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Research Article

Density and population parameters of sea cucumber *Isostichopus badionotus* (Echinodermata: Stichopodidae) at Sisal, Yucatan

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ABSTRACT. The density and population parameters of the sea cucumber *Isostichopus badionotus* from Sisal, Yucatan, Mexico were determined during the fishing season. Belt transects of 200 m^2 were set in 10 sampling sites at two fishing areas. All organisms within the belt were counted and collected. In the harbor, 7,618 sea cucumbers were measured and weighed: the population parameters were determined using FISAT II. Mean densities of *I. badionotus* in April 2011, September 2011 and February 2012 were 0.84 ± 0.40, 0.51 ± 0.46, and 0.32 ± 0.17 ind m^{-2}, respectively. Sea cucumber total length varied from 90 to 420 mm, with a uni-modal distribution. The growth parameters were: L_∞ = 403 mm, K = 0.25, and t_o = -0.18, with an allometric growth (W = $2.81L^{1.781}$). The total mortality was 0.88, whereas natural mortality was 0.38, fish mortality was 0.50 and the exploitation rate 0.54. Even when sea cucumbers fishery in Sisal is recent and in development with a high density (5570 ind ha^{-1}), it is necessary to establish management strategies to protect the resource, such as an annual catch quota, catching size (>280 mm length), monitoring of population density, and reproduction and larval distribution.

Keywords: *Isostichopus badionotus*, Echinodermata, fisheries, population dynamic, catch, Gulf of Mexico.

INTRODUCTION

Sea cucumber represents an important fishery resource around the world since they have provided food and economic resources to small-scale fisherman for centuries (Conand, 1997). In many regions, they have been widely exploited for traditional food and medicinal purposes, which has led to a rapid decline of their natural populations, mainly in the Indo-Pacific, the traditional fishing grounds. This fact has led to the implementation of new fishing areas, where sea cucumbers are not consumed nor fished traditionally, such as the Galapagos Islands in Ecuador, Baja California in the Mexican Pacific and recently Yucatan in the Gulf of Mexico (Bruckner *et al.*, 2003; Bruckner, 2006; Conand, 2017).

In Mexico, the sea cucumber catch began in 1980, in shallow waters of the Baja California coast, and the fishery was focused on the species *Isostichopus fuscus* (Reyes-Bonilla & Herrero-Pérezrul, 2003). This species has received some research attention (Fajardo-León & Vélez-Barajas, 1996; Herrero-Pérezrul *et al.*, 1999; Reyes-Bonilla & Herrero-Pérezrul, 2003), although in just a few years the resource showed a drastic decline in abundance, with no evidence of recovery, and the fishery has been permanently closed for eight years (Reyes-Bonilla & Herrero-Pérezrul, 2003).

In Yucatan State, the sea cucumber is caught since 2006, with the purpose of offering an alternative to fishermen during the ban of other resources (octopus, lobster, and fishes) and to optimize the seafood processing facilities in Sisal Harbor. In 2011, the Mexican government authorized permits to cooperative fishermen to catch sea cucumber for three months (February, April and May), although this fishing period has varied every year (DOF, 2011; Poot-Salazar *et al.*, 2015; Hernández-Flores *et al.*, 2015). Approximately 1,080 ton was legally caught in 2011, although there are some reports of the same amount of illegal catch increasing in the area (Diario de Yucatán, 2011). In fact, there is not enough information about the density, biology, and ecology of the species fished to allow the design of management plans for a sustainable exploita-

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tion. Research on sea cucumbers is scarce for the Yucatan Peninsula; Fuente-Betancourt *et al.* (2001) evaluated the potential fishery in the Mexican Caribbean. In the Gulf of Mexico, Zetina-Moguel *et al.* (2003) mentioned three species as the most important by their size and abundance to the fishery. These species were distributed along the Yucatan coast in waters 20-30 m deep, apparently with a geographic segregation: *Astichopus multifidus*, more abundant in the Campeche coast, *Isostichopus badionotus*, and *Holothuria floridana* more abundant at Yucatan coast. In 2007, Rodríguez-Gil (2007) described the potential of the fishery and mentioned the same species distributed along the Yucatan coast, whereas López-Rocha (2011) evaluated the weight-length relationship and assessed population density in Sisal, recently, other studies have been realized in Yucatan coast (Hernández-Flores *et al.*, 2015; Poot-Salazar *et al.*, 2015). There are no other specific reports about biomass evaluation or population dynamics that offer information for a sustainable use of the resource. Therefore, the aims of this study were: 1) to determine sea cucumber density in the fishing area, and 2) to offer information related to the population parameters in order to understand the species biology.

