Population Biology of the Spiny Lobster (*Panulirus argus*) in Jamaican Waters

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ABSTRACT

A time series of length frequency data on the spiny lobster (*Panulirus argus*) collected from commercial fisheries in Jamaica between November 1985 and March 1987 is analyzed to obtain estimates of population parameters. The von Bertalanffy growth parameters L_∞ and K are estimated using the ELEFAN 1 method. The growth parameters are then used to generate a recruitment pattern. A length converted catch-curve is constructed from which total mortality and mean selection size are estimated. Total mortality (Z) is split into natural mortality (M) and fishing mortality (F). Population size and exploitation pattern are estimated by Jones length cohort analysis. Yield per recruit and biomass per recruit are estimated using Beverton and Holt yield per recruit analysis.

INTRODUCTION

The spiny lobster *Panulirus argus* is widely distributed in the coastal waters and on the offshore banks around Jamaica. It is a highly priced resource and represents an important component of the total landings of the Jamaican commercial fisheries. The largest concentration of lobsters are to be found on the Pedro Bank which accounts for approximately 60% of the fishery (Figure 1). The stocks, particularly on the northern coast have, however, been depleted by overfishing (Aiken, 1983; Aiken and Haughton, 1987). The Jamaica Fisheries Division estimates that total landings of *P. argus* in Jamaica increased from about 260 tonnes in 1981 (Sahney, 1983) to about 680 tonnes in 1986. Prior to 1982 the Jamaican lobster fishery was primarily an artisanal fishery. Lobsters were taken along with a large variety of fish in the Z-shaped antillean fish traps. Skin divers using spearguns also made catches. Since 1982, however, there has been a marked increase in the exploitation of the lobster resource. This has been stimulated by a rapid expansion of the local tourist industry and an improvement in the competitiveness of Jamaican lobster in the North American market. In 1982 a new industrial fishery targeting the lobster on the Pedro Bank was started. This fishery comprises about five lobster boats in the 25–30 meter size class, each using 1000–1500 Florida type wooden lobster traps. The Florida type traps have been described by Simmons (1980).

In addition to the industrial fishery, a small number of artisanal fishermen,

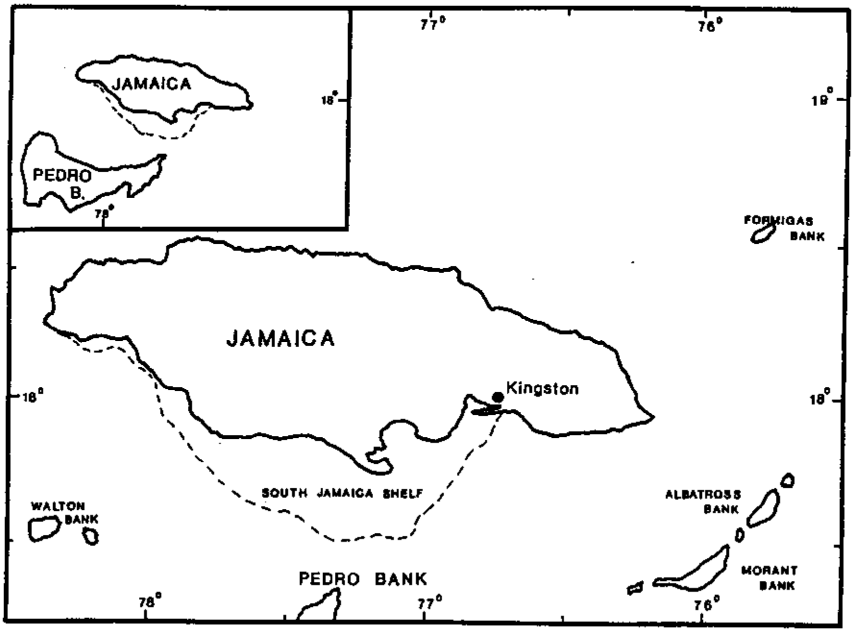

Figure 1. Map of Jamaica and the Pedro Bank.

since 1982, have exclusively fished for lobster using either lobster traps or divers. The divers are sometimes equipped with scuba equipment and spearguns. Most of the artisanal fishermen, however, continue to catch lobster as by-catch in the Z-shaped antillean traps.

The fishing effort for lobster has been increasing rapidly since the early 1980's; there have been an increase in the number of fishermen entering the fishery, in the number of traps being used, and in the number and size of fishing vessels entering the fishery.

