Management of Juvenile Spiny Lobster (*Panulirus argus*) Based on Estimated Biological Parameters from Grand Bahama Island, Bahamas

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RESUMEN

La administración de pesquerías es una necesidad crítica a través de todo el Caribe, Centro América y América del Sur. La contaminación, el ineficaz uso de los recursos naturales en estas regiones y los abusos en la pesca pasan desapercibidos de los gobiernos y de las personas que no pueden reconocer ni aquilatar las consecuencias en el futuro.

Este trabajo presenta un examen de las investigaciones llevadas a cabo en las activas colonias juveniles de langostas espinosas. Las langostas espinosas juveniles *Panulirus argus* fueron marcadas en las costas sur y norte de Gran Bahama, en las Bahamas, cerca de West End, entre mayo de 1976 y marzo de 1978. Los cálculos se basaron en la abundancia, tasas de crecimiento y mortandad y el reclutamiento, tanto en las etapas juveniles como en la existencia de especies comerciales.

Se ha demostrado la importancia de áreas de cría para la pesquería. También se han analizado el tamaño mínimo y el papel que juegan los puntos de escape en la administración de las pesquerías. Finalmente se someten a la consideración de los representantes de las regiones del Caribe y Centro y Sur América una serie de metas y un plan general de administración.

INTRODUCTION

The spiny lobster, *Panulirus argus* (Latreille), fishery is the most important fishery of the Bahamas. In recent years it has undergone rapid expansion to the present level of 1,181 to 2,268 metric tons (4-5 million pounds) harvested annually. The fishery is beginning to show symptoms of regional overfishing (excessive decline in catch per unit effort) which will require management decisions in the future. To place harvest on a sustained yield basis some insight must be gained into the population dynamics of pre-recruit stages. Such research could aid future management decisions by providing important information on the abundance, population structure and potential for recruitment of juvenile spiny lobsters.

Objectives were to: (1) determine the abundance of juvenile lobsters in the study area, (2) estimate the growth rate of juvenile lobsters, (3) determine mortality rates of juveniles and (4) estimate the number of recruits that become available to the fishery and the season of recruitment.

METHODS

Lobsters were collected by standard lobster traps (Smith, 1958; Cope, 1959), by modified lobster traps, by diving with a hand net and by bully netting (Crawford and De Smidt, 1922). The animals collected by bully nets were recaptured specimens returned by commercial fishermen; tags were returned to the author. Standard traps were modified by placing 5.1 cm (2 in) chicken wire over the trap opening, which then selected for lobsters less than 50 mm carapace length (CL) (Chittleborough,

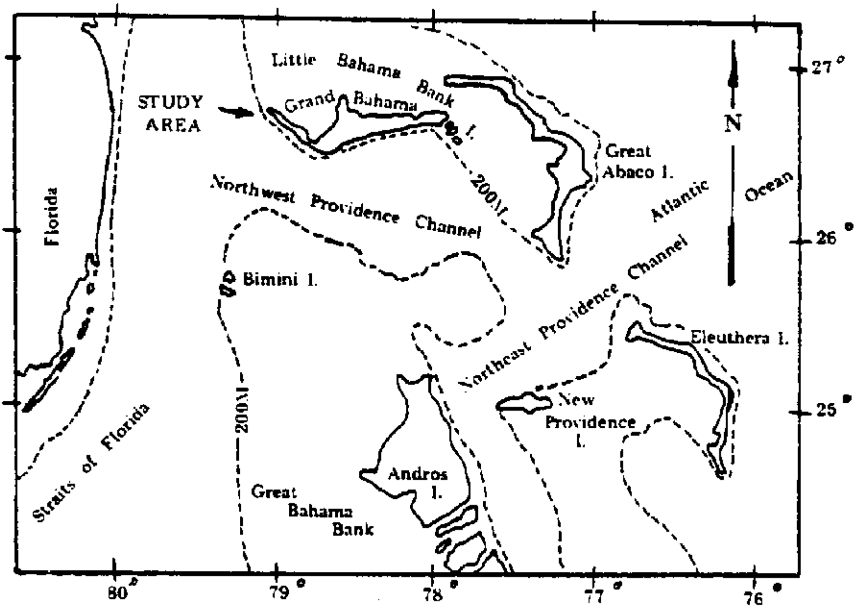

Figure 1. Map of a portion of the Bahama Islands showing the location of the study area.

1974). The slat width was reduced by placing 0.64 cm (1/4 in) plastic mesh over the trap itself. Northern shore collections consisted primarily of animals captured while diving with a hand net. Southern shore collections were almost entirely trap-caught animals.

Carapace length (CL), the distance from the inter-orbital ridge to the posterior edge of the carapace, was measured to the nearest 0.1 mm. Sex, molt condition, location and effort were recorded. Lobsters were tagged with a plastic sphyrion tag manufactured by the Floy Tag Company. The tag was anchored in the flesh between the tail and carapace, slightly off-center to avoid damaging the intestine and slightly into the carapace. Severely injured and dying lobsters were not tagged so as not to bias recapture results.

Juvenile spiny lobsters were tagged on the northern and southern shore of Grand Bahama, Bahama Islands (Fig. 1) near West End between May 1976 and March 1978. Nine hundred and fifty-four lobsters were tagged on the northern shore and 2,252 on the southern shore of Grand Bahama, Bahama Islands. An additional 740 lobsters were captured and examined but not tagged.

Population Size

Population size was estimated using Peterson's (1892) method as modified by Bailey (1951) to the Lincoln Index:

$$N = \frac{M(n+1)}{m+1} \quad \text{and Var } (N) = \frac{M^2 (n+1)(n-m)}{(m+1)^2 (m+2)}$$

where: N = total population, M = total number of tagged lobsters, n = number of lobsters in a subsequent sample, and m = number of tagged lobsters in that sample.

Peacock (1974) noted that the number of free, tagged lobsters was subject to continual change. There is an instantaneous increase at the end of each month because the number of tagged lobsters released in that month is known. There is a decrease due to mortality and migration. These changes in the number of free, tagged lobsters were taken into account when estimating the stock size.

The percent tag retention must be evaluated when studying population dynamics of lobsters. Floy FD-68B tags were lost by *P. argus* at approximately 10% per molt for the first three months after tagging in a south Florida study (Davis, 1978). Using Davis' (1978) tag loss rate and the estimated losses to mortality and migration, the number of free, tagged lobsters in the population was adjusted by assuming a tag loss of 3.8% per month and a decline of 5.1% per month due to mortality and migration (total correction was a 8.9% decrease per month).

Growth Rate

Two aspects of growth were studied: (1) the number of molts per year and (2) the increase in CL per molt.

The number of molts per year was estimated by Munro's (1974) method. Munro (1974) estimated the inter-molt period (IMP) in a tagging study by assuming that at the time of tagging, individuals are randomly distributed throughout their molt cycle and that 50% will therefore have molted when one-half of their IMP has elapsed. When the percentage of recaptured lobsters that molted reaches 50% or more, one-half of the IMP will have elapsed. The IMP is then twice the days free required for one-half of the recaptured lobsters to have molted.

