

## Management of a Tropical Fish Pot Fishery for Maximum Sustainable Yield

DAVID K. STEVENSON  
*College of Resource Development  
University of Rhode Island  
Kingston, Rhode Island 02881*

### INTRODUCTION

Coral reefs and adjacent shallow-water environments are productive "oases" in otherwise nutrient-depleted tropical seas which support abundant and diverse fish populations and active artisanal fisheries. One of the principal artisanal fishing gears used on coralline fishing grounds in the Caribbean is the wire fish pot. Available information indicates that annual harvests from coralline shelf areas in the Caribbean may range from a low of 0.5 metric tons (mt) per km<sup>2</sup> to as much as 4.0 mt per km<sup>2</sup> (Stevenson and Marshall 1974) as compared to a generally accepted harvest rate of 2.0 mt/km<sup>2</sup> for demersal stocks trawled from temperate zone fishing grounds. Juhl (1971) reported a total catch of 100,000 mt from reef areas in the Caribbean during 1968. Given the general lack of technological change in the artisanal fisheries in the last decade, this catch has probably changed very little. Assuming an average sustained harvest rate of 1.1 mt/km<sup>2</sup>, Munro (1973) predicted a potential catch of 750,000 mt from Caribbean reef areas. The artisanal reef fishery clearly merits more attention than it has heretofore received if these fisheries are to be developed and the resources properly managed.

Total estimated landings (fish and shellfish) from inshore Puerto Rican waters in 1975 were 2310 mt (Suarez-Caabro, personal communication). During 1974, 72% of the total fish landed in Puerto Rico were derived from wire fish pots (Rolón, 1975). Spiny lobster are an economically important component of pot catches: 29% of the ex-vessel value of pot landings in 1974 were due to lobster.

The major fishing ground for the Puerto Rican pot fishery is the 520 km<sup>2</sup> of coralline shelf off the southwest coast of the island (Fig. 1). The average depth over most of the shelf is 30 m; the substrate is composed of a coralline sand with isolated coral heads and reefs (Fig. 2). Pots are set in 10-60 m, usually in the vicinity of the submerged fringing reef which shoals to 10 m on the outer edge of the shelf and near the numerous shallow patch reefs closer inshore. The inshore pots are operated from small open boats 5- to 7-m long with outboard motors. Offshore fishing grounds are exploited by a fleet of perhaps a dozen larger (7-12 m) sloop-rigged sail boats which are equipped with in-board engines and small gasoline-powered pot haulers. These vessels make daily trips and haul 40-60 pots per trip. Each pot is left for 4-5 days. The fishery is seasonal; fish predominate during the wet season (June-November) and lobster during the dry season (October-April).

An analysis of the commercial landings from 81 pot hauls during 1973-74 revealed an average catch rate of 5 kg of fish per haul worth \$2.08 (ex-vessel value). The fish exploited by this fishery are small; the average weight of 2300 fish landed from the same 81 pot hauls was 0.18 kg/fish.

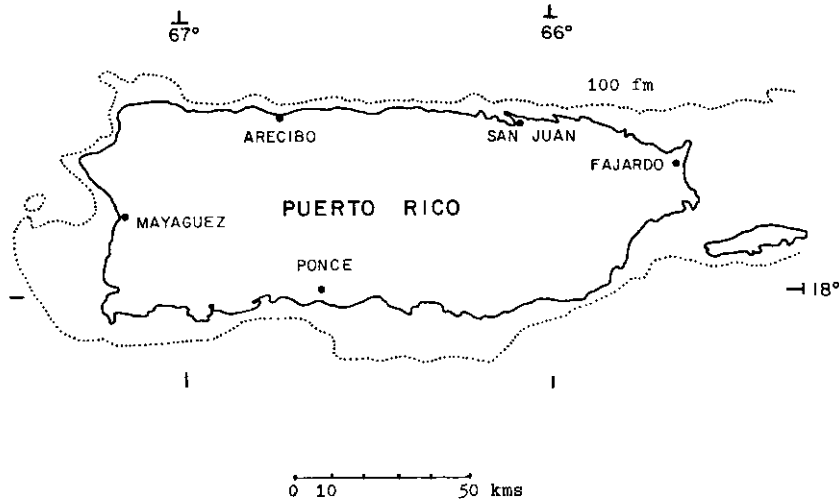


Figure 1. The island of Puerto Rico showing major cities and the 100 fm contour.

Research was conducted aboard a commercial pot vessel in Puerto Rico during 1973-74 for the purpose of estimating growth and mortality rates for the principal fish species harvested by the pot fishery. The objective was to apply parameter estimates to the Beverton-Holt yield model to determine the degree to which each species population was over- or under-exploited and to recommend appropriate management procedures for the fishery. The 10 species selected for this study (Table 1) accounted for approximately 80% of the weight landed from the previously mentioned 81 pot hauls.

## METHODS

### Data Collection and Compilation

Parameters were estimated from length data for fish captured in 3.4-cm and 4.2-cm (maximum aperture) wire-mesh fish pots operated in different locations (Fig. 2) on the southwest coast of Puerto Rico.<sup>1</sup> Over 10,000 individual fish were measured during 39 fishing trips aboard commercial pot vessels during three sampling periods in 1973 and 1974. Sampling was conducted for a total of 13 weeks during a 14-month period. All pots were of similar volume (0.70 m<sup>2</sup> or 25-30 cu ft) with entrances of nearly equal size and were operated by experienced fishermen. No data were collected from damaged pots since the escape of smaller fish through holes in the pots produced biased length-frequency data.

Length measurements were compiled into frequency tables by species, location, and mesh size for each fishing season. Length intervals were, in most cases,

<sup>1</sup> The chicken wire used to construct wire fish pots is composed of roughly hexagonal meshes. Both mesh sizes which were sampled were commonly used by the fishermen and were equivalent to 1-in and 1.25-in *minimum* aperture.