MATERIAL AND METHODS

The length composition data used in this study were collected from the commercial fishery during the period November 1985 to March 1987. All the data analyzed were from the Pedro Bank except those used in the calculation of the length/weight relationship, when samples taken from the southern shelf and Morant Bank were included in the analyses.

Samples were collected and analyzed either on board the vessels as they arrived in port, or at a lobster processing plant usually within a few hours after the lobster arrived. Random numbers were used to select the bags of lobster to be analyzed.

Carapace measurement were taken whenever it was possible. Since the large lobster boats usually discard the cephalothorax or head at sea, it was not always possible to measure carapace length (CL). When the carapace was not available, the length of the telson was measured and converted to carapace lengths using the regression equations given by Haughton and Shaul (1989). The telson length (TSL) is defined as the distance from the tip of the telson to the groove of its connection with the last tail segment. The tail and telson are opened out flat while measuring. All length measurements were recorded to the nearest millimeter below. Weights were recorded in ounces and pounds and later converted to grams.

The data was analyzed with the aid of the length composition based fish stock assessment computer programs "LFSA" (Sparre, 1987) and "ELEFAN" (Brey & Pauly, 1986).

RESULTS

Size Composition

During the study period, 9,968 lobsters were collected, of which 5,096 were males and 4,872 females. Hence, the sex ratio was: 1.04 males to 1.00 females; close to unity. The size range was from 55 mm to 177 mm carapace length (CL) (Figure 2), but the single largest specimen (177 mm CL) was not used in the analyses to avoid having a length class (*i.e.*, 170–175 mm) with zero frequency. The mean carapace length of the males and females were 100.5 mm and 92.5 mm respectively. The modal lengths for males and females were 92.5–97.5 mm CL and 87.5–92.5 mm CL respectively. The carapace lengths of the males are consistently larger than those of the females. Males and females combined had a mean size of 96.5 mm CL and a modal size of 90–95 mm CL.

Full recruitment to the fishery at Pedro Bank occurs at 90–95 mm CL for both sexes. The mean length of the fully recruited males and females were 105.6 mm CL and 100.4 mm CL respectively.

Growth and Recruitment Pattern

Samples of 178 female and 211 males *P. argus* collected from the southern Jamaican shelf and Pedro Bank during 1985–1986 produced the following length/weight relationships:

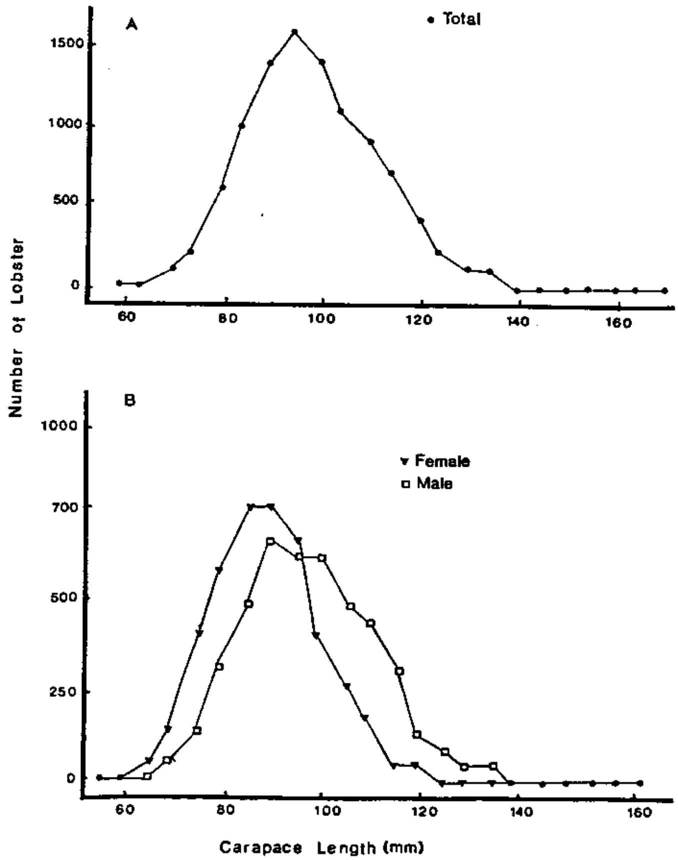

Figure 2. Length frequency data for *P. argus* from Pedro Bank, Jamaica.