Litchfield and Wilcoxon (1948) presented a method for the solution of dose-effect experiments of the all-or-none type, which was adapted to analyze molting in spiny lobsters. The fact that a lobster in a sample has either molted or not molted led to the adoption of the all-or-none dose effect type analysis. Days free and percent molted corresponded to dose and effect respectively. This method allowed the use of zero and 100% molted data in fitting a regression line relating percent molted to days free by least squares. The method also provided a simple test for goodness of fit of the line together with the estimate of confidence limits.

It was assumed that the growth pattern could be described by the von Bertalanffy growth model. Carapace length at recapture was regressed on CL at tagging for individuals that showed an increase in size. The asymptotic length (L_∞) of *P. argus* in the Bahamas is unreported; therefore, the mean asymptotic length of 190 mm CL used by Munro (1974) for Jamaican lobsters was assumed to be a close approximation for the Bahamas. Regression lines were calculated and drawn through the estimated L_∞ of 190 mm CL and through the means of the lengths at marking and recapture in each case. However, one disadvantage is that variability of the lengths at marking and recapture is lost by averaging their values to obtain one point. The line is then fitted through this averaged point and the L_∞ value of 190 mm. The slopes (k_i) were used to calculate the coefficient of growth by the following formula:

$$k_i = e^{-K_i}$$

where: k_i = slope, K_i = growth coefficient per molt, and e = base of the natural logarithm. The coefficient (K_i) per molt is estimated and then multiplied by the estimated number of molts per year to give the annual coefficient of growth (Munro, 1974).

Mortality Rate

Mortality rates were estimated using the same method used by Munro (1974). The coefficient of mortality, Z, was derived from Beverton and Holt's (1956) formula:

$$Z = \frac{K(L_\infty - \bar{l})}{\bar{l} - l_c}$$

where: K = annual coefficient of growth, l_c = CL when fully recruited, $\bar{l}$ = mean CL of recruited stock and L_∞ = asymptotic length.

One important modification to Munro's (1974) method was made. The L_∞ used to determine K values was 190 mm, the same as used for the growth rate estimation procedure. This is appropriate because K is the rate that describes growth of lobsters from the smallest observed sized to the asymptotic length. However, when calculating Z, the mean carapace lengths in this study were much smaller than in Munro's (1974) study. Therefore, when using Beverton and Holt's (1956) formula, L_∞ values that correspond to carapace lengths of maximum observed sizes were used. These values on the northern shore were 95 mm for males and 90 mm for females. After this modification estimates of Z realistically represent natural mortality occurring in the juvenile and sub-adult population (CL less than 76 mm).

Recruitment

The number of recruits was estimated from a catch curve (Ricker, 1975). This curve was constructed based on the estimated population size and size frequency distribution of the cohort to be recruited. The logarithm of estimated abundance was regressed on size. The number of lobsters available at 86 mm (the minimal legal size in the Bahamas) was an estimate of the number of recruits to the fishery.

RESULTS AND DISCUSSION

The population density on the northern shore (Table 1) ranged from 84/ha in 1976 to 1230/ha during 1977/78, with a mean of 686/ha (σ=575). Southern shore population density (Table 1) was 328/ha in 1976/77 and 766/ha in 1977/78. The mean population density on the southern shore was 547/ha (σ=310), approximately 20% less than the mean northern shore population density. Density estimates of juveniles and adults in the Caribbean varied from 15 - 65 lobsters/ha in lightly fished and un-fished areas of the Virgin Islands and Torgugas (Olsen et al., 1971; Herrnkind et al., 1975; Davis, 1977). Density estimates observed in my study ranged from 84 - 1230 lobsters/ha, higher densities than reported elsewhere in the Caribbean. The seasonal fluctuations in stock size are shown in Figure 2.

The mean of the three methods (Munro, 1974; Litchfield and Wilcoxon, 1948; linear regression) for estimating molting frequency was designated as the best estimate (Table 2). Northern shore IMP's were estimated to be equal to or slightly below the 90 days estimated by Munro (1974) for Jamaican lobsters. The number of molts per year reported for this study agrees well with those reported by Travis (1954). Buesa (1965) found that in Cuba lobsters molted twice per year after 3 years of age or over 200 mm total length. In Barbuda there were no sharply defined molting peaks with 10% ± 5% of lobsters ranging from 50 - 100 mm CL molting in

Table 1. Population density (N) on the northern (area sampled = 25,688m^2) and southern (area sampled = 222,400m^2) shores of Grand Bahama

Date	N	N/m^2	95% CI	N/ha
Northern Shore Population Density				
1976	215	8.4×10^{-3}	$\pm\ 2.0 \times 10^{-3}$	84
1977	1910	74.4×10^{-3}	$\pm 27.8 \times 10^{-3}$	744
1977/78	3161	123.0×10^{-3}	$\pm 67.1 \times 10^{-3}$	1230
Southern Shore Population Density				
1976/77	7291	32.8×10^{-3}	$\pm\ 8.8 \times 10^{-3}$	328
1977/78	17035	76.6×10^{-3}	$\pm 39.9 \times 10^{-3}$	766

any given month (Peacock, 1974). There were no major differences in molting frequency between the sexes. The highest peaks of molting frequency occurred during spring and summer when water temperature is warmest, resulting in rapid growth.

Northern shore lobsters molt 4.1 - 5.1 times per year (Table 2). The annual growth coefficient of males was 0.1386 - 0.2560 and for females 0.0935 - 0.2219 (Table 3). Southern shore lobsters molt 2.4 - 2.8 times per year (Table 2), with an annual growth coefficient for males of 0.0842 - 0.1240 and 0.0308 - 0.0795 for females (Table 3). The smaller coefficients for southern shore lobsters were related to the larger size of lobsters found there and their slower growth rates. Munro (1974) estimated K = 0.2146 by combining data from Florida and Belize for lobsters with a CL between 50 and 120 mm. Northern shore males and females grew slightly slower than those studied by Munro (1974), while southern shore males grew approximately half as fast. Southern shore females grew at approximately 25% of Munro's (1974) estimated rate. Munro (1974) estimated that all lobsters in his study molted 4 times per year, whereas in this study the northern shore lobsters molted 4.1 times per year and southern shore lobsters molted only 2.6 times per year. The difference in molt frequency caused the annual growth coefficient estimated for southern shore lobsters to be lower than Munro's (1974) estimate. Olsen et al. (1971) reported growth coefficients for lobsters in the Virgin Islands of K = 0.432 for males and females (males K = 0.436 and females K = 0.319) which is a faster growth rate than that reported by Munro (1974) and that for my northern and southern shore lobsters. The CL range for the estimate of Olsen et al. (1971) was 37 - 178 mm, with a preponderance of juvenile and pre-recruits (CL less than or equal to 80 mm) which presumably had relatively fast growth rates.