Table 1. List of the ten species investigated on the southwest coast of Puerto Rico during 1973-74 with the percent composition by weight as estimated from 81 pot hauls during two different fishing seasons

Family Genus and Species	Percent of total landings	
	Sept-Oct 1973	May-June 1974
Serranidae (groupers, hinds)		
<i>Epinephelus guttatus</i>	25.1	13.3
<i>Cephalopholis fulva</i>	11.1	9.7
Carangidae (jacks)		
<i>Caranx ruber</i>	4.4	2.8
Pomadasyidae (grunts)		
<i>Haemulon plumieri</i>	7.5	22.7
Mullidae (goatfishes)		
<i>Pseudupeneus maculatus</i>	14.5	3.8
Holocentridae (squirrelfish)		
<i>Holocentrus ascensionis</i>	8.8	2.8
<i>Holocentrus rufus</i>	3.7	7.6
Scaridae (parrotfish)		
<i>Sparisoma aurofrenatum</i>	6.3	6.4
<i>Sparisoma chrysopterum</i>	1.0	7.3
Sparidae (porgies)		
<i>Calamus pennatula</i>	0.5	0.9
TOTAL	82.9	77.2

5 or 10 mm. Individual length-frequency distributions were combined for different locations in cases where the composite sample revealed the same number of size groups with more or less identical modal lengths as in the original, uncombined samples. For cases in which the ranges of sizes retained by different meshes were not significantly different (no size selectivity), samples collected in different mesh sizes were also combined.

#### Parameter Estimation

##### Growth ( $K, L_{\infty}$ )

Growth was assumed to conform to the von-Bertalanffy growth function

$$l_t = L_{\infty} (1 - e^{-K(t - t_0)}) \quad (1)$$

where  $l_t$  = length at any age  $t$   
 $L_{\infty}$  = the maximum limiting length attained by individuals in the population  
 $K$  = the annual instantaneous growth rate  
 $t_0$  = the time (age) at which growth begins

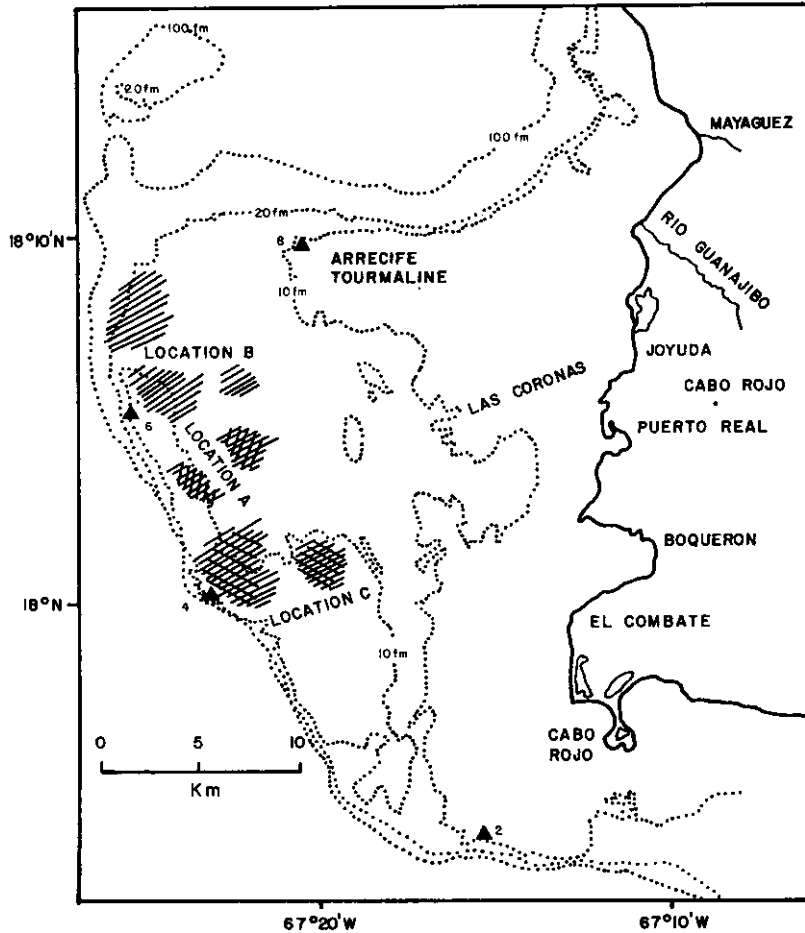


Figure 2. The southwest coast of Puerto Rico: a small-scale map which shows the coastline and depth contours. The triangles indicate the position of navigation buoys. Inland place names indicate landing points for the pot fishery. Major underwater reef features are also identified. Three general fishing grounds worked by offshore pot vessels from Puerto Real (locations A, B, and C) are indicated by cross-hatching.

The growth rate  $K$  can be estimated from the length increments of individual size groups between sampling periods without absolute age information by transforming the von-Bertalanffy growth equation into the following linear regression equation (Ricker, 1975):

$$\log_e (L_{\infty} - l_t) = \log_e L_{\infty} + kt_o - kt \quad (2)$$

where  $l_t$  = the mean length of a given size group at time  $t$   
 $t$  = the relative time of sampling beginning at  $t=0$   
 $k$  = the slope of the linear regression

Thus, in graphical form, values of  $Y = \log_e (L_\infty - l_t)$  were plotted against  $t$  when  $t$  was equal to the time interval between the first and succeeding samples (0, 8, and 12 months). The slope of the resulting regression was, for each size group, equal to  $k$  and an average monthly growth rate was calculated for *all* size groups from the individual  $k$  regression coefficients. An average annual instantaneous growth rate for each size group was estimated by multiplying the average monthly growth rate by twelve.

In order to estimate  $k$  from equation (2), values of  $L_\infty$  must either be known or estimated from repeated trial-and-error fits of the regression equation to observed  $l_t$  and  $t$  data using different values of  $L_\infty$  until the best fit is obtained. However, since all regression analyses in the present study were performed with a very limited number of points (there was a maximum of three sampling periods represented), the trial-and-error estimation procedure was not attempted. Instead,  $L_\infty$  estimates were based on (1) the maximum observed length ( $l_{max}$ ) in catch data from Puerto Rico or from a series of independent studies of reef fish populations in Jamaica, and (2) trial-and-error regressions for Jamaican catch data as performed by Munro and co-workers. Estimates of  $L_\infty$  are presented in Table 2. Estimates which were based on maximum observed lengths were selected such that  $L_\infty$  was equal to or slightly more than the largest observed  $l_{max}$  either in Jamaica or Puerto Rico.

Mean length estimates were determined for individual size groups in each seasonal length frequency distribution by means of a parameter estimation technique derived by Hasselblad (1966) and executed on an IBM 370/155 computer according to a program developed by Tomlinson (1971). This program (NORMSEP) estimated the mean length, variance, and percent composition of normally-distributed component size groups by means of iterative solutions of maximum likelihood estimates for each parameter. This process involved solving a partial differential equation for an approximation to the logarithm of the likelihood function with respect to each parameter when each equation was set equal to zero. Initial estimates of the means, variances, and proportions for each size group were performed using maximum likelihood estimates for one-sided truncated normal distributions (Hald 1952).

