The Status of the Red Hind Fishery in Puerto Rico and St. Thomas As Determined by Yield-Per-Recruit Analysis

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ABSTRACT

The red hind, *Epinephelus guttatus*, is an important component of the shallow water fishery resources of Puerto Rico and St. Thomas. Declining landings and the possible loss of larger individuals from commercial catches have led to concern over the condition of stocks in both areas. A preliminary yield-per-recruit analysis indicated that in Puerto Rico and St. Thomas, the current fishing level is approximately 50% and 20% greater, respectively, than theoretically optimum levels of fishing, as defined by $F_{0.1}$ criteria.

Fishing pressure should be reduced considerably in Puerto Rico, and to a lesser extent in St. Thomas, to achieve harvest at $F_{0.1}$. Yield-per-recruit would not increase significantly by increasing size at entry to the fishery at current levels of fishing pressure. A short-term management option is the protection of the annual spawning aggregations from all fishing activity. These are believed to be particularly vulnerable to heavy fishing pressure. At current exploitation levels, this measure may be the only practical means of maintaining the red hind as a commercially viable fishery resource. A more long-term option for the reduction of fishing pressure on all components of the fishery unit would be the creation of marine preserves.

INTRODUCTION

The red hind, *Epinephelus guttatus*, is an important component of the shallow water resources of Puerto Rico and the U. S. Virgin Islands. It is fished by fish trap and hook and line. By weight, it is the most important grouper species taken commercially in Puerto Rico (Matos and Sadovy, 1989), and in a fisheries-independent survey of western Puerto Rico was found to comprise approximately 35% of the total grouper landings between 1986 and 1988 (Rosario, 1989).

Over the last decade, landings of grouper species in Puerto Rico have shown a marked decline (Figure 1 - grouper species were not distinguished in the data collected) (Weiler and Suárez-Caabro, 1980; García-Moliner and Kimmel, 1986; Collazo and Calderón, 1988; Matos and Sadovy, 1989). This decline is unlikely to be the result of decreasing fishing effort. In the 1970's fishing effort increased (CFMC, 1985), and during 1984 – 1989 there was relatively little change in effort (fishing trips) in the shallow water fishery (Dennis *et al.*, in prep).

Since red hind comprise a sizeable proportion of grouper landings, it is reasonable to conclude that the landings of this species have similarly declined.

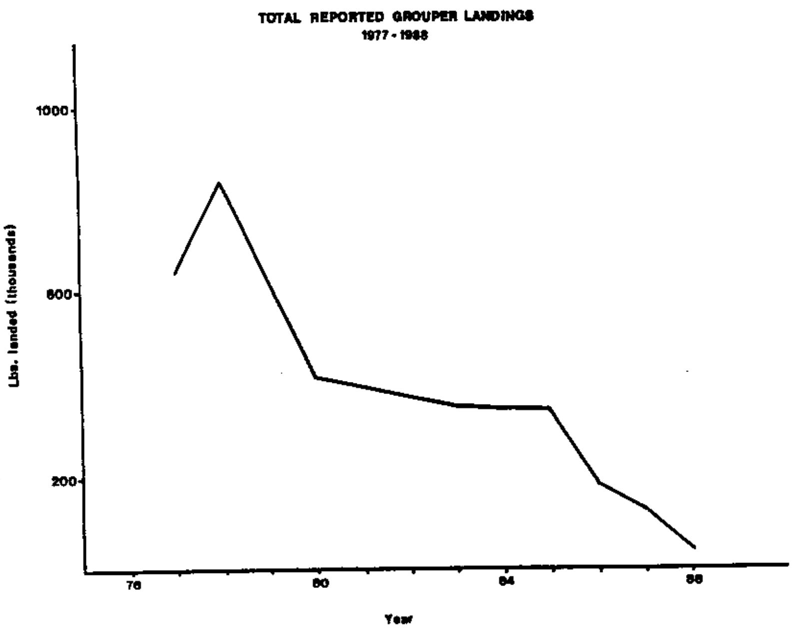

Figure 1. Total reported landings, in thousands of pounds, of grouper (all grouper species combined) between 1977 and 1988 for Puerto Rico. Data collected by the Fisheries Research Laboratory, CODREMAR.

