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The fishery of pelagic shrimp aviú *Acetes paraguayensis* in eastern Brazilian Amazon

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ABSTRACT

The pelagic shrimp, *Acetes paraguayensis* Hansen, 1919, is an ecologically important species with an enormous socioeconomic value for the human populations in the regions where it occurs. This species also has considerable potential for shrimp farming, although few details are known of its biology. This study investigated the artisanal exploitation of *A. paraguayensis* stocks in the northern Brazilian municipality of Santarém over 16 months, focusing on the types of equipment most used to harvest of this shrimp, the fishing dynamics, and production patterns. The matapi trap was the principal method used of harvesting *A. paraguayensis* in the study region, conforming to a typically artisanal, small-scale fishing production system. This study results provide an essential research tool for developing conservation and management strategies and the eventual establishment of farming protocols.

Keywords: amazon artisanal small-scale fishery; shrimp traps; freshwater shrimps; Tapajós River.

A pesca do camarão pelágico aviú *Acetes paraguayensis* na Amazônia oriental brasileira

RESUMO

O camarão pelágico, *Acetes paraguayensis* Hansen, 1919, é uma espécie ecologicamente importante, de enorme valor socioeconômico para as populações humanas localizadas nas regiões produtoras. Essa espécie tem também um potencial considerável para o cultivo, embora poucas informações sejam conhecidas da sua biologia. Assim o presente estudo investigou a exploração artesanal das populações de *A. paraguayensis* no município paraense de Santarém, no Norte do Brasil, por 16 meses, concentrando-se nos tipos de equipamento mais utilizados para sua captura, na dinâmica pesqueira e nos padrões de produção. O matapi foi o principal método utilizado, configurando-se como um sistema de produção pesqueira tipicamente artesanal de pequena escala. Os resultados do presente estudo constituem importante instrumento de investigação para o desenvolvimento de estratégias de conservação e gestão e o eventual estabelecimento de protocolos de cultivo.

Palavras-chave: pesca artesanal de pequena escala na Amazônia; armadilhas para camarões; camarões de água doce; rio Tapajós.

INTRODUCTION

The shrimp species of *Acetes* are distributed primarily in coastal and estuarine waters in the tropical and subtropical regions of the western Indo-Pacific, the Atlantic, and the eastern Pacific oceans (Omori, 1975, 1977). These shrimps play a vital role in the food webs of coastal waters, as both predators and prey (Xiao and Greenwood, 1993).

In addition to their ecological importance, these shrimps are a commercially important source of human food (Omori, 1978; Holthuis, 1980) and are also used as feed in farming and aquaculture (Xiao and Greenwood, 1993; Amin et al., 2009b; Oh et al., 2011). *Acetes* are an especially important resource in Asia, where these shrimps are targeted by several different types of fisheries, which produce 75% of the world's total catch (DOF, 2012). These shrimps are processed in different ways and exported to many countries around the world (Arshad et al., 2008; Amin et al., 2009a; Oh et al., 2010).

Three *Acetes* species – *Acetes americanus* Ortmann, 1893; *Acetes marinus* (Omori, 1975), and *Acetes paraguayensis* Hansen, 1919 – are found in Brazil (D'Incao and Martins, 2000), although there is no dedicated fishery, like those found in Asia and

other parts of the world, except in some parts of the Amazon region, where these shrimps are known as aviús or aviuns and often constitute one of the principal sources of income for traditional local communities. *A. paraguayensis* is the only member of the genus found exclusively in freshwater habitats (Collins and Williner, 2003; Melo, 2003; Magalhães and Pereira, 2007). This species is widely distributed in South America, being found in Bolivia, Colômbia, Venezuela, Suriname, Peru, Paraguay, Argentina, and Brazil (Melo, 2003; Magalhães and Pereira, 2007; Pileggi et al., 2013).

A. paraguayensis is harvested widely by artisanal fisheries in the Amazon region. However, despite the economic and ecological relevance of the species, its life history is still poorly known, and there are very less data on the characteristics of this shrimp in its natural environment. However, the species is known to have enormous potential for aquaculture.

Studies of the harvesting patterns of *A. paraguayensis* are of considerable importance for understanding the life cycle and biology of the species, given that research on these parameters is virtually non-existent. Previous studies of *A. paraguayensis* have explicitly focused on its geographic distribution (Aldrich, 1962) and feeding behavior (Collins and Williner, 2003). However, they did not specify the methods used to capture the study specimens. As few data are available on the biology of *A. paraguayensis*, this may account for its fisheries' lack of published accounts.

Given the lack of data on the biology and ecology of *A. paraguayensis*, particularly its economic importance for the traditional riverside populations of the Amazon region (e.g., extractives, quilombo communities, and indigenous groups). This population practice subsistence fishing and have an extremely low Human Development Index (HDI). This study investigated these fishery activities, fishing techniques, and the equipment most used to harvest the study species on the Tapajós River in the municipalities of Santarém and Aveiro.

The study also aimed to:

1. determine the methods used by local shrimpers,
2. identify the most productive harvesting strategies,
3. record the number of effective shrimping days of the most productive equipment,
4. verify the existence of new shrimping stations,
5. determine the periods of peak catches, and
6. estimate the cost of each type of equipment.

These data should contribute to optimizing this fishery activity by supporting the creation of the legal mechanisms necessary for its regulation and the eventual introduction of public policy to guarantee the long-term management and conservation of the resource.

MATERIALS AND METHODS

The municipality of Santarém (02°25' S, 54°42' W) has an area of 24,154 km² (Rabelo et al., 2017). Mean annual precipitation is 2096 mm, with the rains occurring between December and May (Souza and Ambrizzi, 2003; Costa et al., 2013). However, this study was carried out based on the water level of the river, which is high in May and low in August (Callède et al., 2002). The municipality is located on the right margin of the Tapajós River and was selected for this study due to the local occurrence of *A. paraguayensis* and the well-established local fishery (Figure 1).

The local *A. paraguayensis* shrimpers used different equipment were recorded *in loco* through personal contact with experienced individuals (Braga and Rebelo, 2014). During this contact, the shrimp gear and activities were photographed for later transformation into diagrammatic drawings. These data were collected during monthly field trips in May 2016 and August 2017. The shrimp stations were georeferenced using a Global position system device (GPS) and plotted on a LANDSAT satellite image. These images were processed in ArcGIS version 10.0 (ESRI, 2010).

