# Spiny Lobster Fishery of the Saba Bank

FAISAL DILROSUN
*Department of Public Health and Environmental hygiene*
*Environmental Division*
*Santa Rosaweg 122*
*Curaçao*
*Netherlands Antilles*

ABSTRACT

Over the past 12 months a comprehensive assessment has been made of the fish stock of the Saba Bank. The assessment was initiated by the Environmental Department of the Government of the Netherlands Antilles in Curaçao, whereby the condition of the fisheries resources of the Saba Bank was to be determined.

Over the past 12 months the Saba Bank fishermen engaged in two types of fishery: spiny lobster (*Panulirus argus*) fishery, and snapper fishery, with two main target species: silk snapper (*Lutjanus vivanus*) and blackfin snapper (*Lutjanus buccanella*). The main fishery activity on the Saba Bank is the lobster fishery; snappers are only targeted sporadically.

The objective of the fish stock assessment program was to collect fishery dependent data on the different target species of the Saba bank.
Alongside data on catch per unit of effort of the lobster fishery, biological data, such as, length frequency, length weight relationship, sex, number of females carrying eggs, and the number of lobsters in ecdysis, were collected.

During the study it became apparent that a high percentage of lobsters landed were under-sized and a substantial percentage of berried lobsters were landed. Furthermore a considerable number of traps were lost, due to passing by traffic and hurricanes. None of these traps were fitted with a biodegradable panel and the lost traps are extremely damaging to the ecology and consequently the fish stock of the Saba Bank.

As a result of this study, the following regulations are now being strictly enforced:

i) Presence of a biodegradable panel in each trap.
ii) Legal size limits for lobsters.
iii) Prohibition to land berried lobsters.
iv) Prohibition to land lobsters in ecdysis.
v) Prohibition to fish without a licenses in both the Saban territorial waters and the Economic Fishery Zone (EFZ) of the Netherlands Antilles.

Collecting fishery data alongside enforcement of the fishery regulations will enable successful management and will in the end result in sustainable exploitation of the fishery resources of the Saba Bank.

KEY WORDS: Spiny lobster, Saba Bank, stock assessment

BACKGROUND AND JUSTIFICATIONS OF THE RESEARCH

The Saba Bank (Figure 1) is a large, totally submerged shallow, marine area off the island of Saba. The Bank is important as a fishery resource for fishermen from Saba, St. Eustatius and St. Maarten.

Frequent reports of decreasing fish stocks, destructive fishing activities of foreign vessels, anchoring of oil tankers and tank cleaning, has raised concerns about the environmental state of the Bank. Meesters et al. (1996), commissioned by the Environmental Section reviewed the Saba Bank in 1996 in combination with a short study on location. He concluded that the habitat of the Saba Bank is particularly important for several reasons:

i) The significance of the sea-current patterns suggest that the reefs are potentially an important source of fish and shellfish larval disposal to the islands of Saba, St Maarten and to the islands in the eastern Greater Antilles;
ii) The coral reefs of the Saba Bank are relatively remote from intense human impact and may not only provide important scientific information on the status of reefs in relatively unspoiled condition, but are also a reserve of biodiversity for the region;
iii) The reefs of the Saba Bank are potentially a resource for dive-tourism and an essential resource for fishing.

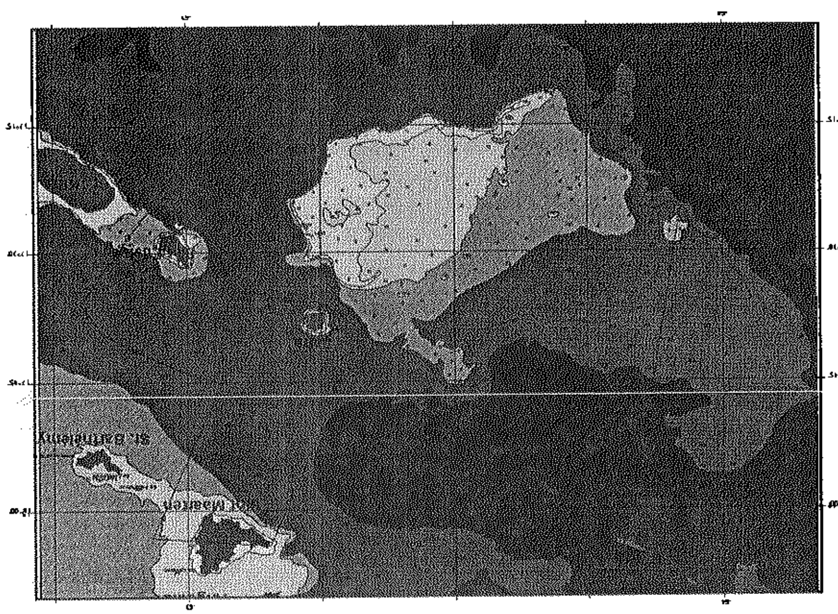

**Figure 1.** Map of the Saba Bank (Scale 1:550,000)

Meesters's study also recommended that a management plan should be developed in order to preserve this unique marine habitat. The National Policy paper "Contours of Environmental & Nature Conservation Policy for the Netherlands Antilles" incorporated this recommendation, and again in the National Nature Policy Plan of 2000 the development of a management plan for the Saba bank is stated as an important objective. As a first step to realize such a management plan, the Environmental Section initiated a comprehensive fishery catch assessment survey in order to get an impression of the fisheries resources of the Saba Bank.

During the time of the assessment (from April 23rd, 1999 to May 30th, 2000) an abundance of fishery dependent data was collected, which will contribute to formulation of an adequate management plan for sustainable exploitation of the fishery resources of the Saba Bank.

## MATERIALS AND METHODS

The Saba Bank Fish fishery monitoring program has collected fishery-dependent data of the Saba Bank fishery from April 23, 1999 to May 30, 2000 commissioned by the Environmental Division of the Department of Public Health and Environmental Hygiene of the Netherlands Antilles, which is located in Curaçao. In an exploited fishery, assessment involves determining the current state of the resource, including the degree of exploitation. Extensive data had to be collected from the Saba Bank fishery in order to estimate population parameters. The monitoring program required several different types of information from the fisheries survey.

Before the program started a schedule was prepared, outlining all activities for the coming period, and establishing the standard way of measuring. Data were collected in the Saba harbor on length-frequency of the catch, collected during daily sampling from the stock, as well as data on total catch and effort. The lobsters (*Panulirus argus*) were measured as consistently and accurately as possible. In Saba harbor the carapace length (CL) of lobsters was measured to the nearest millimeter and 150 male and female lobsters were measured and weighed in order to obtain a reliable length-weight relationship. A kitchen-scale was used for this purpose. The length of the carapace of the lobsters was measured with a caliper.

During sampling, data were collected to obtain specific biological parameters useful in either estimating yield, or providing a basis for fisheries management strategies. In addition to the catch and effort data of the lobster fishery, biological data, such as, length frequency, length-weight relationship, sex, number of females carrying eggs, and the number of molting lobsters (lobsters in ecdysis) were collected.

Catch and effort data were collected on a daily basis in Saba harbor, including also the fishing grounds and species composition of the catch.

The data were entered on a data form, and later entered into Microsoft Excel, and/or MS-Access. Catch and effort data of landings on Saba and St. Maarten were stored in a central database (MS-Access) located in Saba, while length-frequency data were stored in MS-Excel files. The required information included date, boat name, fishing hours, number of gear hauled, soak time, weight of catch and by-catch. Furthermore the monitoring program included a frame survey. The frame survey was conducted to detect the landing practices and to count the number of boats, the number of gear types, and the number of fishermen. The fishermen were interviewed in order to obtain this information.

An important part of the monitoring program consisted of giving feedback to all parties involved. At regular intervals the preliminary results and progress of the program were presented, which resulted in an excellent participation of the fishermen in the monitoring program. The collected fishery dependent data are now available at the Department of Public Health and Environment in Curaçao.

## RESULTS

### Catch and Effort Data

During the project a lobster catch of 89,235 kilograms was recorded. Although this is the great majority of the catch, not all lobsters caught were recorded. In order to obtain the approximate total lobster catch a raising factor is used to correct the recorded catch. An estimated 11.5 % of the lobster catch was not included in the records. This percentage is based on the number of days no data was collected. Total catch then comes to about 100 tons.

(Figure 2) displays the total lobster catch and effort distributed over the time of the project. The lobster catch and effort over the year fluctuates considerably (Figure 2). The hurricane season (from July till December) had a great impact on the lobster catch and effort. Lobster catch and sale were fairly good from May, 1999 till August, 1999. September is considered the month most hurricanes occur, and consequently tourism decreases during this month. September, October and November are considered low season months for tourism and as a result there is only limited sale for lobsters. On October 20, 1999 hurricane José passed over the Windward islands, followed by hurricane Lenny on November 18-19. These hurricanes had a negative influence on the lobster catch and fishing effort, since most fishermen took their boats out of the water before the hurricanes, and lost a considerable number of gear. Although the fishermen suffered great losses i.e. gear, boats, etc., the lobster catch increased substantially within two months after the hurricane season, in an attempt to meet the demand for lobsters, since the months of December to May are considered high season months for tourism.

### Biological Data

*Size* —The carapace length (i.e. the distance from the base of the supraorbital horns to the posterior edge of the carapace) is the usual measure of body length in spiny lobster. The fishery law of the Netherlands Antilles forbids catching of lobsters with a carapace length smaller than 9.5 cm. This carapace length is approximately equivalent to a total body length of 25 cm, and a weight of 680 gram. This minimum length originated from the Harmonized Fisheries Legislation Project, guided by the FAO, which had the objective to match the fisheries legislations of the islands of the Lesser Antilles.

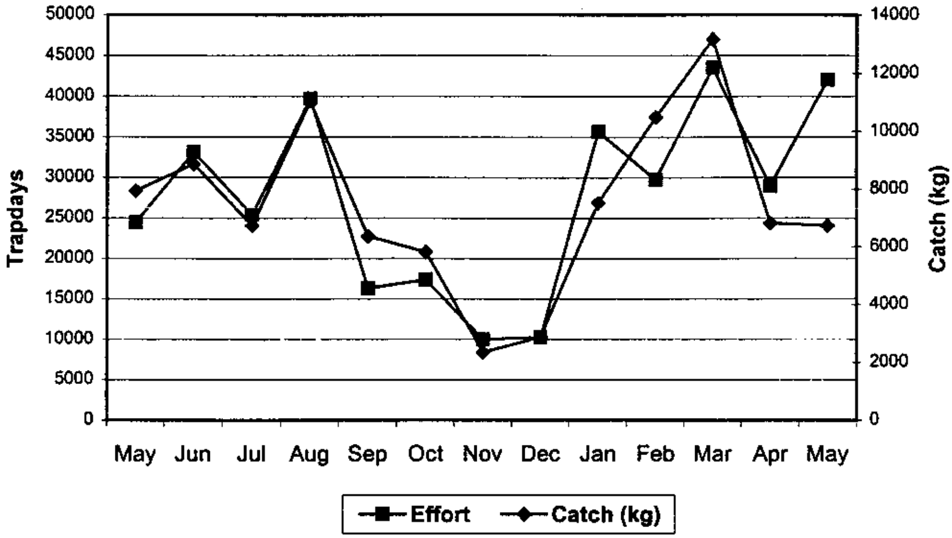


**Figure 2. Distribution of the monthly lobster catches and effort from May, 1999 to April, 2000.**

From April 23, 1999 to, May 30, 2000 53,522 lobster traps were hauled and 70,914 spiny lobsters, (*Panulirus argus*) with a corresponding weight of 89,235 kilograms were recorded caught. The carapace length (CL) of 29,802 lobsters was measured. The total amount of lobsters sampled, the percentage of lobsters with a CL of less than 9.5, the average length and average weight of the sampled lobsters are shown in Table 1. The average CL displays a fall in the months of April to September. Length-frequency analysis of the lobster catch shows that this maybe due to recruitment of small lobsters.

