Arquivos de Ciências do Mar

CURRENT MANAGEMENT AND EXTERNALITIES IN LOBSTER FISHERIES EXPLOITATION ON THE CONTINENTAL SHELF OF CEARÁ, BRAZIL

Gestão atual e externalidades na exploração pesqueira da lagosta na plataforma continental do Ceará, Brasil

João V. Mendes Santana[1], Soraya D. S. Neves[2], Soniamar Z. R. Saraiva[3],Charles Adams[4], Raul Cruz[5]

ABSTRACT

In this study we analyzed the current models of extraction and management of Brazilian spiny lobster resources and looked into the problems caused by different types of associated externalities. The Brazilian continental shelf is not divided into fishing zones, making it impossible to prevent the concentration of fishing vessels and effort. The lobster production and wholesale marketing chain is complex: vessels of varying size and different legal or illegal methods and fishing gear are used, none of which are selective, and a significant part of the production is sold to middlemen who retain a large percent of the profits. In general, fishermen disregard existing regulations on resource use and access. This is equivalent to a regime of nonproperty (open access) in which individuals can directly take possession of resources. Unrestricted access leads to overexploitation of common property, making rational allocation of resources impossible and generating negative externalities.

Keywords: Panulirus argus*, Brazil, management, externalities, spiny lobsters.*

RESUMO

Neste estudo analisamos os atuais modelos de extração e gestão de recursos brasileiros de lagostas espinhosas e investigamos os problemas causados por diferentes tipos de externalidades associadas. A plataforma continental brasileira não é dividida em zonas pesqueiras, o que torna impossível evitar a concentração de embarcações e esforço de pesca. A cadeia de produção e comercialização da lagosta espinhosa é complexa: são utilizadas embarcações de variados tamanhos e diferentes métodos e equipamentos de pesca, legais ou ilegais, nenhum dos quais é seletivo, e grande parte da produção é vendida a atravessadores que retém um elevado percentual dos lucros. De um modo geral, os pescadores desrespeitam os atuais regulamentos sobre o uso e acesso ao recurso. Isso equivale a um regime de acesso aberto no qual o pescador individual pode se apossar diretamente do recurso. O acesso irrestrito leva à exploração predatória da propriedade comum, impede a alocação racional de recursos e gera externalidades negativas.

Palavras-chaves: Panulirus argus*, Brasil, gestão, externalidades, lagostas espinhosas.*

[1] Instituto Federal de Educação, Ciências e Tecnologia do Ceará (IFCE) — Campus Acaraú, Av. Des. Armando de Sales Louzada, s/n, CE. E-mail: joaovicentesantana@gmail.com

[2] Departamento Engenharia de Pesca, Avenida Humberto Monte, s/n - Campus do PICI, Universidade Federal do Ceará, Brazil. E-mail: sorayasnsol@gmail.com

[3] Instituto Federal de Educação, Ciências e Tecnologia do Ceará (IFCE) — Campus Acaraú, Av. Des. Armando de Sales Louzada, s/n, CE. E-mail: cefetpesca@gmail.com

[4] Professor do Florida Sea Grant College Program University of Florida, Gainesville, Florida, 32611, U.S.A. E-mail: cmadams@ufl.edu.

[5] Professor Titular do Programa de Pós-Graduação em Ciências Marinhas Tropicais - Universidade Federal do Ceará, Instituto de Ciências do Mar, Av. da Abolição, 3207, Bairro Meireles - CEP:60165-081 – Fortaleza - CE - Brasil. E-mail:rcruzizquierdo@gmail.com (autor correspondente).

INTRODUCTION

The spiny lobsters *Panulirus argus* (Latreille, 1804) and *Panulirus laevicauda* (Latreille, 1817) are commercially exploited along the Brazilian coast, from Amapá to Espírito Santo. The resource is one of the most important in the country, and stakeholders include a range of different social and economic sectors in coastal regions (Fonteles-Filho, 2000; Ivo *et al.*, 2013).

Stocks are exploited by a lobster fishing fleet operating either in shallow and middle waters (<50 m) or at greater depths (50-100 m). Lobster fishing is practiced at up to 100 m, using a variety of methods and gear (Silva et al. 2013), but information available to describe the number of active lobster fishermen, fishing gear and boats, abundance, effort and landings is highly inconsistent. Along the Brazilian coast, spiny lobsters are often captured with baited traps, especially a rectangular single-entrance trap referred to as *manzuá* or *covo* (in Portuguese). In the 1980s, a larger, double-entrance trap (in Portuguese: "cangalha") was common in some locations in Ceará (Fonteles-Filho, 2000). Albeit currently illegal, bottom trawlnets (in Portuguese, *caçoeira*) have been used since the early 1960s (Moura, 1963) and artificial shelters (in Portuguese, *marambaia*) have been used since 2000 (Nascimento, 2006).

The lobster fishing season is officially closed from December to May (180 days), during which period regulations prohibit the use of trawlnets, commercial diving at natural and artificial shelters and the capture of red lobsters (*P. argus)* with a tail length of less than 130 mm (75 mm carapace length) and green lobsters (*P. laevicauda*) with a tail length of less than 110 mm (65 mm carapace length) (Dias-Neto, 2008). However, due to weak enforcement and lack of fishing monitoring, laws and regulations designed to protect spiny lobster resources are frequently violated, making efforts at sustainable fisheries management ineffective and creating a scenario of overfishing and crisis in the sector (Cavalcante *et al.*, 2011).

Arnason (1999) and Seijo *et al*. (1997) showed that open-access regimes eventually lead to overexploitation, generating negative externalities for artisanal fishermen themselves. These externalities can be of an environmental, social, market or economic nature. And, such externalities can create positive or negative impacts. In addition, Bromley (1991) described the rights and duties associated with different fishing resource property regimes and offered a coherent discussion on open-access scenarios which closely reflects the current problems characterizing Brazilian lobster fisheries.

The objective of the present study was to evaluate the current extraction, organization and management of spiny lobster resources on the continental shelf off the State of Ceará in the form of a case study. To do so, a preliminary analysis of fishing grounds, social relations and property rights was conducted, identifying the some evident externalities generated by the exploitation of this resource. Finally, potential management options are discussed.

MATERIAL AND METHODS

Description of the study area

With a coastline facing north and northeast, the coastal state of Ceará in Northeastern Brazil (Figure 1). *P. argus* and *P. laevicauda* occur on the continental shelf off Ceará, from Barroquinha to Icapuí, covering a shoreline of 578 km, corresponding to 8.5% of the Brazilian coast (6573 km) (Cruz et al. 2011). The continental shelf off Northeastern Brazil is relatively wide and shallow, followed by an abrupt drop off starting at a depth of approximately 60 m. The coastal waters of Northeastern Brazil feature extensive calcareous algae banks, especially off Ceará and Rio Grande do Norte, possibly due to the absence of major rivers and, consequently, very small amounts of fluvial discharge (Coutinho & Morais, 1970).

Economic and fisheries descriptive data

Statistical information from the databases of Center for Research and Management of Fishing Resources on the Coast of Northeastern Brazil (CEPENE) and Brazilian Institute of the Environment and Renewable Natural Resources (IBAMA) covering the period 1999-2006, in addition to data provided by the Ministry of Fisheries and Aquaculture (MPA), were used to analyze the current status of spiny lobster fisheries in 20 municipalities in Ceará. Unfortunately, data by region, state and municipality have not been compiled consistently since the early 1990s. The total number of fishermen was estimated from information obtained from MPA (2014) and the General Registry of Fishermen.