Local knowledge of the shrimping grounds was obtained through interviews, based on semi-structured questionnaires (n=120), which were applied to local shrimpers either at fishing ports and/or in their residences (Brito et al., 2015; Zacardi et al., 2017). The study area corresponds to all the localities or communities referred to most frequently by the interviewees, as areas in which *A. paraguayensis* is caught regularly. The data collected in the interviews were the type of fishing equipment, the material used to make this gear, its dimensions, and the cost of producing a device. In addition, registering the fishing gear operation, the mean monthly production, the most productive type of equipment, the number of effective fishing days on which the equipment was used, and the most productive time of year were included. A total of 120 fishermen dedicated exclusively to aviú fishing, a subsistence fishery, were interviewed.

RESULTS

Most of the *A. paraguayensis* harvested in the Santarém region are sold in the Pará state capital (Belém) and other regions. Some of the catch is exported to other states of northern Brazil. According to the most experienced local fishers, harvesting this vital resource became a commercial enterprise approximately 30 years ago. Before this, all the *A. paraguayensis* caught were discarded as bycatch of the operations that targeted the local Amazon prawn, *Macrobrachium amazonicum* Heller, 1862. These interviewees reported that a local fisherman had the idea of cooking and salting the aviú, making this shrimp widely acceptable to the local population. Subsequently, demand for this resource increased considerably. According to the interviewees, during the early days of this fishery, enormous aggregations of *A. paraguayensis* were found frequently, parallel to the river margin, migrating in the current direction, during the flood or rainy periods.

A total of 66 new fishing grounds were identified in this study. However, the GPS could not distinguish many sites due to their proximity, which meant they were attributed the exact coordinates.

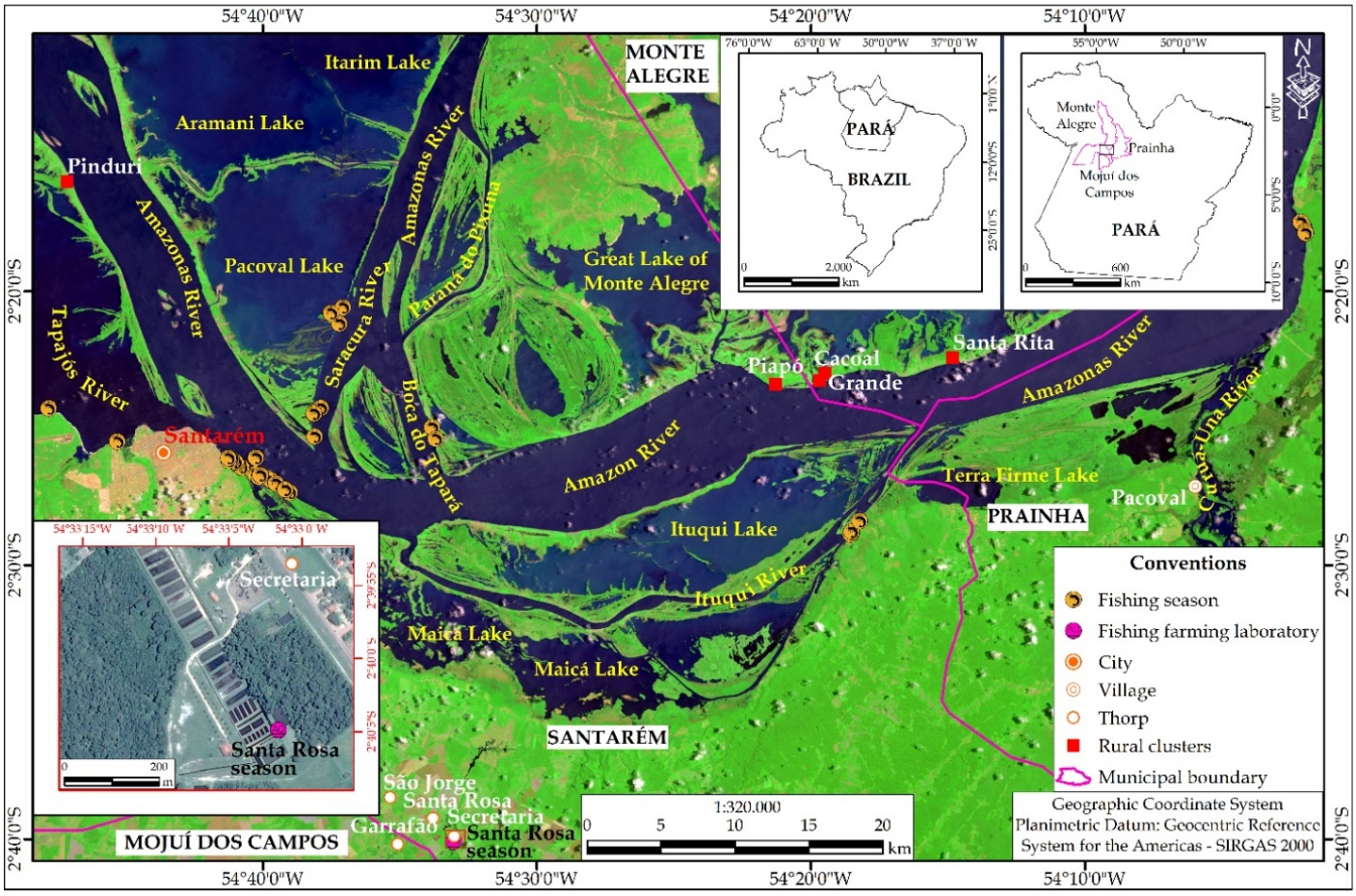

Figure 1. Location of the *A. paraguayensis* shrimping stations identified within the study area.

Six of the stations were thus eliminated, leaving a plot of 60 Fishing grounds (Figure 1). Thus, a total of six different types of equipment are currently used to harvest *A. paraguayensis* in the study region, of which five are active methods (Hayes et al., 1996): drag-netting with cloth, drag-netting, dip-netting (Aveiro and Santarém types), and boat-drawn dip-netting (Santarém). The only passive method was the matapi shrimp trap (Lagler, 1978), also used in Santarém. The six techniques are described in detail below.

a. Drag-net made of cloth (mosquito net) – one of the first types of equipment used in the region, due to its simplicity. The net consists of an ordinary piece of polyester cloth, either rectangular or square in shape, usually green in color, with a 1.30 mm mesh, a length of 2.00–5.00 m, and a height of 1.00–1.50 m (Figure 2A). In most cases, the net has no perforations, or straps to support the attachment of poles, floats, or weights, nor any purse for the accumulation of the catch. The *mosquito* net is operated against the crowding of animals, which happens in the late afternoon and at dawn, covering a small and varied area (up to 5.0 m) and/or until the desired amount has been captured (Figure 2B-E).

b. Drag-net – this type of net is similar to mosquito net, although it is more extensive (±7.00 m) and typically has some handle. The upper and lower extremities of the net are sewn to form an open-ended hem through which polyamide lines (0.50 mm) are threaded, with their ends being made into a handle using a bowline knot. The upper handles are gripped in the hands, while the lower ones are looped around the big toe or by a wooden handle attached to the ends (Figure 3A). The net is dragged against the animal crowding, at dawn or in the late afternoon, with a larger swept area (±20.00 m). The *modus operandi* is similar a *mosquito* net, with the two shrimpers walking parallel to the margin while holding the upper and lower extremities of the cloth and/or net in their hands (or feet) in the near the margin, at depths of no more than 1.50 m (Figure 3B, C).

