

Natural diet of the spiny lobster, *Panulirus echinatus* Smith, 1869 (Crustacea: Decapoda: Palinuridae), from São Pedro and São Paulo Archipelago, Brazil

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(With 3 figures)

Abstract

The natural diet of the spiny lobster (*Panulirus echinatus*) from the São Pedro and São Paulo Archipelago was determined by stomach contents analysis of sixty-eight adult lobsters collected during October 2002, March, July and August 2003. Food items were grouped by gross taxa representing 11 food categories. Analysis included a qualitative (Frequency of Occurrence of item *i* - FOi) and a quantitative method (Volume of item *i* - Vi). A Feed Index (FI = FOi x Vi / 100) proposed by Lauzanne (1975) was also used to indicate the importance of each food category (>50: dominant, 25-50: essential, 10-25: unimportant, <10: secondary). The most important food category determined by % FOi and % Vi, was fish, followed by crustaceans, green algae, calcareous algae, and rocks. The remaining food categories contributed to less than 30% of FOi and 10% of Vi. Although the Feed Index revealed no dominant food category in the diet of *P. echinatus*, fish was considered essential, crustaceans unimportant, and the remaining food categories were classified as secondary. According to the analysis, *P. echinatus* can be properly classified as an omnivorous and a generalist species, because it consumes a great diversity of organisms in several trophic levels. This species presents an opportunistic behaviour, feeding on the prey available at substratum. Future studies should address variations in natural diet related to sex, reproductive cycle, and seasonality.

Keywords: feeding habits, spiny lobster, Palinuridae.

Dieta alimentar da lagosta espinhosa, *Panulirus echinatus* Smith, 1869 (Crustacea: Decapoda: Palinuridae), do Arquipélago São Pedro e São Paulo, Brasil

Resumo

A dieta alimentar da lagosta espinhosa, *Panulirus echinatus*, do Arquipélago São Pedro e São Paulo foi determinada a partir da análise de conteúdo estomacal de sessenta e oito espécimes adultos, coletados em outubro de 2002, março, julho e agosto de 2003. Os itens alimentares foram agrupados em grandes taxa, representando 11 categorias. As análises incluíram um procedimento qualitativo (Frequência de Ocorrência do item *i* - FOi) e um método quantitativo (Volume do item *i* - Vi). Também foi utilizado o Índice Alimentar (IA = FOi x Vi / 100) proposto por Lauzanne (1975) para indicar a importância de cada categoria (>50: dominante, 25-50: essencial, 10-25: não-importante, <10: secundário). A categoria alimentar mais importante determinada pela FOi e Vi foi peixe, seguida de crustáceos, alga verde, alga calcária e rochas. As categorias alimentares restantes contribuíram com menos de 30% da FOi e 10% do Vi. Embora o Índice Alimentar não tenha revelado nenhum item dominante na dieta alimentar de *P. echinatus*, a categoria peixe foi considerada como essencial, crustáceos como não-importante e as categorias restantes foram classificadas como secundárias. De acordo com as análises, *P. echinatus* pode ser corretamente classificada como sendo uma espécie onívora e generalista, uma vez que se alimenta de uma grande diversidade de organismos em diferentes níveis tróficos. Esta espécie apresenta um comportamento oportunista, alimentando-se principalmente de presas disponíveis no substrato. Para estudos futuros, recomenda-se que sejam realizadas análises considerando variações da dieta alimentar associada ao sexo, ao ciclo reprodutivo e à sazonalidade.

Palavras-chave: hábitos alimentares, lagosta espinhosa, Palinuridae.

