PART I LOBSTER ASSESSMENT REPORTS

edited by P.A. Medley

1 REPORT ON WORKSHOPS HELD IN BELIZE CITY AND MERIDA

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1.1 BACKGROUND TO THE WORKSHOPS

This report covers the methods, progress, results and conclusions of two international workshops on assessment and management of the Caribbean spiny lobster, *Panulirus argus*. The workshops were held in Belize City, Belize, from 21 April to 2 May 1997, and Mérida, Mexico, from 1 to 12 June 1998, respectively. Both were sponsored by the CARICOM Fisheries Resources Assessment and Management Program (CFRAMP) and the FAO/DANIDA Project GCP/INT/575/DEN.

The workshops were also organised as training exercises in data processing, stock assessment and report writing. Lecture notes on useful methods were prepared and presented by the consultants Gonzalez-Cano and Restrepo (see Part III).

The Caribbean spiny lobster occurs from North Carolina in the United States of America and Bermuda in the north to Rio de Janeiro, Brazil, in the south. In an east-west direction, it occurs from the Gulf of Mexico to the Antilles islands. It is found in coral reef and rocky areas and extends to a depth of up to 90m (Cervignón *et al.* 1993).

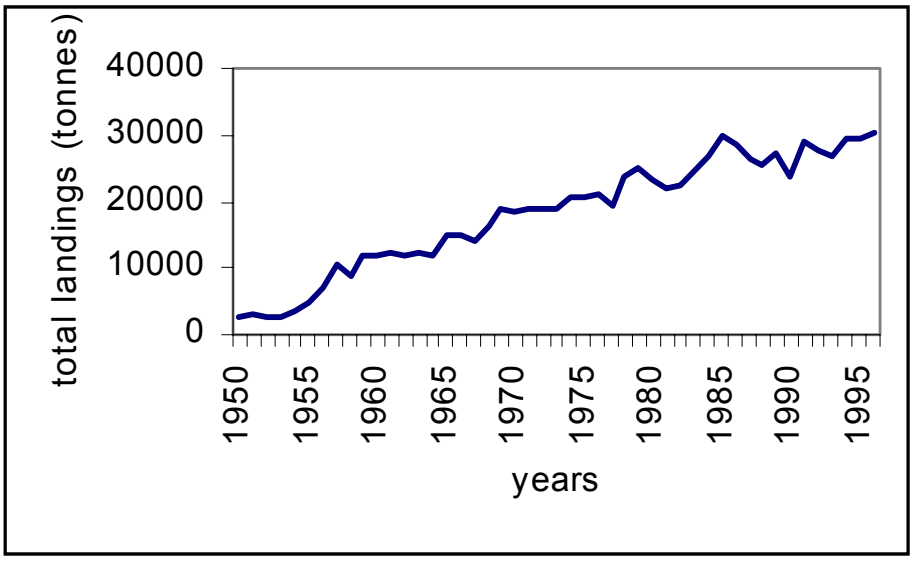

Figure 1.1 Landings of *P. argus* from all countries in the WECAFC area from 1950 to 1996, as recorded on the FAO Fishstat database

The fisheries for this species make a major economic and social contribution to many of the nations of the region (See Chapter 2). Over 30 000 tonnes of spiny lobster were recorded on the FAO database, Fishstat, as having been landed in 1996, following an almost linear increase in annual landings since 1950, the earliest year for which these data are available (Figure 1.1).

This steady increase over a period of nearly 50 years is cause for concern and indicated the need for an urgent examination of the status of the lobster resources in each of the lobster producing nations and in the region as a whole. These workshops were initiated to play a role in addressing this need.

The stock or stocks of spiny lobster cross many national boundaries and this imposes specific difficulties and requirements for their effective management. The necessity for managing transboundary stocks (i.e. either shared, as in the case of lobster, or straddling) over their entire range is well understood, and is reflected in the Code of Conduct for Responsible Fisheries, which encompasses the precautionary approach. The Code of Conduct for Responsible Fisheries was unanimously adopted by the FAO Conference in November 1995. It describes the principles and standards which should be applied in the conservation, management and development of all fisheries and also covers the capture of fish, processing and trade of fish and fish products, fishing operations, aquaculture and the integration of fisheries into coastal area management. The Code is aimed at members and non-members of the FAO, fishing bodies, subregional, regional and global organisations, both governmental and non-governmental, and all people involved in fisheries and activities related to fisheries.

The Code is not binding and its implementation is voluntary. However, it is consistent with, and parts are based on, the United Nations Convention on the Law of the Sea of 1982. It contains provisions already covered by other legally binding instruments such as the Agreement to Promote Compliance with International Conservation and Management Measures by Fishing Vessels on the High Seas, 1993.

All aspects of the Code are highly relevant to the spiny lobster fisheries in the WECAFC area and should be studied by the relevant authorities. However, considerations in the management of transboundary resources are particularly relevant to the two lobster workshops. There is little doubt that the spiny lobster resource of the region is transboundary. The working hypothesis for this workshop was that there are four separate sub-stocks and, through larval drift, there are probably also significant exchanges between these sub-stocks (see Chapter 4). Where resources are transboundary, effective management requires that the stock is managed over the full range of its distribution (Code of Conduct, 7.3.1). The implications of this, and other requirements for responsible utilisation of transboundary resources, can be summarised as follows.

1. For transboundary fish stocks... the States involved should co-operate to ensure effective conservation and management of the resources. This should be achieved ... through a ... fisheries organisation or arrangement (Code of Conduct, 7.1.3).
2. To be effective, fisheries management should be concerned with the whole stock unit over its entire area of distribution (Code of Conduct, 7.3.1).
3. In order to conserve and manage transboundary fish stocks... management measures should be compatible. Compatibility should be achieved in a manner consistent with the rights, competencies and interests of the States concerned (Code of Conduct, 7.3.2).
4. States... should foster and promote international co-operation and co-ordination ...including information gathering and exchange, fisheries research, management and development (Code of Conduct, 7.3.4).
5. States should compile fishery-related and other supporting scientific data relating to fish stocks... in an internationally agreed format and provide them in a timely manner to the organisation... should agree on a mechanism for co-operation to compile and exchange such data (Code of Conduct, 7.4.6).

1.2 PARTICIPATING COUNTRIES

Participants from the Bahamas, Belize, Brazil, Colombia, Cuba, the Dominican Republic, Honduras, Jamaica, Mexico, Nicaragua, the United States of America and Venezuela attended both meetings, while Bermuda and St Lucia were represented only at the 1998 and 1997 meetings respectively. Haiti was invited to participate in the meetings, but was unable to attend. Inputs from the Turks and Caicos Islands were presented through a consultant. Lists of participants and staff are presented at the end of this section. Country statements were prepared for each workshop, based on a given outline. The two statements as presented in Part II of this document were combined, with the exception of those for Nicaragua, the USA and Venezuela.

1.3 WORKSHOP OBJECTIVES

The overall objectives of the workshops were as follows.

1. To undertake stock assessments for each country, using the data that were available and using methods that were appropriate to the resource dynamics, fishery and data in each country.
2. To consider the management and fishery implications for each country of the results obtained from the stock assessments.
3. To interpret the national results in terms of sub-regional and regional linkages, including sharing of the stock and fishery interactions.
4. For those countries where sufficient progress could be made in the underlying stock assessments, to implement bioeconomic models using economic data from the country and results from the stock assessments. For those countries that did not have the data necessary to achieve this objective, some basic training in the application and use of bioeconomic models was to be provided.
5. To characterise the population dynamics of the stock(s) so as to build models to examine the implications of alternative management regimes, including costs, benefits and uncertainty considerations. As a result of time constraints, this objective could only be realised for some countries and only at the national, rather than the stock or sub-stock level.

Within these overall objectives, greatest emphasis was placed on obtaining the best estimate of the status of the stocks. As far as possible, assessments included evaluation of variability in recruitment to the juvenile stocks and fisheries, differences in underlying assumptions and their affect on results, and consideration and description of other sources of error. Some level of stock assessment was attempted for each country but, depending on the data available, the assessments ranged from simple length-converted catch curve analysis to age-structured ADAPT-type analyses (see Part III).

Careful consideration was given at the 1997 workshop to the likely stock structure of *P. argus* in the WECAFC region. While no conclusive statements could be made on the existence of discrete stocks, it was agreed that, for working purposes at least, four possible sub-stocks could be identified, based on the distribution of the species, the nature of the coastal shelf and the prevailing currents within the region.

These ‘sub-stocks’ are:

- Brazil, possibly including Venezuela;
- Colombia, Nicaragua, Honduras and Jamaica;
- Mexico, Belize and southern Cuba;

- Northern Cuba, United States of America (Florida), Bahamas, Turks and Caicos Islands and Bermuda.

Because the available data were almost exclusively based on national monitoring and sampling, assessments were undertaken by country, but the national results within each 'sub-stock' were then considered sub-regionally:

- Group 1: Brazil and Venezuela
- Group 2: Belize, SW Cuba and Mexico
- Group 3: The Bahamas, Bermuda, North Cuba, the Turks and Caicos Islands and Saint Lucia
- Group 4: Colombia, Honduras, Jamaica, Nicaragua and the Dominican Republic

Full bioeconomic analyses could only be undertaken on three national fisheries, which had the most data available and on which the most complete stock assessments were carried out during the second workshop. These were the Gulf of Batabanó (Cuba), Isla Mujeres (Mexico) and Brazil. These bioeconomic analyses, reported in Chapter 9, included consideration of some of the most important sources of uncertainty, and generated indicators of the economic and biological performance of a range of different management options. At the end of the 1998 workshop, some time was still needed to be spent by the national participants on checking the models developed and the data used in them, and also on exploring other management alternatives. Nevertheless, these models now represent very valuable decision-making tools, and can and should be utilised to advise and inform the decision-makers in each country on management options available to them and their impacts.

In most, if not all of the other countries for which full bioeconomic analyses could not be undertaken, the stock assessment results provided new and important information on the status of the resources and fisheries and highlighted the general nature of any management actions required. Descriptions of the analyses undertaken and the results are provided in Chapters 5 to 8 inclusive.