As shown in the table, 28.0 percent of the lobsters sampled over the past 12 months had a CL of less than 9.5 cm. The high percentage of under-sized lobsters has been reason for serious concern, because it could indicate that the lobster stock of the Saba Bank was being over-harvested. The latter was reason for the Government to take action to halt the high percentages of under-sized lobsters. The Coast Guard of the Netherlands Antilles has started to enforce the fishery regulations. After the first control on 21st of March one could notice that the fishermen practically stopped landing illegal size lobsters. Consequently, the average CL increased as the number of under-sized lobsters landed decreased.

**Table I.** Number of lobsters measured per month, number of lobsters with a carapace length (CL) less than 9.5 cm and average CL sampled

| | # Measured | # CL < 9.5 | % CL < 9.5 | CL avg. (cm.) |
|---|---|---|---|---|
| April | 1,377 | 203 | 14.7 | 11.5 |
| May | 2,562 | 607 | 23.7 | 11.0 |
| June | 3,518 | 1109 | 31.5 | 10.6 |
| July | 2,245 | 830 | 37.0 | 10.5 |
| August | 3,468 | 1,420 | 40.9 | 10.2 |
| September | 2,191 | 924 | 42.2 | 10.0 |
| October | 1,857 | 598 | 32.2 | 10.4 |
| November | 681 | 180 | 26.4 | 10.9 |
| December | 1,655 | 468 | 28.3 | 10.7 |
| January | 2,930 | 750 | 25.6 | 10.8 |
| February | 1,892 | 480 | 25.4 | 10.8 |
| March | 3,230 | 540 | 16.7 | 11.1 |
| April | 1,146 | 76 | 6.6 | 11.7 |
| May | 1,050 | 81 | 7.7 | 11,7 |
| Total: | 29,802 | 8,266 | 28.0 | 10.7 |

In the size composition of the catches, length-frequencies of male lobsters exceed those of female lobsters. Furthermore both absolutely and relatively more under-sized females than under-sized males are captured. A length-converted catch curve (assuming $L_\infty = 19.00$ and $k = 0.3$) for males and female lobsters gives a Z (total mortality) males = 0.97 and a Z females = 1.9. This indicates a much higher fishing mortality of female lobsters with an equal natural mortality (M = 0.4 - 0.5). In other words female lobsters are much more liable to enter the traps than males. In Florida males attain the size of 7.6 mm CL in an average of 23 months, whereas females require an average of 30 months (Muller et al. 1997). Catches on the Saba Bank consist for a large part of lobsters of 3 -5 years of age. Legal sized lobsters (9.5 mm CL) have the approximate age of 4-5 years, whereas 3 years old lobsters are predominantly under-sized.

The percentages of under-sized lobsters captured are particularly high in the relative shallow parts of the Saba Bank.

Analysis of the monthly length-frequency graphs shows that on the relative shallow fishing grounds in particular, the smaller lobsters were more frequently being captured than on the other fishing grounds. It is possible that the shallower parts of the Bank are the habitat of the sub-adults (7.0 - 9.0 mm CL), which migrate to the deeper parts of the Saba Bank as they grow bigger. Recruitment is visible particularly in the shallow parts of the Bank in the months June-September/October and less in the deeper fishing grounds.

**Reproduction**

*Male/Female ratio* — In general the percentage of male lobsters exceeds the percentage of female lobsters. During the winter months however the percentage of female lobsters among the lobsters sampled increased substantially, and in the month of February even surpassed the percentage of male lobsters.

*Berried lobsters and lobsters in ecdysis* — Size of first maturity was found to be in the range 7.8-8.3 cm CL for all countries in the Western Central Atlantic Fishery (WECAF) region. In Brazil, the size at first maturity was estimated at 201 mm total length by Soares and Cavalcante (1985). For Cuba, the smallest size that a berried lobster was captured was 6.7 cm CL (Cruz and León 1991), and the estimated sizes at 50% and 100% maturity were 8.1 and 9.7 cm CL respectively. In the Turks and Caicos Islands, tar spot data were recorded from sampled landings. A logit model was used to separate seasons and size (Medley and Ninnes 1997). The results largely agree with other assessments, size at first maturity was 8.3 cm CL, 50% fecundity occurred at 9.3 cm CL and full fecundity at approximately 10.8 cm. CL. The smallest size that a berried lobster was captured on the Saba Bank during the time of the monitoring was 7.6 cm CL.

Besides legal size limits for lobsters the Fishery Law of the Netherlands Antilles also prohibits landing berried lobsters, and lobsters in ecdysis (molting lobsters). Berried lobsters and spermatophoric mass on the female's sternum (tar spot) were observed during the whole period of the project.

Table 2 shows the number of berried lobsters and the number of lobsters in ecdysis among the lobsters sampled from August, 1999 to May, 2000.

As is very clear from the table, the fishermen practically discontinued landing berried lobsters and lobsters in ecdysis after the Government commenced to enforce the fishery regulations on March 21, 2000.

**Table 2.** Number of female lobsters sampled, percentage of berried lobsters, and percentage of lobsters in ecdysis from April 23, 1999 to May 30, 2000.

| | # Measured | females sampled | # berried lobsters | % berried lobsters | # lobsters ecdysis | % lobsters ecdysis |
|---|---|---|---|---|---|---|
| August | 3,468 | 1,282 | 59 | 4.6 | 0 | 0.00 |
| September | 2,191 | 814 | 49 | 6.0 | 1 | 0.05 |
| October | 1,857 | 685 | 32 | 4.7 | 2 | 0.11 |
| November | 681 | 298 | 5 | 1.7 | 1 | 0.15 |
| December | 1,655 | 786 | 9 | 1.1 | 3 | 0.18 |
| January | 2,930 | 1,381 | 19 | 1.4 | 12 | 0.41 |
| February | 1,892 | 981 | 17 | 1.7 | 4 | 0.21 |
| March | 3,230 | 1,450 | 162 | 11.2 | 6 | 0.19 |
| April | 1,262 | 489 | 1 | 0.20 | 0 | 0.00 |
| May | 1,047 | 405 | 2 | 0.49 | 2 | 0.19 |
| Total: | 20,213 | 8,571 | 353 | 4.1 | 29 | 0.14 |

## DISCUSSION AND SIGNIFICANCE OF THE WORK

During the monitoring program it became evident that the Saba Bank fishery sector is of great importance to the island economy of Saba. The Saba Bank lobster fishery has developed into a viable semi-industrial fishery, and the means of production used in the fishery are among the most advanced utilized in the Netherlands Antilles. The contribution of the Saba Bank fishery sector, which generated approximately 1.1 million US$ in 1999, is substantial to the island economy of Saba (GDP 15.7 million US$);

i) The sector provides employment to a relatively large number of people (8% of the economically active population). About 20 people generate a living exclusively from the fishery, while a relatively large group of approximately 30 people find part-time employment in it and so generate additional income in the fishery sector;
ii) The added value and the generation of foreign exchange to the island economy of Saba are high.

It became apparent that a substantial part of the landings of lobsters consisted of illegal lobster catch. High percentages of under-sized lobsters and berried lobsters in the catch are a serious concern. Of all lobsters sampled during the study, 28 percent were under-sized. Practically all fishermen were landing large numbers of under-sized lobsters, which was encouraged by the restaurants, since small lobsters sell faster than large lobsters.

Throughout the course of the survey, relatively large amounts of berried lobsters were landed. It became apparent that certain fishermen were consistently landing berried lobsters, while others did not, unless there was a high demand for lobsters on the market. Most fishermen were willing to adhere to the regulations, but as others were repeatedly landing berried lobsters, they felt the "obligation" to do the same.

Although several fishery regulations have been in existence for quite some time, until recently they were not adequately enforced. The effectiveness of management measures is directly related to the extent they are accepted by the fishermen, and to the level of enforcement by the authorities. Most of the Saba Bank fishermen have the environmental awareness to exploit the resources of the Saba Bank in a sustainable manner. They are willing to adhere to the regulations, as long they are consistently and without exception enforced by the Government.

Enforcement is a key factor to create sustainable fisheries. The benefit to the resource users will only increase if the resource is effectively protected. As a direct result of this catch assessment survey, the Coast Guard of the Netherlands Antilles has commenced to strictly enforce the fishery regulations.

The following regulations are currently being enforced:

i) Requirement of valid fishing licenses for both the Saban territorial waters and the Economic Fishery Zone (EFZ) of the Netherlands Antilles;
ii) Use of the biodegradable panel;
iii) Legal size limits for lobsters;

iv) No landing of berried lobsters;
v) Legal mesh size;
vi) No landing soft-shell lobsters (lobsters in ecdysis).

The implementation of the fishery regulations by the Coast Guard of the Netherlands Antilles resulted in a substantial decline in illegal fishery activities:

i) The number of under-sized lobsters decreased, and practically no berried lobsters and lobsters in ecdysis were brought in;
ii) Illegal (non-licensed) fishing activities from both foreign and domestic vessels have practically stopped.

Regulation practices in the Netherlands Antillean lobster fishery differ slightly from those in the region. Regulations in the region rest on three main bases; minimum legal size, limited entry, and closed season.

**Legal Size**

The minimum legal size regulation in the Netherlands Antilles (minimum CL of 9.5 cm) is intended to allow the lobsters to achieve sexual maturity and to have the opportunity to spawn at least once, in order to preserve the stock's reproductive capacity. Other regional minimum legal sizes include: Cuba, 6.9 cm CL, (Estela de León and Puga 1997), Mexico, 7.4 cm CL, (Sosa-Cordero et al. 1997), USA, 7.62 cm CL, (Muller 1998), Jamaica, 7.62 cm CL, (Grant 1997), Bahamas, 8.25 cm CL, (Deleveaux et al. 1998), Bermuda, 9.2 cm CL, (Luckhurst 1998), St Lucia, 9.5 cm CL, (Joseph 1997), and Venezuela 12.0 cm CL, (Fernandez 1997). One can notice that the legal size in the Netherlands Antilles is among the highest, thus most restrictive, in the region.

Countries with a high level of management and research and large stocks can reduce their legal size, and adjust total fishing effort whenever necessary; for countries that do not possess the mechanisms to quickly adjust total fishing effort when necessary, such a more restrictive legal size is needed.

**Limited Entry**

Most of the WECAF-nations such as Bermuda, Cuba, the USA, Mexico, Colombia, Honduras, Jamaica, Nicaragua, Brazil, and Venezuela have some system of limited entry in place, where either the number of fishermen and/or the number of fishing units is restricted. In both the Saba island territorial waters as the Netherlands Antillean waters (EFZ) no lobster fishing can take place without a fishing license, but there are no restrictions to the number of fishing units per vessel. However, within the framework of the National Fishery Law it is possible to introduce such restrictions quite easily via a National Decree.

**Closed Season**

The main lobster producing countries in the region have a closed season in place. The closed season regulation has three main objective:

i) Ensure reproduction during the peak spawning period;
ii) Protect the molting period;
iii) Allow growth and thus increase in weight, of a major part of the population (Cruz 1998).

The Netherlands Antilles has no closed season regulation in place as yet, but it might consider either closing the lobster fishery during the spring months in order to ensure reproduction during the peak spawning period or closing the lobster fishery during the hurricane season. During the hurricane season lobster sale and, consequently, fishing effort are traditionally low.

Closing the lobster fishery during the hurricane season has the following advantages:

i) Prevent loss of fishing gear;
ii) Allow precise counting and tagging of the lobster traps;
iii) Allow growth and thus increase in weight, of a major part of the population (Cruz 1998).

Furthermore, the fishery regulations in all countries include a permanent prohibition to catch or land lobsters in ecdysis and female lobsters in reproductive condition. This also applies in the case of the Netherlands Antilles.

LITERATURE CITED

Develeaux, V., G. Bethel. 1997. National Report on The Spiny Lobster Fishery in the Bahamas. Pages 166-172 in: *FAO Fisheries Report No 620*. Rome, Italy. Estela de León and M. R. Puga. 1997. Lobster Fisheries in Cuba. Pages 201-206 in: *FAO Fisheries Report No. 620*. Rome, Italy..