FEMALE: $W = 0.00499*CL^{2.62}$ (grams, millimetres)
MALE: $W = 0.00316*CL^{2.71}$ (grams, millimetres)

The 95% confidence interval constructed around the coefficients have ranges of 2.64–2.78 for males and 2.52–2.73 for females. The overlapping confidence intervals indicate, therefore, that male and female *P. argus* do not differ significantly in their length-weight relationship.

Estimates of the growth parameters and their corresponding ESP/ASP ratios computed from the ELEFAN package are given in Table 1.

The ESP/ASP ratios for the males and females are substantially different.

Table 1. Von Bertalanffy growth parameters for *P. argus* derived from ELEFAN 1 (K = growth coefficient; L_∞ = asymptotic length).

	K(y-1)	L_∞(mm)	ESP/ASP	STARTING PT.
MALE:	0.24	210	0.354	sample 15, Lt. 108
FEMALE:	0.28	195	0.526	sample 1, Lt. 82
COMBINED:	0.26	205	0.443	sample 7, Lt. 94

The higher ESP/ASP ratio (0.526) obtained for the females suggest that the estimated growth parameters gave a better fit for the female than the corresponding parameters for the males.

Figure 3 shows the von Bertalanffy growth curves for male and female constructed using the growth parameters derived from ELEFAN 1 (assuming t-zero = 0). Females have a higher growth rate and attain their maximum size more quickly than the males. It should, however, be noted that growth in males and females are almost the same for the first 4–5 years, but thereafter the growth rate of the females decreases much faster than that of the males.

The recruitment patterns were estimated by projecting the length frequency samples backward onto the time axis using the growth parameters computed above. Year round recruitment with a single peak was observed for both males and females (Figure 4).

Mortality Rates and Selection Ogives

The instantaneous rate of total mortality (Z) was estimated by length converted catch curve analysis (Pauly, 1984; Sparre, 1986) for males, females, and males and females combined. Good fits to the descending right-arm section of the catch curves were obtained for all three analyses. The correlation coefficients for the regressions varied between 0.987 and 0.996. The values of Z obtained were 2.19 for males, 2.88 for females, and 2.50 for both sexes combined. The graph of the catch curve for both sexes of *P. argus* combined is presented in Figure 5.

The instantaneous rate of natural mortality (M) was estimated for Pauly's (1980) empirical formula:

$$Ln(M) = -0.0152 - 0.279*Ln(L_\infty) + 0.6543*Ln(K) + 0.463*Ln(T)$$

where K = annual coefficient of growth, L_∞ = asympototic length (total) and T is the average temperature of the fishing ground in degrees centigrade. The value of T used to determine M was 28 °C. The estimated M for males was 0.59, for females 0.67, and for both sexes combined 0.62.

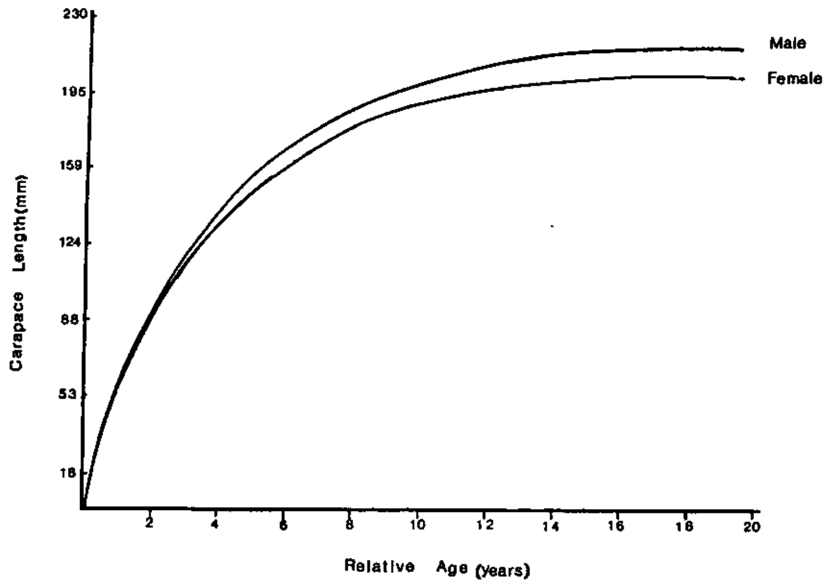

Figure 3. Von Bertalanffy growth curves for male and female *P. argus* from Pedro Bank, Jamaica.