Finally, the results of the stock assessments undertaken for each country and sub-region were considered within the regional context and regional patterns and features considered and described (See Chapter 10). Responsible fisheries management requires co-operation in research and management between countries sharing common resources. The existing management regimes in the region were considered in the light of the results of the workshop and the requirements for improved management were considered, with particular emphasis on regional requirements.

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2 REGIONAL REVIEW

N. M. Ehrhardt

The spiny lobster, *Panulirus argus*, is widely distributed in the Central Western Atlantic Ocean from Brazil to Bermuda. The species sustains fisheries which are second only to penaeid shrimps as the economically most important fisheries in the region with a total ex-vessel value of about US$350 million in 1995 (Fig. 2.1). Historic overall landings (Fig. 2.2) show that the fisheries started in the early 1960s, as demand for spiny lobsters increased in the markets of more developed countries. This fishery expansion as depicted by trends in landings appeared to have reached a stable level in 1984 since during the period 1984-1997, landings have oscillated between 35000 and 42000 tonnes whole weight with only a slight increasing trend (Fig. 2.2). An asymptotic historic landing growth model fitted to the data in Figure 2.2 indicates that long-term average landings may be constrained about an asymptotic maximum landing level of 43500 metric tons whole weight. The indication is, therefore, that at present spiny lobster resources in the region may be generating landings that are close to their maximum.

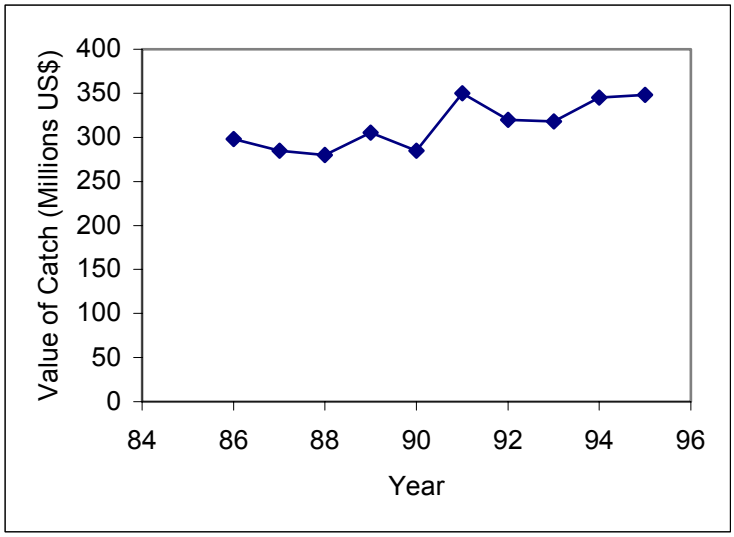


Figure 2.1 Annual value of reported landings of *P. argus*

Spiny lobster fisheries are mostly artisanal or semi-industrial. This is the consequence of spiny lobsters being highly accessible and cacheable with simple gear types such as spears, aggregating devices (casitas or condominium), traps and gillnets. On the other hand, the high ex-vessel prices paid for the product (US$4 to US$25 kg^{-1} depending on the fishery/country) attracts many small-scale fishers. In this regard, spiny lobsters are a unique resource when compared with other fishery resources in the region, in that it generates a relatively high return on the low capital investment in boats and gear. These conditions result in a generally low opportunity cost for other fishery resources in tropical fisheries, thus increasing the fishing pressure over spiny lobsters.

The main spiny lobster resources in the Central Western Atlantic Ocean are principally located on the larger continental shelf - reef areas of the region. Thus, the shelves of Brazil (what is believed to be the most up-stream stock), Honduras-Nicaragua, Belize-Mexico, Florida, the Bahamas, and south of Cuba are conspicuous areas where main fisheries are located. A review of landings by countries indicates that 6 countries associated with those areas are producing between 70 and 80% of the overall regional landings (Fig. 2.3). Cuba historically produced the largest landings in the region followed by Brazil, the Bahamas, the

United States, Honduras and Nicaragua. Generally, landing trends by these countries show rather large inter-annual variability.

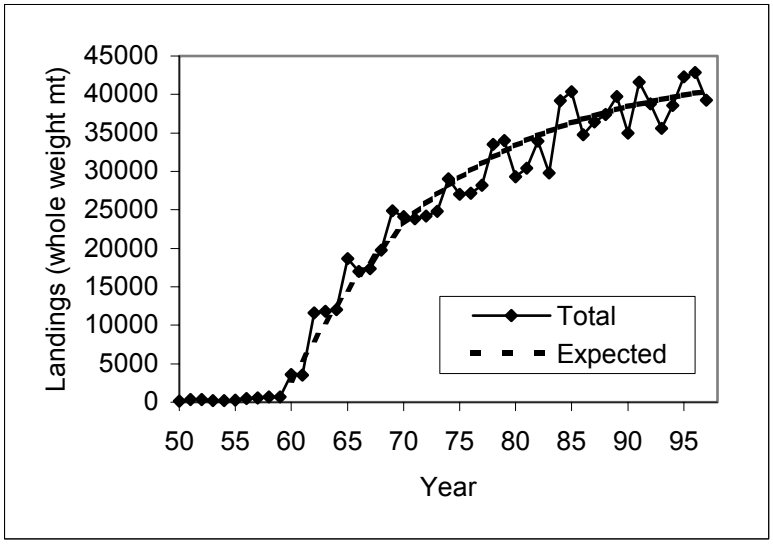


Figure 2.2 Total landings of spiny lobster. The expected landings are generated from a simple asymptotic model, and can be used to extrapolate to the maximum landings, in this case of about 43500 tonnes

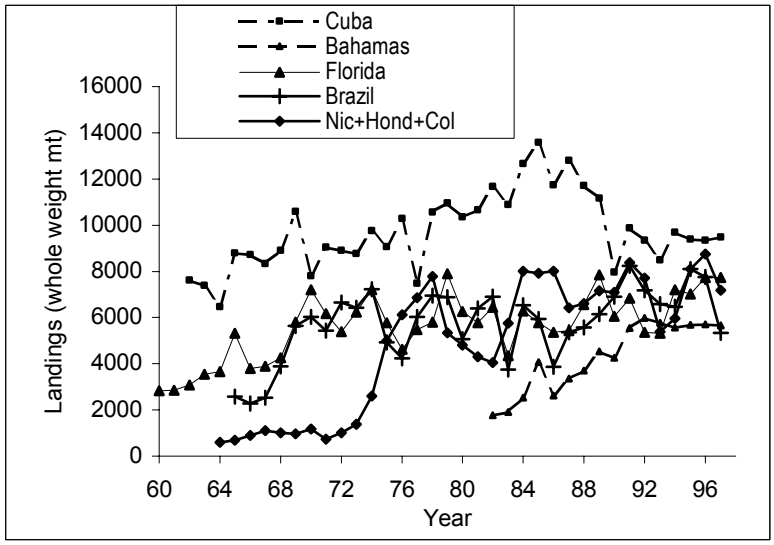


Figure 2.3 Landings broken down by shelf area

Some of these main fisheries were still developing in the 1970s, while in the mid-1980s declining landing trends were followed by increasing trends in the 1990s. The exception to these patterns is the fishery in Cuba where after many years of stable landings, a significant steady decrease in landings is observed starting in 1989. Landings of the most important spiny lobster producing countries have converged toward landing levels which are in the range 6000 to 8000 tonnes whole weight per year during the 1991-1997 period (Fig. 2.3).

Figure 2.4 shows the landing trends historically observed in Mexico and Belize. A similar general trend is observed during the later half of the time series (1986-1997). Less conspicuous trends are observed between historic landings in Florida and the South of Cuba (Batabanó Bay area; Fig. 2.5), but strikingly, landing trends observed in Brazil and Florida are very well correlated (Fig. 2.6). Similarities in spiny lobster production trends may be indicative of similar biological processes that may be present in the sub-regional stocks

sustaining these fisheries or that pueruli may be transported for long periods of time in the ocean currents thus potentially recruiting in other regions. These linkages, however, need to be established because of the obvious regional versus country implications of fishery management strategies that could be implemented to optimise use of these resources.

