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Fishery Management Analyses for Reef Fish in Biscayne National Park: Bag and Size Limit Alternatives

Natural Resource Technical Report NPS/NRPC/WRD/NRTR — 2007/064

ON THE COVER
Recreational Fishing in Biscayne National Park
Photograph by: James Tilmant

Fishery Management Analyses for Reef Fish in Biscayne National Park: Bag and Size Limit Alternatives

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Introduction

The Florida Keys coral reef ecosystem, including Biscayne National Park, is inhabited by more than 400 fish species and supports multibillion-dollar fishing and tourism industries (Johns et al. 2001). Over recent decades, reef fish populations have declined owing to a variety of human-related stressors, most notably fishing and habitat alterations (Ault et al. 1998, 2005a). These fishes are intensively exploited (Ault et al. 1998, 2001, 2002, 2005b) by a rapidly growing human population and recreational fishing fleet (**Figure 1**), but fishing mortality affects the species differentially (Musick et al. 2000; Coleman et al. 2000).

Biscayne National Park (BNP) is in the process of developing a new General Management Plan (GMP) to set resource management directions for the Park for the next 15-20 years. The region was set aside under Park stewardship to conserve some of our nation's most prized and significant natural, historic, and cultural resources, and to provide for their recreational enjoyment. BNP offers one of the most promising opportunities to contribute to not only the conservation of fish species and their habitats, but also to help ensure that the tradition of quality fishing experiences can continue for generations to come. Within the aegis of the GMP, the Park has also begun development of a Fisheries Management Plan (FMP) as a long-term guide to management decisions related to sustainable fish and shellfish stocks within the park. The FMP is being developed cooperatively by the park and the Florida Fish and Wildlife Conservation Commission (FWC) with input from members of government agencies, area universities, and the public. The FMP addresses, to the extent possible, the status of fish populations in the park, describes desired conditions of fisheries and fish habitat, and details ways to reach or maintain those conditions. Fishery management concerns are really two-fold: (1) declines in the abundance of fish; and, (2) loss of quality fishing opportunities. This report is focused on evaluation of fisheries management alternatives to meet the Park's resource management goal of sustainable fisheries resources.

Our research focus has been to quantify the reef fish community response to exploitation in the Florida Keys (Ault et al. 1998, 2005b), and to evaluate alternative management strategies that may help build sustainable fisheries. Two principal data sources have been utilized: (1) fishery-independent, synoptic diver-based reef fish visual census (RVC) surveys of species composition, abundance, and size structure, including target and non-target species (Bohnsack et al. 1999; Ault et al. 2002); and, (2) fishery-dependent, BNP creel census surveys of target exploited species for species composition, abundance, and size structure. The principal stock assessment indicator variable to quantify population status was average length (Lbar) of the exploited part of the population, which is a metabolic-based indicator that is highly correlated with population size (Beverton and Holt 1957; Ricker 1963; Pauly and Morgan 1987; Ault and Ehrhardt 1991; Ehrhardt and Ault 1992; Kerr and Dickie 2001; Ault et al. 2005b). For exploited species, Lbar reflects the rate of fishing mortality. Because body size is broadly correlated with trophic level, large individuals and species are often top predators. Biomass declines of these animals are usually the most marked community response to exploitation (Ault et al. 1998; Pauly et al. 1998; Gislason and Rice 1998; Kerr and Dickie 2001).

We used abundance and size structure data from underwater visual observations and angler-intercept creel surveys for a suite of exploited reef fishes as a basis to estimate exploitation status for the Florida Keys ecosystem and Biscayne National Park. Our objective was to apply robust statistical algorithms using abundance, size composition, and average size data to estimate mortality simultaneously for a suite of reef fish species under the same levels of nominal fishing effort to provide a first-order estimate of the reef fish community response to exploitation. Once exploitation levels were identified, then alternative fishery management actions such as bag and size limits were evaluated in terms of their efficacy to achieve sustainable populations and meet Park resource management goals.

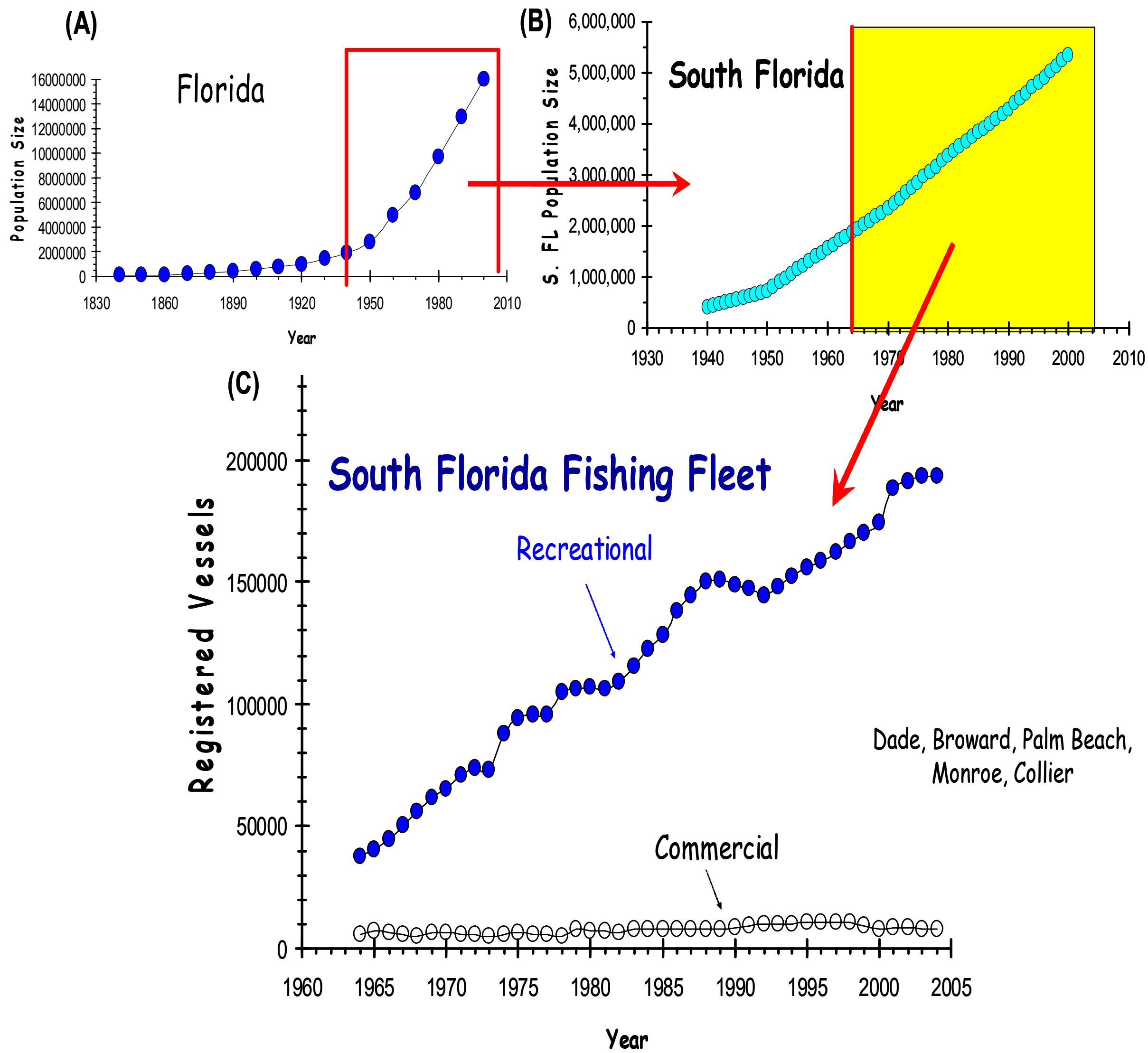

Figure 1.- Growth of: (A) Florida's human population from 1840-2000; (B) south Florida region human population 1940-2000; and (C) south Florida commercial and recreational fishing fleets from 1964-2004.

Alternative Fishery Management Actions Considered

Improvements in the reef fish stocks at Biscayne can ultimately only be made through either a reduction in the fishing mortality rate that is presently occurring or, in some cases, by shifting harvest to larger size fish thereby allowing an increase in reproduction to occur. A reduction in fishing mortality could be achieved through:

1. A reduction in the overall amount of angler effort allowed to fish within the Park,
2. Removal of some of the fish population from exploitation pressures (i.e. creating spatial closures), or
3. A reduction in the number of fish that anglers take (harvest) from among those caught through reduced bag limits.

A shift in harvest to larger fish could be achieved through an increase in size limits.

An increase in the minimum legal size may result in a temporary reduction in the number of fish harvested (and thus fishing mortality) while the newly protected fish grow to the new size limit. However, once fish in the population reach the new minimum size limit, overall fishing mortality rates are likely to be similar to earlier levels reflective of the current level of fishing effort. As a result, the spawning potential of the stock may be substantially improved because of the increased ages at which fish are first subjected to harvest, thus building up the stock's reproductive capacity.

Within this study we have focused only on the potential benefits that could be gained from either more restrictive size and/or bag limits within the fisheries and our analysis is limited to these management alternatives.

Methods

Stock Assessments

Table 1. provides life history parameters for Florida reef fishes taken from Ault et al. (1998, 2005b) and Claro et al. (2001). Natural mortality rate (M) was estimated from lifespan, applying the procedure of Alagaraga (1984). Total instantaneous mortality rate (Z) was estimated using the method of Ehrhardt and Ault (1992), which is based on length at first capture (L_c), maximum length in the stock (L_λ), and average length in the "exploited stock" (Lbar, i.e., those individuals equal to and/or larger than the minimum size limit), in conjunction with the Bertalanffy growth parameters K and L_∞. Estimates of Z were computed using an iterative numerical algorithm (LBAR; Ault et al. 1996; FAO 2003), and annual estimates of fishing mortality rate (F) were obtained by subtracting M from Z. All input values are given in **Table 1** (from Ault et al. 2005b).

Table 1.- Life history input parameters and estimated population parameters for Florida reef fish (Table 2 from Ault et al. 2005b). Maximum ages a_λ used in this analysis were: 29 yr for red grouper (SEDAR 2006, S. Callay, pers. comm..); 33 yr for black grouper (Crabtree & Bullock 1998); 29 yr for mutton snapper (Burton 2002); 28 yr for gray snapper (Fischer et al. 2003); and, 18 yr for white grunt (Murie and Parkyn 2005).

Table 2. Life history input parameters and estimated population parameters for Florida reef fish (a_0 and W_∞, parameters of the von Bertalanffy equation; L_m, length at maturity; B_{msy}, expressed as proportion of unfished stock biomass; for other symbols see text).

	Input parameters								Estimated parameters					
Species	a_λ (y)	K (y^{-1})	L_∞ (mm)	a_0 (y)	W_∞ (kg)	L_m (mm)	L_c (mm)	L_λ (mm)	M (y^{-1})	Lbar (mm)	F (y^{-1})	SPR (%)	B_{msy}	B/B_{msy}
Groupers (Serranidae)														
Rock hind (*Epinephelus adscensionus*)	12	0.19	486	−2.16	2.27	336	200	454	0.25	288	0.19	31	0.22	1.44
Graysby (*E. cruentatus*)	15	0.13	415	−0.94	1.14	198	200	363	0.20	233	0.56	36	0.63	0.57
Red hind (*E. guttatus*)	17	0.21	393	−0.83	1.09	251	180	383	0.18	251	0.24	24	0.34	0.70
Goliath grouper (*E. itajara*)	37	0.05	2 394	−3.62	244.9	978	600	2 178	0.08	1 161	0.04	53	0.27	1.96
Red grouper (*E. morio*)	17	0.15	938	−0.10	11.9	437	500	869	0.18	592	0.41	27	0.47	0.57
Nassau grouper (*E. striatus*)	17	0.15	940	−1.08	12.0	480	600	870	0.18	635	1.19	13	0.47	0.26
Black grouper (*Mycteroperca bonaci*)	20	0.16	1 200	−0.30	31.6	597	600	1 153	0.15	709	0.60	10	0.41	0.26
Scamp (*M. phenax*)	21	0.13	1 000	−1.36	19.3	491	500	932	0.14	550	1.05	6	0.42	0.15
Yellowfin grouper (*M. venenosa*)	15	0.17	860	0.00	15.7	527	500	792	0.20	542	1.18	6	0.45	0.13
Snappers (Lutjanidae)														
Mutton snapper (*Lutjanus analis*)	14	0.13	939	−0.74	14.1	279	400	798	0.21	493	0.41	29	0.45	0.63
Schoolmaster (*L. apodus*)	12	0.18	570	0.00	3.28	148	250	504	0.25	315	0.45	31	0.46	0.67
Gray snapper (*L. griseus*)	12	0.14	722	−0.86	5.25	233	250	557	0.25	309	0.70	15	0.39	0.39
Dog snapper (*L. jocu*)	12	0.10	854	−2.00	10.2	300	300	790	0.25	368	0.47	22	0.39	0.57
Lane snapper (*L. synagris*)	10	0.10	618	−1.73	3.24	205	200	418	0.30	258	0.27	42	0.39	1.09
Yellowtail snapper (*Ocyurus chrysurus*)	14	0.21	455	−0.71	4.24	197	250	433	0.21	297	0.53	27	0.49	0.56
Wrasses (Labridae)														
Hogfish (*Lachnolaimus maximus*)	23	0.08	913	−1.78	14.1	166	300	786	0.13	340	1.00	6	0.36	0.18
Grunts (Haemulidae)														
Margate (*Haemulon album*)	10	0.17	753	−0.45	8.57	426	200	578	0.30	297	0.50	8	0.21	0.39
Tomtate (*H. aurolineatum*)	11	0.09	310	−1.28	1.89	130	150	280	0.28	203	0.00	100	0.42	2.41
French grunt (*H. flavolineatum*)	12	0.18	295	0.00	0.57	176	160	235	0.25	205	0.00	100	0.42	2.38
Cottonwick (*H. melanurum*)	9	0.32	350	−0.50	0.82	203	160	333	0.33	208	0.61	17	0.34	0.51
Bluestriped grunt (*H. sciurus*)	8	0.30	413	0.00	1.36	205	180	404	0.37	233	0.65	21	0.37	0.57
White grunt (*H. plumieri*)	8	0.19	512	−0.78	3.06	177	170	411	0.37	227	0.54	25	0.35	0.70

Theoretically, Lbar in year t is expressed as

$$\overline{L}(t) = \frac{F(t)\int_{a_c}^{a_\lambda} N(a,t)\ L(a,t)\ da}{F(t)\int_{a_c}^{a_\lambda} N(a,t)\ da} \quad , \qquad (1)$$

where a_c is the minimum age at first capture, a_λ the oldest age in the stock, N(a,t) the abundance for age class a, L(a,t) the length at age, and F(t) is the instantaneous fishing mortality rate at time t. In practice, Lbar is usually estimated in the length range $L_c - L_\lambda$. Estimates of average length and the corresponding variances were obtained from length composition data derived from both the fishery-independent Florida Keys reef fish visual census (RVC) program (e.g., Bohnsack et al. 1999; Ault et al. 2001), and the fishery-dependent Biscayne National Park creel census (Harper et al. 2000, Ault et al. 2001) by applying standard statistical procedures (Sokal and Rohlf 1981). Non-normality of length observations was corrected by log-transformation. In theory, with knife-edged selection (full and constant) by the gear for all sizes/ages in the population above the minimum size of fish landed (i.e., seen in the creel survey) will be equal to average size in the exploited phase of those fish that remain in the sea (i.e., seen in the RVC). The Lbar method exhibits relatively robust properties for assessing exploitation impacts. In addition to having zero-bias properties at equilibrium, the method is also relatively insensitive to trends in recruitment (Ehrhardt and Ault 1992; Quinn and Deriso 1999; Ault et al. 2005b). The Lbar estimator also has desirable properties for detecting statistical differences at the lower range of exploitation rates that should allow discrimination between sustainable and non-sustainable rates (Ault et al. 2005b).

A numerical cohort-structured model (Ault and Olson 1996; Ault et al. 1998) was used to conduct simulation analysis of uncertainty properties of F estimates based on average size, and to compute several fishery management reference points of stock status, or "*sustainability benchmarks*", including yield-per-recruit (YPR), spawning potential ratio (SPR), and limit control rules. A conceptual diagram of the length-based numerical population simulation model used in these analyses is given in **Figure 2**.

The benchmarks used to evaluate sustainable exploitation in terms of a limit control rule were: F_{msy} (F generating maximum sustainable yield, MSY); B_{msy} (population biomass at MSY); and SPR (spawning potential ratio; Mace 1997; Restrepo and Powers 1999). We defined F_{msy} as F = M. The REEFS models the age-size distribution of the population from larvae to mature adults to maximum size-age using a number of population dynamic functions to regulate birth, growth and survivorship processes, including selection and harvest by the fishery. The length-based computer algorithm embodies a stochastic age-independent continuous population model for ensemble numbers at given lengths

$$\widetilde{N}_\gamma(L_\gamma, t) = \int_{a_r}^{a_\lambda} R(\tau - a) S(a) \theta(a) P(L \mid a) da \,, \qquad (2)$$

where R(τ - a) is cohort recruitment lagged back to birth date, S(a) is survivorship to age a, θ(a) is sex ratio at age *a* to account for hermaphroditic life histories common to tropical reef fishes, and P(L | a) is the probability of being length *L* given the fish is age *a*.

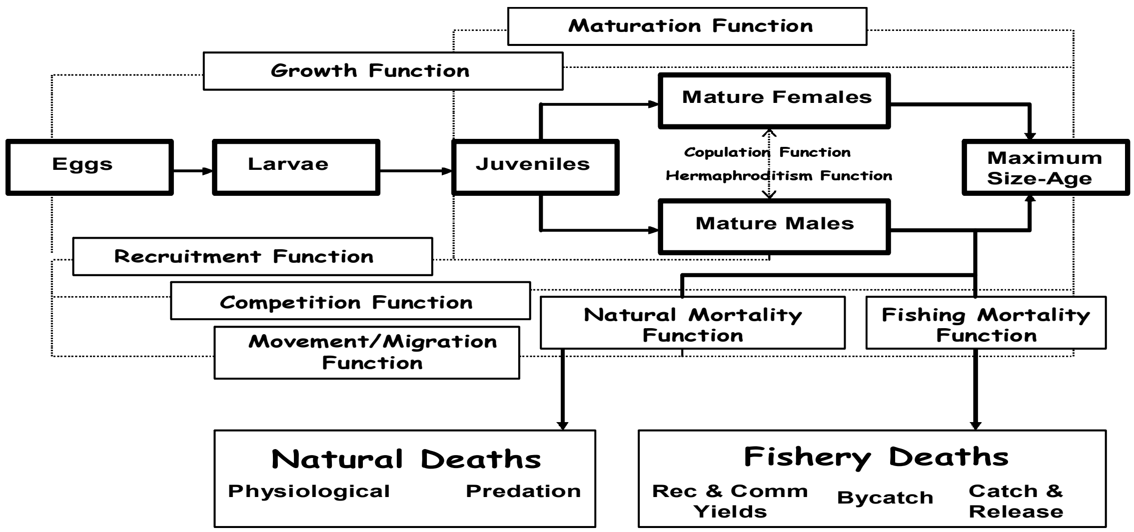

Figure 2.- Conceptual diagram of the REEFS length-based numerical population simulation model used in the assessment of sustainability benchmarks for reef fishes in Biscayne National Park and the Florida Keys.

