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research paper

Conservation strategy for the sea cucumber (*Isostichopus badionotus*) fishery in Cuba

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ABSTRACT.—The biological characteristics of the sea cucumber, *Isostichopus badionotus* (Selenka, 1867), which include slow movement, late sexual maturity, density-dependent reproduction, and a low recruitment rate, make it vulnerable to overexploitation. Since 1999, Cuba has been harvesting this species, and maintaining this activity at a profitable level. Of the six fishing zones in which the species is caught, the yield in the southern Camagüey zone in the southeast region produces the greatest biomass. Fisheries-dependent and -independent indices were combined to evaluate status and develop strategies for fisheries management off the southern coast of Camagüey. This entailed establishing quantitative benchmarks using catch and effort data from the Santa Cruz del Sur enterprise for the period 2003–2014. There was a reduction in sea cucumber biomass and abundance during this period, and catch rates have been above maximum sustainable yield for the last 3 yrs. We propose that the quotas based on 15%–25% of the fishing potential be reduced to 10%. We recommend applying quotas only in those places where the densities are higher than 0.45 cucumbers per 100 m^2 and closing fisheries where the density is lower. The application of the dynamic surplus production model, together with independent indicators of the fishery, are useful tools for management of the species and should be applied to the sea cucumber fisheries around the island.

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The sea cucumber, *Isostichopus badionotus* (Selenka, 1867), is an important fisheries resource for Cuba's export economy. Cuba is the third largest exporter of sea cucumbers in Latin America, after Peru and Ecuador (Espinosa et al. 2012). The Cuban fishery of this species began when a Korean company became associated with Caribbean Sunfish N.V. and Neneka C.A. (Alfonso et al. 2000). These two seafood companies signed a joint venture service contract with the Cuban Fisheries Research Center to investigate the island's potential. In their study, the research center obtained a preliminary estimate of the catch potential and species of commercial interest. The results allowed the partners to carry out an economic feasibility study for the exploitation and procurement of dried sea cucumber. The Korean party then

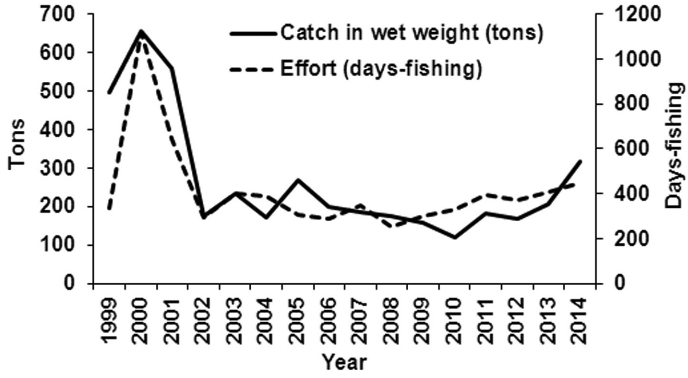

Figure 1. Commercial catch and effort data from the Cuban sea cucumber *Isostichopus badionotus* fishery from 1999 to 2014.

provided the knowledge, techniques, and infrastructure for the exploitation, production, and commercialization of sea cucumbers in Cuba, and the commercial capture of *I. badionotus* began in August 1999. During the first year, extractions were made only in the fishing zone of the Granma Province in the southeastern region (Alfonso 2006). In 2001, studies were carried out to expand catches to other fishing areas in the southeast and in the province of Holguín in the northeastern region. In the following years, new exploration of this resource was carried out in other regions of the Cuba, which allowed sea cucumber harvests to occur in six provinces.

