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BIOLOGICAL SCIENCES

Harvesting the cockle *Leukoma pectorina* (Lamarck, 1818) on Algodoal-Maiandeua Island (Pará, Brazil): techniques, bio-ecology, and ethnoecological knowledge

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Abstract: The ecological and ethnological aspects of the harvesting of the cockle, *Leukoma pectorina* (Bivalvia: Veneridae), were investigated on Algodoal-Maiandeua Island, on the Amazon coast of Brazil. Ethnobiological data were collected through informal conversations, semi-structured interviews, and observations of the harvesting and processing of bivalves on the island. Following the ethnobiology study, the cockle beds were surveyed to evaluate the density of *L. pectorina*, body size and the meat yield of the cockles in the months of dry and rainy seasons. In the study area, cockling is a manual and artisanal activity, and *L. pectorina* is typically harvested by mothers with little formal education. The cocklers make their own tools, cockles are prepared in the family environment, and the majority of the catch is sold to commercial establishments on the island. Cockling is a sporadic activity used to complement the family income, and is more common during the dry season, when tourism increases on Algodoal-Maiandeua Island. The cockles are also larger and population density is higher during this season, and the cocklers themselves recognize this period as providing the most productive harvest. These findings reinforce the value of traditional knowledge for both scientific research and the planning of the management of coastal fishery resources.

Key words: Veneridae, clam, artisanal fishing, ethnobiology, Amazonian coast.

INTRODUCTION

The harvesting of the benthonic organisms that inhabit the coastal and estuarine environments along the 8000 km of the Brazilian coast provides local populations with both income and dietary resources. The official Brazilian fishery statistics show that crustaceans (≈57,344 t.year^{-1}) contribute approximately 10% of the country's annual marine catch, and mollusks (≈13,989 t.year^{-1}) around 3% (MPA 2011). The culture of mollusks and crustaceans also produces approximately 84,000 t.year^{-1}, which represents around 20% of the total Brazilian aquaculture production (MPA 2011). An estimated 8000 t.year^{-1} (CEPNOR 2011) of crustaceans (crab and shrimp) are produced by the Brazilian state of Pará, both wild-caught and cultivated, although there are no official statistics on the harvesting of mollusks.

Despite the lack of official statistics, the majority of the invertebrate catch of Brazilian fisheries is known to be produced by artisanal operations, which support various riverside communities with subsistence resources and a monetary income (Silva 2014a). The Brazilian Ministry of Fisheries and Agriculture, through its General Registry of Fishery Activities, has estimated that almost one million artisanal

fishers exist in the country (MPA 2014). In general, however, few reliable data are available on the country's artisanal fisheries, given the complexity of this sector, including the diversity of resources harvested, and the range of techniques used, in addition to the lack of attention from policy makers (Vasconcelos et al. 2007).

In Brazil, the artisanal harvesters of invertebrates, that generally operate in shallow and intertidal waters, are known as "marisqueiras" or shellfishers. The harvesting of shellfish is one of the most traditional fishery activities, and is generally undertaken by autonomous producers, typically in individual or family units (Diegues 1983, Schaeffer-Novelli 1989). The bivalves of the order Veneroidea, which are exploited artisanally by coastal communities throughout Brazil, are known by a number of different local names, such as "sarnambi", "berbigão", "vôngole", "papafumo", "amêijoa", and "marisco-rei" (Moreira 2006, Pezzuto & Souza 2015). *Anomalocardia brasiliana* (Gmelin 1791) is the cockle most exploited in Brazil, in particular in the south (Schaeffer-Novelli 1989, Silva-Cavalcanti & Costa 2011) and northeast (Silva-Cavalcanti & Costa 2010, 2011) of the country. On the Amazon coast, in the northern of Brazil, artisanal cockling focuses on *A. brasiliana* and *Leukoma pectorina* (Lamarck 1818), with the latter being the species most harvested and consumed in the state of Pará (Borcem et al. 2011).

The bivalve *L. pectorina*, which is denominated by its synonym *Protothaca pectorina* in many studies, is endemic to the Atlantic Ocean, being found between the Caribbean and southern Brazil (Huber 2010). In Brazil, the species is found in all coastal states between Pará, in the north, and Santa Catarina, in the south (Rios 2009, Guerón & Narchi 2000). *Leukoma pectorina* is found typically in the intertidal zone of sheltered bays and coves, buried at a depth of approximately 7 cm (Guerón & Narchi 2000) in mixed sediment (sandy, muddy, and gravelly substrates) (Lins et al. 2015).

Cocklers, like other traditional fishers, have an invaluable understanding of the species they exploit, and the functioning of the ecosystems inhabited by these resources (Freitas et al. 2012). The combination of the traditional knowledge of fishing communities with scientific data is essential for the establishment of reliable public policies for the development of effective conservation measures, management plans, and socio-environmental programs that support artisanal fisheries (Diegues 2000, Olsson & Folke 2001, Valbo-Jørgensen 2010).

Algodoal-Maiandeua Island, in northeastern Pará, is endowed with scenic natural landscapes and a number of fragile environments, such as beaches, mangroves, coastal restinga vegetation, saltmarsh, and dune fields, which, together with the cultural characteristics of the island, make this locality one of the principal tourist destinations on the Amazon coast (Quaresma 2000). These characteristics led to the transformation of the island into an Environmental Protection Area (EPA), known as the Algodoal-Maiandeua EPA, through Pará state decree 5621 of November 27th 1990. The Algodoal-Maiandeua EPA was established to preserve the island's natural resources, and contribute to its sustainable development, in particular through the implantation of ecological tourism. Cockles (*L. pectorina*) are exploited intensively by the local communities (Santana 2004). Apart from studies of its functional anatomy (Guerón & Narchi 2000) and reproductive biology (Matos et al. 1997, Silva 2014b), little is known of the characteristics of *L. pectorina* populations or their exploitation by cocklers.