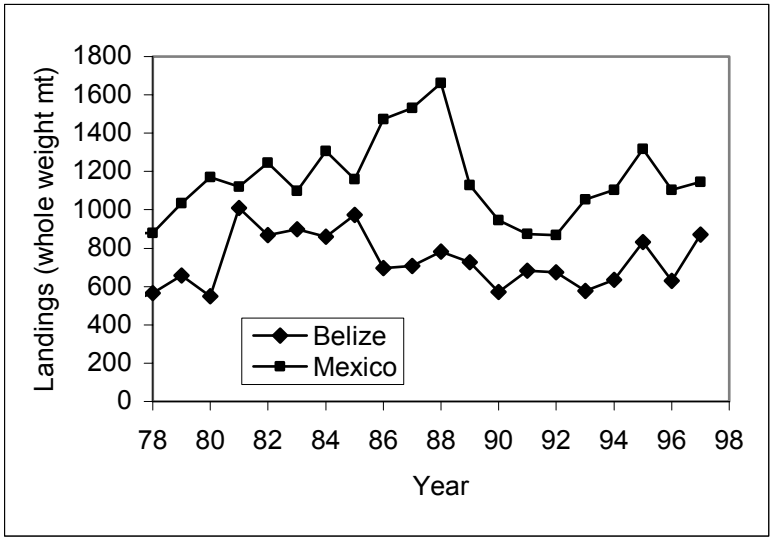


Figure 2.4 Landings from Belize and Mexico

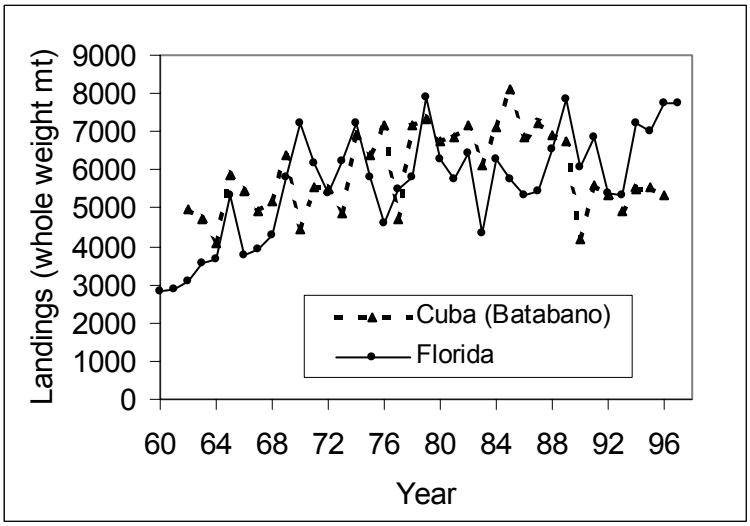


Figure 2.5 Landings from SW Cuba and Florida

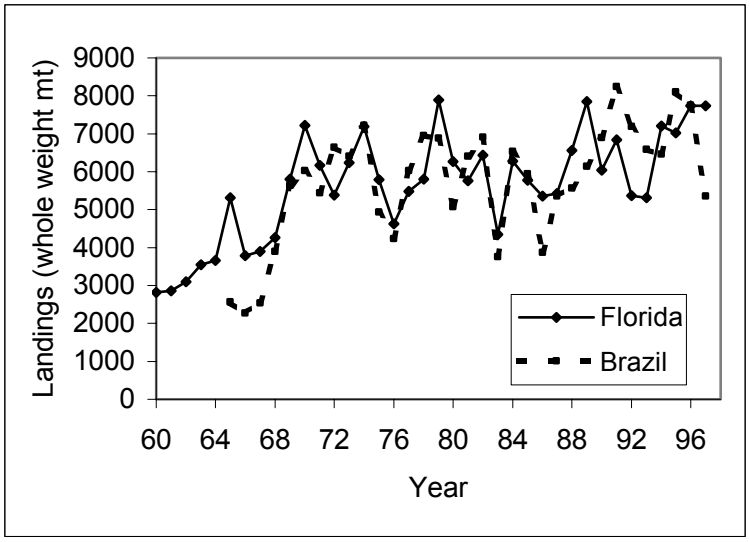
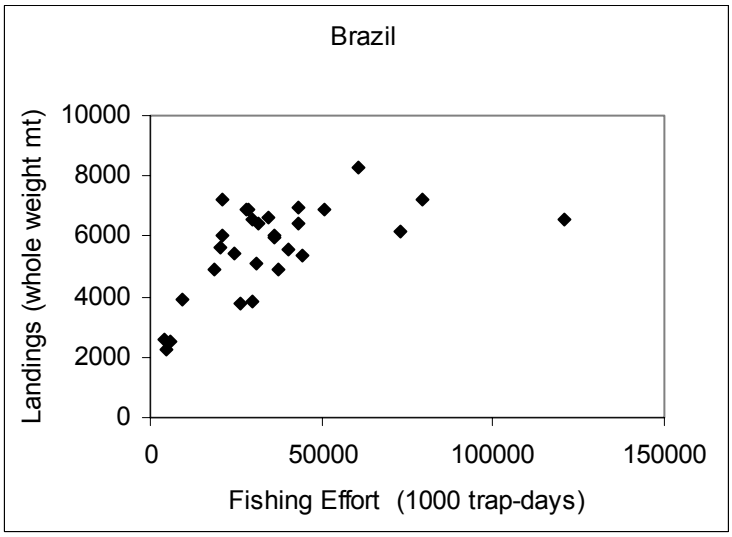


Figure 2.6 Landings from Florida and Brazil



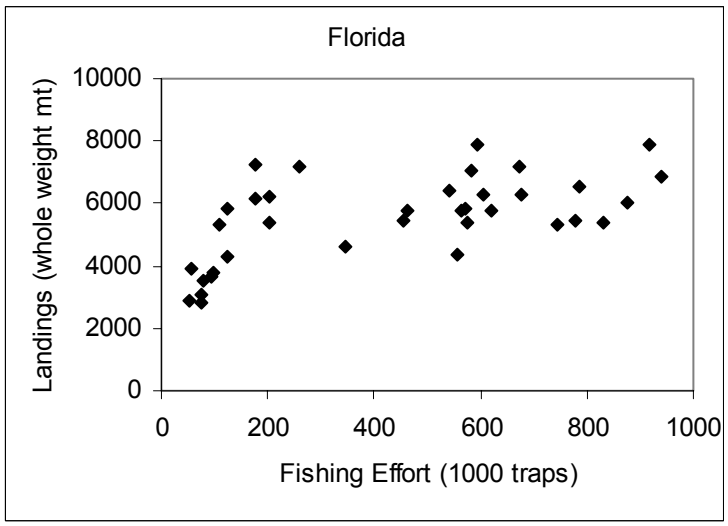


Figure 2.7 Catch and effort for Brazil and Florida fisheries

In most countries in the region spiny lobster fisheries are of open access. However, due to an excess of fishing effort, some countries, such as the United States and Bermuda, have recently adopted measures to limit access. In the case of Cuba, access to spiny lobster fishing is already strictly controlled, therefore production planning allows optimisation of lobster production in that country. In general, limitation of fishing effort in these three countries appears to have facilitated implementation of management strategies to optimise use of this resource. This is in clear contrast to open access fisheries where over-capitalisation seems to be a common feature. In an analysis performed at the second workshop, it is pointed out that significant increases in fishing effort have been reported in the Honduras-Nicaragua fisheries and that artisanal fleets are conspicuously replacing industrial fleets in Brazil in spite of the very high levels of fishing effort already deployed in this fishery. Figure 2.7 shows trends of landings and fishing effort levels in the Brazil and in the Florida fisheries including the era of open access. From the figure it is evident that effort levels have far exceeded the levels required to obtain similar landing levels in these two countries. For this reason a trap reduction programme was established in 1992 in the Florida fishery with the aim of reducing fishing effort from about 1 million traps to less than 300 thousand. It is believed that the later amount of effort should generate similar landings as with 1 million traps, but with a considerably higher average catch per trap.

Because of the artisanal nature of these fisheries, catch and effort statistics are difficult to collect or to document properly in meaningful time and space scales. This difficulty prevents more accurate analysis of the regional characteristics of the fisheries, the evolution of fishing effort and fishing tactics, as well as the effectiveness of fishery management. Given the extraordinary value of these fisheries, long range stock assessment work should be implemented under the sponsorship of the countries and industries involved, so as to secure the future sustainability of spiny lobster production through wise management.

3 BIOLOGY

A.M. Arce and M. E. de León

3.1 INTRODUCTION

The following review of the biology of spiny lobster was used as a source of information for the stock assessments carried out during the workshop. This section is not exhaustive, but does provide an overview of the current perceptions on life history, growth and mortality for this species. In using all the information of this section, careful consideration should be given to the uncertainty surrounding many of the results. In most cases no standard errors or other measures of accuracy are given for parameter estimates. Those interested in using estimates are urged to seek out original papers to verify the accuracy of reported results.

3.2 LIFE HISTORY

The spiny lobster *Panulirus argus* is able to utilise a variety of environments and it changes habitats several times during its ontogenetic development. The species ranges from Bermuda and North Carolina (USA) to Rìo de Janeiro in Brazil.

After mating, females may move several kilometres to the edges of the reefs or coastal shelves to incubate and release larvae (Buesa, 1965). The larvae are planktonic in oceanic waters where they are thought to spend 6-10 months, including 11 pelagic larval stages (Lewis *et al.*, 1952; Baisre, 1964; Sims and Ingle, 1967). During their long period in the plankton, the larvae become widely distributed throughout the Caribbean ocean (Alfonso *et al.* 1991; Baisre *et al.*, 1978). The phyllosoma larvae metamorphose into pueruli, which swim across the continental or insular shelf to arrive at the coast every month of the year, but with a main settlement peak in September-December (Cruz *et al.*, 1995; Briones, 1994; Young, 1991; Peacock, 1974 and Bannerot *et al.*, 1992). The pueruli settle in clumps of *Laurencia* (Marx and Herrnkind, 1985; Herrnkind and Butler, 1986; Lalana *et al.* 1989) associated with 29 species of algae (Brito and Seers, 1994) and occasionally in the algal web on submerged mangrove roots (Witham *et al.*, 1964). After settlement pueruli moult and become post-puerulus, known as the algae phase (Butler *et al.*, 1997) with a size range of 6 - 15mm CL. Post-pueruli become juveniles between 10-15 months after settlement (Cruz *et al.*, 1995; Davis, 1978). Post-algal sizes 26-35mm CL still occupy vegetated habitats, but late juveniles (>35mm CL) and sub-adults (70-76mm CL) tend to occupy patches of reef habitats without vegetation (Arce *et al*., 1997). Juveniles leave the settlement (post-algae juveniles) and seek refuge in caves, coral reefs, sponges and soft corals (Herrnkind *et al.*, 1994). Older juveniles migrate offshore and recruit to the fishery at 76mm CL (Cruz *et al*., 1986a; Davis, 1978). In Florida males attain the size of 76mm CL in an average of 23 months, whereas females require an average of 30 months (Muller *et al*., 1997). Figure 3.1 illustrates the average times required to pass from one stage to the next, based on data from Cuba.