1. Introduction

In Brazil, three species of spiny lobsters (Palinuridae) are harvested: *Panulirus argus* (Latreille), *P. laeviscauda* (Latreille) and *P. echinatus* Smith. Two of these (*P. argus* and *P. laeviscauda*) have fishery regulation, such as minimum size of capture and allowed periods of capture, only *P. echinatus* does not have legal management due to the lack of biological information. This species is distributed along the Atlantic Ocean and prefers offshore regions with rocky substrates, occurring particularly in oceanic islands, such as the São Pedro and São Paulo Archipelago, Fernando de Noronha, Rocas Atoll, Trindade, Cape Verde, Canary, Ascension and Saint Helena (Vianna, 1986; Pinheiro et al., 2003). Information about *P. echinatus* from the São Pedro and São Paulo Archipelago is restricted to few studies (e.g. Edwards and Lubbock, 1983; Pinheiro et al., 2003; Pinheiro and Lins-Oliveira, 2006). Edwards and Lubbock (1983) quote that this species is the most abundant decapod in the São Pedro and São Paulo Archipelago, and has great ecological importance in that region. Pinheiro et al. (2003) analyzed the population biology of *P. echinatus* in the archipelago and proposed that this population presents a sexual polymorphism linked to length and weight, by which males are bigger and heavier than females. Pinheiro and Lins-Oliveira (2006) studied the reproductive biology of this species.

Knowledge of an animal species natural diet is essential for studies on its nutritional requirements, its interactions with other organisms and its potential for culture (Williams, 1981). The objective of this study is to describe general feeding habitats of *P. echinatus* from the São Pedro and São Paulo Archipelago, attempting to

better understand the biology of this important fishery resource.

1.1 Study area characterization

The São Pedro and São Paulo Archipelago (SPSP) constitutes a remote group of islets in the equatorial mid-Atlantic ($0^{\circ} 55' N$ and $29^{\circ} 21' W$), about 1,100 km from the northeast coast of Brazil (Figure 1). Fauna and flora from the SPSP Archipelago are of notable interest because of its isolation, intermediate between South America and Africa, and its small size. Charles Darwin, who landed with HMS Beagle, conducted the first biological report of the SPSP in February 1832. However, most of the biological information was taken from the visit of HMS Challenger (Edwards and Lubbock, 1983). Later, the Cambridge Expedition arrived on the Archipelago and although it did not add greatly to the knowledge of the Archipelago's biology, it contributed by essentially delimiting habitat areas (Edwards and Lubbock, 1983). According to these authors, *P. echinatus* is the major benthic decapod present at the SPSP, revealing the eminent importance of this population for the trophic ecology in that place. In the SPSP *P. echinatus* are distributed to a depth of 25 m and they are present in caves and crevices.

For this study, lobsters were collected from a protected area called the bay (Figure 1). The depth in this area varies from 10 to 30 m. This place is protected by Cabral, Northeast, Southeast and Belmonte Islands and is sheltered from the winds and external currents, even though there is a great flux of water draining the bay from east to west, which passes through the Southeast and Belmonte Islands.