Given the environmental and economic importance of *L. pectorina*, it is necessary to

understand both its ecological characteristics and its exploitation by the local communities to provide guidelines for the rational management of the resource. In this context, the present study (i) characterized the harvesting of *L. pectorina* in the EPA Algodoal-Maiandeua, in terms of techniques, processing, and sale, (ii) compiled the social profile of the local cocklers, and recorded their ethno-ecological knowledge on the local environment and its resources, and (iii) collected data on the biology and ecology of the species (density of organisms in the local cockle beds, and the length, weight, and meat yield of the cockles), which were contrasted with the ethnobiological data.

MATERIALS AND METHODS

Study area

Algodoal-Maiandeua Island (0º34'32.535" S, 47º35'18.651" W) covers an area of approximately 3100.34 hectares, and is located in the municipality of Maracanã, on the Brazilian Atlantic coast, in the state of Pará (Figure 1). The island has a population of approximately 1800 inhabitants, distributed primarily in four villages, Algodoal, Camboinha, Mocooca, and Fortalezinha, of which, Algodoal is the largest (SEMAS 2012).

The local climate is humid tropical with a mean annual temperature of 27.7±1.1°C (Martorano et al. 1993) and annual precipitation (30-year record) ranging from 2300 mm to 2800 mm (Moraes et al. 2005). Precipitation varies considerably over the course of the year, with a well-marked rainy season from January to July (total rainfall approximately 1700 mm) and a dry season between August and December, with total rainfall of 500 mm (Moraes et al. 2005). The region is dominated by semidiurnal macrotides, with amplitudes of 4 m to 6 m (Araujo da Silva et al. 2009).

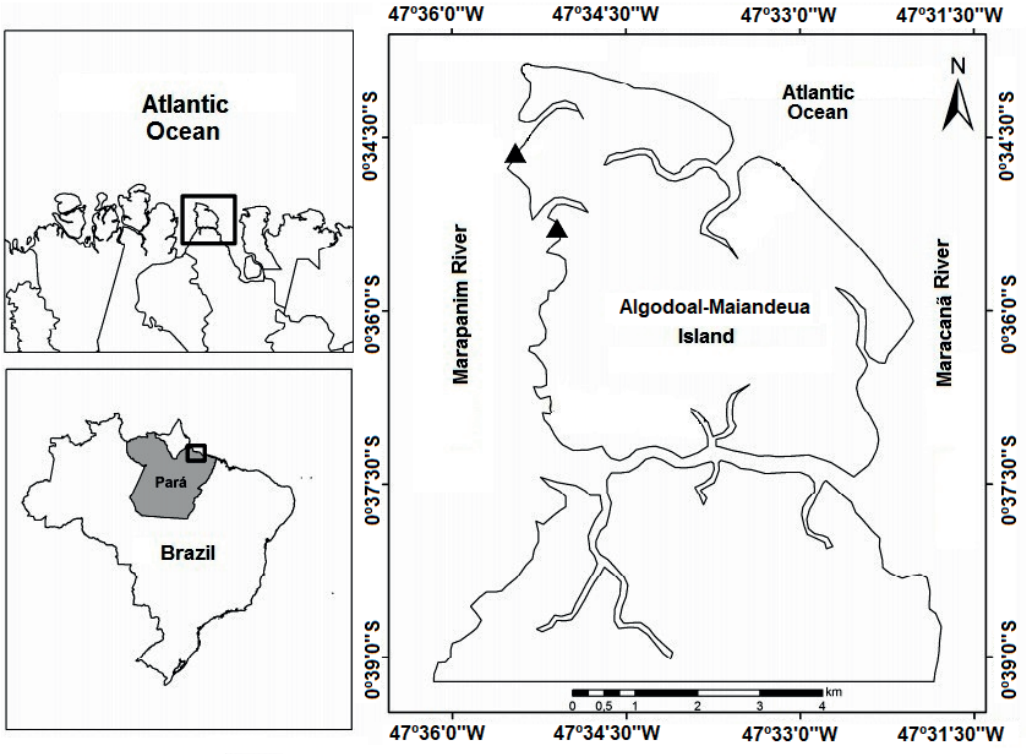

Figure 1. The study area, Algodoal-Maiandeua Island in Maracanã, coast of Pará (Brazil).

Collection of ethnographic data

The villages of Algodoal and Camboinha were selected as the focus of the present study because of their relatively large populations and proximity to the island's most productive *L. pectorina* beds (SEMAS 2012). Data were collected in two phases, with the first consisting of the selection of the informants, and the second, the collection of the ethnographic data. During the first phase, which lasted from September to December 2011, local commercial establishments (hotels and restaurants) were visited to identify their principal suppliers of cockles. These visits led to the selection of the first informants, while the additional informants were chosen using a snowball approach, through which a potential informant is indicated by a member of the community that has already been interviewed (Patton 2002). During this phase, the informants to be interviewed during the second phase were defined, based on their experience (at least one year) as a shellfish harvester. A total of 36 harvesters were interviewed between September and December 2011. During the second phase, between March and June 2012, data were obtained through the application of 25 harvesters. The interviews were based on a standardized, semi-structured questionnaire with both open (N = 10) and closed (N = 10) questions (Schensul et al. 1999), divided into four categories: (1) the characterization of the cockling community (sex, age, schooling, and cockling experience), (2) biological characteristics of the species (size, density, seasonality, and reproduction), (3) cockling (harvesting methods, capture effort, production), and (4) the supply chain (sale strategies and market, prices, and income). Data were also collected through participant observation during the harvesting of the cockles, with direct contact being maintained with the local community to provide more reliable insights into their daily routine, without the interference of their extractive activities.