Brazilian government agencies kept yearly updated databases of total lobster landings in Ceará for the period 1983-2011, within which a time series of landings by species is available for the years 1965-1990 (Ivo & Pereira 1996). An empirical equation reported by Cruz *et al*. (2013*a*) was used to estimate

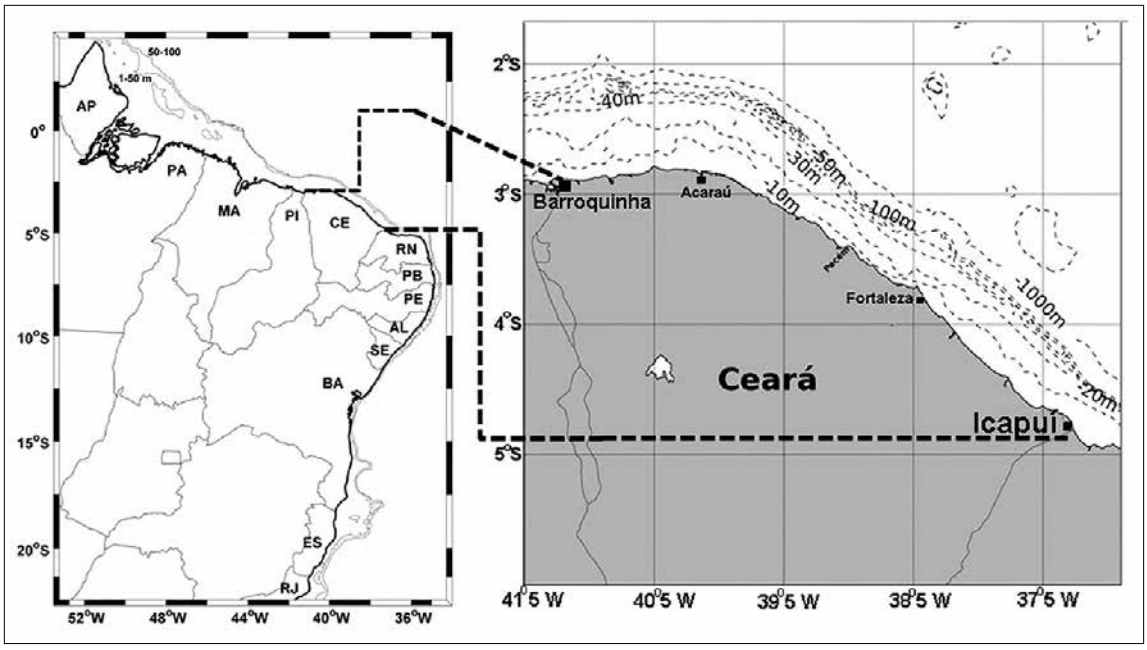

Figure 1 - Left: Area on the Brazilian continental shelf (depth: 1-100 m) exploited by the spiny lobster (*Panulirus argus* Latreille, 1804, and *Panulirus laevicauda* Latreille, 1817) fishing fleet. States along the coast: Amapá (AP), Pará (PA), Maranhão (MA), Piauí (PI), Ceará (CE), Rio Grande do Norte (RN), Paraíba (PB), Pernambuco (PE), Alagoas (AL), Sergipe (SE), Bahia (BA), Espírito Santo (ES) and Rio de Janeiro (RJ). Right: Spiny lobster fishing grounds off the state of Ceará, from Barroquinha (03°01'08''S; 41°08'10''W) to Icapuí (04°42'47''S; 37°21'19''W), with indication of depth in meters. Fortaleza is the state capital. Acaraú is a port of lobster landed.

the volume of *P. argus* landed between 1991 and 2011: red spiny (*P. argus*) lobster landings (t) = 225.17 + 0.6752 * total lobster landings (t). Subsequently, the volume of green spiny (*P. laevicauda*) lobsters landed was found by subtracting red spiny lobster landings from total lobster landings.

Lobster export revenues for the period 1983-2011 were obtained from technical reports issued by CEPENE and the Alice Web system (System of Analysis of Foreign Trade Information). Other economic information (such as lobster prices) was obtained through interviews with local fishermen and salesmen. Brazilian Real (BRL) was converted to US dollars (USD) based on the official exchange rate in December 2014 (BRL 1 = USD 0.37).

Interviews with artisanal fishermen

Brazilian artisanal lobster fishermen rarely volunteer to give interviews. Since the vast majority employs clandestine fishing gear and frequently takes undersized lobsters, obtaining information about the location of the fishing grounds, the volume of lobsters landed the number and types of gear and the depth at which the traps are deployed is a problematic process. This difficulty was overcome through direct interviews with artisanal fishermen in the coastal community of Ceará.

Using a questionnaire prepared by the authors, randomly selected artisanal fishermen from communities in Acaraú, Cruz and Camocim (western reaches of Ceará) were interviewed in January, February and November 2012. The questionnaire solicited a variety of items addressing demographic aspects, characteristics of fishing vessels, characteristics of fishing trips and local marketing arrangements.

Sampling

The fishing grounds off Acaraú (Figure 1) was chosen to conduct the study on the variation in length composition of *P. argus* in artificial shelters (AS) fishing grounds at a depth of 3-10 m (shallow water) and baited traps (BT) deployed at a depth of 30-50 m (deep water). They were inspected monthly at two depth ranges. Variation in carapace length collected in 2014 was calculated for each depth range. The animals were classified according to gender, the carapace length (CL) was measured with a 200-mm caliper (precision: 1 mm).

RESULTS

Description of fishermen

Due to the reluctance of most potential interviewees, our final sample was limited to 126

participants selected for the quality of the information provided. The number of active lobster fishermen living in coastal communities (by region, state and municipality) is not well defined, making it difficult to determine the statistical relevance of our sample.

The interviewed fishermen from Acaráu, Cruz and Camocim exploited lobsters and other resources. Less than half (44%) were owners of the vessel used in their activities and the remainder (56%) were hired and paid by the vessel owner, with payment taking the form of a percentage of the landings, or hired by the fishing industry for a fixed wage, with no share of landings.

The fishermen were between 23 and 60 years old (23-30 years = 17%; 31-40 years = 21%; 41-60 years = 51%). Most were married (76%) and the main income earners of the household. Almost half (31-45%) were illiterate, 27% had enrolled in but not completed elementary school, and 25% had graduated from elementary school. Only one interviewee (2%) had been to high school, but had not graduated. All interviewed fishermen were male.

More than half the fishermen (61%) earned up to 500 BRL (183.2 USD) per month, 19% earned between 500 BRL and 1000 BRL (366.4 USD), and 10% earned between 1000 BRL and 2000 BRL (732.7 USD). Only two interviewees reported earning over 3500 BRL (1282 USD) per month. In short, fishermen in the region were predominantly middle-aged, married, illiterate and the main providers of the household, earning less than one official Brazilian minimum wage (788 BRL, 248.4 USD).

Fishing grounds and fisheries

Spiny lobster fishing grounds along the Brazilian coast are not divided according to state or municipal jurisdiction. In other words, there ar e currently no regulations preventing the concentration of fishing efforts and the clustering of fishing vessels in specific locations. Duly licensed vessels can exploit fishing grounds anywhere in the country, with no restrictions on effort, the number of vessels or the number and type of gear (provided the gear is legal). For example, according to fishermen and experts, an undetermined proportion of the lobster fishing fleet of Acaraú (Ceará) spends part of the season exploiting fishing grounds farther north (Pará). During the journey to their final destination off Northern Brazil, these vessels exploit fishing grounds off the states of Piauí and Maranhão. Likewise, vessels from Rio Grande do Norte often exploit resources in waters off Ceará. Landings may be sold informally anywhere along the coast or disembarked in harbors where the tails are submitted for processing. However, according to the interviewed lobster fishermen, long fishing trips have become a less attractive strategy due to soaring diesel prices. The situation seems ripe for the adoption of a zoning plan.

No property rights system exists, i.e. cooperatives of fishermen or fishing companies through which the allocation of resources could be optimized. Property rights naturally befall those who control the means of production (vessel and gear).

Characteristics of vessels and fishing routine

When fishing for lobsters, most fishermen (64%) worked on wind-powered vessels, while 36% used engine-powered vessels (n=46), of which 38% used outboard motor and 62% central motor.-

Wind-powered vessels (length < 8 m) are unsuitable for trips longer than one day. Thus, most interviewees (55%) reported leaving at night and returning in the morning. In contrast, 27% reported spending over 25 days on each fishing trip, using larger, engine-powered vessels (length >12 m). The remainder (18%) used engine-powered vessels (length 8-12 m), but the trips were shorter (5-20 days).