Few large red hind are taken in Puerto Rico (all coasts combined, Bohnsack *et al.*, 1986; Matos and Sadovy, 1989), although they are still caught at Mona Island, 64 kilometers west of Puerto Rico, where fishing pressure for grouper is believed to be much lower (Rosario, 1989). While such size differences could simply reflect natural geographic variations in size range, recent analyses of length-frequency data from St. Thomas suggest that larger red hind may be more scarce than they were in the past (Beets and Friedlander, 1992). Furthermore, fishermen in both Puerto Rico and St. Thomas are reporting declines in catch taken during the, once highly productive, annual spawning aggregations.

While the probable decline in landings and sizes taken in St. Thomas and Puerto Rico are but qualitative indicators of overexploitation, red hind exhibit a number of life history characteristics, in common with other groupers, which make them particularly vulnerable to overfishing (Colin *et al.*, 1987; Bannerot *et al.*, 1987; Manooch, 1987; Ralston, 1987; Bohnsack, 1989). They are long-lived and slow-growing (Sadovy *et al.*, 1989), form brief annual spawning aggregations (Colin *et al.*, 1987; pers. obs.), and exhibit a protogynous (female to male sex change) sexual strategy (Burnett-Herkes, 1975; Sadovy, unpubl.).

The impact of heavy fishing on protogynous species, although largely unknown, is potentially more severe than on gonochores (Bannerot *et al.*, 1987, Huntsman and Waters, 1987; Bohnsack, 1989). The brief annual spawning aggregations, at traditional locations, of some grouper species are heavily fished in many areas. The spawning stocks are thus particularly vulnerable to overfishing.

Trends similar to those reported in Puerto Rico have been noted in red hind stocks elsewhere, as well as in other groupers (Bohnsack, 1989). In Bermuda, for example, striking decreases in pounds landed were reported for six grouper species between 1975 and 1981 (Bannerot *et al.*, 1987). In Jamaica, heavily exploited areas had fewer large red hind than lesser exploited areas (Thompson and Munro, 1974). In the late 1960's, the Nassau grouper, *Epinephelus striatus*, was one of the most important of all shallow water species taken commercially in Puerto Rico (Suárez-Caabro, 1970), now it is rarely seen (Bohnsack *et al.*, 1986). Two aggregations of this species in the U. S. Virgin Islands, one south of St. Thomas and one on Lang Bank northeast of St. Croix, have experienced heavy fishing pressure and have essentially disappeared (Olsen and LaPlace, 1979; Beets and Friedlander, 1992).

Concern for the status of the red hind prompted the Caribbean Fishery Management Council to fund a study on its age and growth in Puerto Rico and St. Thomas (Sadovy *et al.*, 1989). Using the information from this study, the following preliminary yield-per-recruit analysis was carried out on these two stocks to determine the status of the fishery.

The yield-per-recruit model is useful for the preparation of management advice, in the absence of full information on stock productivity, because it provides a partial stock assessment. It allows evaluation of the response of yield to changes in fishing mortality and size of recruitment on which to base management regulations. The yield-per-recruit model predicts the ratio of the weight of numbers of fish caught during the life span of a cohort to the initial number of individuals of the cohort that enter the fishing grounds. It expresses these yields as a surface responding to the independent variables F (fishing mortality) and t_c (age of recruitment to the fishery) (Huntsman *et al.*, 1983).

METHODOLOGY

Fish Samples

Fish samples used for the age and growth study (Sadovy *et al.*, 1989) were taken by hook and line and fish trap in western Puerto Rico (trap mesh size = 1.25 in. (3.2 cm.)) and St. Thomas (trap mesh size = 1.50 in. (3.81 cm.)). A few additional small individuals were also taken by fish anaesthetic to ensure sampling of the youngest age classes. Samples were collected between September, 1987 and January, 1989. A total of 1684 fish were sampled in Puerto Rico, of which 624 were aged, and 501 fish were taken in St. Thomas, of which 162 were aged. For the following analyses, ages were taken from the aged sub-samples and length data from the total samples of fish collected (Sadovy *et al.*, 1989). Age was determined from sectioned otoliths, and validated by marginal increment analysis and field studies. Size-frequency distributions of aged red hind taken by hook and line in Puerto Rico were compared with those taken by fish trap, using a Kolmogorov-Smirnov two-sample test (Siegel, 1956), to check for possible sampling bias by gear (Figure 2). Data for St. Thomas were not available by gear. The effect of depth distribution of catch on the age structure could not be evaluated, although samples were taken throughout the commercially fished depth range.