Collection of biological and ecological data

Data were collected in the December 2012 (dry season) and March 2013 (rainy season) at the cockle bed of Algodoal village. This bed was selected because it was the largest, and most exploited. During each excursion, six samples were collected randomly from the lower midlittoral zone, where most cocklers were active. On each month, two transects (15 m each) perpendicular to the water line were randomly distributed on intertidal zone examined. Samples were obtained using seven quadrats of 25 cm x 25 cm (625 cm^2), randomly selected along transects (three replicates in transect 1 and four replicates in transect 2; with a distance of at least 1m between replicates). Within each quadrant, the sediment was removed to a depth of 10 cm. The samples were chilled and removed immediately to the laboratory for processing. The *L. pectorina* specimens encountered in each sample were counted, measured (Total Length [TL] = greatest anteroposterior length) using a vernier caliper, and weighed (Total Weight [TW] = total wet weight (shell + mantle); Shell Weight [SW], and Meat Weight [MW] = wet weight of the soft parts) using an analytical balance with a precision of 0.1 g.

Data analysis

For each sample (month), nonlinear regression analysis were applied to the relationship between the weight (total, shell, soft parts) of the specimens and their total length, considering the general model $y = ax^b$, where y = the respective weight of the specimen, x = the length of its shell, and *a* and *b* are the allometric parameters (Gaspar et al. 2002). The *a* value represents the initial growth rate, while *b* represents the relationship between

the different variables and the length of the cockle. The parameters *a* and *b* were estimated by the Gauss-Newton method of least-squares progressive iteration. The significance of the regressions was determined using the F-test (Sokal & Rohlf 1994). The relationship between the two variables is considered to be isometric when the *b* value is close to 3, with values above 3 indicating positive allometry, and those below 3, negative allometry. To test whether the value of *b* in the weight-length relationship was significantly different from the value of isometry (b = 3), the Student t-test was applied. The meat yield was estimated by equation Y = 100 x MW/TW. The condition factor was calculated by the ratio between MW and SW (Santos et al. 2014). The relationship between condition factor and total length was evaluated using linear regressions, which were also tested for significance using the F-test (Sokal & Rohlf 1994).

The data on the size, weight, meat yield, condition factor, and density of the organisms were compared between months using an Analysis of Variance (ANOVA). Prior to the ANOVA, the normality of the data was verified using the Shapiro-Wilks test, and the homoscedasticity of the variances, using the Cochran test. Whenever necessary, the data were transformed by the Log (x+1) (abundance) or arcsine (meat yield and condition factor). A 5% significance level was considered for all analyses. The statistical analyzes were performed through the Past 3.0 and SYSTAT 7.0 programs.

RESULTS

The cocklers

The *L. pectorina* harvesters, or cocklers, are predominantly women, between 19 and 70 years of age (87% of the individuals interviewed), had little formal education (14% were unschooled, and 58% had an unfinished elementary school education), 63% were married or in a stable relationship, and 71% had children. All but one (98%) of the interviewees were natives of the state of Pará, 50% were born in the municipality of Marapanim, and 93% have lived on Algodoal-Maiandeua Island for more than 10 years. Almost two-thirds (64%) of the women declared themselves to be homemakers, while the others were students (23%) or employed in general services in the island's guest houses (13%). None of the interviewees declared themselves to be "fishers" or "cocklers". Around half the cocklers are married to or live with artisanal fishermen (not cocklers), and cockling is an activity that contributes to the family income. The men varied in age from 25 to 59 years, all had an unfinished elementary school education, and declared themselves to be fishermen.

Most (80%) of the interviewees revealed that they had been cockling for more than 10 years (range: 3–60 years), with 76% being involved in this activity since their childhood, learning to extract the cockle meat from the shells from family members, such as mothers and grandmothers. Overall, 40% of the cocklers confirmed that the children participated in the harvesting and processing of the cockles. During the study, children and adolescents, of between 9 and 14 years of age, were observed participating in the cockling activities, helping their mothers, aunts, and grandmothers.

Techniques used to harvest, process, and sell the cockles

The cockles are harvested in areas with rocky fragments (lateritic arenite) interspersed with mud and sand, in the midlittoral (Figure 2a). The cockles are harvested only during the daily ebb and low tides, during a 3-4 hour period. During the spring tides (full and new moons), the harvesting period may last up to six hours. The cocklers typically use only hats or caps

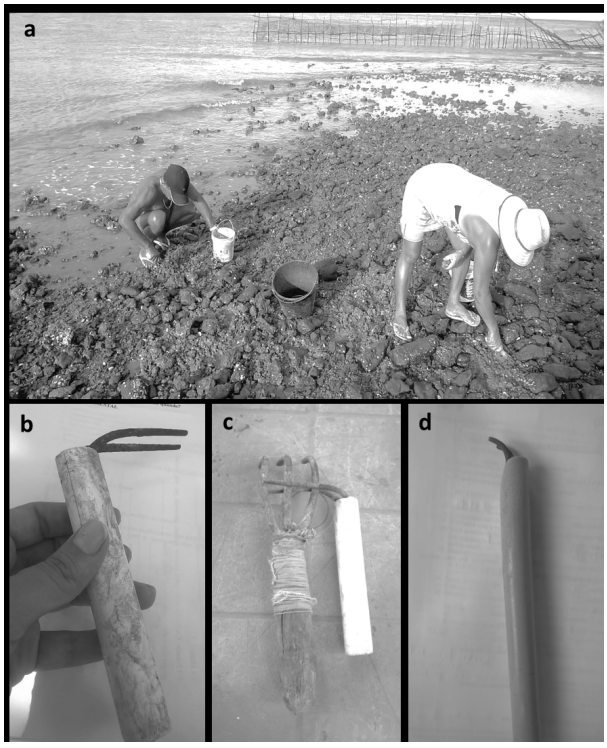

Figure 2. (a) The harvesting of *Leukoma pectorina* on Algodoal-Maiandeua Island (Maracanã, Pará coast). (b-d) Types of "cockling hooks" made by local cocklers.

to protect themselves from the sunlight, and crouch or squat over the substrate to retrieve the bivalves (Figure 2a). Most of the cocklers use a tool known as a "cockling hook" to dig the bivalves out of the sediment. This tool is made locally from a PVC tube, a piece of wood, and wire, and is very similar to a garden rake (Figure 2b-d). Kitchen knives are also used as tools.