Analysis of each polymodal length frequency distribution was repeated for different numbers of component size groups and using different values for the length at which adjacent size groups overlapped until a result was obtained which accounted for all size groups present in preceding samples, excepting those which could be assumed to no longer remain vulnerable to capture and "new" groups recently recruited to the fishery. A chi-square goodness-of-fit test was also used to indicate which polymodal frequency analysis produced the least divergence between observed and predicted length frequencies.

Table 2. Maximum limiting lengths ( $L_{\infty}$ ) and annual instantaneous growth rates (K) estimated from length frequency data for three sampling periods during 1973-74. Estimates of  $L_{\infty}$  were either based on trial-and-error regressions of  $\log_e(L_{\infty}-L_t)$  versus sampling time (see text) or on observed maximum lengths and are appropriately labelled.

Species	$L_{\infty}$ (mm)	Obs.	Calc.	K
<i>Epinephelus guttatus</i>	520*	—	—	0.22
<i>Cephalopholis fulva</i>	340†	—	—	0.44?
<i>Caranx ruber</i>	520+	—	—	?
<i>Haemulon plumieri</i>	420‡	—	—	0.26
<i>Pseudupeneus maculatus</i>	270§	—	—	0.28
<i>Holocentrus ascensionis</i>	300	—	—	0.26
<i>Holocentrus rufus</i>	230	—	—	0.29
<i>Sparisoma aurofrenatum</i>	260	—	—	0.20
<i>Sparisoma chrysopteron</i>	370	—	—	?
<i>Calamus pennatula</i>	285	—	—	?

References: Thompson and Munro, 1974a; Thompson and Munro, 1974b; Billings and Munro, 1974; Munro, 1974a.

Once a satisfactory frequency analysis was selected for a given sample, two guidelines were used to deduce the most probable mean length progression for each size group: (1) once vulnerable to capture, each size group had to be accounted for in each catch record until it reached a size that was no longer harvested, and (2) growth of a size group between any two sampling periods could not be negative.

The importance of these two criteria is best illustrated with an example. In the example shown in Figure 3, size groups A, B, and C had to be accounted for in the fall 1974 data since they were clearly indicated in the previous two samples. However, the overlapping of groups B and C (and perhaps D) in the Fall 1974 data was so extreme that only one mean length could be satisfactorily determined and the third data point in the linear regression analyses for groups B and D was eliminated (Fig. 4) as was the intermediate mean length for group A.

The second criterion required that the third group in the Spring 1974 sample (200 mm mean length) could *not* be size group D since this interpretation would infer negative growth. The single predominant peak in the last sample was therefore assumed to belong to group C. This interpretation resulted in similar annual growth rate estimates for each group (Fig. 4).

Presumed mean length progressions were also based on the assumption that no additional size groups were recruited to the fishery during the intervals between sampling. Also, progressions which resulted in very low ( $K < 0.1$ ) or very high ( $K > 1.0$ ) growth rates were rejected. Valuable guidelines to the most acceptable growth rates for most of the species investigated were provided by the published growth estimates of Munro and co-workers in Jamaica.

## H. ASCENSIONIS

ALL MESHES

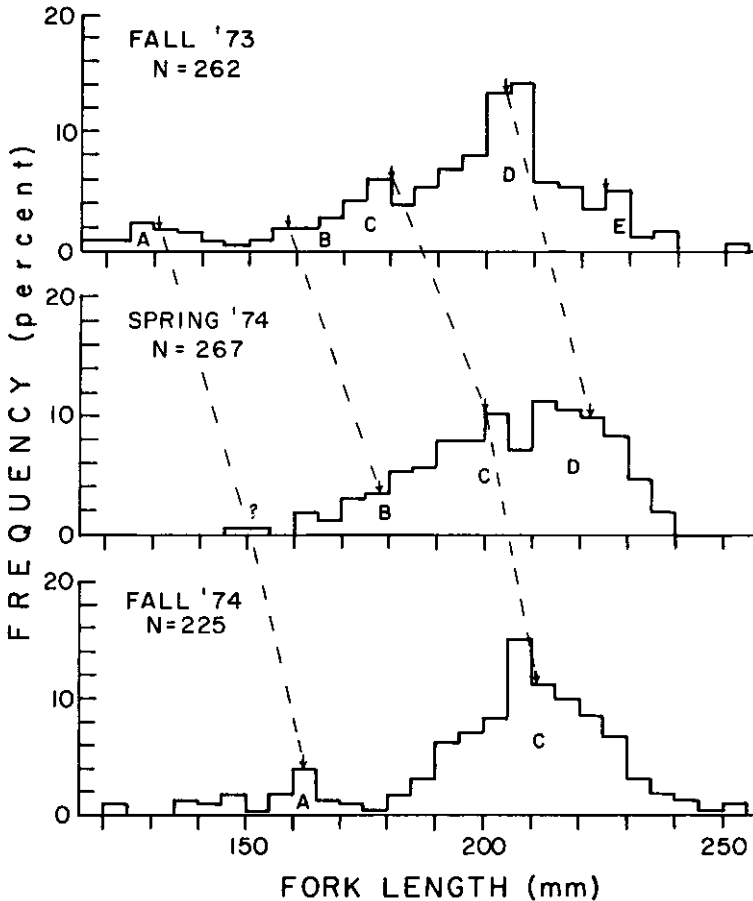


Figure 3. Seasonal length frequency distributions for *Holoцентrus ascensionis* captured in wire fish pots with different mesh sizes off the southwest coast of Puerto Rico during 1973-74. The mean lengths for component size groups as determined by computerized polymodal frequency analysis are shown by the small arrows and the inferred mean length increments for size groups A, B, C, and D by the dotted lines.

Because length data were only collected on three occasions and since many mean lengths could not be satisfactorily determined, many of the linear regressions used to estimate growth were composed of only two data points. Statistical analyses of variance were performed for all three-point linear regressions.