The number of crew depended on the size and type of vessel. Thus, small wind-powered vessels usually carried three (20%) or four (25%) fishermen, whereas engine-powered vessels had crews of 5 (27%), 6 (9%) or 7 (18%) fishermen.

The fishermen using small wind-powered vessels reported catching 2-10 kg (61%). In engine-powered vessels the average landings amounted to 10-90 kg for 19.5% of the interviewees, and to 100 kg or more for 19.5%. Perhaps long-range, engine-powered fishing vessels may catch over a ton of lobsters during a single trip.

Fishing methods and catch characterization

Previous studies on lobster fishing have established that three basic fishing methods are used along the coast of Ceará: BT, scuba diving in AS and bottom nets (BN). A total of 2083 lobster were harvested from AS at a depth of 3-10 m, out of which 22% were caught as juveniles (16-50 mm CL), 65% pre-recruits (50-73 mm CL) and only 13% mature lobster. However, it is evident in BT at a depth of 30-50 m the total harvest (N= 1500) composition are basically mature lobster (96%). The size distribution at depth is shown in Figure 2.

On the other hand, in this region we do not have information about the BN, according to our findings above fishermen using in more deep waters

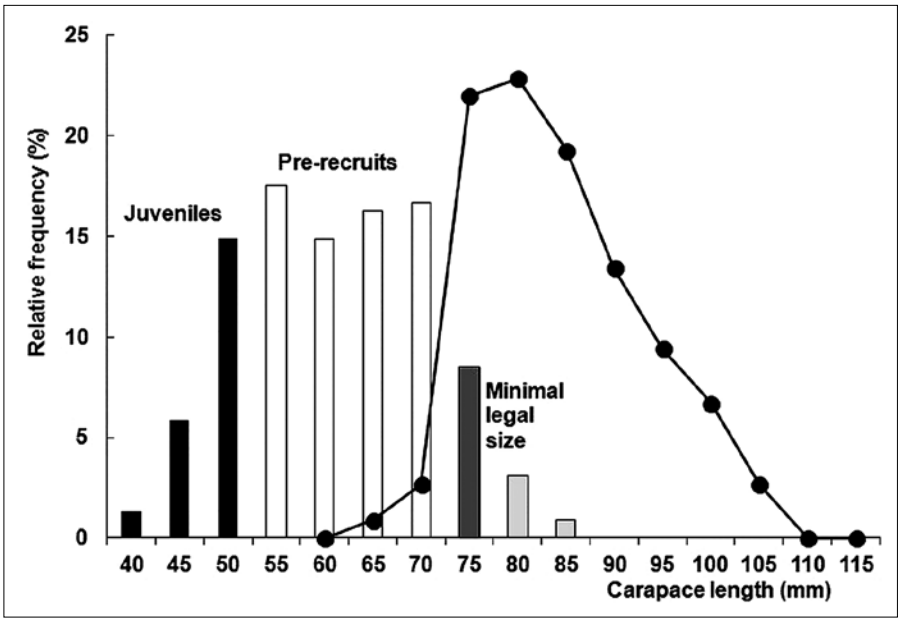

Figure 2 - Size composition of spiny lobster (*Panulirus argus*) for the year 2014 (January-December) in artificial shelters and at traps fishing grounds. Column: shallow waters (3-10 m). Line with point black: deep waters (30-50 m).

(50-100 m) farther north, Amapá and Pará region, where they cannot use traps. However, fishermen generally admit only to using traps, due to the current ban on the two other methods.

BT is non-selective, and different types of bait may be used. Many fishermen (42%) reported using sea catfish (whole or heads), while 11% used heads of piramutaba catfish (*Brachyplatystoma vaillantii*), 6% used unidentified small fish, 4% used the heads of unidentified fish, or ray (2%) or shrimp heads (2%). Non-seafood-related products were frequently reported, such as bacon (18%), coconut shells (9%) and cow hooves (6%).

A variety of other non-targeted organisms are captured as by-catch in lobster traps. According to the interviewed fishermen, the most important by-catch is snappers and grunts (60%), including species that are predators of lobster (Table 1).

Trends in landings and markets

The records of *P. argus* catches in Ceará date from 1983 (1299 t). Annual catch increased to nearly 2200 t by 1985, but plummeted to 1161 t in 1986. A record

Table I - Fauna associated as by-catch in lobster traps in Brazil. Some species of the family Lutjanidae, Serranidae, Balistidae, as well as octopuses and other fish which are potential predators of juvenile and mature lobsters.

Family	Species	Vernacular name	%
Lutjanidae	*Lutjanus synagris*	Lane snapper	16
	Lutjanus analis	Mutton snapper	13
	Ocyurus chrysurus	Yellowtail snapper	2
	Lutjanus jocu	Dog snapper	1
	Lutjanus spp.	-	1
		Subtotal snappers	**33**
Haemulidae	*Haemulon plumieri*	White grunt	18
	Conodon nobilis	Barred grunt	5
	Haemulon flavolineatum	French grunt	4
		Subtotal grunts	**27**
Ephippidae	*Chaetodipterus faber*	Spadefish	6
Scaridae	*Sparisoma* spp.	Parrotfish	3
Carangidae	*Caranx chrysos*	Blue runner	3
Muraenidae	*Gymnothorax funebris*	Green morey	2
Malacanthidae	*Caulolatilus chrysops*	Goldeneye tile fish	0.5
Acanthuridae	*Lopholatilus villarii*	Tile fish	0.5
Serranidae	*Epinephelus* spp.	Grouper	1
Acanthuridae	*Acanthurus* spp.	Lancet fish	1
Rhinobatidae	*Rhinobatos* spp.	Guitarfish	1
Scyllaridae	*Scylarides spp.*and *Parribacus antarcticus*	Slipper lobsters	2
Balistidae	*Balistes vetula*	Queen triggerfish	8
-	*Octopus* spp.	Octopus	4
	Others: fish species, crabs and seashells		8
		Subtotal others	**40**
		Total	**100**

high was set five years later, in 1991 (2670 t). A decreasing average trend was observed between 1992 and 2007 (739 t), followed by an increasing trend from 2008 to 2010 (1721 t). Between 2009 and 2011, production was rather stable. Revenues from Brazilian lobster exports have grown steadily over the last decade, from USD 40.1 million in 2000 to USD 50 million in 2011 (Figure 3).

The capture, sale and marketing of spiny lobsters comprise a complex process. As discussed, several fishing methods are employed using nonselective gear and vessels of varying size, and the catch is often sold to middlemen at a suboptimal price, approx. 50 BRL/kg tail (18.52 USD/kg) or 17 BRL/kg whole lobster (6.30 USD/kg). The middlemen sell the catch to the processing industry or on the domestic market (hotels and restaurants) at a considerable profit, approximately 57 BRL/kg tails (21.10 USD/kg) or 23 BRL/kg whole lobsters (8.51 USD/kg). In other words, fishermen apparently lose approximately 15-35% profit by selling their catch to middlemen, because they likely do not have the financial or educational ability to do anything else but to sell to a middleman.

In some cases, seafood buyers finance fishing trips for vessel owners in the form of money or supplies on condition that the lobster catch is sold directly to those buyers. The vessel owners's profits depend on the amount financed. The fishermen receive a small percentage of the sales and a subsidy from the government equivalent to one minimum wage (788 BRL in 2015) per month during the closed season. Some middlemen also finance fishing trips for vessel owners, pay the industry to process the catch and export the product under their own trademark.

Lobster landings vary from state to state. Records covering the years 2002-2006 show Ceará in the most important with an average 39.7%, followed by Rio Grande do Norte (16.4%), Pará (15.9%) and Bahia (12.1%). The remaining lobster-producing states totaled 15.8% on the average. Overall, Ceará was responsible for nearly half the Brazilian lobster production between 1999 and 2006, with record yields in 2000 (46%) and an all-time low in 2003 (22%).