Since population biomass B(a,t) is the product of numbers-at-age times weight-at-age, yield in weight Y_W from a species was calculated as

$$Y_w = (F, L_c, t) = F(t) \int_{L_c}^{L_\lambda} B(L \mid a,t) dL = F(t) \int_{L_c}^{L_\lambda} N(L \mid a,t) W(L \mid a,t) dL \quad . \tag{3}$$

Spawning stock biomass (SSB), a measure of stock reproductive potential, was obtained by integrating over individuals in the population between the minimum size of sexual maturity (L_m) and the maximum size (L_λ),

$$SSB(t) = \int_{L_m}^{L_\lambda} B(L \mid a,t) dL \quad . \tag{4}$$

Spawning potential ratio (SPR) is a management benchmark that measures the stock's current reproductive potential to produce optimal yields on a sustainable basis

$$SPR = \frac{SSB_{\exp loited}}{SSB_{un \exp loited}} \quad . \tag{5}$$

Estimated SPRs are compared to U.S. Federal standards which define 30% SPR as the overfishing threshold at which the stock is no longer sustainable at the current exploitation levels.

Creel Survey Length Composition and Catch Rates

Park personnel provided BNP Creel Survey length composition and catch-effort data that were grouped into two time periods, 1995-98 and 2000-2004. These data were analyzed for trends in Lbar, size composition, and catch rates for reef fish taxa. Sampled trips were classified into bay, reef, and pelagic categories based on location information from interviews and the species composition of a given trip, e.g., trips exclusively targeting or capturing pelagic species such as dolphinfish or king mackerel were designated as 'pelagic'. Pelagic trips were excluded from the analysis to distinguish between valid and invalid zero-catch trips for a given reef fish species or species group. Some reef fish species were frequently captured in bay environments as well as in offshore reef habitats; consequently, 'bay' trips were included in the analysis for these species. Size composition data were used to estimate Lbar (described above) and to compare size structures among species between the two time periods for the consistency of size- frequency distributions above the current minimum size of first capture (i.e., size limit), and the proportion of fish landed that were below the minimum legal size.

Observed fish landings from the creel surveys were analyzed in two ways. First, Landing Rate (LPUE) was computed for reef fish species using angler-hours as the unit of effort. The log(x+LPUE) transformation was applied to LPUE observations, in which x was set to the minimum observed value of LPUE, to alleviate skewness in LPUE frequency distributions. Second, to facilitate evaluation of bag limits, landings-effort data were computed in terms of landings per angler-trip (i.e., number of fish landed and kept per person-trip).

Sustainability Benchmarks

Sustainability metrics and benchmarks (e.g., Sustainable Fishing Mortality Rate 'F', Yield per Recruit 'YPR', and Spawning Potential per Recruit 'SPR') were computed by considering the life history and population dynamics of each reef fish stock, broken into age-size (**Figure 3**).

The relationships among various fishery decision metrics are shown in **Figure 4** and **Figure 5,** using hogfish as an example. The relationship between the average size fish in the population (Lbar) and the rate of fishing mortality (F) is depicted along with the expected population length compositions at three levels of fishing mortality ($F = 0$; $F = F_{msy}$; $F = F_{2001}$) in Figure 4**. Figure 4** also shows how confidence intervals about estimates of Lbar and F can affect interpretation of the population status. Although the 95% confidence interval (CI) of Lbar is larger at F_{msy} than at F_{2001}, the corresponding CI of F is higher at F_{2001} owing to the non-linear relationship between Lbar and F. The non-linear relationship also results in asymmetric CIs of F that are more pronounced at higher exploitation rates. Thus, using average length of fish in the population to estimate F has high statistical power for discerning between sustainable and overfished levels of F, but has low power for discerning between overfished and severely overfished levels of F. Figure 5 illustrates the relationship between spawning potential ratio (SPR) and yield-per-recruit (YPR) at various levels of fishing mortality.

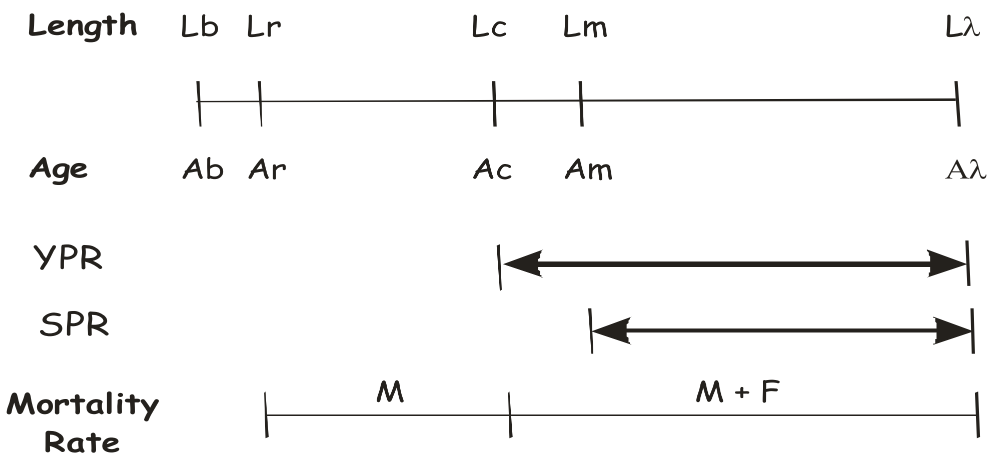

Figure 3.- To evaluate fishery sustainability metrics (F) in terms of sustainability benchmarks (YPR, SPR), one must first consider the fish life history in terms of stanzas that operate between birth (a_b), the age (a_r) or size (L_r) of recruitment to the fishery to the maximum age (a_λ) or size (L_λ) in the fishery during which natural mortality (M) operates throughout. Fishing mortality (F) occurs with knife-edged selectivity between the minimum size of first capture (L_c) and L_λ. During that exploited period, total mortality (Z) is the sum of the competing risks of death, i.e., $Z = M + F$. Animals are reproductive between the size of maturity (L_m) and maximum size/age.

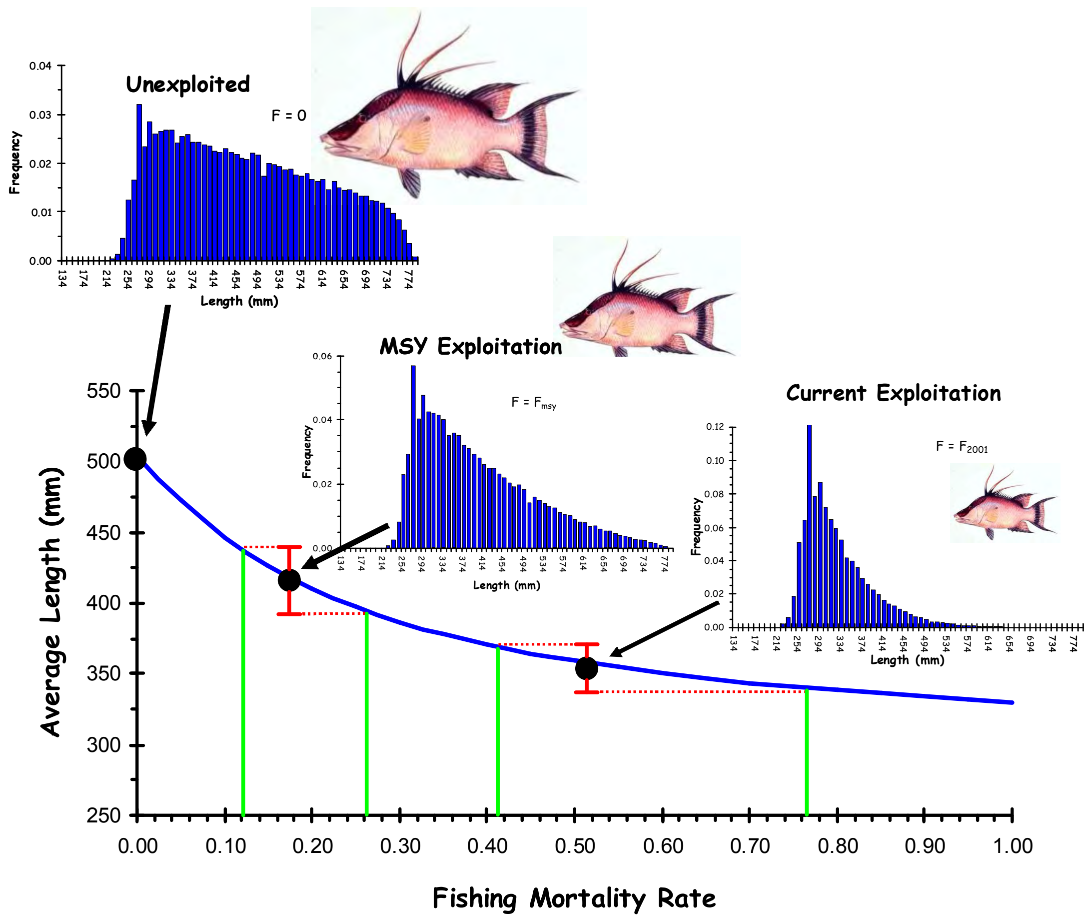

Figure 4.- Relationship of Lbar in the exploited phase and fishing mortality F for hogfish, and the variation in F estimates (dotted horizontal bars) resulting from variation in Lbar (dashed vertical bars). Insets show representative population length frequency compositions at F_0, F_{msy}, and F_{2001}.

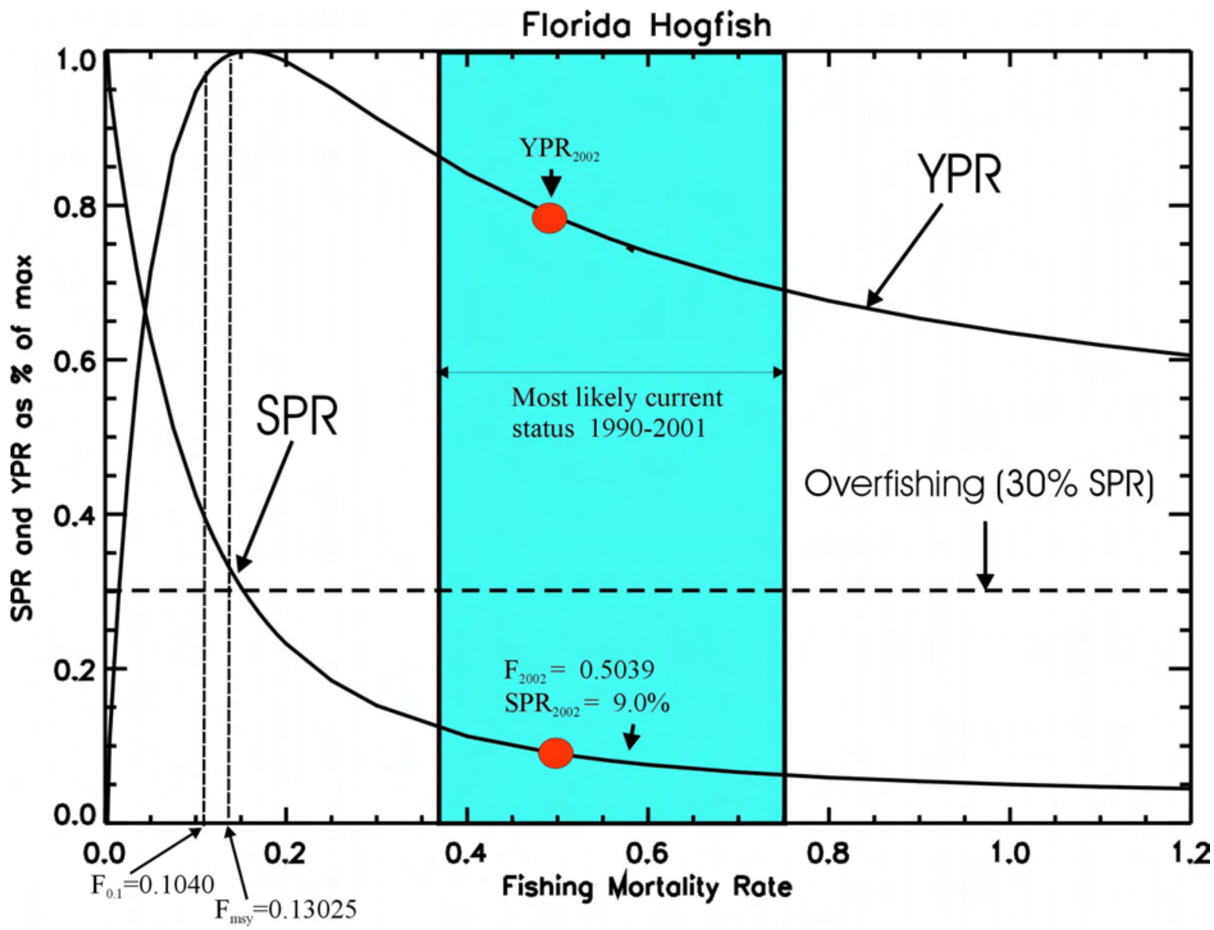

Figure 5.- Theoretical relationship of the fishery sustainability decision metrics spawning potential ratio (SPR) and yield-per-recruit (YPR) to fishing mortality rate (F) for hogfish. Graph shows position of maximum sustainable yield (MSY) and Fmsy that are used to compute limit control rules under the precautionary approach to fishery management.

Assessment of Management Alternatives

Decreased Bag Limits –
Although in most cases, improvements in population benchmarks of sustainability will not be possible through reduced bag limits, the observed average number of fish landed per person-trip, together with the observed proportion of fishermen interviews in which the species was landed based on the Biscayne NP creel surveys, was used to evaluate the potential effects of reducing the bag limit on fishing mortality rates whenever more than 5% of the trips landing the species exceeded one per person-trip.

Increase in Legal Size Limits –
Because substantial gains in population benchmarks may be possible through increases in the minimum size of first capture (i.e., raise the minimum size limits for groupers, snappers and grunts), which would reduce the effective fishing mortality rates on specific size/age groups in the population, we evaluated the potential effects of increasing minimum size limits for all the species. In this analysis, we followed first- order principles of identifying what potential increases in minimum sizes of exploited reef fish species would maximize the analytical objectives according to "eumetric" fishing, i.e., the optimum combination of minimum size of first capture L_c given a particular fishing mortality rate F that results in maximal yields in weight and/or numbers of fish (*inter alia* Beverton & Holt, 1957).

Results

Sustainability Status of Exploited Reef Fish Stocks in South Florida

Mortality estimates, based on average length from fishery-independent size composition data collected in 2002 by the reef fish visual census (RVC) from the Florida Keys region, could be considered to represent a conservative estimate of fishery conditions in BNP. Estimated population parameters based on an analysis of the Keys wide data for 22 species of reef fish are provided in **Table 1**. Estimates (circa 2002) of SPR for Florida Keys reef fishes from the RVC data are also graphed in **Figure 6**. In general, we found that the majority of species in the snapper-grouper complex for which estimates could be made are below the 30% SPR federal standard for stock sustainability.

Values of the F/F_{msy} ratio plotted against the B/B_{msy} ratio (**Figure 7**) suggest that most species of the snapper–grouper complex experience overfishing (F-ratio >1, B-ratio <1; Restrepo and Powers 1999) and have been subject to unsustainable rates of exploitation in recent years. Overfishing appears most severe for long-lived, slow-growing fish (cf. **Table 1**).

Biscayne Stock Status and Management Alternatives

To look more specifically at the Biscayne National Park (BNP) fish stocks, we evaluated creel data for 7 key reef fish species (i.e., black grouper, red grouper, mutton snapper, gray snapper, yellowtail snapper, hogfish, and white grunt) from boat ramp creel surveys conducted in Biscayne National Park from 1995 to 2004. Estimates of the average size fish within the legally

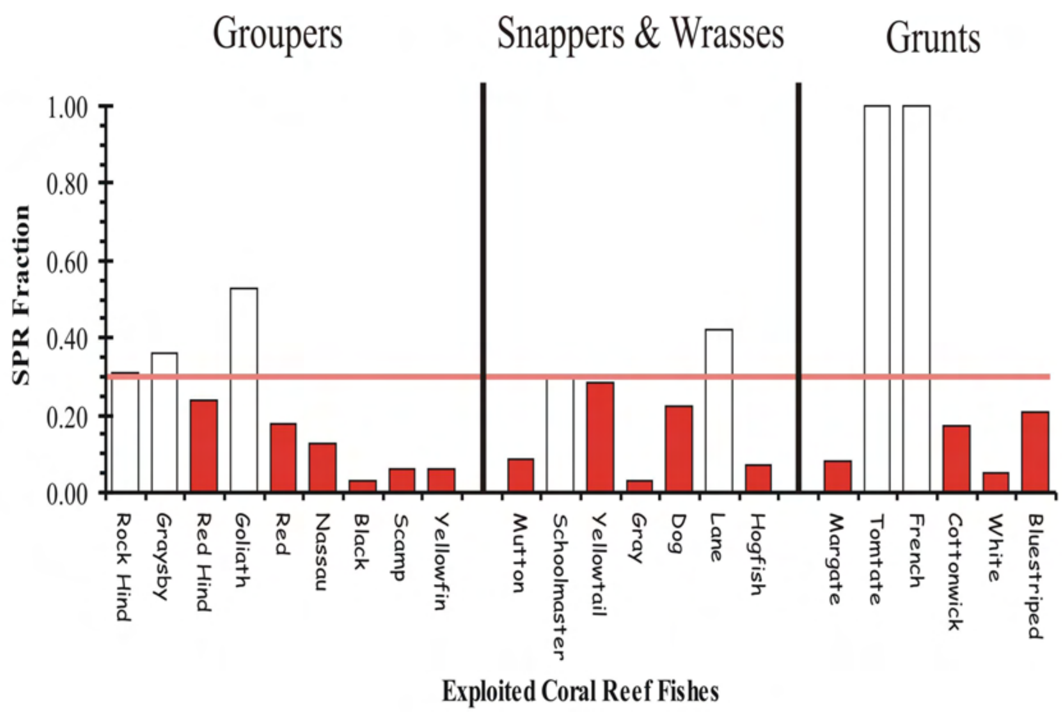

Figure 6.- SPR analysis for exploited reef fishes in the Florida Keys for the period 2000-2002. Dark bars indicate overfished stocks, open bars indicate stocks that are above the 30% SPR standard (blue horizontal line).

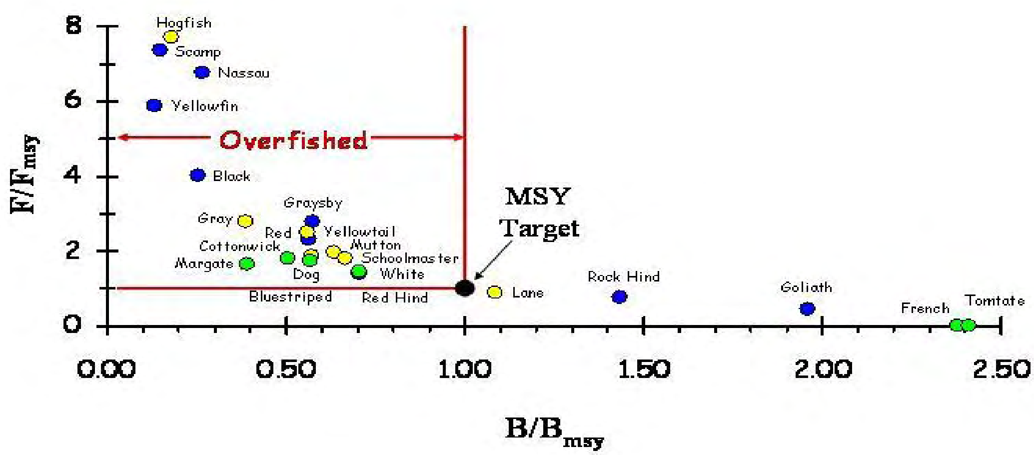

Figure 7.- Plot of F/F_{msy} ratio against B/B_{msy} ratio for fishes in the snapper-grouper complex in the Florida Keys region for 2002 (blue, groupers; yellow, snappers and wrasses; green, grunts). From Ault et al. (2005b).

harvested population (Lbar) and landing rates for BNP fish are summarized in **Tables 2A and 2B**, respectively. These data, together with the known life history parameters for each of these species (**Table 1**), were then used to calculate estimates of current fishing mortality rates, stock biomass, SPR and YPR for each of the key reef fish species **(Table 3)**.