Injuries significantly reduced growth rate. On the northern shore non-injured males grew 51% more rapidly than injured males and non-injured females grew 13% more rapidly than injured females. Southern shore lobsters had a similar depression of growth rate due to injuries. Non-injured males on the southern shore grew 28% more rapidly and non-injured females 25% more slowly than injured lobsters. Davis

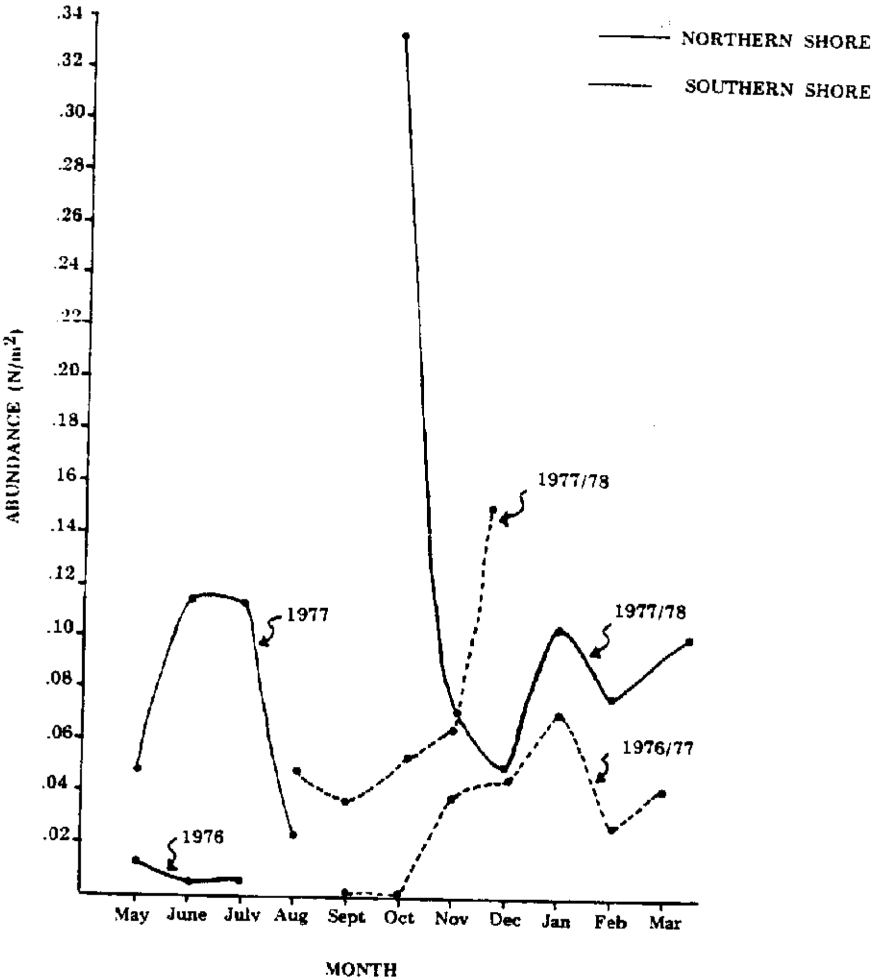

Figure 2. Fluctuations in stock size with season and years.

(1979) and Davis and Dodrill (1980) reported a similar depression of growth rate by injuries.

The size of individual lobsters also affects growth rate. Smaller individuals molt more frequently and should have more rapid growth rates. Non-injured male pre-recruits ($50 \geq CL < 76$ mm) on the northern shore grew 49% more rapidly than non-injured male juveniles ($CL < 50$ mm), while female pre-recruits grew 47% more rapidly. On the southern shore, large non-injured pre-recruits grew 195% more rapidly than small non-injured pre-recruits recaptured within 90 days of release and 88% more rapidly when all recaptures were included.

Table 2. Summary of molt frequency results obtained by three different methods with the mean representing the best estimate (The results from Travis (1954) are presented for comparative purposes)

Northern Shore	Munro's (1974) Method	Litchfield and Wilcoxon's (1948) Method	Simple Linear Regression	Mean of Three Methods	Travis' (1954) Theoretical	Travis' (1954) Observed
CL < 50mm	4.1	4.8	3.4	4.1	5	-
50 ⩽ CL < 76mm	4.1	5.4	5.9	5.1	3-5	3-5
Southern Shore						
50 ⩽ CL < 76mm	2.8	2.8	2.4	2.7	3-5	3-5
76 ⩽ CL < 86mm	2.4	2.9	3.1	2.8	3-4	3-5
CL > 86mm	2.4	1.5	2.9	2.3	3-4	3-4

Juvenile lobsters remain on the nursery grounds, and the mortality coefficients for that size class accurately reflect natural mortality (Table 3). The coefficients were Z = 0.1983 (18.0%) and 0.2658 (23.3%) for males and females respectively. Inclusion of animals ⩾ 50 mm CL from my northern shore population would introduce a potential over-estimating bias for the natural mortality coefficient because there is emigration by lobsters ⩾ 50 mm CL from the mangrove nursery area into the reef area.

The mortality coefficients for pre-recruit, northern shore lobsters with 50 ⩾ CL < 76 mm were 0.2040 (18.5%) and 0.5704 (43.5%) for males and females respectively. These mortality coefficients include natural mortality and emigration from the nursery ground to the reef area. Assuming that mortality is constant between the two size classes, if the natural mortality estimate for CL < 50 mm is subtracted from the mortality estimates of the 50 ⩾ CL < 76 mm size class the result is an estimate of the annual "emigration" coefficient which was 0.0057 for males and 0.3046 for females. This indicates that females make up a larger percentage of the migrating population in the 50 ⩾ CL < 76 mm size class.

Mortality coefficients for the exploited southern shore include components due to natural mortality, fishing mortality and emigration. Pre-recruit lobsters with 50 ⩾ CL < 76 mm had a mortality coefficient of Z = 0.3231 (27.6%) for males and Z = 0.5242 (40.8%) for females, not too different from coefficients obtained for northern shore lobsters in this size class. Those pre-recruits with 76 ⩾ CL < 86 mm had a mortality coefficient of Z = 1.1500 (68.3%) for males and Z = 1.9455 (85.7%) for females. Mortality estimates for size class 50 ⩾ CL < 76 mm possibly were underestimated due to the low annual growth coefficient estimated from the Walford plots. The instantaneous mortality was higher for females in both size classes.