### *Total mortality (Z)*

Once annual growth rates were estimated, instantaneous rates of total annual mortality were estimated from average annual 1973-74 length frequency distributions for each species and for each mesh size according to the following equation derived by Beverton and Holt (1956):

$$L_{\infty} = 300$$

$$\bar{K} = 0.26$$

### H. ASCENSIONIS

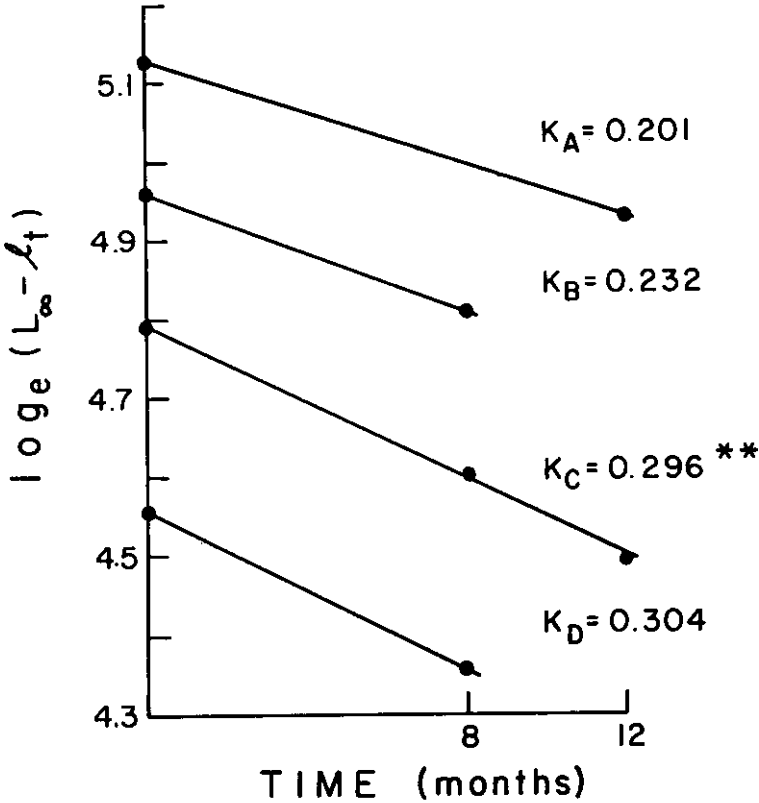


Figure 4. Annual instantaneous growth rate estimation for *Holocentrus ascensionis* based on the progressions of mean lengths ( $l_t$ ) for size groups A, B, C, and D shown in Figure 3. The maximum limiting length ( $L_{\infty}$ ) was assumed to equal 300 mm. The single three-point regression was statistically significant at  $p=0.05$ . The average growth rate estimate for all four size groups was 0.26.

$$Z = K(L_{\infty} - \bar{l}) / (\bar{l} - l')$$
(3)

- where
- $K$  = instantaneous annual growth rate
  - $L_{\infty}$  = the maximum limiting length
  - $l'$  = the smallest length that was fully represented in the average annual catch record
  - $\bar{l}$  = the average length of fish larger than  $l'$



To avoid statistical bias due to unequal sample sizes in the different seasons, average annual length-frequency data were compiled by computing the average percent frequency for each length class during the three sampling periods. Since length data were collected on two occasions in the fall and only once in the spring, the spring frequencies were weighted by a factor of two in order to obtain unbiased annual frequencies.

The parameter  $l'$  was defined as the lower boundary of the first length class that was 100% retained by the gear, i.e. the first distinct frequency maximum in the annual length frequency distribution. As such,  $l'$  could also be considered as the size at first capture. Because the selection of  $l'$  was not completely objective in every case,  $Z$  estimates were often repeated for different estimates of  $l'$  (Table 3). The parameter  $\bar{l}$  was estimated from a coded array of successive frequencies for all length classes from  $l'$  upwards.

#### *Natural and fishing mortality (M and F)*

Natural mortality estimates used in this study were based on length-frequency data obtained from underexploited populations on Pedro Bank, located about 80 km south of Jamaica. Assuming that fishing mortality was not a factor, Munro and co-workers estimated the parameters  $l'$  and  $\bar{l}$  from annual length frequency distributions obtained during exploratory fishing operations on Pedro Bank and solved equation (3) for the ratio  $M/K$ . Natural mortality estimates for three of the species studies in Puerto Rico were estimated directly from published Pedro Bank length data using known growth estimates from Jamaica or Puerto Rico (Table 4). However, in all three cases, published  $M/K$  estimates were recalculated from available annual length frequency distributions for a new value of  $l'$  which was consistent with the definition used to estimate total mortality rates.

Since the published  $M/K$  estimates for three additional species were higher than published  $Z/K$  estimates for exploited populations of the same species, there was considerable doubt as to their accuracy and therefore "true"  $M/K$  ratios were estimated to be 75% of the published  $Z/K$  ratios from exploited areas on Pedro Bank. This procedure seemed reasonable since Munro and Thompson (1973) reported that there was an active commercial fishery only in the vicinity of the small cays on the eastern end of Pedro Bank, an area which composes only 13% of the total area of the Bank. Natural mortality was calculated from the adjusted  $M/K$  ratios using known growth rates (Table 4).

For the remaining two species, no reliable  $M/K$  estimates were available from Pedro Bank and therefore a range of probable estimates were derived from  $M/K$  ratios equal to 0.33, 0.50, and 0.66 the lowest known  $Z/K$  ratios.

#### **Relative Yield Estimates**

Relative yield per recruit estimates were determined from a set of yield tables published by Beverton and Holt (1964). These yield tables are based on a modified version of the original Beverton-Holt yield equation in which age parameters were replaced by length parameters and fishing mortality  $F$  was replaced by the ratio of fishing mortality to total mortality ( $F/Z$ ). Thus, the relative yield per recruit for each species was determined from estimates of the following three

Table 3. Annual instantaneous total mortality rates ( $Z$ ) for eight species estimated from annual length frequency data averaged for two Fall and one Spring catch records for 3.4-cm and 4.2-cm maximum-aperture wire-fish-pots operated on the southwest coast of Puerto Rico during 1973-74. Total mortality was estimated from the equation  $Z/K(L_{\infty}-\bar{L})/(\bar{L}-1')$  with known growth rates (see text). Calculations were repeated in some cases for two values of  $1'$  and  $\bar{L}$ . Total sample size equals  $N$ .

Species	Mesh Size (cm)	N	$1'$	$\bar{L}$	Z
<i>E. guttatus</i>	3.4	704	190	244	1.13
			220	260	1.42
	4.2	758	230	276	1.17
<i>C. fulva</i>	3.4	449	190	221	2.39
	4.2		200	231	2.20
<i>C. ruber*</i>	3.4 & 4.2	284	170	226	1.26
<i>H. plumieri</i>	3.4	293	180	239	0.80
	4.2		190	240	0.92
			220	251	1.44
<i>P. maculatus</i>	3.4	1098	165	184	1.31
	4.2		737	180	201
<i>H. ascensionis</i>	3.4	393	185	204	1.33
			200	211	2.02
	4.2	298	215	225	2.02
	3.4 & 4.2	754	205	218	1.61
<i>H. rufus</i>	3.4 & 4.2	545	180	189	1.38
<i>S. aurofrenatum</i>	3.4	447	155	183	0.54
			170	191	0.64
	4.2		973	185	203

\*Data available for Fall 1973 and Fall 1974 sampling periods only and were based on captures in depths 20-40 m.

variables: (1) the exploitation rate  $E$  which was equal to  $F/Z$ , (2) the parameter "c" which was equal to the calculated length at 50% retention ( $\bar{L}_s$ ) divided by  $L_{\infty}$  and (3) the ratio of natural mortality to growth ( $M/K$ ).