Fernandez, J.C. 1997. La pesqueria de langostas en Venezuela. Pages: 123-127 in: *FAO Fisheries Report No. 620*. Rome, Italy..

Grant, S. 1997. National Report of Jamaica. Pages: 220-230 in: *FAO Fisheries Report No. 620*. Rome, Italy.

Joseph, W. 1997. Saint Lucia Country Report. Pages: 257-259 in: *FAO Fisheries Report No. 620*. Rome, Italy.

Luckhurst, B.E. 1997. National Report of Bermuda. Pages 180-182 in: *FAO Fisheries Report No. 620*. Rome, Italy.

Meesters, E.H., H. Nijkamp, and L. Blijvoet. [1996]. Towards sustainable management of the Saba Bank. Aide Environment Amsterdam, the Netherlands. 58 pp. Unpubl. Ms.

Muller, R., 1997. Additional Report of the United States of America Pages: 281-284 in: *FAO Fisheries Report No. 620*. Rome, Italy.

Soares, C.N.C. and P.P.L. Cavalcante. 1985. Caribbean Spiny Lobster (*Panulirus argus*) and smooth tail spiny lobster (*Panulirus laevicauda*) reproductive dynamics on the Brazilian Northeastern coast. Pages 200-217 in: *FAO Fish Report No. 327*. Rome, Italy.

Sosa-Cordero, E., V. Ríos Lara, A.M. Acre, and M.A. Cabrera Vázquez, 1997. La Pesquería de Langosta en México, Yucatán y Quintana Roo. Pages: 231-240 in: *FAO Fisheries Report No. 620*. Rome, Italy.

# Preliminary Estimations of Growth, Mortality and Yield Per Recruit for the Spiny Lobster, *Panulirus argus*, in St. Croix, USVI

IVAN MATEO and WILLIAM J. TOBIAS
*Division of Fish and Wildlife, Department of Planning and Natural Resources*
*Room 203 Lagoon Street Complex*
*Fredericksted, St.Croix*
*US Virgin Islands 00840*

## ABSTRACT

Preliminary growth and mortality parameters for the spiny lobster *Panulirus argus* were estimated from length frequency data collected from the St. Croix commercial fisheries from 1995 through 1999 using the FISAT software package. The corresponding values of $L_\infty$ for female spiny lobsters using ELEFAN I ranged from 170 to 177 mm CL, and K values were 0.20 to 0.23. For males the $L_\infty$ values ranged from 185 to 197 mm CL, and K values ranged from 0.23 to 0.28. The length-converted catch curve and Beverton and Holt Z estimates ranged from 1.24 to 1.91 for males and 0.8 to 1.58 for females. The Z estimated from Jones length cohort analysis ranged from 0.83 to 1.15 for males and 0.65 to 0.83 for females. The exploitation ratios from length catch curve ranged from 0.73 to 0.82 for males and 0.58 to 0.76 for females. Meanwhile, exploitation rates from Jones length cohort analysis ranged from 0.59 to 0.70 for males and 0.47 to 0.64 for females. Nevertheless, average exploitation ratios from the two different methods were well above the optimum exploitation rate (E = 0.5) suggesting that the St. Croix spiny lobster is overfished. The Beverton relative yield per recruit model analysis for 1999 for males implies that with values of E = 0.66 and Lc = 95.4 mm the current lobster fishery is harvesting approximately 98% of the potential yield. Likewise, the analysis for females shows that with a value of E = 0.58 and Lc = 89.36 mm the fishery is harvesting 95% of the potential yield in females. According to these results, it is very important for all fishery agencies in the US Caribbean to reevaluate the status and conditions of the spiny lobster stocks and the definitions of overfishing for this economically important resource.

KEY WORDS: Growth, mortality, *Panulirus argus*

## INTRODUCTION

The spiny lobster, *Panulirus argus*, is the most economically important crustacean caught throughout the entire Caribbean, and it is widely distributed in the Western Atlantic from Bermuda to Brazil (FAO 1993). In St. Croix, US Virgin Islands (USVI), the spiny lobster is fished commercially by free diving, scuba diving, and by fish traps. This species represented almost 6% of the total catch reported during 1998 - 1999 (Tobias 2000). The fishery has been managed under territorial and federal jurisdictions with a fishery management plan (FMP) administered by the

Caribbean Fishery Management Council (CFMC) since 1985 after indications of overfishing were observed in the US Caribbean during the early 1980s (CMFC 1985). The established regulations are:

i) A minimum size of 89 mm in carapace length,
ii) A prohibition against retaining egg-bearing lobsters,
iii) A requirement to land lobster whole, and
iv) Gear restrictions prohibiting the use of poisons, drugs or other chemicals as well as spears, hooks explosives, or similar devices in harvesting spiny lobsters.

Growth and mortality parameters have been estimated for the spiny lobster throughout the Caribbean using different techniques, such as tagging studies (Munro 1974, Olsen and Koblic 1975, Clairovin 1980, Waugh 1981, Lozano et al. 1991, Muller et al, 1997) and length frequency analysis from commercial fishery data (Baez et al. 1991, Phillips et al. 1992, Haughton and King 1992, Leon et al. 1995). However, estimating growth rates of *P. argus* by length frequency analysis has been unsuccessfully attempted for the USVI (Bohnsack et al. 1992). On the last spiny lobster stock assessment workshop held by the Caribbean Fishery Management Council, the scientific panel attempted to build reliable yield per recruit analysis models using length frequency data from the Puerto Rico and USVI commercial fisheries. However, they could not get reliable estimates of growth parameters, such as $L_\infty$ (asymptotic length) and K (body growth coefficient), for various reasons: data were limited and carapace measurements were to the nearest one tenth inch, which was too wide an interval to show distinct size frequency peaks.

This study attempts to evaluate the use of length frequency analysis based upon biostatistical data from the St. Croix commercial lobster fishery to estimate growth and mortality parameters, and to construct a reliable yield per recruit analysis.

## METHODS

Information of historical landings, harvest rates, and fishing effort data (i.e. number of boat trips, number of traps) was obtained through the National Marine Fisheries Service (NMFS) Cooperative Statistics Program. Biostatistical data of *P. argus* were collected by port agents from 1995 to 1999. Each lobster was weighed to the nearest 25 g. Carapace length (CL) was measured to the nearest 0.1 mm and sex was determined. The sample size per month ranged from 0 to 636 individuals per month. Biostatistical data were entered into the Trip Interview Program (TIP) developed by the National Marine Fisheries Service (NMFS), Southeast Fishery Science Center. Later, the data were converted and analyzed in Excel. To enhance modal definition for length frequency analysis, samples were pooled tri-monthly for each year and assigned a single collection date for each year. Differences on length frequency distributions by sex and by years were examined using Kolmogorov-Smirnov test (KS) (Sokal and Rohlf 1981).

**Estimation of Growth Parameters and Mortality**

Analysis of growth parameters assumes Von Bertalanffy growth: $L_t = L_\infty (1 - Le^{k(t-t_0)})$, where $L_t$ is the carapace length at time $t$, $L_\infty$ is the asymptotic length an individual would reach if it lived indefinitely, and $k$ is the rate at which $L_\infty$ is approached. The growth parameters $L_\infty$ and K were estimated using ELEFAN I from the FISAT software package (Gayanilo et al. 1995). Comparisons of different estimates of growth parameters were done using the empirical equation of Pauly and Munro (1984): phi= $\text{Log}_{10}$ K + 2 Log $_{10}$ ($L_\infty$).

Instantaneous total mortality (Z) (Beverton and Holt, 1957), fishing mortality (F) and length at first capture (Lc) were calculated using length-converted catch curve (Ricker, 1975, Pauly 1984). These analyses were performed by converting the data of each monthly sample to percent frequency and then weighting by square roots of the sample size. Giving all monthly samples equal weight prevents a single large monthly sample from being a major source of bias or from overly affecting the total annual sample. Since estimates of natural mortality (M) of spiny lobster in the USVI are unknown, we are using estimates from literature for subsequent analysis (M = 0.34) CFRAMP/FAO Spiny Lobster Stock Assessment Workshop (CFRAMP 1997). Exploitation rates were calculated with the Pauly and Soriano (1986) exploitation rate formula: E=F/Z. Jones' length cohort analysis (Jones 1984) was used to estimate stock size biomass, as well as total and fishing mortalities and exploitation ratios. Yield per recruit analyses were conducted using Beverton and Holt yield/recruit relative (Y'/R) and biomass/recruit relative (B'/R) models (Beverton and Holt 1957). Maximum sustainable yield (MSY) for *P. argus* was calculated using Fox (1970) and Schaefer (1954) surplus yield models. Catch data and effort data, which could be used to calculate MSY, were available for the 1993 - 1998 fishing seasons.

## RESULTS

**Commercial Landings Data**

Spiny lobster landings increased steadily from 1978 to 1998, from landings of 3,400 kilograms (kg) to more than 17,700 kg. Average landings during the 1980s were 3,550 kg while in the 1990s averaged 13,732 kg (Figure 1). Divers accounted for approximately 85% of the total landings throughout the years from 1990 to 1998 (Figure 2). Fishing effort for 1993 - 1998 fishing seasons (as defined by number of fishing trips) has averaged about 4,690 trips per year (Figure 3) while number of fish traps per year averaged about 1,488 traps (Figure 4). Mean total catch per unit effort (CPUE) for 1993 - 1998 fishing seasons varied from 2.9 kg per trip in 1993 to 4.5 kg in 1998 (Figure 5). The number of kilograms landed per fishing trips by gear for 1993-1998 fishing seasons has averaged 7.2 kg per trip for divers and 0.7 kg for fish traps. Mean CPUE by trap averaged 1.3 kg per trap (Figure 6).

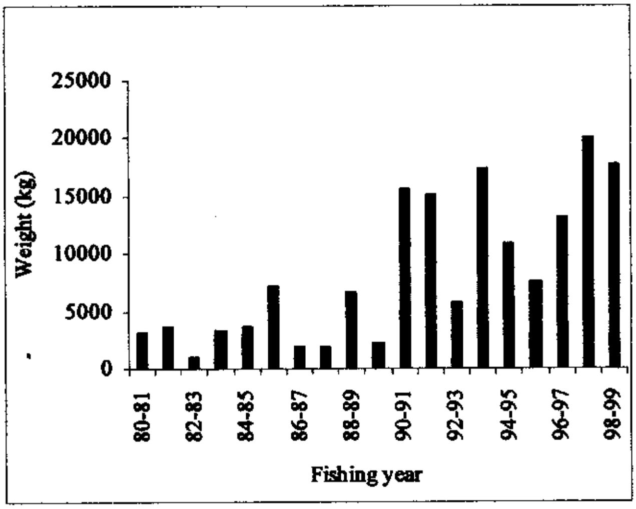


**Figure 1.** Spiny lobster *P. argus* commercial landings from fishing years 1980 - 1998 in St. Croix USVI.

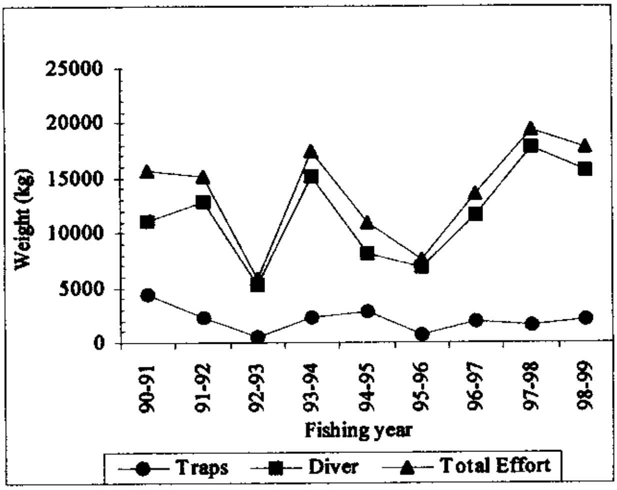


**Figure 2.** Landings of *P. argus* reported by gear and all gears combined during the 1990 - 1998 fishing years in St. Croix, USVI.