The estimates reported for northern shore lobsters lie below the range of Z = 0.413

Table 3. Summary of estimated biological parameters of populations of *Panulirus argus* captured on northern and southern shores of Grand Bahama. The estimates are presented in four size classes for the northern shore and southern shore (l_c = CL of first size class fully recruited; $\bar{l}$ = mean CL of the recruited stock)

		Northern Shore			Southern Shore		
		CL < 50 mm	both size classes	50 ≤ CL < 76 mm	50 ≤ CL < 76 mm	both size classes	76 ≤ CL < 86 mm
K		0.1275		0.2356	0.0327		0.1000
K	both size classes		0.1816			0.0664	
l_c	M	37.5mm		57.5mm	72.5mm		77.5mm
l_c	M both size classes		47.5mm			77.5mm	
l_c	F	42.5mm		57.5mm	72.5mm		77.5mm
l_c	F both size classes		42.5mm			72.5mm	
$\bar{l}$	M	60.0mm		77.6mm	83.3mm		86.5mm
$\bar{l}$	M both size classes		66.9mm			86.5mm	
$\bar{l}$	F	57.9mm		67.0mm	79.4mm		83.0mm
$\bar{l}$	F both size classes		57.9mm			79.4mm	
L_∞	M		95.0mm			190.0mm	
L_∞	F		90.0mm			190.0mm	
Z*	M	0.1983		0.2040	0.3231		1.1500
Z	M both size classes		0.2630			0.7636	
Z	F	0.2658		0.5704	0.5242		1.9455
Z	F both size classes		0.3785			1.0643	
A†	M	0.1799		0.1845	0.2761		0.6834
A	M both size classes		0.2313			0.5340	
A	F	0.2334		0.4347	0.4080		0.8571
A	F both size classes		0.3151			0.6550	

*$Z = K(L_\infty - \bar{l}) / (\bar{l} - l_c)$ = Instantaneous mortality

†$A = 1 - e^{-Z}$ = Annual Mortality Rate

to 1.77 reported for the Caribbean (Buesa, 1965; Olsen et al., 1971; Munro, 1974), except for females with $50 \geq CL < 76$ mm. Estimates for southern shore lobsters lie within the Caribbean range, except for males with $50 \geq CL < 76$ mm and females with $76 \geq CL < 86$ mm, which lie slightly below and slightly above the Caribbean range respectively. However, the difference was not great and might be due to a short-term fluctuation in the population abundance rather than a characteristic mortality rate. The range of mortality coefficients reported from Australia (Chittleborough, 1970; Chittleborough and Phillips, 1975) for *P. cygnus* ($CL < 40$ mm) was 0.066 - 1.095 which is slightly lower than values reported from the Caribbean.

Northern shore lobsters were considered to be sub-adults when a CL of 76 mm was attained. Animals with $CL < 76$ mm were fully recruited (that is, they are fully represented by the length-frequencies) at 47.5 mm and 66.9 mm for males and females respectively. According to the definition of Chittleborough and Phillips (1975) recruitment for a particular year class depends on: (1) initial density, that is, the density of larval settlement; (2) the strength of pre-existing year-classes in the nursery area; (3) fluctuations in the density of their prey; and (4) fluctuation in the density of their predators.

There was an influx of lobsters ranging from 20 - 35 mm CL into the nursery area during March-April (1977) (Fig. 3). This group represents recruitment into the juvenile stage by lobsters that have recently settled out of the larval stage. These lobsters grow during the approximately 5 months they remain in the nursery area and subsequently are recruited to the sub-adult stage at 76 mm CL during July and August. There also was an influx of lobsters ranging from 20 - 35 mm CL during November - December (1977) and January - February (1978). The size of these influxes was less than that in March - April (1977) but indicated that some recruitment also takes place during the winter months.

Recruitment of lobsters with $CL < 76$ mm on the northern shore was very low in 1976 (5/ha) and probably does not accurately reflect true recruitment (Table 4). In 1977 recruitment was 546 lobsters/ha and increased to 596 lobsters/ha in 1977/78. The scientific literature on recruitment in *P. argus* is very scarce and there are few reported estimates for the genus *Panulirus*. In Australia (*P. cygnus*) Chittleborough (1970) observed a mean density of recruits of 1298 lobsters/ha ($\sigma = 1546.9$) from 1965 - 69. However, during 1969 Chittleborough (1970) noted an initial density of only 88 recruits/ha on one Australian reef.

On the southern shore lobsters were recruited into the exploited stock ($CL \geq 86$ mm). Recruitment varied from 45 lobsters/ha in 1976/77 to 209 lobsters/ha in 1977/78 (Table 4). Some tag returns indicated that lobsters were recruited from the northern shore nursery grounds after migrating around the end of Grand Bahama Island (Fig. 1). Most recruitment occurred during July - December (Fig. 4). Tag returns showed a movement from the nursery area towards the tip of the island. On the southern shore lobsters moved in a west to east direction. Lobsters become fully recruited to the southern shore offshore trap fishery at 77.5 mm and 72.5 mm for males and females respectively. Aiken (1977) reported full recruitment of Jamaican lobsters at 80 - 89 mm CL for the Port Royal fishery, 70 mm CL for the Old Harbor Bay fishery and 80 - 89 mm CL for males and 70 - 79 mm CL for females in the Rocky Point fishery. Buesa (1965) reported peak recruitment in Cuba between December

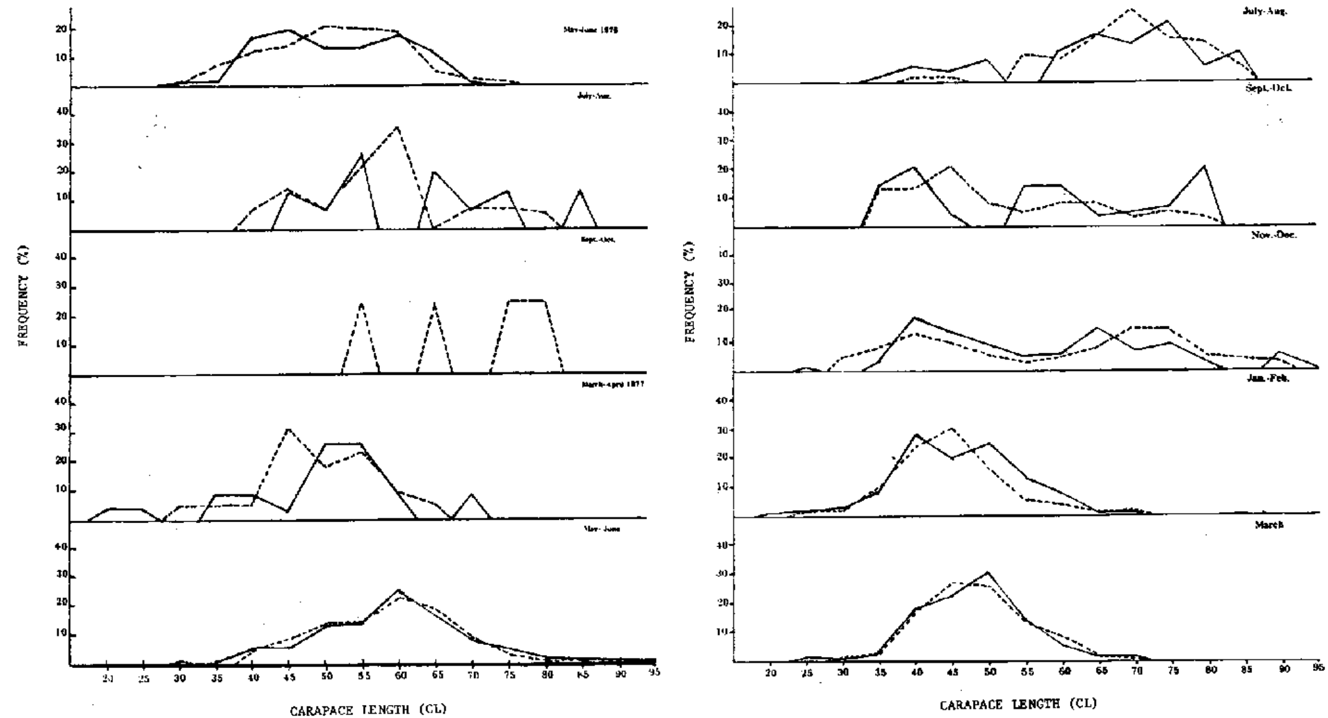

Figure 3. Length frequency distribution (%) for northern shore lobsters (males ______; females ______). The numbers of specimens collected for the periods shown above were: May-June 1976, male 85, female 101; July-August 1976, male 15, female 16; Sept.-Oct. 1976, male 0, female 4; March-April 1977, male 23, female 22; May-June 1977, male 241, female 217; July-Aug. 1977, male 53, female 49; Sept.-Oct. 1977, male 29, female 38; Nov.-Dec. 1977, male 54, female 78; Jan.-Feb. 1978, male 113, female 90; March 1978, male 132, female 106.