Since the observed selection ranges for given mesh sizes were asymmetrical, the mean selection length  $\bar{L}_s$  was calculated as

$$\bar{L}_s = \frac{\sum 1_y \Delta F_y}{\sum \Delta F_y} \quad (4)$$

Table 4. Annual instantaneous natural mortality rates (M) for eight species captured in wire-fish-pots on the southwest coast of Puerto Rico during 1973-74 based on natural mortality/growth ratios (M/K) for unexploited populations on Pedro Bank and on known growth rates. Published M/K ratios were recalculated for adjusted length at first capture data ( $l'$ ). In other cases, M/K was estimated from known Z/K values or estimated as a range of values.

Species	M/K	K	M	Remarks
<i>E. guttatus</i>	2.45	0.24*	0.59	M/K adjusted for new $l'$
<i>C. fulva</i>	2.08	0.63*	1.31	M/K = 75% Pedro Cays Z/K
<i>C. ruber</i>	4.00	0.24*	0.96	M/K adjusted for new $l'$
<i>H. plumieri</i>	1.00	0.26	0.26	Probable range of M/K values
	1.50	0.26	0.39	
	2.00	0.26	0.52	
<i>P. maculatus</i>	2.20	0.28	0.62	M/K adjusted for new $l'$
<i>H. ascensionis</i>	3.81	0.26	1.00	M/K = 75% Pedro Cays Z/K
<i>H. rufus</i>	2.86	0.29	0.83	M/K = 75% Pedro Cays Z/K
<i>S. aurofrenatum</i>	1.00	0.20	0.20	Probable range of M/K values
	1.50	0.20	0.30	
	2.00	0.20	0.40	

\*Growth rates reported from Jamaica.

where  $l_y$  = the midpoint of the  $y^{\text{th}}$  length class in the observed selection range for a given mesh size

$\Delta F_y$  = the increment in frequency corresponding to the  $y^{\text{th}}$  length class

Thus, for given estimates of E and M/K, observed values of c were compared with the expected values of c (equals  $c'$ ) at eumetric yield, i.e. when the maximum sustainable yield per recruit was attained with the least amount of exploitation and the optimum mesh size. Species for which observed c was *less* than expected  $c'$  were overexploited; a reduction in fishing effort or the use of a larger mesh would increase  $\bar{l}_s$  relative to  $L_{\infty}$  and improve yield. Species for which observed c was *greater* than expected  $c'$  were underutilized and an increase in fishing effort or the use of a smaller mesh would improve yield.

Note that for the purpose of yield assessments the exploitation rate E was held constant while maximum yield per recruit was evaluated in terms of the mean selection length. In reality, adjustments in the value of  $\bar{l}_s / L_{\infty}$  would be accompanied by changes in the exploitation rate and appropriate management decisions would have to be evaluated in terms of *both* parameters.

## RESULTS

### Growth and Total Mortality Estimates, By Species

#### *Epinephelus guttatus*

A mean annual instantaneous growth rate ( $K$ ) equal to 0.24 was estimated from progressions for four size groups in 3.4-cm mesh and three in 4.2-cm mesh-length data. Two of these progressions were complete for all three seasons, but were statistically insignificant. The maximum limiting length ( $L_{\infty}$ ) was assumed to equal 520 mm as reported by Thompson and Munro (1974a) who also reported  $K=0.24$  in Jamaica. The annual total mortality rate ( $Z$ ) for 3.4-cm mesh was greater than  $Z$  in 4.2-cm mesh owing to the size selectivity of the gear.

#### *Cephalopholis fulva*

Growth and total mortality estimates for this species were both considerably higher than for any other. A single two-point size progression in 4.2-cm mesh data resulted in  $K=0.44$  when  $L_{\infty}$  was assumed to equal 340 mm. Polymodal frequency analysis for 3.4-cm mesh-length data was unsatisfactory. A growth rate equal to 0.63 was reported by Thompson and Munro (1974a) from Jamaica. Growth was apparently rapid enough that no single size group remained in the exploitable size range for as long as a year. Total mortality was more pronounced in the smaller mesh as a result of the size selectivity of the gear.

#### *Caranx ruber*

Size selectivity by mesh was negligible, but there was a significant variation in the sizes captured according to depth. Length data for the two meshes were combined in two fall shallow-water length frequencies, but no progressions were observed and growth could not be estimated. The total mortality estimate was based on  $K=0.24$  and  $L_{\infty}=520$  mm as reported by Thompson and Munro (1974b).

#### *Haemulon plumieri*

This species was captured in shallow water (<40 m) in both mesh sizes with no apparent size selectivity. The progressions of three size groups sampled in 4.2-cm mesh-pots during all three seasons produced  $K=0.26$  when  $L_{\infty}$  was assumed to equal 420 mm. A single linear regression which was complete for the entire year was significant at  $\varphi=.05$ . Billings and Munro (1974) reported  $K=0.32$  for inshore populations in Jamaica and  $K=0.37$  for offshore populations. Total mortality was greater in the larger mesh apparently because this species was not captured selectively by the two meshes. The  $Z$  estimate of 0.92 in 4.2-cm mesh seemed more acceptable and was used in subsequent yield analyses.

#### *Pseudupeneus maculatus*

There was a pronounced effect of mesh size on the lengths of fish captured owing to the elongated shape of this species. Growth estimates were based on the progressions of five size groups, two in the smaller mesh and three in the larger. A single three-point regression was statistically significant at  $\varphi=.05$ . Using an assumed  $L_{\infty}$  equal to 270 mm,  $K$  was estimated to equal 0.28. The marked difference in total mortality rates for the two different mesh sizes was expected for a species which showed such a pronounced size selectivity.

Munro (1974a) reported that male and female *P. maculatus* in Jamaica attained different maximum lengths (270 mm for males and 250 mm for females) and significantly different growth rates (0.70 and 0.35 respectively), but no such variation in the growth of presumed male and female size groups was demonstratable in the Puerto Rican data. No attempt was made to estimate K or Z by sex.