The cockles harvested by each individual are stored in buckets, baskets, and "onion sacks", before being rinsed to remove the excess sand and mud, and then carried to the cocklers' homes. Each individual harvest, per day, one or two 10-liter buckets or a 30-kg sack of cockles which produce, after processing, 1 kg (one bucket) to 2 kg (two buckets or a sack) of cockle meat. One kilogram of meat requires an average of 928±26 (SE) cockles, of a mean length of 27.3±5.5 (SE) mm.

The cockles are processed at the cockler's home, generally under the command of the women. Processing begins with an additional rinse to remove any further residues, such as mud or saltwater (Figure 3a). The cockles are then pre-cooked in hot water in large saucepans until the shells open (Figure 3b). The soft parts of the mollusk, which the cocklers refer to as cockle "dough" or "mince" is removed manually (Figure 3c), and placed in plastic bags for freezing and storage.

The cockles are either consumed by the household (96% of the families consume their own produce) or sold (70% of the interviewees). However, all the interviewees confirmed that cockles were consumed by their families "no more than once a month". The produce of a majority (71%) of the cocklers had been ordered by the guest houses and restaurants in Algodoal village, tourists or sporadic residents on the island. The cockles were sold by the cocklers or other members of their families directly to these consumers, with no middlemen being involved in any of the cases.

Most (90%) of the interviewees sell their cockles without the shells. The price of the produce varies according to the demand. During vacation periods or bank holidays, a kilogram of shelled cockles (meat) is sold for R$ 30.00–35.00 ($ 9.93), whereas at other times, when there are fewer tourists, a kilogram may be sold for only R$ 20.00 ($ 5.68). This means that a cockler can earn no more than R$ 70.00 ($ 19.86) for a day's work. In addition to selling or consuming the cockle meat, 20% of the cocklers referred to alternative uses for the shells, including building material for houses and sidewalks, handicrafts, for the decoration of walls and floors, and fertilizer for the family plantation.

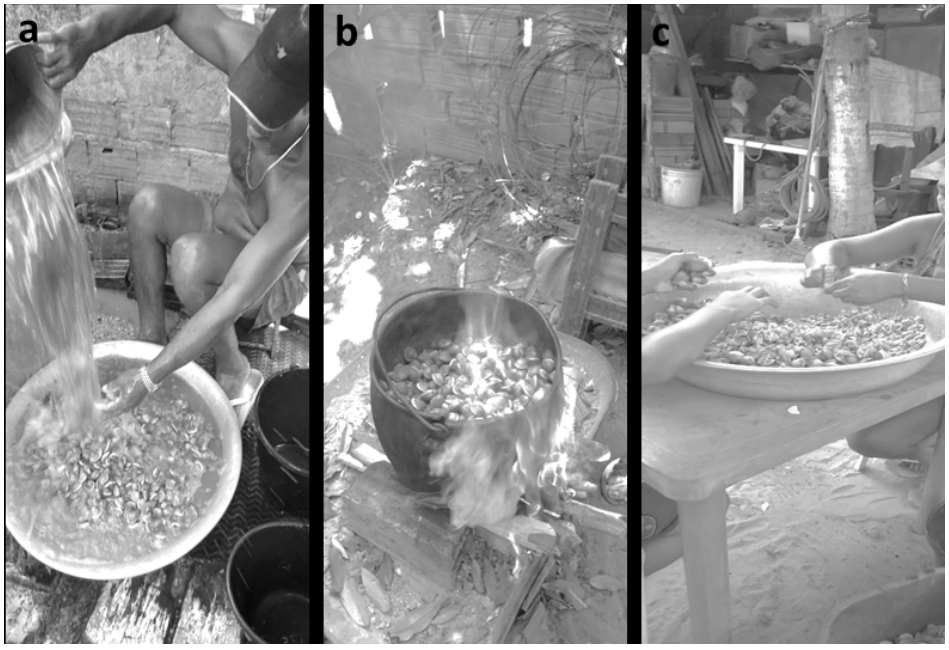

Figure 3. Processing of *Leukoma pectorina* on Algodoal-Maiandeua Island in Maracanã, on the coast of Pará (Brazil). (a) Rinsing harvested cockles; (b) Pre-cooking to open the shells; (c) separation of the soft parts (meat) from the shell.

Social and ethnoecological perspective

The cocklers interviewed reported that the largest quantities of cockles are harvested from the more humid and muddiest areas of the midlittoral. Cockles can be harvested at any time of year, although the interviewees were unanimous with regard to the fact that the largest cockles were found in the "summer" (dry season), between July and December, which is also when the species is most abundant. Some cocklers believe that density has decreased due to the heavy rains that "sweeten" the water and bivalve meat.

Most (75%) of the cocklers had perceived a reduction in cockle stocks in recent years. The most experienced cockler reported that "in the old days" (5–10 years ago), cockles were much more abundant. Some of the cocklers reported that the bivalve was difficult to find in some months of 2007. The principal reason (for 70% of the interviewees) for the reduction in stocks was the increase in the number of individuals harvesting cockles within the study area, including many from other localities on the mainland, such as Marudá, in the municipality of Marapanim. Other interviewees responded that the decline in stocks was due to a loss of quality of the island's environment, resulting from the increase in tourism, although no specific type of impact was identified.