Table 4. Recruitment on the northern and southern shores of Grand Bahama. The number of recruits during the sampling period was multiplied to yield an estimation of annual recruitment. The catch curve equation was used to estimate recruitment

Date	Number Recruits (95% CI)	Number Recruits (corrected to 12 months)	Number Per m^2	Recruits per ha	Regression Equation
Northern Shore Recruitment (area sampled = 25,688m^2) (CL = 76mm)					
1976	5.5 ± 2.4 (3 mo)	22.0	0.9×10^{-3}	9	$\hat{Y} = 3.2309 - .0328X$
1977	48.8 ± 2.4 (4 mo)	146.4	5.7×10^{-3}	57	$\hat{Y} = 4.1809 - .0328X$
1977/78	80.9 ± 2.4 (6 mo)	161.8	6.3×10^{-3}	63	$\hat{Y} = 4.3933 - .0327X$
Southern Shore Recruitment (area sampled = 222,400m^2) (CL = 86mm)					
1976/77	731.1 ± 1.9 (7 mo)	1253.3	5.6×10^{-3}	56	$\hat{Y} = 7.25 - .051X$
1977/78	1714.0 ± 1.9 (5 mo)	4113.6	18.5×10^{-3}	185	$\hat{Y} = 7.62 - .051X$

and February while Olsen et al. (1971) noted a peak in recruitment of lobsters of 80 mm CL during the fall and spring for Puerto Rico. Recruitment in the Antigua and Barbuda fishery peaked during the autumn and winter with an influx of maturing lobsters (CL 80 - 89 mm, 2 - 2.5 years old) (Peacock, 1974).

The decrease in density of juvenile *P. cygnus* by movement from shallow water to the fishing grounds in Australia coincides with a sharp increase in catch rate by the fishery at the beginning of December for fishermen operating just outside the coastal reefs (Chittleborough, 1970). This indicated a pulse of recruitment into the commercial fishery during the austral summer. A similar occurrence in the Bahamas, during the fall, was reported by Waugh and Waugh (1977) for my study area where catch per trap day increased from 0.1507 pounds in September 1976 to 0.5590 pounds whole lobster in October 1976, an increase of 271%. The increase was due to recruitment of lobsters into the fishable stock. Peacock (1974) also reported a recruitment of lobsters in the 70 - 90 mm CL range into the Barbuda offshore bank fishery during September to February.

FISHERY MANAGEMENT

There is an acute need for fisheries development and management throughout the Caribbean, Central and South America. Overfishing, pollution and inefficient use of natural resources in these regions often occur without the people or government being able to recognize and fully appreciate the consequences.

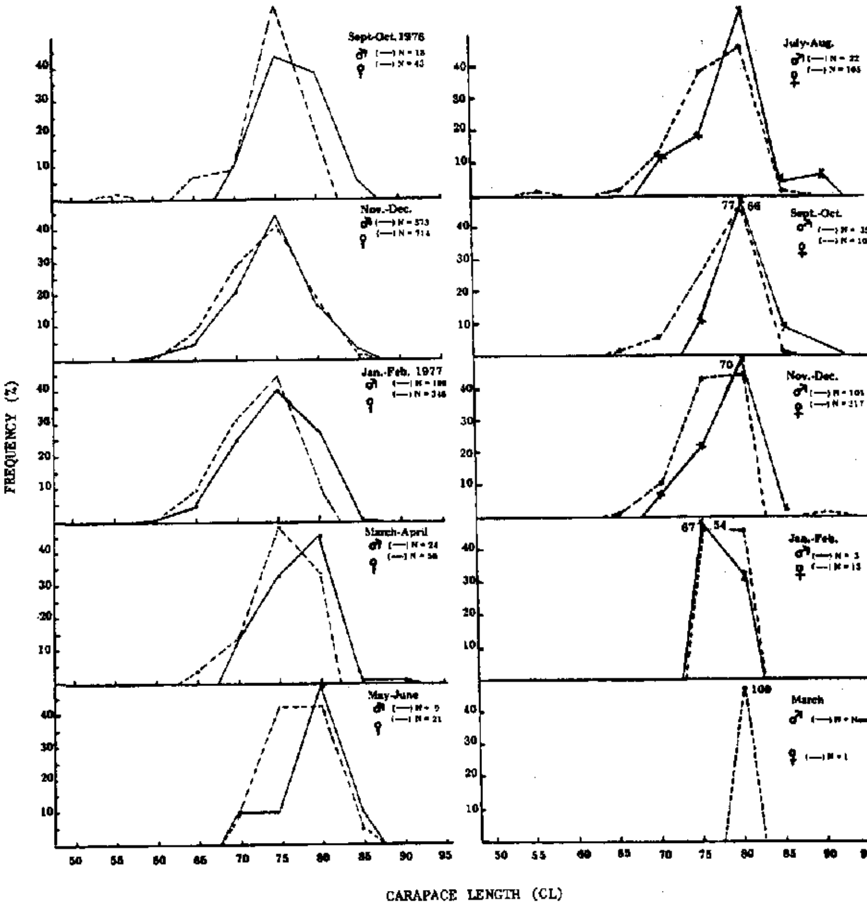

Figure 4. Length frequency (%) distribution for southern shore lobsters (males ______; females _ _ _ _ _ _).

Fisheries management in the Third World has traditionally been formulated by groups unfamiliar with the socio-economic and cultural aspects of the peoples involved. The results are often regulations and development suited to the needs of larger, more industrialized countries and not the specific needs of the country in question.

Background fisheries science is discussed by Lackey (1974). A general review of the evolution of fisheries management philosophy (Nielsen, 1976), fishery management (Herrington and Nesbit, 1943) and optimum sustainable yield (Roedel, 1975) set the stage for the economic aspects of fishery management (Sokoloski, 1973) and extended fisheries jurisdiction (Anderson, 1977) that confront a country attempting to manage its fisheries resources. Prochaska and Baarda (1975) outline Florida's management programs dealing with fisheries.

The working party on lobster resources in the Western Central Atlantic (Anon, 1978), two conferences held in Florida (Seaman and Aska, 1974; Seaman and Jones, 1975) and a "White Paper" on the Florida spiny lobster fishery (Beardsley et al., 1975) outline the need for and types of research necessary for proper management.