#### *Holocentrus ascensionis*

Despite evidence of size selection by mesh, individual sample sizes were low and growth was estimated from combined mesh length data and size progressions for four groups. One regression was complete for the entire year and was significant at  $\varphi=.05$ . Average annual instantaneous growth was equal to 0.26 when  $L_{\infty}$  was set equal to 300 mm. The lower total mortality rate estimate for 3.4-cm mesh ( $Z=1.33$ ) seemed more likely since size selectivity was a factor and since a total mortality estimate for a combined 3.4-cm and 4.2-cm mesh average annual data set was intermediate between 1.33 and 2.02.

#### *Holocentrus rufus*

This species showed no apparent size selectivity by mesh and was restricted to shallow water. Growth was estimated from two progressions in combined mesh data, one of which was complete for all three sampling periods and was significant at  $\varphi=.01$ . The maximum limiting length was assumed to equal 230 mm and K was equal to 0.29. Total mortality was estimated from combined mesh length data averaged over all sampling seasons.

#### *Sparisoma aurofrenatum*

This species was also restricted to shallow water and showed significant size selection by mesh. Growth estimates from the 3.4-cm mesh-length data were rejected since the inferred growth rates increased consistently for older size groups. Four size progressions were revealed in the 4.2-cm mesh data, two of which produced three-point regressions. One of these regressions was not significant, the other was significant at  $\varphi=.05$ . The average growth rate was equal to 0.20 when  $L_{\infty}$  was equal to 260 mm. Total mortality estimates were essentially the same regardless of mesh size.

#### *Sparisoma chrysopterygum* and *Calamus pennatula*

Growth rates were not estimated for these two species owing to uncertain size increments between sampling periods. No growth information was available from Jamaica. In the absence of K estimates, total mortality rates could not be estimated.

#### Natural and Fishing Mortality Rates (M and F)

Annual instantaneous mortality estimates for six species ranged from 0.60 to 1.30 (Table 4) when M/K was either based on length frequency data from unexploited populations on Pedro Bank (with adjusted  $l'$  values) or on a 75% estimate of Z/K values obtained from length data for lightly fished populations

on Pedro Bank. The natural mortality estimate for *C. fulva* (1.31) was considerably higher than for any other species. Natural mortality rates were estimated for three probable M/K values for *H. plumieri* and *S. aurofrenatum* and indicated a range of M estimates from 0.20 to 0.52. No M/K estimates were available for either *S. chyrsopterus* or *C. pennatula*.

Fishing mortality estimates for individual species with variable  $1'$  values (Table 5) captured in either 3.4-cm or 4.2-cm mesh sizes ranged from 0.30 to 1.10. The exploitation rate E (equal to F/Z) ranged from 0.25 to 0.58, but the majority of cases were between 0.40 and 0.50.

#### Exploitation Relative to Eumetric Yield

From the yield tables published by Beverton and Holt (1964), values of the exploitation rate E and the parameter c (equal to the mean selection length  $\bar{L}_s$  divided by  $L_\infty$ ) at eumetric yield were compared with observed values of the same two parameters for each mesh size and the optimum value of c (equals  $c'$ ) at eumetric yield was predicted while E was held constant. The following results were indicated (Tables 5 and 6).

Two species (*E. guttatus* and *H. plumieri*) were slightly overexploited in both mesh sizes. The evidence, however, was less convincing for *H. plumieri* since the natural mortality rate was unknown and yield assessments were performed for a range of probable values of M. Overexploitation was indicated for exploitation rates exceeding 0.35 in the smaller mesh and exceeding 0.43 in the larger mesh.

Table 5. Relative yield assessments for five species with known natural mortality rates captured in two mesh sizes of wire-fish-pots on the southwest coast of Puerto Rico during 1973-74. Observed values of the parameter c (when c is equal to  $\bar{L}_s/L_\infty$ ) were compared with optimum values ( $c'$ ) at eumetric yield per recruit for known estimates of the exploitation rate E (=F/Z) and M/K. Overexploitation was indicated when  $c'$  exceeded c and underexploitation when c exceeded  $c'$ . Higher values are underlined.

Species	Mesh (cm)	$1'$	$\bar{L}_s$	c	F	Z	E	$c'$
<i>E. guttatus</i>	3.4	190	185	.36	0.54	1.13	.48	<u>.42</u>
		220	188	.36	0.83	1.42	.58	<u>.46</u>
	4.2	230	206	.39	0.58	1.17	.50	<u>.42</u>
<i>C. fulva</i>	3.4	190	180	<u>.53</u>	1.08	2.39	.45	.44
	4.2	200	189	<u>.56</u>	0.89	2.20	.40	.42
<i>P. maculatus</i>	3.4	165	150	<u>.56</u>	0.69	1.31	.53	.45
	4.2	180	174	<u>.65</u>	0.31	0.93	.33	.37
<i>H. ascensionis</i>	3.4	185	173	<u>.58</u>	0.33	1.33	.25	.26
		200	181	<u>.60</u>	1.02	2.02	.50	.34
	4.2	215	202	<u>.68</u>	1.02	2.02	.50	.34
<i>H. rufus</i>	3.4 & 4.2	180	168	<u>.73</u>	0.55	1.38	.40	.36

Table 6. Relative yield assessments for two species with unknown natural mortality rates captured in two mesh sizes of wire-fish-pots on the southwest coast of Puerto Rico during 1973-74. Natural mortality was estimated as a range of probable values. Additional parameters are the same as in Table 5.

Species	Mesh (cm)	$l'$	$\bar{L}_s$	c	M	F	Z	E	$c'$
<i>H. plumieri</i>	3.4	180	169	.40	0.26	0.54	0.80	.68	<u>.66</u>
				.40	0.39	0.41	0.80	.51	<u>.52</u>
				.40	0.52	0.28	0.80	.35	<u>.40</u>
	4.2	190	181	.43	0.26	0.66	0.92	.72	<u>.66</u>
				.43	0.39	0.53	0.92	.58	<u>.56</u>
				.43	0.52	0.40	0.92	.43	<u>.43</u>
<i>S. aurofrenatum</i>	3.4	155	149	.54	0.20	0.34	0.54	.63	<u>.64</u>
				<u>.54</u>	0.30	0.24	0.54	.44	<u>.50</u>
				<u>.54</u>	0.40	0.14	0.54	.26	<u>.36</u>
	3.4	170	155	<u>.64</u>	0.20	0.44	0.64	.69	<u>.58</u>
				<u>.64</u>	0.30	0.34	0.64	.53	<u>.54</u>
				<u>.64</u>	0.40	0.24	0.64	.38	<u>.42</u>
	4.2	185	160	<u>.62</u>	0.20	0.42	0.62	.68	<u>.52</u>
				<u>.62</u>	0.30	0.32	0.62	.52	<u>.52</u>
				<u>.62</u>	0.40	0.22	0.62	.35	<u>.42</u>

Observed yield per recruit for *E. guttatus* in 4.2-cm mesh pots was very close to eumetric yield; a reduction in E to 0.45 and an increase in  $\bar{L}_s$  to 210 mm would maximize yield.