MATERIALS AND METHODS

Study area

Sisal is located on the north-east coast of the Yucatan State, in the Gulf of Mexico. The fishing area is located up to 25 km off the coastline at 10-30 m deep (21°00'-21°30'N, 90°00'-90°30'W), data were collected in 10 samplings sites: S1 to S10 (Fig. 1). The sea floor is mainly covered with *Thalassia testudinum*, *Syringodium filiforme*, and macroalgae. Climate is warm and arid with rains in summer and a high percentage of rain in winter, BS_o (h´) w (x´) according with Köppen climatic classification; the mean water temperature is 29°C, and the area is dominated by the Lazo Current (Delgado-Carranza *et al.*, 2011).

Sea cucumber identification

Sea cucumber taxonomy was based on the presence of calcareous forms, such as the shapes and combination of microscopic spicules that are part of skeletal components in the body wall (Hickman, 1998). These spicules have different shapes, such as towers, rosettes, C-shaped, rods, buttons, and plates, and they are species specific. For *I. badionotus* the calcareous spicules are typically towered with 12 or 14 terminal spines, C-shaped structures bigger than basal disk in towers, and big rods, a complete key is described by Caycedo (1978).

Thirty sea cucumber specimens (different sizes and color) were collected from the field at the fishing areas. A slice 1 $cm^2 \times 1$ mm thick was dissected from the dorsal epidermis of each individual. In the laboratory, each sample was placed in a small test tube with 3 mL of commercial bleach. Samples were left for approximately 60 min or until the body wall had dissolved and the ossicles settled to the bottom, resembling fine white sediment. Using a pipette, the precipitated spicules were transferred to a microscope slide, covered with a coverslip and the spicules morphology was examined with a microscope at 40x and 100x magnification (Hickman, 1998). For the determination of species, we used the identification keys of Caycedo (1978), Pawson & Pawson (2008) and De Entrambasaguas (2008).

Density

To estimate sea cucumber density, data were collected by fisherman and by us. In each site (10) were set belt transects 50 m long and 4 m wide (Fig. 1) during the official fishing season (April-May 2011 and February-March 2012). All organisms observed within transects were collected using hookah diving (10 to 25 m depth), placed in mesh bags, transported to the boat, and put in a cooler with ice and seawater, this method is used by all fishermen to preserve the product, thus producing a relaxation in the organisms. In September 2011, out of the fishing season, eight transects were installed in the same area, and sea cucumbers were counted, but not collected.

Sea cucumbers were measured for total length (L_t) using a flexible plastic tape, 1 mm precision; along the dorsal profile of the body. The total and eviscerated weight of each sea cucumber was registered with an electronic balance at 0.5 g precision. The weight-length relationship $W_t = a\ L_t^b$ (Cone, 1989) was obtained by using data from May 2011 and February 2012.

Length-frequency data analysis

With the data of May 2011, February and March 2012 and the size-frequency data, grouped in 1 cm modal composition intervals, were calculated the parameters of the von Bertalanffy growth model (Ricker, 1975) using the computer software FiSAT II (Gayanilo *et al.*, 1996). The following routines were used: Powell-Wetherall (to estimate L_∞), Shepherd (to estimate K, individual growth coefficient), and Pauly's (1984) empirical equation (to obtain t_0, the theoretical age at zero length) and the length-weight relationship was calculated. Total mortality (Z) was calculated by the catch curve, natural mortality was obtained according to Pauly´s equation; whereas exploitation rate was calculated with E = F/Z, and considering that E_{optims} occurs when F = M (Gayanilo *et al.*, 1996).