Three types of dip-net (or hand-net) were identified during this study. One type was observed in the municipality of Aveiro and is identified here as the Aveiro type. The two other types were recorded in Santarém, and while one is an ordinary dip-net, the other is boat-drawn.

c. Dip-net (Aveiro type) – this net is spherical or semispherical, with a polyester cloth mesh, and an opening, or "mouth", made of an iron hoop (of varying sizes) to which the net is attached (Figure 4A, B).

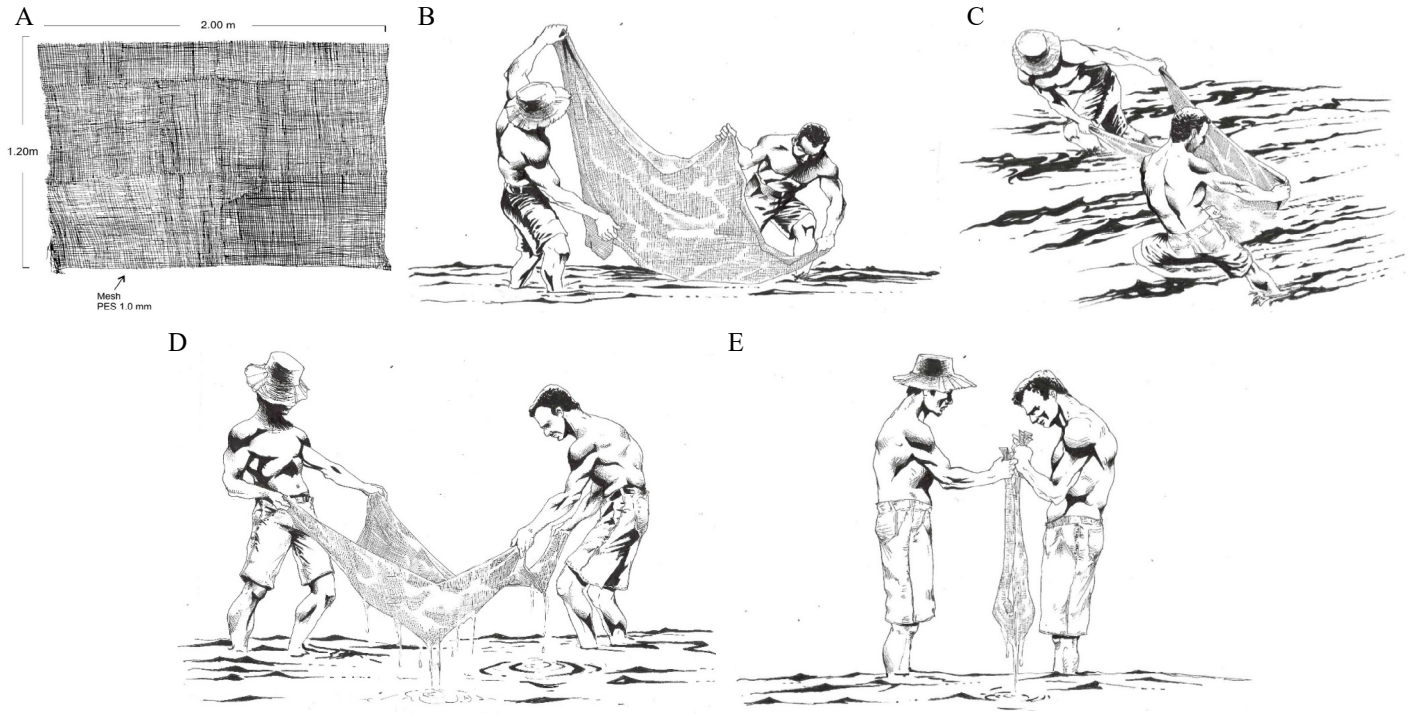

Figure 2. Fishing gear known as drag-net made of cloth (mosquito net) in the study area (A) and showing your operation (B-E). PES: polyester. Illustration of Edson R. Miranda.

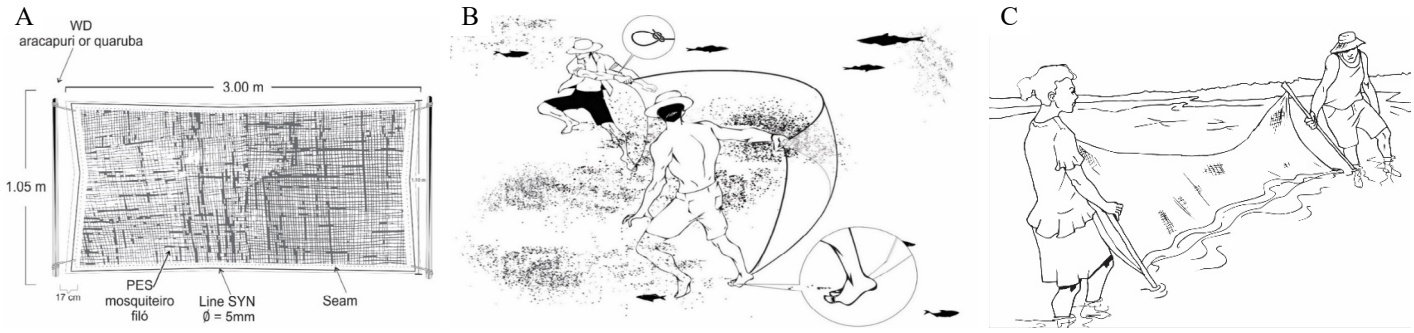

Figure 3. Diagrams showing fishing gear drag-net (A) and your operation: with handles (B) and with wooden handles (C). PES: polyester; WD: wood; SYN: synthetic fiber. Illustration of Edson R. Miranda.

