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Mollusks preyed by *Octopus insularis* (Mollusca, Cephalopoda) in a tropical area in northeastern Brazil

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Abstract: The diet and feeding strategy of *Octopus insularis* were determined based on the shells found inside the pots used in its fishery. The data showed the versatility of this opportunist predator in overcoming barriers, represented by the shell of their prey.

Key words. diet, predation strategy, gastropods, bivalves

Resumo. Moluscos predados por *Octopus insularis* (Mollusca, Cephalopoda) em uma área tropical no nordeste do Brasil. A dieta e estratégia de forrageamento de *Octopus insularis* foram determinadas com base nas conchas encontradas nos potes utilizados em sua pescaria. Os dados mostraram a versatilidade desse predador oportunista em superar a barreira representada pela concha de sua presa.

Palavras-chave. dieta, estratégia de predação, gastrópodes, bivalves.

Octopus insularis Leite & Haimovici, 2008 is a medium-sized species that has short, robust arms with deep webs. These features make this species capable of capturing small prey hidden in the hard substrate and even capture more than one prey simultaneously (Leite *et al*. 2008). Octopuses usually kill their shelled prey by drilling a small hole in the shell, through which they inject a secretion that will relax or even kill the prey (Pilson & Taylor 1961). Shallow-water octopuses create mounds near their burrows with the remains of their food, which show their food selectivity (Summers 1983). The goals of this study were to determine the mollusk species preyed by *Octopus insularis* based on the shell remains found inside the pots used in the octopus fishery between 2009 and 2014, and to investigate the predation strategy of *O. insularis* through the analysis of the location of drill holes in the shells.

The fishery of octopus with the use of baitless pots has been carried out since 2005 along the coast of Itarema, Ceará, northeastern Brazil (02°24.84' S, 039°54.61' W) (Braga *et al*. 2007) (Fig. 1). The longline baitless pots used to capture octopuses were placed at a depth of 30 m along the coast. The shells found within the pots between 2009 and 2014 were collected and taken to the Laboratory of Marine Invertebrates of Ceará (LIMCE) of the Universidade Federal do Ceará. The specimens were identified to the lowest taxonomic level possible with the help of a specialized bibliography (Rios 2009). All material analyzed was deposited in the Malacological Collection "Prof. Henry Ramos Matthews" - Series B of the Universidade Federal do Ceará. The shells were analyzed in order to determine the number and location (spire, body whorl, or inner lip) of the holes presented in the shells. Observations were also carried out on the presence of non-complete perforations in shells, called here predation attempts, which were counted and had their location registered.

It was found that 51 species of Mollusca from the octopuses pots belonged to two major taxa: Bivalvia (13 species distributed among seven families) (Table I) and Gastropoda (37 species distributed among 21 families) (Table II). In Bivalvia, Veneridae was the most representative family with four species (*Callista maculata*, *Chione*

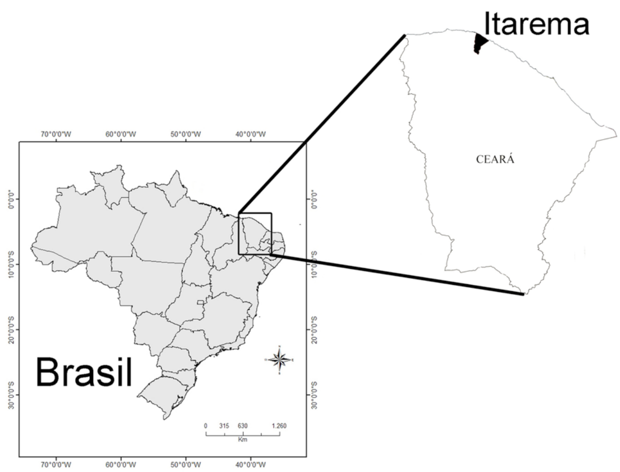

Figure 1. Itarema, Ceará, northeast Brazil.

paphia, *Ventricolaria rigida*, and *Dosinia concentrica*). The most representative family in Gastropoda was Strombidae, with four species (*Strombus pugilis*, *Aliger costatus*, *Aliger gallus*, and *Eustrombus goliath*). None of the analyzed bivalve shells showed any holes. The bivalve species *Miltha childrenae* was found lining the inside of the pots. The perforations found in the gastropod shells varied in relation to their number and location according to each species (Table III). Among the 144 gastropod specimens analyzed, 113 (78.5%) had predation marks located on the spire (69 individuals - 61.1%), inner lip (33 individuals - 29.2%), and body whorl (11 individuals - 9.7%) (Fig. 2). Thirteen species showed incomplete predation marks (predation attempts) in the spire and in the body whorl (Table III). The gastropods *Cypraecassis testiculus*, *Artemidiconus selenae*, *Conus* cf. *regius*, *Phyllonotus oculatus*, *Tonna pennata*, *Niveria suffusa*, *Pusula pediculus*, *Turbo canaliculatus*, and *Turritella exoleta* showed no marks of predation attempts.