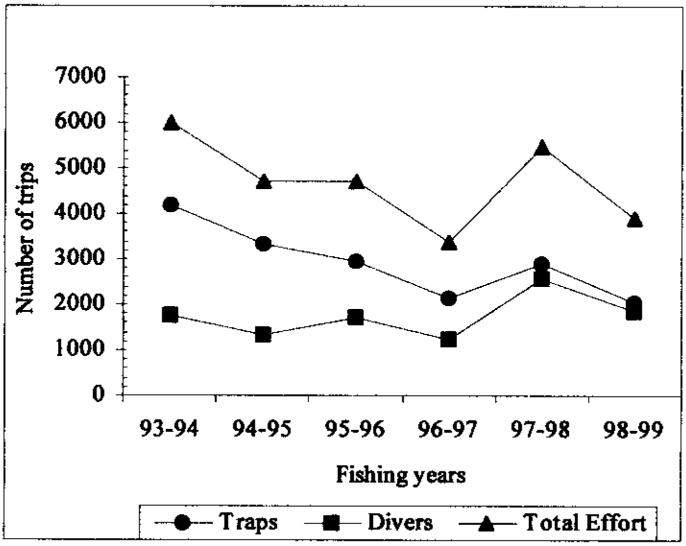


**Figure 3.** Number of fishing trips by gear and all gears combined (total effort) during the 1993-1998 fishing years in St. Croix, USVI

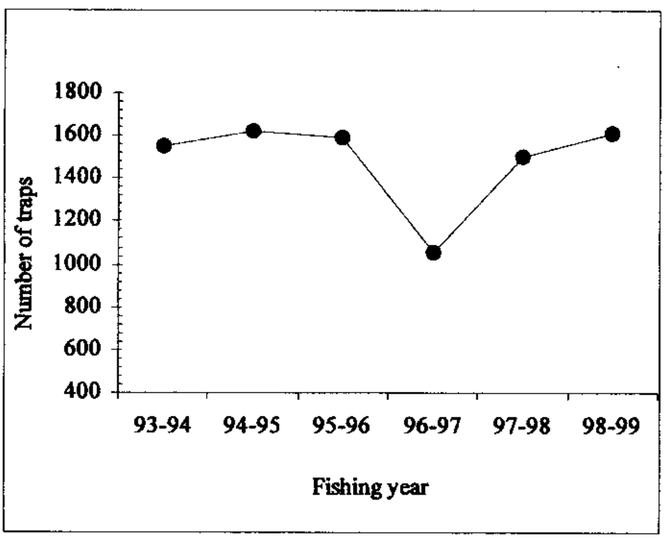


**Figure 4.** Total number of traps per fishing years 1993 - 1998 in St. Croix, USVI

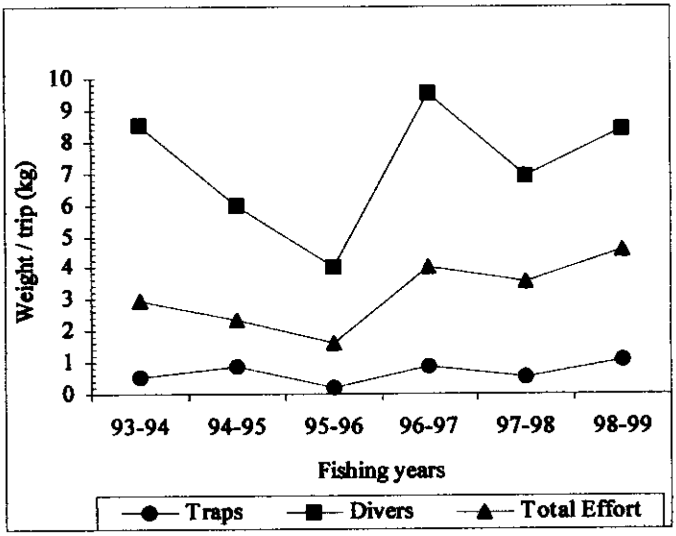


**Figure 5.** Average weight (kg) per trip by gear and all gears combined (total effort) for *P. argus* during the 1993 - 1998 fishing years in St. Croix, USVI.

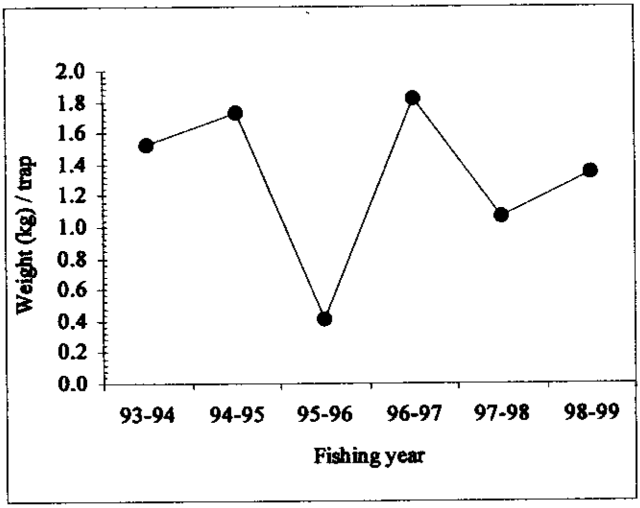


**Figure 6.** Mean catch (kg landed) per trap for *P. argus* during the1993 - 1998 fishing years in St. Croix, USVI.

**Size Distribution**

During the period of 1995 - 1999, 2,862 lobsters were measured, of which 1,734 were males and 1,128 females. The male:female sex ratio was skewed toward males (1.5) most likely because females with eggs were not landed, and this caused to bias the ratio. The size range was from 75 mm to 190 mm carapace length (CL). The mean CL for males and females were 108.44 mm and 103.42 mm, respectively. The average modal lengths for males and females were 100 mm and 93 mm, respectively. CL for males was significantly larger than those of the females (KS, p = 0.014) (Figure 7). Less than 4% of the lobsters measured from 1995 to 1999 were under the legal size limits. When average lengths were compared by years, there was a significant decline in mean CL in males from 1995 to 1999 (KS, p = 0.01) but not in females (KS, p = 0.16).

**Growth and Mortality Parameters**

The estimated values of $L_\infty$ for females ranged from 170 to 177 mm CL (Table 1), and K values ranged from 0.20 to 0.23. For males the $L_\infty$ values ranged 185 to 197 mm CL, and K values ranged from 0.23 to 0.28. These results showed that males had a faster growth rate and attained their maximum size more quickly than females. Females had higher good fitness indices (Rn) of ELEFAN I.

The length-converted catch curve and Beverton and Holt Z estimates ranged from 1.24 to 1.91 for males and 0.8 to 1.58 for females (Table 1). Length at first capture (Lc) for males ranged from 94.8 to 108.6 mm and 89.3 to 93.3 mm for females. The Z estimated from Jones length cohort analysis ranged from 0.835 to 1.15 for males and 0.65 to 0.83 for females (Table 2). The exploitation ratios from length converted catch curve ranged from 0.73 to 0.82 for males and 0.58 to 0.76 for females. Whereas, exploitation rates from Jones length cohort analysis ranged from 0.59 to 0.70 for males and 0.475 to 0.64 for females. Average exploitation ratios from the two different methods were well above the optimum exploitation rate (E = 0.5) suggesting that the St. Croix spiny lobster is overfished.

Estimates of stock size and fishing mortality were obtained using Jones length cohort analysis (Table 3). The results suggest that approximately 91,530 lobsters in the 82 to 84 mm range were recruited to the fishery for 1999. The total catch for 1999 was approximately 57,300 lobsters. Estimate of total biomass was 87 metric tons (t). The total number of survivors was 33200. The mean fishing mortality and exploitation ratio for fully recruited length groups was 0.472 and 0.581 for females while 0.663 and 0.670 for males, respectively. Due to the tendency of length catch curve methods to overestimate mortality parameters due to variable recruitment and migration of larger specimens we decided to use the results from Jones length cohort analysis for the yield per recruit analysis.

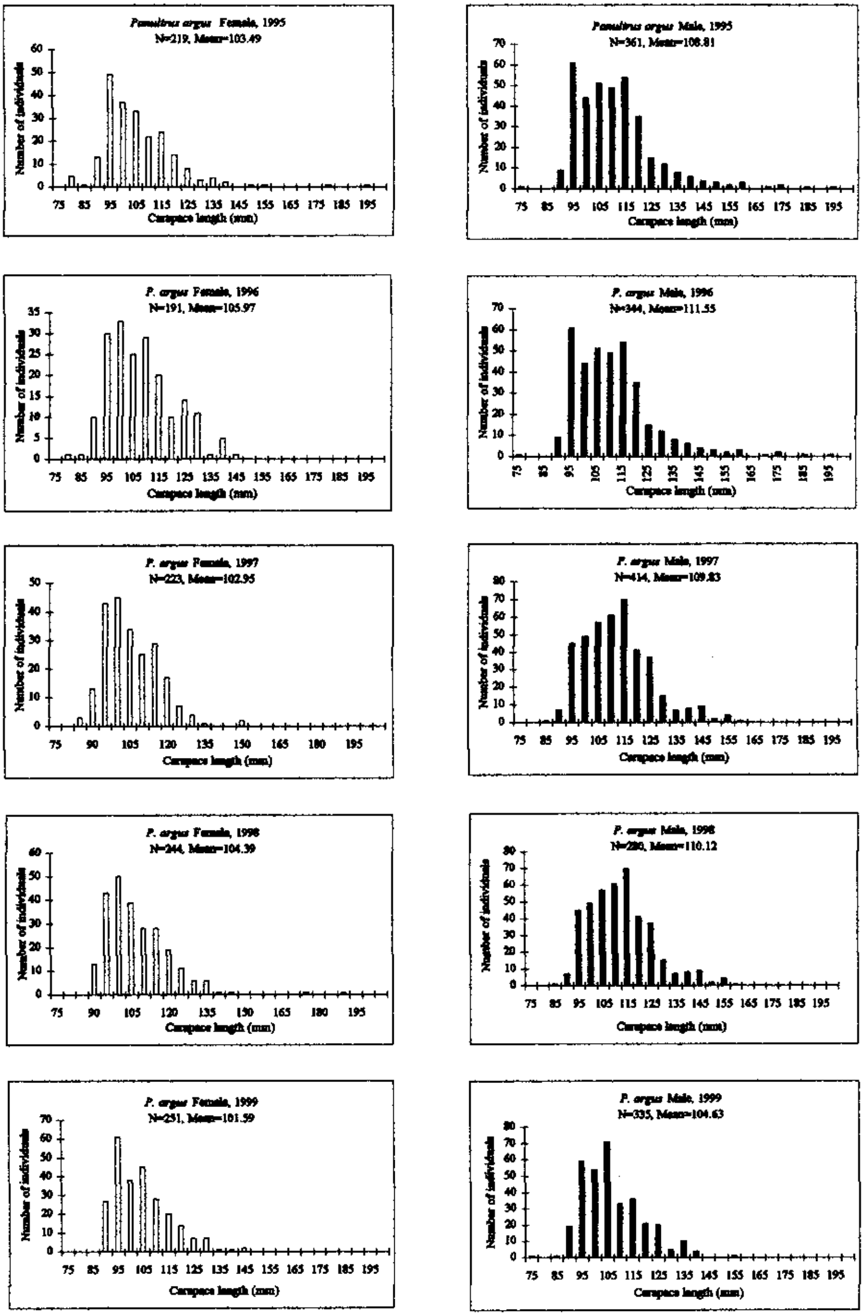


**Figure 7.** Length frequency distributions for male and female spiny lobster, *P. argus*, for the 1995 - 1999 fishing years in St. Croix, USVI.