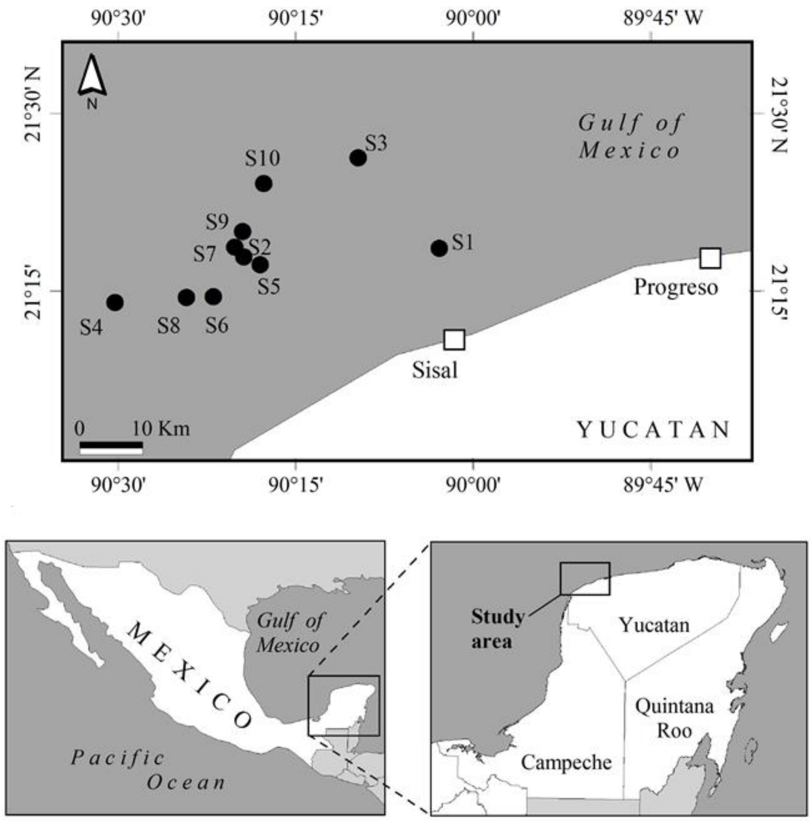

Figure 1. Study area and sampling points at Sisal, Yucatan.

RESULTS

The shape and composition of the spicules embedded in the body wall are frequently used as taxonomic characters. In the case of *I. badionotus* in Sisal, the spicules remained intact, with little fractioning (especially of the plates), and the proportion of different types of spicules were constant in the different samples. According to the morphometric analysis of the calcareous ossicles, and based in the presence higher percentage of towers and plates with dishes with homogeneous size hole, and specific structures like C-Shaped spicules in less proportion and rods present exclusively in this species, as mentioned in the taxonomic key by Caycedo (1978), we found that 99% of the catch corresponded to *I. badionotus* (Fig. 2).

Mean density in April 2011 was 0.84 ± 0.40 ind m^{-2}, with a maximum at S4 of 1.43 ind m^{-2}. Density showed a downward trend in the following sampling months: in September mean density was 0.51 ± 0.46 ind m^{-2}, whereas in February 2012 was 0.32 ± 0.17 ind m^{-2}, considering the global mean density for all months we obtained 0.5570 ± 0.345 ind m^{-2} (Table 1).

A total of 7,618 sea cucumbers were measured in the harbor, during the fishing seasons, 2,615 corresponded to May 2011, 970 to February 2012 and 4,033 to March 2012. The data collected in April 2011 (2,732) were used only for density calculations and size analysis, however, they were not including in the population parameters analysis.

Sea cucumber's length varied from 90 to 420 mm. In April 2011 the mean size was 226.10 ± 4.31 mm, and in May 2011 the median size was 228.50 ± 4.07 mm (Figs. 3a-3b). During 2012, we registered a median size of 236.10 ± 2.79 mm in February, whereas in March was 249.40 ± 3.65 mm (Figs. 4a-4b). In all cases, the distribution of frequencies was unimodal.

With the length frequency data, we determined the von Bertalanffy equation to be $L_t = 403\ (1-e^{-(0.25\ (t-0.18))})$. The total mortality rate was 0.88, with a natural mortality of 0.38. In consequence, the fish mortality was 0.50 and the exploitation rate 0.54.

The values of the coefficients of the weight-length equation were: a = 2.811 and the exponent b = 1.741. The correlation coefficient was R^2 = 0.72 (Fig. 5). A Student's t-test was applied confirming that the growth was allometric ($P < 0.05$).