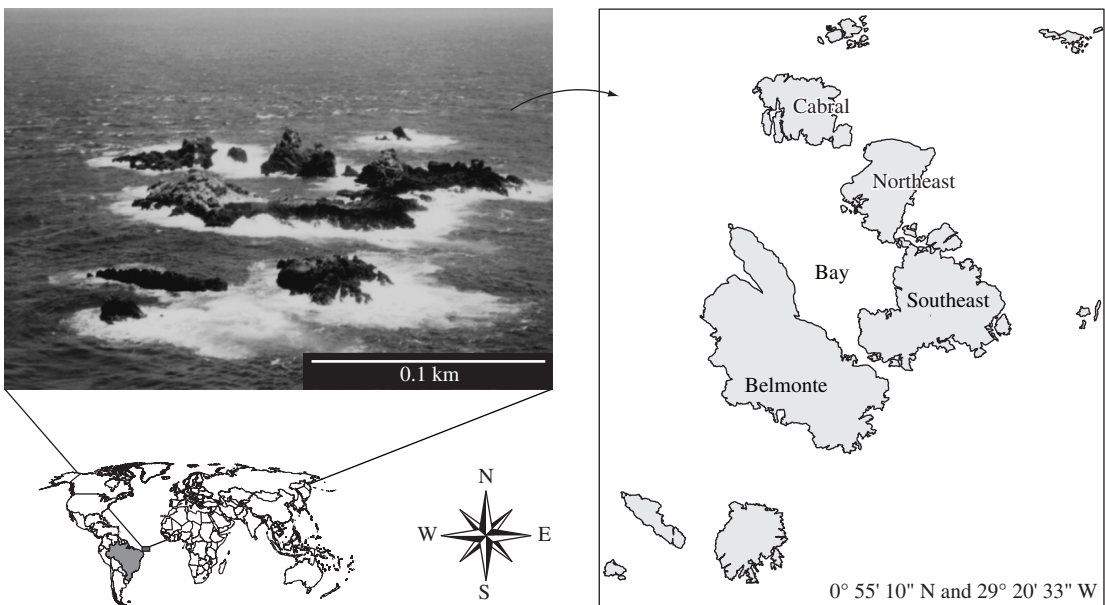


Figure 1. Study area. Aerial view of São Pedro and São Paulo Archipelago, Brazil. (Photo: Brazil Navy).

2. Material and Methods

2.1. Lobster sampling

A food analysis of sixty-eight specimens of *P. echinatus* from the SPSP collected during October 2002 and March, July and August of 2003 was conducted.

Lobsters were collected by traps, cast out at dusk and retrieved in the early morning. At the upper part inside the trap, a small container with bait was attached. This container had some holes to enable the odor to escape but to prevent lobsters from accessing the contents.

The total length (cm) was measured for all sampled lobsters and unexpected trawl selectivity was verified collecting mainly individuals over 12 cm in length (Figure 2) because of the mesh size (5 cm). According to Pinheiro and Lins-Oliveira (2006), this length characterizes an adult population. These authors calculated the medium length for the first maturation of *P. echinatus* between 13.5 and 14 cm of total length.

2.2. Analysis

Before the descriptive investigation, an analysis of the stomach repletion degree (GR) was conducted and a score was estimated: empty (I), partially full (II) and full (III). Only lobsters whose stomachs were considered partially full or full were analyzed (Joll and Phillips, 1984; Jernakoff et al., 1993) (Figure 3). This analysis is particularly true in decapods, because the stomach wall is not distensible as it is in fishes and places a relatively uniform limit on the maximum gut volume (Maller et al., 1983), providing a reasonably reliable means, even though the visual estimates of gut fullness is subjective (Hyslop, 1980; Williams, 1981; Cartes and Sarda, 1989; Jernakoff et al., 1993; de Lestang et al., 2000; Mantelatto and Christofolletti, 2001; Oh et al., 2001).

To conduct the descriptive analysis, 11 arbitrary food categories were created (Table 1). Items were recognized by optical stereomicroscope and identified to gross taxa because of their fragmentation and partial digestion. This identification was conducted with help from the Federal University of Rio Grande do Norte (northeast Brazil) specialists.

Gut contents were analyzed descriptive and qualitatively by frequency of occurrence (FOi) for each food category (Equation 1) (Aguilar and Malpica, 1993).

$$FO_i = \frac{\text{number of stomachs with item } i}{\text{number of stomachs examined}} \times 100 \quad (1)$$

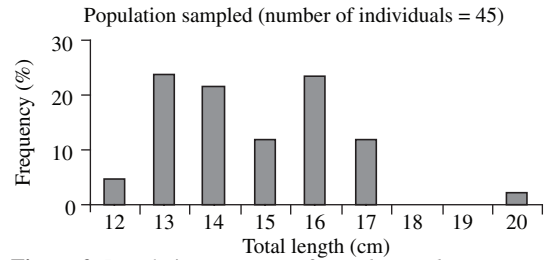


Figure 2. Population structure of *Panulirus echinatus* sampled from São Pedro and São Paulo Archipelago.

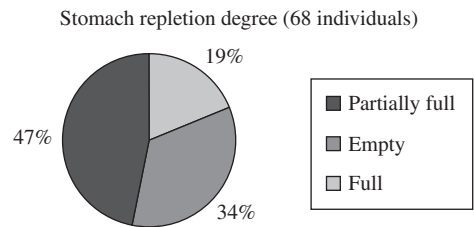


Figure 3. Stomach repletion degree of *Panulirus echinatus* sampled from São Pedro and São Paulo Archipelago.