None of the interviewees was aware of the existence of an off-season for the harvesting of cockles. Even so, all were aware of the importance of harvesting only the largest bivalves, in order to "let the smaller ones grow". In other words, they were conscious of the need to overlook the juveniles in order to maintain the stocks of cockle for the following harvest. In addition to the intrinsic environmental concerns of the interviewees, the harvesting of small cockles was considered to be unproductive. In particular "larger cockles" were important so that a smaller quantity of bivalves would need to be harvested to guarantee a kilogram of meat.

Bio-ecology

The overall density of *L. pectorina* in the Algodoal cockle bed was 939 ind. m^{-2} ±154 SE,

with no significant variation between months ($F_{(1,12)}$ = 2.7; p= 0.12), although the mean density recorded in December (mean = 1003 ind.m^{-2} ±55.7 SE) was higher than in March (874 ind.m^{-2} ±53.3 SE). The cockle shells were significantly longer ($F_{(1,702)}$ = 140.3; p < 0.01) in December (mean length = 27.1 mm ±0.2 SE) than in March, when the mean length was 22.7 mm ±0.3 SE (Figure 4a). Also, all three mean weights (total, shell, and soft parts) were significantly (Tables SI - SVII, Supplementary Material) higher in December than in March (Figure 4b). All three mean weights (total, shell and soft parts) also correlated significantly (r^2 =0.8; p < 0.05) with the total length of the cockle in both months, and the fit was best in March (Table I). The species presented negative allometric growth, with *b* values lower than 3 (Table I), that is, the weight is grow at a rate relatively smaller than the total length.

The mean meat yield of the cockles was 20% overall, but was significantly higher ($F_{1,702}$= 126.1; p < 0.01) in December (22% ± 0.3 SE) than in March (18% ± 0.3 SE). The condition factor (MW: SW) also varied significantly between months ($F_{1,702}$ = 137.4; p < 0.01), and was much higher in December (mean = 0.22 ± 0.01 SE) than in March (0.17±0.00 SE). The meat yield and condition factor of the cockles did not vary systematically in relation to the length of the shell, which indicates that these parameters cannot be accounted for by the variation in shell length, given the low coefficients of determination (r^2 < 0.15) and the non-significant F values (Figure 5).

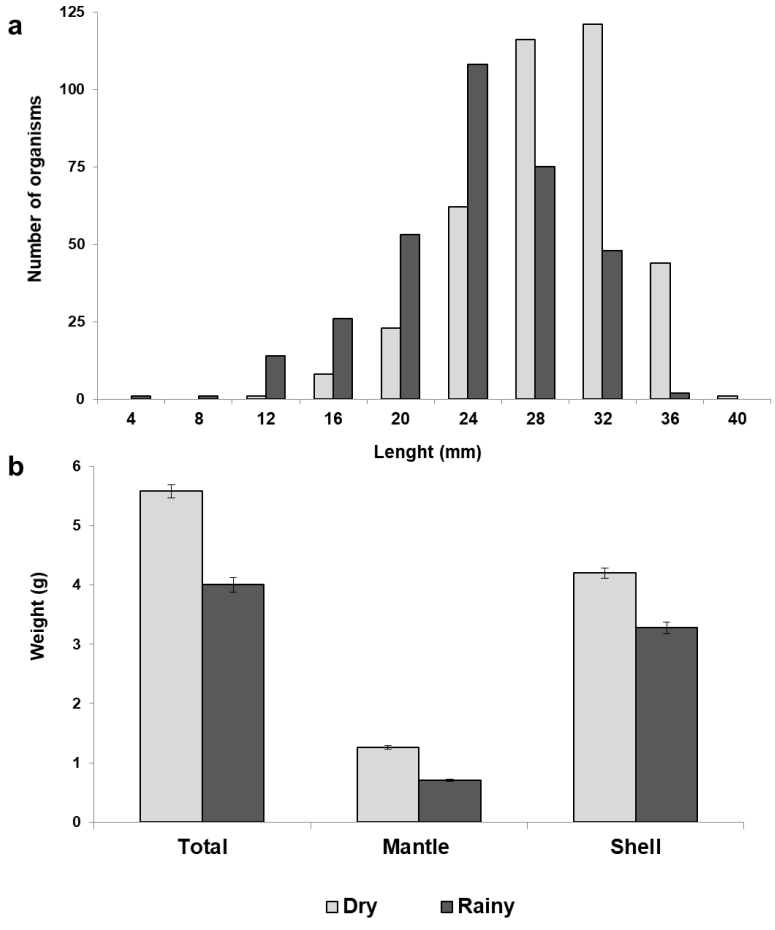

Figure 4. Shell length classes (a) and mean (±SE) weights (b) of *Leukoma pectorina* harvested in December 2012 (dry season) and March 2013 (rainy season) on Algodoal-Maiandeua Island in Maracanã, on the coast of Pará (Brazil).

Table I. Equations for estimating *Leukoma pectorina* weights and their determination coefficients (r^2). TL = total shell length; TW = total wet weight (shell + soft parts); MW = meat weight (wet weight of the soft parts); SW = shell weight. * indicate significant relationships (p <0.05).

Relations	Categories	Equations	r^2
TW X TL	December	$TW = 0.0013 \times TL^{2.53}$	0.9096*
	March	$TW = 0.0012 \times TL^{2.57}$	0.9725*
	Grouped periods	$TW = 0.0014 \times TL^{2.87}$	0.9556*
MW X TL	December	$MW = 0.00005 \times TL^{2.97}$	0.8227*
	March	$MW = 0.0002 \times TL^{2.58}$	0.8984*
	Grouped periods	$MW = 0.00008 \times TL^{2.42}$	0.8710*
SW X TL	December	$SW = 0.0021 \times TL^{2.29}$	0.8343*
	March	$SW = 0.0008 \times TL^{2.60}$	0.9705*
	Grouped periods	$SW = 0.0015 \times TL^{2.41}$	0.9251*