Growth Parameters

The von Bertalanffy growth parameters used in the analysis (taken from Sadovy *et al.*, 1989) are shown in Table 1 where:

L_∞ = asymptotic length (fork length, FL, in mm)
K = Brody growth coefficient (Ricker, 1975)
t_o = theoretical age (years) at zero length
W_∞ = asymptotic weight (whole weight in g) at L_∞ as determined by length-weight regressions for each location:
Log W = –5.21+3.14*LogFL (Puerto Rico);
Log W = –4.68+2.94*LogFL (St. Thomas)
(Sadovy *et al.*, 1989).
t_c = age at first capture in years which corresponds with l_c, the median length (in mm) of first capture

The size-frequency distribution of aged and unaged fish samples combined was used to determine median l_c. The distributions had a distinct mode at 250 mm for Puerto Rico and 280 mm for St. Thomas (Sadovy *et al.*, 1989). This mode was taken to represent the minimum size of full recruitment to the fishery. The median of the size distribution of all fish smaller than the minimum size of full recruitment was determined to be l_c. The value of t_c at l_c was then determined from growth curves (Sadovy *et al.*, 1989).

Mortality Estimates

Instantaneous rates of natural mortality (M) were estimated from the linear regression equation of Ralston (1987):

$$M = 0.0189 + 2.06\ K$$

The formula of Ralston was considered most appropriate for the yield-per-recruit analysis because it was calculated for tropical snappers and groupers, rather than a wide diversity of families of fish from all latitudes

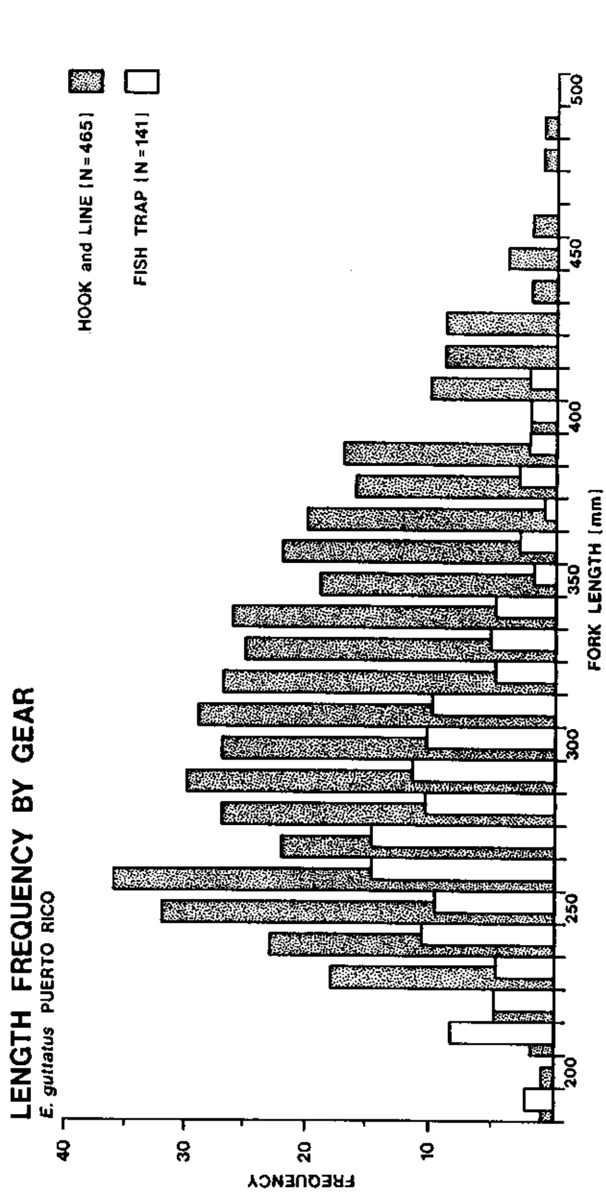

Figure 2. Size-frequency distributions (Fork length in mm) of hook and line (N=465) and trap caught (N=141) *Epinephelus guttatus* in Puerto Rico.

