EFFECT OF LOBSTER SIZE VARIATION ON CATCHES ON THE CONTINENTAL SHELF OFF CEARÁ, BRAZIL

Efeito da variação do comprimento da lagosta sobre as capturas na plataforma continental do Ceará, Brasil

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ABSTRACT

In this study we evaluate to what extent variation in length class composition of P. argus at two depth ranges (1-10 m and 30-50 m) is reflected in the overall biomass and how this affects the management of spiny lobster resources on the continental shelf off Ceará. Lobster catches consisted mainly of large juveniles (42-50 mm CL) and pre-recruits (50-73 mm CL) in shallow waters, and of adults (80-109 mm CL) at intermediate depth (30-50 m). Based on selectivity curves, the size at first capture (L_{50}) in shallow waters was 12% smaller than the minimum legal size (MLS). A 13% or a 21% increase would be required to reach the current MLS (75 mm CL) or the ideal MLS (80 mm CL), respectively. In contrast, at intermediate depth L_{50} was greater than the MLS. Pre-recruits (50-73 mm CL) comprised 86% of catches (98% of the mean biomass) in shallow waters and 26.1% (55% of the mean biomass) at intermediate depth. If the L_{50} for shallow waters were raised to the current MLS or the ideal MLS, the biomass would increase by 79 and 84%, respectively.

Keywords: Panulirus, minimum legal size, fishing mortality, biomass.

RESUMO

O estudo trata da variação da composição por tamanho da lagosta vermelha em duas faixas de profundidade (1-10 m and 30-50 m), para avaliar seu efeito na biomassa do recurso e suas implicações na gestão da pesca ao longo da plataforma continental cearense. Constatou-se diferença entre as distribuições de comprimento nos setores amostrados, havendo maior ocorrência de juvenis (42-50 mm CC) e pré-recrutas (50-73 mm CC) no SR e de indivíduos maiores no SI. A partir das curvas de seletividade, observou-se que, no SR, o tamanho de primeira captura (L_{50}) foi 12% menor que o tamanho mínimo legal (TML) de 75 mm CC, sendo necessário um aumento de 13% para que o atinja, e de 21% para que atinja o tamanho mínimo ótimo (80 mm). Por outro lado, o SI apresentou L_{50} maior que o TML. Verificou-se também, no SR, que 86% das capturas correspondem a indivíduos pré-recrutas (50-73 mm CC), enquanto no SI, essa porcentagem caiu para 26,1%. As biomassas médias (B_m) calculadas para o SR e o SI foram constituídas por 98 e 55% de indivíduos menores que o TML, respectivamente. No SR, ao se elevar o L_{50} até que atinja o TML e o tamanho mínimo ótimo ocorrem incrementos de 79 e 84% na biomassa, respectivamente.

Palavras-chaves: Panulirus, tamanho mínimo legal, mortalidade por pesca, biomassa.

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INTRODUCTION

The red spiny lobster (*Panulirus argus* Latreille, 1804) and the green spiny lobster (*Panulirus laevicauda* Latreille, 1817) are the most abundant lobster species and the most economically important fishing resource on the continental shelf off Ceará (a coastal state in Northeastern Brazil). Other less abundant species, such as the painted spiny lobster (*Panulirus echinatus* Smith, 1869) and slipper lobsters (Scyllaridae), are occasionally captured but are of negligible economic interest (Cruz *et al.*, 2013b).

Brazilian legislation allows the use of two types of non-selective lobster traps but, despite their illegality, gillnets nets and artificial shelters are widely employed in order to increase catches. As landings decline, subsistence fishermen often sacrifice quality to quantity to safeguard their income (Madrid & Cruz, 2013).

The Brazilian red spiny lobster population is distributed into two stocks, one in shallow waters (<50 m) and one in deeper waters (50-100 m). Both stocks are heavily exploited, especially pre-recruits and young animals under minimum legal size (MLS) (75 mm CL) and older individuals in deeper waters. The latter consist mainly of large and highly reproductive animals, such as egg-bearing females (Cruz *et al.*, 2013*b*). This pattern of exploitation is likely the main reason for the observed fluctuations in spiny lobster landings, although other factors, such as the combination of adverse environmental conditions, anthropic impacts and recruitment dynamics, should be taken into account as well.