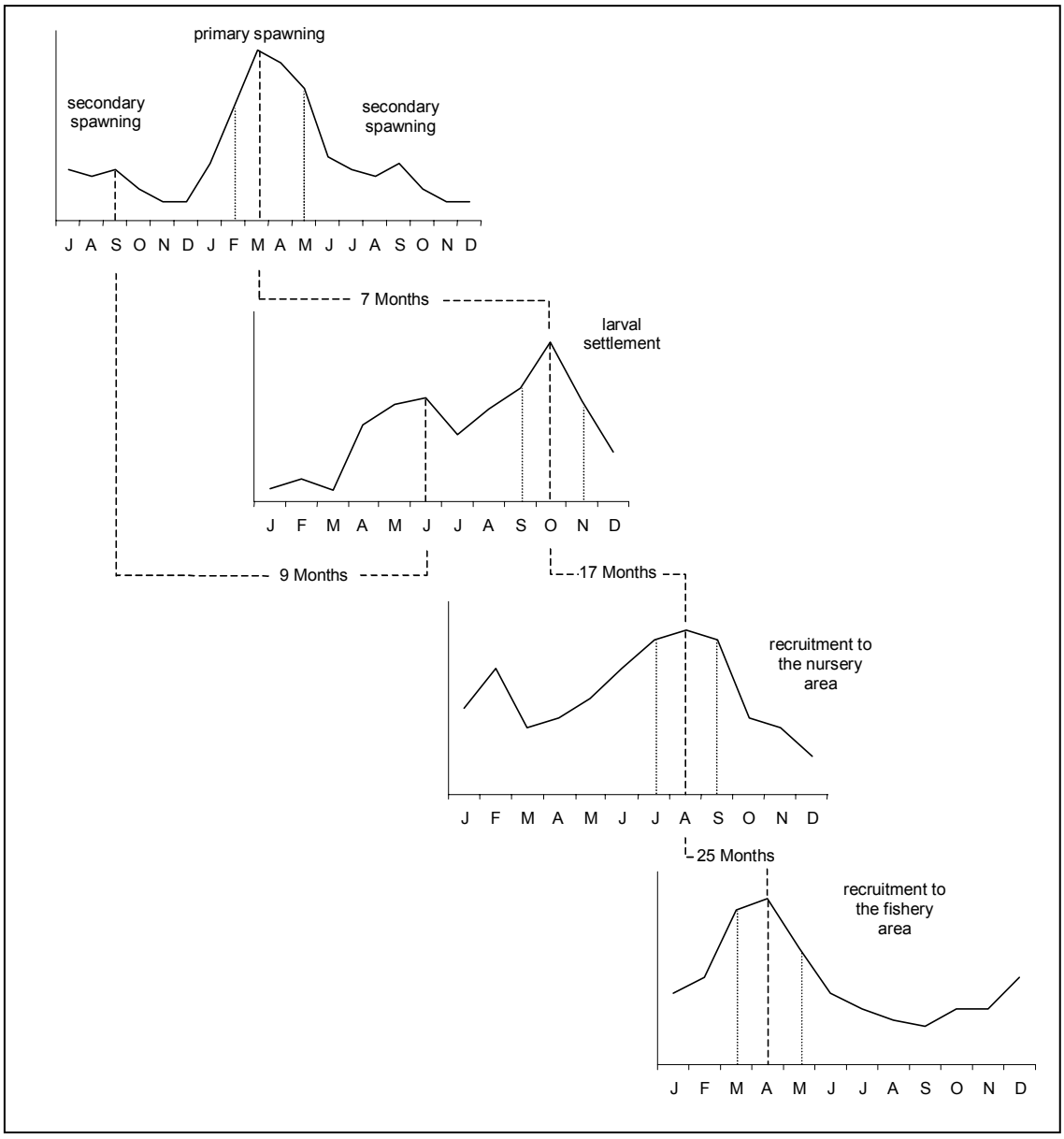


Figure 3.1 Life history periods as suggested by seasonal peaks in indices

3.3 REPRODUCTION

3.3.1 Seasonality

Panulirus argus reproduction appears to be consistently higher in the spring and summer months (March-July) although this activity is observed all year round (Table 3.1). In Cuba, reproduction occurs throughout the year with greatest numbers of berried females occurring between March to May and a subsidiary peak in September.

On the Nicaraguan shelf the greatest reproductive activity has been observed during March and September-November (Castaño and Cadima 1993). In Colombia, main peaks of reproduction were reported for May and from September to October, although reproductive activity was also observed all year round (Gallo *et al*., 1998). However, as these last results

are not consistent with other reports in the region (Table 3.1), they should be verified through further studies.

Table 3.1 Mean monthly relative frequencies of females in the process of reproduction

	Brazil	Belize (South)	Belize (Central)	Cuba	Mexico, Quintana Roo	Turks & Caicos Islands	USA, Florida	Nicaragua
	Ivo (1996)	FAO (1968b)	FAO (1968b)	Cruz & León (1991)[1]	Ramirez (1996)	Medley & Ninnes (1997)[2]	Lyons *et al*, (1981)	Castaño & Cadima (1993)
	%Mature	%Berried	%Berried	% B&S[3]	% B&S[3]	%Tar spot	% B&S[3]	% Berried
J	6.4			8	15	19.5	0.4	2.5
F	12.5			17	22	20.0	0.3	6
M	16.3			27	32	51.6	6.2	15.5
A	12.9			26	40	61.1	19.3	2.5
M	12.5			20	32	54.8	22.7	5
J	11.7			10	25	71.4	32.4	12.5
J	7.8			8	25		21.3	2.5
A	4.5	11.8	0.6	7	19	50.2	16.4	2.5
S	3.3	35.5	1.3	9.5	14	33.2	15.8	17.5
O	4.5	52.3	10.5	11	9	33.2	5.8	10
N	5.8	41.7	4.8	2	6	19.2	3.4	11
D	1.6	33.6		2	8	28.3	1.6	2.5

[1]Data are used from the years 1982 to 1989

[2]Estimates use a logit model to correct for size bias in the sample.

[3]% B&S- Berried and spermatophored females

3.3.2 Size

Size at first maturity was found to be in the range 78-83mm CL for all countries. In Brazil, the size at first maturity was estimated at 201mm total length by Soares and Cavalcante (1985). For Cuba, the smallest size that a berried lobster was captured was 67mm CL (Cruz and León, 1991) and the estimated sizes at 50% and 100% maturity were 81mm and 97mm CL, respectively. In the Turks and Caicos Islands, tar spot (spermatophore) data were recorded from sampled landings. A logit model was used to separate season and size (Medley and Ninnes, 1997). The results largely agree with other assessments, size at first maturity was 83mm, 50% fecundity occurred at 93mm and full fecundity at approximately 108mm CL (Fig. 3.1).

For the Nicaraguan shelf, the most frequent reproductive sizes were 85-89 mm CL; however, berried females of 70-74mm CL have also been reported (Castaño and Cadima, 1993). For Colombia, the estimated size at 50% maturity was 92mm CL, however, the smallest female carrying eggs was only 72mm CL (Gallo *et al*. 1998).
In 1996, the Florida Department of Environmental Protection collected data to develop a lobster fecundity model (Cox *et al.* 1997). Female lobsters with eggs were observed from April through to October. In the first season of sampling, the number of eggs (E) from 129 females ranged from 147 000 (72mm CL) to 1 952 000 (141mm CL) and the following fecundity-length relationship was obtained:

$E = 98.34\, L_T^2 - 1\,261\,651$ ($r^2 = 0.91$, n = 129, for the size range 72-141 mm)

A relationship between fecundity and carapace length estimated for SW Cuba was:

$$E=0.5911\ L_C^{2.9866}$$

Ivo and Gesteira (1986) estimated the following functional relationship between total length and fecundity:

$$E = -801536 + 4610.5\ L_T$$

This equation was transformed (approximately) into one based on carapace length using a morphometric transformation (Rios, 1991):

$$E = -1031600 + 17474.2\ L_C$$

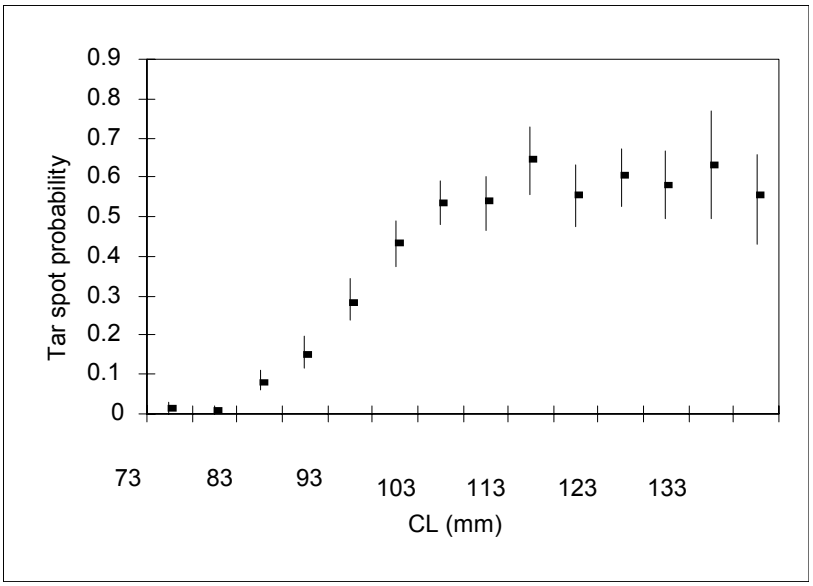


Figure 3.1 Tar spot probabilities for female lobsters estimated from a logit model, Turks and Caicos Islands (Medley and Ninnes, 1997)

3.4 MORPHOMETRIC CONVERSIONS

Available morphometric conversions are presented in Table 3.2. No standard errors are available for parameter estimates, and models should therefore be treated with caution. Cuba's morphometric conversion estimates were derived from the largest sample, and also featured the widest size range (including fishery independent samples) over the longest period (1960-1990). In the absence of local data, it was recommended that Cuba's morphometric models be used for practical reasons. Cuba reported puerulus (at settlement) mean carapace length equal to 5.8mm, post-puerulus (after one moult) mean carapace length equal to 7.0mm.