In Ceará between 2002 and 2006, the municipalities Itarema and Acaraú had the greatest production of spiny lobsters (500-610 t), followed by Fortaleza, Beberibe and Icapuí (200-300 t), Camocim, Trairi and Fortim (100-200 t), Amontada, Itapipoca, Cascavel and Aracati (50-100 t) and Barroquinha, Cruz, Paraipaba, Paracuru, São Gonçalo do Amarante, Caucaia and Aquiraz (< 50 t) (Figure 4).

Based on the physical configuration of the shoreline and the landings registered for each municipality, a division of fishing grounds is conceivable which would facilitate the monitoring and management of fishing resources in Ceará. Thus, it would be desirable to establish three zones of fisheries management: West (from Barroquinha to Itarema), Center (from Amontada to Aquiraz) and East (from Cascavel to Icapuí). According to this division, lobster landings would be greatest in the East Zone (200-300 t), followed by the West Zone (100-200 t) and the Central Zone (50-100 t) – see Figure 5.

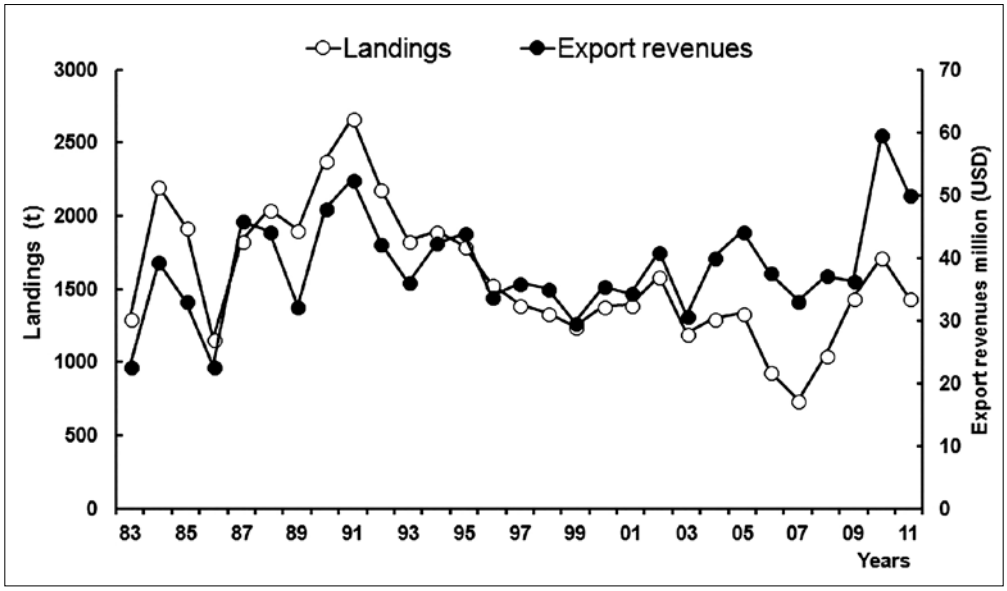

Figure 3 - Trends of landings of red spiny lobsters (*Panulirus argus* Latreille, 1804) on the continental shelf off Ceará and lobster export revenues (in million USD).

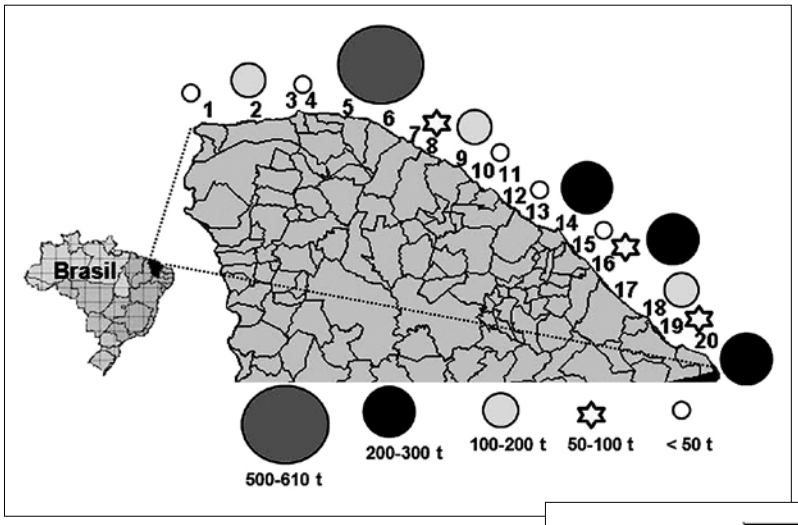

Figure 4 - Average annual landings of spiny lobsters (*Panulirus argus* Latreille, 1804, and *Panulirus laevicauda* Latreille, 1817) according to municipality (1=Barroquinha, 2=Camocim, 3=Jijoca [no production], 4=Cruz, 5=Acaraú, 6=Itarema, 7=Amontada, 8=Itapipoca, 9=Trairi, 10=Paraipaba, 11=Paracuru, 12=São Gonçalo do Amarante, 13=Caucaia, 14=Fortaleza, 15=Aquiraz, 16=Cascavel, 17=Beberibe, 18=Fortim, 19=Aracati, 20=Icapuí). Period: 1999-2006.

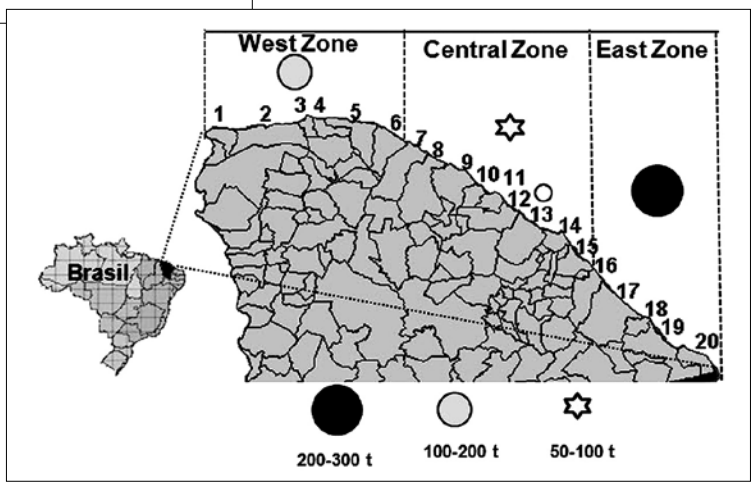

Figure 5 - Average annual landings of spiny lobsters (*Panulirus argus* Latreille, 1804, and *Panulirus laevicauda* Latreille, 1817) according to fishing zone (West Zone: 1=Barroquinha, 2=Camocim, 3=Jijoca [no production], 4=Cruz, 5=Acaraú, 6=Itarema; Central Zone: 7=Amontada, 8=Itapipoca, 9=Trairi, 10=Paraipaba, 11=Paracuru, 12=São Gonçalo do Amarante, 13=Caucaia, 14=Fortaleza, 15=Aquiraz; East Zone: 16=Cascavel, 17=Beberibe, 18=Fortim, 19=Aracati, 20=Icapuí). Period: 1999-2006. Colum bar shallow water.

DISCUSSION

Lobster resources and property regimes

Ceará is the most important lobster producer along the Brazilian coast. Since this region accounts for 40% of total Brazilian catches, the strong fluctuations observed in yields are probably due to the capture of undersized lobsters (>50%), leading to growth overfishing in shallow waters (Cruz *et al*., 2013*b*).

Lobster fishing grounds include a variety of habitats, such as reef structures and dense beds of different types of calcareous algae at 20 m or deeper (Coutinho & Morais 1970). These habitats provide abundant shelter and, according to Eggleston (1991), reduce predator pressure. They also provide the spiny lobster, a key predator in several benthic ecosystems (Tegner & Levin 1983; Edgar 1990), with a highly diversified diet of invertebrates (Kempf *et al*., 1968), especially mollusks and crustaceans, during each stage of development.