Cuba (Buesa, 1965; Cruz, 1981; Cruz *et al.*, 1986 & 1991; Cruz, 2002), Florida (Muller & Doug, 1997) and Mexico (Briones, 1994) have monitoring systems covering different stages in the life cycle of *P. argus*. In Brazil, Fonteles-Filho & Ferreira (1991) devised a sampling system for spiny lobster landing sites in Northeastern Brazil in order to evaluate the size composition of the local populations and also identified a number of factors potentially jeopardizing the reliability of the collected information. Cruz *et al.* (2011) proposed a random stratified system for lobster fishing boats operating at 1-100 m depth with which important and previously unavailable information on lobster fishing biology could be collected on a monthly basis.

The current levels of spiny lobster biomass on the Brazilian continental shelf are unknown, but the spatial/temporal reduction in commercial landings between 1974 and 1991 and the intensification of fishing efforts targeted at deep-water *P. argus* stocks suggest spiny lobster populations may be decreasing (Cruz *et al.*, 2011). Cushing (1971), King (1995) and Goñi (1998) believe that the observed decline in fisheries is related to a reduction in recruitment due to low levels of spawning stock.

In this study we look at how variation in length class composition of *P. argus* at two depth ranges is reflected in the overall biomass and how this affects the management of spiny lobster resources on the continental shelf off Ceará State.

MATERIAL AND METHODS

The continental shelf off Ceará State

The red and green spiny lobsters are distributed throughout the continental shelf off Ceará at a depth of 1-100 m, from the municipality of Barroquinha (03°01'08″ S; 41°08'10″ W) to the municipality of Icapuí (04°42'47″ S; 37°21'19″ W), covering a costal stretch of 573 km and an area of 42,205 km² (Figure 1).

Coutinho & Morais (1970) studied the sedimentary fascies and ocean floor topography off Northeastern Brazil at a depth of 1-50 m, describing reef structures, calcareous algae beds and a sandy fraction of variable size. The coastline of Ceará is represented by the diversified topographic profile off Mundaú (between 02°44'0″ S; 39°01'05″ W and 03°02'0″ S; 39°16'05″ W), followed by an almost vertical drop-off into the ocean basin at 25 nautical miles from the shore.

Terminology

In this study we adopted the terminology of Herrnkind *et al.* (1994), Acosta & Butler, (1999), Cruz *et al.* (2007), and Cruz & Bertelsen (2009) for the different stages in the life cycle of *P. argus*: (a) puerulus (4-6 mm carapace length (CL), when the animals migrate towards coastal habitats (Acosta & Butler, 1999), (b) post-puerulus or solitary juvenile algal phase (6-16 mm CL), (c) gregarious juvenile (16-50 mm CL), (d) pre-recruit (50-73 mm CL), (e) recruit (74-79 mm CL; mean: 76.8 mm CL), and (f) adult (≥80 mm CL).

Sampling

The fishing grounds off Ceará (2°56'S, 39°47'W) was chosen to conduct the study on the variation in length composition of *P. argus* in the area more vulnerable to the fishing effort at 1 to 50 m
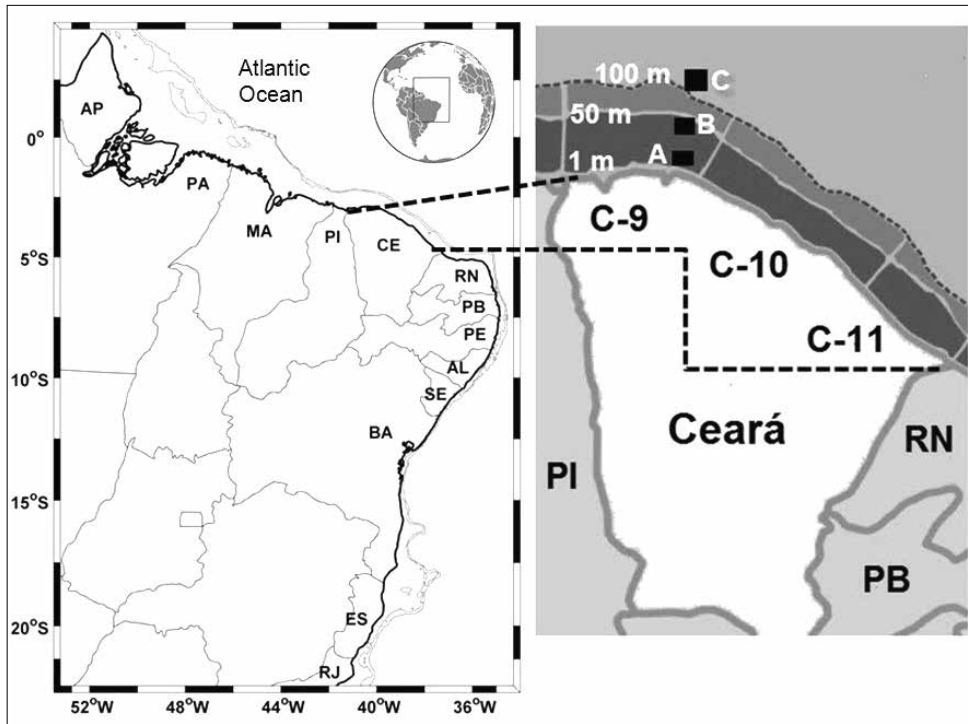
Figure 1 - Brazilian continental shelf showing spiny lobster (*Panulirus argus* Latreille, 1804 and *Panulirus laevicauda* Latreille, 1817) fishing grounds (1-100 m) by state, and sampling zones by isobaths. States: Amapá (AP), Pará (PA), Maranhão (MA), Piauí (PI), Ceará (CE), Rio Grande do Norte (RN), Paraíba (PB), Pernambuco (PE), Alagoas (AL), Sergipe (SE), Bahia (BA) and Espírito Santo (ES). A: shallow waters (1-10 m), B: intermediate depth (30-50 m) and C: deeper waters (50-100 m). C9, C10, C11: Lobster sampling areas (modified from Cruz et al., 2011).