This net consists of three parts: an iron hoop, a wooden pole, and cloth mesh. It is currently the type of net most used by shrimpers, in particular in the municipality of Aveiro, given that it allows the user to remain at the water's edge, rather than having to enter the water, as in the case of the drag-nets, to catch the shrimp. This reduces considerably the risk of being injured by stingrays (*Potamotrygon* spp.), which are abundant in the study region. To use this type of net, the shrimper remains stationary, waiting for signs of an aggregation of shrimp. The hoop can be made of iron rods, either 3/8" (10.00 mm) or 5/8" (16.00 mm) in diameter, or bicycle wheels, to form a ring with a mean diameter of 0.57 m (Figure 4A, B).

On average, the net has a mean length of 0.70 m and a mean height of 0.62 m, while the pole is 2.46 m long. The pole is rounded, and its exact length and diameter vary per the size of the shrimper's hands to facilitate its use. The net has a mesh of 1.30 mm and is sewn onto the metal ring using Denier 210/12 monofilament polyamide line, with a resistance of 17.20 kgf. During the use of this net, the shrimper may stand at the water's edge, or on a boat or some other structure. When an aggregation of shrimp is spotted, moving on the flow of the current, the shrimper hold the pole firmly with both hands and places the hoop in the water in the opposite direction to the flow of the water and the movement of the shrimp (Figure 4C). The pole allows the shrimper to cast the net into the water at an appropriate distance (depending on the length of the pole), before drawing the net back through the water, just under the surface. The net is then cast repeatedly, until the desired quantity of shrimp has been caught. The use of this net requires a great deal of physical force, which limits its deployment, typically to shallow waters of no more than 1.00 m in depth (Figure 4C).

d. Dip-net (Santarém type) – this net has a similar *modus operandi* to the Aveiro type, but is used at depths of up to 1.50 m, and it has a distinct configuration. This net is more extensive and rectangular, rather than round, and is composed of four parts – a rectangular hoop of iron rods, a wooden pole, the net, and two lines fixed to the opposite extremes of the hoop, crossing in the middle (Figure 5A, B).

The material used to make this net consists of iron rods (3/8" or 5/8") of either 2.20 m or 1.60 m in length, a net (1.30 mm mesh) with a depth of 2.50 m, a rounded wooden pole with a mean length of 2.50 m, and varying diameters. The net is made of four pieces of cloth sewn together. The lines attached to the hoop and pole are made of threaded synthetic fiber of varying thickness and length. The shrimpers wait for signs of an aggregation of shrimp, which is when they begin using the net, once again, casting it into the water in the opposite direction to the flow of the water and the movement of the shrimp. During the operation of the net, one shrimper pulls on the lines attached to the extremities of the hoop, while the other holds the pole firmly, helping with the retrieval of the catch, and the removal of the net to the margin of the river. Given the considerable effort involved in the operation of this type of net, its use is limited, and at the present time, it is rarely used.

e. Boat-drawn dip-net (Santarém) – this type of equipment is rarely used. It consists of two components: a rectangular iron hoop and a net. The hoop is made of soldered iron rods, 3/8" or 5/8" in diameter, typically 1.08 m in length and 0.60 m in

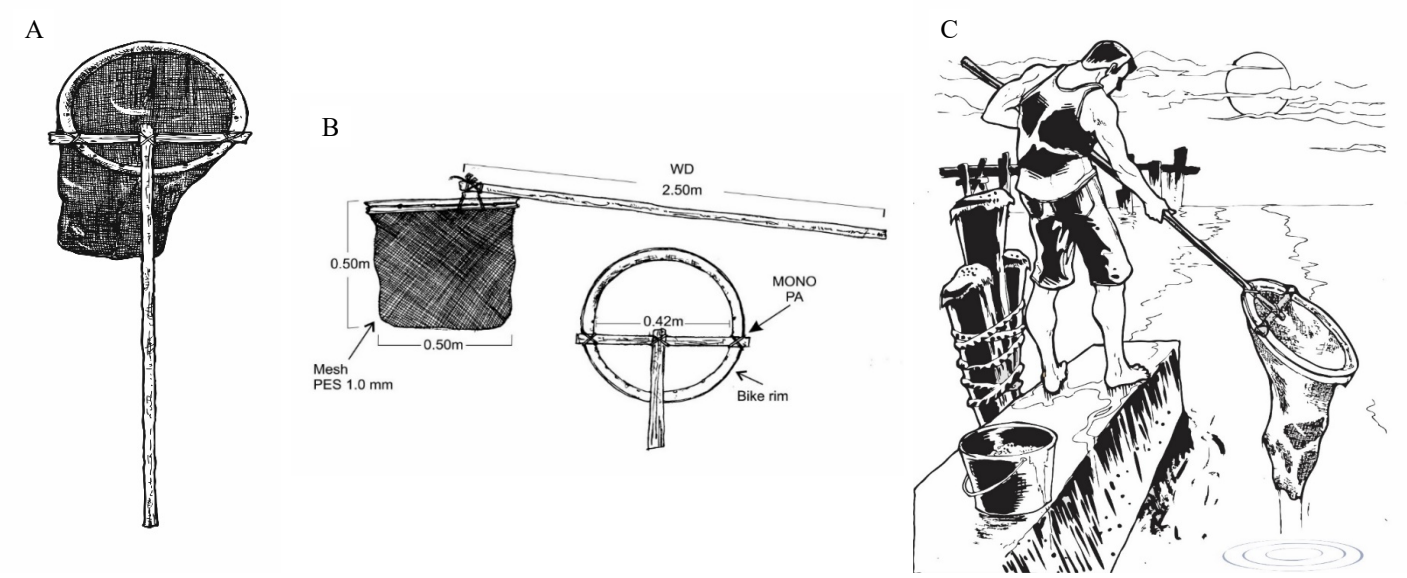

Figure 4. Equipment dip-net (Aveiro type) used to harvest *A. paraguayensis* in the study area (A and B) and showing your operation (C). PES: polyester; WD: wood; PA: polyamide; MONO: monofilament. Illustration of Edson R. Miranda.