The instantaneous rates of fishing mortality F, and the exploitation rates E, were computed from the estimates of Z and M obtained above. The fishing mortality for the females was F = 2.21, compared to F = 1.60 for the males. The estimates of exploitation rate was E = 0.77 for females and E = 0.73 for males.

Theoretical estimates of selection ogives for the lobster fishery at Pedro Bank were obtained using the results of the catch curve analyses. Graphs of the selection ogives for male and female *P. argus* are presented in Figure 6. The

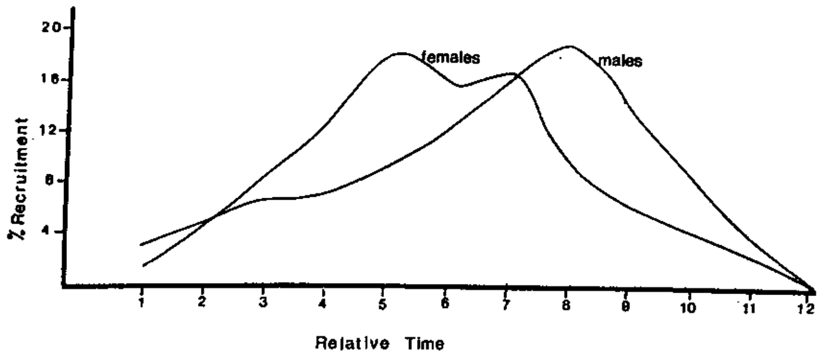

Figure 4. Recruitment pattern for male and female *P. argus* from Pedro Bank, Jamaica.

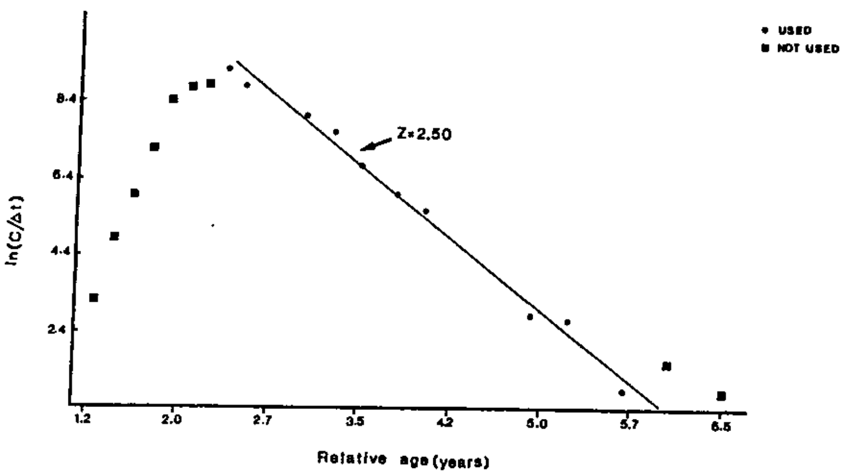

Figure 5. Length-converted catch curve for *P. argus* from Pedro Bank, Jamaica.

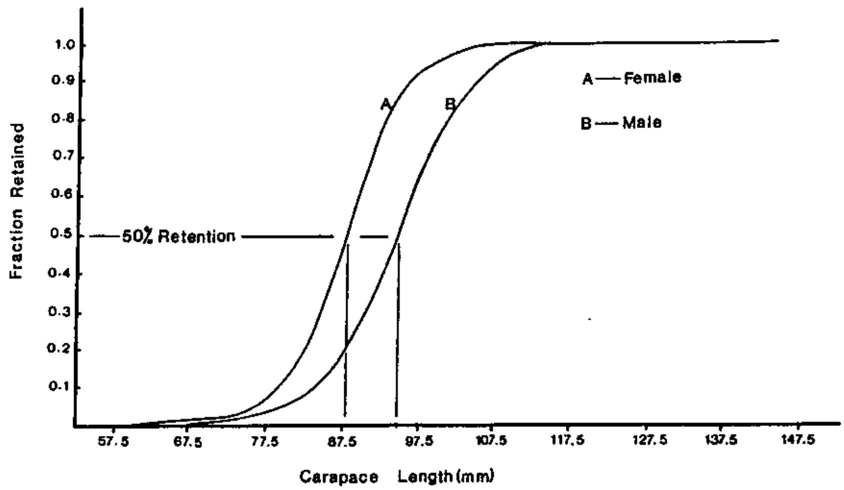

Figure 6. Selection curves for male and female *P. argus* from Pedro Bank, Jamaica caught with Antillean traps.