(Cruz *et al*., 2013). Because there is a relationship between the carapace length and the depth catch (Cruz & Bertelsen, 2009) we selected two fishing depths: shallow waters (1-10 m) and intermediate waters (30-50 m), where field evidence has shown the habitat of juvenile-preadult and adult respectively. Monthly random field surveys were undertaken on the area C9 (Figure. 1) at two depth ranges using lobster fishing boats with not selective traps. Deeper waters (50-100 m), which comprise over one third (16,028 km^2) of the shelf area (Cruz *et al*., 2011), were not sampled for the present study. Silva *et al*. (2003) reported that the lobster fishery at 50 to 100 m is more developed in the northern region.

A total of 347 red spiny lobsters were collected at random (shallow waters, n=124; intermediate depth, n= 223) in August and September, 2013. The animals were classified according to sex, the carapace length (CL) was measured with a 200-mm caliper (precision: 1 mm), female in reproductive condition (carrying eggs and/or a spermatophore mass) and molt stage were determined. In addition, we registered the number of traps (*manzuás*) and the depth at which the lobsters were caught. Mean CL values were calculated for each depth range and each month of sampling. The sampling methodology was described in detail by Cruz *et al*. (2011 and 2013*b*).

The total weight-carapace length equation (W_t = 0.002582 × CL$^{2.7461}$) (Cruz, 2002) was used to calculate the average individual weight in each length class. The carapace length class was grouped in an interval of 4 mm, for example: 50-54, 55-59, 60-64 up to 105-109.

Analysis of virtual population

Fishing mortality (F) and the number of surviving individuals (N) were calculated for the red spiny lobster stock on the continental shelf off Ceará using Jones (1984) cohort analysis based on carapace length. Complete spiny lobster landing composition data were available for the period 2000-2011. The current cohort was replaced by a "pseudo-cohort", assuming a constant parameter (recruitment and fishing mortalities at each age remained constant during the period of exploitation). Thus, we assumed that the picture presented by all length classes during a year is reflected in a single cohort throughout life. This process originated the size structure of the population and the fishing recruitment rate.

The model was fitted with the following data:
1) Based on the growth parameters calculated by Ivo & Pereira (1996) for Northeastern Brazil, the mean carapace length (both genders) was estimated as CL$_\infty$ = 180.75 mm; K = 0.24 year^{-1}; t_o = 0.
2) Natural mortality was calculated with the empirical equation proposed by Cruz *et al*.,

(1981): $M = -0.0277 - 0.0004 \times CL_\infty$ (mm) $+ 0.5397 \times K$ (year^{-1}) $+ 0.0119 \times T$(°C), considering an annual (2012) mean sea temperature of 27°C (Teixeira & Machado, 2013),

3) A linearized catch curve was used to estimate total mortality (Z), which in turn was used to calculate fishing mortality: $F = Z - M$.