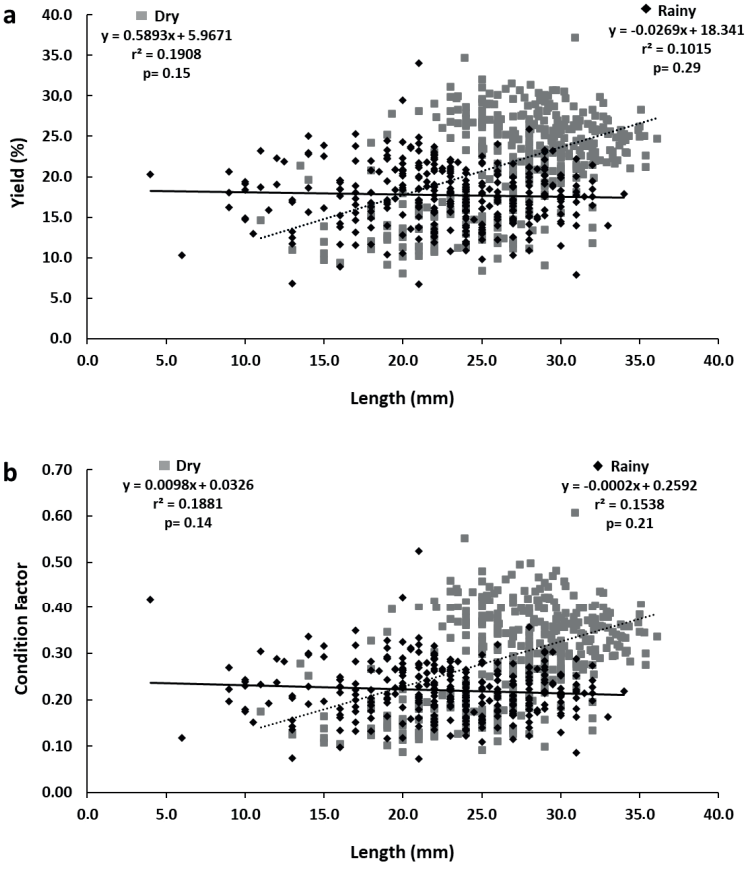

Figure 5. Relationship between total shell length the *Leukoma pectorina* specimens collected on Algodoal-Maiandeua Island in Maracanã, on the coast of Pará (Brazil) and (a) meat yield and (b) condition factor (ratio meat weight: shell weight).

DISCUSSION

Cocklers and shellfish harvesting

The exploitation of *L. pectorina* is typical of artisanal fishery activities, with the cocklers developing their own tools and techniques. Artisanal fishers typically work alone, or with family members or unsalaried assistants, to harvest all types of aquatic resource (Clauzet et al. 2005). In coastal areas, artisanal fishers tend to exploit environments close to the shore, given that their vessels and other equipment have a limited range, and in many cases, the fishing grounds are reached overland (Clauzet et al. 2005, Vasconcelos et al. 2007).

The harvesting of *L. pectorina* on Algodoal-Maiandeua Island is a predominantly female activity, which generally represents a complementary source of family income and subsistence, as observed in the exploitation of other mollusk species in Brazil (Souto & Martins 2009, Freitas et al. 2012, Walter et al. 2012) and other coastal regions of the world (Berkes 2015). In recent decades, the participation of women in artisanal fisheries in Brazil has grown considerably and they play an increasingly important role in the social debate in regions where the local economy is based on fishery resources, although this participation is not recognized in the official statistics (Maneschy 2000, Palheta et al. 2016). While fishing on the open sea is a masculine activity, the women are responsible for the activities on land, including domestic tasks and earning additional family income (Maneschy 1995, Geistdoerfer 1989).

The cocklers of Algodoal-Maiandeua have a mean age of 34 years (amplitude 9–70 years), which is within the range recorded for other groups of artisanal fishers in Brazil. In the Ponta do Tubarão Sustainable Development Reserve in the Brazilian state of Rio Grande do Norte, the mean age of fishers was 31.5 years, and those interviewed were 12–50 years old (Dias et al. 2007). Freitas et al. (2012) recorded a mean age of 42 years (22–83 years) for the cocklers of Barra Grande in the Parnaíba Delta EPA in the Brazilian state of Piauí. In the estuary of the Paraíba do Norte River in Paraíba, the mollusk harvesters were 20–60 years old (Nishida et al. 2004).

In the present study, most of the cocklers were poorly-educated (14% unschooled and 58% with an unfinished elementary school education), lower rates than those recorded in the Parnaíba Delta EPA (17% and 35%, respectively) by Linhares et al. (2008). At Ponta do Tubarão, 52.6% of the cocklers were unschooled and 21% had an unfinished elementary school education (Dias et al. 2007). Results similar to those obtained from the Algodoal-Maiandeua EPA have been recorded in other coastal communities in the municipality of Bragança, in northeastern Pará, including Tamatateua (Oliveira 2007), Ajuruteua Beach (Pereira et al. 2006), and Bonifácio village (Krause & Glaser 2003, Vieira et al. 2013). The limited education of the cocklers of the Algodoal-Maiandeua EPA is typical of the rural population of Brazil, in particular in the north of the country (IBGE 2010). The most recent census showed that 29.8% of the adult population (over 15 years old) living in rural areas is illiterate, reaching 60% in the elderly (over 60 years of age) population (IBGE 2010). This situation is related primarily to the low income levels and inaccessibility of the education system in rural areas (PNAD 2015).

Algodoal-Maiandeua Island has only a single elementary school, which attends to the whole population (SEMAS 2012). To continue their education, the islanders must travel to the towns of Maracanã and Marapanim, on the mainland. These logistic difficulties, together with the conflicting demands of other activities, such as farming, fishing, and work in the tourism sector, all contribute to the nonattendance of

school (Vieira et al. 2013). In the specific case of the women, precocious pregnancy and marriage also contribute to absenteeism (SECAD 2007, Dias & Teixeira 2010), which is consistent with the situation of the cocklers from Algodoal-Maiandeua Island, given that 63% were married, and 71% had children.