Given that we found all seven of the key species currently have SPR values that are below the 30% SPR Federal standard for stock sustainability (**Table 1)**, we evaluated the potential impact (in terms of SPR and YPR) of changing the size limit for each species, given the current fishing mortality rate *F*. For these analyses, we assumed that that the current estimated fishing mortality rates would continue unabated at their most recent levels, although they will most likely even increase over time with increasing regional human population size. Thus, for each species, fishing mortality *F* was kept fixed at the current estimated rate and then the minimum size limit was raised to the apparent optimal (i.e., eumetric) level. Summary results of this analysis for the "optimum" minimum harvest size (L_c) are also included in **Table 3,** along with the amount of change in each of the fish population metrics that would be associated with achieving this optimum. Results are provided in greater detail for each species in the following sections.

Table 2A.- Biscayne National Park Creel survey estimates of average size (Lbar) for seven key species of the snapper-grouper complex for two time periods. The *n* is the number of legal harvest size fish measured, *Lbar* is average size of legally landed fish in cm, *se* is standard error of mean Lbar for lower *lw* and upper *up* bounds; and, *LCI* is lower and *UCI* upper 95% confidence intervals.

	Creel Survey Period												
	1995 - 1998							2000 - 2004					
Species	n	Lbar	lw_se	up_se	LCI	UCI		n	Lbar	lw_se	up_se	LCI	UCI
Black grouper	31	69.05	0.96	0.97	67.10	71.04		13	69.70	2.25	2.32	64.80	74.76
Hogfish	492	34.74	0.23	0.23	34.29	35.20		487	33.63	0.17	0.17	33.28	33.97
Red grouper	64	53.51	0.41	0.42	52.68	54.34		53	54.91	0.62	0.62	53.67	56.16
Mutton snapper	48	49.86	1.36	1.40	47.13	52.68		81	47.79	0.79	0.80	46.22	49.39
Gray snapper	979	29.16	0.14	0.14	28.88	29.44		891	28.81	0.13	0.13	28.56	29.05
Yellowtail snapper	385	28.66	0.15	0.15	28.36	28.96		644	29.56	0.15	0.15	29.26	29.86
White grunt	1878	21.70	0.05	0.05	21.59	21.81		1126	22.14	0.07	0.07	22.00	22.28

Table 2B.- Comparison of trip success and average landing rate per person for selected species of the snapper-grouper complex for trips sampled in Biscayne National Park creel survey for the periods 1995-1998 and 2000-2004. Total trips is defined as the total number of boat trips seeking the reef fish species (i.e. fished within the area of the park where these species are found), kept fish are successful trips where at least 1 of the species was landed, and % kept fish is the fraction of total trips seeking the species that were successful for the species. Trips conducted in reef habitats were used in the computations for all species; trips conducted in bay environments were also included for gray and mutton snapper. Hogfish results are based on spearfishing trips; results for other species are based on hook-and-line trips. Mean landing rates (LPUE) and standard errors SE are in units of fish landed-per-angler-hour (or fish landed-per-diving-hour for spearfish trips).

	1995-1998							**2000-2004**					
Taxa	Total Trips	Kept fish	%Kept fish	n	Mean LPUE	SE		Total Trips	Kept fish	%Kept fish	n	Mean LPUE	SE
Groupers													
Black grouper	658	10	1.52%	657	0.001492	0.000014		1090	15	1.38%	1073	0.001080	0.000004
Red Grouper	658	33	5.02%	657	0.002843	0.000045		1090	57	5.23%	1073	0.002630	0.000034
Snappers													
Gray Snapper	1153	251	21.77%	1156	0.012387	0.000491		1664	310	18.63%	1638	0.015890	0.000407
Hogfish	186	124	66.67%	179	0.271950	0.023060		169	139	82.25%	167	0.286000	0.026527
Mutton snapper	1153	48	4.16%	1153	0.002316	0.000026		1664	92	5.53%	1638	0.002220	0.000027
Yellowtail snapper	658	110	16.72%	658	0.013579	0.000428		1090	167	15.32%	1073	0.009720	0.000316
Grunts													
White grunt	658	212	32.22%	662	0.046480	0.002949		1090	206	18.90%	1072	0.018020	0.000684

Table 3.- Impacts of size limit changes from current status to eumetric (optimal) levels of reproductive and yield sustainability benchmarks for 7 key exploited reef fished in Biscayne National Park. *B(0)* is unexploited stock biomass; *B(msy)* is stock biomass at the fishing mortality rate that produces maximum sustainable yield (msy); *F* is the current estimated fishing mortality rate; L_c is the length of first capture; t_c is the age of first capture (harvest); *B* is the stock biomass; *SPR* is the spawning potential ratio; *Lbar* is the average legal size fish observed landed; *YPR* is the estimated yield-per-recruit in weight; and, *YnR* is yield-per-recruit in numbers . Changes in metrics from current to optimal for each species are listed in the last six columns as absolute change (upper row) and percentage change (italics, lower row). Δ*Wbar* is change in weight of the average fish.

					Current									Optimal									Changes			
Species	B(0)	B(msy)	F	Lc	Lc	tc	B	SPR	Lbar	YPR	YnR	Lc	Lc	tc	B	SPR	Lbar	YPR	YnR	ΔLc	ΔSPR	ΔLbar	ΔWbar	ΔYPR	ΔYnR
				mm	inches	years			mm	kg	#	mm	inches	years			mm	kg	#	inches		mm	kg	kg	#
Black grouper	2115503	830978	0.84	610	24.02	3.42	63107	0.0298	711	4.24	0.68	1077.67	42.43	10.00	659598	0.3118	1077	9.22	0.37	18.4	0.3	366.4	16.4	5.0	-0.3
																				76.7	*945.2*	*51.6*	*279.2*	*117.4*	*-45.0*
Hogfish	752428	284138	1.01	300	11.81	3.25	52082	0.0692	341	0.49	0.59	568.80	22.39	10.50	332686	0.4421	590	0.92	0.23	10.6	0.4	248.8	3.2	0.4	-0.4
																				89.6	*538.8*	*72.9*	*391.5*	*87.4*	*-60.7*
Red grouper	362162	165816	0.35	500	19.69	5.41	64010	0.1767	593	1.49	0.45	648.35	25.53	8.75	129330	0.3571	701	1.70	0.32	5.8	0.2	108.0	2.1	0.2	-0.1
																				29.7	*102.0*	*18.2*	*69.1*	*13.9*	*-29.1*
Mutton snapper	472512	185548	0.52	400	15.75	3.67	39695	0.0840	494	1.27	0.58	702.53	27.66	10.00	179630	0.3802	742	2.10	0.30	11.9	0.3	248.4	4.8	0.8	-0.3
																				75.6	*352.5*	*50.3*	*169.2*	*65.3*	*-48.0*
Gray snapper	181823	65089	0.85	250	9.84	2.33	5586	0.0307	308	0.34	0.70	544.84	21.45	9.50	64453	0.3545	566	0.85	0.33	11.6	0.3	257.7	2.1	0.5	-0.4
																				117.9	*1053.8*	*83.6*	*329.2*	*147.7*	*-53.6*
Yellowtail snapper	34584	16218	0.45	250	9.84	2.42	9881	0.2857	295	0.28	0.42	291.94	11.49	4.25	16083	0.4650	345	0.28	0.28	1.7	0.2	50.4	0.3	0.0	-0.1
																				16.8	*62.8*	*17.1*	*56.3*	*1.2*	*-32.5*
White Grunt	57634	19301	0.76	170	6.69	1.50	2793	0.0485	228	0.18	0.66	378.47	14.90	6.50	22721	0.3942	400	0.40	0.29	8.2	0.3	171.7	1.2	0.2	-0.4
																				122.6	*713.5*	*75.3*	*489.3*	*121.7*	*-56.5*

Black Grouper

Harvest impacts are of particular concern for long-lived fishes like black grouper (*Mycteroperca bonaci*), who live several decades (maximum age is 33 years, Crabtree and Bullock 1998), and ultimately reach large body size and weight (**Figure 8**). Generally, long-lived, slow-growing fishes tend to be exceptionally sensitive to even relatively low fishing mortality rates, and as exploitation increases there is significant truncation of the older, mature size/age classes in a process known as “juvenescense”, i.e., making the population younger through excessive fishing mortality (**Figure 9**). For black grouper this is a bit like clear-cutting an old growth forest, that is, the older-larger size groups that accumulate at relatively low fishing mortality rates are “cut down” with increased exploitation, so that the number of large, mature fish is greatly reduced. Cohorts (groups of fish born in the same year) from long- lived fishes like black grouper generally do not reach maximum biomass until ages > 10 years (e.g., **Figure 8**). Note that the cohort reproductive effort (i.e., fecundity) increases exponentially through these years and suggests that maximum reproductive potential is reached for black grouper > 40 in (102 cm). Truncation of population size structure and thus stock biomass through exploitation results in the direct reduction of older, mature and fecund sizes/ages, leading to reduced stock reproductive potential that will have substantial negative impacts on recruitment and ultimately stock sustainability.

Current Condition of Stock

The current minimum size limit for black grouper is 24 in or 61 cm TL in Atlantic ocean and Monroe County waters (FWC 2007). The average size of black grouper legally landed (i.e. among those fish of legal harvest size) in BNP during 2000-2004 was 69.7 cm TL as compared to 69.1 cm TL during 1995-1999 (**Table 2A**). This is below the 70.9 cm (28 in) average size observed landed in the entire exploited population throughout the Florida Keys as estimated through the reef fish visual census surveys in 2002 (**Table 1**, Ault et al. 2005b). The average size of legal black grouper landed in BNP corresponds to an estimated fishing mortality rate F of 0.98 and translates to a stock SPR< 3% (**Table 3**). This is an order of magnitude less than the desired SPR of 30%. The distribution of sizes landed for BNP is shown in **Figure 10**. Only 41 black grouper were landed by 658 boats interviewed that had fished the reef area of the park during the years 1995-1998, and this decreased to 17 for 1,090 creel surveys conducted during the period 2000-2004. About 24% of those fish landed in BNP were smaller than the legal minimum size of capture (**Figure 10**). The landings-per-angler-trip has been very low throughout the 1990’s to the present (left panels, **Figure 10**; **Table 2B**). The current bag limit for black grouper in Florida is 2 per person per day (FWC 2007), included within 5 per person per day Grouper aggregate bag limit. In BNP over the period of 1995-1998, less than 1.6% of all surveyed trips fishing the reef area landed (kept) 1 or more black grouper (**Table 2B**). This percentage decreased slightly for the period 2000-2004. The overall average landing rate (LPUE) for black grouper in the most recent years was 0.00108 fish-per-angler-hour. This suggests that one legal black grouper is caught for every 1000 hours of angler-fishing.

These statistics all indicate that the current rate of exploitation on black grouper in BNP is very high, and the population size structure is highly truncated to small fish, most of which are too young and small to reproduce.

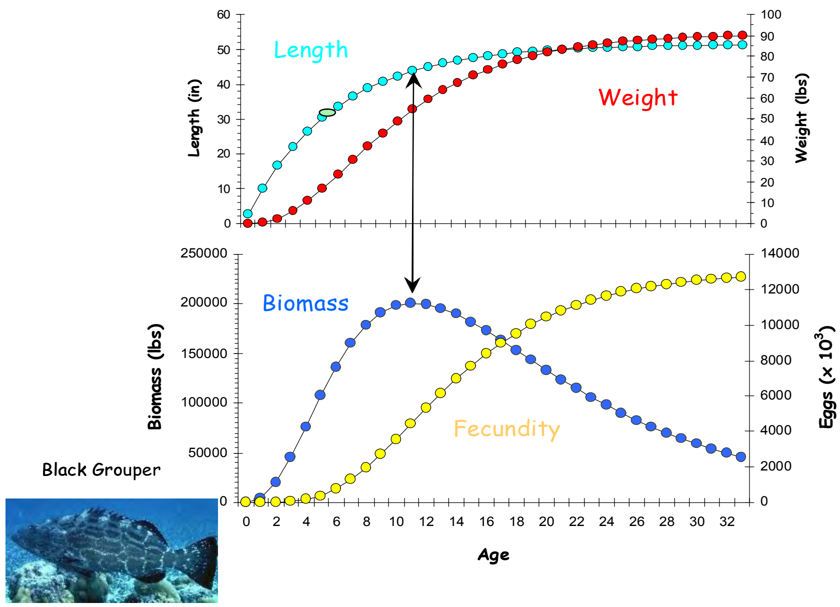

Figure 8.- Demographic and population-dynamic relationships for black grouper (*Mycteroperca bonaci*).

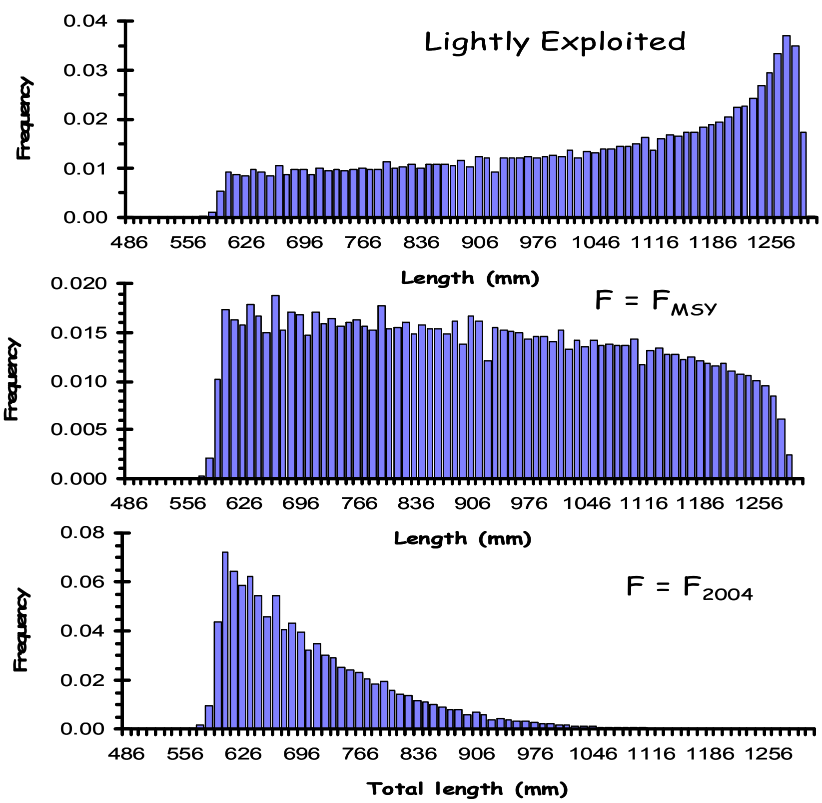

Figure 9.- Process of "juvenescence" of a black grouper population when: (upper panel) lightly exploited; (middle panel) exploited at MSY; and, (lower panel) current exploitation level in the Florida Keys.

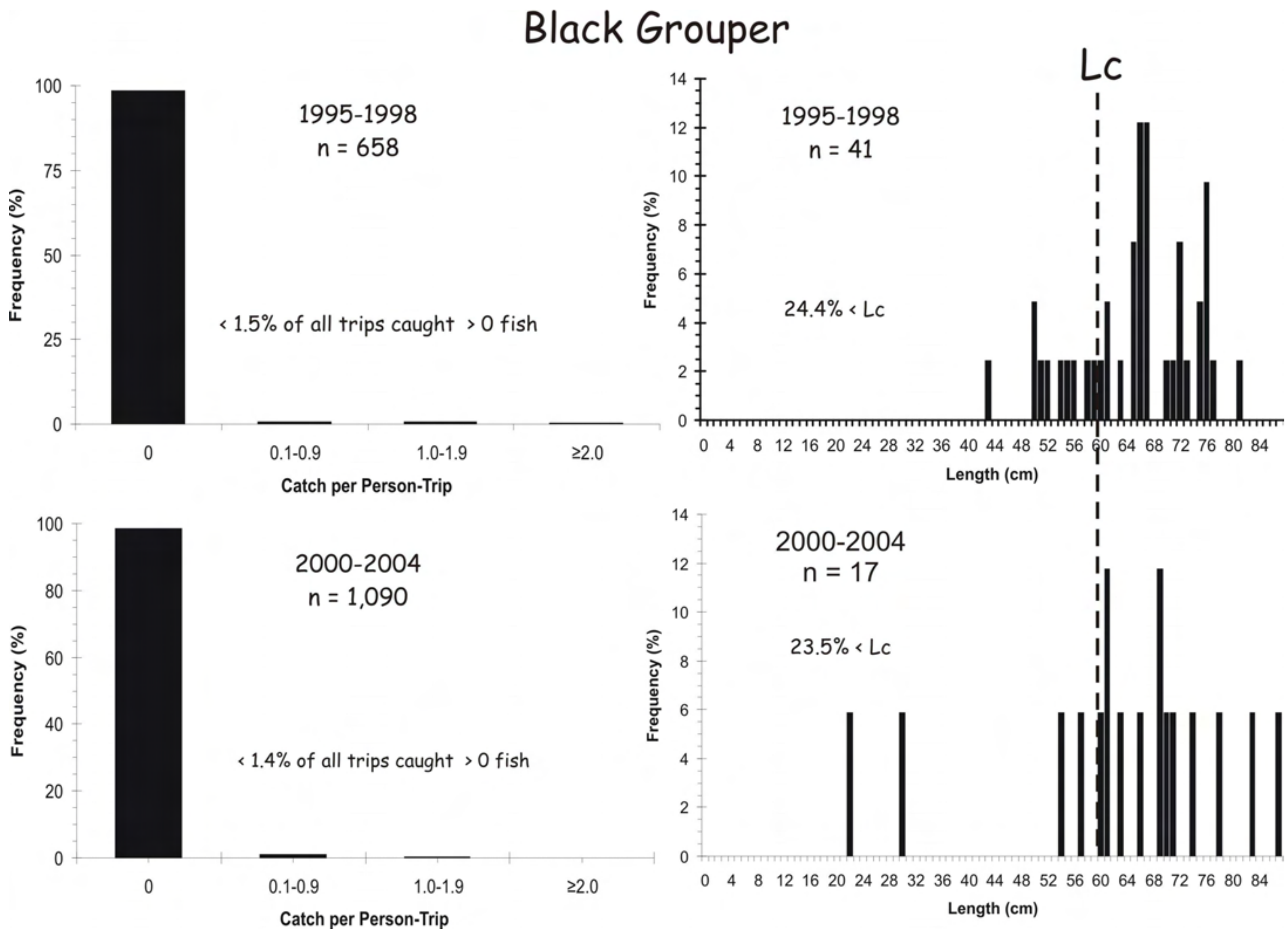

Figure 10.- Comparison of landings per person (left panels) and size distributions of landings (right panels) for Biscayne National Park creel data for black grouper (*Mycteroperca bonaci*) for the periods 1995-1998 (top panels) and 2000-2004 (bottom panels). Vertical dashed line is the current minimum legal harvest size.