Details of the assumptions and equations underlying VPA can be found in Sparre & Venema (1998).

The highly productive spiny lobster fishing areas off Ceará display an array of different habitats, including reef structures and dense calcareous algae beds at a depth of 20 m or more (Coutinho & Morais, 1970). This provides lobsters with a variety of safe natural shelters and habitats which, according to Eggleston (1991), tend to reduce predator pressure. Moreover, such a biotope is rich in invertebrate species (Kempf *et al.*, 1968), especially mollusks and crustaceans on which lobsters feed at different development stages. Thus, the study area is characacterized by clusters of red spiny lobster stock, with little mobile size classes, as shown by tagging studies (Paiva & Fonteles-Filho, 1968; Fonteles-Filho & Ivo, 1980).

The selectivity curve of mean carapace length was calculated from the length-linearized catch curve, a methodology originally proposed by Pauly (1984) for fish and employed by Cruz *et al.* (2013b) to evaluate spiny lobster fisheries on the Brazilian continental shelf.

Fishing mortality (F) depends on selectivity (S). Thus, if $S_L = 0$, then $F_L = 0$. Conversely, if $S_L = 1$, then F_L = high. Consequently, based on the results of the length cohort analysis, fishing mortality (F) may be expressed as: F (current) = F_L (m) $\times S_L$ (current), where F_L (m) is maximum fishing mortality and S_L (current) is the current selectivity curve. When L_{50} was calculated from the selectivity curve, the result was an estimated 13% increase to attain the current MLS (75 mm CL) and a 21% increase to attain the ideal MLS (80 mm CL) suggested by Bertelsen & Matthews (2001). The new F values for L_{50} (13% and 21%) were obtained with the equation: F (new) = F (m) × S (new).

The number of surviving lobsters was calculated with the equation (Sparre & Venema, 1998):
$N(L1) = [N(L2) \times H(L1, L2) + C(L1, L2)] \times H(L1, L2)$
where N = number of surviving lobsters attaining a CL of L1.
$H(L1, L2)$ = natural mortality factor = $[(L_\infty - L1) / (L_\infty - L2)]^{M/2K}$
The exploitation ratio: $F/Z = C(L1, L2) / [N(L1) - N(L2)]$

where: C (L1, L2) = number of landed lobsters with a CL between L1 and L2.
Fishing mortality: $F = M \times (F/Z) / (1 - F/Z)$
Mean biomass: $B_m = (NL2 - NL1) / (Z \times W_m)$
where: B_m = mean biomass, and W_m = mean weight.

Using Microsoft Office Excel, the model was developed by Cruz *et al.* (2013b) for spiny lobster fisheries on the Brazilian continental shelf.

RESULTS

Variation in carapace length

In the samples collected in 2013, the two depth ranges (shallow and intermediate) differed significantly with regard to the distribution of length classes (Figure 2). In shallow waters (1-10 m), 86% of the animals were pre-recruits (50-77 mm CL) while 14% were adult (80-89 mm CL) with no signs of reproductive activity. At intermediate depth (30-50 m), adult animals (80-100 mm CL) were predominant (75%), while pre-recruits represented only 25%.

Selectivity as a function of length class composition

The two selectivity curves based on depth range indicate the possibility of catching lobsters of a given size. The size at first capture was estimated to be 66 mm CL (Figure 3) and 77 mm CL (Figure 4) in shallow waters and at intermediate depth, respectively.

An increase in the size of the captured lobsters produces a corresponding increase in the average selection length, thereby changing the F values in the model. Thus, the length at first capture (L_{50}) on the selection curve for shallow waters (66 mm CL) is 12% smaller than the MLS (75 mm CL), but a 13% or 21% increase in L_{50} would render a selection length of 75 and 80 mm CL, respectively (Figure 3). At intermediate depth, L_{50} is greater than the MLS (77 *vs* 75 mm CL), but a 13% increase in L_{50} is enough to attain the ideal MLS of 80 mm CL (Figure 4).

Stock structure at shallow and intermediate depths

The results of the length cohort analysis were organized into non-constant time intervals to obtain a matrix, assuming that the structure of all size classes registered (range: 50-109 mm CL) during a given average period reflected the structure of a pseudo-cohort for the period 2000-2011.