Table 3.2 Morphometric conversion equations by country

Location	Sex	Relationship	Reference
Belize	Γ+E	$L_C = 2.6142\ S_{2L} + 8.5148$	Fisheries Dept. /
	Γ+E	$L_C = 0.5441\ L_t + 3.1627$	CFRAMP
	Γ+E	$L_C = 1.392\ S_{2w} + 6.6738$	(unpublished data)
Brazil	Γ	$L_C = 0.6071\ L_t - 5.2631$	Ivo (1996)
	E	$L_C = 0.5432\ L_t + 0.3442$	Rios (1991)
	Γ+E	$L_C = 0.379\ L_T - 4.99$	
	Γ+E	$Lt = 0.612\ L_T + 5.62$	
	Γ+E	$W_T = 6.6\ 10^{-05}\ L_T^{2.90}$	
Cuba	Γ	$L_T = 2.519\ L_C + 32.8431$	$40 \leq L_C \leq 160$
	E	$L_T = 2.9290\ L_C + 9.8740$	$30 \leq L_C \leq 130$
	Γ+E	$L_T = 2.5402\ L_C + 36.3535$	$30 \leq L_C \leq 160$
	Γ	$L_C = 0.3925\ L_T - 11.7974$	$120 \leq L_T \leq 430$
	E	$L_C = 0.3374\ L_T - 2.3439$	$110 \leq L_T \leq 400$
	Γ+E	$L_C = 0.3838\ L_T - 11.6569$	$110 \leq L_T \leq 430$
	Γ+E	$L_C = 0.29\ L_T + 0.29$	$15 \leq L_T \leq 60$
	Γ	$W_T = 0.00207\ L_C^{2.792}$	Cruz *et al.* (1981)
	E	$W_T = 0.00279\ L_C^{2.736}$	
	Γ+E	$W_T = 0.00460\ L_C^{2.630}$	
Florida, USA	Γ	$W_T = 0.00287\ L_C^{2.71}$	Estimates
	E	$W_T = 0.00195\ L_C^{2.81}$	determined during
	Γ	$W_T = 3.38\ W_t - 23.8$	1997 working
	E	$W_T = 2.97\ W_t - 0.327$	group session
Mexico,Yucatan	Γ	$L_T = 1.47 + 1.39\ L_t$	Zetina *et al.* (1996)
	E	$L_T = 2.42 + 1.34\ L_t$	
	Γ	$L_C = 0.81 + 0.59\ L_t$	
	E	$L_C = -0.06 + 0.45\ L_t$	
	Γ	$W_T = 0.05\ L_T^{2.93}$	
	E	$W_T = 0.62\ L_T^{2.72}$	
Mexico, Bahía de la Ascensión	Γ	$L_C = 0.65\ L_t - 9.11$	Coba-Cetina
	E	$L_C = 0.56\ L_t - 1.23$	(1990)
	Γ+E	$L_C = 0.611\ L_t - 5.44$	
	Γ	$L_C = 3.064\ S_{2L} - 0.016$	
	E	$L_C = 2.749\ S_{2L} + 5.57$	
	Γ	$L_t = 4.38\ S_{2L} + 22.83$	
	E	$L_t = 4.69\ S_{2L} + 16.63$	
México ,Quintana Roo	Γ	$L_C = 0.672\ L_t - 0.98985$	Gonzalez-Cano
	E	$L_C = 0.5687 L_t + 0.01377$	(1991)
	Γ	$L_t = 1.3568\ L_c + 2.7894$	
	E	$L_t = 1.5542\ L_c + 1.98659$	
	Γ	$L_T = 1.6430\ L_t - 0.87812$	
	E	$L_T = 1.5476\ L_t + 0.02239$	
	Γ	$L_t = 0.5876\ L_T + 1.08196$	
	E	$L_t = 0.61937\ L_T + 0.70223$	
	Γ	$L_c = 0.4122\ L_T - 0.71368$	
	E	$L_c = 0.3722\ L_T - 0.12092$	
	Γ	$L_T = 2.32684\ L_c + 2.72253$	
	E	$L_T = 2.54141\ L_c + 1.75760$	
	Γ	$W_t = 0.031236 * L_t^{3.18764}$	
	E	$W_t = 0.044841 * L_t^{3.02943}$	

S_{2L} = 2nd segment length (mm), S_{2w} = 2nd segment width (mm), L_C = Carapace length (mm), L_t = Tail length (mm), L_T = Total length (mm), Total weight = W_T (g), Tail weight = W_t (g)

3.5 GROWTH

Numerous factors (notably temperature, maturation and season) affect the growth of spiny lobster *Panulirus argus*. Several studies reported sex-specific growth rates, with a higher rate

for males than for females. For example, Hunt and Lyons (1986) reported that the growth rate for females was 33.3% lower than the estimate for males. However, such sex-specific growth differences have not been found in juveniles (<76mm CL).

3.5.1 von Bertalanffy Growth Model

Many estimates of spiny lobster growth have been obtained in the region since the 1960s using a variety of methods, primarily length-frequency based analyses (Table 3.3) Obtaining reliable estimates of von Bertalanffy growth parameters from length-frequency analyses depends on many factors, particularly on the range of sizes represented in the samples. The León *et al*. (1995) estimates for spiny lobsters in Cuba were considered to be the most reliable during the 1998 working group session. These estimates were derived using the SLCA method and were based on a large sample size collected during the 1990s covering the widest range of size classes.

Table 3.3 Von Bertalanffy growth parameter estimates

Zone	Sex	Method	K	L_∞	ϕ'	T_o	References
Bahamas	Γ	Unknown	0.26	190	3.93[1]		Waugh (1980)
	E		0.23	190			
Bermuda	Γ	Unknown	0.18	204	3.83[1]	0.82	Evans (1988)
	E		0.15	192		1.0	
Brazil	Γ	Modal Progression Analysis	0.34	141	4.11[1]		Santos *et al.* (1964)
	E		0.38	148			
Brazil	Γ	ELEFAN	0.229	257	4,19		Ivo (1996)
	E		0.236	233			
Brazil	Γ	SLCA	0.26	207	3.97		González Cano and Rocha (1995)
	E		0.18	162			
Cuba, SW	Γ	Bhattacharya	0.22	169	3.79	-0.70	Cruz, *et al.* (1981)
	E		0.31	139		0.08	
Cuba, SW	Γ+E	Bhattacharya	0.16	174	3.68	0.32	Buesa (1972)
Cuba, SW	Γ	ELEFAN	0.29	250	4.19		Báez, *et al.* (1991)
	E		0.31	209			
Cuba, SW	Γ	Tagging	0.27	250	4.15[1]		Phillips, *et al.* (1992)
	E		0.39	171			
Cuba, SW	Γ	ELEFAN	0.31	190	3.95[1]		León, *et al.* (1994)
	E		0.24	174			
Cuba, SW	Γ	Fournier	0.21	178	3.81[1]		Báez, *et al.* (1994)
	E		0.21	171			
Cuba, SW	Γ	SLCA	0.24	184	3.85[1]	0.45	León, *et al.* (1995)
	E		0.18	155		0.37	
Cuba, SE	Γ		0.22	186	3.88[1]	0.44	

Zone	Sex	Method	K	L_∞	ϕ'	T_o	References
	E		0.22	156		0.41	
Cuba, NE	Γ		0.23	185	3.83[1]	0.44	
	E		0.19	153		0.38	
Cuba, NW	Γ		0.22	175	3.85[1]	0.43	
	E		0.22	166		0.42	
Cuba, all areas	Γ		0.23	185	3.86[1]	0.44	
	E		0.19	155		0.37	
Florida, USA	Γ+E	Tagging	0.34	190	4.09[1]		Davis (1977)
Florida, USA	Γ+E	Tagging	0.25	190	3.95[1]		Warner *et al*. (1977)
Jamaica	Γ+E	MPA	0.22	192	3.89[1]		Munro (1974)
Martinique	Γ	Unknown	0.25	190	3.93[1]		Clairovin (1980)
	E		0.23	188			
Mexico, Isla Mujeres	Γ	SLCA	0.24	198	3.95[1]	0.41	Gonzalez-Cano (1991)
	E		0.22	165		0.86	
Mexico, Isla Mujeres	Γ	SLCA	0.25	217	4.04		González Cano and Rocha (1995)
	E		0.22	146			
Mexico, Isla	Γ	SLCA	0.30	142	3.72[1]		Arce (1990)
Mujeres	E		0.30	122			
Mexico, Bahía de la Ascención	Γ	Fabens	0.20	257	4.09[1]		Lozano-Alvarez *et al.* (1991a)
	E		0.25	215			
Nicaragua	Γ	ELEFAN	0.23	169	3.89		Castaño and Cadima (1993)
	E		0.40	160			
	Γ+E		0.3	161			
Virgin Islands, USA	Γ	Tagging	0.44	153	3.88[1]		Olsen and Koblic (1975)
	E		0.32	133			
Sub-regional	Γ	ELEFAN	0.23	180	3.97[1]	-0.84	Estimates made during the 1997 working group session.
Nicaragua, Jamaica, Colombia	E		0.21	163		-0.95	
	Γ+E		0.26	190		-0.68	

3.5.2 Discrete Moult Models

Several studies in the region have presented growth models that include the two distinct components of lobster growth: moult increment and inter-moult period (or moult interval). Arce *et al*. (1991) used the unit step function to model discrete growth increments. The model requires an age at initial size, which was defined as time of settlement (in this case), and values of moult increments (mm) and inter-moult periods (weeks) to describe the lobster cohort growth, in a single equation. Muller *et al*. (1997) modelled moult interval using generalised linear models to estimate the probability of an individual moulting and the moult increment as a function of carapace length, time, sex, season and location. Similarly, Zetina and Ríos (in press) developed two step-shape models for spiny lobster growth. Parameters were estimated using the likelihood equations and Bayesian methods.

Although the moult-based model is apparently a more realistic fit to model the growth in spiny lobsters (Caddy, 1977), the simple von Bertalanffy function is still widely applied. This primarily results from the fact that the former type of model tends to have more rigorous data requirements (such as from tagging or other experimental studies) and it is not easily incorporated into many standard stock assessment techniques.

3.6 NATURAL MORTALITY

It was found that most reliable estimates for M ranged between 0.3-0.4 year^{-1}. As for other marine species, obtaining good natural mortality estimates is a difficult task. However, the consistent pattern emerging from a variety of methods (Table 3.4) suggests an average natural mortality is likely to lie in this range.

3.7 SUMMARY AND RECOMMENDATIONS

It is apparent from the review of biological information that several aspects of the biology of spiny lobster remain uncertain. Interpretation of models and parameters vary across the range for this species. This may be partly due to statistical observation errors, but could also reflect genuine changes in this species' biology between areas and over time. Unfortunately it is not possible to make the distinction between observation errors and systematic changes as much of the necessary information is missing from the published reports.