Studies from Florida (Marx & Herrnkind, 1985; Herrnkind *et al*., 1988) and Cuba (Herrera *et al*., 1991) show that juveniles and adults of *P. argus* prey on an array of different invertebrates, especially mollusks and crustaceans, as supported by physiological laboratory studies (Diaz-Iglesias *et al*., 2002). The abundance of shelter and food on the continental shelf off Ceará is favorable to the maintenance of large lobster stocks. Conversely, as stated by Eggleston (1991), scarcity of shelter is a limiting factor for the abundance of lobsters on reefs and algae beds.

The use of liftable wooden-frame lobster BT with one or two entrances is legal. However, because the traps are not selective, undersized lobsters are often caught (depending on location) along with highly diversified by-catch (Table I), with a tendency to increase by-catch with depth (Ivo *et al*., 1996). In addition, Cruz *et al*. (2013*b*) suggested productivity may be compromised if the lobster traps become saturated with by-catch—a question that remains to be investigated.

According to Bromley (1991), fishing resources may be subject to different property regimens: state

property, private property, common property and non-property (open access). In Brazil, fishing resources are state property, with a managing agency in charge of enforcement and inspection, but fishermen commonly disregard the rules of proper use and access. Enforcement has been shown to be woefully inadequate to ensure compliance with existing regulations in the region (Cavalcante *et al*., 2011). In practical terms, it is equivalent to a regime of non-property (open access), in which individuals can directly take possession of resources. According to Arnason (1999) and Seijo *et al*. (1997), open access and unrestricted use lead to overexploitation of common property resources, make it impossible to allocate such resources rationally, and thereby generating negative externalities.

In the absence of lobster fishing regulations (other than the closed season), fishermen compete with one another to land the greatest possible volume, catching undersized lobsters and employing seemingly productive but illegal fishing methods such as BN (Moura, 1963) and AS (Cruz *et al*., 2011). The vast extension of Brazilian lobster fishing grounds and the lack of effective management, control and law enforcement render lobster fisheries disorderly and unsustainable. The number of fishermen, boat, and type of boat required by fishing zone for a rational management of the lobster resource has not been determined. In view of the well-documented inefficiency of the current management approach and the ambiguous nature of the property regime, a new management plan and zoning system must be developed urgently which takes into account the Brazilian socioeconomic reality and the biology and ecology of wild lobsters and their interplay with oceanic processes.

Externalities and market inefficiencies

An externality is defined as an unanticipated side effect that either benefits or harms a "third party" not directly involved in an activity (Tietenberg & Lewis, 2014). Similarly, market inefficiencies or failures, refer to when an incomplete set of market information and signals cause resulting prices, costs and quantities to be different from what would emerge from a more competitive market (Henderson & Quandt, 1980). These externalities and market inefficiencies are addressed in the discussion below and provide a basis for the suggested management options that follow.

The fishing methods and gear described above are associated with several types of externalities. An example of technological and dynamic externalities, as suggested by Seijo *et al*., (1997) and Wachsman (2003), respectively, is seen in the capture of lobsters using BN and BT which impact the structure of both target populations and by-catch, potentially compromising the productivity of fellow fishermen by changing the relative abundance of targeted species other than lobster (*e.g*. fish, Table I). Likewise, increasing the fishing effort, or using a method which requires less effort (*e.g*. AS), is likely to deplete resources shared with other fishermen. Thus, Clark (1980) observed that fishermen engage in overfishing because they are unconcerned about the social consequences of their behavior and about other fishermen's ability to exploit the resource.

The use of BN and AS drastically alters the substratum of lobster habitats, thereby creating techno-ecological externalities, a concept introduced by Seijo *et al*. (1997). Both types of gear are associated with reduced levels of settlement of spiny lobsters at different stages, slipper lobsters and other organisms in the benthic ecosystem, some of which may be the object of other fisheries.

Related to these externalities are the so-called sequential externalities (Figure 6). The small wind-powered fishing vessels (artisanal fleet) and larger engine-powered fishing vessels (industrial fleet) act on different components of the population structure. This generates very complex negative externalities for red lobsters and other stocks, especially as artisanal fleet catch large numbers of juveniles and pre-recruits in shallow waters (> 50%) according to Cruz *et al*. (2013*b*). The industrial fleet take adult lobsters at different reproductive stages (including berried females) in deeper waters (> 50 m) where the greatest reproductive potential is found and more than 50% of the lobster stock consists of mature adults (Silva *et al*., 2008, Cruz *et al*., 2014). In a scenario of unchecked expansion of fishing efforts, lobster catches by small boats in shallow waters reduce the abundance of adults, thereby generating negative externalities for operators of industrial vessels. Likewise, increasing efforts in deeper waters eventually reduces the reproductive stock to the detriment of the recruitment of the following generations (cohorts), thereby generating negative externalities for small-scale fishing vessels. As a result, target species are overexploited, possibly along with other components in the catch assemblage.

As act as ecological traps generating impacts for which the expression "biomass agglomeration externalities" may be suggested. AS are often deployed clandestinely on fishing grounds in shallow waters (3-10 m) causing an increase and redistribution