Figure 2 - Length frequency distribution of the red spiny lobster (*Panulirus argus* Latreille, 1804) sampled in 2013 in shallow waters (1-10 m) and at intermediate depth (30-50 m) on the continental shelf off Ceará State.
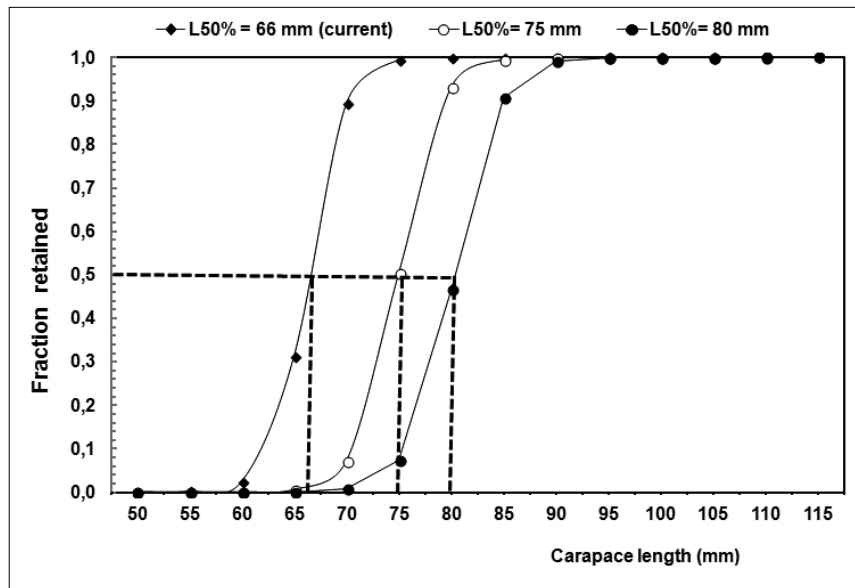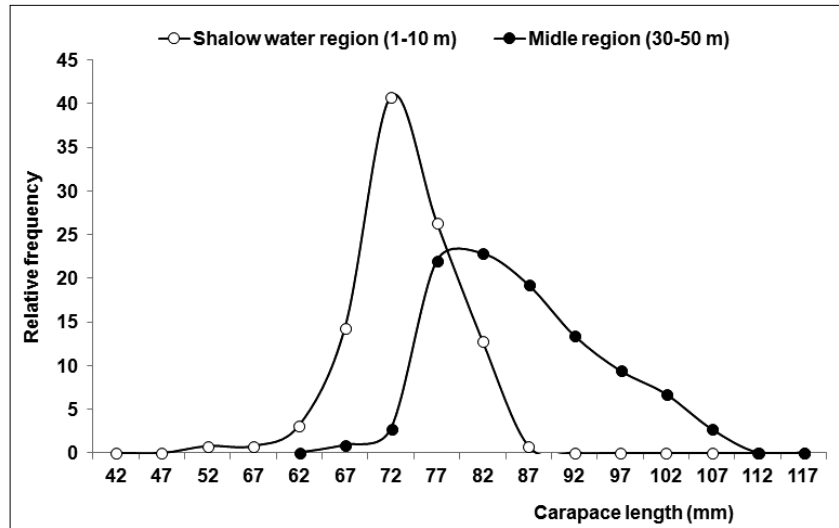

Figure 3 - Current (L_{50} = 66 mm carapace length) and estimated selectivity curves (L_{50} = 75 and 80 mm carapace length) for the red spiny lobster (*Panulirus argus* Latreille, 1804) sampled in 2013 in shallow waters (1-10 m) on the continental shelf off Ceará State.
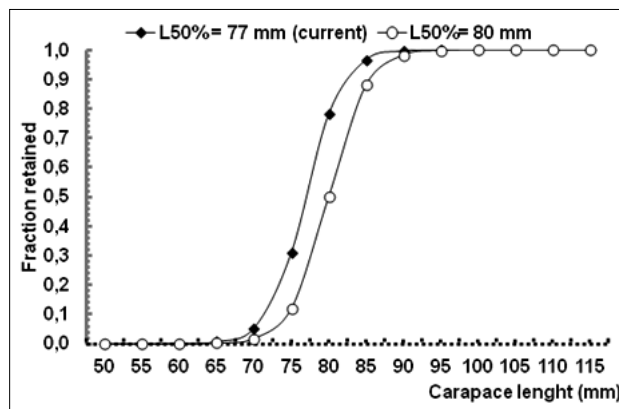

Figure 4 - Current (L_{50} = 77 mm carapace length) and estimated selectivity curves (L_{50} = 80 mm carapace length) for the red spiny lobster (*Panulirus argus* Latreille, 1804) sampled in 2013 at intermediate depth (30-50 m) on the continental shelf off Ceará State.