Uncertainty is particularly important in growth models as they form an integral part of many stock assessment methods, particularly where the species cannot be aged directly, as is the case of the spiny lobster. Errors in growth estimates can lead to incorrect assessments and poor management decisions.

It is necessary to address the problem in two ways. Firstly, the degree of uncertainty should be assessed with respect to the models and the parameters. This can be useful in stochastic simulations and incorporated in local studies using Bayesian methods. Secondly, uncertainty could be reduced by combining data sets for analyses and to produce more reliable parameter estimates. This may be of particular value in morphometric studies, where a significant difference between measurements can be used to test for stock differences.

Analysis of growth may require special consideration. Current models tend to agree on growth rates between 75 and 100mm CL, but differ wildly outside these sizes. It should be possible to develop a model based on the wide variety of available data, particularly tagging data, that will provide a state-of-the-art growth model, which may be adapted to each region.

Table 3.4 Estimates of natural mortality (year^{-1})

Country	Sex	Method	M	Author
Bahamas	Γ+E	?	0.36	Ehrhardt
Brazil	Γ+E	Pauly (1980)[3]	0.30	Ivo (1996)
Colombia	Γ	Empirical formula[2]	0.54	Gallo *et al.* (1998)
	E		0.51	
	Γ+E		0.62	
Cuba	Γ+E	Tagging	0.26	Buesa (1972)
	Γ+E	Tagging	0.44	Cruz *et al.*, (1986a)
	Γ+E	Empirical formula[2]	0.34	Cruz *et al.* (1981)
Florida, USA	Γ+E	Pauly (1980)[3]	0.42	Powers and Sutherland (1989)
Florida, USA	Γ+E	Longevity	0.30	Muller *et al.* (1997)
Jamaica	Γ	Pauly (1980)[3]	0.59	Haughton (1988)
	E		0.67	
	Γ+E		0.62	
Nicaragua	Γ	Empirical formula[2]	0.41	Estimated during the 1998 working group session
	E		0.50	
	Γ+E		0.45	
Virgin Is.	Γ	Tagging	0.46	Olsen and Koblic (1975)
	Γ		0.43	
	E		0.52	
Turks & Caicos	Γ+E	Depletion model[4]	0.36	Medley and Ninnes (1997)

[1]The working group used as an average value for longevity of 13.9 years from Ivo (1996), in conjunction with the model for natural mortality of Hoenig (1983) where the relation between Z and longevity (T_m) is: $Z = 1.46 - 1.01\ T_m^{1.01}$.

[2]Cruz *et al* (1981) developed an empirical equation to estimate crustacean natural mortality based on mortality and growth parameters and mean water temperature from a number of data sets, similar to Pauly's equation used for finfish:

$M = 0.0277 - 0.0004 * L_\infty + 0.5397 * K + 0.0119 * T$

Where L_∞ = CL (mm), K = Growth rate (year^{-1}) and T = Temperature (^oC). Using this equation, M values for the region range between 0.3 and 0.35 year^{-1}.

[3]Pauly's (1980) method was developed for finfish and is unreliable for crustaceans, which may explain the generally higher values obtained through this method. Where possible, these values should be re-estimated using Cruz *et al.* (1981) method.

[4]The depletion model provides an estimate independent of growth models and size data.

4 REVIEW OF LARVAL RECRUITMENT PATTERNS AND VARIABILITY IN SPINY LOBSTER (*Panulirus argus*)

R. Cruz, B. Luckhurst and R. Muller

The Caribbean region is the main lobster producer, at a world scale, standing for 17% (about 33 000 tonnes) of the average total world production of lobsters (200 000 t) in the period 1978-1991. *Panulirus argus* is the most abundant species and of high commercial importance. Understanding recruitment to the fishable stock of a species depends on knowledge of the oceanic processes and biological factors that operate during the different phases of the long life cycle. However, for the species *P. argus* only limited data exist on the puerulus and juvenile phases and their relationship with environmental variables.

Collectors have been used successfully to catch the puerulus stage of spiny lobster in Bermuda, Florida, Mexico and Cuba. Three types of collectors have been developed in the region, to investigate levels of settlement. These include the modified Witham types, used in Bermuda (Luckhurst, unpublished data) and Florida (Hunt, pers. comm.); the Gusi Collector, used in the Mexican-Caribbean (Briones, 1994) and the Phillips collector (Phillips, 1972) modified in Cuba (Cruz *et al*., 1991).

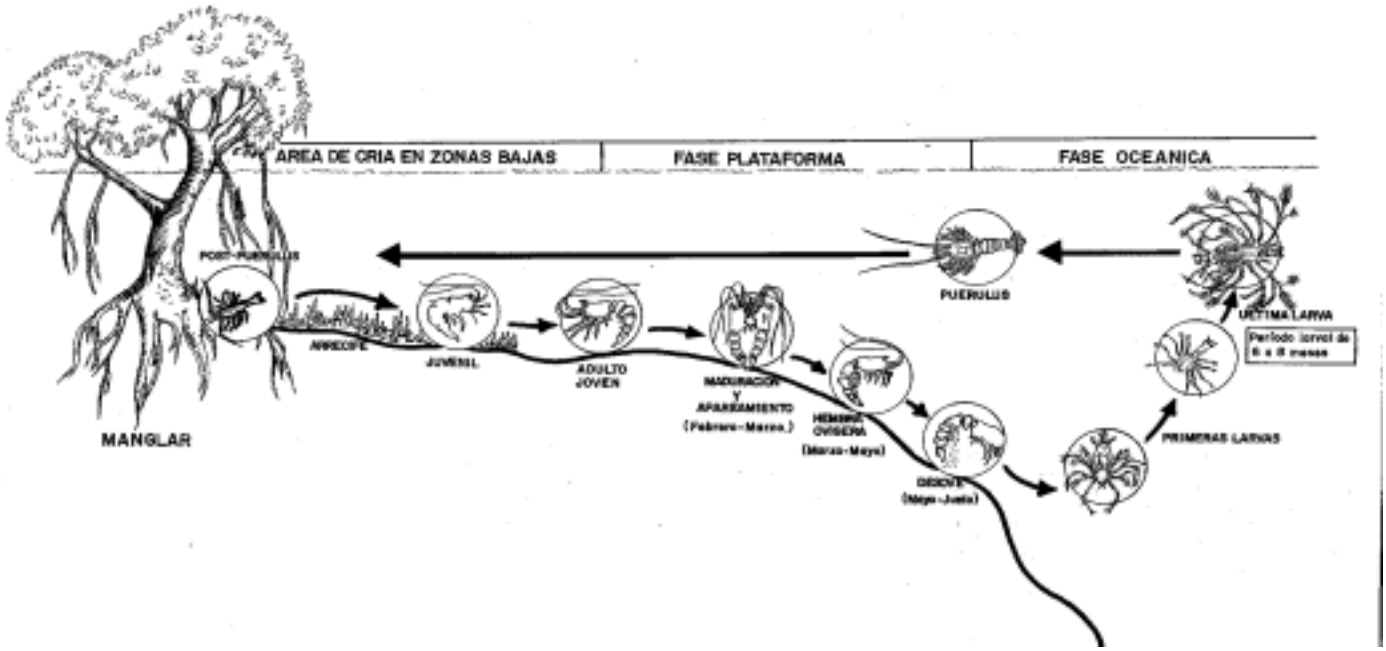


Figure 4.1. Life cycle of the Caribbean spiny lobster *Panulirus argus*

As has been described in Section 3.2, the Caribbean spiny lobster *P. argus* is able to utilise a variety of environments and changes habitats several times during its ontogenetic development. A summary of the life cycle is presented in Figure 4.1. This includes 11 stages of oceanic phyllosoma larvae, over a period of 6–10 months. During this long planktonic phase the larvae become widely distributed throughout the Atlantic Ocean. The phyllosoma larvae metamorphose into the puerulus stage, which swims across the continental or insular shelf to arrive at the coast. This occurs throughout the year, but with a main settlement peak in September-December. Puerulus become juveniles ten months after settlement. The juveniles concentrate in shallow water (nursery area). Older juveniles tend to migrate into deeper water and recruit to the fishery at 76mm CL (Florida and Cuba). Mating takes place mainly in February–March.

The puerulus settlement at different locations in the Caribbean in the period since 1988 is compared in Figures 4.2 and 4.3. There were variations in this pattern of settlement between Bermuda, Florida Keys, Mexico (Bahia de la Ascensión) and Cuba (Gulf of Batabanó). The three last regions showed that some settlement occurred throughout the year. In contrast, for the stations in Bermuda (St. Catherine, Whale, Bailey's and Flat's), the settlement period is concentrated basically between two months (August – September) and the magnitude of larval recruitment was much lower during the rest of the year (Fig. 4.3).

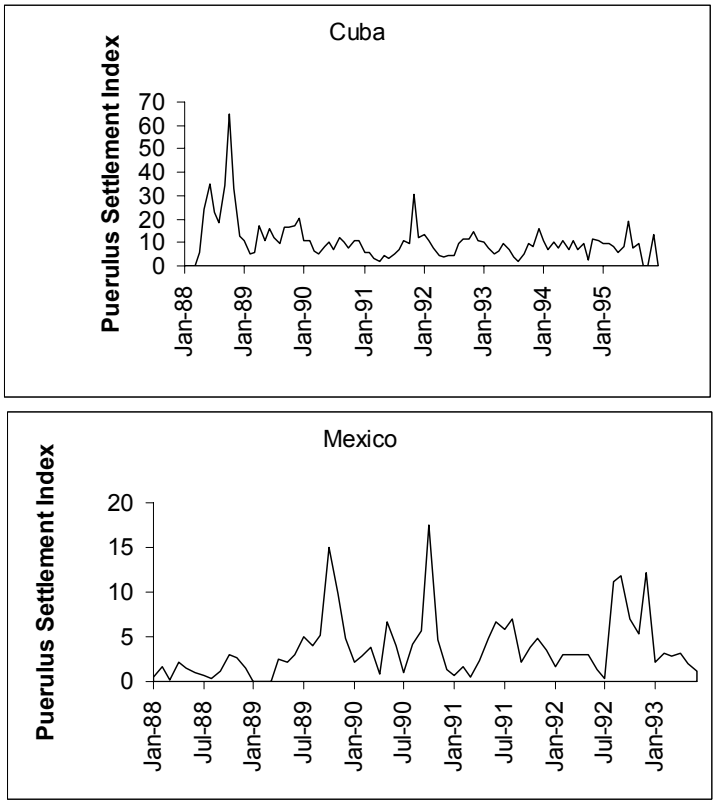


Figure 4.2 Monthly *Panulirus argus* pueruli in the south of Cuba and the Mexican Caribbean

When comparing the relative abundance of pueruli between these locations, significantly different settlement levels were observed. The causes of the differences between areas in the magnitude of pueruli recruitment into the coastal zones is unknown, but will depend mainly on variability of the oceanic processes and size of the breeding stock.