Management Alternatives

Obviously, further restrictions on bag limits for a species where the average rate of fish landed is nearly 0 fish per person per trip (**Table 2B**) is a quite meaningless management endeavor. Because the current minimum size limit and average size fish in the exploited population for black grouper appears to be resulting in over harvest and reducing the population below a desirable spawning potential ratio, the potential benefits of changing the minimum size of capture was explored.

Equilibrium contours of black grouper YPR in kg were obtained by computation of YPR from all reasonable combinations of F and size/age at first capture (a_c) (**Figure 11**). The line of maximum yield for each rate of fishing mortality is shown as a dotted-line on Figure 11. Equilibrium spawning potential ratio (SPR)-per-recruit contours for black grouper obtained from any combination of F and a_c are shown in **Figure 12**. The current status of black grouper (i.e.SPR< 3%) in the Park and the Florida Keys coral reef ecosystem overall suggests that the population has been overfished. Note that the line of maximum yield (**from Table 11**) produces an SPR equal to or above the 30% SPR federal standard, irrespective of fishing mortality rates above current. This suggests that precautionary management should either greatly reduce fishing mortality or raise the minimum sizes of first capture to relatively high ages-size (> 10 years and 40 in) for black grouper. Raising the minimum size limit would allow the animals to mature, reach their biomass and yield potential, and to at least ensure reproductive replacement of a spawning pair and thus population sustainability. Thus, an increase in the probability of a juvenile fish reaching a larger, more mature size is needed to allow the stock to adequately reproduce and sustain the population if the current rate of fishing mortality is not reduced. An increase in the size limit to 48 in TL (107 cm) or to eumetric (the maximum equilibrium state for YPR given the current rate of fishing mortality) would increase the YPR by more than 90%, and the SPR by more than 1200% (**Table 3**). An increase of minimum size to near eumetric levels would keep the SPR at or above the 30% SPR Federal standard.

In general, recovery of population biomass for long-lived fishes may take decades to achieve resource management goals, even if fishing mortality rates were set to zero for substantial segments of population size/age classes (**Figure 13**). Such a transition period would result in a decrease in numbers of fish caught per recruit, but in the long run the fishery yield- per-recruit would increase substantially (i.e., fish in the catch would be bigger, and with future likely increased recruitment from a larger mature stock there would be more of them).

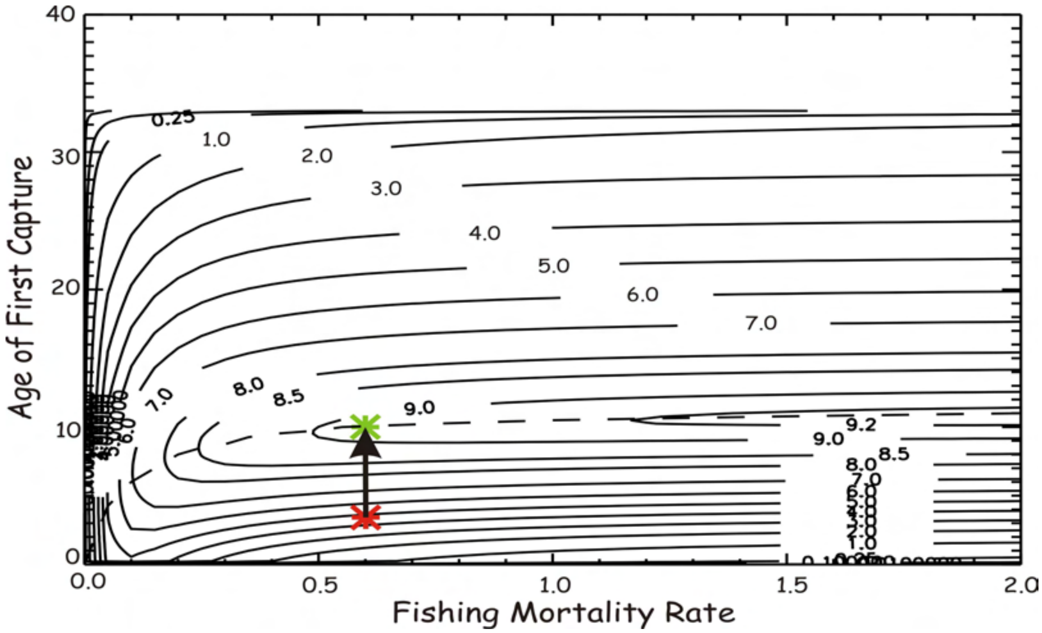

Figure 11.- Equilibrium contours for yield-per-recruit in kg for black grouper (*Mycteroperca bonaci*) obtained from any combination of F and t_c. The dashed line joins the maxima of yield-age of first harvest (i.e., minimum size/age limit) curves (i.e., eumetric line). The stars indicate the current value of F and t_c, and the arrow points to the eumetric values.

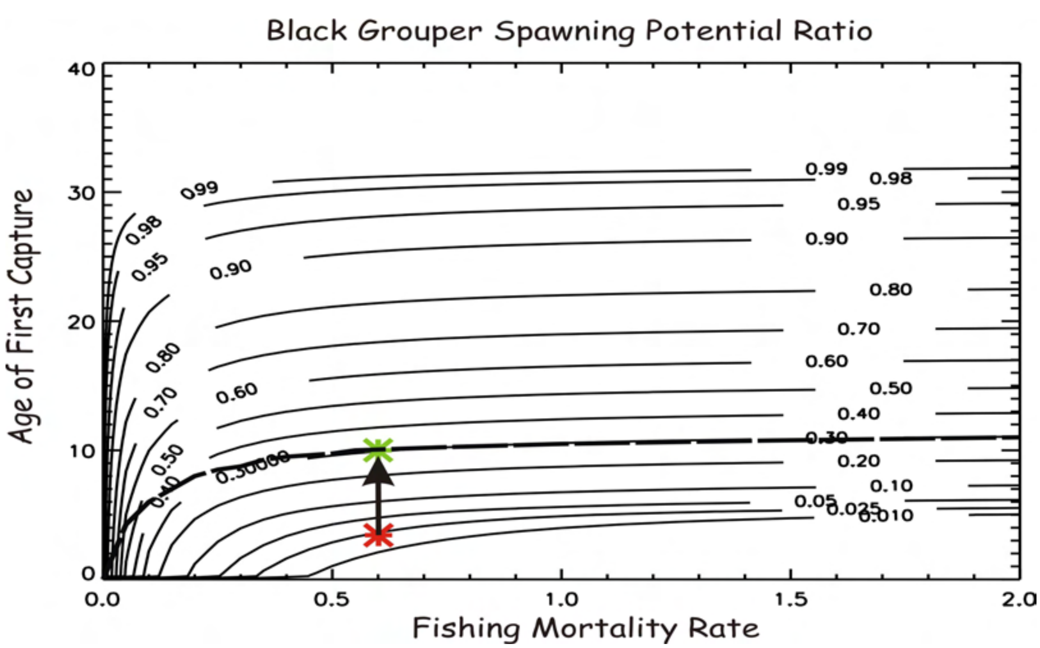

Figure 12.- Equilibrium contours for spawning potential ratio (SPR)-per-recruit for black grouper (*Mycteroperca bonaci*) obtained from any combination of F and t_c. The dashed line joins the maxima of SPR-age of first harvest (i.e., minimum size/age limit) curves (i.e., eumetric line). The stars indicate the current value of F and t_c, and the arrow points to the eumetric values.

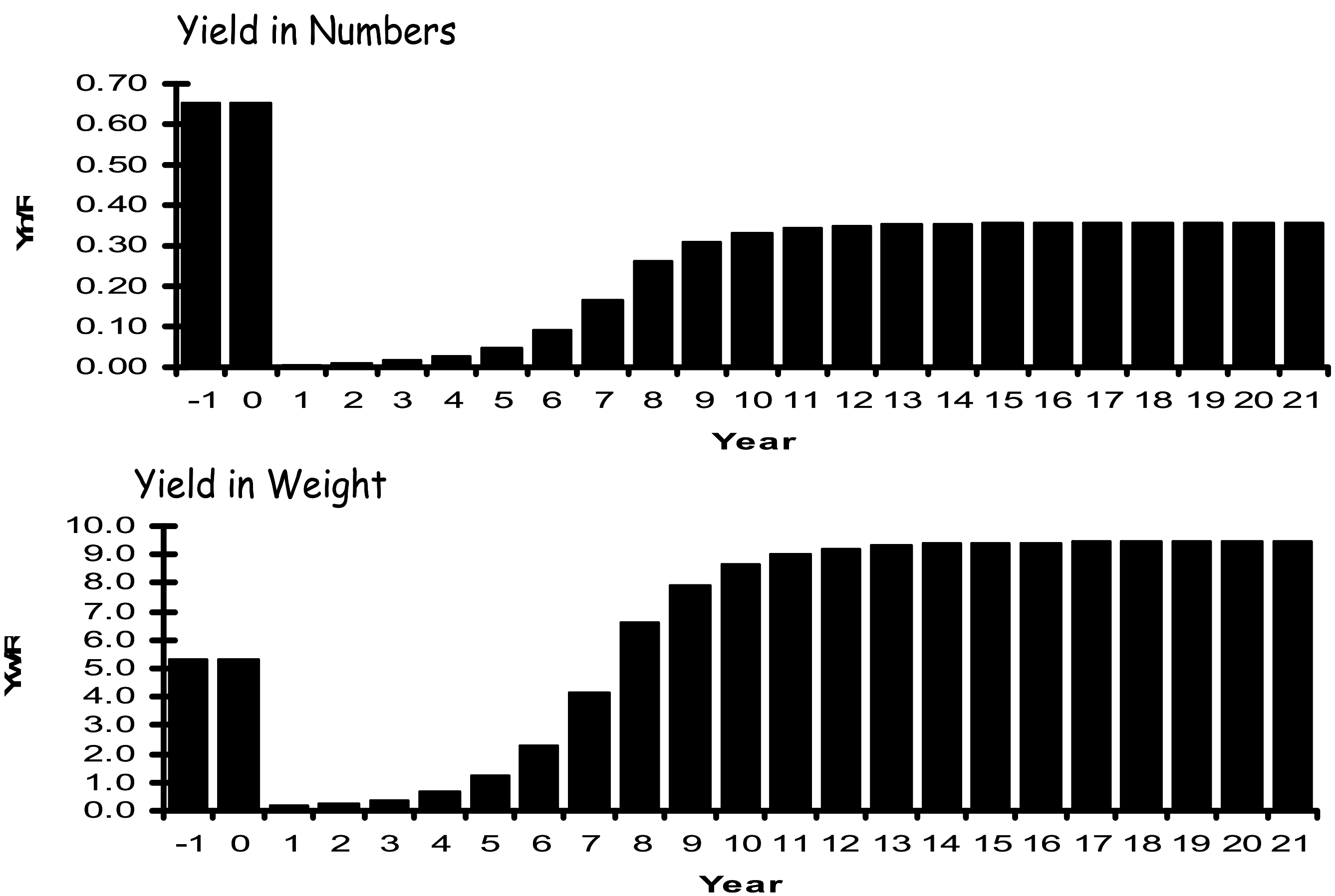

Figure 13 .- Simulation of transitional yields in number of fish and weight in the catch per recruit showing the time required for population recovery of black grouper when size limits are theoretically changed from current levels (i.e., 24 inches or 610 mm) to maximum sustainable yield (eumteric fishing) at 40 inches (1016 mm). Full recovery to new equilibrium takes at least two decades.

Hogfish

Current Condition of Stock

The current minimum size limit for hogfish (*Lachnolaimus maximus*) is 12 in FL (30.4 cm). The average size of hogfish legally landed in BNP during 2000-2004 was 34.7 cm FL as compared to 33.6 cm FL during 1995-1999 (**Table 2A**). This is close to the 34 cm average size observed in the entire exploited population throughout the Florida Keys estimated through the reef fish visual census surveys (**Table 1**; Ault et al. 2005b). The average size of legal (at or above minimum size) hogfish landed in BNP corresponds to an estimated fishing mortality rate F of 1.14 and stock SPR< 7% (**Table 3**). The size composition of hogfish landed, as estimated from the creel surveys during both 1995-1999 and 2000-2004, is shown in **Figure 14 (**right panels). Five-hundred eighty hogfish were observed landed in 186 creel census surveys of spearfishermen conducted during the years 1995-1998, and this increased to 622 for 169 creel surveys conducted during the period 2000-2004. Even though hogfish were taken by spear-fishermen who could easily discern sizes of fish prior to capture, more than 15% of those fish landed in the period 1995-1998 were below the minimum legal size (**Figure 14**). This fraction of undersized illegal hogfish increased to 21.7% in 2000-2004.

The landings-per-angler-trip (spear-fishing trips) has been up to 9 fish throughout the 1990's to the present (**Figure 14**). Notably, the current bag limit for hogfish in Florida is 5 per person per day (FWC 2007). This suggests that a significant proportion of landings at BNP exceeded the legal bag limit (i.e., about 4 to 10% of those surveyed). About 70% of all spearfishing trips recorded by the creel census for the period 1995-1998 landed hogfish (**Table 2B**) and this percentage increased to 82% for the period 2000-2004. Slightly more than 50% of the spearfishermen landed more than one hogfish during the 1995-1998 period and this increased to about 61% during the 2000-2004 survey. The overall landing rate of about 0.28 fish per angler-hour has remained relatively steady, meaning 1 fish is speared for every four hours of angler (diver) effort.

Although the success rates for spearing hogfish and the average number of fish landed per spearfisherman were better than for many of the other reef species we examined, the average size of fish within the exploitable population still suggests that the current rate of exploitation on hogfish in BNP is very high and the population size structure is highly truncated. The current SPR of < 7% in the Park and the Florida Keys coral reef ecosystem on the whole suggests that the population is seriously overfished. Thus, a substantial reduction in fishing mortality or actions to increase the probability of a juvenile fish reaching a larger more mature size is needed to improve reproductive success and potentially sustain the resource.

Management Alternatives

Since about 82% of the boats participating in spearfishing have been successful landing one or more hogfish, and over 61% of the spearfishermen landing hogfish landed two or more per person-trip, a substantial reduction in fishing mortality would likely be attained by reducing the present 5 per person-per day bag limit. Reducing hogfish bag limits to one fish per-person per day, would have the potential to reduce the average number of hogfish being landed by as much as 64%, provided none of the fish left untaken were then taken by that portion of spearfishermen who are currently unsuccessful (i.e., landings just redistributed among other fishermen).

Some redistribution of take among fishermen is likely to occur, but given that a relatively high percentage of spearfishermen observed are already landing at least one fish, a severe reduction in bag limit (to one fish per person) and strict enforcement of the regulation (elimination of the illegal take currently observed) would likely reduce overall fishing mortality considerably. Even if all of the currently unsuccessful spearfishermen were able to successfully land one fish under a one-fish bag limit (i.e. 100 % of the fishermen landed one fish due to redistribution of those not taken) and all illegal take were eliminated, the average number of fish landed per 100 spearfishermen would drop from approximately 202 fish presently to 100 fish (a 50% reduction in fishing mortality).

Reducing bag limits, and restricting take of sub-legal fish would obviously help this resource, but this would not reduce the fishing mortality rate sufficiently to ensure stock sustainability at the current 12 inch minimum size limit (**Figure 16**); therefore, the potential benefits of changing the minimum size of capture was explored. An analysis of optimal yield-per-recruit in relation to size at first harvest for hogfish is shown in **Figure 15** based on equilibrium contours for yield-per-recruit in kg for any combination of F and a_c. Equilibrium spawning potential ratio (SPR)-per-recruit contours obtained from various combinations of F and a_c are shown in **Figure 16**. Note that placing the minimum size of first capture at or above the optimum yield-per-recruit line produces an SPR > 40%, well above the federal standard of 30% SPR, irrespective of whether fishing mortality rates stay or may exceed the current estimated rate. This suggests that precautionary management should raise the minimum sizes of first capture for hogfish to a relatively high size-age (> 22 in or 10 yr). This strategy would allow the animals to mature, reach their biomass and yield potential, and to at least ensure reproductive replacement of a spawning pair and thus population sustainability. We did not factor in release mortality in our analyses, which would argue for even more conservative minimum size limits. An increase of minimum legal size to the optimum yield level at the current rate of fishing mortality (i.e. 56 cm or 22.3 in) would increase the YPR by about 90%, and SPR by more than 538% to an SPR of >44% (**Table 3**). This would be well above the 30% SPR Federal standard. In addition, the average size (length) of fish in the catch would nearly double, and the average weight would more than triple.

If a one fish bag limit was imposed that resulted in a decrease in fishing mortality rates of 50% or more as described above (i.e., from 0.50 to 0.25), we estimate that a sustainable SPR of greater than 30% could be achieved under a minimum size limit of approximately 19.5 inches.

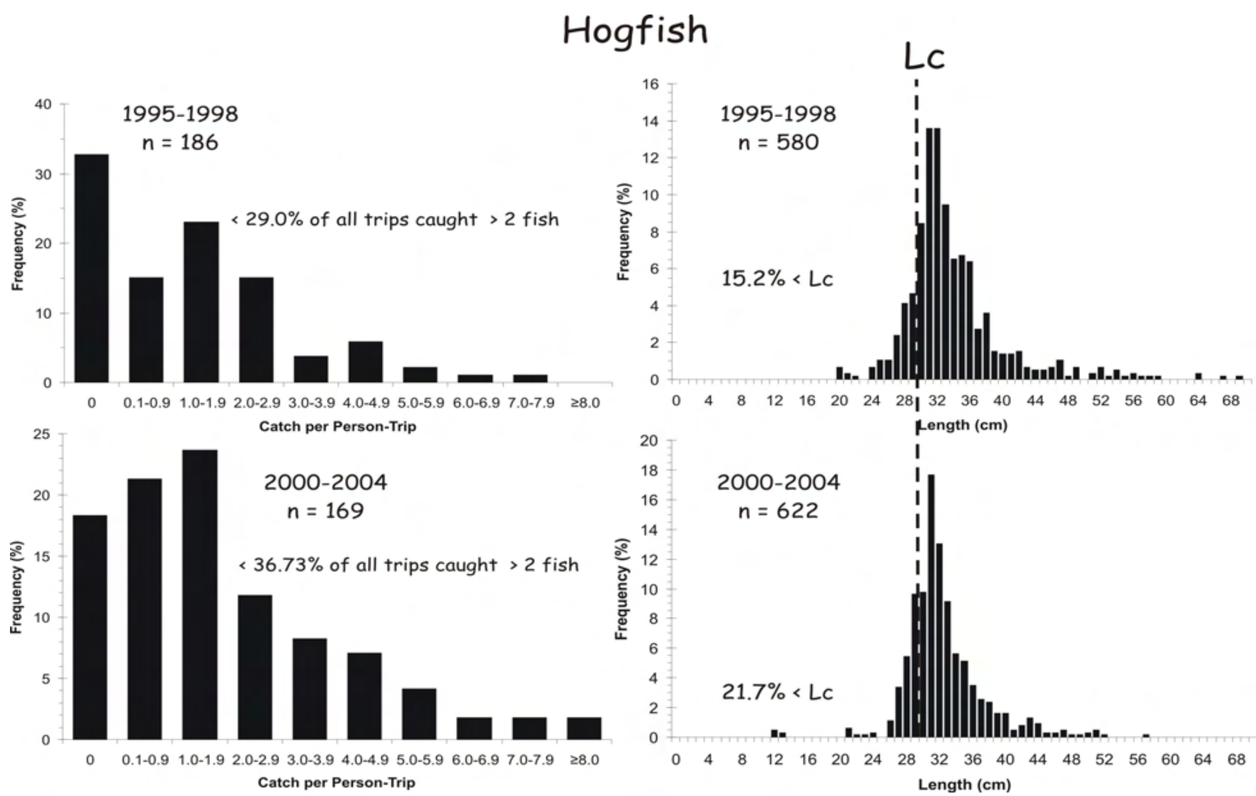

Figure 14.- Comparison of landings per person (left panels) and size distribution of landings (right panels) for Biscayne National Park creel data for hogfish (*Lachnolaimus maximus*) for the periods 1995-1998 (top panels) and 2000-2004 (bottom panels). Vertical dashed line is the current minimum legal harvest size.