Table 1. Parameter estimates for yield-per-recruit analyses

Parameter	Puerto Rico	St. Thomas
K	0.101	0.071
L_∞ (mm)	514.5	601.0
t_0(yrs)	-2.94	-4.69
W_∞ (g)	2040	3093
M	0.23	0.16
t_c (yrs)	1.8	1.3
l_c (mm)	233	257
t_m (yrs)	17	18
Z	0.54	0.33
Z (S.E.)	0.08	0.04
Z ages (yrs)	6-12	6-12
Z time period	1976-1982	1976-1982
F	0.31	0.17
$F_{0.1}$	0.20(M=0.23)	0.14(M=0.16)
$F_{0.1}$ (M+50%)	0.28(M=0.35)	0.18(M=0.24)
$F_{0.1}$ (M–50%)	0.12(M=0.12)	0.10(M=0.08)

(Pauly, 1980).

To estimate instantaneous rates of fishing mortality (F), the instantaneous rates of total mortality (Z) were determined by analysis of catch curves (Ricker, 1975) for otolith-aged fish (Figure 3). The descending right hand limb of the catch curves from ages 6 to 12 (1976 – 1982) was used to determine Z. Age of full recruitment prior to age 6 could not be established from the catch curves because of their form, and sample sizes beyond age 12 were less than 4. Instantaneous rates of fishing mortality (F) could be estimated for each location using values of M and Z in the equation: $F = Z - M$.

For preliminary determination of the current theoretical optimal level of fishing mortality (F_{opt}), $F_{0.1}$ criteria were calculated for both St. Thomas and Puerto Rico stocks ($F_{0.1}$ is defined as the fishing mortality at which the marginal increase of yield per recruit is 1/10th of the marginal increase at $F = 0$). $F_{0.1}$ has been used as a management tool in preference to F_{max} (the fishing mortality rate that maximizes yield-per-recruit for a given age at first capture), especially where yield curves approach asymptotes as F increases (Gulland and Boerema, 1973; Deriso, 1987). Given that yield-per-recruit analysis does not take into account the effect of fishing on reproductive potential, use of $F_{0.1}$ is even more warranted when considerations of life history and reproductive biology suggest particular susceptibility to recruitment overfishing.

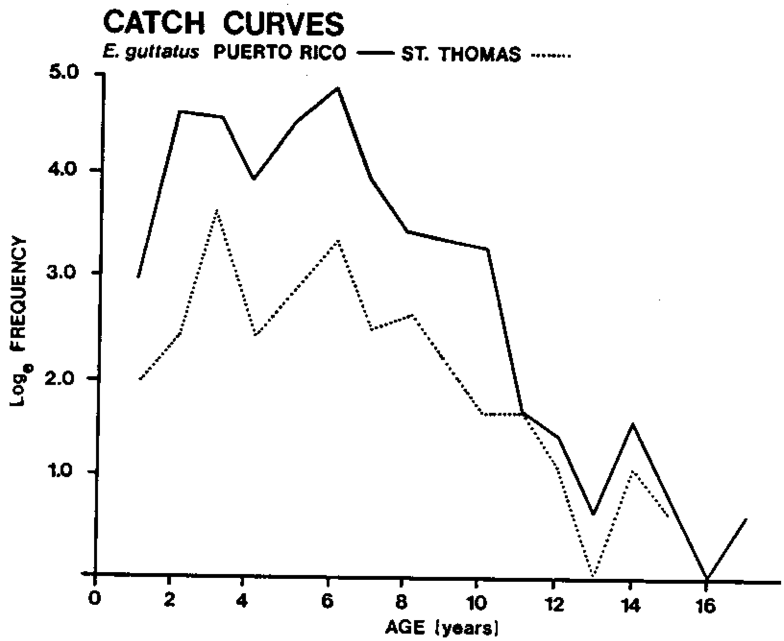

Figure 3. Catch curves for red hind, *Epinephelus guttatus*, from Puerto Rico (solid line) and St. Thomas (dotted line) for 1971-1987. Abscissa - age in years; ordinate - $\log_e$ frequency. Fish taken by hook and line and fish trap combined (data from Sadovy *et al.*, 1989).