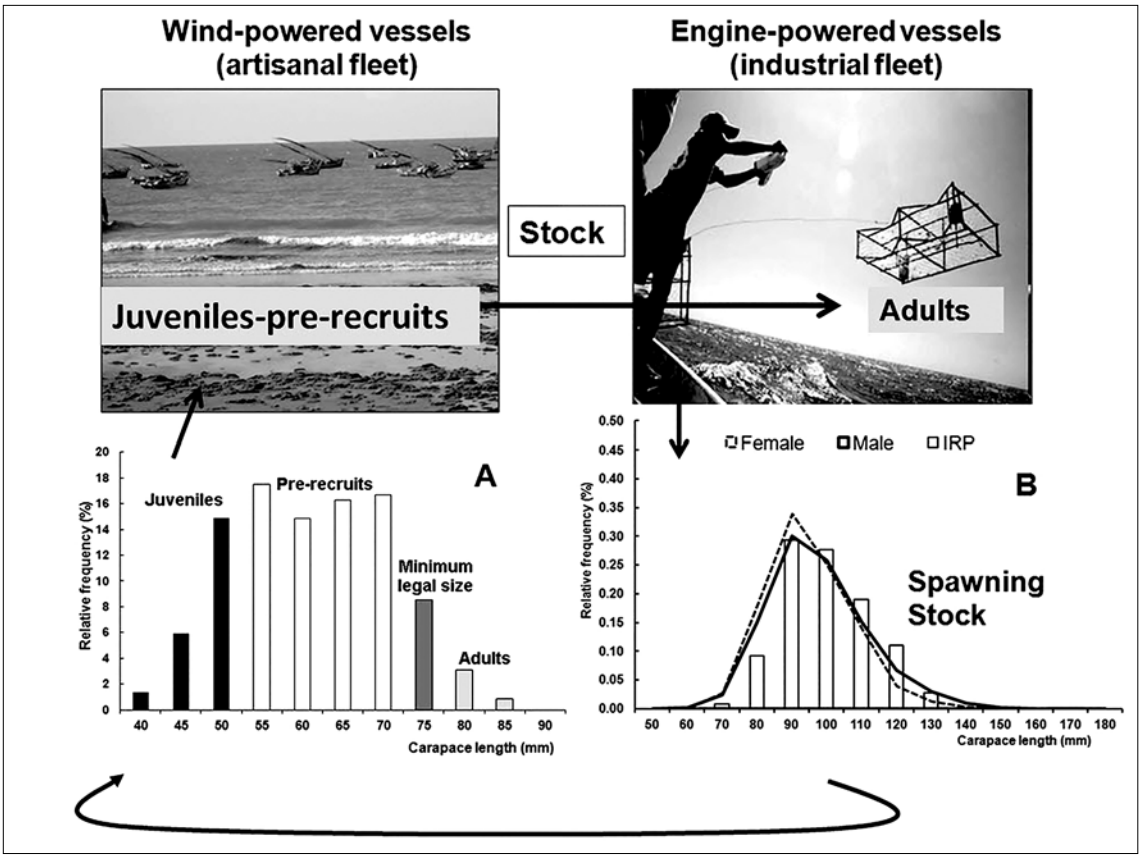

Figure 6 - Summary of the dynamics of lobster fisheries on the Brazilian continental shelf. By exploiting lobsters outside the recommended size range, the artisanal fleet and the industrial fleet affect the size structure of the lobster stock, thereby generating sequential negative externalities for one another. Picture on the left: the artisanal fishing fleet exploits primarily juveniles and pre-recruits in shallow waters (3-6 m). Picture on the right: the industrial fishing fleet exploits primarily adult lobsters in deeper waters. The relative size structure of spiny lobsters exploited by each fleet is represented in figures A and B. A) Size composition of juveniles and pre-recruits on the coast of Acaraú (modified from Cruz et al., 2015). B) Relative size structure of female/male spiny lobsters caught on the continental shelf off Northern Brazil. IRP = index of reproductive potential (white bar) for the period 2001-2003 (modified from Cruz et al., 2014). The curved arrow below the figures represents the relationship between spawning stock and recruitment (juveniles).

of the exploitable lobster biomass due to the large proportion of undersized lobsters captured: between 60% (Nascimento, 2006) and 88% (Cruz *et al*., 2015) (Figure 7). Polovina (1991) concluded that if artificial shelters aggregate juveniles, thereby making them more accessible to capture, the exploitable biomass may increase as the size of the individuals at entry to the fishery decreases (growth overfishing). Cruz and Borda (2013) provided evidence that the increasing use of AS concentrates lobster biomass in a small area and increases catch rates at low cost-effort. However, with rational management practices and effective law enforcement, shelters could also be used to generate biomass agglomeration externalities favorable to lobster populations and fisheries.

In addition, Brazilian AS may impose environmental externalities (negative or positive). For example, the AS deployed in areas covered with vegetations causing an as of yet unmeasured negative impact on the benthic ecosystem, as it reported by Cruz *et al*. (1986) in the insular shelf of Cuba, and impose a marine pollution too, originating an environmental damage as negative externality. In exploited but protected lobster population the AS effect can generates a positive environmental impact on fisheries resources (positive externality). Such effects could be explained in terms of the feeding interactions, for example Cruz & Borda (2013) suggest that the fauna associated with refuge represents an addition to the diet of the lobsters; this very likely increases feeding efficiency and may provide an explanation for the observed increase in colonization and growth rates (Cruz & Phillips, 2000). The availability of safe habitats and refuge tends to reduce predator pressure (Eggleston, 1991), although natural mortality drops rapidly with size and age.

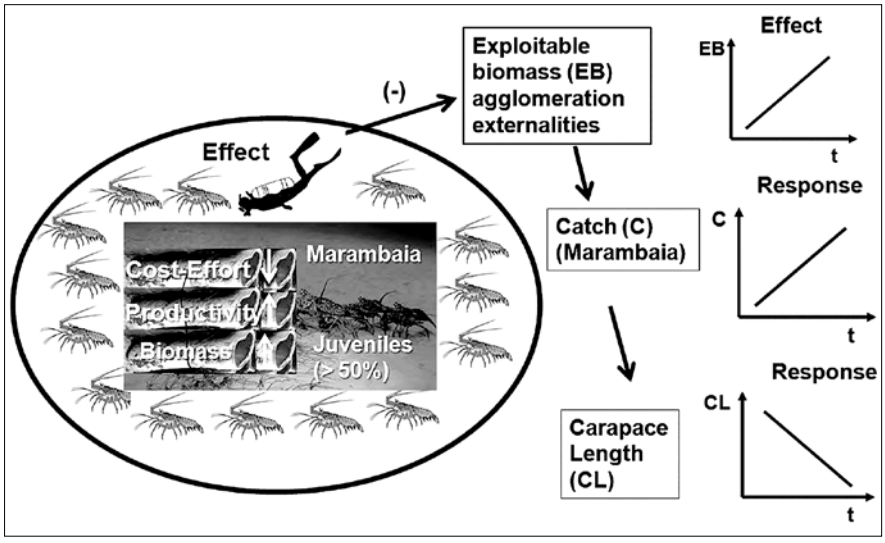

Figure 7 - Summary of the impact of artificial shelters (marambaias) on spiny lobster fisheries on the Brazilian continental shelf. Deployed in shallow waters, the shelters are mostly colonized by juveniles and pre-recruits. Over time, the use of shelters generates exploitable biomass agglomeration externalities (effect) reflected at two levels of response: increasing catches and decreasing carapace length. Further the *marambaias* generated environmental externalities, involve some perturbation of the benthic ecosystem (negative externality) because when they are deployed in the sea floor affecting the biota under refuge (Cruz et al., 1986) and generate unmeasured negative externalities. However, can generate a positive environmental impact on fisheries resources (positive externality) increasing the growth rates, accessibility to the refuge (Cruz & Borda, 2013) and reduce predators pressure (Eggleston, 1991) mainly exploited but protected lobster population.

Market inefficiencies

Lobster fishermen in Brazil operate as price takes in the market. The first buyers, or middlemen, exert substantial market power over the fishermen. This results in the fishermen having few, if any, alternative market outlets for their product. Due to the resulting low "dockside" prices, the income earned by fishermen is relatively small considering the catch volume. By having almost total control over the determination of the wholesale price of lobster (tail and whole), middlemen make a considerable dent in fishermen's earnings, generating negative impacts manifested by low prices. The latter differ from other forms of market inefficiencies, such as when fishermen are encouraged to increase effort to reduce market prices (Wachsman 2003; Datta & Mirman 1999). Market inefficiencies are detrimental to the economic status of lobster fishermen, whether self-employed or hired, and turn lobster fishing into a virtual subsistence activity, while the greater part of the profit goes to middlemen and processing plants (Figure 8). This market phenomenon could be reduced by providing greater market power to fishermen. One method of providing this market power may be through the development of lobster fishermen cooperatives. However, for harvester cooperatives to be successful, the fishermen must be highly organized, committed to a common marketing objective, be willing to make the necessary investment, and have the ability to function as their own marketing agents. Such activities can require

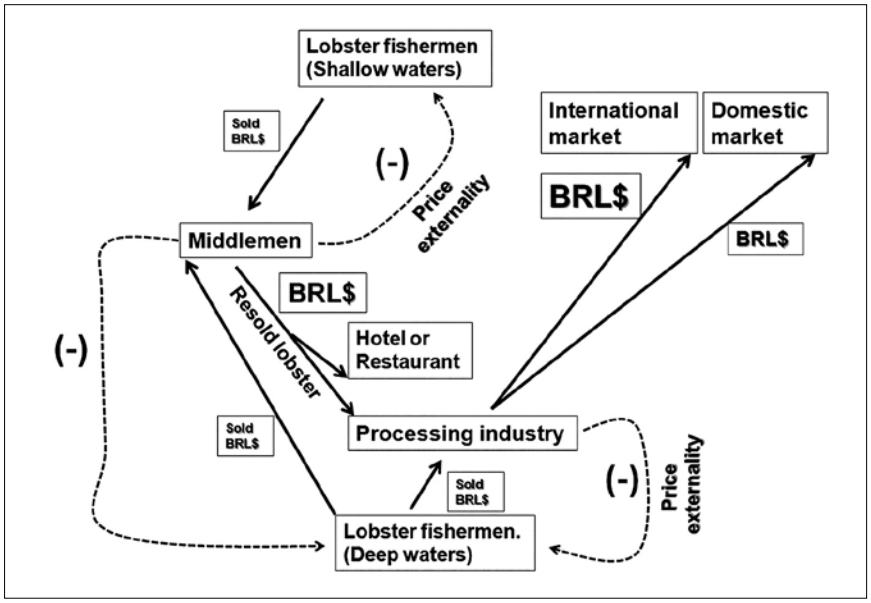

Figure 8 - Flow chart of the spiny lobster production and wholesale chain in Ceará, Brazil. Lobster fishermen operating in shallow and deep waters, respectively, are affected by negative price externalities generated by middlemen and the processing industry. Differences in sales prices are indicated by differences in the size of the symbol BRL$.

education and financial resources that may be unattainable by typical fishermen.