**Table 1.** Estimates of length ($L_\infty$), body growth rate (K), goodness of fit index (Rn), age at birthday ($T_0$), fishing mortality (F), exploitation ratio (E=F/Z), and length at first capture (Lc) by sex for the spiny lobster, St. Croix, USVI.

| Sex/ Parameters | $L_\infty$ | K | Rn | $T_0$ | $Z_1$ | $Z_2$ | F | E | Lc |
|---|---|---|---|---|---|---|---|---|---|
| Male | | | | | | | | | |
| 1995 | 197 | 0.28 | 0.155 | 0.35 | 1.84 | 1.82 | 1.48 | 0.81 | 94.80 |
| 1996 | 195 | 0.26 | 0.182 | 0.38 | 1.91 | 1.84 | 1.50 | 0.82 | 108.67 |
| 1997 | 185 | 0.24 | 0.142 | 0.42 | 1.43 | 1.24 | 0.90 | 0.73 | 100.10 |
| 1998 | 193 | 0.25 | 0.141 | 0.40 | 1.41 | 1.44 | 1.10 | 0.76 | 96.12 |
| 1999 | 191 | 0.23 | 0.144 | 0.44 | 1.60 | 1.90 | 1.56 | 0.82 | 99.18 |
| Female | | | | | | | | | |
| 1995 | 172 | 0.23 | 0.142 | 0.45 | 1.17 | 1.22 | 0.88 | 0.72 | 91.38 |
| 1996 | 172 | 0.20 | 0.161 | 0.52 | 0.80 | 0.87 | 0.53 | 0.61 | 91.63 |
| 1997 | 177 | 0.23 | 0.176 | 0.45 | 1.28 | 1.58 | 1.24 | 0.78 | 93.34 |
| 1998 | 170 | 0.20 | 0.142 | 0.52 | 0.83 | 0.81 | 0.47 | 0.58 | 90.10 |
| 1999 | 173 | 0.22 | 0.180 | 0.47 | 1.25 | 1.41 | 1.07 | 0.76 | 89.30 |

$Z_1$= Beverton and Holt,Z

$Z_2$=Length Catch Curve Z

**Table 2.** Estimation of abundance (N), biomass (T), fishing mortality (F), exploitation ratio (E), and instantaneous total mortality (Z), by sex using Jones length cohort analysis for the spiny lobster at St. Croix, USVI.

| Sex/ Parameter | N | T | F | E | Z |
|---|---|---|---|---|---|
| Male | | | | | |
| 1995 | 41862 | 37.53 | 0.82 | 0.71 | 1.16 |
| 1996 | 40805 | 34.84 | 0.61 | 0.64 | 0.95 |
| 1997 | 91036 | 83.31 | 0.50 | 0.59 | 0.84 |
| 1998 | 47440 | 43.92 | 0.59 | 0.63 | 0.93 |
| 1999 | 49299 | 42.35 | 0.67 | 0.66 | 1.01 |
| Female | | | | | |
| 1995 | 37208 | 32.08 | 0.54 | 0.62 | 0.88 |
| 1996 | 45561 | 42.54 | 0.31 | 0.48 | 0.65 |
| 1997 | 38487 | 32.99 | 0.60 | 0.64 | 0.94 |
| 1998 | 63984 | 56.25 | 0.38 | 0.53 | 0.72 |
| 1999 | 51450 | 45.05 | 0.47 | 0.58 | 0.81 |

**Table 3.** Comparison of length ($L_\infty$) and body growth rate (K) by sex using Pauly's equation $\Phi$ (phi) (Pauly 1984) for the spiny lobster from different areas in the Caribbean.

| Area | Sex | ($L_\infty$) | K | $\Phi$ (phi) | Source |
|---|---|---|---|---|---|
| Brasil | M | 141 | 0.34 | 3.82 | Dos Santos et al., 1964 |
| | F | 148 | 0.38 | 3.92 | |
| USVI | M | 153 | 0.44 | 4.01 | Olsen and Koblick, 1975 |
| | F | 133 | 0.32 | 3.72 | |
| Martinique | M | 190 | 0.25 | 3.96 | Clairovin, 1980 |
| | F | 188 | 0.23 | 3.91 | |
| Bahamas | M | 190 | 0.26 | 3.97 | Waugh, 1981 |
| | F | 190 | 0.23 | 3.92 | |
| Cuba | M | 169 | 0.22 | 3.80 | Cruz et al., 1981 |
| | F | 139 | 0.31 | 3.77 | |
| Bermuda | M | 204 | 0.18 | 3.87 | Evans, 1988 |
| | F | 192 | 0.15 | 3.74 | |
| Cuba | M | 142 | 0.30 | 3.78 | Baez et al., 1991 |
| | F | 122 | 0.3 | 3.65 | |
| Mexico | M | 257 | 0.2 | 4.12 | Arce et al., 1991 |
| | F | 215 | 0.25 | 4.06 | |
| Mexico | M | 198 | 0.24 | 3.97 | Gonzalez-Cano, 1991 |
| | F | 165 | 0.22 | 3.77 | |
| Cuba | M | 250 | 0.27 | 4.23 | Phillips et al., 1992 |
| | F | 171 | 0.39 | 4.06 | |
| Jamaica | M | 210 | 0.24 | 4.02 | Haughton and King, 1992 |
| | F | 195 | 0.28 | 4.03 | |
| Nicaragua | M | 169 | 0.23 | 3.82 | Castano and Cadima, 1993 |
| | F | 160 | 0.40 | 4.01 | |
| Cuba | M | 190 | 0.31 | 4.05 | Leon et al., 1994 |
| | F | 174 | 0.24 | 3.86 | |
| Cuba | M | 178 | 0.21 | 3.82 | Baez et al., 1994 |
| | F | 171 | 0.21 | 3.81 | |
| Cuba | M | 185 | 0.23 | 3.90 | Leon et al., 1995 |
| | F | 154 | 0.19 | 3.65 | |
| Brazil | M | 207 | 0.26 | 4.04 | Gonzalez-Cano and Rocha, 1995 |
| | F | 162 | 0.18 | 3.67 | |
| Mexico | M | 217 | 0.25 | 4.07 | Gonzalez-Cano and Rocha, 1995 |
| | F | 146 | 0.22 | 3.67 | |
| Brazil | M | 257 | 0.229 | 4.02 | Ivo, 1996 |
| | F | 233 | 0.236 | 3.92 | |
| St. Croix | M | 192 | 0.25 | 3.96 | Mateo and Tobias, 2000 |
| | F | 172 | 0.22 | 3.81 | (this study) |

## Yield Estimates

The Beverton relative yield per recruit model for males in 1999 implies that with values of E =0.66 and Lc =95.4 mm the current lobster fishery is harvesting approximately 98% of the potential yield (Figure 8a). Likewise, the analysis for females show that with a value of E= 0.58 and Lc= 89.36 mm the fishery is harvesting 95% of the potential yield in females (Figure 8b). The results also indicate that the current levels of fishing pressure have not exceeded the maximum sustainable levels. The $E_{MSY}$ (exploitation rate at itsmaximum sustainable yield) for males and females (0.71 and 0.72, respectively) have not been surpassed by the current exploitation ratios (0.66 and 0.58).

Estimates of MSY varied from 15,300 to 15,500 kg within the two models. The number of trips required to harvest the MSY ranged from 5,688 to 7,644 trips.

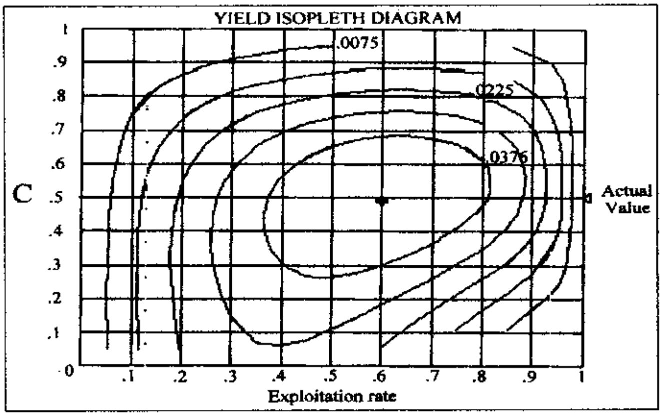


**Figure 8a.** Yield per recruit isopleth for male P. argus as a function of exploitation ratio (E) and size at first capture relative to asymptotic length (C).

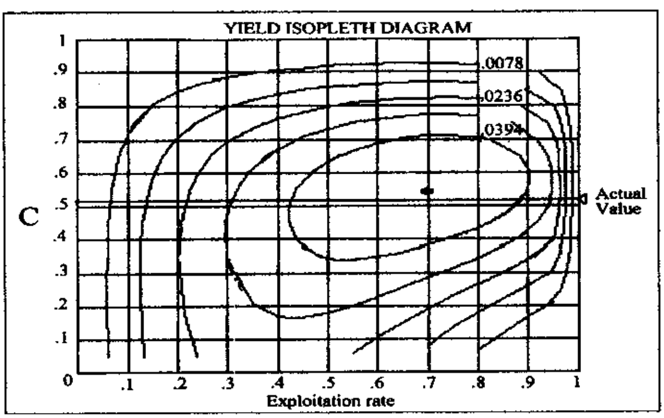


**Figure 8b.** Yield per recruit isopleth for female P. argus as a function of exploitation ratio (E) and size at first capture relative to asymptotic length (C).

## DISCUSSION

The estimation of growth and mortality rates for *P. argus* by any presently known method is quite troublesome in nature. The adequacy of Von Bertalanffy (1938) growth functions as a reliable description of growth rates in *P. argus* depends on the validity of the assumption that growth rate is constant throughout the year (Leon et al. 1995). However, this is not the case for *P. argus* where molting frequency varies seasonally (Lipcius 1985). Previous works by Munro (1974) and Lipcius (1985) state that lobster growth is a function of two processes – molting frequency and change in size during molting. Munro (1974) stated that *P. argus* had an average of four molts per year with length increment between 5 and 8 mm in each molt. Molting frequencies do not remain constant and change throughout life. Therefore, *P. argus* juveniles have successive molts till they reach sexual maturity, and individuals of larger size molt once a year and they reproduce twice during spring-summer season.

Overall, the growth curves estimated using ELEFAN I represented a rather poor fit to the peaks in the restructured data. The goodness of fit (Rn), that can reach to a maximum of 1, was generally low ranging from a minimum of 0.142 to a maximum of 0.182. The relatively poor fit of the growth curves was probably a result of spawning year all round and the effects of seasonal growth. Previous studies on estimates of growth parameters indicate that *P. argus* is long lived, slow growing, and has low rates of natural mortality (Munro 1974, Olsen and Koblic 1975, Clairovin 1980, Waugh 1981, Lozano et al. 1991, Baez et al. 1991, Phillips et al. 1992, Haughton and King 1992, Leon et al. 1994, Leon et al. 1995). However, comparisons of growth rates by females and males found on different areas have several discrepancies. While authors such as Cruz and de Leon (1991), Baez et al. (1991), Lozano et al. (1991), Phillips et al. (1992) Castano and Cadima (1993), Haughton and King (1992) and Ivo (1996) give higher K values for females, other workers found that females had lower growth rates than males (Olsen and Koblic 1975, Clarovin 1980, Waugh 1981, Evans 1981, Gonzalez-Cano 1991, Leon et al. 1994, Leon et al. 1995, Gonzalez-Cano and Rocha 1995). These differences may be due to the sample size used and the different methods used to estimate growth. Furthermore, in some of these studies data on smaller sizes or larger sizes above 120 mm are scarce, therefore diminishing the precision and accuracy of $L_\infty$ as well as K values. Nevertheless, Kanciruk (1980) states that *P. argus* males attain larger sizes at a faster growth rate than females similar to other species from the Panuliridae family (*P. guttatus*). This is suggested that female lobsters need to allocate their metabolic energy between growth and reproduction. Table 3 gives estimates of growth parameters for *P. argus* from different parts of the Caribbean. Growth coefficients from *P. argus*, sexes combined, are generally low ranging from 0.16 to 0.45. Estimates of $L_\infty$ have been reported to vary from 154 to 225 mm. Our estimate of growth performance index (3.96) from *P. argus* males lies well within a 95% confidence interval (3.86 - 4.03) of phi (φ) based on a mean of 3.97 (SE = 0.03). Similarly, for females our estimate of growth performance index (3.86) lies well within a 95% confidence interval (3.78 - 3.97) of phi based on a mean of 3.85

(SE = 0.03). In brief, the results from this study are in agreement with other growth studies of *P. argus.*

Estimation of mortality parameters in *P. argus* is also difficult due to the lack of accurate age-based data and the migratory behavior of this species (Baisre and Cruz 1994). Shifts in length frequency distributions toward larger sizes in deeper waters are known for many marine organisms including the spiny lobster (Kanciruk and Hernkind 1976, Lyons et al. 1981, Baisre and Cruz 1994), reflecting ontogenetic migrations from inshore/shallow areas to offshore/deeper areas. This can produce a major problem. If migration of larger individuals into deeper waters had an effect on the length frequency distribution data from this study, it is expected that the mortalities derived from the catch curve and Beverton and Holt formula would be overestimated. The amount of bias will depend on the magnitude of K and $L_\infty$ values and will increase if K values are low and $L_\infty$ are high.