Table 2 Selection parameters for *P. argus* from Pedro Bank

	MALE	FEMALE	COMBINED
Lc (50%) mm CL:	94.4	87.8	92.0
Tc (50%) rel. yrs:	2.49	2.09	2.29

mean selection lengths and ages (relative) obtained are presented in Table 2.

Population Estimates and Exploitation

Estimates of stock size and fishing mortality were obtained from length composition data using Jones Length Converted Cohort Analysis (Jones, 1984; Sparre, 1986). The results of the analysis are given in Table 3. The total number of survivors in the population on Pedro Bank at the end of 1986 was estimated at 8.9 million with a biomass of approximately 4,000 tonnes. The mean fishing mortality on the fully recruited length groups was F = 1.28 for males and F = 2.11 for females.

Yield per recruit (Y/R) and biomass per recruit (B/R) were calculated using

Table 3. Jones length converted cohort analysis of Pedro Bank *P. argus* population.

Length Interval	Catch no.	Total no.	Biomass (kg)	F	Total catch	N	Biomass (kg)	F
55-60	177	662196	123387	0.00	71	680945	139083	0.00
60-65	531	610742	142547	0.01	639	625224	158807	0.01
65-70	531	561396	161340	0.01	2130	571641	177780	0.03
70-75	3304	514488	179381	0.04	8236	519333	194438	0.12
75–80	8024	467328	195147	0.12	25702	464002	206801	0.40
80-85	16874	418260	206846	0.26	42600	395386	207526	0.77
85-90	28261	363736	210929	0.50	52256	315703	193282	1.17
90-95	34987	302128	203637	0.73	54315	233483	165317	1.63
95-100	35518	238911	185689	0.92	46008	156845	127458	2.03
100-105	34574	180550	160671	1.16	29749	95664	88614	2.07
105-110	27671	128387	129977	1.27	19028	56289	59064	2.17
110-115	26373	87815	100548	1.77	13277	31388	37101	2.71
115-120	19529	52650	67818	2.18	4686	14834	19646	1.78
120-125	8437	27824	40121	1.62	2840	8388	12389	1.82
125-130	5900	16312	26212	1.90	1562	4503	7386	1.75
130-135	2596	8577	15296	1.44	1136	2345	4253	2.50
135-140	1888	4921	9702	1.81	426	904	1807	2.23
140-145	708	2418	5253	1.22	213	350	769	2.93
150-155	354	857	2237	1.62	-	-	-	-
155-160	59	374	1066	0.49	-	-	-	-
160-165	118	244	755	1.69	-	-	-	-
165 plus	59	84	283	1.38	-	-	-	-
Total	256768	4651567	2172197		304946	4177316	1801734	

the Beverton and Holt (1957) yield per recruit model, and expressed as a function of fishing mortality in the form suggested by Gulland (1983). Figure 7 show the yield per recruit and biomass per recruit for the *P. argus* stocks on the Pedro Bank.

The yield per recruit curve indicated an F_{max} *i.e.*, the fishing mortality rate with a maximum yield per recruit of 1.99 and a maximum sustainable yield per recruit of 577g. It should be noted, however, that the yield per recruit curve is flat topped. The fisheries management reference point $F_{0.1}$, *i.e.*, the fishing mortality corresponding to the point on the curve where the slope is one-tenth of the slope at the origin, was 0.56, with a corresponding yield per recruit of 500g. The virgin stock biomass per recruit obtained was 2,460g.

