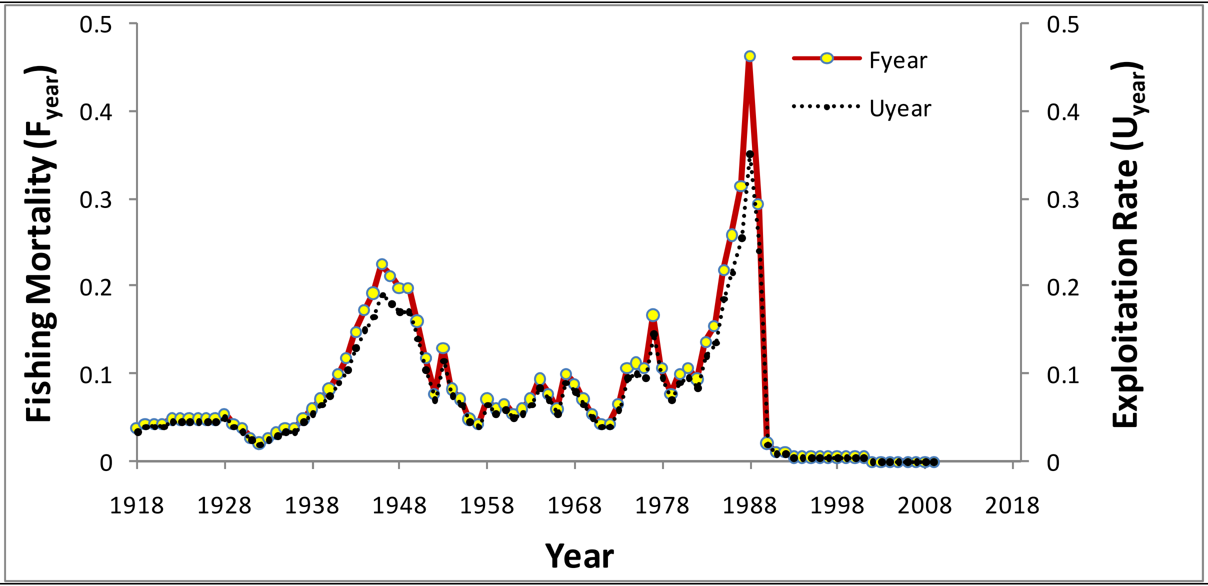
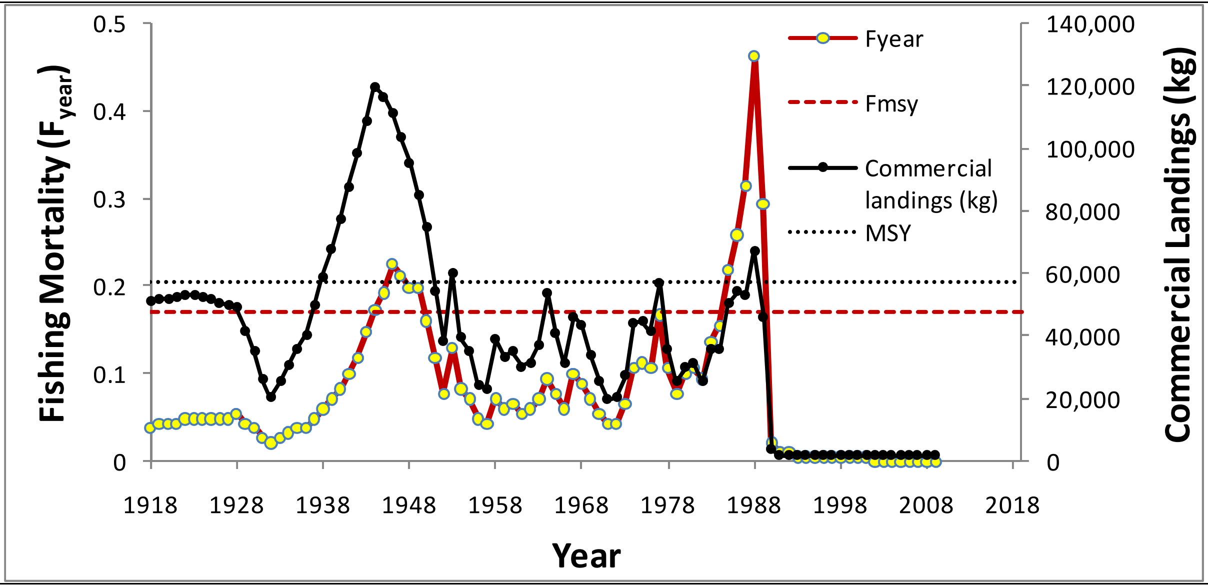
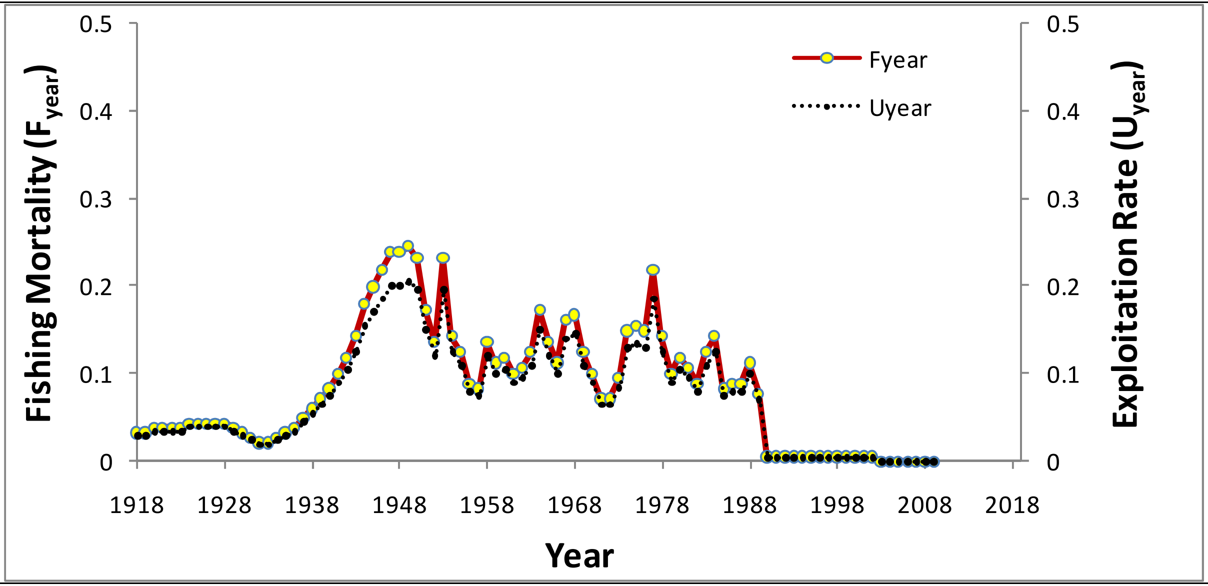