Octopus insularis is an opportunistic predator, consuming a wide variety of prey. An earlier study (Matthews-Cascon *et al*. 2009) recorded the presence of 32 mollusk species (17 gastropods and 15 bivalves) in pots used in *O. insularis* fisheries in three regions along the coast of Ceará (Icapuí, Fortaleza, and Itarema). In Itarema, Matthews-Cascon *et al*. (2009) recorded 14 mollusks species (six gastropods and eight bivalves) in 2007. The present study provides an update of Matthews-Cascon *et al*. (2009) data with the addition of 37 mollusk species found in the octopus pots along the coast of Itarema, between 2009 and 2014, reinforcing the opportunistic predator habit of *O. insularis*. When analyzing the foraging behavior of *Octopus insularis*, Leite *et al*. (2009) considered it to be an opportunistic predator which, being a time-minimizing forager, adopts various predatory tactics depending on the environmental variables and body size. This kind of behavior was also observed by Bouth *et al*. (2011). We cannot make inferences about the food preferences of *Octopus insularis* in this study because there is no information on environmental diversity at the site of the fishery and also because the methodology is not suitable for this purpose.

With the exception of the species *Miltha childrenae*, the absence of puncture marks in all bivalve and some gastropods species can shows the versatility of *Octopus insularis* in overcoming the barrier formed by the shell of their prey.

Table I. Bivalve species found in the pots used in the octopus fishery *Octopus insularis* Leite & Haimovici, 2008 in Itarema, Ceará, northeastern Brazil.

Family	Species	Total analyzed (n. of valves)
Arcidae	*Anadara notabilis* (Röding, 1798)	1
Glycymerididae	*Glycymeris decussata* (Linnaeus, 1758)	2
	Glycymeris undata (Linnaeus, 1758)	1
Veneridae	*Dosinia concentrica* (Born, 1778)	1
	Ventricolaria rigida (Dillwyn, 1817)	2
	Callista maculata (Linnaeus, 1758)	5
	Chione paphia (Linnaeus, 1767)	2
Cardiidae	*Trachycardium muricatum* (Linnaeus, 1758)	3
	Trigoniocardia media (Linnaeus, 1758)	1
Lucinidae	*Codakia orbicularis* (Linnaeus, 1758)	5
	Miltha childrenae (Gray, 1824)	6
Pectinidae	*Pecten ziczac* (Linnaeus, 1758)	4
Spondylidae	*Spondylus americanus* Hermann, 1781	21

Table II. Gastropod species found in the pots used to catch *Octopus insularis* Leite & Haimovici, 2008 in Itarema, Ceará, northeastern Brazil.

Family	Species	Total analyzed (n. of individuals)
Bullidae	*Bulla striata* Bruguière, 1792	2
Bursidae	*Bursa granularis* (Röding, 1798)	1
Calliostomatidae	*Calliostoma jujubinum* (Gmelin, 1791)	1
Cassidae	*Cypraecassis testiculus* (Linnaeus, 1758)	3
	Semicassis granulata (Born, 1778)	1
Conidae	*Artemidiconus selenae* (van Mol, Tursch & Kempf, 1967)	1
	Conus cf. *regius* Gmelin, 1791	1
Cypraeidae	*Luria cinerea* (Gmelin, 1791)	13
	Erosaria acicularis (Gmelin, 1791)	7
	Propustularia surinamensis (G. Perry, 1811)	1
	Macrocypraea zebra (Linnaeus, 1758)	1
Fasciolariidae	*Aurantilaria aurantiaca* (Lamarck, 1816)	2
Harpidae	*Morum matthewsi* Emerson, 1967	3
	Morum oniscus (Linnaeus, 1767)	6
Marginellidae	*Bullata matthewsi* (Van Mol & Tursch, 1967)	15
	Bullata lilacina (G. B. Sowerby II, 1846)	9
Mitridae	*Mitra barbadensis* (Gmelin, 1791)	2
Muricidae	*Phyllonotus oculatus* (Reeve, 1845)	2
Naticidae	*Polinices lacteus* (Guilding, 1834)	1
	Natica marochiensis (Gmelin, 1791)	1
	Natica tedbayeri Rehder, 1986	3
Olividae	*Eburna lienardii* (Bernardi, 1859)	6
	Oliva circinata (Marrat, 1871)	5
Ranellidae	*Cymatium femorale* (Linnaeus, 1758)	3
	Ranularia cynocephalum (Lamarck, 1816)	3
	Charonia variegata (Lamarck, 1816)	1
Strombidae	*Strombus pugilis* Linnaeus, 1758	1
	Eustrombus goliath (Schröter, 1805)	5
	Aliger gallus (Linnaeus, 1758)	9
	Aliger costatus (Gmelin, 1791)	20
Tonnidae	*Tonna pennata* (Mörch, 1853)	1
Triviidae	*Niveria suffusa* (J.E. Gray, 1827)	1
	Pusula pediculus (Linnaeus, 1758)	1
Turbinellidae	*Turbinella laevigata* Anton, 1838	2
Turbinidae	*Turbo canaliculatus* Hermann, 1781	2
Turritellidae	*Turritella exoleta* (Linnaeus, 1758)	2
Volutidae	*Voluta ebraea* Linnaeus, 1758	5