The existence and general acceptance of such an asymmetrical relationship between fishermen and middlemen (none of the interviewed fishermen identified it as a problem) is a consequence of typical fishermen being characterized by illiteracy and complete dependence on middlemen. The lack of a means of transportation and storage is one of the main obstacles to the marketing of products and accumulation of capital by fishermen. The acceptance of meager profits on the part of artisanal fishermen is a classic example of what psychologists call "the social trap" (Platt, 1973): a situation in which a cooperative solution with obvious social benefits cannot be reached due to lack of confidence, education, and financial ability. Hardin (1968) describes it as *the tragedy of the commons*, where multiple individuals acting independently (though rationally) and strictly motivated by self-interest, end up exhausting a limited common resource.

Management options and recommendations

To avoid this negative impact (sequential externality) on lobster resources, fishermen should reduce effort by abstaining from taking lobsters under the legal minimum size of 75 mm (CL). This would allow the average lobster size and weight to increase enough to obtain an annual harvest of approximately 4 200 t (Cruz *et al*., 2013*b*). Likewise, abstaining from capturing berried females and older lobsters (>135 mm CL) in deeper waters (50-100 m) would significantly increase the reproductive potential of the species (Cruz *et al*., 2014) and perhaps also increase the overall quality of the eggs in the population (MacDiarmid & Sainte-Marie 2006). Eventually, the risk of low recruitment and a fishery collapse would be averted. The strategy would generate a positive sequential externality in a competitive scenario.

To compensate for these externalities, policy makers have proposed a number of management instruments, such as compliance and law enforcement, output taxes, input taxes, output quotas, input quotas and individual transferable quotas (Hanley *et al*., 1997). However, since no updated information is available on effort, landings, costs, number of fishermen and gear, and since the existing management models have so far been ineffective, adoption of a system of total allowable catch (TAC) and quotas per state and fishing zone appears more feasible. Conversely, Petursdottir *et al*., (2001) suggested that setting of a TAC without further regulations, invariably leads to a rush for the catch (lobster), resulting in even fiercer competition than under the open-access fisheries. But according to Wachsman (2003), the setting of TACs is practical and quotas can be adjusted periodically.

As we have shown, the deplorable situation of spiny lobster fisheries along the Brazilian coast is the result of a steady increase in fishing effort and the use of improper fishing methods over the last four decades, thereby depleting stocks and degrading the benthic ecosystem. Cavalcante & Furtado-Neto (2012) proposed innovative measures such as the implementation of individual transferable quotas (ITQs) and compulsory landing of live lobsters, and called for a revision of the current management plan (Dias-Neto, 2008). However, above-named authors did not present an actual management plan or outlined the steps required to ensure the sustainability of lobster fisheries. Copes (1986) had previously published a critical analysis of the use of ITQs in fisheries, illustrated with examples of implemented plans and their outcome.

For example, perhaps the first management option is propose an initial TAC of 1300 t for Ceará region, based on average landings between the years 2000 and 2011. The TAC could be allocated among the three fishing zones proposed in this study (Fig. 5), as regional lobster quotas, thus avoiding the concentration of fishing effort and stock related externalities (increased costs resulting from dwindling stocks) (Runge 1981). According to Wachsman (2003), however, dividing the TAC quota among the fishermen boat by fishing zones may be better. We recommend implementing this management option in the fishing zone of Ceará State (e.g. re-evaluating the abundance of lobster in the fishery annually and adjusting the quotas at different levels of TAC). Afterward, this could be expanded by evaluation other lobster stocks in a broader region, leading to the establishment of TACs and fishing quotas in other lobster fishing zone within the continental shelf of Brazil.

Nevertheless, due to the multiple species and complex logistics involved in the management of Brazilian lobster fisheries, Cruz *et al*. (2013*ab* and 2014) do not believe the establishment of a TA C quota is enough to preserve lobster stocks in Brazilian waters, but suggest investing more effort in enforcement and control measures, including the following: (i) lobster traps should be furnished with escape gaps for undersized lobsters, (ii) the use of

undersized lobsters (decoys) in traps should be avoided, because directly affects the recruitment ,(iii) BN and AS should be eliminated, iv) an optimal minimum legal size of 80 mm CL should be established for *P. argus* and *P. laevicauda*, (v) a maximum legal size should be established (135 mm CL for *P. argus* and 100 mm CL for *P. laevicauda*), (vi) the capture of berried females should be prohibited, (vii) a closed season should be instituted to protect berried females and ensure recruitment, (viii) a marine protected area with year-round fishing prohibition should be implemented to protect juveniles in nursery grounds, (ix) a deep-water (50-100 m) marine protected area should be implemented on the continental shelf off northern Brazil, from Amapá (5°25'N - 51°00'W) to the western reaches of the coast of Pará (0°55'N - 46°38'W), covering a total surface area of 64,230 km^2, (x) a monitoring program collecting catch and effort data should be implemented to help assess lobster stocks adequately, and xi) a lobster monthly monitoring program should be carried out at different depths.

Based on the assumption that Brazilian stocks of *P. argus* and *P. laevicauda* are closed metapopulations, with no exchange with other Atlantic spiny lobster populations (Cruz *et al.*, 2014), a comprehensive revision of legislation and management models for Ceará and other lobster-producing states is a crucial step in the recovery of commercial and non-commercial stocks of spiny lobsters.

Acknowledgements - This work is based upon research carried out by the authors (Professors and Postgraduate students). Gratitude is extended to the Instituto de Ciências do Mar (Labomar-UFC) for logistic support.

REFERENCES

Arnason, R. Minimum information management in fisheries. *Can. J. Econ.*, v.23, p.630-653, 1999.

Bromley, W.D. Testing for common versus private property: Comment. *J. Environ. Econ. Manag.*, n.2, p.92-96, 1991.

Cavalcante, P.P.L. & Furtado-Neto, A.M.A. Implementação de quotas individuais transferíveis e do desembarque compulsório de lagosta viva como estratégia de ordenamento da pesca. *Arq. Ciên. Mar*, Fortaleza, v.45, p.49-59, 2012.

Cavalcante, P.P.L.; Furtado-Neto, A.M.A.; Costa J.M. & Neves, S. S. *Ordenamento da pesca da lagosta: uma experiência desordenada.* Premius, 253 p., Fortaleza, 2011.

Clark, C.W. Restricted access to common-property fishery resources: a game theoretical analysis, p.117-132, i*n* Liu, P. (ed.), *Dynamic optimization and mathematical economics.* Plenum Press, New York, 1980.

Copes, P. A Critical review of the individual quota as a device in fisheries management. *Land. Econ.,* n.62, p.278-291, 1986.

Coutinho, P.N. & Morais, J.O. Distribución de los sedimentos em la plataforma continental Norte y Nordeste del Brasil. *Arq. Ciên. Mar,* Fortaleza, v.10, p.79-90, 1970.

Cruz, R. & Borda, C.A. Estimation of abundance and spatial distribution of *Panulirus* argus using different methodologies in artificial shelter, trap and coral reef fisheries. *J. Crust. Res.*, v.86, p.158-181. 2013.

Cruz R.; Brito, R.; Diaz, E. & Lalana, R. Ecologia de la langosta (*Panulirus argus*) al SE de la isla de la Juventud. I - colonización de arrecifes artificiales. *Rev. Invest. Mar.*, n.7, p.1-17, 1986.