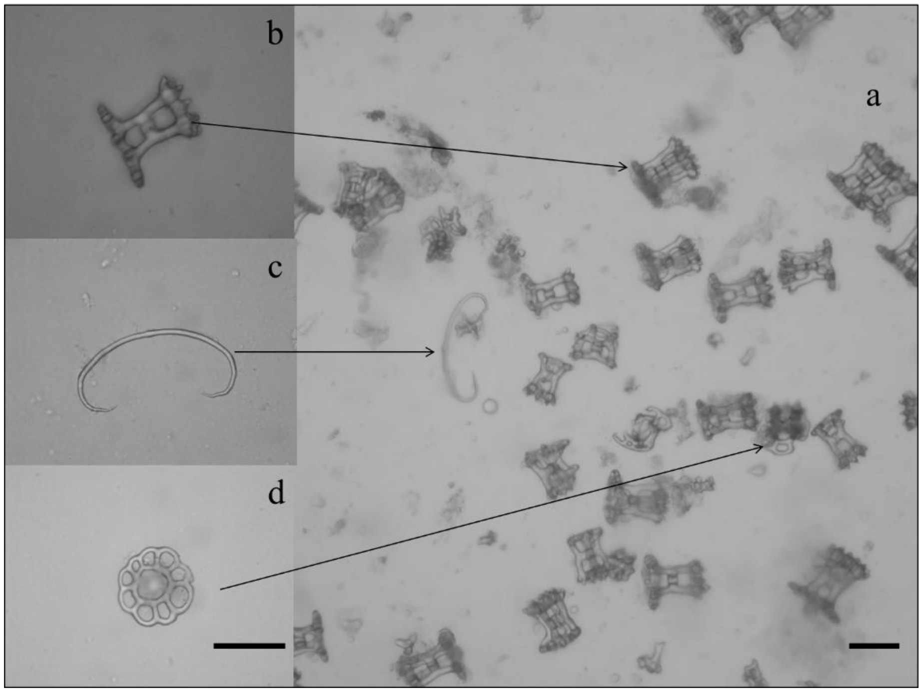

Figure. 2. a) General image of calcareous spicules specific to *I. badionotus* (Bar = 30 µm), b) towers, c) C-shaped spicules, and d) disk (Bar = 30 µm).

Table 1. Sea cucumber (*I. badionotus)* density in transects at fishing areas at Sisal Yucatan, Mexico.

Transect	Sampled area (m^2)			Nº individuals			Density (ind m^{-2})			Global mean
	Apr	Sep	Feb	Apr	Sep	Feb	Apr	Sep	Feb	
1	200	200	200	24	294	45	0.12	1.47	0.23	
2	200	200	200	173	188	62	0.86	0.94	0.31	
3	200	200	200	220	55	13	1.1	0.28	0.07	
4	200	200	200	286	99	135	1.43	0.5	0.67	
5	200	200	200	72	36	51	0.36	0.18	0.26	
6	200	200	200	187	56	53	0.93	0.28	0.27	
7	200	200	200	230	29	64	1.15	0.15	0.32	
8	200	200	200	148	65	24	0.74	0.33	0.12	
9	200		200	176		81	0.88		0.41	
10			200			42			0.21	
Total sea cucumbers	1800	1600	2200	1516	822	706				
Mean density							0.84	0.51	0.32	0.557
Standard deviation							0.40	0.46	0.17	0.345

DISCUSSION

In the Yucatan Peninsula, three commercial species of sea cucumbers have been reported: *A. multifidus, I. badionotus,* and *H. floridana* (Zetina-Moguel *et al.*, 2003), the same species composition was reported by Rodríguez-Gil (2007) in the area of Progresso. Apparently, there is a specific distribution of sea cucumbers in the Yucatan Peninsula: *H. floridana* and *A. multifidus* are most abundant in the Campeche coast, whereas *I. badionotus* is more abundant in the Yucatan coast, with a minor abundance of *H. floridana* (Ramos, *pers. comm.*). In this study we found that 99% of the catch corresponded to *I. badionotus,* confirming that *I. badionotus* is the most abundant species in Yucatan coast.