a. Estimated exploitation rates (U) and fishing mortality rates (F; calculated from U) by year.



b. Commercial landings series (1918-2009), and fishing mortality rate per year (calculated from exploitation rate (U) by year in relation to MSY and F_{MSY}.

Figure 5.2. Annual estimates for exploitation rate (U = C/B) and calculated fishing mortality rates (from estimates of U) for goliath grouper off the southeastern U.S.A, 1918 – 2009, obtained from Stochastic SRA runs, with scenarios assuming the standard deviations for recruitment anomalies of 0.98.



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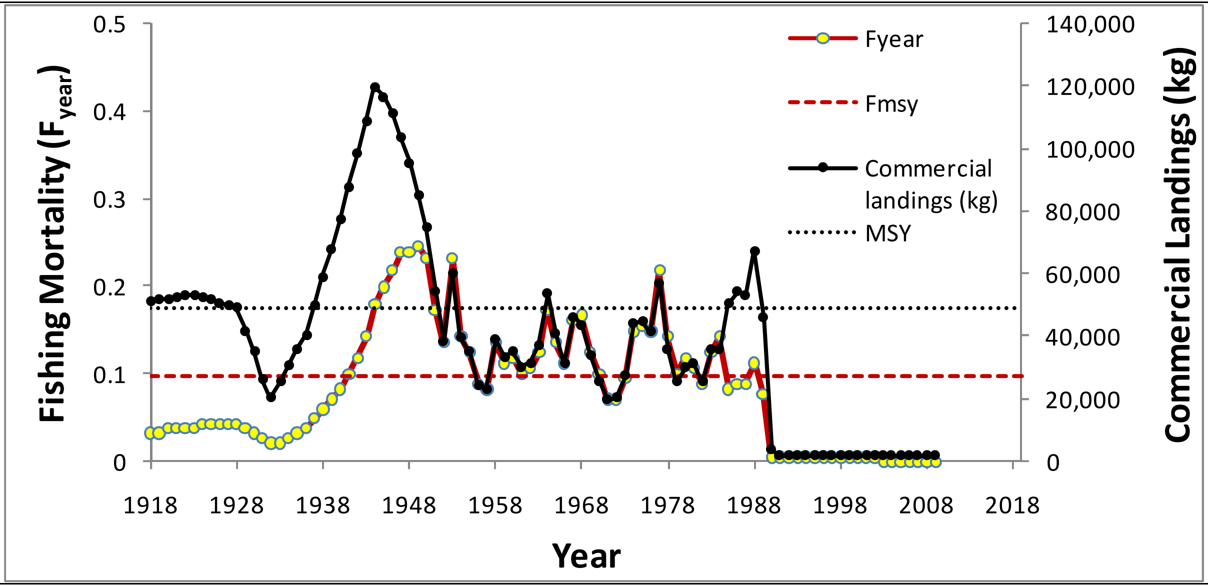