A working party on stock assessment of lobster resources in the Western Central Atlantic (Anon, 1978) noted that ". . . few biological and ecological details necessary for the rational management of this resource are available . . . available data on the biology of these species were, in most cases, not derived from detailed studies and are generally superficial . . . a fundamental aspect of lobster biology is the question of whether larvae spawned in a given area remain there or whether these larvae are transported to other areas in the region by prevailing ocean currents and therefore form the recruitment population for those areas."

The minimum data required for management were determined to be (Anon, 1978): (1) quantities caught, (2) species composition of catches and (3) fishing effort. Further, fishing effort should be standardized for the following gear: (1) Traps: The measure of effort is catch per day soaked which requires information on number of traps, soak time (days), size of trap (m^3) and duration of fishing trip. (2) Nets, spears and hand capture: The measure of effort is catch per day and requires knowledge of the number of men, number of units of gear and length of trip. (3) Size and type of vessel: In the case of mother ships, both the number of mother ships and smaller boats is required to measure effort.

Untreated sewage, dredging and turbidity associated with sewage outfall construction have a detrimental effect on lobsters (Craig, 1974) and on the water quality of areas suitable for tourist participation. It must be remembered that tourism is often the most valuable segment of a country's economy. Rational management of the lobster resource will enhance the tourist trade.

Before making specific management recommendations, the rationale for these actions must be fully developed. The greatest danger facing the more developed spiny lobster fisheries is recruitment overfishing. It is traditionally held that relatively long lived, fecund animals (of which lobsters are one) do not have a strong stock: recruitment relationship. That is, the number of larval lobsters settling out is not dependent on the number of berried females. However, this is not the case with the spiny lobster. Morgan (1980) measured the abundance of the spawning stock in *P. cygnus* from commercial catch records and related it to the settlement of puerulus larvae about 9 months later as estimated by Chittleborough and Phillips (1975). The resulting stock: recruitment relationship (Morgan, 1980) is shown in Figure 5. While it is generally understood that density dependent factors acting on juveniles result in the fluctuating recruitment to the fishable stock, if the number of berried females is sufficiently reduced the potential for recruitment overfishing exists. Morgan (1980) points out that an increase in the spawning stock would provide added protection against a large reduction in the number of settling pueruli.

Reproductive potential by size class also affects recruitment. Kanciruk and Herrnkind (1976) estimated a size class-index of reproductive potential relationship (Fig. 6). Their results show that the present Florida minimum size of 76 mm (3.0 in) CL does not adequately protect the spawning stock. Indeed, this may further support the belief that the majority of Florida recruitment originates from lobsters in the Caribbean area. The Bahamian minimum size of 86 mm (3.4 in) CL allows a

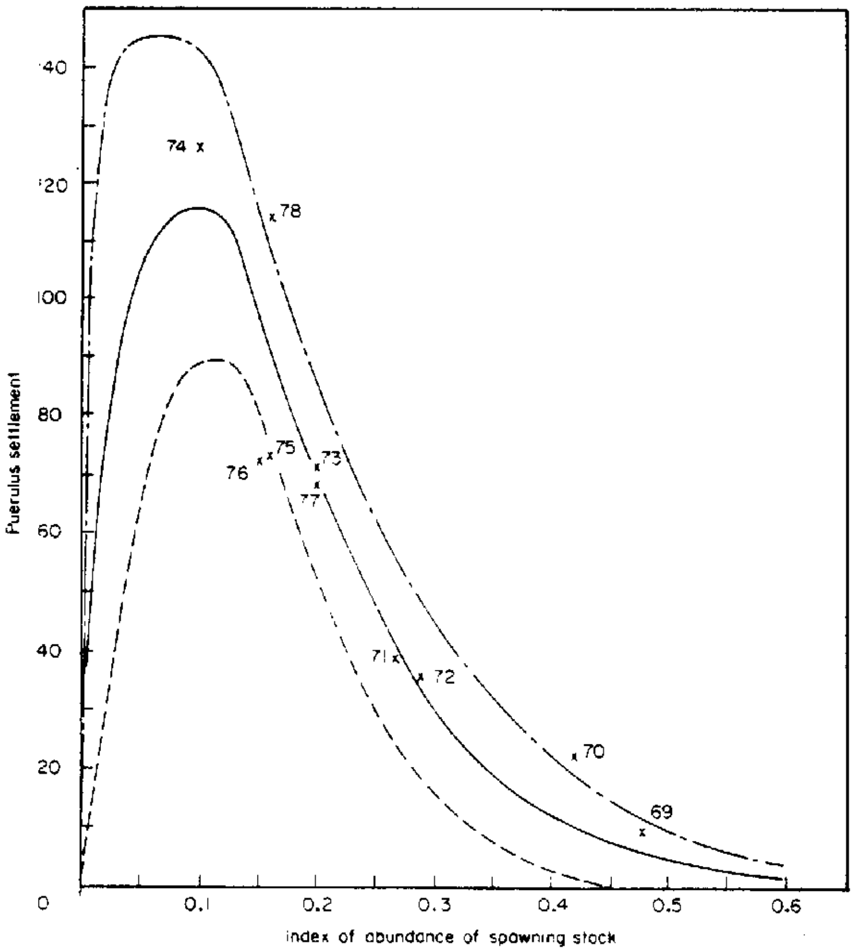

Figure 5. The relationship between the abundance of the spawning stock of *Panulirus cygnus* and the subsequent settlement of puerulus larvae for the years 1969-78, together with the 95% confidence limits (Source: Morgan, 1980).

significant portion of the spawning stock to reproduce and seems to ensure that recruitment overfishing would not occur.

The importance of nursery areas to the lobster fishery has been demonstrated (Bowen, 1971; Peacock, 1974, 1976; Davis, 1979; Waugh, 1980). Juvenile lobsters grow rapidly in the nursery areas with low mortality rates and subsequently are recruited to the commercial fishery. Injuries to juveniles in a south Florida nursery area resulted in a 39% reduction in growth rate (Davis, 1979). In south Florida it is customary to use sublegal size lobsters as attractants in the inshore fishing areas. Lyons (personal communication) found that holding and transporting sublegal size lobsters resulted in a significant mortality rate. As Davis (1979) points out lobster