Total mortalities (Z) from length catch curves and Beverton and Holt (1957) formula ranged from 1.24 to 1.91 for males and 0.8 to 1.58 for females. These mortality estimates are more in agreement with data using length based methods from other highly exploited lobster populations in the region such as those of the Bahamas: Z = 1.44 (Waugh 1981); Jamaica: Z = 2.19 males, 2.88 females (Haughton and King 1992); Florida: Z = 2.59 (Warner et al. 1977), Z = 4.09 (Lyons et al., 1981), Z = 1.18 (Powers and Bannerot, 1984), Z = 1.85 (Powers, 1985); Brazil Z = 1.27 (Fonteles-Filho 1994). However, average Z from Jones length cohort analysis for males ranged from 0.83 to 1.16 while females average instantaneous mortalities ranged from 0.72 to 0.83. These values were in agreement with other lobster stock assessment studies using length/age structured methods such as in Florida: Z = 1.09 for females, Z = 1.19 for males (Muller et al. 1997); Mexico: Z = 0.95 (Zetina and Rios 1998); St. Kitts: Z = 1.09 (Goodwin et al. 1986).

Exploitation rates from males and females calculated from all methods were greater than the accepted optimum level of 0.5 and suggest that the lobster populations in St. Croix are being overfished. MSY calculated from Schaeffer and Fox model were around 15,500 kg per year. Lobster landings in St. Croix have exceeded this figure in 1990 - 1991, 1993 - 1994, 1997 - 1998, and 1998 - 1999 fishing seasons. Given the limited data, these calculations should be treated cautiously. The implication is that the fishery is fully exploited.

The reliability of Beverton yield per recruit analysis and its application to lobster populations is limited by the quality of the input parameters (Baisre and Cruz 1994). This model does not consider the effect of variable recruitment. It also assumes that spiny lobster growth conforms a Von Bertalanffy growth function, and total mortality estimates are greatly affected by growth and natural mortality rates. Mortality estimations by length catch curves and Beverton and Holt formula are often overestimated by growth parameters affected by different factors such as variable recruitment and migration (Baisre and Cruz 1994). We decided to calculate yield per recruit using estimates of mortalities from Jones length cohort analysis because age and length structured models assume neither constant recruitment nor constant mortalities across ages or size classes (Muller et. al. 1997). Consequently, they effectively model the patterns of the fishery because of their high precision.

According to the yield per recruit analysis, increasing length at first capture Lc with the current level of effort will not result in an increase of Y/R. Likewise, no gain in Y/R would be expected if effort were increased with the current length at first capture. Species that are slow growing and long lived such as *P. argus* can be susceptible even at low levels of exploitation. By maintaining the fishery at the present level or slightly lower, it will permit the harvest of most of the potential yield but might potentially affect the spawning stock. A more conservative approach would be warranted, given the Beverton model does not account for the effect of fishing pressure on the spawning stock.

Although the mortality estimates may be subject to considerable errors as consequences of the biases in the data collected from the commercial fishery and the violations of assumptions made during analyses, the present level of fishing mortality appears to be much greater than the optimum required level for the lobster fishery. The results of the yield per recruit analysis show that fishing pressure should be decreased considerably in St. Croix. Possible management options include implementation of catch quotas, seasonal closures, or limitation on the number of fishermen or traps.

Based on the *P. argus* life history characteristics and the present results from the yield per recruit analysis and surplus production models, the most promising of the various management options for the reduction of fishing pressure on the spiny lobster would be to create a seasonal closure of the fishery. Given the current law enforcement limitations around St. Croix, this option has the best chance to be implemented. Enforcement requirements would be limited on a temporal and spatial scale, and the closure would have little impact on other sectors of the fishery.

Finally, it is very important for all fishery agencies in the US Caribbean to reevaluate the status and conditions of the spiny lobster stocks and the definitions of overfishing regarding this economically important resource. According to the SAFE report (Bohnsack et al. 1992), the assessment team concluded that St. Croix lobster populations appeared to be healthy at the levels of fishing effort based on data from 1987 to 1989, and recommended increased compliance with the minimum size regulation. Our present results indicate that lobster populations in St. Croix are apparently overfished. Besides the enforcement of fishery regulations, successful management of the US Virgin Islands spiny lobster fishery will depend on more intensive biological research together with new approaches to stock assessment in order to improve the management decisions.

## ACKNOWLEDGMENTS

We wish to express our gratitude to port agents William Ventura and Hector Rivera who collected the data. We thank NMFS Cooperative Fisheries Statistics Program for providing the funds for this research. Special thanks go to Mr. Josh Bennet, NMFS Cooperative Fisheries Statistics Program for data management. We also thank Dr. Richard Appeldoorn, Dr. George Dennis, Dr. Robert Muller, and Tom Matthews for reviewing the manuscript. And finally we would like to thank St. Croix commercial fishermen for their cooperation during this study.

LITERATURE REVIEW

Arce, A.M., J.C. Seijo, and S. Salas. 1991. Estimación del crecimiento de la langosta *Panulirus argus* mediante funciones de singularidad. *Rev. Invest. Mar.* **12**(1):184-192.

Baez, M., E. Díaz, R. Brito, and R. Cruz. 1991. Edad y crecimineto de la langosta en la plataforma suroccidental de Cuba. *Rev. Invest. Mar.* **12**(1-3):193-201.

Baez, M., E. Carmenati., and R. Coyula. 1994. Edad y crecimineto de la langosta *Panulirus argus*a partir del analysis de frequencias de tallas en la platoforma suroccidental de Cuba. *Rev. Cub. Mar.* 15.

Baisre, J. and R. Cruz. 1994. The Cuban Spiny lobster fishery. Pages 119-131 in: B.F. Phillips, J.S. Cobb, J. Kittaka (eds.) *Spiny Lobster Management*. Fishing News Books, London, England.

Beverton, R.J.H. and S.J. Holt. 1957. On the dynamics of exploited fish populations. *Ministry of Agriculture Fisheries Investigations Series 11*. **19**: 1-533.

Bohnsack, J., S. Meyers, R. Appeldoorn, J. Beets, I. Sadovy, and D. Matos. 1992. Stock assessment of Spiny lobster *Panulirus argus* in the US Caribbean. Final Report submitted to Caribbean Fishery Management Council. 26 pp.

Castano, O. and Cadima, E. 1993. Biología y evaluación de la langosta espinosa *Panulirus argus*. Simposio sobre evaluación y Manejo de las pesquerías de Crustaceos en Nicaragua, Managua. Nicaragua 6-7 Diciembre 1993. Centro de Investigacion de Recursos Hidrobiológicos (CIRH)/NORAD) 53 pp.

CFMC. 1985. Caribbean Fishery Management Council, Spiny Lobster Fishery Management Plan. 32 pp

CFRAMP. [1997]. CFRAMP/FAO Spiny Lobster Stock Assessment Workshop. Belize. In Press

Clairovin, N. 1980. Contribution a l'etude du stock de langouste *Panulirus argus* en Martinique. *Science et Peche Bull. Peches Marit.* **300**:7-18.

Cruz, R., R. Coyulla, and A.T. Ramírez. 1981. Crecimiento y mortalidad de la langosta espinosa (*Panulirus argus*) en la plataforma suroccidental de Cuba. *Rev. Cub. Inv. Pesq.* **6**(4):89-119.

Cruz, R. and M.E. de Leon. 1991. Dinámica reproductiva de la langosta *Panulirus argus* en el archipiélago cubano. *Rev. Invest. Mar.* **12**(1-3): 234-245.

Dos Santos, E.D., R.S. da Costa, and S.J.C. de Moura. 1964. Growth of the spiny lobster *Panulirus argus* quantitatively aspect. *Arq. Est. Biol. Mar. Univ. Ceara, Fortaleza* **4** (2): 41-44.

Evans, C.R. 1988. Population dynamics of spiny lobster *Panulirus argus* and *P. guttatus* at Bermuda 1986/87. Final Report to Overseas Development Administration, UK. 98 pp.

FAO. 1993. Marine Fishery Resources of the Antilles: Lesser Antilles, Puerto Rico and Hispaniola, Jamaica, Cuba. FAO Fisheries Technical Paper. No. 326. Rome. 235 pp.

Fonteles-Filho, A.A. 1994. State of the lobster fishery in the north-east Brazil. Pages 108-118 in: B.F. Phillips, J.S. Cobb, J. Kittaka (eds.) *Spiny Lobster Management*. Fishing News Books. London, England.

Fox, W.W. 1970. An exponential surplus-yield model for optimizing exploited fish populations. *Transactions of the American Fisheries Society* **99**(1): 80-88

Gayanilo, F.C. Jr., P. Sparre, and D. Pauly. 1995. The FAO-ICLARM stock assessment tools (FISAT) Users's Guide FAO Computerized Information Series Fisheries, #8. Rome FAO. 126 pp.

Gonzalez-Cano, J.M. 1991. *Migration and Refuge in the Assessment and Management of the Spiny Lobster Panulirus argus in the Mexican Caribbean.* Ph.D. Dissertation. Imperial College. London, England. 478 pp.

Gonzalez-Cano, J.M. and C.A.S. Rocha. 1995. Problems on the estimation of growth parameters for the spiny lobster *Panulirus argus* in the Caribbean and Northeast of Brazil. Proceedings of the World Fisheries Congress Theme 5: Assessment, methodologies and management.

Goodwin, M.H., S.J, Heyliger, and R.M. Wilkins. 1986. Progress report on development of a management plan for the St. Kitts / Nevis Spiny lobster fishery. Fisheries Division, Ministry of Agriculture, St Kitts. 19 pp.

Haughton, M. and D. King. 1992. Stock assessment of the Spiny lobster *Panulirus argus* in Jamaica. *Proceedings of the Gulf and Caribbean Fisheries Institute* **42**:119-126.

Ivo, C.T.C. 1996. Biologia pesca e dinamica populacional das langostas *Panulirus argus* (Latreille) e *Panulirus laevicauda* (Latreille) (Crustacea:Palinuridae ), capturadas ao longo da plataforma continental do Brasil, entre os estados do Amapa e do Espiritu Santo. Tese de Doutorado, departamento de Hidrobiologia , Universidad Federal de Sao Carlos, Sao Carlos. 277 pp.

Kanciruk, P. and W.F. Herrnkind. 1976. Autumnal reproduction in the spiny lobster *Panulirus argus* at Bimini, Bahamas. *Bulletin of Marine Science* **28**:601-623.

Kanciruk, P. 1980. Ecology of juvenile and adult (spiny lobsters). Pages 59-96 in: J.S. Cobb, B.F. Phillips (eds.) *Biology and Management of Lobsters, Vol. II.* Academic Press. New York, New York USA.