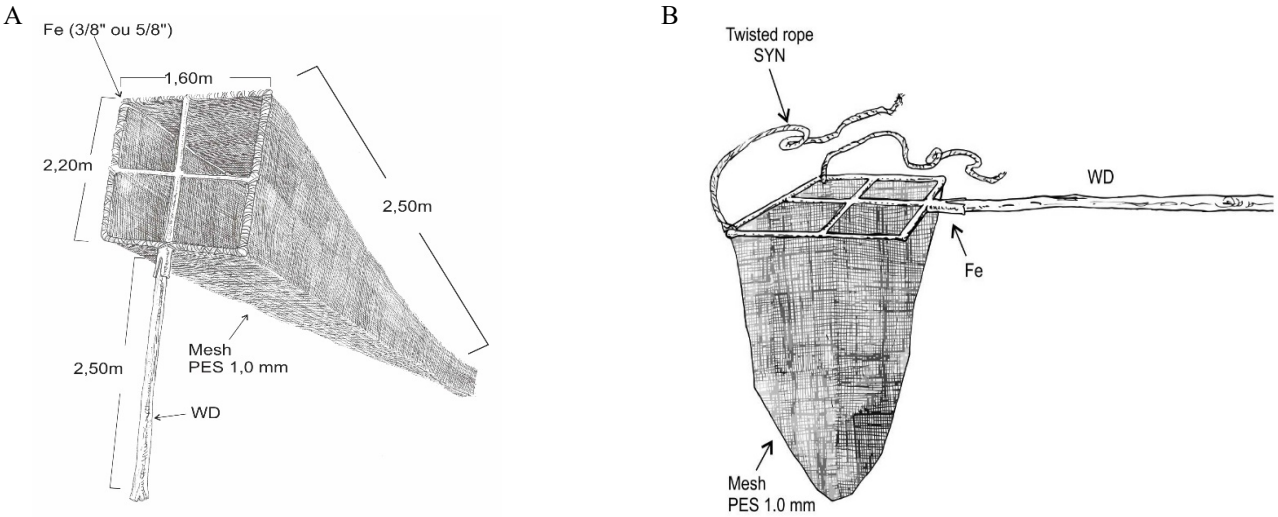

Figure 5. Dip-net (Santarém type) in the study area used to harvest *A. paraguayensis* (A and B). PES: polyester; WD: wood; Fe: iron; SYN: synthetic fiber. Illustration of Edson R. Miranda.

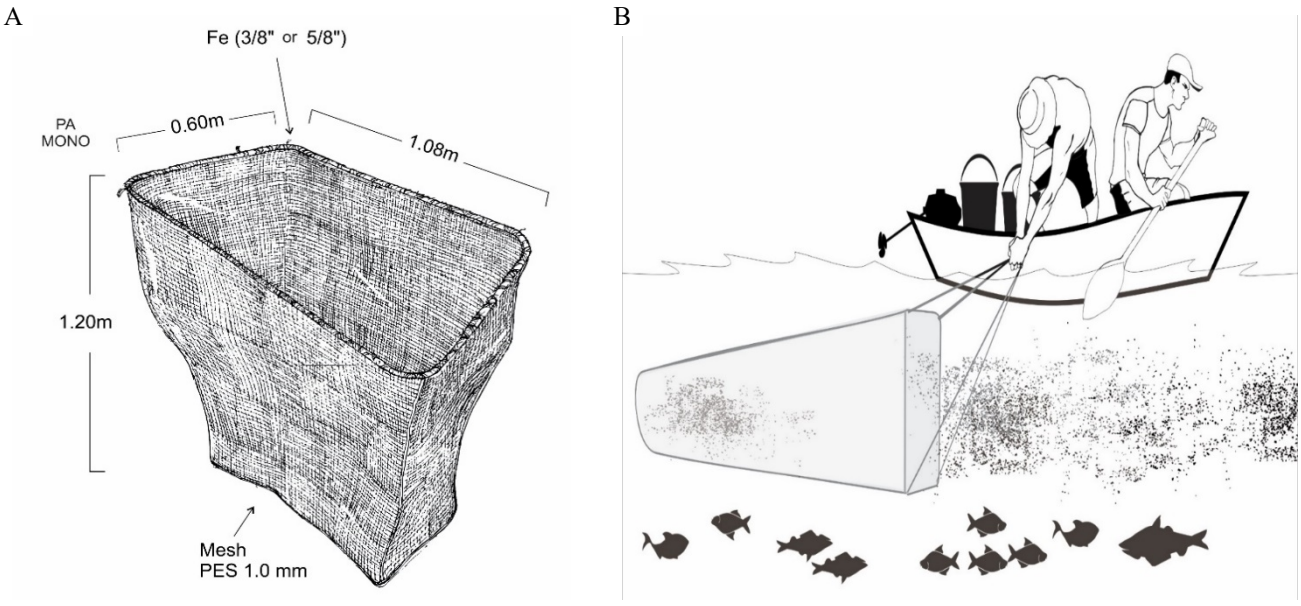

Figure 6. Fishing gear boat-drawn dip-net (Santarém type) (A) and your operation (B). PES: polyester; Fe: iron; PA: polyamide; MONO: monofilament; SYN: synthetic fiber. Illustration of Edson R. Miranda.

height. The net consists of four pieces of cloth sewn together. To operate this type of net, the shrimpers first observe the river to detect an aggregation of shrimp and then load the net onto the stern of the boat, typical a dugout canoe, 7.00–8.00 m in length, which is rowed in the direction opposite to the current and movement of the shrimp (Figure 6A, B).

The net is drawn behind the boat, just below the surface of the water. Once the desired amount of shrimp has been harvested, the catch is retrieved from the net and stored in containers located in the bottom of the boat. The shrimp are captured at depths of up to 1.50 m.

f. Matapi (shrimp trap) – the technique most used in the study area. The matapi has two components, the trap itself, which is removable, and a fixed, weir-type fence (Figure 7A).

The first traps used to capture *A. paraguayensis* were made of wood and were square in shape. No fence was used, and the traps were fixed in place using four wooden stakes, which were much smaller than those used in this day. Nowadays, the framework of the matapi is made of soldered iron rods, either 3/8" (10.00 mm) or 5/8" (16.00 mm) in diameter (Figure 7B), which is covered in netting, typically mosquito-net. The traps come in a number of different shapes, e.g., square or rectangular, but predominantly semicircular (Figure 7A-D).

Two types of matapi were identified during the study period:

1. trap with single entrance or "mouth" and
2. trap with a double entrance, although in both cases, the opening is 0.02±0.03 m wide (Table 2).