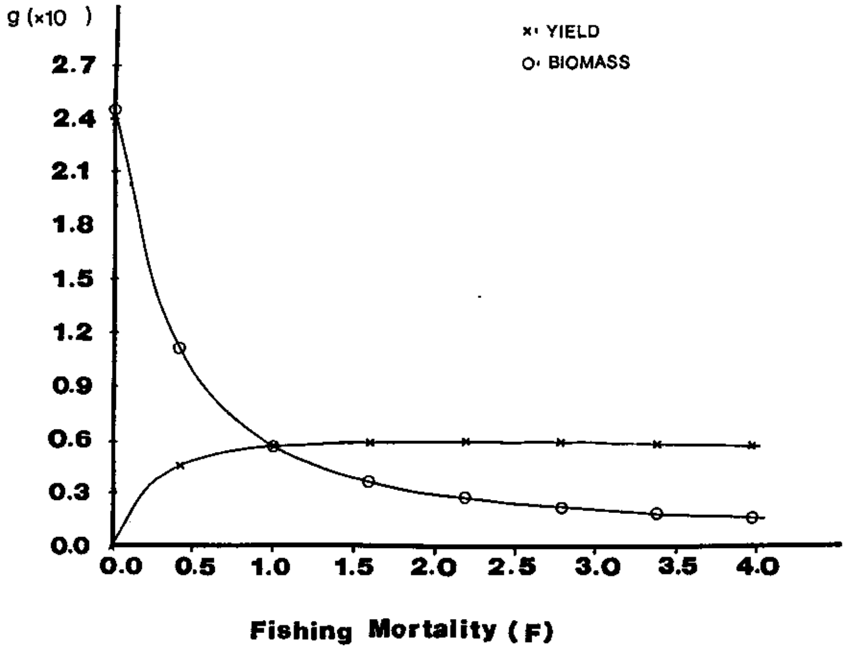

Figure 7. Yield per recruit and biomass per recruit for *P. argus* from Pedro Bank, Jamaica.

DISCUSSION

Munro (1983a) studied the lobster populations on the Pedro Bank between 1969 and 1973 when they were still largely unexploited. The mean lengths of males and females calculated from the data collected by Munro (1983a) were 118.2 mm CL and 102.3 mm CL respectively, compared with 100.5 mm CL and 92.5 mm CL obtained by the present investigation. Munro (1983a) reported modal lengths of 110-119 mm CL and 90-99 mm CL for males and females respectively. The modal size classes are, therefore, significantly lower than those estimated by Munro (1983a). The size class at which full recruitment to the fishery at Pedro Bank occurs in 90-95 mm CL for both sexes. The mean of the fully recruited males and females are 105.6 mm CL and 100.4 mm CL respectively, compared to 126.7 mm CL and 104.7 mm CL obtained by Munro (1983a, 1983b). The reduction in the mean and modal size of increase in fishing pressure that has occurred over the last decade. The mean and modal size of the lobster population reported here are still well above the minimum legal size of 76mm CL, and slightly greater than the mean size at maturity of 84-90mm CL (Aiken, 1983).

The sex ratio obtained during the present study is close to unity and is supported by the values reported in the literature (Lyons *et al.*, 1981; Munro, 1983a, 1983b).

Results from the present study indicate that the length/weight relationship for male and female *P. argus* are not significantly different. This is in agreement with the findings of Munro (1983a). The value of the exponent (b) obtained by Munro (1983a) was 2.74, and is therefore within the 95% confidence interval obtained in this study.

Growth in lobster is affected by several factors, including temperature, maturation, injuries, and handling and exposure (Lyons *et al.*, 1981; Davis, 1981; Tamm, 1980). Growth occurs as a function of two processes, the frequency of moult and the increase in size during the moult before the new exoskeleton hardens. The Gulf of Mexico and South Atlantic Fisheries Management Councils (1982) reviewed the literature on growth in lobster and reported that *P. argus* moults approximately four times per year, with an intermoult increment of 5-8 mm.

Munro (1983a, 1983b) calculated growth parameters from the results of tagging experiments in Belize, and obtained a K value of 0.21 per year and L_∞ of 190 mm CL for males and females combined. The Gulf of Mexico and South Atlantic Fishery Management Councils (1982) reported that the most likely range of K was 0.20 to 0.30 per year and arbitrarily selected the midpoint of the range (K = 0.25) as the best estimate for male and female combined. This is very close to the value of (K= 0.26) obtained in this study for combined data.

It should be emphasized that the von Bertalanffy growth curve describes the average growth of a cohort of *P. argus* rather than the growth of an individual lobster, which would be represented by a "stepwise" curve as a consequence of the moulting process. Furthermore, the curve does not describe growth during the larval stages. It seems reasonable, however, to assume that the curve begins with the puerulus, which is like a miniature adult, and includes the juvenile and exploited stages of history. If the larval life is further assumed to be about 6 months, crude approximations of the length at absolute age may be obtained by adding six months to the relative age derived from the growth analysis. Lobsters measuring about 47 mm CL would, therefore, be approximately 1.6 years old, and the mean selection age, Tc, should be about 2.8 years.