Jones, R. 1984. Assessing the effects of changes in exploitation patterns using length composition data (with notes on VPA and cohort analysis). *FAO Fisheries Technical Paper* **256.** 118 pp.

Leon, M.E., R. Puga, and Y.R. Cruz. 1994. Estimación de los parámetros de crecimiento del *Panulirus argus* del Golfo de Batabano, Cuba. *Rev. Cub. Inv. Pesq.* **18**(10): 9-12.

Leon, M.E., R. Cruz, and R. Puga. 1995. Actualización de la edad y el crecimiento de la langosta espinosa *Panulirus argus*. *Rev. Cub. Inv. Pesq.* **5**:3-9.

Lipcius, R.N. 1985. Size dependency reproduction and molting in spiny lobster and other long-lived decapods. Pages 129-148 in: H. Wenner (ed.) *Crustacean Issues, Vol. 3: Factors in adult growth.* Balkema, Rotterdam, Holland

Lozano, E., P. Briones, and B. F. Phillips. 1991. Fishing characteristics, growth and movements of spiny lobster *Panulirus argus* in Bahía de la Ascención, Mexico. *Fisheries Bulletin* **89**(1):79-89.

Lyons, W.G., D.G. Barber, S.M. Foster, F.S. Kennedy, and G.R. Milano. 1981. The Spiny Lobster *Panulirus argus*, in the middle and upper Florida keys: Population structure, seasonal dynamics and reproduction. *Florida Marine Research Publication* **38**:1-38.

Muller, R.G., J.H. Hunt, T.R. Matthews, and W.C. Sharp. 1997. Evaluation of effort reduction in the Florida Keys spiny lobster *Panulirus argus*, fishery using an age-structured population analysis. *Marine and Freshwater Research* **48**:1045-1058.

Munro, J.L. 1974. The biology, ecology, exploitation, and management of Caribbean reef fishes: crustaceans (spiny lobster and crabs). *Res. Rep. Sool. Dpr. Univ. West Indies.* **3**(VI). 57 pp.

Olsen, D. and I.G. Koblic. 1975. Population dynamics ecology and behavior of spiny lobster *Panulirus argus* of St. John, Virgin Islands 2 Growth and mortality. *Natural History Museum of Los Angeles Bulletin* **20**:17-21.

Pauly, D. 1984. Fish population dynamics in tropical waters: a manual for use with programmable calculators. ICLARM Studies and Reviews 8. Manila, Philippines. 325 pp.

Pauly, D. andJ.L. Munro. 1984. Once more on the comparison of growth of fish and invertebrates. *Fishbyte* **2**(1):21.

Pauly, D. and M.L. Soriano. 1986. Some practical extensions to Beverton and Holt relative yield per recruit model. Pages 491-496 in: J.L. Maclean, L.B. Dizon, and L.V. Hosillo (eds.) *The First Asian Fisheries Forum.* Asian Fisheries Society. Manila, Philippines.

Phillips, B.F., M.J. Palmer, R. Cruz, and J.T. Trendall. 1992. Estimating growth of the spiny lobster *Panulirus cygnus*, *Panulirus argus*, and *Panulirus ornatus*. *Australian Journal of Science Research* **45**(5).

Powers, J.E. 1985. An update of spiny lobster assessment data. National Marine Fisheries Service, Southeast Fisheries Center ML1-85-28. 10 pp.

Powers, J.E. and S.P. Bannerot. 1984. Assessment of spiny lobster resources of the Gulf of Mexico and southeastern United States. National Marine Fisheries Service, Southeast Fisheries Center, Miami, FL. 25 pp.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. *Bulletin of the Fisheries Research Board of Canada* 191. 382 pp.

Schaefer, M.B. 1954. Fisheries dynamics and the concept of maximum equilibrium catch. *Proceedings of the Gulf and Caribbean Fisheries Institute* **6** 53-63.

Sokal, R.R. and F.J. Rohlf. 1981. *Biostatistics, 2nd Edition.* Freeman. San Francisco, California USA.. 859 pp.

Tobias, W. [2000]. State/Federal Cooperative Fishery Statistics Program. Final Report, Government of the US Virgin Islands. In Press.

Von Bertalanffy, L. 1938. A quantitative theory of organic growth. *Human Biology* **10**(2):181-213.

Warner, R. E., C.L. Combs, and D.R. Gregory. 1977. Biological studies of the Spiny lobster, *Panulirus argus* in South Florida. *Proceedings of the Gulf and Caribbean Fisheries Institute* **29**:166-183.

Waugh, G.T. 1981. Management of juvenile spiny lobster *Panulirus argus* based on estimated biological parameters from Grand Bahamas Island Bahamas *Proceedings of the Gulf and Caribbean Fisheries Institute* **33**:271-289

Zetina, M.C.and G.V. Rios. 1998. Estimación del tamaño de la población de langosta *Panulirus argus* en las costas de Yucatán, usando diferentes modelos de evaluación. *Proceedings of the Gulf and Caribbean Fisheries Institute* **50**: 163-175.

# Movement Patterns of Tagged Spiny Lobsters *Panulirus argus* on the Bermuda Reef Platform

BRIAN E. LUCKHURST, TAMMY TROTT, NORBERT SIMMONS and SARAH MANUEL
*Division of Fisheries*
*P.O. Box CR52*
*Crawl CRBX*
*Bermuda*

ABSTRACT

A tagging program for spiny lobsters (*Panulirus argus*) commenced in April 1997 using mainly sub-legal sized (< 92 mm CL) lobsters obtained from commercial trap fishers during the lobster open season (September 1- March 31). As of October 2000, a total of 576 lobsters have been tagged with Floy anchor T-bar tags. There have been 51 recaptures of tagged lobsters to date for a recapture rate of 8.9 %. The longest distance (point-to-point) moved by a recaptured lobster was 45.9 km, which is essentially the length of the long axis (NE to SW) of the Bermuda reef platform. Similar movements by other recaptured lobsters demonstrate that movements of this magnitude occur in both directions on the platform. All recaptures except one have been reported by commercial lobster trap fishers, the one exception being a recapture reported by a recreational lobster diver. The mean straight-line distance travelled by all recaptured lobsters regardless of time at liberty was 12.2 ( ± 11.4, SD) km. The range of days at liberty was 9 - 700 days with a mean value of 294 (± 168 SD) days. The assessment of movement patterns of spiny lobsters is an important element in the management of the limited entry lobster fishery because of the use of defined trapping areas on the reef platform as an integral part of the management program.

## INTRODUCTION

Traditionally, commercial lobster fishing around Bermuda was conducted using Antillean arrowhead wire traps set on the reef platform and two offshore banks. These traps were used for both lobsters and fish with the funnel configuration and baiting procedure being modified dependent on the target species.

Knowledge of spiny lobster movement patterns on the Bermuda reef platform is limited. Sutcliffe (1952) examined the size frequency and sex ratio of lobsters caught in traps around Bermuda during the summer months. He found that migrations were associated with breeding and that there was as a definite relationship between depth and/or distance from shore and size of lobsters. Evans and Lockwood (1996) conducted a tag-recapture program for sub-legal sized (< 92 mm CL) *P. argus* on the Bermuda reef platform from August 1986 to September 1987. They concluded that undersized lobsters, particularly females, were capable of swift and lengthy migrations.

In 1990, the use of fish traps was banned as a management measure to aid in the recovery of overfished reef fish stocks. As a consequence, the commercial harvest of spiny lobsters was curtailed as the same traps were used for lobsters. As the spiny lobster population was considered to be healthy, an experimental fishery was established to develop and test designs for a lobster-specific trap which would have a minimal reef fish by-catch. After testing several different designs and sizes with commercial fishers (Ward and Luckhurst 1996), an acceptable trap design was developed. In 1996, a highly regulated limited entry commercial lobster fishery was established (Luckhurst 1999) with the Bermuda Government leasing fixed allotments of standard lobster traps to licence holders on an annual basis. For the first three months of the lobster season (1 September- 30 November), trapping is restricted to waters beyond the 10-fathom bathymetric contour. However, for the remaining four months of the season (December - March) fishers are permitted to bring their traps into one of two designated inshore areas (see Figure 1). The central portion of the reef platform is permanently closed to commercial lobster fishing and acts as a reservoir for spiny lobster where there is only limited recreational lobster diving.

The availability of lobsters to the commercial fishery in the two designated inshore areas is dependent to some extent upon the movement of lobsters from surrounding localities into the two areas to replenish lobster numbers as they are removed by the fishery. One of the management concerns in developing this spatial configuration for the fishery was that these two inshore areas might become depleted of lobsters due to the concentrated fishing effort. The objective of the present study was to increase our understanding of spiny lobster movement patterns over the Bermuda reef platform by conducting a long term tag-recapture study to evaluate movements in relation to the spatial configuration of the fishery.

## METHODS

The tagging program for spiny lobsters began in April 1997 and is ongoing, but the results reported in this paper are inclusive of those obtained up to October 2000.

The majority of the lobsters used in this tagging program were obtained during the last two months of each spiny lobster season (February, March). Sub-legal sized lobsters (< 92 mm carapace length (CL)) were obtained from commercial trap fishers. Each lobster was measured (CL), sexed, tagged between the carapace and abdomen on its dorsal side with a Floy anchor T-bar tag, and then released on the reef platform. Global Positioning System (GPS) readings were taken at each release site.

When a tagged lobster was recaptured, the site of capture was noted, the lobster was re-measured (for growth increment) and then returned to the fisher, provided it was of legal size (min. 92 mm CL), otherwise it was returned to the sea. It was not always possible to obtain all of the requested data for the recaptured lobster. GPS readings for the site of recapture were often not available and thus the recapture location was estimated based on information provided by the fisher.

For each recaptured lobster, the sites of release and recapture were plotted on a chart of Bermuda (British Admiralty chart No. 334) and the distance between the two points was measured to give the straight-line distance (km) moved by the lobster. This is a minimum estimate of distance travelled as there was no active tracking of tagged lobsters. Also, the time at liberty (days) (= date of release to date of recapture), and growth increment (mm) (= CL at recapture - CL at release) were calculated.

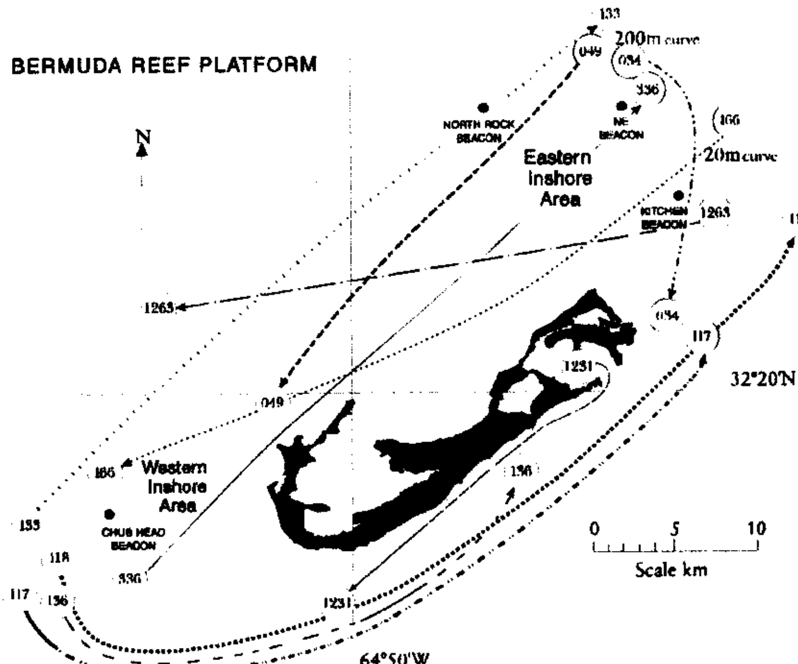


**Figure 1. Map of Bermuda reef platform indicating minimum distance tracks of selected tagged lobsters and location of the two inshore areas designated in the lobster management program.**

## RESULTS

Five hundred and seventy-six *P. argus* were tagged between April 1997 and October 2000. By the end of October 2000, 51 tagged lobsters were recaptured (Table 1) for a recapture rate of 8.9 %. All but one of the tag returns were from commercial trap fishers, the one exception was a lobster caught by a recreational diver.