The single entrance matapis are smaller and are set in deeper water (≥2.00 m), while the double traps (Figure 7B) are used at shallower (≤2.00 m) sites. Luminous attractors, consisting of electric light bulbs, are installed above the traps located in the vicinity of utility poles, which provide electricity through illegal wiring installations. These attractors are used only in the months when *A. paraguayensis* is abundant in the study area (Figure 7A). The openings at the front of the trap are funnel shaped (Table 1), permitting the animals to enter the trap, but once they have entered the trap, they are unable to escape. These narrow openings, which provide access to the interior of the trap, are linked to the extremities of the frame in a V-shape, extending over the full height of the trap, which is variable (Figure 7B-D). These openings lead to a small hatch, which is used to retrieve the catch and remains closed during the operation of the trap. The matapi is a "false" refuge, designed to facilitate the access of the shrimp to the internal compartment, from which they are unable to escape.

The matapi also has a weir-type fence, known locally as the "esteira," which consists typically of a single length of netting attached (sewn) to a series of wooden stakes, which are driven into the substrate as supports. This fence may vary in length from 1.50 to approximately 40.00 m, depending on the topographic configuration of the shrimping station, and the financial resources of the shrimper (Figure 7A, Table 1). The wooden stakes are spaced regularly at 1.00 or 0.50 m intervals, depending on the site. The assemblage and installation of the fence generally takes 2 to 2½ h. Several weights of different sizes are used to stretch the fence tight and fix it to the bottom substrate. The fence is invariably installed perpendicular to the beach, and in the opposite direction to the local currents and movement of the shrimp, given its function to force the animals to move toward the trap. The fence increases the efficiency of the technique by funneling the shrimp toward the trap entrance, where they are

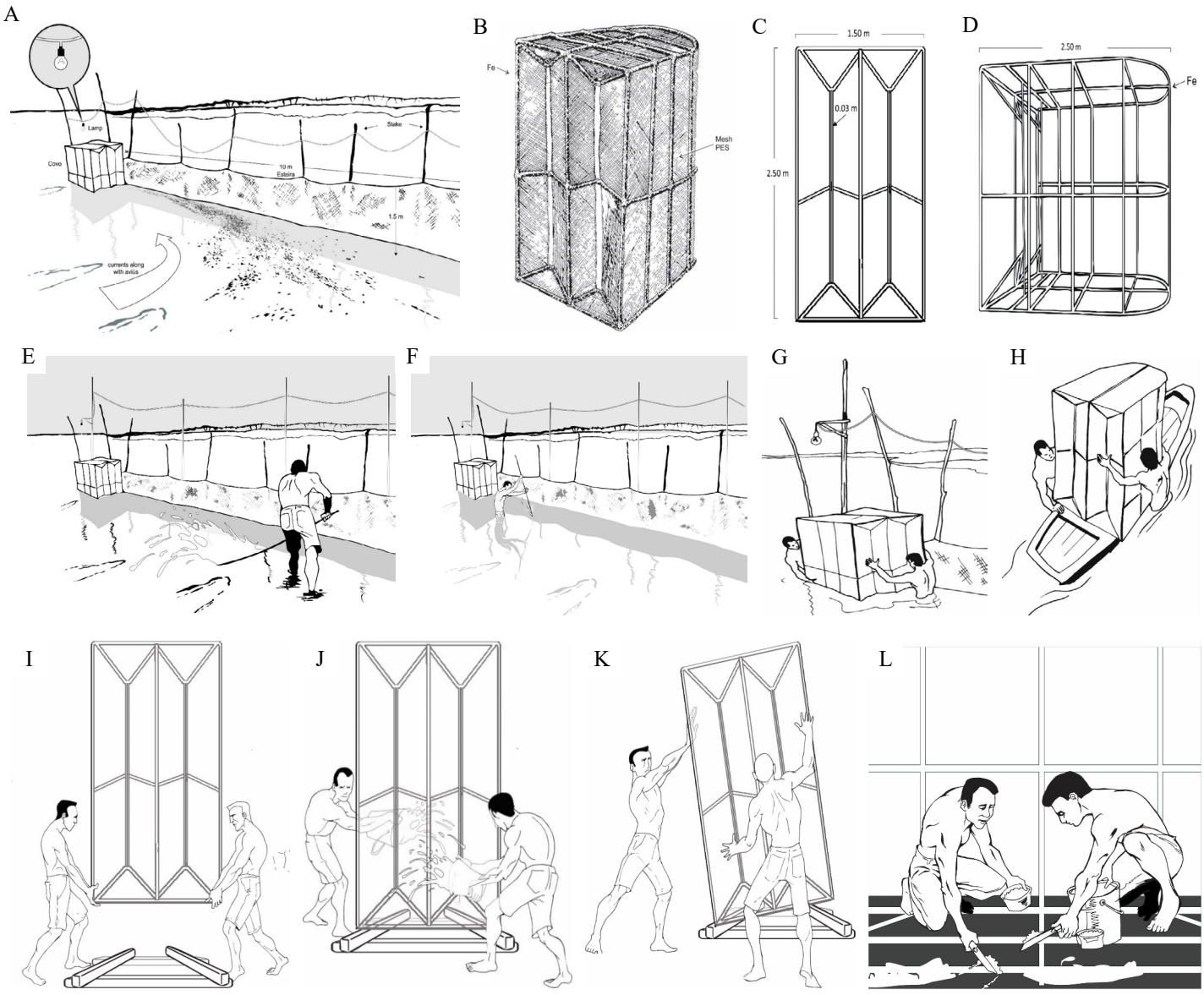

Figure 7. Type of equipment used to harvest *A. paraguayensis* in the study area in the region of Santarém, northern Brazil: (A) shrimp trap (matapi) with luminous attractor; (B) matapi with netting; (C and D) matapi frame. Diagrams showing the operation of the matapi, the technique most used in the study area (E-L). PES: polyester; WD: wood; Fe: iron; PA: polyamide; MONO: monofilament; SYN: synthetic fiber. Illustration of Edson R. Miranda.

captured (Figure 7A).In Santarém, the matapis were installed at depths of 1.50–1.85 m. During the dry season months (June through November), when the river level is low, some of the traps are removed from the river, due to the formation of sandbanks and beaches, which attract seasonal visitors and tourists. The shrimpers report that these visitors often damage their matapis. During this period, the traps are repaired. At the beginning of January, the traps were installed once again in the Tapajós River, when the rains caused the level of the water to rise. In general, the operation of the traps involves at least two, and up to four or five individuals. To install the traps, the shrimpers leave their home port in the early hours of the morning (04:00–05:00 h), and travel 15–30 min, to the nearest shrimping stations, or as much as 2 or 3 h, to the more distant sites.