The mean global density, considering both sampling periods, was 5570 ind ha^{-1}, a similar value to other countries. In Cuba, a density of 8,800 ind ha^{-1} has been reported in an established fishery (Alfonso *et al.*, 2000; Toral-Granda *et al.,* 2008). In the Yucatan coast, López-Rocha (2011) found a median density 217 ind

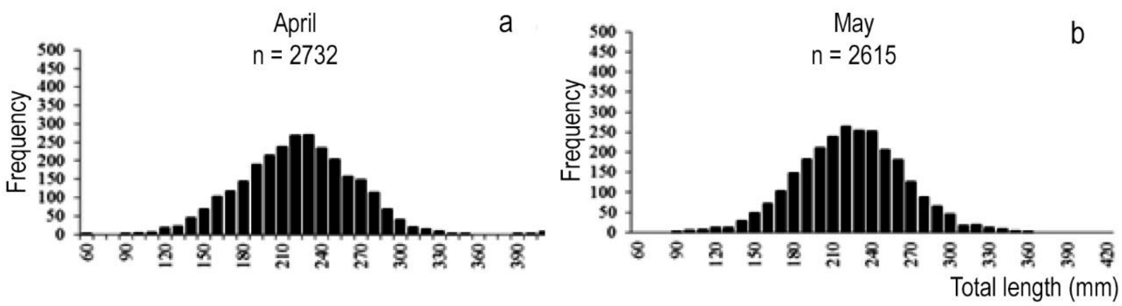

Figure 3. Length-frequency distribution of sea cucumbers at Sisal Yucatan, samples collected in a) April, and b) May 2011.

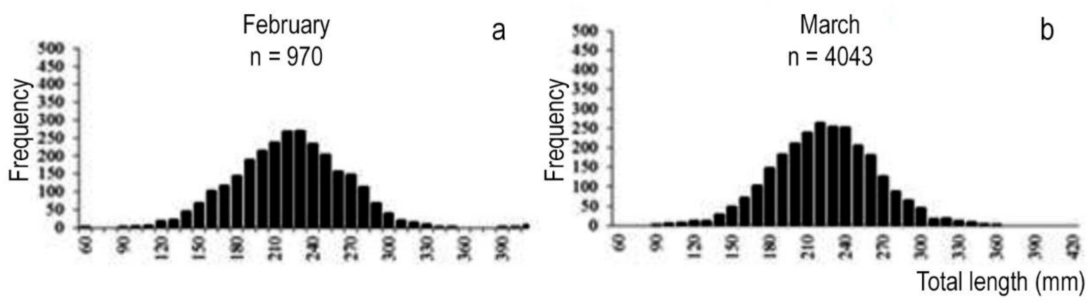

Figure 4. Length-frequency distribution of sea cucumbers at Sisal Yucatan, samples collected in a) February 2012, and b) March 2012.

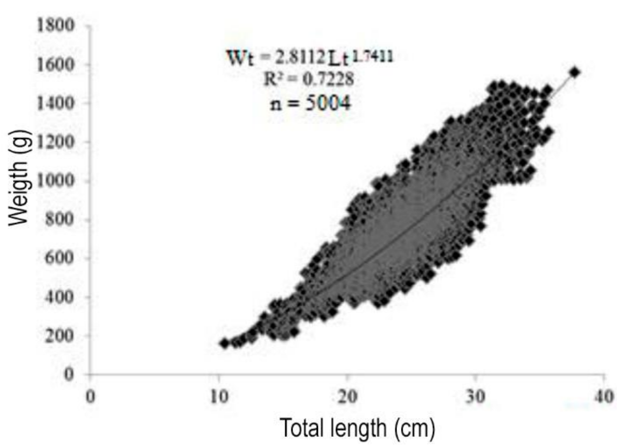

Figure 5. Weight-length relationship of the sea cucumber *I. badionotus* at Sisal, Yucatan, Mexico.

ha^{-1} for *I. badionotus* in Sisal, whereas Rodríguez-Gil (2007) found a density varying between, 267 to 437 ind ha^{-1} in Progreso, Yucatan. Density evaluations carried out in 2000-2001 at the central and east coast of Yucatan were significantly lower and varied from 5 to 25 ind ha^{-1} (Rodríguez-Gil, 2007). A density of 0.072 ind m^{-2} was reported by Poot-Salazar *et al.* (2015) in fishing areas near to Progreso Yucatan and a similar value was informed by Hernández-Flores *et al.* (2015). There are no more data for this fishing area; however, it is evident that the differences in density may be due to different sampling methods, or heterogeneous and patchy distribution of sea cucumber, which may lead to underestimating densities (López-Rocha, 2011). In Panama, population surveys showed that *H. mexicana* was the most abundant species (161.8 ind ha^{-1}), followed by *I. badionotus* (117.4 ind ha^{-1}) (Guzmán & Guevara, 2002). In Baja California, Mexico, Reyes-Bonilla *et al.* (2008) found a density of 1000 ind ha^{-1} for *I. fuscus* in Cabo Loreto National Marine Park, whereas in Galapagos Island, a density 230 ind ha^{-1} was shown by Toral-Granda & Martínez (2004), in both sites there is an intense fishing of sea cucumber.