The remaining five species for which yield assessments were performed were all significantly underexploited. The greatest degree of underexploitation was observed for the two *Holocentrus* species and for *P. maculatus* captured in 4.2-cm mesh pots. *P. maculatus* harvested in 3.4-cm mesh pots were also underexploited, but not as notably. Results for *S. aurofrenatum* were also less clear since natural mortality rates were estimated for a range of M/K values, but underexploitation was consistently indicated for intermediate and low fishing mortality rates. The coney (*C. fulva*) was underexploited, but not to the same degree as the others. An increase in the exploitation rate to 0.55 and a reduction in the parameter c to slightly less than 0.50 would be required in order to achieve eumetric yield per recruit. The exploitation rates required to achieve maximum sustainable yield per recruit for the other four species were believed to be 0.60 or even higher.

#### DISCUSSION

The two overexploited species captured in fish pots on the southwest coast of Puerto Rico during 1973-74 could be distinguished from the five underexploited species on the basis of their size. *E. guttatus* reached a maximum observed length (420 mm) that was 100 mm larger than any other species for which yield was

evaluated while *H. plumieri* has a considerably deep body. The underexploited species reached a maximum observed length of 300 mm and were therefore vulnerable to retention in size-selective wire fish pots over a more reduced length range than larger species or species with deep bodies.

Exploitation rates estimated for individual species harvested in Puerto Rico during 1973-74 were generally lower than those reported for the same species harvested on the intensively fished south coast of Jamaica and higher than those reported from commercially exploited oceanic banks south of Jamaica (Munro, 1974b). The annual harvest per unit area on the south coast of Jamaica in 1968 was 1.2 mt per km<sup>2</sup> (Munro, 1974b) while in Puerto Rico, harvest of reef fish on the southwest coast reached 0.8 mt per km<sup>2</sup> in 1974, suggesting that the Jamaican shelf was more productive and supported more abundant fishery resources.

With the exception of *C. fulva*, annual instantaneous growth rates ranged from 0.20 to 0.30 while annual instantaneous natural mortality rates varied from 0.60 to 1.00. Ratios of natural mortality to growth were therefore generally high. An important consequence of high M/K ratios for any exploited fish population is that the critical size (and age) which prevails at maximum sustainable yield is low and conflicts with the minimum size at maturity. A comparison of observed mean selection lengths for 3.4-cm and 4.2-cm meshes with length-at-maturity estimates reported by Munro et al. (1973) indicated that significant proportions of the catch for five species, at least, were sexually immature (Table 7). Even larger proportions would be vulnerable to capture before the fish actually spawned for the first time.

Table 7. Lengths at maturity ( $l_m$ ) defined as the lower boundary of the first size class which contained 25% or more ripe or spent fish and compared with mean selection lengths in two mesh sizes for six species captured in the wire-fish-pot fishery of southwest Puerto Rico during 1973-74. Data were collected Jamaica. Data for two species were by sex.

Species	Length at Maturity* (mm)	Mean Selection Lengths (mm)	
		3.4 cm mesh	4.2 cm mesh
<i>E. guttatus</i>	≤250	185-188	206
<i>C. fulva</i>	≤160	180	189
<i>C. ruber</i>	240	170+ (both meshes)	
<i>H. plumieri</i>	220	169	181
<i>P. maculatus</i>	♂ 180	150	174
	♀ ≤160		
<i>S. aurofrenatum</i>	♀ 160	149-155	160

\*Data were from Munro, 1974b, except for *S. aurofrenatum* which were provided by Peter Reeson, personal communication.



The probable age compositions of the catch records for individual species were determined by converting relative lengths-at-age ( $l_t$ ) to absolute lengths-at-age. This was accomplished by arbitrarily assigning absolute ages to observed lengths-at-age until an age assignment which produced a satisfactory fit of the von-Bertalanffy growth curve for the estimated values of  $K$  and  $L_\infty$  to the inferred lengths at absolute age was obtained. This process was facilitated by the selection of a single birthdate (time of year) for the cohorts in each species population on the basis of published reports of the spawning behavior of reef fish in Jamaica (Munro et al. 1973). The agreement between observed and inferred  $l_t$  data following age assignments was, in most cases, remarkably good.

The inferred length-at-age information indicated that the maximum age attained by most species was 12-15 years and the exploited age range was from 1.5 to 7 years. The mean age at first maturity for the six species listed in Table 7 was 3.1 years and the mean value of  $l_m / L_\infty$  was 0.53, indicating that 50% or more of the growth of these species was achieved before sexual maturity. Apparently, *C. fulva* attains a maximum age of 7 years, matures during the first year of growth and remains in the exploitable size range from age 1 year to 2.5 years. The inferred absolute age compositions of catches for *P. maculatus* were based on the assumption that adjacent size groups represented male and female fish which grew at different rates even though a single growth rate was estimated for this species. *C. fulva* was assumed to spawn twice a year as suggested by Munro et al. (1973).

Optimum mesh size predictions and calculations of expected changes in yield following hypothetical mesh increases were performed following methods outlined by Gulland (1961; 1964) for *E. guttatus* and *H. plumieri*. These methods permitted the calculation of expected yield relative to an actual baseline yield for different mesh sizes during two phases. These two phases were: (1) an initial phase immediately following hypothetical mesh increases when yield would be reduced to below original levels by the loss of fish between the new minimum size at capture and the original minimum size at capture; and (2) a later phase when the biomass of the population would be increased by the additional growth of fish which are retained at a larger minimum size by the new mesh. The ultimate long-term catch would therefore be a sustainable, equilibrium catch. The time period necessary for the transition from immediate decreases in catch to long-term equilibrium yields was also estimated.

Results indicated that maximum yield for *E. guttatus* would be achieved in 4.6-cm mesh. Long-term sustainable yield was predicted to increase by only 0.4% over actual yields in 4.2-cm mesh and by 3.4% in relation to yield in 3.4-cm mesh. Immediate predicted reductions in catch ranged from 6 to 17% of actual yield. A period of 4 years would be necessary to attain equilibrium catches.