Yield-per-Recruit Analysis

The Beverton and Holt (1957) yield-per-recruit model, written for use in Lotus 1-2-3 (Sluczanowski, 1985), was used. The form of the equation is:

$$
\begin{aligned}
Y/R = \; & 100\, W_{\infty} F \exp(F t_c) \Big[\{\exp(-Z t_c) - \exp(-Z t_m)\} / Z \\
& + 3 \exp(K t_o) \{\exp(-(Z+K) t_m) - \exp(-(Z+K) t_c)\} / (Z+K) \\
& - 3 \exp(2K t_o) \{\exp(-(Z+2K) t_m) - \exp(-(Z+2K) t_c)\} / (Z+2K) \\
& + \exp(3K t_o) \{\exp(-(Z+3K) t_m) - \exp(-(Z+3K) t_c)\} / (Z+3K) \Big] B_{max}
\end{aligned}
$$

where t_m = maximum age contributing to the fishery (17 years in Puerto Rico, 18 years in St. Thomas), and B_{max} is the maximum expected biomass per recruit of an unfished year-class. The program accepts as input: W_∞, L_∞, K, t_o, t_m, M and ranges of instantaneous fishing mortality (F) and age at first capture t_c. The assumptions of the model are discussed below. Since the yield-per-recruit analysis is sensitive to the estimate of M, a sensitivity analysis was carried out using values of M + 50% and M - 50% (Vetter, 1988). The values of $F_{0.1}$ was determined for the extreme estimates of M, and the possible impact of errors in the estimation of M established.

RESULTS

The estimated values of Z, M, F, etc., are shown in Table 1. The estimated values of M fall within the general range 0.09 – 0.35 reported for most *Epinephelus* and *Mycteroperca* species examined (Huntsman *et al.*, 1983; Bannerot, 1984; Ralston, 1987), and are thus considered to be reasonable. The sizes (fork length) of red hind taken in Puerto Rico by fish trap differed significantly from those taken by hook and line ($D = 0.229$; $p < 0.01$) (Figure 2); the value of Z for Puerto Rico for hook and line only was 0.51, and for both gears combined was 0.54. Seventy-five percent of Puerto Rico samples were taken by hook and line, hence insufficient trap-caught individuals precluded estimation of Z for traps alone. Since the value of Z for combined gears in Puerto Rico (0.54) was similar to that for individuals taken exclusively by hook and line (0.51), and since the catch curves by gear type were similar in form (*i.e.* each with a double peak) (Figure 3), it was determined that gear selectivity had little effect, in the present data set, on the estimated values of Z using catch curve analysis. Therefore, values of Z estimated for combined gears were used.

Yield-per-recruit at current t_c for both Puerto Rico and St. Thomas is shown in Figure 4. Yield isopleth diagrams (Figures 5 and 6), which show the response of yield-per-recruit (expressed as a percent of B_{max}) to both F and t_c over a wide range of both parameters, allow the best selection of t_c for a given F, or the best F for a given t_c. The value of M as determined directly from the Ralston (1987) equation, for both stocks, was used for the analysis.

The assumption of the Beverton and Holt model of instantaneous or "knife-edge" selection is considered reasonable for the red hind since recruitment occurs over a fairly limited range of lengths (150–250 mm FL in Puerto Rico; 200–300 mm FL in St. Thomas) (Pauly and Soriano, 1986) (Table 2). The von Bertalanffy growth model applies to the Puerto Rico stock, although that of St. Thomas does not appear to fit this model well in early growth. The assumption of isometric growth holds for both stocks

DISCUSSION

The results of the yield-per-recruit (Y/R) analysis indicate that, in common with other grouper species (Huntsman *et al.*, 1983), a large fraction of the potential yield of red hind in both Puerto Rico and St. Thomas is taken at low