The types of equipment used to harvest fish and other aquatic organisms may vary considerably, depending on the objectives of the fisher, which may include the increase in the catch per unit of effort or the selection of a given species (Monteles et al. 2010). In both the harvesting of *L. pectorina* in northern Brazil, and that of *A. brasiliana* in the south of the country, the equipment used is known as a "hook", although its components and the techniques used to harvest the mollusks vary considerably (Pezzuto & Souza 2015). In southeastern Brazil, the *A. brasiliana* "hook" is a manual dredge, composed of a metal basket with a wooden handle (Pezzuto & Souza 2015). In the Brazilian Northeast, by contrast, *A. brasiliana* is harvested using a 1-cm mesh net fixed to a circular hoop, which is dragged by handles (El-Deir 2009) or by digging the substrate manually (Freitas et al. 2012).

These different techniques are directly related to the characteristics of the substrates in which the mollusks are found. Whereas *A. brasiliana* is found typically in shallow sandy or sandy-muddy substrates, which allow for the use of nets or dredges (Pezzuto & Souza 2015), the layers of shells and other hard materials found in the more muddy substrates inhabited by *L. pectorina* (Guerón & Narchi 2000) limit the use of this type of equipment. On Algodoal-Maiandeua Island, the cocklers have developed tools appropriate to the type of substrate, which impedes the use of dredges or manual digging.

Despite the use of specific tools, cockling on Algodoal-Maiandeua Island can be considered to be a rudimentary activity, conducted with virtually no safety equipment and little protection from sunlight. Exposure to the sun is a major risk for fishers in tropical regions, and may result in serious skin problems, as observed in other regions of Brazil (Freitas et al. 2012, Goiabeira 2012). The cockles are processed in the family households, where the sanitary conditions are inadequate, under Brazilian legislation, for the handling of fresh or frozen fishery products destined for commercial sale (Brasil 2007), a potentially serious public health problem. The irregularities observed during the present study included the use of untreated water, inadequate containers, and the presence of domestic animals and insects in the work areas.

The sale of *L. pectorina* meat occurs without the involvement of intermediaries, the cocklers or members of their families sold cockles directly to consumers. This is a condition different of the *A. brasiliana* commercialization in Brazilian coast (Silva-Cavalcanti & Costa 2011), in which usually there is the participation of a middle-man, who exports the production from the community. The middle-man buys the production of a whole community or centralizes the production and, a second middle-man takes it to the consumers centers (Silva-Cavalcanti & Costa 2010, 2011). Although *L. pectorina* is consumed by the cocklers' families, the majority of the harvest is destined for sale to the restaurants and guest houses of Algodoal village. The frequency of cockling, and the price of the produce, are controlled by local tourism, which peaks during the summer vacation season, in July (early dry season), and during prolonged bank holidays, such as Carnival (rainy season) and Christmas/New Year (late dry season).

The biology and ecology of *Leukoma pectorina*

The density of *L. pectorina* in the Algodoal cockle bed was highest in the dry season month (December), when the cockles were larger and heavier. An increase in the abundance of organisms during periods of dry weather in estuarine environments has been recorded in the populations of a number of other benthic invertebrates on the Amazon coast (Rosa Filho et al. 2009, Silva et al. 2011, Braga et al. 2013). In general, this pattern reflects an increase in the salinity of the water, and greater primary productivity. Salinity is a major factor determining the distribution of estuarine mollusks in tropical regions (Quayle & Newkirk 1989, Dame 2011). Low salinity or marked oscillations in this parameter may provoke osmotic stress, which leads to a reduction in feeding and growth rates, and an increase in mortality (Mcfarland et al. 2013).

While no data are available on the tolerance of *L. pectorina* to salinity, *A. brasiliana* is known to survive in a salinity range of 17–42, although values below 24 may provoke osmotic stress, and an increase in mortality (Leonel et al. 1983, Monti et al. 1991). Laboratory studies have shown that, while *A. brasiliana* tolerates an ample variation in salinity, phytoplankton filtration is optimal at a salinity of between 30 and 35, while the animals stop feeding at salinities below 20 (Lavander 2013, Lima et al. 2010). Salinity may vary from 7 to 24 during the rainy season in the Marapanim estuary, where Algodoal-Maiandeua Island is located (at its outer limit), and from 27 to 35 during the dry season (Aviz et al. 2016).

The mean yield of the *L. pectorina* cockle meat recorded in the present study was 20%, a value higher than those recorded for other bivalves in Brazil, such as the oyster, *Crassostrea rhizophorae* (Guilding, 1828)(6–16%; Portella 2005, Christo 2006) and the mussel, *Perna perna* (Linnaeus, 1758), with a mean meat yield of 11% (Beirão et al. 2000). The values recorded for *L. pectorina* at Algodoal are also higher than those recorded for *A. brasiliana* in Piauí (mean = 9.52 ± 1.03%; Freitas et al. 2012), Paraná (mean = 18%; Boehs et al. 2008), and Santa Catarina (mean values of 17.13% and 16.65%; Aveiro 2007).

The meat yield and condition factor were higher on Algodoal-Maiandeua Island in the dry season month. The condition factor provides an index of the optimal period for investment in reproduction (sexual maturation and the production of gametes), as well as the nutritional condition and stress of the organisms (Absher & Christo 1993, Aswani et al. 2004). The higher values recorded in the dry season were due to the larger mass of soft parts in the cockles harvested, which indicates a greater investment in reproductive structures (gonads and gametes) or optimal conditions for feeding and growth, possibly related to the higher salinity of the estuary (Lavander 2013, Lima et al. 2010).