Table 1. Description of food categories determined in this study.

Item	Description
Fish (FI)	Category composed of tissue, bone and fish scales.
Digested Material (DM)	Floating soup of digested material.
Crustacean (CR)	Category that consists mainly of carapace, antenna and chelas from crustacean.
Green Algae (GA)	Algae, especially from <i>Caulerpa</i> genus.
Calcareous Algae (CA)	Calcareous algae.
Rocks (RO)	Rock fragments. Besides the ingestion of this item must be accidental, we decided to include it as a food item, since it could be associated with a series of organisms (ex. bacterium, microalgae, fungus).
Synthetic Material (SM)	Nylon cable. The ingestion of this item is accidental, but we chose to register it due to its notable volume.
Non-Identified Material (NI)	Non-Identified material.
Coralline Algae (CO)	Coralline algae.
Molusks (MO)	Primarily mollusk shells.
Other Organisms (OO)	A wide variety of items presented in the stomachs, including hydrozoans, bryozoans, fire worms and two different kinds of cnidarians: gorgonacea and corallimorphs.

Despite the fact that FOi does not consider the volume of items, it does allow a visual notation of the relative importance of each food item and represents important data for ecological studies (Pillay, 1952).

The Volume (Vi) of each item within the stomach was determined by visual estimates using the volumetric method. This gives a quantitative idea of the stomach composition. To minimize the subjectivity associated with estimating the volume of food categories by sight, a millimetric Petri dish was used and the relative volume of each item to the total volume was estimated (Fonteles-Filho, 1989).

Hyslop (1980) recommends at least two different methods to analyze stomach contents. Hence, a Feed Index (FI) was determined (Lauzanne, 1975) (Equation 2).

$$FI = \frac{FOi \times Vi}{100} \quad (2)$$

This index combines the food preference and biomass, and gives a score of importance of each item, establishing the selectivity of food (<10 secondary; 10-25 unimportant; 25-50 essential; >50 dominant).

3. Results

Results obtained in this study reveal fish (FI) as the principal food category, both in % FOi and % Vi, followed by crustaceans (CR) representing 66.67% of the frequency of occurrence and 18.20% of the total volume. Green algae (GA) composed 51.11% of the frequency of occurrence and 13.73% of the total volume. Calcareous algae (CA) represented 48.89% of the frequency of occurrence and only 7.89% of the total volume. This item was followed by rocks (RO) that represented 42.22% of the frequency of occurrence and 2.24% of the total volume. The other items grouped contributed to less than 10% of the total volume (Table 2).

The analysis of the Feed Index did not verify dominant items, but FI was considered essential (27.15),

CR was unimportant (12.13) and the other items were judged as secondary to compose the diet of *P. echinatus* (Table 2).

4. Discussion

Spiny lobsters are considered key predators in various benthic habitats and their selective predation can have important effects on the structure of benthic communities (Phillips et al., 1980). The food finding behaviour and the selection of spiny lobsters is primarily based on chemoreception (Phillips et al., 1980). Adult spiny lobsters are nocturnal foragers and their diet includes mollusks, crustaceans, echinoderms and polychaeta (Kanciruk, 1980).

Decapods are classified as omnivorous presenting both carnivorous and saprophagous characteristics (Joll and Phillips, 1984; Stoner and Zimmerman, 1988; Mayfield et al., 2000; Cannicci et al., 2002; Sainte-Marie and Chabot, 2002). The variety of different classes of food items and the large number of organisms in the diet of *P. echinatus* indicates that it can be properly classified as a generalist feeder. Joll and Phillips (1984) defined *P. cygnus* (George) as typically opportunist, having a wide diet feeding primarily on small prey, they used a term "searcher" to classify this behaviour. This aspect is evident in results for this study, corroborating with the nonselectivity of prey by *P. echinatus*. Fernandes (1985) quoted echinoderm as the most important item composing the diet of *Panulirus argus* on the Continental Shelf of Brazil. In such an area, echinoderms are very abundant, which contrasts with the study area, where echinoderms are very scarce (Edwards and Lubbock, 1983; in situ observations). Edwards and Lubbock (1983) registered the presence of only two specimens of the urchin *Euclidaris clavata* (Mortensen) and many of the small ophiuroids *Ophiactis savignyi* (Müller and Troschel) in shallow waters. They also quoted that holothuroids *Isostichopus badionotus* (Selenka) and *Holothuria (Halodeima) manningi* (Pawson) were occasionally encountered. In this analysis, this item is completely

Table 2. Results of gut contents for *Panulirus echinatus*.