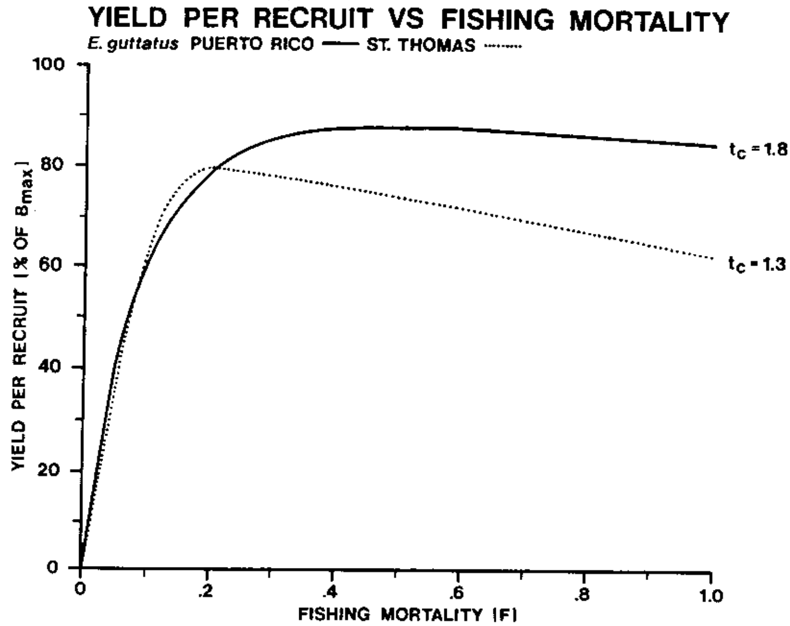

Figure 4. Yield-per-recruit expressed as a percentage of maximum biomass for red hind, *Epinephelus guttatus,* against fishing mortality for age at first capture, t_c (*E. guttatus* in Puerto Rico = solid line, t_c = 1.8 years, M = 0.23; *E. guttatus* inSt. Thomas = dotted line, t_c = 1.3 years, M = 0.16).

levels of fishing mortality. Although current levels of fishing on both stocks are close to F_{max} they greatly exceed the theoretical economically optimum level of fishing mortality ($F_{0.1}$), especially in the case of Puerto Rico.

For example, 85% of the maximum Y/R is available at F = 0.3 in Puerto Rico, and 80% at F = 0.2 in St. Thomas. Current age at median length of first capture (t_c) and fishing mortality permit harvest at near maximum Y/R in both locations but F levels are 50% greater than estimated F_{opt} ($F_{0.1}$) in Puerto Rico, and 20% greater in St. Thomas. The sensitivity analyses of the estimates of M indicate that even if this were increased by 50%, current F would still exceed $F_{0.1}$ in Puerto Rico, and would approximately equal $F_{0.1}$ in St. Thomas. Hence, certainly Puerto Rico, and very likely St. Thomas, stocks are growth overfished, *i.e.*, current fishing mortality is too high to allow sufficient fish to grow large enough to realize optimum levels of yield-per-recruit. Furthermore, these results do not take into account recruitment-related phenomena, or a number of other