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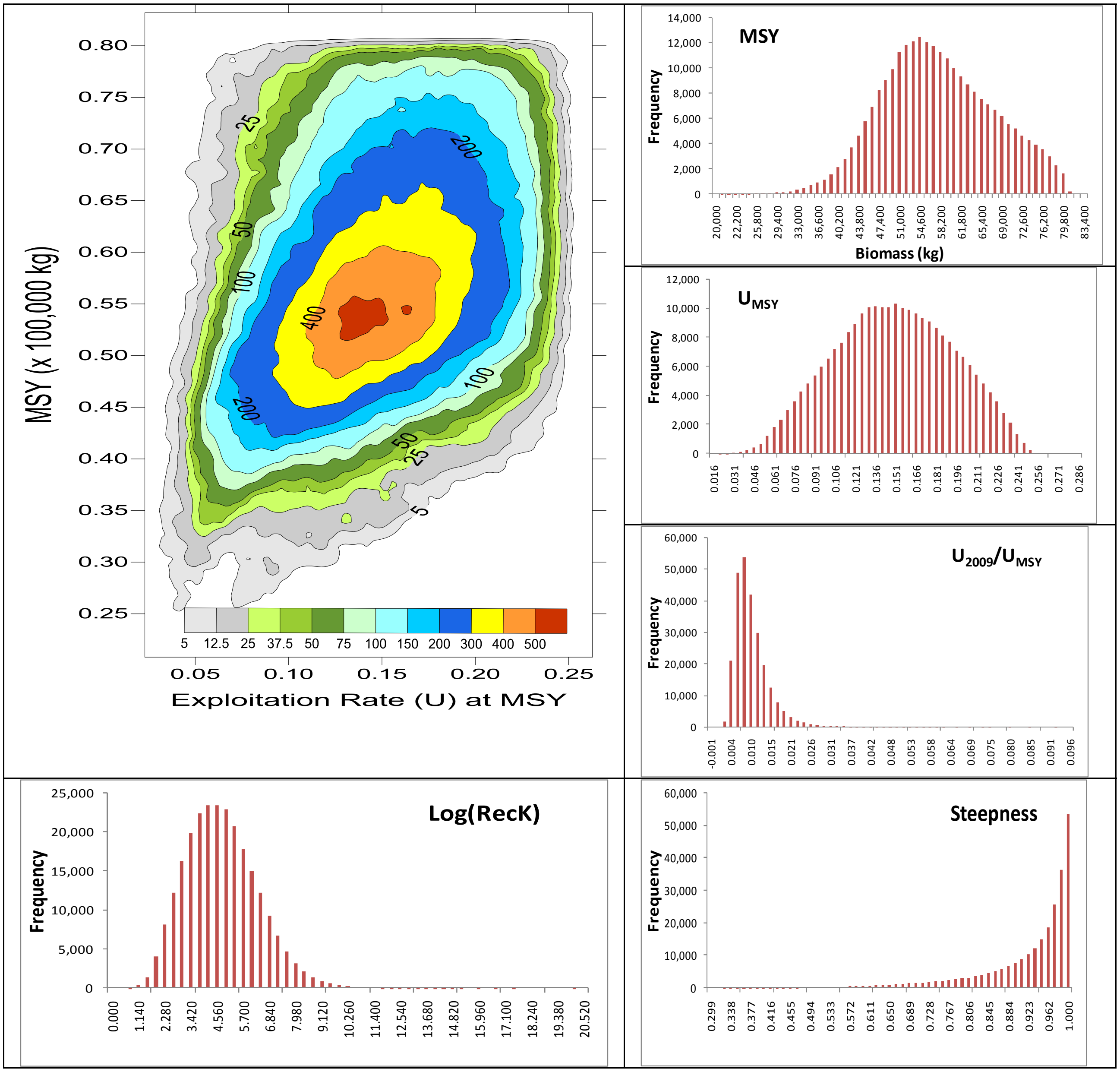

Figure 5.4. Stock Reduction Analysis of goliath grouper commercial landings. Results are the model configuration with the standard deviation for recruitment anomalies set to 0.98. Sample distribution estimates for MSY and U_{MSY} from last 250,000 of 1 million accepted chains out of 2.65 million MCMC trials. Data were binned and contoured. Bounds on MSY were based upon historical commercial landings, and ranged from 13,740 to 80,000 kg, and on U_{MSY} from 0.02 to 0.25. Separate plots of frequencies from MCMC runs for MSY, U_{MSY}, U_{2009}/U_{MSY}, log(RecK), and steepness (calculated from RecK) are also presented.