Lobster catches in shallow waters consisted of 86% pre-recruits (50-74 mm CL) and 14% adults (80-84 mm CL). Landings ranged from 0.0227 to 1.16 million individuals, with a total of 2.8 million in the period 2000-2011 (Table I). Displaying a very different composition, lobster catches at intermediate depth consisted of 3.7% pre-recruits, 22.4% recruits (74-79 mm CL) and 73.9% adults (80-109 mm CL) (Table II). Annual landings ranged from 0.0083 to 0.178 million, with a total of 0.906 million in the period 2000-2011.

The average number of young surviving lobsters (Ni) in the stock was approximately 3.15 million (50-54 mm CL) in shallow waters and 1.13 million (65-69 mm CL) at intermediate depth (Tables I and II). Considering F values of 0.113 (shallow) and

0.051 (intermediate), the total number of individuals in each stock was 13.11 million and 5.2 million, respectively. The yield for each fishing stock is 814 t and 504 t, respectively, showing that 62% of the spiny lobster fishing effort on the continental shelf off Ceará is concentrated on younger animals.

Variations in fishing mortality and biomass

By increasing the selection curve (L_{50}), fishing patterns were changed and a new series of estimates for F was obtained. Since F is a continuous function of carapace length, if the size at first capture is increased from 66 mm CL to 75 or 80 mm CL, F values decrease considerably (to or near zero) for the length class of 50-70 mm CL. Thus, as a result of the increase in L_{50}, F displays a negative tendency (Figure 5).

Table I - Jones' length based cohort analysis, using carapace length, of the red spiny lobster *Panulirus argus* (Latreille, 1804) in shallow depth (1–10 m) of the continental shelf off Ceará State, 2000 - 2011. Current average selection length (L50). M= 0.35.

Carapace length (CL - mm)	Number of lobsters landed	Number of surviving lobsters (N)	Fishing mortality (F)	Yield (kg)	Biomass (t)
50-54	22735	3153537	0.113	3027	1515
55-59	90940	3056172	0.447	15578	1187
60-64	409230	2890019	2.044	88310	928
65-69	1159486	2406708	6.665	309603	652
70-74	750255	1182856	8.394	244110	275
75-79	363760	399531	11.503	142319	81
80-84	22735	24070	6.300	10572	8
85-89	0	0	0.000	0	0
90-94	0	0	0.000	0	0
95-99	0	0	0.000	0	0
Total	2819141	13112892		813520	4644

Table II - Jones' length based cohort analysis, using carapace length, of the spiny lobster *Panulirus argus* (Latreille, 1804) in intermediate depth (30–50 m) of the continental shelf off Ceará State, 2000 - 2011. Current average selection length (L_{50}). M= 0.35.

Carapace length (CL - mm)	Number of lobsters landed	Number of surviving lobsters (N)	Fishing mortality (F)	Yield (kg)	Biomass (t)
65-69	8279	1131563	0.051	2211	605
70-74	24838	1074797	0.156	8082	489
75-79	202844	1002221	1.438	79361	361
80-84	157307	757048	1.411	73153	240
85-89	178006	566291	2.159	97388	151
90-94	161447	363555	3.138	102978	81
95-99	86933	186674	3.156	64123	37
100-104	62095	91478	5.051	52581	15
105-109	24838	25695	8.699	23986	3
Total	906587	5199322		503862	1981

Decreasing in inverse proportion with carapace length (Figure 6), the mean biomass (B_m) was calculated to be 4644 t for stocks in shallow waters and 1981 t for stocks at intermediate depth. In the former depth range, 98% of the mean biomass consisted of animals below the MLS (<75 mm CL), with an average length at first capture of 66 mm (CL). In the latter depth range, 55% of the mean biomass consisted of animals below the MLS (65-75 mm CL), while 45% consisted of pre-adults and adults (>75 mm CL).