The matapis remain in the water for at least 24 h and, at most, 48 h, to minimize damage or the chance of being stolen. To remove the catch, the shrimpers place either four logs (obtained from the local forest) in a square (one side parallel to the margin) or three logs perpendicular to the margin (Figure 7I). In some cases, a wooden pallet, known as a "jirau," is used. When they enter the water, the most experienced shrimpers hit the surface loudly with an oar or a pole (Figure 7E), and as they walk through the water toward the trap, they sweep the river bottom ahead of them with this oar/pole (Figure 7F) to scare off any stingrays that

may be present. The matapi is then untied, removed (Figure 7G), and either placed on the boat, when there is no available beach, or on a "jirau" (see above) made of logs, on dry land (Figure 7H, I). When the netting is matted thickly with debris (organic or inorganic), the shrimpers use plastic buckets to throw water onto the trap to help clean off the dirtiest parts, sometimes using brushes to scrub the netting, while tipping the trap over slightly. The trap is invariably tipped in the opposite direction from the access hatch, to concentrate the catch of shrimp (Figure 7J-L).

A knife is then used to cut the line that holds the hatch closed, and the catch is retrieved by one of the shrimpers, who climbs inside the trap (Figure 7L), while the others illuminate the trap with flashlights, when the operation takes place pre-dawn. The shrimper inside the trap stands or crouches on the iron frame or on wooden boards placed on top of the frame and uses the blunt side of the knife to scrape the shrimp into heaps, while also retrieving other animals (fish or prawn) manually (Figure 7L). The *A. paraguayensis* catch is gathered and stored in plastic buckets or disused food containers, with a capacity of 13.00–16.00 kg. The catch is then transported either directly to a fish market for the sale of the fresh produce or to the shrimpers' homes for processing (cooking and salting). During the aviú season, the fresh shrimp is sold in Santarém for approximately R$ 15.00 kg^{-1}, while the dry or salted product is marketed at R$ 20.00–25.00 kg^{-1}. Processed shrimp may reach a much higher price during the off-season, as determined by the economic laws of supply and demand.

The matapi may often generate a considerable quantity of bycatch, mostly fish of small size. The commercial species in the bycatch include the *tucunarés* (*Cichla monoculus* Spix & Agassiz, 1831; *Cichla temensis* Humboldt, 1821), aracus (*Schizodon fasciatus* Spix & Agassiz, 1829; *Leporinus fasciatus* Bloch, 1794), and sardines (*Triportheus albus* Cope 1872; *Triportheus angulatus* Spix & Agassiz, 1829). Other species are included like water snakes (*Helicops infrataeniatus* Jan, 1865); a number of other fish, including acarís (*Hypostomus emarginatus* Valenciennes, 1840; *Liposarcus pardalis* Castelnau, 1855), acarás-disco (*Symphysodon aequifasciatus* Pellegrin, 1904), acarás (*Acarichthys heckelii* Muller & Troschel, 1848; *Geophagus proximus* Castelnau, 1855), and the much-feared stingrays (*Potamotrygon constellata* Vaillant, 1880; *Potamotrygon* aff. *hystrix* Muller & Henie, 1841; *Potamotrygon*

Table 1. Measurements of the matapi shrimp traps and weir-type fences used to harvest *A. paraguayensis* recorded in the region of Santarém, in northern Brazil.

Trap				Fence	
Length	Width	Height	Entrance	Length	Height
(m)				(m)	
2.50	1.50	2.50	0.03	20.00	3.00
2.00	1.70	1.60	0.02	7.00	1.50
1.00	1.40	1.20	0.02	3.00	2.00
2.50	3.00	2.00	0.03	10.00	2.50
1.50	2.00	2.00	0.02	10.00	2.50
2.00	1.00	2.00	0.03	5.00	2.00
2.00	1.50	2.00	0.03	8.00	2.00
2.50	1.20	1.75	0.03	4.00	1.00
2.00	1.50	1.30	0.02	4.00	1.00

Table 2. The different types of equipment used to harvest *A. paraguayensis* in the region of Santarém, northern Brazil, details of their use, and production costs.

Characteristic	Type of equipment					
	Cloth drag-net	Polyester mesh drag-net	Dip-net (Aveiro type)	Boat-drawn dip-net	Dip-net (Santarém type)	Matapi
Type of method	Active	Active	Active	Active	Active	Passive
Local denomination	Drag-net; "Panada"; "Lanço"	Drag-net; "Panada"; "Lanço"	Dip-net; "Puxada"	Dip-net	Dip-net; "Puxada"	Harvest
Operational depth (m)	±1.50	±1.50*	±1.00	±1.50	±1.50	1.50–1.85
Number of operators	2	2	1	1	2	2–4
Number of operations per day	5±6	6±10	10±20	4±5	10±20	1
Duration of operation (h or min)	10–15 min	3–4 min	10–15 min	10–20 min	2 h	24–48 h
Distance moved during use (m)	4.0±5.0	±20.0	0	±10.0–15.0	±10.0	0
Cost to make (U$)**	7.86	23.62	28.19	30.19	40.91	345.61

*Up to chest height; **United States dollar exchange rate used to calculate the fishery costs (1 US$=R$ 3.12).

motoro Muller & Henie, 1841; *Potamotrygon scobina* Garman, 1913); and many other less important species. Details of the different types of shrimping equipment used in the Santarém region are presented in Table 2.

DISCUSSION

Shrimps of the genus *Acetes* are typically harvested in calm waters, such as muddy intertidal zones or shallows, no more than 5.00 m deep (Omori, 1975, 1978). *Acetes* fisheries are found primarily in Asia and, to a lesser extent, in Africa and South America (Omori, 1975; Xiao and Greenwood, 1993). Many species such as *Acetes chinensis* Hansen, 1919, *Acetes serrulatus* Kroyer 1859, *Acetes erythraeus* Nobili, 1905, *Acetes japonicus* Kishinouye, 1905, *Acetes indicus* H. Milne Edwards, 1830, *Acetes vulgaris* Hansen, 1919, and *Acetes sibogae* Hansen, 1919 are exploited commercially (either individually or in combination) in India, Thailand, Malaysia, Singapore, Indonesia, the Philippines, China, Japan, and Taiwan (Holthuis, 1980; Li et al., 1986; Zhang, 1986; Otto et al., 2001). These fisheries men use many different techniques, particularly trawling (hand drag-nets on beaches or trawls in the open sea) and other types of the net, such as purse seines and weirs (Wei et al., 1985; Khan, 1987; Jiddawi and Ohman, 2002). Trawlers may catch these shrimps up to 5.0 nautical miles off the coast (Noh and Yew, 1995; Ogawa, 2004), and a majority of the catches of these fisheries are landed in Malaysia (DOF, 2012).