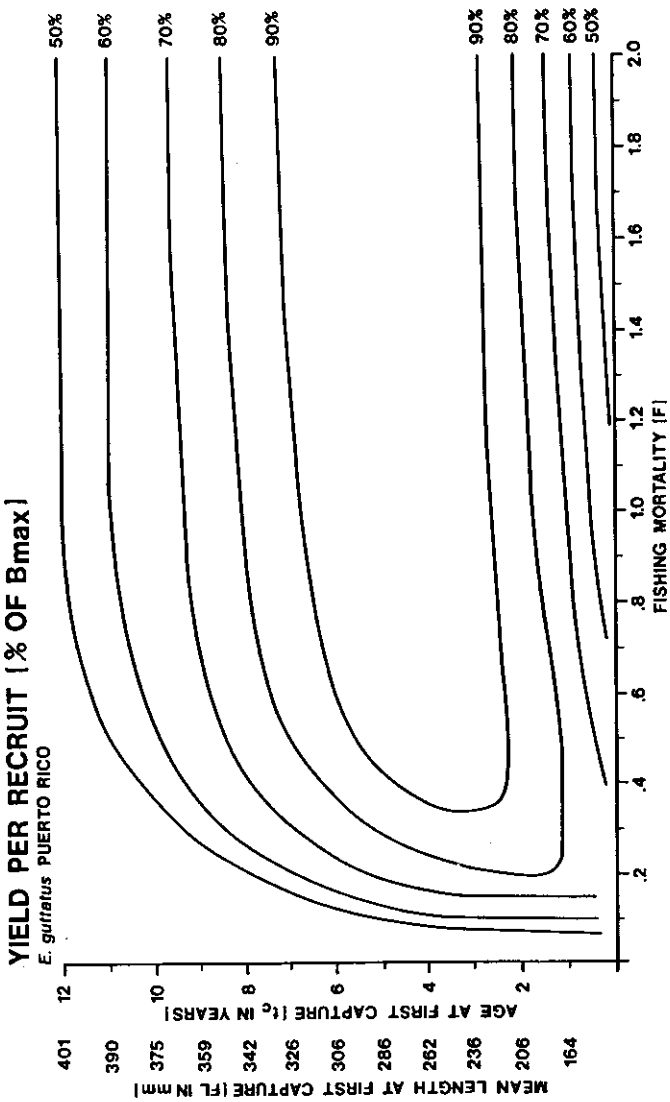

Figure 5. Yield isopleth diagram showing response surface of yield-per-recruit as a percentage of maximum biomass with changes in fishing mortality and ages and lengths at first capture for *Epinephelus guttatus* in Puerto Rico (M = 0.23).

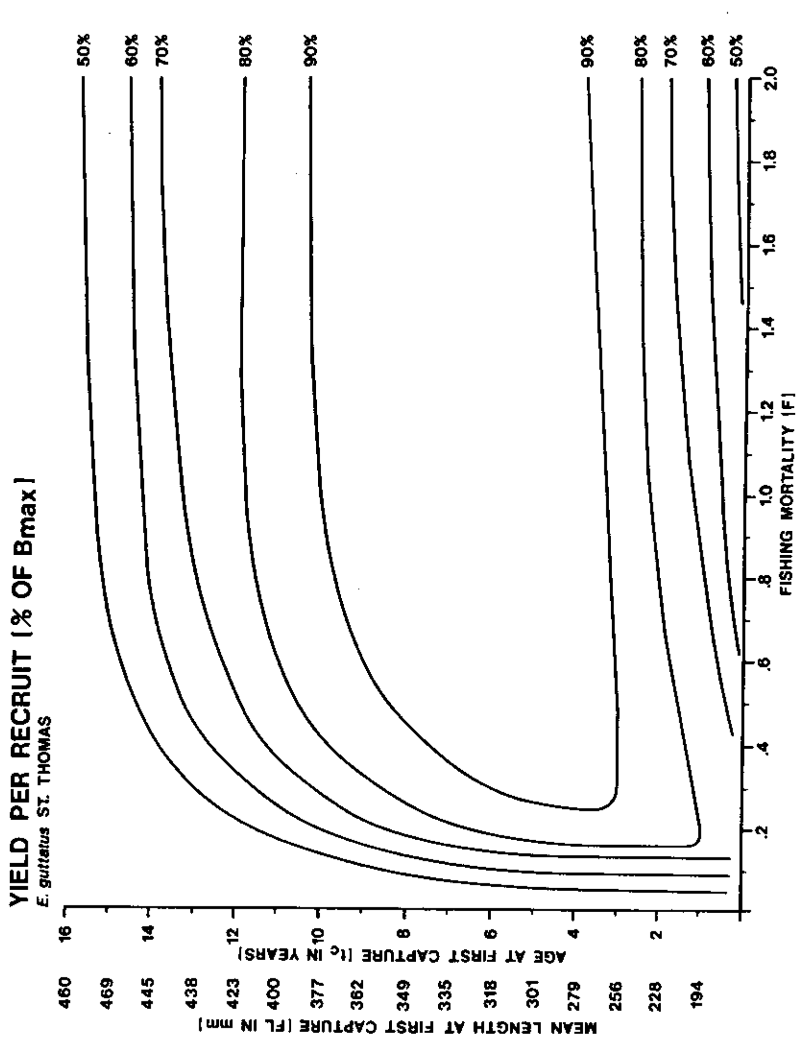

Figure 6. Yield isopleth diagram showing response surface of yield-per-recruit as a percentage of maximum biomass with changes in fishing mortality and ages and lengths at first capture for *Epinephelus guttatus* in St. Thomas (M = 0.16).

Table 2. Probabilities of capture for Puerto Rico and St. Thomas stocks of the red hind, *Epinephelus guttatus* (Pauly and Soriano, 1986).