If an efficient management method were adopted and the local lobster fishermen respected the MLS of 75 mm CL, the spiny lobster biomass in shallow waters would increase by 75%, which is equivalent to 21789 t. If the MLS were increased to 80 mm CL, a B_m of approximately 28843 t would be achieved (Table III). Increasing the MLS is not a primary concern in the
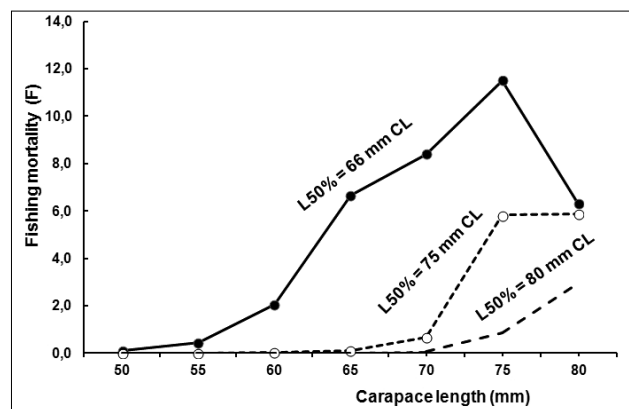

Figure 5 - Fishing mortality (F) according to carapace length in relation to selectivity curves (L_{50}) for the red spiny lobster (*Panulirus argus* Latreille, 1804) sampled in 2013 on the continental shelf off Ceará State.
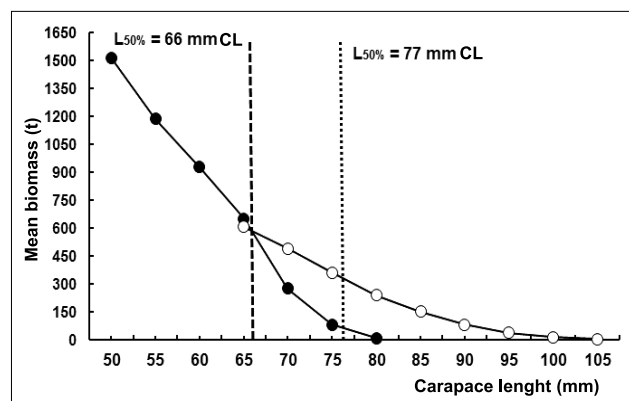

Figure 6 - Behavior of mean biomass according to carapace length in relation to selectivity curves: L_{50} = 66 mm carapace length (shallow waters, 1-10 m) and L_{50} = 77 mm carapace length (intermediate depth, 30-50 m) for red spiny lobster (*Panulirus argus* Latreille, 1804) sampled in 2013 on the continental shelf off Ceará State.

exploitation of stocks at intermediate depth since the average length at first capture (77 mm CL) is greater than the MLS (75 mm CL).

Table III - Jones' length based cohort analysis, using carapace length, of the redspiny lobster (*Panulirus argus* Latreille, 1804) in shallow depth (1–10 m)) of the continental shelf off Ceará State, showing 13% and 21% increases in current average selection length (L_{50}). M = 0,35.

Carapace length (CL - mm)	13% increase (75 mm CL) in current average value of L_{50} = 66 mm CL			21% increase (80 mm CL) in current average value of (L_{50} = 66 mm CL		
	Fishing mortality (F)	Total mortality (Z)	Biomass (t)	Fishing mortality (F)	Total mortality (Z)	Biomass (t)
50-54	0,004	0.37	1956	0.001	0.371	1973
55-59	0.011	0.38	2545	0.002	0.372	2609
60-64	0.037	0.41	5499	0.005	0.375	5975
65-69	0.123	0.49	9304	0.013	0.383	11952
70-74	0.667	1.04	2321	0.066	0.436	5526
75-79	5.821	6.19	155	0.842	1.212	792
80-84	5.864	6.23	8	2.966	3.336	16
Total	--	--	21789	--	--	28843

DISCUSSION

Stock exploitation status

The size at first capture (L_{50}) tends to increase towards deeper waters. Thus, while L_{50} ranges from 61 to 66 mm CL between the isobaths of 1 m and 10 m, it is 77 mm CL at intermediate depth (30-50 m) and 96 mm CL in the deeper waters (50-100 m) of Northern Brazil (Cruz *et al.*, 2013*b*). In other words, average carapace length and reproductive activity are positively correlated with depth, a well documented characteristic of this species (Cruz & Bertelsen, 2009). The results of the present study with regard to the lobster fishing areas off Ceará match the results published by Cruz *et al.* (2013*b*) regarding the impact of size on spiny lobster fisheries on the Brazilian continental shelf.