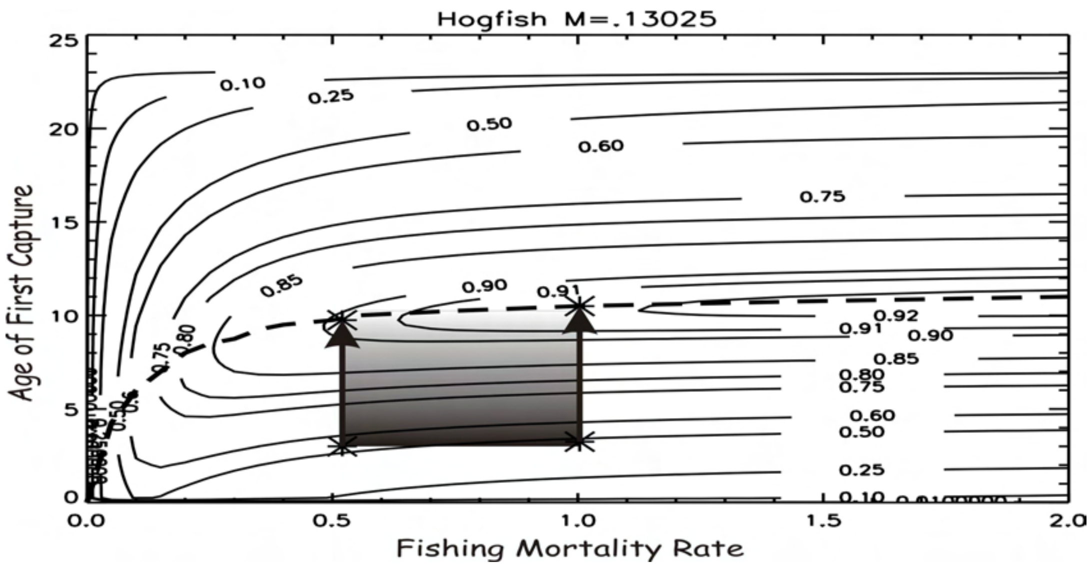

Figure 15.- Equilibrium contours for yield-per-recruit in kg for hogfish (*Lachnolaimus maximus*) obtained from any combination of F and t_c. The dashed line joins the maxima of yield-age of first harvest (i.e., minimum size/age limit) curves (i.e., eumetric line). The stars indicate the current value of F and t_c, and the arrow points to the eumetric values. Note that the eumetric fishing line produces an SPR equal to or above the 30% SPR federal standard, irrespective of fishing mortality rates above current. Shaded box is the 05% CI of exploitation for the Florida-wide stock, with BNP on upper right end of probability distribution.

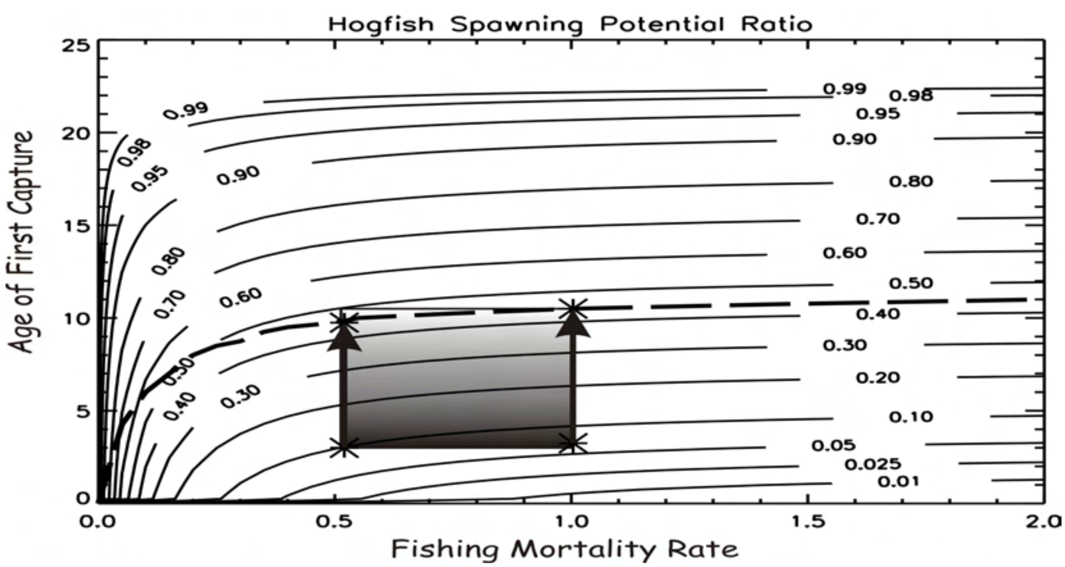

Figure 16.- Equilibrium contours for spawning potential ratio (SPR)-per-recruit for hogfish (*Lachnolaimus maximus*) based on F and t_c. The dashed line joins the maxima of SPR-age of first harvest (i.e., minimum size/age limit) curves (i.e., eumetric line). The stars indicate the current value of F and t_c, and the arrow points to the eumetric values. Shaded box is the 05% CI of exploitation for the Florida-wide stock, with BNP on upper right end of probability distribution.

Red Grouper

Current condition of stock

The current minimum size limit for red grouper (*Epinephelus morio*), is 20 in TL (50.8 cm). The average size of red grouper legally landed in BNP during 2000-2004 was 54.9 cm TL as compared to 53.5 cm TL during 1995-1999 (**Table 2A**). This is below the 59.2 cm TL average size observed in the entire exploited population throughout the Florida Keys as estimated through the reef fish visual census surveys. (**Table 1**; Ault et al. 2005b). The average size of legally landed red grouper at BNP corresponds to an estimated fishing mortality rate *F* of 0.89, which translates to a stock SPR< 9% (**Table 3**). These data indicate that the park's red grouper population is more severely fished than the broader population of the entire Florida Keys where the overall fishing mortality rate is estimated to be 0.35 with an SPR of about 18% (**Table 3**).

The distribution of sizes landed for BNP is shown in **Figure 17**. Eighty-seven red grouper were observed landed within 658 creel surveys of boats that had fished the reef area of the park during the years 1995-1998, and this decreased to 75 for 1,089 creel surveys conducted during the period 2000-2004. About 26% of those fish landed in BNP during 1995-1998 were smaller than the legal minimum size of capture (**Figure 17**), and this fraction of undersized illegal red grouper increased to 29% in 2000-2004.

The landings-per-angler-trip for red grouper has been extremely low during the past decade (**Figure 17, Table 2B**). Only 57 of 1090 boats interviewed from reef area fishing trips landed red grouper. Notably, the current bag limit for red grouper in Florida is 1 per person per day (FWC 2007). The overall observed landing rate of about 0.003 fish per angler-hour has remained relatively steady, meaning 1 fish is taken for every 333 hours of effort. About 5% of all reef fishing trips recorded by the creel census landed a red grouper (**Table 2B**).

These statistics indicate that the current rate of exploitation on red grouper in BNP is not sustainable and the population size structure is highly truncated. The current spawning potential per recruit for red grouper (i.e., SPR< 9%) in the Park and the Florida Keys coral reef ecosystem overall (SPR <18%) suggests that the population is overfished. Thus, a substantial reduction in fishing mortality or actions to increase the probability of a juvenile fish reaching the larger, more mature, size groups is needed to improve reproductive success and potentially sustain the resource.

Management alternatives

Given the current bag limit for red grouper is already only one fish per person per day, reducing the bag limit is not an option if the fishery is to remain open. Therefore, we explored the potential benefits of changing the minimum size of legal landing to improve stock sustainability. An analysis of optimal yield-per-recruit in relation to the size at first harvest is shown in **Figure 18**. Equilibrium contours for yield-per-recruit in kg obtained from various combinations of F and a_c indicate that the maximum yield-per-recruit at the current rate of fishing mortality for red grouper in BNP would be obtained if fish were between 8-9 years old when first subjected to harvest. Equilibrium spawning potential ratio (SPR)-per-recruit contours obtained from any combination of F and a_c are shown in **Figure 19**. Note that placing the minimum size of first capture at or above the maximum YPR line produces an SPR > 30%, which is above the federal standard for stock sustainability, irrespective of whether fishing mortality rates stay or may exceed the current estimated rate. This suggests that precautionary management should raise the minimum sizes of first capture for red grouper to a relatively high size-age (> 25 in or 9 yr). An increase of minimum legal size to produce the maximum YPR would increase the YPR by about 14%, and SPR by more than 102% to an SPR > 35% (**Table 3**). In addition, the average size (length) of fish in the catch would increase by about 20%, and the average weight would increase by more than 70%.

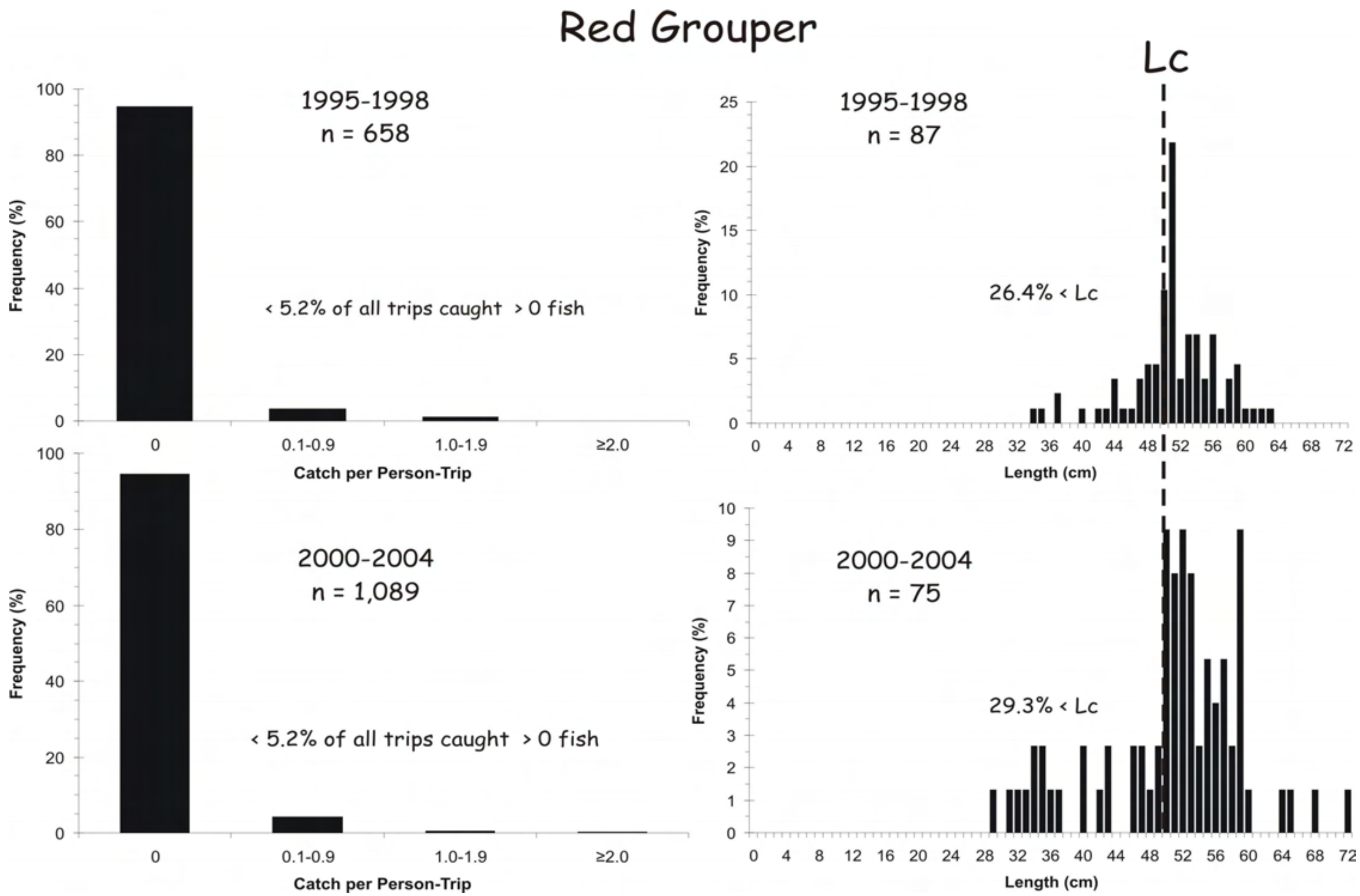

Figure 17.- Comparison of landings per person (left panels) and size distribution of landings (right panel) for Biscayne National Park creel data for red grouper (*Epinephelus morio*) for the periods 1995-1998 (top panels) and 2000-2004 (bottom panels). Vertical dashed line is the current minimum legal harvest size.

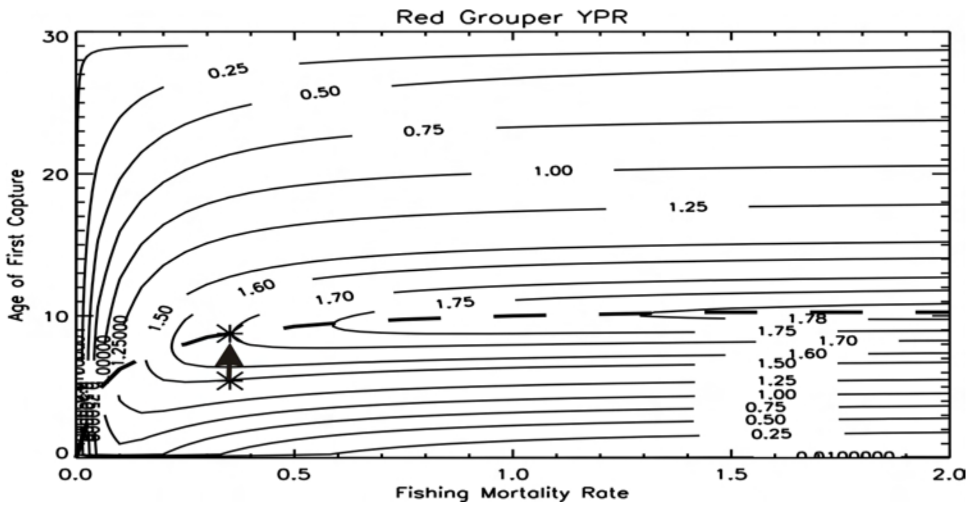

Figure 18.- Equilibrium contours for yield-per-recruit in kg for red grouper (*Epinephelus morio*) obtained from any combination of F and t_c.. The dashed line joins the maxima of yield at a given age of first harvest. The stars indicate the current value of F and t_c, and the arrow points to the eumetric values.

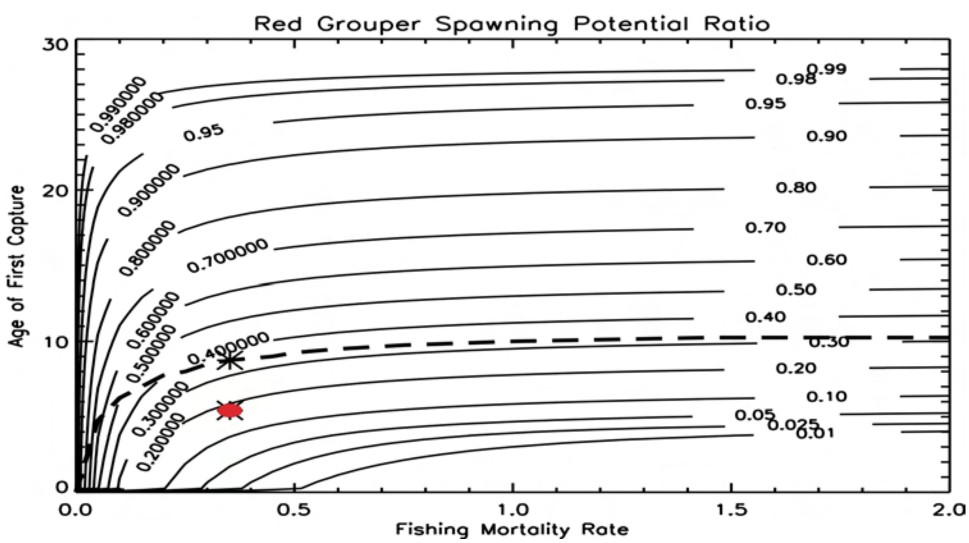

Figure 19.- Equilibrium contours for spawning potential ratio (SPR)-per-recruit for red grouper (*Epinephelus morio*) obtained from any combination of F and t_c. The stars indicate the current value of F and t_c, and the arrow points to the eumetric values. Note that the eumetric fishing line produces an SPR equal to or above the 30% SPR federal standard, irrespective of fishing mortality rates above current.

Mutton Snapper

Current condition of the stock
The current minimum size limit for mutton snapper (*Lutjanus analis*) is 16 in TL (40.6 cm). The average size of legally landed mutton snapper in BNP during 2000-2004 was 47.8 cm TL as compared to 49.9 cm TL during 1995-1999 (**Table 2A**). This is very close to the 49.3 cm TL average size observed in the entire exploited population throughout the Florida Keys as estimated through the reef fish visual census surveys (**Table 1**; Ault et al. 2005b). The average size of legal mutton snapper observed harvested at BNP corresponds to an estimated fishing mortality rate F of 0.66, which translates to a stock SPR< 7% (**Table 3**). The overall size composition of mutton snapper observed landed at BNP is shown (right panels, **Figure 20**). During the years 1995-1998, 99 mutton snapper were recorded in 1,152 creel surveys of boats fishing either the reef or bay areas of the park, and this increased to 128 mutton snapper for 1,661 creel surveys conducted during the period 2000-2004. About 37% of the mutton snapper landed in BNP during 2000-2004 were smaller than the legal minimum size (**Figure 20**).

The landings-per-angler-trip for mutton snapper have rarely been in excess of one fish throughout the 1990's to the present (**Figure 20**). Notably, there is no current bag limit for mutton snapper in Florida, but they are included in the 10 per person per day snapper aggregate bag limit (FWC 2007). Only about 4% of all trips fishing the reef or bay areas recorded by the creel census for the period 1995-1998 kept mutton snapper (**Table 2B**). This percentage increased to about 6% for the period 2000-2004. Less than 2% of all trips landed more than one fish (**Figure 20**). The overall catch rate of about 0.002 fish per angler-hour has remained relatively steady over the survey years, meaning 1 fish is captured for every 500 hours of effort. These statistics all indicate that the current rate of exploitation on mutton snapper in BNP is very high and the population size structure is highly truncated. The current estimated spawning potential per recruit for mutton snapper (i.e., SPR< 7%) in the Park and the Florida Keys coral reef ecosystem (SPR< 9%) suggests that the population is seriously overfished and not sustainable at present harvest rates. Thus, substantial reduction in fishing mortality or actions to increase the probability of juvenile fish reaching the larger, more mature size groups is needed to improve reproductive success and potentially sustain the resource.