Octopus can use different modes of predation, such as opening, breaking, or boring the shell (Hughes 1980, Mather *et al*. 2010). Anderson & Mather (2007) reported that the technique of chipping bivalve shells, held by some octopus species, allows for the subsequent injection of venom, which weakens the adductor muscles that keep the valves together. Those authors based this assumption on the observation that the chips were located in the posterior or anterior regions of the shells, close to the adductor muscles. Such inferences, however, could not be made with the bivalve shells obtained during this study because the handling of the material during the octopus fishing had damaged the shells, especially the edges, which are the most fragile parts of the shell. On the other hand, the absence of marks may be related to the octopuses' behavior to accumulate hard substrates at

Table III. Analysis of boreholes and predation attempts in gastropods found in the pots used in the octopus fishery *Octopus insularis* Leite & Haimovici, 2008 in Itarema, Ceará, northeastern Brazil.

Species	Total analyzed • N. of individuals preyed (N boreholes)	Site of predation (n. of individuals preyed)	N. individuals with mark attempt (n. marks)	Site of attempt (n. of individuals with marks attempt)
Bulla striata	2•1 (1)	inner lip (1)		
Bursa granularis	1•1 (1)	spire (1)		
Calliostoma jujubinum	1•1 (1)	spire (1)	1(1)	spire (1)
Semicassis granulata	1•1 (1)	spire (1)		
Luria cinerea	13•13 (13)	inner lip (12)/ body whorl (1)		
Erosaria acicularis	7•5 (5)	inner lip (5)		
Propustularia surinamensis	1•1 (2)	inner lip (1)		
Macrocypraea zebra	1•1 (1)	body whorl (1)		
Aurantilaria aurantiaca	2•2 (2)	spire (1)/ body whorl (1)	1 (1)	spire (1)
Morum matthewsi	3•2 (2)	spire (2)		
Morum oniscus	6•6 (6)	spire (5)/ inner lip (1)		
Bullata matthewsi	15•12 (12)	inner lip (7)/ body whorl (3)/ spire (2)	2 (2)	body whorl (2)
Bullata lilacina	9•8 (8)	inner lip (4)/ spire (4)	1 (1)	body whorl (1)
Mitra barbadensis	2•2 (2)	spire (1)/ body whorl (1)		
Polinices lacteus	1•1 (1)	spire (1)	1 (2)	body whorl (1)
Natica marochiensis	1•1 (1)	inner lip (1)	1 (3)	body whorl (1)
Natica tedbayeri	3•3 (3)	body whorl (3)	1 (1)	spire (1)
Eburna lienardii	6•4 (4)	spire (4)	2 (2)	spire (2)
Oliva circinata	5•3 (3)	spire (3)		
Cymatium femorale	3•3 (3)	spire (3)		
Ranularia cynocephalum	3•2 (2)	inner lip (1)/ spire (1)	1 (2)	spire (1)
Charonia variegata	1•1 (1)	spire (1)	1 (1)	spire (1)
Strombus pugilis	1•1 (1)	spire (1)		
Eustrombus goliath	5•5 (5)	spire (5)	1 (1)	spire (1)
Aliger gallus	9•8 (8)	spire (8)	1 (1)	spire (1)
Aliger costatus	20•17 (17)	spire (17)		
Turbinella laevigata	2•2 (3)	spire (2)		
Voluta ebraea	5•5 (9)	spire (5)	1 (2)	spire (1)

the entrance of their shelters during periods of inactivity (Mather *et al*. 2010). In this way, bivalves and gastropods without predation marks found here will be considered as potential preys of *O. insularis*. More studies are needed to confirm these species as octopus preys.

The boreholes found in most gastropod shells (28 species) confirm the predation of *O. insularis*. The position of the boreholes on the spire in the ventral side of the shell close to or over the site of attachment of the columellar muscle is probably to make possible the injection of the poisoning from the salivary gland to relax the animal and then to pull the soft body from the aperture.

Figure 2. Location of predation marks on gastropod shells collected in pots used for fishing octopus *Octopus insularis* Leite & Haimovici, 2008 in Itarema, Ceará, northeastern Brazil. From left to right: young *Eustrombus goliath* (Schröter, 1805) (borehole in the spire), *Bullata matthewsi* (Van Mol & Tursch, 1967) (borehole in the inner lip) and *Macrocypraea zebra* (Linnaeus, 1758) (borehole in body whorl).

A chemical attack on the shell is involved in the formation of the boreholes, with an alternation between periods of the scraping by the radula and etching (Runham *et al*. 1997). Mather *et al*. (2012) raised the possibility that as octopuses are able to learn during foraging, their ability to locate prey is impacted by individual personality differences. These authors observed that within the same population, there was both generalist and specialist individuals whose prey included crustaceans, bivalves, and gastropods. Analyses of prey by *Octopus insularis* provide important information about the eating habits of this species and contribute to the knowledge of the biodiversity of the Brazilian coast.

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