The size structure was unimodal, with a median size of 220 mm and a range from 95 to 420 mm, with a high abundance of adults; this pattern is shared with other data collected in the Caribbean. In Panama, Guzmán & Guevara (2002) also found a unimodal distribution, with a median size of 250 mm. The unimodal population structures of *I. badionotus* may indicate a constant recruitment to the populations (Avalos-Castillo *et al.*, 2017). López-Rocha (2011) found in Sisal, Yucatan, that length varied from 140 to 300 mm with a mean length of 220 mm, whereas Poot-Salazar *et al.* (2015) informed of a medium size of 230 mm to *I. badionotus* at Sisal and considering the resource overexploited. Reports from fisheries in Venezuela indicate sizes between 110-320 mm for *I. badionotus* (Buitrago & Boada, 1996; Rodríguez-Milliet & Pauls, 1998). The latter reports suggest that the fishery was based on individuals somewhat below the minimum reproductive age, estimated at 180 mm for *I. badionotus* (Buitrago & Boada, 1996; Rodríguez-Milliet & Pauls, 1998). Considering the size structure in Venezuela, similar lengths were obtained for *I. badionotus* (200-300 mm) (Rodríguez-Milliet & Pauls, 1998). There are no reports on growth parameters of *I. badionotus* in the Gulf of Mexico, but it is clear that the species has a low growth rate, with adult lengths varying from 350 to 500 mm. Herrero-Pérezrul *et al.* (1999) found a growth equation for *I. fuscus* with similar growth parameters (b = 1.83; a = 1.142) as *I. badionotus* in the Gulf of Mexico.

Most sea cucumbers grow allometrically (Bulteel *et al.*, 1999). Probably because small individuals are relatively flatter than adults, suggesting that the change in shape and inner volume may be necessary to allow gonad growth (Toral-Granda *et al.*, 2008). In Yucatan, López-Rocha (2011) also reported an allometric growth, with $b = 1.045$ and $a = 27.44$ ($R^2 = 0.3685$), whereas Herrero-Pérezrul & Reyes-Bonilla (2008) as well found an allometric growth in the case of *I. fuscus* in Espiritu Santo, Baja California.

In general, it is accepted that the invertebrate fisheries are developed with species without previous biological or density information and this is true for sea cucumbers (Lovateli *et al.*, 2004; Anderson *et al.*, 2011). It is very important to generate fishery and biological information, in order to establish the first management measures for the resource exploitation. The high demand and economic value of some sea cucumber species have led to its exploitation in sites where they are not regionally consumed. The lack of information and management strategies may cause overexploitation. Sea cucumbers are susceptible to overexploitation due to many factors: low mobility, distribution in shallow waters, late maturity, density-dependent reproduction, and low recruitment (Conand 1983, 2005).

It has been accepted that sea cucumbers fisheries worldwide are generally poorly managed and many of them are in decline (Perry *et al.*, 1999; Toral-Granda *et al.*, 2008; Anderson *et al.*, 2011). Little is known for all sea cucumber species in the Gulf of Mexico, with sparse information on the few species that may be of commercial interest. The ecology and larval distribution of *I. badionotus* are unknown, as with many species of sea cucumber (Conand, 1983). Density and size distribution are parameters that define the state of the fishery in any moment, a density higher than 0.45 ind ha^{-1} may permit the ecological and biological cycles in sea cucumber populations (Toral-Granda & Martínez, 2004). At Sisal there seems to exist a high sea cucumber density, and the population is composed of adults. However, it is necessary to design management strategies to protect the resource of overexploitation such as: establish an annual catch quota, catching size (>280 mm total length), implement a surveying program of the population density, and initiate studies on reproduction and larvae distribution research.

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