Management Alternatives
Since <2% of all trips caught more than one Mutton snapper per person, reducing bag limits to even one fish would unlikely reduce the fishing mortality rate sufficiently to achieve an adequate SPR to ensure stock sustainability. Restricting the rather large (percent) take of sub-legal fish would obviously help this resource, but the current minimum size limit for mutton snapper also appears to be resulting in over harvest and reducing the population below a desirable spawning potential ratio. Therefore, the potential benefits of changing the minimum size of capture was explored. An analysis of optimal yield-per-recruit in relation to size at first harvest is shown in **Figure 21**. Equilibrium contours for yield-per-recruit in kg obtained from any combination of F and a_c indicate that the maximum yield-per-recruit at the current rate of fishing mortality for mutton snapper in BNP would be obtained if fish were at least 10 years of age when first subjected to harvest. Equilibrium spawning potential ratio (SPR)-per-recruit contours obtained from any combination of F and a_c are shown in **Figure 22**. Note that placing the minimum size of first capture at or above the maximum YPR line produces an SPR > 40%, well above the

federal standard for stock sustainability of 30% SPR, irrespective of whether fishing mortality rates stay or may exceed the current estimated rate. This suggests that precautionary management should raise the minimum sizes of first capture for mutton snapper to a relatively high size-age (> 27 in or 10 yr). This strategy would allow the animals to mature, reach their biomass and yield potential, and to at least ensure reproductive replacement of a spawning pair and thus population sustainability. We did not factor in release mortality in our analyses, which would argue for even more conservative minimum size limits. An increase of minimum legal size to produce the maximum YPR would increase the YPR by about 65%, and SPR by more than 353% to an SPR of > 38% (**Table 3**). In addition, the average size (length) of fish in the catch would increase by about 50%, and the average weight of a fish would be more than 1.5 times greater.

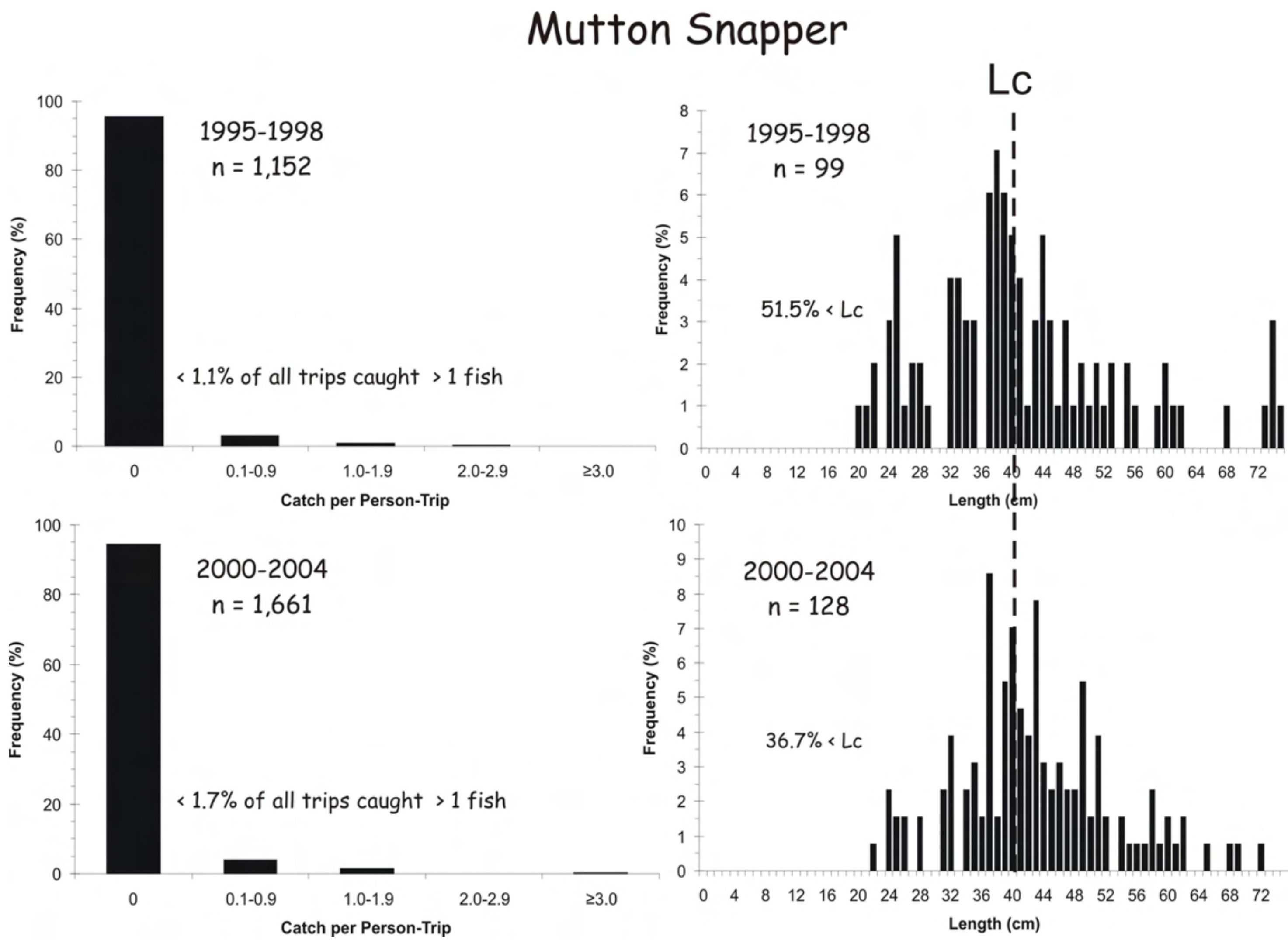

Figure 20.- Comparison of landings per person (left panels) and size distributions of landings (right panel) for Biscayne National Park creel data for mutton snapper (*Lutjanus analis*) for the periods 1995-1998 (top panels) and 2000-2004 (bottom panels). Vertical dashed line is the current

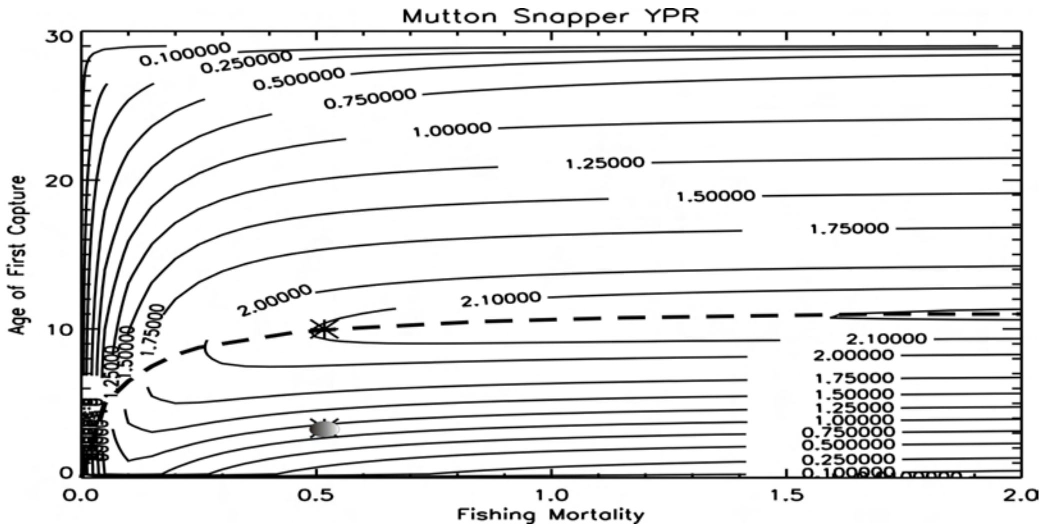

Figure 21.- Equilibrium contours for yield-per-recruit in kg for mutton snapper (*Lutjanus analis*) obtained from any combination of *F* and t_c. The dashed line joins the maxima of yield-age of first harvest (i.e., minimum size/age limit) curves (i.e., eumetric line). The stars indicate the current value of *F* and t_c, and the arrow points to the eumetric values.

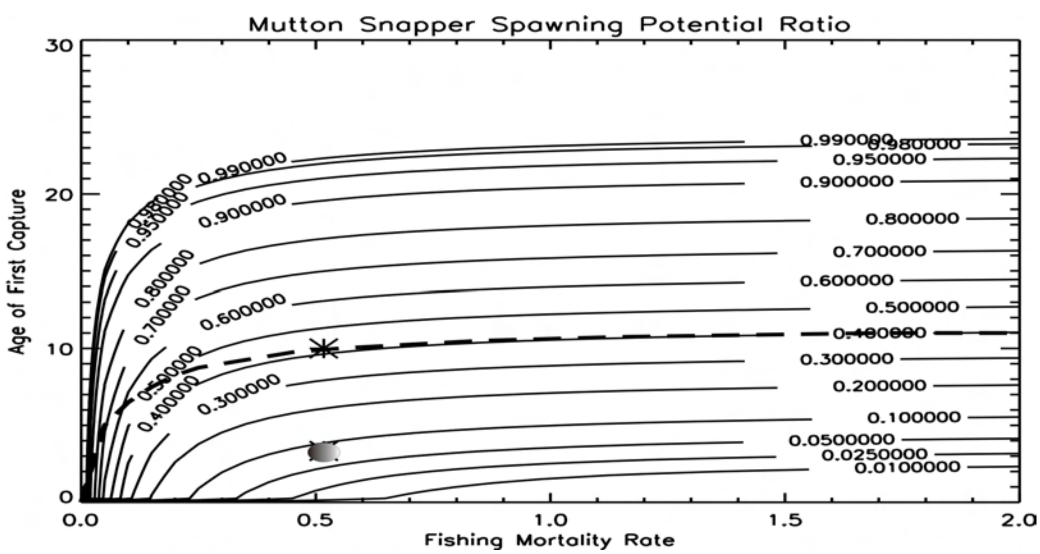

Figure 22.- Equilibrium contours for spawning potential ratio (SPR)-per-recruit for mutton snapper (*Lutjanus analis*) obtained from any combination of *F* and t_c. The dashed line joins the maxima of SPR-age of first capture (i.e., minimum size/age limit) curves (i.e., eumetric line). The stars indicate the current value of *F* and t_c, and the arrow points to the eumetric values. Note that the eumetric fishing line produces an SPR equal to or above the 30% SPR federal standard, irrespective of fishing mortality rates above current.

Gray Snapper

Current condition of stock

The current minimum size limit for gray snapper (*Lutjanus griseus*) is 10 in TL (25.4 cm). The average size of gray snapper legally landed in BNP during 2000-2004 was 28.8 cm TL as compared to 29.2 cm TL during 1995-1999 (**Table 2A**). This is below the 30.9 cm average size observed in the entire exploited population throughout the Florida Keys estimated through the reef fish visual census surveys (**Table 1**; Ault et al. 2005b). The average size of gray snapper legally landed at BNP corresponds to an estimated fishing mortality rate *F* of 1.44, which translates to a stock SPR< 2% (**Table 3**). This rate of fishing mortality is close to twice that estimated for the entire exploited stock throughout the Florida Keys. The overall size composition of gray snapper landed, as estimated from the creel survey, is shown in **Figure 23** (right panels) . About 1,099 gray snapper were recorded in 1,158 creel surveys of boats fishing the reefs and bay conducted during the years1995-1998, and this decreased to 1,027 for 1,661 creel surveys conducted during the period 2000-2004. About 11% of those fish landed in BNP were smaller than the legal minimum size of capture during 1995-1998 (**Figure 23**), and this percentage increased to 13% in 2000-2004.

The landings-per-angler-trip have ranged up to 6+ fish throughout the 1990's to the present, although <12% of the trips surveyed had kept more than one gray snapper (**Figure 23**). The current bag limit for gray snapper in Florida is 5 per person per day and they are included in the 10 per person per day snapper aggregate bag limit (FWC 2007). This suggests that a small proportion of landings at BNP exceeded the legal bag limit (i.e., about 0.5 to 1.5% of those fish surveyed). About 22% of all fishing trips to the reef or bay areas recorded by the creel census for the period 1995-1998 kept gray snapper (**Table 2B**). This percentage decreased to < 19% for the period 2000-2004. The overall catch rate of about 0.01 fish per angler-hour has remained relatively steady, meaning 1 fish is captured for every 100 hours of effort.

These statistics all indicate that the current rate of exploitation on gray snapper in BNP is very high and the population size structure is highly truncated. The current estimate of spawning potential per recruit for gray snapper (i.e., SPR< 2%) in the Park and the Florida Keys coral reef ecosystem (< 4%) suggests that the population is seriously overfished and not sustainable in its current condition. Thus, a substantial reduction in fishing mortality or actions to increase the probability of a juvenile reaching the larger, more mature size groups is needed to improve reproductive success and potentially sustain the resource.

Management alternatives

Even though less than 11% of the fishing trips successful for gray snapper harvested more than one fish per person during the most recent survey, we believe a reduction in bag limit could greatly help reduce overall fishing mortality on this species, although probably not enough to achieve a spawning potential per recruit that would ensure sustainability. If bag limits were reduced from the current 5 fish per angler-trip to one fish per angler-trip, overall fishing mortality within the park could potentially decrease by 52.4%. However, this amount of reduction in F would not be likely be achieved due to some redistribution of the catch to currently unsuccessful fishermen and some continued losses due to hooking mortality.

The exact amount of reduced fishing mortality a one fish bag limit would achieve is not known, but even a 50% reduction in fishing mortality would not ensure stock sustainability at the current minimum harvest size limit (**Figure 24**). Therefore, the potential benefits of changing the minimum size of harvest was explored. An analysis of optimal yield-per-recruit in relation to size at first harvest for gray snapper is shown in **Figure 24**. Equilibrium contours for yield-per-recruit in kg obtained from any combination of F and a_c are shown within this figure. The maximum YPR at the current rate of fishing mortality for gray snapper in BNP would be obtained if fish were between 9-10 years old when first subjected to harvest. Equilibrium spawning potential ratio (SPR)-per-recruit contours obtained from any combination of F and a_c are shown in **Figure 25**. Note that placing the minimum size of first capture at or above the line of maximum YPR produces an SPR > 30%, which is above the federal standard for sustainability, irrespective of whether fishing mortality rates stay at or exceed the current estimated rate. This suggests that precautionary management should raise the minimum sizes of first capture for gray snapper to a relatively high size-age (> 21 in or 9.5 yr). An increase of minimum legal size to produce the maximum YPR would increase the YPR by about 147%, and SPR by more than 1053% to an SPR of > 35% (**Table 3**). In addition, the average size (length) of fish in the catch would nearly double, and the average weight would more than triple.

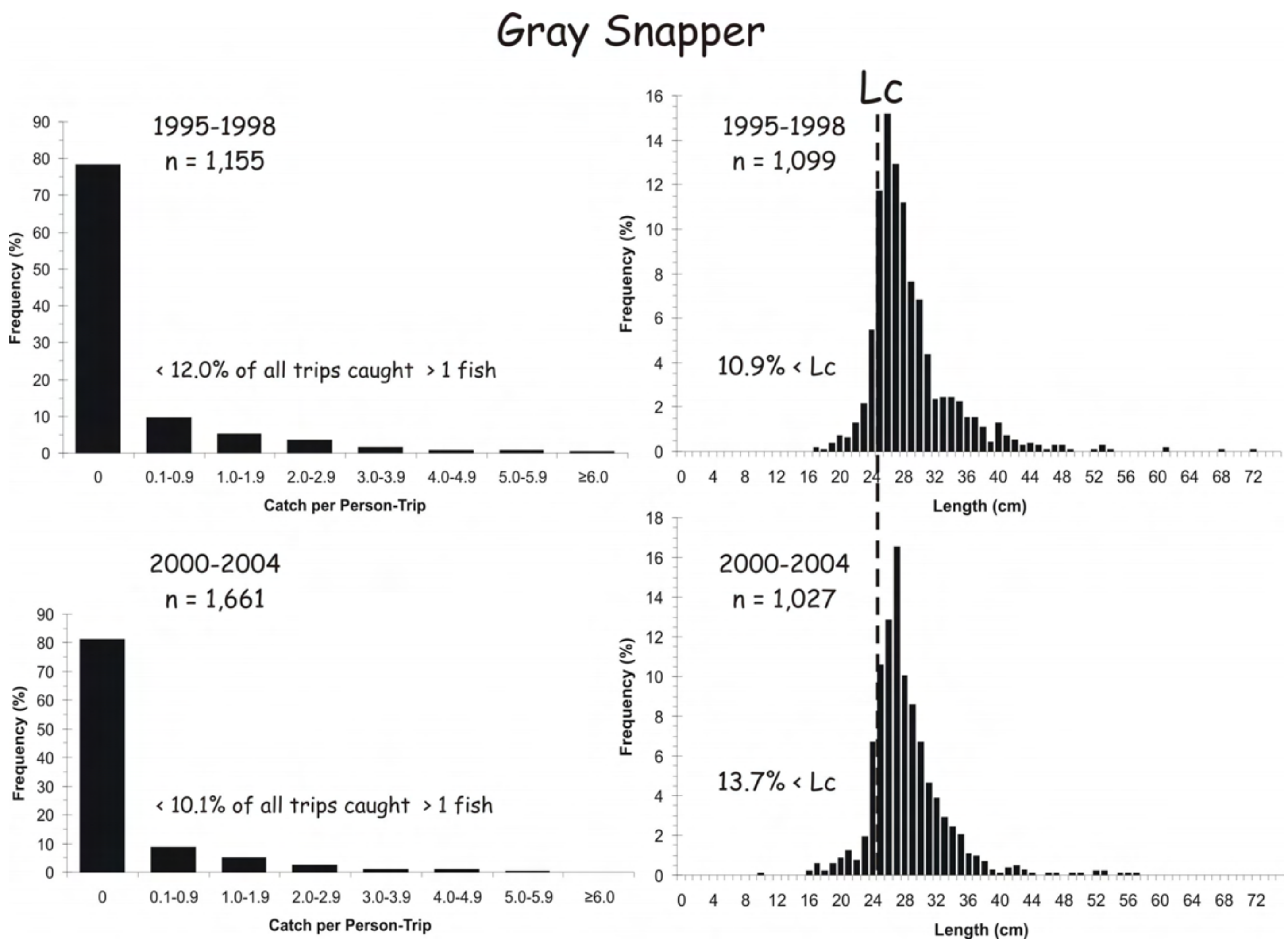

Figure 23.- Comparison of landings per person (left panel) and size distributions of landings for Biscayne National Park creel data for gray snapper (*Lutjanus griseus*) for the periods 1995-1998 (top panels) and 2000-2004 (bottom panels). Vertical dashed line is the current minimum legal harvest size.