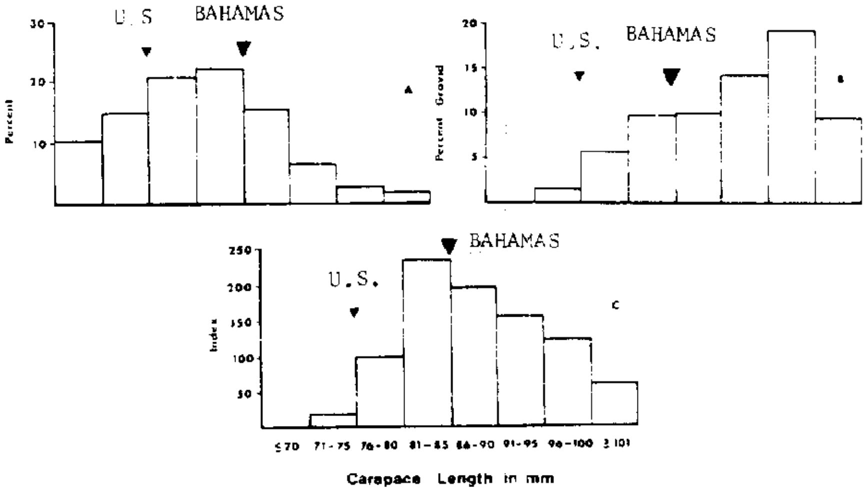

Figure 6. A. size-frequency of all females. Arrows indicate minimum legal size. B. Percent of all gravid females vs. size class. Note larger females were more frequently observed to carry eggs. C. Index of reproductive potential vs. carapace length. The bulk of egg production is generated by large females in the population even though they make up a small proportion of total females (Source: Kanciruk and Herrnkind, 1976).

sanctuaries would eliminate fishing related alterations of the sublegal lobster population density and age structure; it would also reduce fishery induced mortality and reductions in growth rate, thereby increasing the yield per recruit from the nursery areas. It would be difficult to justify establishing nursery areas for lobsters in countries where they are caught incidentally to fish, or caught on a small scale. However, large catches of reef fish can conflict with tourism in near shore areas (Peacock, 1976). He recommends establishing marine parks or reserves as areas that retain their natural diversity such as entire reefs preferably of 2 square miles or more. This rationale benefits the tourist trade and also protects the important lobster nursery areas.

Thus far we have discussed establishing marine parks to protect the near shore nursery areas, which results in the near shore fishery redirecting effort to the outer reef and offshore areas. Here also the juvenile population must be protected against growth-inhibiting injuries and resulting mortality. Lyons (personal communication) found that lobsters escape from traditional south Florida lobster traps at rates of only 5.6 to 8.4% per week. These traps also effectively retain lobsters larger than 55 mm CL (Austin et al., In press).

There are two devices available which can reduce handling and subsequent injuries of sublegal lobsters: escape gaps (Bowen, 1971; Anon, 1973; Stasko, 1975; Morgan, 1980) and grid sorters (Anon, 1972; Anon, 1977; Foster and Weidner, 1977). Experiments with lobsters ranging in CL from 57 to 110 mm showed that an escape gap of 52 mm retained only 31.4% of shorts and allowed only 1.2% of the legal catch to pass through (Anon, 1973). Therefore, the 52 mm escape gap saved approximately 69% of the sorting by hand. The Western Australia escape gap of 54 mm retains at a larger size underwater as opposed to out of the water (Anon, 1973). Grid sorters consist of a 3- by 5-foot grid with steel bars spaced 50 mm (2 in) apart with a chute below the sorter through the gunwale and overboard (Anon, 1972). Traps are unloaded onto the grid sorter and the shorts fall through into the water while the legal lobsters are retained. Grid sorters have been required on all South Africa rock lobster boats since 1973 (Anon, 1977). In an experiment, seven traps with escape gaps caught 545 lobsters; bags over the escape gaps showed that 128 shorts (22.8%) escaped through the gap while 238(43.6%) escaped through the grid (Anon, 1972). Further, of those retained by the grid sorter, only 15(2.7%) were shorts; therefore, of the total catch, 164(30.9%) were legal size lobsters (Anon, 1972).

In highly exploited lobster fisheries, escape gaps and grid sorters could be used to reduce the amount of handling and injuries and resultant decrease in growth rate and yield per recruit. However, in fisheries where lobsters are essentially a by-catch, these devices would be an unnecessary burden to fishermen. In south Florida short lobsters are used as attractants by a portion of the inshore fishery. Once an effective alternative bait has been developed, escape gaps and grid sorters could be highly effective in reducing the numbers of shorts handled by the fishery.

MANAGEMENT PLAN

These recommendations are made with the majority of lobster fishing countries in mind. They will not be appropriate for the more fully utilized or more developed fisheries.

The single most important aspect of management, given the lack of adequate funding that is inherent in this area, is data collection. Information on (1) quantities caught, (2) species composition of catches, (3) fishing effort and (4) length frequency relationship can and must be collected even by the smallest country. With this information, rational management decisions can be made in the future.

Spiny lobsters are a renewable resource and as such must be allowed to reproduce. There is doubt expressed in the literature as to whether a 76 mm CL minimum size (Florida and Australia) allows sufficient reproduction to replenish the stocks. Perhaps a safer minimum size would be 86 mm CL (Bahamas). If after establishing a data collection network a particular country has more manpower and funding available, research to determine the most appropriate minimum size deserves the highest priority. This along with determining the origin of recruitment (local versus pan-Caribbean) will ensure a continual larval supply to the fishery and prevent recruitment overfishing.

Management at this stage consists of continual data collection, determination of larval origin and ensuring that sufficient reproduction occurs. Closing inshore areas as marine parks where large concentrations of juvenile lobsters are found could be used to protect lobsters and at the same time provide a natural area suitable for observation and education by both the local population and tourists.

Finally additional research, preferably on a pan-Caribbean scale to reduce duplication of effort and coordinate and efficiently utilize the limited financial resources available throughout the area, should be undertaken. The magnitude and seasonality of larval and post-larval recruitment must be estimated; the relationship between larval and post-larval populations and their subsequent recruitment into the juvenile and adult stages must be understood; and finally, growth and mortality estimates as well as abundance estimates must be made for all developmental stages of spiny lobsters. With a complete understanding of all stages of the lobster's life cycle, the fishery can be managed effectively to ensure that it will be a prosperous industry in the future.

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LITERATURE CITED

Aiken, K.A.
1977. Jamaica spiny lobster investigations. Pages 11-22 *in* Symposium on progress in the Caribbean and adjacent regions. Caracas 1976. FAO Fish. Rep. No. 200. 547 pp.

Anderson, L.G. (ed.).
1977. Economic impacts of extended fisheries jurisdiction. Ann Arbor Science Pub. Inc. 428 pp.

Anon.
1972. Grid sorters aid conservation of rock lobster. Aust. Fish. 31(5): 8-9.

——— 1973. Effectiveness of rock lobster grid sorters. Aust. Fish. 32(9): 6.

——— 1977. Deck grid rock lobster sorters more efficient. Aust. Fish. 36(8): 29.

——— 1978. Western Central Atlantic Fishery Commission. Working party on assessment of fish resources and working party on stock assessment of shrimp and lobster resources. Cartagena, Colombia, 18-23 November 1977. Report of the joint meeting. FAO Fish. Rep. 211: 103 pp.

Austin, C.B., G.T. Waugh and S.K. Chan.
In press. Estimation of unrecorded spiny lobster, *Panulirus argus,* catch from recorded landings. Fish. Bull.

Bailey, N.T.J.
1951. On estimating the size of mobile populations from recapture data. Biometrika 38: 293-306.

Beardsley, G.L., T.J. Costello, G.E. Davis, A.C. Jones and D.C. Simmons.
1975. The Florida spiny lobster — A white paper. Florida Sci. 38: 144-149.