The pattern of puerulus settlements in the Florida Keys showed a larger peak in the beginning of the year (February-March) with the lowest index occurring in August (Fig. 4.4). The Bermuda stations showed only one peak in August. The south coast of Cuba and the Mexican Caribbean showed two peaks per year, one in May and the larger peak in October. In other areas studied in the Caribbean the settlement followed a very similar seasonal pattern, from November-December in Jamaica (Young, 1991) and September and May in Antigua (Peacock, 1974 and Bannerot *et al.* 1992, respectively).

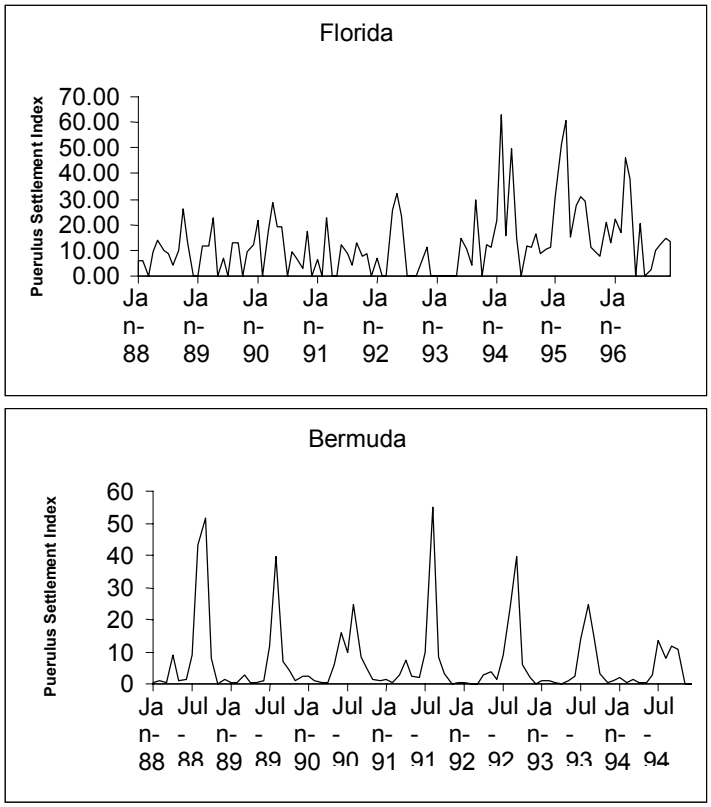


Figure 4.3 Monthly *Panulirus argus* pueruli in Florida Keys and Bermuda

Table 4.1 Maximum cross-correlations of pueruli with environmental series showing maximum time lags in months. Gulf of Batabanó, Cuba

Locations	SOI		W (km/h)		T (° C)		S (‰)		RF (mm)	
	R	Lag	R	Lag	R	Lag	R	Lag	R	Lag
Hicacos	0.47	1	0.48 (SW) 0.52 (NW)	5 2	0.49	7	0.23	14	0.25	9
Matías	0.48	6	0.46 (SW)	3	0.34	4	0.25	14	0.23	9
Cantiles	0.49	5	0.46 (SW)	3	0.45	4	0.39	16	0.30	5

SOI – Southern Oscillation Index, W (km/h) – Direction of Wind, T (C°) – Water Temperature, RF – Rainfall, R = maximum cross correlations, L = lags (months) and NS = not significant (95 %) (Cruz *et al.*, in press).

When comparing the spawning season with the maximum puerulus settlement in the different regions, an estimation of the duration of the larval phase can be obtained. In the Mexican Caribbean and south of Cuba it is between 6 to 7 months respectively (Fig. 4.5 and 4.6) and in Florida it is between 9 and 10 months (Fig. 4.7). The mechanism of retention in the area south of Cuba (Garcia *et al.*, 1991) and between Dry Tortugas and the Florida Keys (Yeung, 1993), and the different temperature of water between these areas, leads to the conclusion that the larvae remain for 6 to 10 months adrift in the ocean. It is not clear how sea temperature influences embryonic development and larval growth.

Environmental variables play an important role in the pelagic stages of spiny lobsters. In the Cuban archipelago the most drastic change seems to be associated with the sea level and the water movements resulting from the winds (Table 4.1), which are affected by ENSO

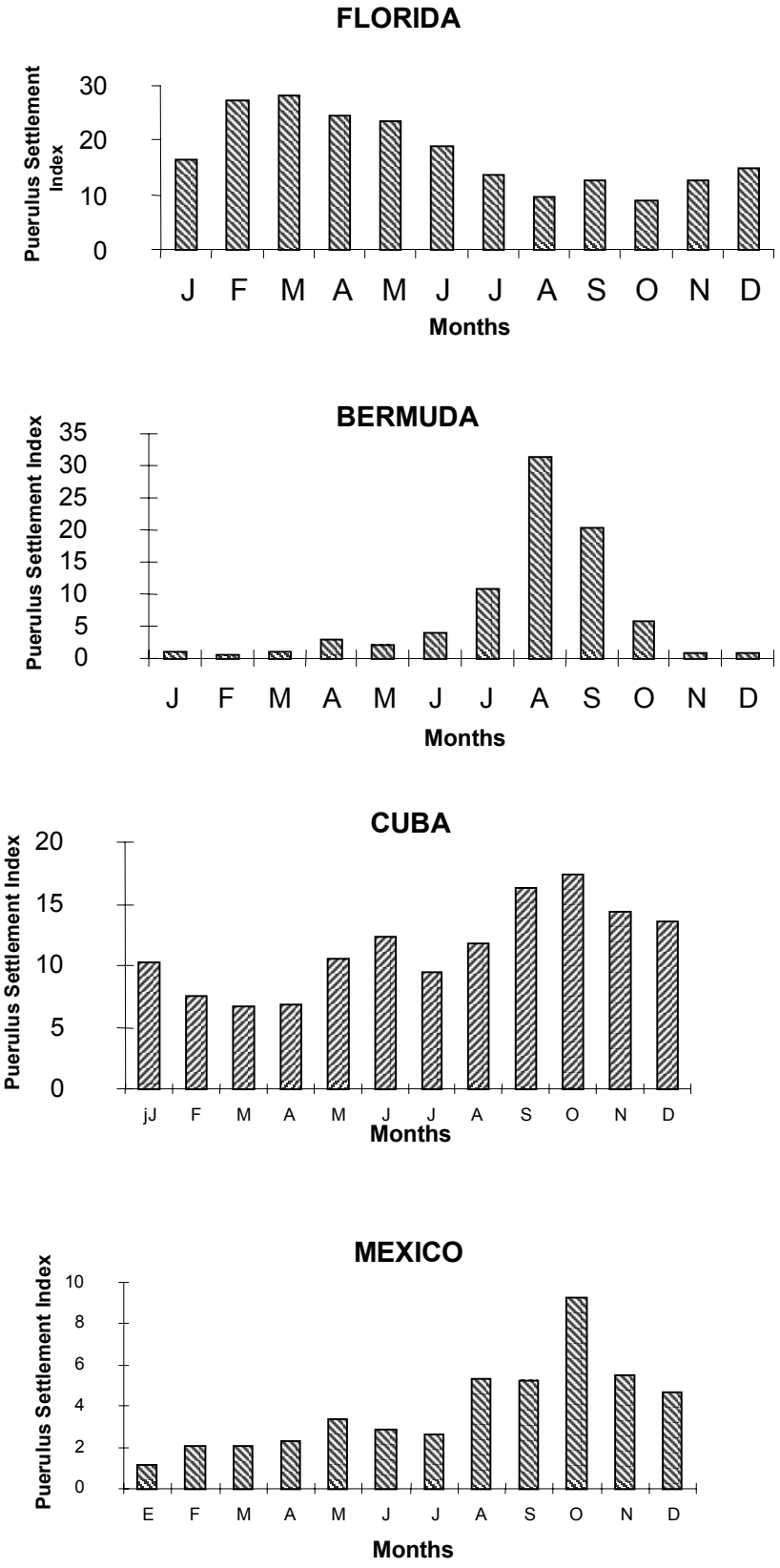


Figure 4.4 Mean monthly pueruli settlement of *Panulirus argus* at Florida Keys, Bermuda, Cuba and Mexico