PUERTO RICO		ST. THOMAS	
Midlength (FL in mm)	Probability	Midlength (FL in mm)	Probability
160	0.0044	210	0.0153
180	0.0410	230	0.1232
200	0.0784	250	0.3297
220	0.2389	270	0.4197
240	0.6763	290	0.6680
260	1.0000	310	1.0000
280	1.0000	330	1.0000
300	1.0000	350	1.0000
320	1.0000	370	1.0000
340	1.0000	390	1.0000

life history characteristics which make this species particularly vulnerable to heavy fishing pressure as discussed below.

The analyses and inspection of the yield isopleth diagrams (Figures 5 and 6) show that at current levels of fishing mortality (F), Y/R would not increase significantly by increasing size at entry (t_c) to the fishery. Likewise, no gain in Y/R would be expected if age at entry remained stable and F increased. In theory, Y/R would increase with increasing F only if t_c were also increased. The yield isopleth diagrams (Figures 5 and 6) indicate the response of Y/R to changes in F and t_c.

The yield-per-recruit analyses are considered to be preliminary because of concerns regarding the assumption of equilibrium conditions for the Beverton and Holt model and for determining Z from the catch curves. Inspection of the catch curves in Figure 3 suggests variation in annual recruitment as one explanation for the irregular form of the "dome"; others could be sexual differences in mortality rates associated with protogyny or undetected variation in fishing effort. Fishermen report substantial variations in the productivity of aggregations from year to year and Erdman (1976) reported two years between 1954 and 1966 in which no well-defined aggregations were recorded. Thus, variable annual recruitment is likely. The possible impact of violations of the assumptions of equilibrium conditions need to be evaluated. Furthermore, the applicability of yield-per-recruit models to sex-changing species in a multispecies complex has yet to be fully established. Nonetheless, the analyses are based on the best available information and may be used to provide a guide for the proposal of management options for this species.

The yield-per-recruit analyses show that fishing pressure should be decreased considerably in Puerto Rico and, to a lesser extent, in St. Thomas to achieve $F_{0.1}$. Since it has been demonstrated that yield-per-recruit models produce predictions leading to non-conservative management policy when used to control F for grouper species (Bannerot, 1984), management measures which aim to regulate fishing pressure should be decidedly conservative. Possible management options include the implementation of catch quotas, the introduction of seasonal or areal closures, or limiting the number of fishermen or units of fishing gear.

For a number of theoretical reasons, long-lived, slow-growing species, like the red hind, are believed to be particularly susceptible to heavy fishing pressure (Bannerot, 1984; Bannerot *et al.*, 1987; Ralston, 1987; Bohnsack, 1989). The red hind is especially vulnerable at the sites and times of the brief annual spawning aggregations. These are easy to locate and are heavily fished, most intensely prior to the time of reproduction (Sadovy, pers. obs.). Hence, not only many adults but also large numbers of potential recruits are eliminated at this time.

Bannerot (1984) identified several other factors which could render species like the red hind particularly vulnerable at the time and place of spawning. In particular, such species could be severely affected if fishing activity over aggregations decreases the proportion of reproductively active males (if sperm is limiting), if the mating system is random, and if mating activity is interrupted by high levels of fishing activity. Field studies are needed to resolve these and other life history issues that could produce particularly negative responses to fishing pressure. There is also a need to consider recruitment levels and adult spawning stock biomass through production models because adult reef fish populations are believed to be recruitment limited (Plan Development Team, 1990).

Based on the yield-per-recruit analyses and the above life history considerations, the most promising of the various management options for the reduction of fishing pressure on red hind stocks of Puerto Rico and St. Thomas, at least in the short-term, is the protection of the spawning aggregations. Given the current law enforcement limitations of the region, this is the measure most likely to succeed. Enforcement requirements would be limited in both time and space, and the impact on fishing activities on other sectors of the fishery would be minimal. This latter consideration is important for a multispecies fishery because management measures targeting single species, but which could impact on others, will be less socially and legally acceptable.

A more promising long-term solution for the effective management of the shallow water fishery as a unit, and its maintenance as a viable commercial fishery, is the creation of permanent preserves which would potentially protect community balance, population age structure and genetic diversity (Plan Development Team, 1990). These preserves would have to be carefully located for maximum benefit to the fishery resources.

At the present time, however, it is likely that protection of spawning aggregations may prove to be the only practical means of maintaining the red hind as an economically viable fishery resource in Puerto Rico and St. Thomas.

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