Beverton, R.J.H. and S.J. Holt.
1956. A review of methods for estimating mortality rates in exploited fish populations, with special reference to source of bias in catch sampling. Rapp. P.-V. Reun. Cons. Perm. Int. Explor. Mer 140(I): 67-83.

Bowen, B.K.
1971. Management of the western rock lobster (*Panulirus longipes cygnus* George). Proc. Indo-Pac. Fish. Coun. 14(II): 139-153.

Buesa, R.J.
1965. Biology and fishing of spiny lobster *Panulirus argus* (Latreille). *In:* Soviet-Cuban fishery research (A.S. Bogdanov, ed.). Translated from Russian by Israel program for scientific translations, Jerusalem 1969 (TT 69-59016): 62-77.

Chittleborough, R.G.

1970. Studies on recruitment in the Western Australian rock lobster, *Panulirus longipes cygnus* George: Density and natural mortality of juveniles. Aust. J. Mar. Freshw. Res. 21: 131-148.

____

1974. Home range, homing and dominance in juvenile western rock lobsters. Aust. J. Mar. Freshw. Res. 25: 227-234.

__________ and B.F. Phillips.

1975. Fluctuations in year class strength and recruitment in the western rock lobster. Aust. J. Mar. Freshw. Res. 26: 317-328.

Cope, C.E.

1959. Spiny lobster gear and fishing methods. U.S. Fish. Wildl. Serv. Fish. Leafl. 487: 1-17.

Craig, A.K.

1974. New developments in the spiny lobster fishery of southeastern Florida. Proc. Gulf and Carib. Fish. Inst. 26: 131-143.

Crawford, D.R. and W.J.J. DeSmidt.

1922. The spiny lobster, *Panulirus argus,* of southern Florida: It's natural history and utilization. Bull. U.S. Bur. Fish. 38: 281-310.

Davis, G.E.

1977. Effects of recreational harvest on a spiny lobster, *Panulirus argus,* population. Bull. Mar. Sci. 27: 233-236.

____

1978. Field evaluation of a tag for juvenile spiny lobster, *Panulirus argus*. Trans. Amer. Fish. Soc. 107: 100-103.

____

1979. Management recommendations for juvenile spiny lobsters, *Panulirus argus* in Biscayne National Monument, Florida. So. Fla. Res. Center Report M-530, U.S. National Park Service. 32 pp.

__________ and J.W. Dodrill.

1980. Marine parks and sanctuaries for spiny lobster fisheries management. Proc. Gulf and Carib. Fish. Inst. 32: 194-207.

Foster, S.D. and D.M. Weidner.

1977. The lobster fisheries in the Republic of South Africa and Namibia, 1975-76. NOAA/NMFS Foreign Fish. Leafl. No. 77-5. 21 pp.

Herrington, W.C. and R.A. Nesbit.

1943. Fishery management. U.S. Fish and Wildl. Serv. Spec. Sci. Rep. No. 18. 69 pp.

Herrnkind, W.F., J. Vanderwalker and L. Barr.

1975. Population dynamics, ecology and behavior of spiny lobster, *Panulirus argus,* of St. John, U.S. Virgin Islands: Habitation and pattern of movements. Results of the Tektite program, V. 2. Nat. Hist. Mus. L.A. County Sci. Bull. 20: 31-45.

Kanciruk, P. and W.F. Herrnkind

1976. Autumnal reproduction in *Panulirus argus* at Bimini, Bahamas. Bull. Mar. Sci. 26: 417-432.

Lackey, R.T.

1974. Introductory fisheries science. VPI-SG-74-02. 275 pp.

Litchfield, J.T., Jr. and F. Wilcoxon.

1948. A simplified method of evaluating dose-effect experiments. J. Pharmacol. Exptl. Therap. 96: 99-108.

Morgan, G.R.

1980. Population dynamics and management of the western rock lobster fishery. Marine Policy, January: 52-60.

Munro, J.L.

1974. The biology, ecology, exploitation and management of Caribbean reef fishes. Part V. I. The biology, ecology and bionomics of Caribbean reef fishes: VI. Crustaceans (Spiny lobsters and crabs). Res. Rep. Zool. Dept. Univ. West Indies No. 3: 57 pp.

Nielsen, L.A.

1976. The evolution of fisheries management philosophy. Mar. Fish. Rev. 38(12): 15-23.

Olsen, D.A., W.F. Herrnkind and I.G. Koblick

1971. Ecological study for the development of lobster management techniques. Puerto Rico Int. Undersea Lab. Spec. Rep. (PRINUL) 1: 1-51.

Peacock, N.A.

1974. A study of the spiny lobster fishery of Antigua and Barbuda. Proc. Gulf and Carib. Fish. Inst. 26: 117-130.

____

1976. Lesser Antillean fisheries, their management and development. Manuscript. Ministry of Overseas Development. 19 pp.

Petersen, C.G.J.

1892. Fiskensbiologiske forhold i Holboek Fjord, 1890-91. Beretning fra de Danske Biolgiske Station for 1890(91), 1: 121-183.

Prochaska, F.J. and J.R. Baarda.

1975. Florida's fisheries management programs: Their development, administration and current status. Agric. Exp. Sta., Univ. of Florida, Bull. 768. 64 pp.

Ricker, W.E.

1975. Computation and interpretation of biological statistics of fish population. Bull. Fish. Res. Bd. Can. 191. 382 pp.

Roedel, P.M. (ed.).

1975. Optimum sustainable yield as a concept in fisheries management. Amer. Fish. Soc. Spec. Pub. No. 9. 89 pp.

Seaman, W., Jr. and D.Y. Aska (eds.).

1974. Research and information needs of the Florida spiny lobster fishery. Conf. Proc. March 12, 1974, Miami, Florida. SUSF-SG-74-201. 64 pp.

__________ and A.C. Jones (eds.).

1975. Review of Florida spiny lobster research. Results and recommendations of a colloquium held October 1 and 2, 1974, in Miami, Florida. Fla. S.G., NMFS. 54 pp.

Smith, F.G.W.

1958. The spiny lobster industry of Florida. Fla. Bd. Conserv. Educ. Ser. 11: 36 pp.

Sokoloski, A.A. (ed.).

1973. Ocean fishery management: Discussions and research. NOAA Tech. Rep. NMFS CIRC-373. 173 pp.

Stasko, A.B.

1975. Modified lobster traps for catching crabs and keeping lobsters out. J. Fish. Res. Bd. Can. 32: 2515-2520.

Travis, D.F.

1954. The molting cycle of the spiny lobster, *Panulirus argus* (Latreille). I. Molting and growth in laboratory maintained individuals. Biol. Bull. 107: 433-450.

Waugh, G.T.

1980. Population dynamics of juvenile spiny lobster, *Panulirus argus*, near Grand Bahama Island. M.S. Thesis, Univ. Miami, Coral Gables, Florida. xi + 195 pp.

__________ and H.R.H. Waugh.

1977. An economical method of trap fishing for spiny lobster, *Panulirus argus*, in the Bahamas. Proc. Gulf Carib. Fish. Inst. 29: 160-165.