Spiny lobsters are caught at all depths on the continental shelf but the fishing gears (traps, artificial shelters and nets) are not selective for lobster stocks or any other associated bottom-dwelling species. This problem can be solved using escape gaps in traps, eliminating the use of nets and artificial shelters. Few researchers have systematically discussed the question of selectivity (Cruz *et al.*, 2013*b*), and current efforts at designing escape gaps and saturation processes in traps by lobster/fish/mollusk are largely unknown. Over 40 years ago,

Paiva *et al.* (1973) demonstrated the negative impact caused to the ecosystem by the use of entangling nets but local authorities have so far been unable to enforce the legislation prohibiting such nets in spiny lobster fisheries.

The interaction between artisanal fishermen carrying out predatory fisheries in shallow waters (catching >50% juveniles and pre-recruits) and the industrial fleet carrying out predatory fisheries in deeper waters (catching large egg-bearing females) has generated highly negative and complex sequential externalities for *P. argus* and *P. laevicauda* stocks. According to the definition proposed by Wachsman (2003) and Bromley (2008), an externality is present when an action by an individual producer affects other parties. In the case of the spiny lobster, the unchecked increase in the effort of the artisanal fishermen tends to reduce the abundance of adults, causing negative externalities for the industrial fleet. Conversely, the unchecked increase in the effort of the industrial fleet in deeper waters tends to decrease the reproductive stock, affecting the recruitment of future generations (cohorts) and jeopardizing artisanal fisheries. In other words, unrestricted access to lobster resources generates a state of over-exploitation of the target species.

With regard to red spiny lobster catches in shallow waters, an increase in the size at first capture from 66 to 75 mm CL (MLS) or to 80 mm CL (ideal MLS proposed by Bertelsen & Matthews, 2001) would increase the available biomass by as much as 79% and 84%, respectively. By the same token, landings would increase in terms of weight and the fishing mortality of juveniles and pre-recruits would decline. In addition, abundance and yield per recruit would increase, as shown by Cruz *et al.* (1991) for the Cuban archipelago. Several authors (*e.g.,* Kanciruk & Herrnkind, 1976; Cruz, 1980; Bertelsen & Matthews, 2001; Silva *et al.* (2003) have demonstrated that, despite comprising a small segment of the stock, large females in deeper waters are more fecund than smaller females in shallow waters (1-10 m) and at intermediate depth (30-50 m). Lobster collected in a depth between 60 and 100 m (northern of Brazil) measuring up to 174 mm CL (males) and 228 mm CL (females), in addition to egg-bearing females measuring up to 231 mm CL (Silva *et al.*, 2008) are reported.

Management status and recommendations

The populations of red and green spiny lobsters on the Brazilian continental shelf have been studied for over 50 years. Research on spiny lobsters has covered a wide range of topics related to biology, fisheries, exploitation, population dynamics, fishing gear, exports, by-catch, trap bait, farming and grow-out of juveniles, physiology, and industrial technology and processing (Cruz *et al.*, 2011). Nevertheless, efforts at managing fisheries and enforcing legislation have been inconsistent and inefficient. Current regulations include a minimum legal size at capture and a closed season (Cavalcante *et al.*, 2011). Since control and compliance with regulations are more effective when the fishermen agree with the measures adopted by the resource managers (Cruz *et al.*, 2013*a*), it would be desirable to raise awareness among fishermen of the importance of protective measures, among other things by way of well-designed outreach programs.

Recently a new outlook on spiny lobster stock management was presented (Cruz *et al.*, 2011, 2013*a/b*) which encourages concentrating efforts on the control of management instruments and the enforcement of regulations in order to restore the commercial stocks of spiny lobsters and associated species. In addition, more studies are required on ecological, biological and life cycle-related aspects of Brazilian spiny lobster populations and their associated oceanic processes.

In general, local red and green spiny lobster stocks are subject to considerable growth overfishing (excessive catches of undersized individuals). Although there is currently no evidence of recruitment overfishing, much effort is applied to the capture of older and highly reproductive animals at greater depths (>50 m), including the indiscriminate exploitation of large egg-bearing females, a practice which increases the risk of recruitment overfishing and fishing collapse (Cruz *et al.*, 2013*a*).

Research has shown that the biomass and yield (kg) of commercial stocks of *P. argus* on the continental shelf off Ceará can be increased by eliminating growth overfishing and changing the MLS from 75 mm CL to 80 mm CL.

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