**Table 1.** Summary data for Bermuda spiny lobster tag-recapture program.

| Tag # | Date of release | Size at release (mm CL) | Sex | Growth increment (mm CL) | Days at Liberty | Distance Moved (km) | Nominal Direction |
|---|---|---|---|---|---|---|---|
| T1209 | 16-Apr-97 | 82.0 | F | 13 | 216 | 14.6 | NNE |
| T1231 | 16-Apr-97 | 91.0 | M | ? | 189 | 20.8 | SW |
| T1263 | 17-Apr-97 | 84.0 | M | 12 | 200 | 22.5 | W |
| T1264 | 17-Apr-97 | 90.0 | F | ? | 700 | 1.6 | S |
| T1280 | 17-Apr-97 | 86.0 | M | 28 | 665 | 4.7 | SW |
| T1330 | 17-Apr-97 | 90.0 | F | 6 | 258 | 3.2 | NW |
| T1358 | 17-Apr-97 | 89.0 | F | ? | 520 | 5.6 | NE |
| T1383 | 17-Apr-98 | 120.0 | M | 15 | 281 | 7.4 | N |
| T0006 | 28-Oct-98 | 85.0 | M | 0 | 21 | 0.0 | - |
| T0021 | 3-Nov-98 | 91.0 | M | ? | 132 | 9.5 | N |
| T0034 | 3-Nov-98 | 88.0 | F | 0 | 9 | 3.4 | N |
| T0048 | 20-Nov-98 | 90.0 | M | ? | 129 | 13.2 | WSW |
| T0049 | 20-Nov-98 | 86.0 | F | 8 | 435 | 27.0 | SW |
| T0055 | 20-Nov-98 | 89.0 | M | 0 | 125 | 6.4 | SW |
| T0057 | 20-Nov-98 | 88.0 | M | ? | 50 | 7.7 | SSW |
| T0060 | 20-Nov-98 | 89.0 | F | 2 | 335 | 13.0 | W |
| T0077 | 20-Nov-98 | 90.0 | M | 23 | 465 | 10.5 | S |
| T0078 | 20-Nov-98 | 88.0 | F | ? | 303 | ? | ? |
| T0082 | 20-Nov-98 | 84.0 | M | ? | 45 | 10.5 | W |
| T0084 | 20-Nov-98 | 85.0 | F | 0 | 55 | 4.7 | WSW |
| T0087 | 20-Nov-98 | 84.5 | F | 23 | 429 | 10.5 | SW |
| T0091 | 20-Nov-98 | 87.0 | M | 22 | 419 | 8.4 | SW |
| T0117 | 1-Dec-98 | 85.0 | M | 13 | 339 | 38.0 | ENE |
| T0118 | 1-Dec-98 | 87.0 | M | 8 | 296 | 45.5 | ENE |
| T0127 | 1-Dec-98 | 87.0 | F | ? | 672 | 9.3 | SSE |
| T0133 | 1-Dec-98 | 87.0 | M | 18 | 359 | 42.6 | NE |
| T0136 | 1-Dec-98 | 82.0 | M | 13 | 286 | 24.1 | ENE |
| T0139 | 1-Dec-98 | 90.0 | M | 20 | 457 | 12.1 | E |
| T0151 | 4-Dec-98 | 87.0 | F | 11.5 | 670 | 1.6 | S |
| T0153 | 4-Dec-98 | 87.0 | F | 8 | 298 | 6.6 | S |
| T0155 | 4-Dec-98 | 85.0 | M | 0 | 108 | 9.7 | SW |
| T0156 | 4-Dec-98 | 87.0 | F | 4.5 | 285 | 10.9 | NW |
| T0163 | 4-Dec-98 | 85.0 | F | ? | 106 | 9.2 | W |
| T0166 | 4-Dec-98 | 87.0 | F | 9 | 419 | 31.5 | SW |
| T0183 | 21-Jan-99 | 87.5 | F | ? | 69 | 12.4 | SE |
| T0188 | 21-Jan-99 | 91.3 | M | 13 | 413 | 7.7 | SE |
| T0216 | 12-Feb-99 | 85.4 | F | 11.6 | 391 | 20.9 | W |
| T0221 | 12-Feb-99 | 81.1 | F | 12.5 | 227 | 12.2 | NE |
| T0267 | 29-Mar-99 | 88.0 | F | 9 | 332 | 5.6 | W |
| T0290 | 1-Apr-99 | 89.0 | F | 9 | 304 | 0.0 | - |
| T0302 | 1-Apr-99 | 87.3 | F | 13 | 280 | 9.5 | NNW |
| T0304 | 1-Apr-99 | 87.8 | F | 7 | 350 | 6.4 | W |
| T0305 | 1-Apr-99 | 92.0 | F | 7.5 | 333 | 3.2 | W |
| T0306 | 1-Apr-99 | 90.9 | M | 19 | 336 | 5.6 | N |
| T0312 | 1-Apr-99 | 90.5 | M | 17.5 | 309 | 7.7 | NNW |
| T0317 | 16-Dec-99 | 84.5 | F | 12.5 | 310 | 4.0 | S |
| T0334 | 16-Dec-99 | 91.5 | M | ? | 297 | 4.0 | S |
| T0336 | 16-Dec-99 | 90.0 | M | 5 | 298 | 45.9 | NE |
| T0346 | 16-Dec-99 | 90.5 | F | ? | 292 | 4.0 | S |
| T0361 | 29-Jan-00 | 88.0 | F | 7 | 233 | 16.4 | SW |
| T0274 | 23-Mar-00 | 90.0 | F | 5 | 163 | 4.8 | SW |

The results indicate that tagged lobsters show highly variable movement patterns. Of the 51 tag-recaptured lobsters, 25% were caught within 5 km of the release site (Table 1) while 10 tagged lobsters undertook movements exceeding 20 Km from their release site. The longest straight-line movement documented in our study was 45.9 km (Table 1) which is essentially the entire length of the Bermuda reef platform. A select number of the longest movements of tagged lobsters on the reef platform are indicated in Figure 1. These results suggest that lobsters readily move in either compass direction following the long axis (NE - SW) of the reef platform. However, as these are straight-line projections, there are no means to determine the actual track followed by tagged lobsters and these projections thus provide only minimum estimates. Active tracking could be accomplished by acoustic tagging of lobsters but this aspect was beyond the scope of the present study.

An example of a relatively rapid movement of a tagged lobster was an individual which moved 9.5 km in just nine days (Table 1). In contrast, two of the tagged lobsters were recaptured at their respective release sites with one being at liberty for over 10 months (Table 1). However, it is not possible to determine whether these lobsters had moved extensively during their time at liberty. A preliminary analysis suggests that there is no clear difference in the average distance moved by sex although the sample size is small. As virtually all of the tagged lobsters were sub-legal (< 92 mm CL), it is not possible to determine if there is a size effect on distance moved. The mean straight-line distance moved by all recaptured lobsters regardless of time at liberty was 12.2 km (± 11.4 SD). This suggests that movements are generally quite extensive although the sample size is insufficient to make a broad generalization.

The range of days at liberty was 9 – 700 with a mean value of 294 days (± 168 SD). Tagged lobsters were released during different months of the season (Table 1) but those released in April could not be recaptured during the five month closed season (April 1 - August 31). This factor could bias the estimate of mean days at liberty. However, the results indicate that lobsters are at liberty on average about 10 months. The longest period at liberty was almost two years (Table 1).

Accurate size measurements were obtained from 38 of the 51 recaptured lobsters allowing an estimate of the growth increment during the time at liberty (Table 1). The five recaptured lobsters which did not moult (zero growth increment) had a mean time at liberty of 64 days. All were released in November/ December when the water temperature is declining and therefore the lack of growth is not unexpected. In comparison, the maximum growth increment was 28 mm CL for a male released at 86 mm CL which remained at liberty for 665 days (Table 1).

## DISCUSSION

The lobsters in our study exhibited highly variable but often extensive movement patterns on the Bermuda reef platform. Sutcliffe (1952) documented movement patterns associated with reproduction. He found that sexually mature females migrated from the reef platform toward deeper water on the southern edge of the platform apparently after mating but before egg hatching. In a further study, Sutcliffe (1953) determined that lobsters larger than 145 mm CL were most frequently found in the lagoon area of the platform and were relatively uncommon further offshore. The majority of these large lobsters were males, and long term trapping results indicated that they did not migrate to the edge of the reef platform. Thus, it appears that smaller but sexually mature lobsters undertake the most extensive movements.

As the lobsters tagged in our study were almost all of sub-legal size (< 92 mm CL), we are unable to comment on movement patterns in relation to size. With a limited data set, Evans and Lockwood (1996) suggested that sub-legal sized lobsters might travel faster than larger, sexually mature individuals. The fastest movement documented in our study was an 88 mm CL female which moved 9.5 km in nine days (Table 1). The short-term movements of tagged lobsters in the study by Evans and Lockwood (1996) were generally smaller.

In terms of distance moved, there were 10 lobsters which were recaptured more than 20 km from their release sites. The maximum distance moved was 45.9 km by a 90 mm CL male with an additional three lobsters moving over 40 km (Table 1). The longest distance recorded by Evans and Lockwood (1996) for a tagged lobster was about 40 km, but the majority moved much smaller distances. Despite comments by Evans and Lockwood (1996) concerning clockwise or counterclockwise movements around the reef platform, it is not possible from conventional tagging data to make such assertions. A program with active tracking would be necessary to determine movement directions.

It is clear from the data presented here that lobsters are capable of extensive movements across the reef platform encompassing the two designated inshore areas used in the limited entry lobster management program. On the basis of these preliminary results, we conclude that lobster movements on the reef platform are probably sufficient to allow for the replenishment of these inshore areas following harvesting by the fishery at current levels of fishing effort. Close monitoring of the fishery will be necessary to ensure that the current management program can continue to provide sustainable harvest levels.

## ACKNOWLEDGEMENTS

We wish to thank all of the commercial lobster fishermen who helped us to obtain sub-legal lobsters for tagging purposes. This program would not have been a success without the cooperation of lobster fishermen who returned tagged lobsters to us, particularly Linwood Outerbridge, Eugene Barnes, Michael Barnes, Leonard Outerbridge, Jason Payne, Robert Lambe and Sinclair Lambe. We appreciate the assistance of Fisheries staff who assisted with tagging and release of lobsters.

LITERATURE CITED

Evans, C.R. and A.P.M. Lockwood. 1996. Long-term migratory behaviour of undersizedspiny lobsters *Panulirus argus* (Latreille) on the Bermuda island shelf. *Gulf of Mexico Science* 14:35-39.

Luckhurst, B.E. 1999. National Report of Bermuda. P. 180 -182. In: FAO / Western Central Atlantic Fishery Commission. Report on the FAO/ DANIDA/ CFRAMP/ WECAFC Regional Workshop on the Assessment of the Caribbean Spiny Lobster (*Panulirus argus*). FAO Fisheries Report No. 620. FAO. Rome, Italy.

Sutcliffe, W. H. Jr. 1952. Some observations of the breeding and migration of the Bermuda spiny lobster, *Panulirus argus*. *Proceedings of the Gulf and Caribbean Fisheries Institute* 4:64-69.

Sutcliffe, W. H. Jr. 1953. Further observations on the breeding and migration of the Bermuda spiny lobster, *Panulirus argus*. *Journal of Marine Research* 12: 173-183.

Ward, J.A. and B.E. Luckhurst. 1996. Development of a lobster-specific trap in Bermuda and fisheries management considerations for the re-establishment of a commercial lobster fishery. *Proceedings of the Gulf and Caribbean Fisheries Institute* 44:566-578.