Cruz, R.; Conceição, R.N.L.; Marinho, R.A.; Barroso, J.C.; Holanda, J.S.; Félix C.S.; Martins, M.E.O.; Santos, F.S.; Silva, K.C.A. & Furtado-Neto, M.A.A. *Metodologias de amostragem para avaliação das populações de lagosta: plataforma continental do Brasil*. Habitat, 142 p., Fortaleza, 2011.

Cruz, R. & Phillips, B. F. The artificial shelters (pesqueros) used for the spiny lobster (*Panulirus argus*) fisheries in Cuba, p.400-419, *in* Phillips, B.F. & Kittaka, J. (eds.), *Spiny lobster management: fisheries and culture*. Blackwell Science Press, 2nd edition, Oxford, 2000.

Cruz, R.; Silva, K.C.A. & Cintra, I.H.A. Assessment of wild lobsters in the continental shelf of Brazil. *Crustaceana*, v.86, p.336-356, 2013a.

Cruz, R.; Silva, K. C. A.; Cintra, I. H. A.; Santana, V. M. J.; Gaeta C. J. Reproductive potential and stock recruitment of the Caribbean and Brazilian metapopulations of the spiny lobster, *Panulirus argus* (Latreille, 1804). *Crustaceana*, v.87, p.1315-1337. 2014.

Cruz, R.; Silva, K.C.A.; Neves, S.D.S.; Cintra, I.H.A. Impact of lobster size on catches and prediction of commercial spiny lobster landings in Brazil. *Crustaceana*, v.86, p.1274-1290, 2013*b*.

Cruz, R.; Teixeira, C.E.P.; Menezes, M.O.B.; Santana, J.V.M.; Neto, T.M.; Gaeta, J.C.; Freitas, P.; Silva, K.C.A. & Cintra, I.H.A. Large-scale oceanic circulation and larval recruitment of the spiny lobster

Panulirus argus (Latreille, 1804). *Crustaceana*, v.88, p.298-323, 2015.

Datta, M. & Mirman, L.J. Externalities, market power, and resource extraction. *J. Environ. Econ. Manag.*, v.37, p.233-255, 1999.

Diaz-Iglesias, E.; Baéz-Hidalgo, M.; Perera, E. & Fraga, I. Respuesta metabólica de la alimentación natural y artificial en juveniles de la langosta espinosa *Panulirus argus* (Latreille, 1804). *Hidro-biológica*, v.12, p.101-112, 2002.

Dias-Neto, J. Plano de gestão para o uso sustentável de lagostas no Brasil: *Panulirus argus* (Latreille, 1804) e *Panulirus laevicauda* (Latreille, 1817). Edições IBAMA, 121 p., Brasília, 2008.

Edgar, G.J. Predator-prey interactions in sea grass beds. III. Impacts of the western rock lobster *Panulirus cygnus* George on epifaunal gastropod populations. *J. Exp. Mar. Biol. Ecol.*, n.139, p.33-42, 1990.

Eggleston, D.B. *Stock enhancement of Caribbean spiny lobster,* Panulirus argus *Latreille, using artificial shelters: patterns of survival and dynamics of shelter selection.* Ph.D. Thesis, College of William and Mary, 143 p., Williamsburg, 1991.

Fonteles-Filho, A.A. The state of the lobster fishery in northeast Brazil. p. 121-134, i*n* Phillips, B.F. & Kittaka J. (eds.), *Spiny lobsters: fisheries and culture.* Blackwell, Oxford, 2000.

Hanley, N.; Shogren, J.F. & White, B. *Environmental economics: in theory and in practice.* University Press, 395 p., Oxford, 1997.

Hardin G. The tragedy of the commons. *Science*, n.162, p.1243-1248, 1968.

Henderson, J.M. & Quandt, R.E. *Microeconomic theory: a mathematical approach.* McGraw Hill Book Company, 3rd edition, 448 p., New York, 1980.

Herrera, A.; Diaz-Iglesias, E.; Brito, R.; González, G.; Gotera, G.; Espinosa, J. & Ibarzábal, D. Alimentación natural de la langosta *Panulirus argus* en la región de los Indios (plataforma SW de Cuba) y su relación con el bentos. *Rev. Invest. Mar.*, n.12, p. 172-182, 1991.

Herrnkind, W.F.; Butler IV, M.J. & Tankersley, R.A. The effects of siltation on recruitment of spiny lobsters, *Panulirus argus*. *Fish. Bull.*, n.86, p.331-338,1988.

Ivo, C.T.C.; Fonteles-Filho, A.A.; Silva, A.C. & Vieira, R.H.S.F. *Cadeia produtiva da lagosta nas regiões Norte e Nordeste do Brasil.* Editora RDS, 218 p. Fortaleza, 2013.

Ivo, C.T. C. & Pereira J.A. Sinopse das principais observações sobre a lagosta *Panulirus argus* (Latreille) e *Panulirus laevicauda* (Latreille), capturadas em águas costeiras do Brasil, entre os estados do Amapá e Espírito Santo. *Bol. Téc. Cient. CEPENE*, v.4, p.7-94, 1996.

Kempf, M.; Coutinho, P.N. & Morais, J.O. *Plataforma continental do Norte e Nordeste do Brasil. Nota preliminar sobre a natureza do fundo.* Marinha do Brasil, Diretoria de Hidrografia e Navegação, v.26, p. 579-600,1968.

Macdiarmid, A.B. & Sainte-Marie, B. Reproduction, p.45-47, *in:* Phillips B.F. (ed.), *Lobsters: biology, management, aquaculture and fisheries.* Blackwell, Oxford , 2006

Marx, J.M. & Herrnkind, W.F. Factors regulating microhabitat use by young juvenile spiny lobsters, *Panulirus argus*: food and shelter. *J. Crust. Biol.,* v.5, p.650-657, 1985.

Moura, S.J.C. Experiência com rede de espera em pescarias de lagosta. *Bol. Est. Pesca*, Recife,. v.3, p.3-9,1963.

Nascimento, R. C. *Impactos sócio-ambientais de marambaias para a pesca da lagosta: o caso de Ponta Grossa, Icapuí-CE.* Dissertação de Mestrado, Universidade Federal do Ceará, 86 p., Fortaleza, 2006.

Petursdottir, G.; Hannibalsson, O. & Turner, J.M.M. Safety at sea as an integral part of fisheries management. *FAO Fish. Circ.,* Roma, n.966, p.1-39, 2001.

Platt J. Social traps. *Amer. Psychol.*, n.28, p.641–651,1973.

Polovina, J. J. Fisheries applications and biological impacts of artificial habitats, p. 153-176, *in*.Seaman Jr., W. & Sprage L.M. (eds.), *Artificial habitats for marine and freshwater fisheries.* Academic Press, New York, 1991.

Runge, C. F. Common property externalities: isolation, assurance, and resource depletion in traditional grazing context. *Am. J. Agric. Econ.*, n.63, p.595-606, 1981.

Seijo, J. C.; Defeo, O.; Salas, S. *Bioeconomía pesquera: teoria, modelación y manejo.* FAO Documento técnico de pesca, 368 p., Roma, 1997.

Silva, K. C. A.; Botelho, K. B.; Cintra, I. H. A.; Aragão J. A. N. Parâmetros reprodutivos da lagosta-vermelha *Panulirus argus* (Latreille, 1804), na costa norte do Brasil. *Bol. Téc. Cient.* n. 8, p. 27-39. 2008.

Silva, K. C. A.; Cruz, R.; Cintra, I. H. A.; Abrunhosa, F. A.. Structure and diversity of the lobster

community on the Amazon continental shelf. Crustac. *Int. J. Crust. Res.* v. 86, p. 1084-1102, 2013.

Tegner, M.J. & Levin, L.A. Spiny lobsters and sea urchins: analysis of prey-predator interaction. *J. Exp. Mar. Biol. Ecol.*, v.73, p.125-150, 1983

Tietenberg, T. & Lewis, L. *Environmental and natural resource economics.* Pearson, 10th edition, 640 p., New Jersey, 2014.

Wachsman, Y. Externalities and management regimes, in *Fisheries Exploitation*, SOEST, 19 p., Honolulu, 2003.