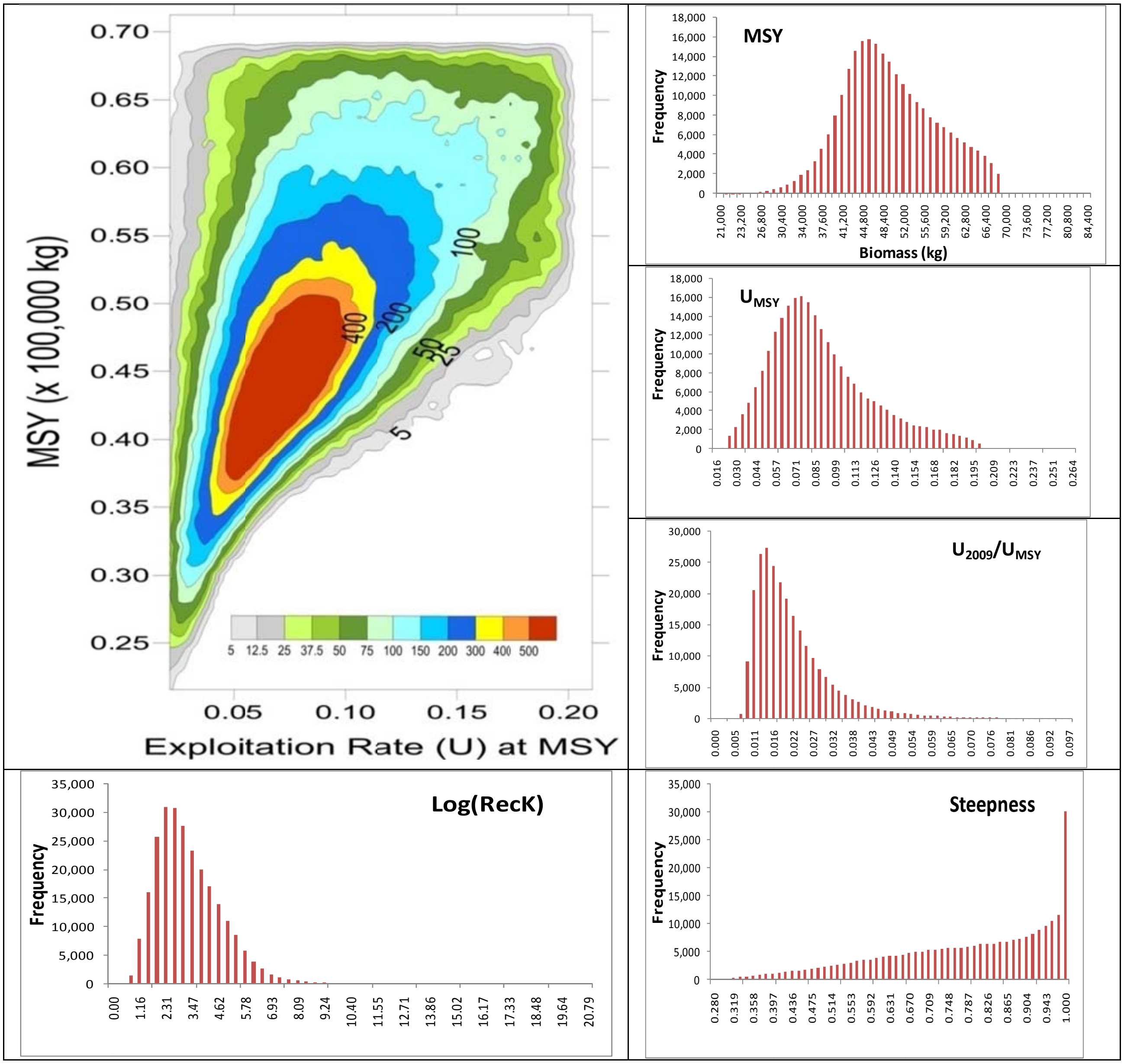

Figure 5.5. Stock Reduction Analysis of goliath grouper commercial landings. Results are the model configuration with standard deviation for recruitment anomalies set to 0.05. Sample distribution estimates for MSY and U_{MSY} from last 250,000 of 1 million accepted chains out of 2.65 million MCMC trials. Data were binned and contoured. Bounds on MSY were based upon historical commercial landings, and ranged from 13,740 to 80,000 kg, and on U_{MSY} from 0.02 to 0.25. Separate plots of frequencies from MCMC runs for MSY, U_{MSY}, U_{2009}/U_{MSY}, log(RecK), and steepness (calculated from RecK) are also presented.

6. References

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