In general, *Acetes* fisheries men use active methods (Hayes et al., 1996), as observed in the present study area, in Santarém and Aveiro, where most (83%) of the operations are based on active techniques, that is, the shrimp are harvested using mobile equipment, rather than traps. The study area appears to be the only location in the world where a passive strategy, i.e., shrimp traps (matapis), is used (Lagler, 1978). These traps are typically installed at a depth of 1.50–1.85 m, require a more significant number of shrimpers (2–4 persons), operate over a much longer time scale (24–48 h), and cost approximately US$ 345.61 to make, a considerably greater investment than the other types of shrimp fishermen equipment (Table 2). Small volumes of *Acetes* shrimp are harvested for sale and consumption by fishers in Myanmar, Vietnam, Sri Lanka, Bangladesh (Omori, 1975), Africa (Jiddawi and Ohman, 2002), Malaysia (Amin et al., 2010; Amani et al., 2011; Arshad et al., 2012), and South America (Holthuis, 1959,1980). In Santarem, these shrimps are harvested primarily for subsistence, with the excess catch being sold. Fishery data on the catches of the marine *Acetes* species are available only for *A. japonicus*, with a total catch of 580,147 tons being recorded between 2003 and 2012, 585,433 tons in 2013, and 556,316 tons in 2014. The reduction of 29,117 tons between 2013 and 2014 (FAO, 2016) indicates an important increase in the fishery pressure on the remaining stocks of the species.

In Brazil, data on the population dynamics of *Acetes* shrimp are available only for *A. americanus* (Simões et al., 2013; Santos et al., 2015). In contrast with other regions of the world, no industrial fishery targets this resource specifically. In the Amazonian state of Pará, *A. paraguayensis* is targeted by artisanal shrimpers, primarily for subsistence, but as an important complement of the income of the region's traditional riverside communities. In general, the *Acetes* shrimping season coincides with aggregation (Omori, 1975; Sehara and Kharbari, 1987). There is some evidence that these aggregations may be related to pre-spawning activities, such as mating and the production of eggs (Achuthankutty et al., 1973; Omori, 1974). These shrimp may also aggregate in river estuaries, which may be related to shifts in light intensity, temperature, wind direction, and variation in maturation and predation rates (Omori, 1975, 1978). In the specific case of *A. paraguayensis*, catches increase during aggregation, which coincides with the rainy season in the Amazon region (December through May), with a peak in production between March and May. This peak in production contrasts with the pattern observed in *M. amazonicum*, a second important shrimp resource in the Amazon region, harvested primarily during the dry season (June through November), resulting in a complementary harvesting pattern between these two shrimp species.

A. paraguayensis is strongly seasonal and migratory, and its abundance in the study area (Santarém and Aveiro) decreases drastically in July and August. It becomes utterly absent from the area between September and November, only beginning to return in December, when can observe small troupes sporadically. These aggregations are highly seasonal in many areas (Omori, 1978), with their location, timing, and density varying considerably over the years. Given this, shrimping is restricted to a few months of the year. This variation results in considerable fluctuations in catches, limiting the commercial viability of the *A. paraguayensis* fisheries, despite their small scale. During this study, field observations showed that the shrimp invariably became entangled in their long antennae and encased in a large quantity of mucous when caught in all the different types of equipment. Furthermore, the large quantities of small fish found in the matapis indicate that these shrimps are an important prey species (Catacutan et al., 2003; Branco, 2005; Jaiswar and Chakraborty, 2005). Further research is needed to determine the proportion of bycatch captured and discarded, on average, in the study region and the potential impacts of the different types of shrimping operations on the local populations of aquatic organisms. These data will be necessary for developing effective conservation and management strategies not only for *A. paraguayensis*, but also for the different bycatch species impacted by the region's artisanal shrimping operations.

CONCLUSION

A. paraguayensis fishing in the Tapajós River is a traditional activity based almost always on empirical knowledge of the fishermen. The largest catches of this species were recorded during the rainy season months, when these shrimp form large aggregations, with catches

peaking in March, followed by April, and then May. During the harvest season (rainy months), the shrimpers work at nightfall and dawn. With the exception of the matapi, all the methods used to harvest *A. paraguayensis* are active, although the matapi appears to be the most effective, principally when used with luminous lures. Even so, trapping also causes the greatest environmental damage, given the large bycatch, largely made up of small, commercially valuable fish. While the seasonal fluctuations in the abundance of *A. paraguayensis* are problematic for the shrimpers, they may play an important role in the regulation and maintenance of stocks, given that they restrict harvesting to only some months of the year, which may help to limit overexploitation of the stocks. Even so, most of the experienced shrimpers interviewed in the region (unpublished data) are aware of a progressive reduction in the catches of *A. paraguayensis*, resulting from overfishing. This process is probably related to the high rates of unemployment in the study region, and the lack of professional qualifications of most residents, which makes the harvesting of *A. paraguayensis* an attractive alternative as a source of subsistence or income, leading to the progressive recruitment of "new" *A. paraguayensis* shrimpers in the region.

This process, together with factors such as the lack of public sanitation, the deforestation of riparian habitats, the pollution of the Tapajós River, and the discharge of the ballast of the oceangoing vessels that navigate the region's waterways, raises causes for concern with regard to the long-term sustainability of *A. paraguayensis* stocks, especially considering the lack of official fishery statistics and the paucity of data on the biology of the species. Any decline in *A. paraguayensis* stocks will have serious implications, not only for the local artisanal fishing communities but also for the aquatic trophic networks on which they depend, given the importance of these shrimp as prey for the fish species exploited for subsistence and local markets. Overall, then, the more efficient exploitation of this fishery resource will depend on reliable data on the life cycle of *A. paraguayensis*, its reproductive biology, and its fishery potential in the study region. The findings of this study, combined with those of future research projects, should contribute to a better understanding of the consequences of the exploitation of *A. paraguayensis* and the development of effective regulatory mechanisms to guarantee the long-term sustainability of its stocks.

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CONFLICTS OF INTEREST

Nothing to declare.

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AUTHORS' CONTRIBUTIONS

Tenório, G.: conceptualization, data curation, formal analysis, investigation, methodology, project administration, resources, software, supervision, validation, visualization, writing the original draft. Cintra, I.H.A.: conceptualization, supervision, writing the original draft. Alves, P.J.O.: methodology. Costa, R.M.C.: methodology, supervision. Medeiros, T.N.: writing original draft, review and editing. Bentes, B.: conceptualization, data curation, formal analysis, investigation, methodology, software, supervision, validation, visualization, writing the original draft, review and editing.

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