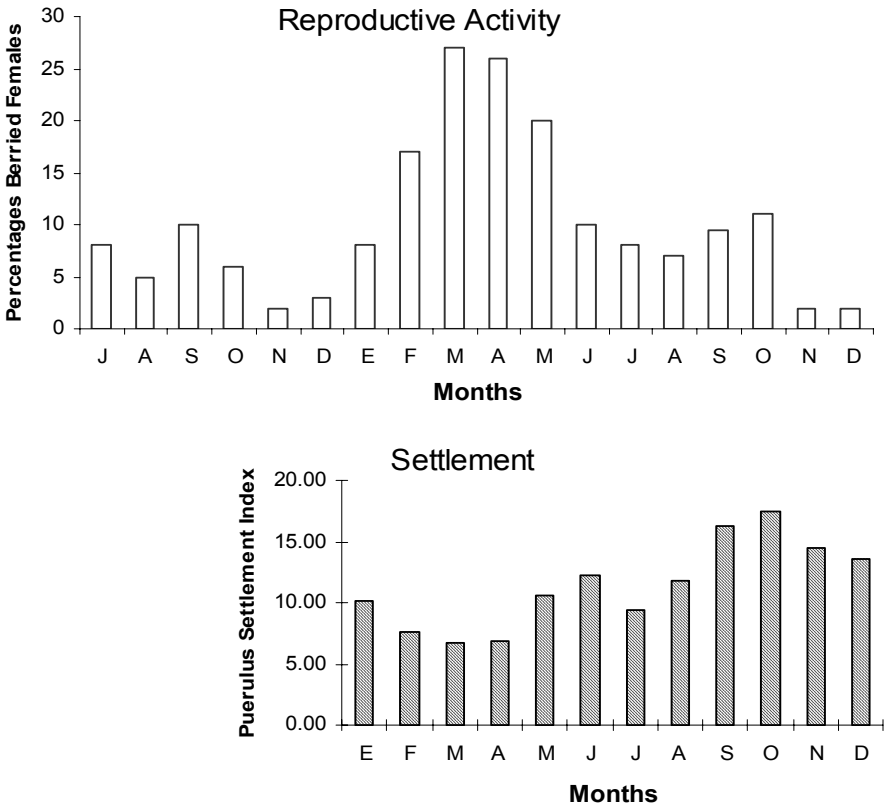


Figure 4.5. Relationships between the spawning season and puerulus settlement in the south of Cuba

events with different magnitudes and intensities (Cruz *et al.* in press). Nevertheless, the factors by which larvae return to the coast are not yet completely understood. For *P. cygnus,* the intensity of the Leeuwin Current, which is related to ENSO events and the impact of westerly winds, constitutes the main cause of variation in the level of pueruli settlement in Western Australia (Pearce and Phillips, 1988; Phillips *et al.*, 1991; Caputi and Brown, 1993; Phillips *et al.,* 1994a). In the Pacific region the changes in the recruitment levels are related to inter-annual variation of ENSO events and with the sea level four years earlier for *Panulirus interruptus* (Pringle, 1986; Phillips *et al.*, 1994b) and *Panulirus marginatus* (Polovina and Mitchum, 1992), respectively.

The data from Bermuda, Cuba, Florida and Mexico provide a clear indication of the importance of the pueruli data in the assessment of recruitment in spiny lobster fisheries. Moreover, the relationships of environmental events with settlement indicate that in the species *P. argus*, *P. cygnus* and *P. marginatus,* oceanic processes are affecting settlement along the coasts of these countries. Further studies of these aspects are necessary.

Recent studies carried out on spiny lobster life cycles indicate that there is a close relationship between the level of pueruli settlement as measured on collectors and abundance of recruits to the fisheries. This occurs 1.5 years (Forcucci *et al.*, 1994) and two years (Cruz *et al.*, 1991; Phillips *et. al.*, 1994a) after settlement in *Panulirus argus* in Florida and Cuba, respectively. Data on puerulus settlement in the south coast have been cross-correlated with the abundance of recruits to the fisheries on the north coast (Fig. 4.8). Significant correlations are observed at lags of 18 and 19 months.

Research on the spiny lobster fisheries should try to produce a better understanding of the relationships between life history and oceanic processes. Workshop results suggest that the planktonic period of the larvae is between 6 to 10 months. Monthly settlement of pueruli showed a seasonal pattern that was very similar within the Caribbean and in Bermuda

(September-December) and different in Florida (February-March). The variations in settlement in the different sites are probably attributable to the variables in the local effect of environmental factors, which control water flow and retention.

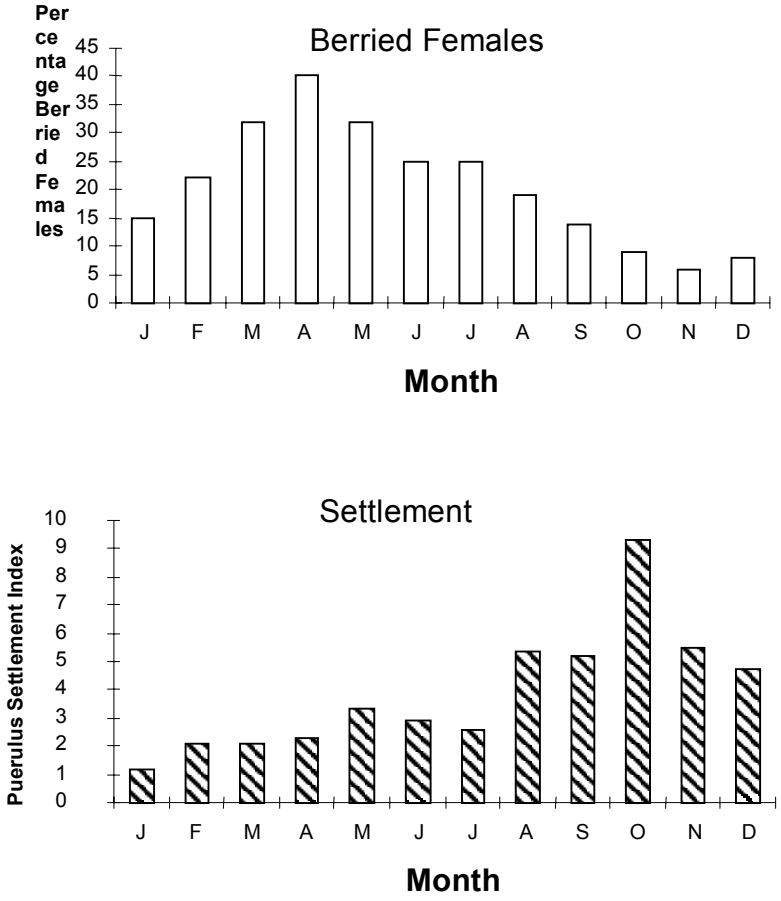


Figure 4.6 Relationships between the spawning season and puerulus settlement in the Mexican Caribbean

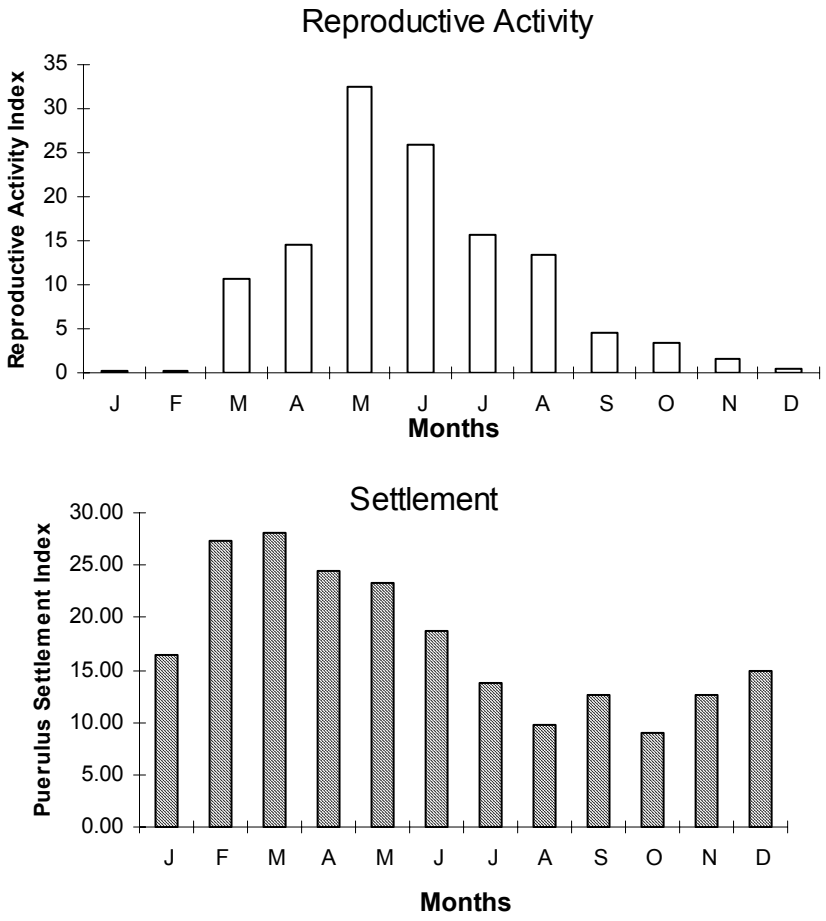


Figure 4.7 Relationships between the spawning season and puerulus settlement in the Florida Keys

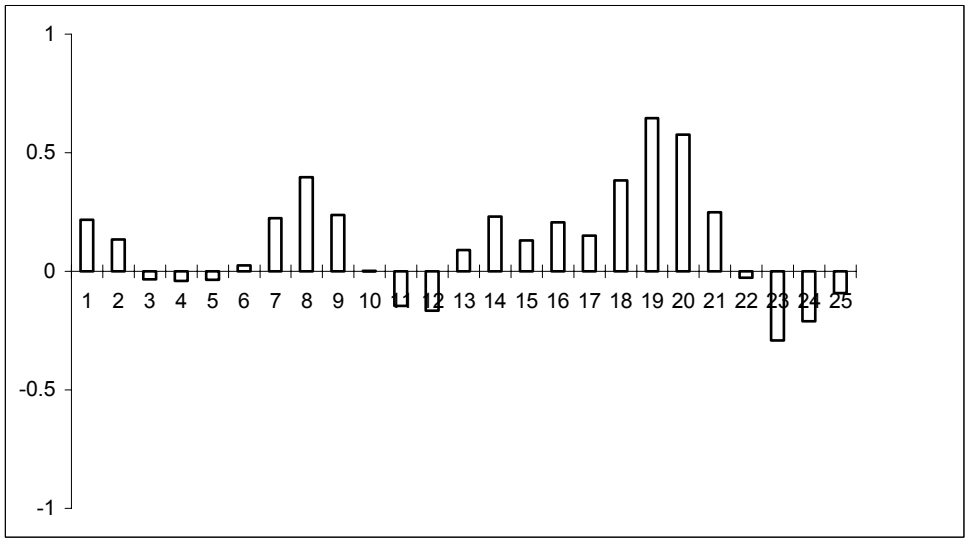


Figure 4.8 Cross correlation between settlement in the south and recruits abundance in the north coast