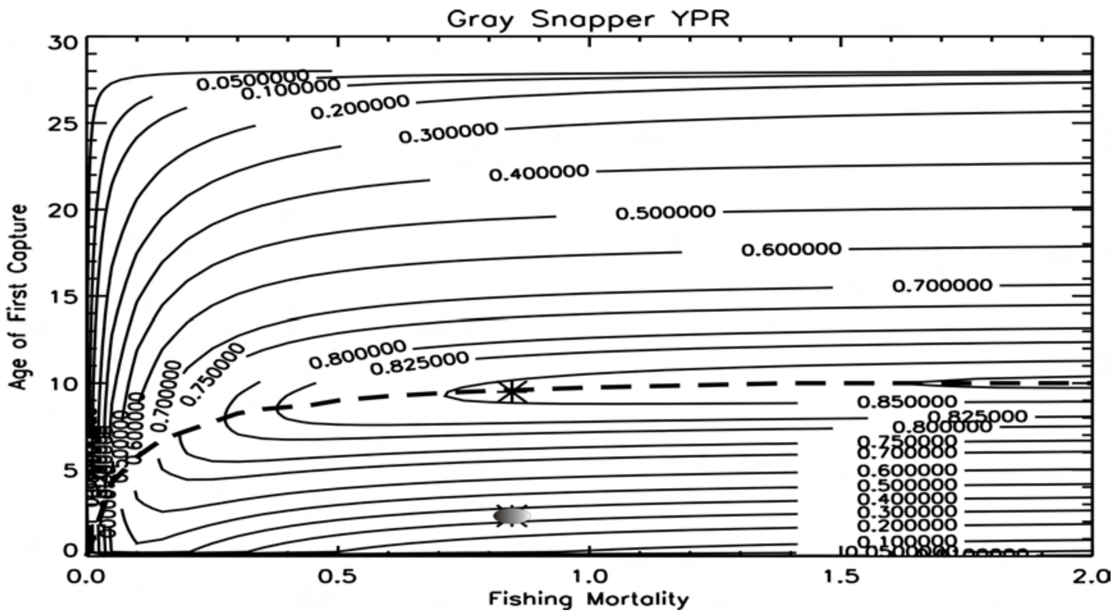

Figure 24.- Equilibrium contours for yield-per-recruit in kg for gray snapper (*Lutjanus griseus*) obtained from any combination of *F* and t_c. The dashed line joins the maxima of yield-age of first harvest (i.e., minimum size/age limit) curves (i.e., eumetric line). The stars indicate the current value of *F* and t_c, and the arrow points to the eumetric values.

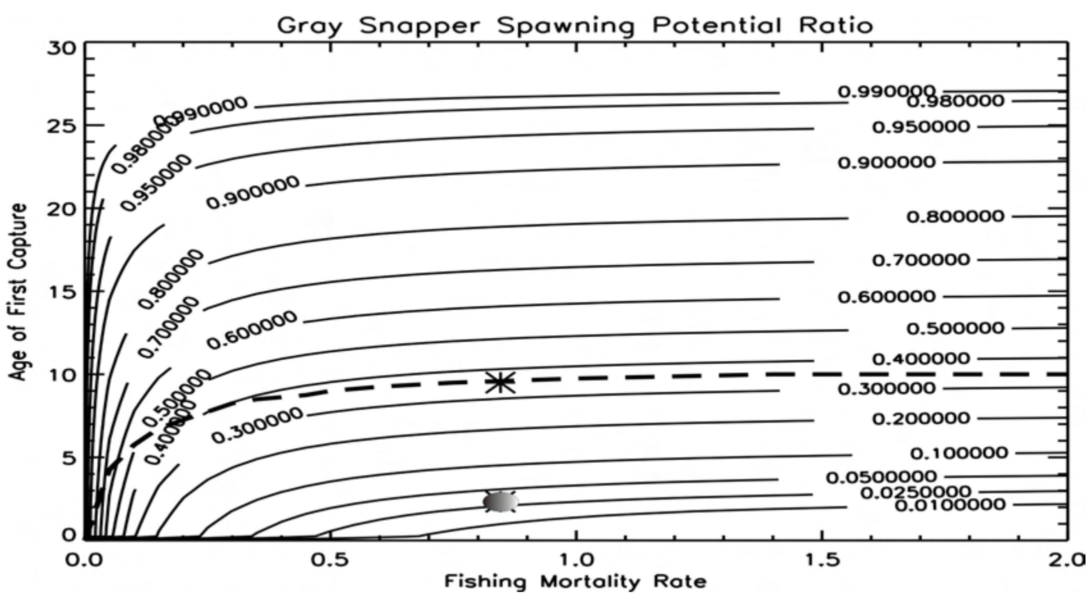

Figure 25.- Equilibrium contours for spawning potential ratio (SPR)-per-recruit for gray snapper (*Lutjanus griseus*) obtained from any combination of *F* and t_c. The dashed line joins the maxima of SPR-age of first harvest (i.e., minimum size/age limit) curves (i.e., eumetric line). The lower star indicates the current value of *F* and t_c, and the arrow points to the eumetric value (upper star). Note that the eumetric fishing line produces an SPR equal to or above the 30% SPR federal standard, irrespective of fishing mortality rates above current.

Yellowtail Snapper

Current Condition of the Stock

The current minimum size limit for yellowtail snapper (*Ocyurus chrysurus*) is 12 in TL (30.5 cm), or approximately 10 in (25.4 cm) fork length (FL). The average size of yellowtail snapper legally landed in BNP during 2000-2004 was 29.6 cm FL as compared to 28.7 cm FL during 1995-1999 (**Table 2A**). This is about the same as the 29.7 cm FL average size observed in the entire exploited population throughout the Florida Keys by the reef fish visual census surveys (**Table 1**; Ault et al. 2005b). The average size of legally landed yellowtail snapper at BNP and throughout the Florida Keys corresponds to an estimated fishing mortality rate F of approximately 0.49, which translates to a stock SPR of 27.5% (**Table 3**). This is very close to the minimum 30% SPR federal standard for stock sustainability and indicates that yellowtail snapper populations are not in as poor a condition as many other targeted reef species but still overfished. The size composition of all yellowtail snapper observed landed at BNP is shown in **Figure 26** (right panels). During the years 1995-1998, 430 yellowtail snapper were recorded in 658 creel census surveys of boats fishing the reef areas of the park, and this increased to 687 yellowtail snapper for 1,090 creel surveys conducted during the period 2000-2004. About 10% of those fish landed in BNP were smaller than the legal minimum size of capture during 1995-1998 (**Figure 26**), and this percentage decreased to 6% in 2000-2004.

The landings-per-angler-trip for yellowtail snapper has been up to 9+ fish throughout the 1990's to the present (**Figure 26**). The current bag limit for yellowtail snapper in Florida is included in the 10 per person per day snapper aggregate bag limit (FWC 2007). Less than 8.2% of all observed trips in 1995-1998, and 8.6% in 2000-2004 landed more than one yellowtail snapper per person. About 17% of all reef fishing trips observed for the period 1995-1998 landed yellowtail snapper (**Table 2B**). This percentage decreased to < 15% for the period 2000-2004. The overall catch rate of about 0.01 fish per angler-hour has remained relatively steady, meaning 1 fish is captured for every 100 hours of effort within the reef area.

These statistics indicate that the current rate of exploitation on yellowtail snapper in BNP, although not nearly as high as most other reef species, is still of concern and additional restrictions on the fishery should be considered to ensure sustainability.

Management Alternatives

Because nearly 10% of the fishing trips to the reef area of the park harvest more than one yellowtail snapper per person, a substantial reduction in the fishing mortality rate of yellowtail snapper could likely be achieved through reduced bag limits. For example, a reduction in the daily bag limit from the current 10 fish to 5 fish per person would result in as much as a 16% reduction in fishing mortality if redistribution of unharvested fish did not occur and illegal landings were eliminated. A one fish bag limit could reduce current rates of fishing mortality by as much as 70% if no redistribution occurred. A 16 % reduction in fishing mortality (i.e., reduced from 0.49 to 0.41) would raise the SPR over the 30% minimum for sustainable populations.

Although reduced bag limits look like they could possibly help improve yellowtail stock status, hooking mortality and redistribution of fish not taken by some of the successful fishermen to some of the fishermen currently not catching the bag limit would be expected to limit these benefits. Therefore, greater gains toward stock sustainability might be achieved through increased minimum size limits. We evaluated potential stock improvements through adjustment in minimum harvest size to that which produced the maximum YPR. An analysis of optimal yield-per-recruit in relation to size at first harvest for yellowtail snapper is shown in **Figure 27**. Equilibrium contours for yield-per-recruit in kg obtained from any combination of F and a_c indicate that the maximum YPR at the current rate of fishing mortality for yellowtail snapper in BNP could be obtained by increasing the age of fist harvest from the present 3 yrs of age to 4 years of age (11.5 inches). Equilibrium spawning potential ratio (SPR)-per-recruit contours obtained from any combination of F and a_c are shown in **Figure 28**. Note that placing the minimum size of first capture at or above the maximum YPR line produces an SPR > 40%, well above the federal standard of 30%, irrespective of whether fishing mortality rates stay or may exceed the current estimated rate. This suggests that precautionary management should raise the minimum sizes of first capture for yellowtail snapper to > 11 in FL (4.5 yr) to ensure stock sustainability. An increase of minimum legal size to the maximum YPR would only marginally increase the YPR (about 1%), but increase the SPR by more than 62% to an SPR of > 46% (**Table 3**), well above the 30% SPR Federal standard. In addition, the average size (length) of fish in the catch would increase by about 20%, while the average weight would increase by about 55%.

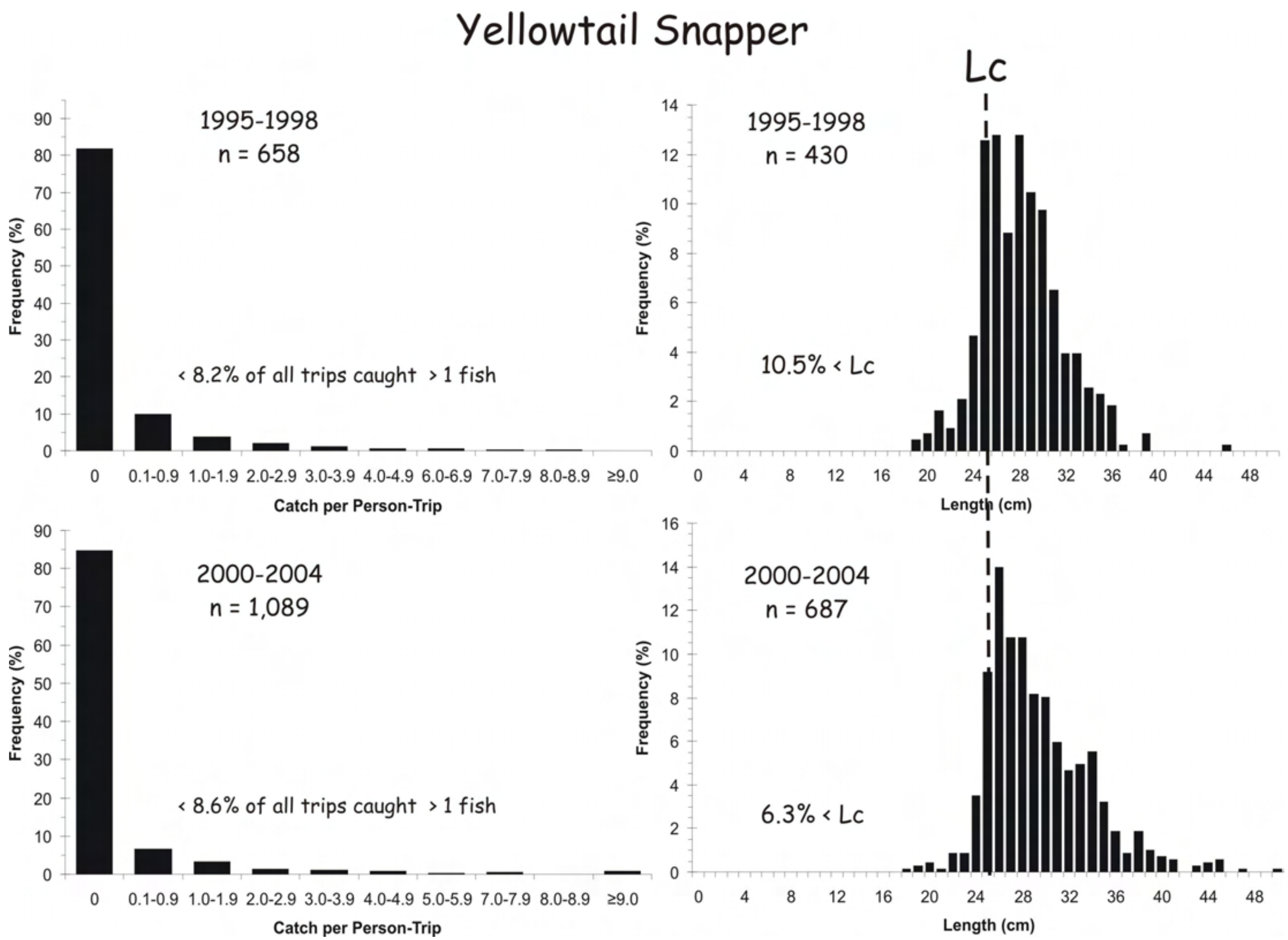

Figure 26.- Comparison of landings per person (left panels) and size distributions of landings (right panel) for Biscayne National Park creel data for yellowtail snapper (*Ocyurus chrysurus*) for the periods 1995-1998 (top panels) and 2000-2004 (bottom panels). Vertical dashed line is the current minimum legal harvest size.

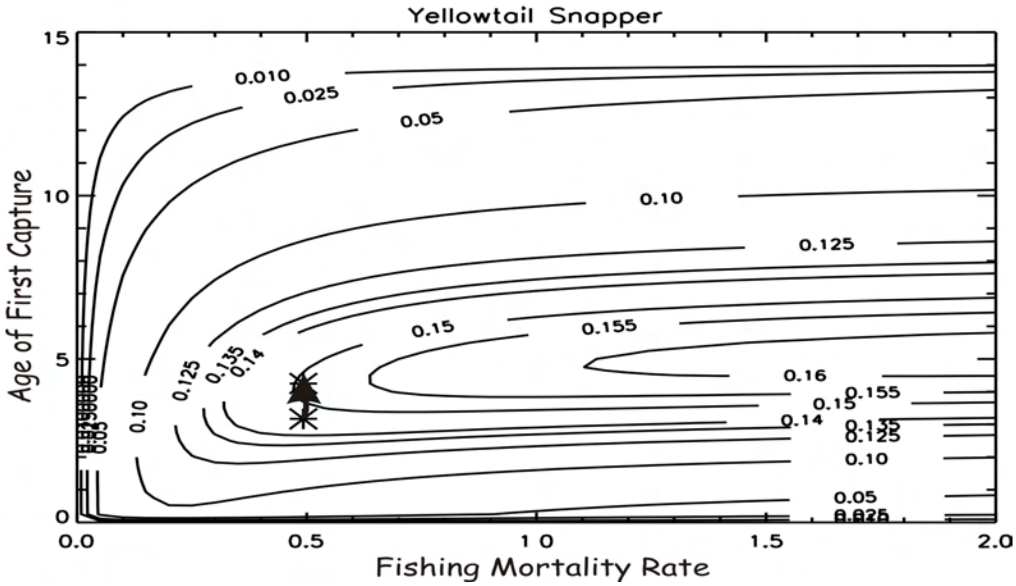

Figure 27.- Equilibrium contours for yield-per-recruit in kg for yellowtail snapper (*Ocyurus chrysurus*) obtained from any combination of F and t_c. The dashed line joins the maxima of yield-age of first harvest (i.e., minimum size/age limit) curves (i.e., eumetric line). The stars indicate the current value of F and t_c, and the arrow points to the eumetric value.

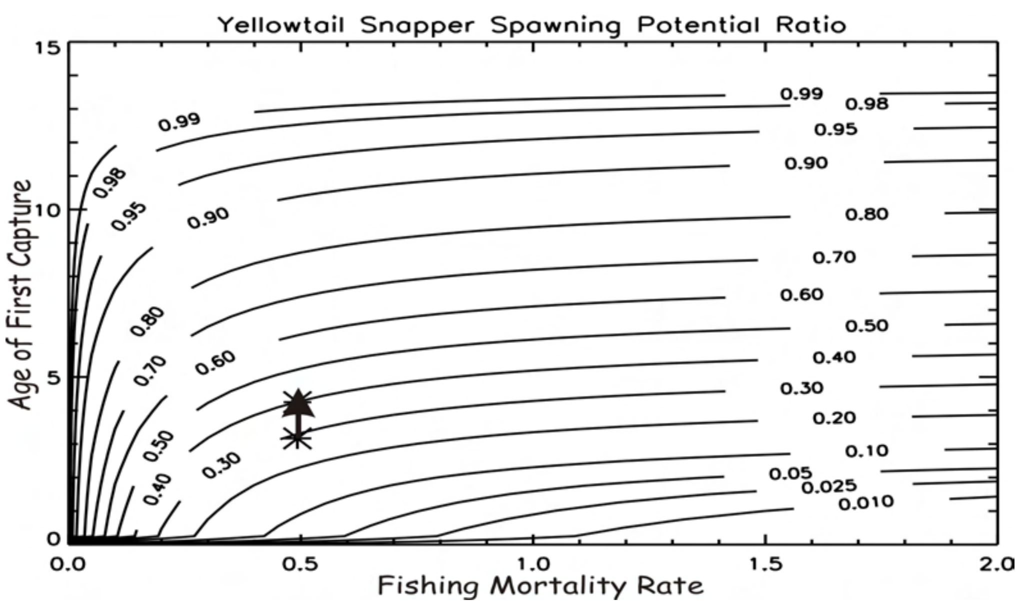

Figure 28.- Equilibrium contours for spawning potential ratio (SPR)-per-recruit yellowtail snapper (*Ocyurus chrysurus*) obtained from any combination of F and t_c. The dashed line joins the maxima of SPR-age of first harvest (i.e., minimum size/age limit) curves (i.e., eumetric line). The lower star indicates the current value of F and t_c, and the arrow points to the eumetric value (upper star). Note that the eumetric fishing line produces an SPR equal to or above the 30% SPR federal standard, irrespective of fishing mortality rates above current.

White Grunt

Current Condition of the Stock
There is no current minimum size limit for white grunt (*Haemulon plumieri*). The average size of white grunt observed landed in BNP during 2000-2004 was 22.1 cm TL as compared to 21.7 cm TL during 1995-1999 (**Table 2A**). This is below the 22.7 cm TL average size in the entire exploited population throughout the Florida Keys as estimated through the reef fish visual census surveys (**Table 1**; Ault et al. 2005b). The average size of white grunt currently landed in BNP corresponds to an estimated fishing mortality rate F of 0.88, which translates to a stock SPR of < 4% for this species (**Table 3**). This suggests that white grunt are seriously overfished within the park. The size composition of white grunt observed landed at BNP is shown in **Figure 29** (right panels). During the years 1995-1998, 1,906 white grunt were recorded in 658 creel surveys of boats fishing the reef areas of the park, and this decreased to 1,131 for 1,090 creel surveys conducted during the period 2000-2004.

The largest landings-per-angler-trip for white grunt at BNP have exceeded 10 fish per person throughout the 1990's to the present (**Figure 29**) and there is no specific bag limit for this species in Florida (FWC 2007). Over 30% of all trips fishing the reef area in 1995-1998 landed more than one white grunt per person, but only about 13% in 2000-2004 landed more than one per person. During the 1995-1998 survey period, approximately 32% all trips fishing within the reef area of the park were observed to have kept white grunt (**Table 2B**). This percentage decreased to < 19% for the period 2000-2004. The overall catch rate for white grunt was 0.05 fish per angler-hour for the 1995-1998 period, and decreased to 0.02 during 2000-2004.

The current status of white grunt (i.e., SPR< 5%) in the Park and the Florida Keys coral reef ecosystem suggests that the population is extremely overfished. In addition it is apparent that the rate of exploitation on this species has increased greatly since the earlier park survey period. Exploitation rates are now very high and stocks are not sustainable at the current rate of fishing mortality. A substantial reduction in fishing mortality and/or actions to greatly increase the minimum size of fish being landed are needed to sustain this resource.

Management Alternatives
Because there are no minimum size limits on white grunt that can be legally landed, a large number of boats fishing for this species have landed multiple numbers of this fish in the past. The proportion of boats with more than one white grunt in their creel has decreased dramatically in recent years, but a substantial reduction in the fishing mortality rate could still likely be obtained through the establishment of a conservative bag limit. For example, if a 5 fish per person bag limit were to be instituted on white grunt, our analysis suggests that fishing mortality could be reduced as much as 18%. A one fish bag limit would reduce fishing mortality by as much as 75% unless a large number of these fish were redistributed into the landings of other fishermen who are not currently exceeding these limits.