Item	Frequency of Occurrence (%)	Volume (%)	Feed index (Lauzanne, 1975)
Fish (FI)	84.44	32.15	27.15
Digested Material (DM)	84.44	16.18	13.66
Crustacean (CR)	66.67	18.20	12.13
Green Algae (GA)	51.11	13.73	7.02
Calcareous Algae (CA)	48.89	7.89	3.86
Rock (RO)	42.22	2.24	0.95
Synthetic Material (SM)	26.67	4.78	1.27
Non-identified item (NI)	26.67	2.38	0.63
Coralline Algae (CO)	20.00	0.98	0.20
Mollusks (MO)	20.00	0.89	0.18
Other organisms (OO)	17.78	0.58	0.10

absent from *P. echinatus* stomachs, revealing the non-selectivity of prey.

The high frequency of occurrence and the great volume of digestive material are justified by the stomach anatomy. The stomach of the lobster is formed by strong muscles that cause a grinding action and a gastric mill, containing three large opposing teeth, one dorsal and two laterals, which triturates and sorts the food particles (Phillips et al., 1980). The consuming of the prey begins at the mouth, with its powerful jaws and continues in the stomach with the gastric mill (Pathwardan, 1935; Herrnkind et al., 1975).

The great presence of fish in the stomachs may not be related to true captures. Fish could have been wounded or dead, as mentioned by Kanciruk (1980).

The item crustacean was composed by carapace and lobster antenna. This fact was also quoted by Joll and Phillips (1984) when studying the diet of *P. cygnus*. These authors pointed out that exoskeleton material was derived from the ingestion of exuvia, rejecting the possibility of cannibalism of newly molted individuals.

Another important fact found in this study is the abundance of algae in the stomachs. In the study area, green algae *Caulerpa racemosa* (Forsskal) form a dense carpet (Edwards and Lubbock, 1983; *in situ* observations). This suggested that the spiny lobster probably eats the green algae to get small invertebrates that live within the algal mat, however Phillips et al. (1980) quote that the great quantity of the green algae reveals that this is not an accidental ingestion. This work shows a relevant presence of algae in the gut contents of *P. echinatus* from the SPSP, but this fact remains doubtful and a study on feeding behaviour is suggested to clarify this matter.

The calcareous algae was considered by the Feed Index as being secondary in the diet of *P. echinatus*, however, this item has a nutritional importance for these organisms, since Palinuridae (spiny lobster) has no calcareous plates (gastroliths) as found in Nephropidae (clawed lobsters). These plates are responsible for storing calcium during molt and allow the new exoskeleton to harden rapidly by mobilizing this store (Phillips et al., 1980). Joll and Phillips (1984) and Mayfield et al., (2000) quoted the presence of coralline algae composing the diet of *Panulirus cygnus* and *Jasus lalandii* (H. Milne Edwards), respectively. Kanciruk (1980) also relates that palinurids usually feed on calcareous organisms. This item corresponds to a great source of calcium carbonate to solidify the exoskeleton.

The presence of rocks in the gut contents is probably an accidental ingestion while feeding on other organisms at the substratum, as spiny lobsters may present scraper habits.

In this way, it is verified that there were no dominant food items suggesting that *P. echinatus* can be considered omnivorous because vegetal and animal food were found in its stomach, generalist because it eats a great diversity of items and an opportunistic browser since it eats the prey available at the substratum. As a

first study, the conclusions held here reveal important aspects of the trophic ecology of the *P. echinatus* in the SPSP. However, more studies are necessary to address variations in natural diet relating to sex, population structure, juvenile phase, reproductive cycle and seasonality.

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