Estimates of total mortality Z reported in the literature vary from $1.72 \leq Z \leq 2.73$ for K = 0.20, to $2.59 \leq Z \leq 4.09$ for K = 0.30 (The Gulf of Mexico and the South Atlantic Fishery Management Councils, 1982). The values of Z obtained in this study (Z = 2.19 and 2.88 for males and females respectively) are within these ranges.

Although estimates of M are required as input in most fish stock assessment models, good estimates are difficult to obtain. In this study M was assumed to be a constant, and was estimated from the empirical relationship derived by Pauly. The values of M obtained (M = 0.59 and M = 0.67 for males and females respectively) appear to be reasonable when compared to the values reported in the literature. Munro (1983b) used catch curve analysis to estimate M (Z = M in unexploited stocks) for *P. argus* from the unexploited parts of Pedro Bank during the 1969-1973 study and obtained values of M = 0.4 for males and M = 0.6 for females. The Gulf of Mexico and South Atlantic Fishery reported that natural mortality appears to be in the range M = 0.30 to 1.00, and arbitrarily selected M = 0.6 as the best estimate of natural mortality for *P. argus* over the entire length range.

It is generally accepted that lobsters gradually migrate to deeper waters as they grow older. If lobsters migrate from the fishing ground and into deeper waters, e.g. onto the steep forereefs, where they are inaccessible to the trap fishery, such migrations would be incorporated in the value of Z, which would, therefore, be over-estimated. The possibility of such migrations occurring on Pedro Bank seems to be high considering that the area suitable for setting lobsters is limited to about 50 meters, whereas lobsters are reported to occur at depths of over 200 meters (Simmons, 1980). The values of F and E calculated from Z and derived from the catch curves could, therefore, be overestimates.

The selection curves presented in the present study are not true selection ogives but rather resultant curves. That is, they reflect the combined effect of gear selection and recruitment (Sparre, 1986). Small lobsters, therefore, may not occur in the catch, either because they are not present in the fishing group, or because they are small enough to escape from the traps.

The selection analysis, Jones Length Cohort analysis, and Beverton and Holt Yield Per Recruit analysis are based on the assumption that the input is representative of a steady state condition with constant Z and constant recruitment.

The results of Jones length cohort analysis suggest that approximately 1.3 million lobsters in the 55–60 mm CL length class are recruited to the fishery each year at Pedro Bank. The population size is approximately 4.9 million, and approximately 0.56 million were captured by the fishery in 1986. The mean fishing mortality, F, on the length groups under full exploitation (greater than 95 mm CL) are F = 2.11, and F = 1.28 for females and males respectively. These values, particularly for the females, are very high. Furthermore, the mean exploitation rate, E, on the length groups under full exploitation are E = 0.77, and E = 0.59 for females and males respectively. These values are greater than the accepted optimum exploitation rate of 0.5 or less (Pauly, 1984) and suggest that the population on Pedro Bank is over-exploited.

The yield per recruit curve for *P. argus* is flat topped. Accordingly, $F_{0.1}$ is a more appropriate fisheries management reference point than F_{max}, and, therefore, reduces the risk of growth and recruitment overfishing. Reducing the fishing mortality from the present level (F = 1.88) to $F_{0.1}$ (0.56) requires a 2/3 reduction in F. Therefore, serious consideration should be given to reducing fishing effort and increasing mean selection length. It is important to emphasize that rational management and exploitation of Jamaica's lobster stocks has wider regional implications. The major source of recruits for the lobster population at Pedro Bank are not likely to be the product of local spawning stocks. Most of the larvae produced by the local spawning stock are likely to be swept up-current to fisheries such as those along the Florida coast and the Gulf of Mexico. Although year-round recruitment of pueruli occurs at Pedro Bank, most of the recruits are probably from spawning stocks in the Lesser Antilles, with small contributions from the local stocks. A Regional Pan-Caribbean management policy is, therefore, basic to the development of an optimal strategy for efficient management and conservation of *P. argus*.

To summarize, the lobster population at Pedro Bank has changed considerably since Munro's (1983a, 1983b) study and the fishing effort has increased significantly over this period. Thus, the present level of fishing mortality appears to be greater than the optimum required for the fishery. From a biological perspective, fishing mortality should be reduced to the $F_{0.1}$ level to reduce the risk of over-exploitation. Finally, much more research is needed to clarify the uncertainty which exists regarding the source of recruits, the settlement of the puerului, the period of larval life, and refinement of the selection estimates.

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