Although bag limits could be helpful in improving the park population of white grunt, size restrictions on harvest will also be needed to ensure stock sustainability. An analysis of optimal yield-per-recruit in relation to size at first harvest for white grunt is shown in **Figure 30**. Equilibrium contours for yield-per-recruit in kg obtained from any combination of F and a_c

indicate that the maximum YPR at the current rate of fishing mortality for white grunt in BNP would be obtained if fish were at least 6.5 years of age when first subjected to harvest. Equilibrium spawning potential ratio (SPR)-per-recruit contours obtained from any combination of F and a_c are shown in **Figure 31**. Note that placing the minimum size of first harvest at or above the maximum YPR line produces an SPR of nearly 40%, which is well above the federal standard of 30% for sustainable stocks, irrespective of whether fishing mortality rates stay or may exceed the current estimated rate. This suggests that precautionary management should raise the minimum sizes of first capture for white grunt to a relatively high size-age (> 14 in or 6.5 yr). An increase of minimum legal size to that which would produce the maximum YPR would increase the YPR by about 121%, and increase the SPR by more than 713% to an SPR of > 39% (**Table 3**). In addition, the average size (length) of fish in the catch would increase by about 75%, while the average weight of a white grunt in the catch would quadruple.

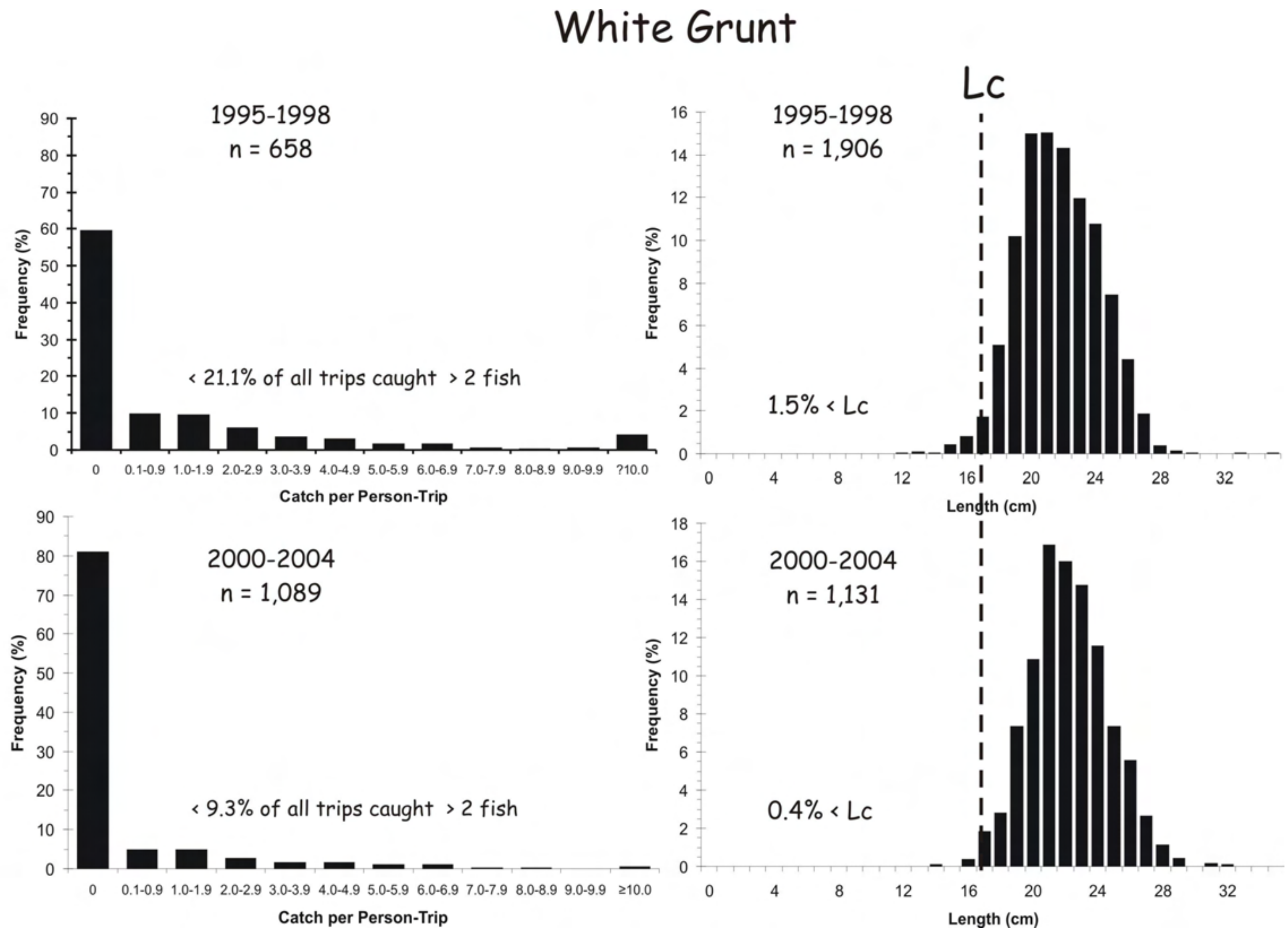

Figure 29.- Comparison of landings per person (left panels) and size distributions of landings (right panel) for Biscayne National Park creel data for white grunt (*Haemulon plumieri*) for the periods 1995-1998 (top panels) and 2000-2004 (bottom panels). Vertical dashed line is the current minimum legal harvest size.

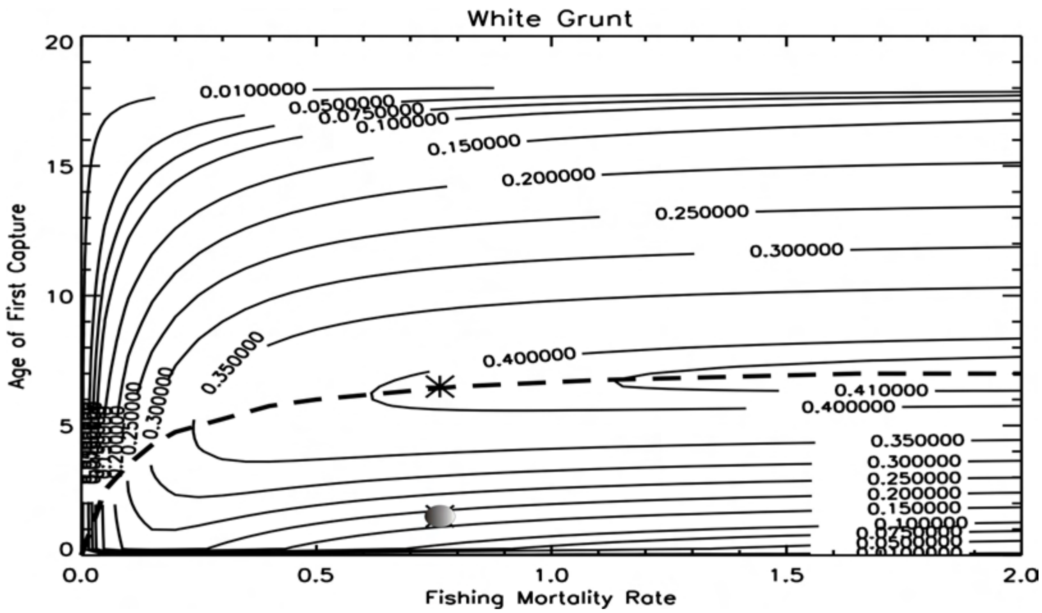

Figure 30.- Equilibrium contours for yield-per-recruit in kg for white grunt (*Haemulon plumieri*) obtained from any combination of *F* and t_c. The dashed line joins the maxima of yield-age of first harvest (i.e., minimum size/age limit) curves (i.e., eumetric line). The stars indicate the current value of *F* and t_c, and the arrow points to the eumetric value.

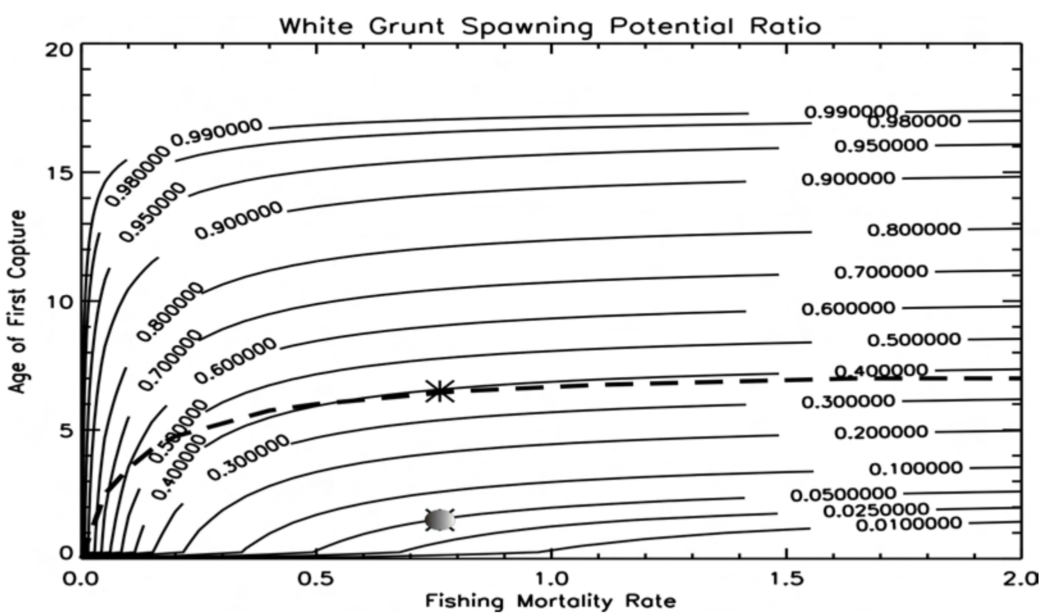

Figure 31.- Equilibrium contours for spawning potential ratio (SPR)-per-recruit for white grunt (*Haemulon plumieri*) obtained from any combination of *F* and t_c. The dashed line joins the maxima of SPR-age of first harvest (i.e., minimum size/age limit) curves (i.e., eumetric line). The lower star indicates the current value of *F* and t_c, and the arrow points to the eumetric value (upper star).

Discussion

There has been a continuous long-term increase in registered recreational boats and fishing effort coupled with human population growth in South Florida. In the last 15 years, the recreational fleet has increased from about 140 thousand registered vessels to over 200 thousand (**Figure 1**) and there is nothing to suggest that recreational fishing effort will not continue to increase into the future within the park and the greater south Florida area. Therefore, reef fish stocks will likely receive greater and greater fishing pressures. Unless some additional restrictions are placed on the recreational fishery, fishing mortality rates for all of the species are likely to continue to increase into the future.

All seven species analyzed in this study were found to have fishing mortality rates that exceed those which are generally considered sustainable for healthy fish populations. None of the park populations equaled or exceeded the minimum 30% spawning potential ratio (SPR) standard generally accepted as necessary for a sustainable fishery stock. Only one species (yellowtail snapper) is even close to sustainability with an SPR of 28%. All of the other species have SPR's of less than 10%, and two of these species (black grouper and gray snapper) less than 2%. It is also apparent that the estimated fishing mortality rates on the park populations for each of the species analyzed are greater than the estimated rates for those species when considering the entire exploited population throughout the Florida Keys, although the entire population rates are also very high and not sustainable. Thus, there is an urgent need for either a reduction in fishing mortality on all species (some more than others), or to raise the average size of the fish in each population such that their reproductive potential is increased to reach a point of population sustainability.

Even though the average number of fish landed per fishing trip for all of the species analyzed was found to be very low, we found a reduction in bag limit could, in some cases, significantly reduce overall fishing mortality rates. Obviously for Black and Red Grouper and for Mutton Snapper, where very few trips even harvested one fish, reductions in bag limits would have little apparent effect or, in the case of red grouper, would close the fishery. But for other species, a bag limit reduction could significantly reduce fishing mortality. For example, a reduction in harvest to one fish per angler per day could result in up to a 30-50% reduction in landings for hogfish, yellowtail snapper, gray snapper, and white grunt, assuming that all of the savings in fish harvested was not redistributed to other currently non-successful boats. What we are facing at Biscayne (and South Florida in general) is that there are currently so many boats fishing, that even though a small percentage are successful harvesting fish (particularly more than 1 fish), the numbers landed still constitute a sizeable overall harvest and thus fishing mortality rates are fairly high. By reducing or eliminating even the small percentage of fishermen landing more than one fish, substantial gains in the reduction of fish harvest could potentially be realized.

However, our analysis indicates that a reduction in bag limits alone will not be sufficient to allow stocks to recover. In most cases, estimates of fishing mortality (F) are so high that the maximum reduction in F attainable through reduced bag limits does not greatly affect the resulting estimated YPR or SPR. Only a radical increase in the size at first capture, thereby greatly increasing a stock's reproductive potential, will allow a stock to approach a desired SPR for the populations of concern. This is particularly true for black grouper, hogfish, mutton snapper, gray snapper, and white grunt. However, for Yellowtail snapper, the average size currently harvested is apparently relatively close to the minimum size needed to achieve a desired SPR.

Expected Response Times to Management Actions

Studies starting with Beverton and Holt (1957) and many others (Quinn and Deriso 1999) have shown that the ratio of natural mortality to growth rate (M/K) of a species can provide a good indication of the rate at which the average length in the population will increase when exploitation is reduced. Ecological interpretation of the plot of SPR dependent on M/K (**Figure 32**) suggests that the greater proportion of those BNP fishes experiencing non-sustainable rates of exploitation (SPR <30%) are those with relatively low M/K values. Fish with M/K values greater than 1.5 could be expected to recover in sustainable population sizes in 5-15 years. However, for those with M/K values less than 1.5, recovery for stocks with SPRs less than 30% may be expected to take 2-3 decades or more. Unfortunately, this means that even if size and bag limits necessary to move BNP exploited reef fish populations toward sustainability were instituted immediately, stocks would not likely reach a sustainable status for at least 10 years for most of the species and as much as 30 years for the grouper species.

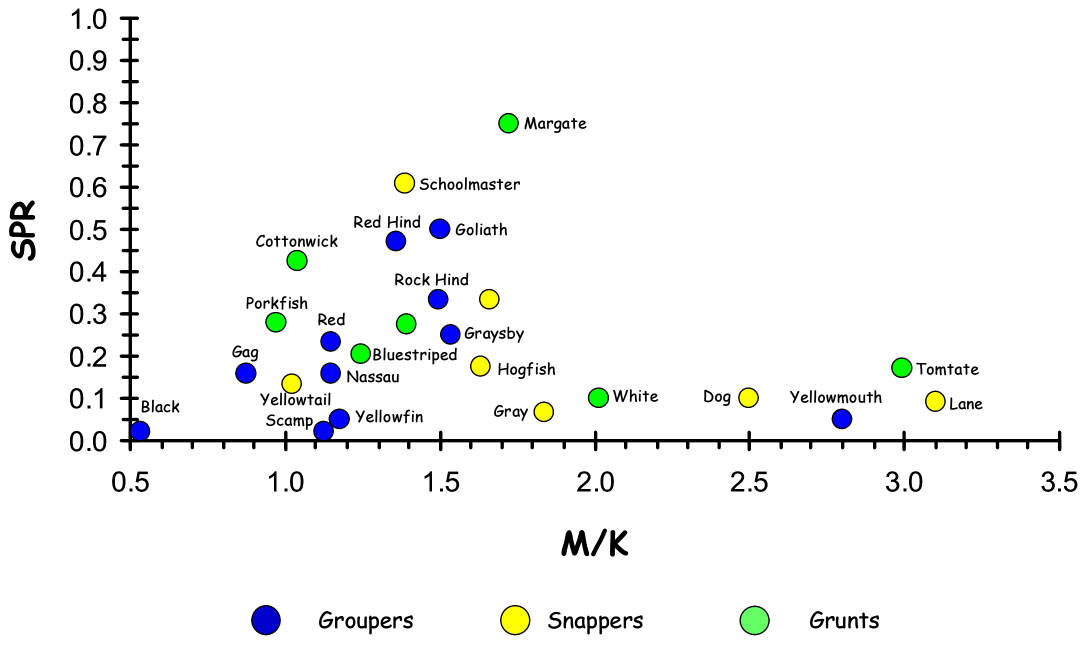

Figure 32.- Plot of estimated spawning potential ratio (SPR) dependent on M/K (natural mortality rate divided by the growth rate) for exploited groupers (blue), snappers and wrasses (yellow), and grunts (green) from the Dry Tortugas.

Limitations with Reduced Bag Limit or Increased Size Limit Strategies

With either an increase in minimum size limits for legal harvest or a reduction in bag limits there will undoubtedly be an unintended increase in catch-and-release mortality incurred as both undersized fish and fish in excess of the allowable bag are released, and this cannot be ignored. This topic has been thoroughly reviewed by Bartholomew and Bohnsack (2005), who reviewed data for more than 200 species and reported that catch-and-release mortalities ranged between 10 and 90%. While catch and release mortality rates vary widely, for the species targeted in the Park, release mortality rates would likely average from 10 to 30%. Catch-and-release fishing has definite mortality consequences for exploited stocks. Some of the principal catch-and-release mortality risk factors are: depth; high water temperatures; and, multiple recaptures (Bartholomew and Bohnsack 2005). Depths in the Park range to > 100 feet on the eastern side. This is more than 4 atmospheres of pressure for a fish brought from depth to the surface, resulting in distension of the gas bladder through the mouth and "bug eyes". Catch-and-release effects are exacerbated by high water temperatures, and the tropical waters of the Park have the highest water temperatures in US coastal marine waters. Many of these species are highly subject to multiple recaptures, usually within 30 days. These rates of mortality are multiplicative, so that less than 50% of the fish will survive 2 or more recapture events. If size limits were greatly increased (while no restrictions are placed on fishing effort) we believe that a fairly large number of fish (of all the species considered here) are likely to be caught and released (perhaps several times) before they reach legal harvest size. There will undoubtedly be some level of hook and release mortality on top of any harvest mortality. Given the percentage of boats that reported catching each species in the creel surveys and hooking mortality rates published elsewhere, there may be significant fishing mortality, even under zero bag limits.

Concerns for Future Growth in the Fishery

In this paper we have only assessed the possibility of improving the sustainability of park reef fish populations by reducing fishing mortality for each of the species through either bag limit reductions or increasing the SPR through increases in size limits. Regardless of additional bag or size limit actions that may be taken, fishing effort is likely to continue to increase and therefore overall fishing mortality is likely to continue to increase (even if it is only hooking mortality in an all catch and release fishery). Therefore, further reductions in the park's fish populations appear to be inevitable when only using these traditional management approaches in trying to achieve sustainable fisheries (i.e., any reduction in mortality due to reduced bag limits will soon be erased by increases in fishing effort because of more people harvesting); or a satisfactory SPR achieved through an increase in size limit, is likely to eventually be reduced due to increased fishing mortality and/or mortality of smaller sized fish from repeated hook and release. The authors believe that the only long-term solutions to sustaining viable fisheries within the park will eventually involve either limiting the amount of fishing effort (i.e., limiting the number of boats and amount of hours they fish), or placing a portion of the population under spatial protection (i.e., geographical areas that are closed to fishing), to ensure that a sufficient number of reproductively viable fish are available to sustain these reef fish populations.

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