Silva (2014b) recorded continuous reproduction in *L. pectorina* on Algodoal-Maiandeua Island, although mature individuals were more common at the end of the dry season, and spawned individuals in the rainy season. This seasonal pattern may account for the greater proportion of individuals in the smaller size classes during the rainy season, due to recruitment events. While no data are available on the duration of the larval development of *L. pectorina*, in *A. brasiliana*, a second venerid also found on the Amazon coast, the planktonic stage lasted 15–30 days (Moüeza et al. 1999).

Ethnoecological knowledge *versus* the bio-ecological data

The local cocklers appeared to be aware of the temporal and spatial variation of *L. pectorina* on Algodoal-Maiandeua Island. In their vernacular, "catch cockles in the stones" (*catar sarnambi na pedra*) refers to the habitat of the species, which is typically found buried in substrates

composed of mud, gravel, and rocks. The species is known to be part of the infauna that inhabits shallow substrates with layers of shells, gravel, and stones, and is most abundant in mudflats with rocky outcrops (Guerón & Narchi 2000). To maximize their harvest, the local cocklers focus on the rocky areas of the lower midlittoral, where the substrate is muddier and more humid. In an intertidal area of the same estuarine system with rock fragments, Morais and Lee (2014) recorded a higher density of this organism in the lower parts of the midlittoral, in comparison with the upper parts (towards the supralitoral). The increasing density towards the infralittoral zone is a common pattern in tropical regions, associated with the longer time the substrate is covered by the tide in this zone (Davidson 2005, Reicherti et al. 2008), which is thus more humid, and suffers less variation in temperature and salinity (Little & Kitching 2000, Davidson 2005).

While the cocklers reported finding *L. pectorina* throughout the year, they confirmed that cockles were most abundant and more easily harvested during the dry season, from July onwards, when they were also larger in size. This pattern coincides with the bio-ecological data, indicating that the cocklers have accumulated a reliable empirical knowledge of the productivity and seasonality of *L. pectorina* within the study area. The intimate relationship between the traditional fishery community and the natural resources it exploits supports the transfer of traditional knowledge from one generation to the next, guaranteeing the long-term exploitation of the local natural resources by the islanders. This cultural heritage should be seen by society as a rich source of popular traditional knowledge, which represents all aspects of the community, from its economic structure to its social and cultural domains (Shiva 2003).

The results of the present study also indicated that the cocklers already practise a degree of management of the *L. pectorina* stocks, by harvesting only larger specimens, based on criteria of productivity, although they are also concerned with the long-term sustainability of their harvests. The reduction in harvesting observed during the rainy season, while determined primarily by a reduction in the demand from local businesses, contributes to the recuperation of stocks. Very similar scenarios have been observed in cockling communities in northeastern Brazil, such as those in the district of Acupe, in Bahia (Souto & Martins 2009), and in the Parnaíba Delta in Piauí (Freitas et al. 2012).

The cocklers interviewed reported a reduction in *L. pectorina* stocks in recent years in the Algodoal-Maiandeua EPA, which demands more time and effort for the harvesting of a given quantity of mollusks. Most cocklers relate this decline in stocks to the overexploitation of the resource, given the larger numbers of cocklers now working the island's cockle beds. The population of northeastern Pará, and especially its coastal towns, has increased considerably over the past few decades (Morais Filho & Rocha 2014), and growing fishery pressure may result in the predatory exploitation of local aquatic resources to satisfy increasing demands for both subsistence and commercial produce (Furtado 1990). The cocklers also indicated tourism as a potential determinant of the decline in stocks.

In recent years, the numbers of tourists visiting Algodoal-Maiandeua Island have grown considerably, in particular following the installation of mains electricity, in 2005 (SEMAS 2012). The growth of tourism has modified the lifestyle of the islanders and the environmental quality of the island. The island was initially occupied by artisanal fishers at the beginning of the twentieth century, and the abundance of fishery resources in the local coastal ecosystems contributed to the establishment of the first village (Quaresma 2000). Most of

the economic activities available on the island, and in particular in Algodoal village, are related to tourism and associated services, including service jobs in restaurants and guest-houses, corner shops, and transportation by boat or carriage. The expansion in real estate has resulted in an increasing population density in ecologically fragile areas, and mass tourism on the island has exacerbated problems such as the lack of an adequate garbage disposal system and the inappropriate treatment of domestic effluents (Quaresma 2000).

Based on the ethnoecological results of our study, it was evident that the fishing pressure on *L. pectorina* populations has increased with the expansion of local tourism, as tourists are the major end customers of cocklers. Overfishing can cause a reduction in the abundance and decrease the mean size of individuals within the population (Durán & Castilla 1989, Sharpe & Keough 1998), which is evident from the decrease in catch and increase in fishing effort (Morales-Bojórquez et al. 2001). In addition, in the areas where *L. pectorina* banks occur, there is increased trampling and anthropogenic debris (mostly plastic) during the summer vacation season (Bezerra et al. 2010), conditions that potentially can impact the intertidal species (Huff 2011, Green 2016).

This narrative emphasizes the need for the continuous evaluation of the natural *L. pectorina* stocks, to guarantee their protection, and sustainable management. While reliable ecological and biological data are essential for the management of environmental resources, it is also necessary to understand the perspective of the human population that exploits these resources to ensure an equilibrium between their socioeconomic interests and the basic precepts of environmental management and sustainability (Fonteles-Filho 2011). The present study is the first to establish a direct link between locally-compiled knowledge and scientific data on *L. pectorina*, one of the mollusks most consumed on the Amazon coast. These findings highlight the importance of compiling local traditional knowledge as a potentially valuable complement to the scientific data, as well as recognizing the importance of this sector of society, which is so frequently marginalized, but should play a fundamental role in the decision-making process for the development of effective strategies for the long-term sustainable exploitation of natural resources.

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SUPPLEMENTARY MATERIAL

Table SI, Table SII, Table SIII, Table SIV, Table SV, Table SVI, Table SVII.

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