Expected yield determinations for *H. plumieri* were less clear, but also indicated modest long-term increases following more significant immediate reductions. For the intermediate natural mortality estimate ( $M=0.39$  and  $E=0.58$ ), an optimum mesh size of either 4.9 or 5.3 cm was predicted to improve yield by only 1% after 2 years, while expected immediate losses would be 4.6% for

4.9-cm mesh. Under more extreme exploitation conditions ( $M=0.26$  and  $E=0.72$ ), a 4 to 5% increase in long-term catch was predicted for 5.3-cm to 6.4-cm mesh sizes after immediate losses of 8-30%. Apparently, the choice of optimum mesh size was less critical for this species than for *E. guttatus*.

No objective basis for determining optimum mesh size and the effect of reduced mesh sizes on yield for the underexploited species was available. Given the considerable degree of underexploitation for many of the smaller species investigated, however, it would seem that mesh sizes of 2.5 cm would significantly increase biomass yield for these species. It would be a mistake, however, to use maximum sustainable biomass yield as the only management objective since it could only be achieved at the expense of the increased capture of immature fish and would pose the problem of marketing very small fish. Indeed, given these problems and the fact that smaller mesh sizes would deplete the populations of *E. guttatus* and *H. plumieri*, mesh size reductions seemed the least attractive management alternative.

A more attractive alternative would be to increase mesh size, perhaps to 4.6 cm. Although catches of the underexploited species, especially *P. maculatus*, would be further reduced, some increase in equilibrium yield for *E. guttatus* and *H. plumieri* could be expected, albeit a modest one. These two species accounted for 50% of the value of landings recorded for 81 pot hauls which were monitored during 1973-74 (Table 1). Perhaps a more important factor is that fewer immature fish would be retained by larger meshes, thus permitting an increase in recruitment. Although it was impossible to quantify this factor, Munro (1974b) considered that a gain of more than 50% in the relative value of pot catches due to increased recruitment would be possible on the exploited south coast of Jamaica following a mesh increase which would produce only a 5% gain in yield per recruit.

A third alternative would be to maintain existing mesh sizes and make no changes. An important feature of this course of action is that a variation in mesh sizes in use at any time permits the fishermen, to the extent that it is possible, to deploy pots of different mesh sizes in different areas where certain species predominate. Aside from possible improvements in yield which might result from increased recruitment, the expected yield and optimum mesh size evaluations for the two overexploited species did not reveal enough overfishing to justify converting all the pots in the fishery to a slightly larger mesh size.

The most striking characteristic of a tropical fish pot fishery is the great variety of species and sizes of fish which are harvested. The species and size composition of the catch is sensitive to small changes in mesh size. Introduction of mesh sizes smaller than 3.4-cm into the Puerto Rican pot fishery would result in severe overfishing of some species while a mesh larger than 4.2-cm would significantly reduce the relative composition of the smaller species in the catch. Another management alternative for tropical fish pot fisheries is to regulate the amount of fishing effort applied. This could be accomplished by limiting the density of pots in use in a given area while maintaining an optimum range of mesh sizes which permits maximum catch diversity.

# Administración de una Pesquería Tropical de Nasas de Alambre para un Rendimiento Máximo Sostenible

## RESUMEN

En el período 1973-74, datos sobre frecuencias de longitud para diez especies de peces capturados en una zona coralina con nasas de alambre fueron recogidos a bordo de lanchas pesqueras en la costa suroeste de Puerto Rico. Con base en estos datos, se estimaron los parámetros necesarios (tasas de crecimiento y mortalidad) para el modelo de rendimiento de Beverton y Holt. El objetivo fue determinar el rendimiento máximo sostenible por recluta para cada especie, relativo al rendimiento actual observado, y recomendar un plan de explotación racional del recurso.

De las operaciones de muestreo realizadas durante tres períodos de aproximadamente un mes cada uno, se obtuvieron estimados de las tasas instantáneas anuales de crecimiento (K), según los incrementos en el tamaño promedio de grupos individuales en cada frecuencia de longitud. Para estimar los tamaños promedios, cada frecuencia de longitud fue analizada a través de un método matemático programado en una computadora. Para seis especies, el intervalo K fue de 0.20 hasta 0.30. Para una séptima especie, K fue igual a 0.44. Valores para la longitud máxima teórica ( $L_{\infty}$ ) se aproximaron en la longitud máxima observada o en estimados de  $L_{\infty}$  publicadas en Jamaica.

Tasas instantáneas anuales de mortalidad total (Z) se estimaron de la distribución promedio de frecuencias anuales de longitudes para cada especie. Estimados de mortalidad natural (M) se hicieron sobre datos de longitud de poblaciones poco explotadas en un banco oceánico al sur de Jamaica, obteniéndose variaciones entre 0.60 y 1.30. Restando M de Z, se obtuvieron estimados de la tasa instantánea de mortalidad por pesca (F).

Basándose en los parámetros conocidos, fue posible determinar la tasa de explotación ( $E = F/Z$ ), la proporción M/K, y el parámetro "c" (= longitud mediana de selección por malla dividido entre  $L_{\infty}$ ). Utilizando estos tres parámetros, se estimó el rendimiento máximo sostenible por recluta con tablas de rendimiento, cuyos valores de c' sobre rendimiento máximo fueron comparados con los valores observados (c) para un valor constante de la tasa de explotación. Dichas comparaciones se hicieron para siete especies e indicaron que había dos de ellas un poco sobre-explotadas y cinco sub-explotadas. Las evaluaciones de rendimiento fueron hechas para dos tamaños de malla corriente en las nasas: 3.4 y 4.2 cm. de apertura máxima.

Un análisis del tamaño óptimo de malla para las dos especies sobre-explotadas y el nivel esperado de rendimiento después de dicho aumento en la malla indicó que, en términos de rendimiento solamente, habría poco motivo para aumentar el tamaño de la malla. Por otro lado, una disminución en la malla podría mejorar la captura de las especies sub-explotadas de una manera significativa, pero resultaría así en una captura de peces más pequeños e inmaduros. El efecto de cambios en la malla sobre reclutamiento a las poblaciones fue un factor difícil de evaluar.

Dada la alta diversidad de peces capturados alrededor de arrecifes de coral, variedad en sus tamaños y vulnerabilidad a la pesca en artes selectivos, como la nasa de alambre, parece que es recomendable seguir pescando con mallas de diferentes tamaños y regular la densidad de nasas para evitar la sobre-explotación del recurso.

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