During the first 3 yrs, an average per year of 570 t of wet weight was captured at the national level; and in the period of 1999–2005, approximately 350–1153 (range of annual averages) sea cucumbers per day were captured per vessel (MIP 2008, GEIA 2014) (Fig. 1). The highest catch in biomass was reached in 2000, after the expansion of the fishery in the waters of the southeast region and new harvests in the bays north of Holguín (Alfonso 2006). The average daily catch since 2002 decreased to 193 t because of reduced fishing effort, mainly as a result of shortages of fuel and oil, together with technical failures, such as boat breakdowns. In addition, a catch ban was implemented in Holguín during 2002 and 2003 following a drastic decrease in the abundance of this species.

Cuba's southeastern region has the highest abundances of *I. badionotus* (Alfonso et al. 2004, Frías et al. 2008), primarily off the southern coast of Camagüey, where the largest annual catches occur. Harvests in this area have represented 36%–70% of the national total. This zone is of great importance for the species, with extensive areas of preferred habitat, which includes cays, shallow sites, and sandy-muddy bottoms associated with seagrass meadows (Alfonso et al. 2004). It is also adjacent to a protected area, Jardines de la Reina National Park, which may provide a significant opportunity for recruitment (spillover) into fishing areas.

A sea cucumber fishery is considered a small-scale operation. It is typically carried out by specialized motorboats that can operate in shallow waters, and occasionally by larger vessels (Sánchez and Delgado 2015). Each ship has a tank that stores compressed air, and divers use a narquilex (hookah) system: a hose is attached to a compressed air tank at one end and to a diver with a nozzle and air regulator at the other. Extraction is by hand. Each vessel has tanks that recycle water to sustain live sea cucumbers throughout the cruise. Fishing is conducted during daylight hours, in depths of 3–15 m (Alfonso and Frías 2003). From the outset, the fisheries have been monospecific (i.e., other species were not of commercial interest). However, in 2015, surveys for the species *Holothuria mexicana* Ludwig, 1875 and *Holothuria floridana* (Pourtalés, 1851) were carried out in the southeast region of Cuba, and limited to an annual catch quota of 34 and 50 t, respectively. *Holothuria mexicana* was also harvested in the northwestern region.

The biological characteristics of the sea cucumber include slow movement, late sexual maturity, density-dependent reproduction, and low recruitment rate, making it very vulnerable to overexploitation. In Cuba, there are several measures of protection for the three commercially exploited species of sea cucumbers. The national minimum legal catch size (ventral length) for *I. badionotus* is 22 cm, except at the Isla de la Juventud, in the southwest, where 19 cm has been established (MINAL 2009). For *H. mexicana*, the minimum length is 14 cm, and for *H. floridana,* 11 cm (MINAL 2015). The collection bag must comply with specified dimensions: the bag opening must be 40 cm in diameter and the basket length, 85 cm. The fishery is closed during the reproductive season, which is June 1 to October 31 for *I. badionotus* (MINAL 2006), and from May 1 to November 30 for the other two species (MINAL 2015). Fishing is governed under a quota regime that is allocated at 20%–25% of the fishing potential or biomass of adult individuals. These quotas are applied to various fishing zones to avoid reductions of the sea cucumber population in different regions. Quotas operate only in areas where density values are adequate to support commercial catches (0.5 individuals 100 m^{-2}) according to the FAO (2010). Fishing is closed in all other areas.

Protection measures have generally allowed this resource to remain sustainable. At present, all fishing regions of the Cuban insular shelf have areas with density levels suitable for commercial harvest. Studies for the conservation of this species, however, are urgently needed to maintain wild populations and a sustainable fishery. As a basis for analysis, density, size and weight are recorded every year to monitor the condition of the population in each region. Here, we assess the status of *I. badionotus* off the southern coast of Camagüey using both fishery-independent and fishery-dependent indices to evaluate whether these methods could be more widely applied to management strategies in Cuba and other regions of the world.

Materials and Methods

The fishing region off the southern coast of Camagüey, an area of approximately 900 km^2, is located on the southeastern shelf of Cuba. In this region, there are seven fishing sites with an average depth of 10 m, and the seafloor is sandy mud, with patches of seagrass (Fig. 2). We used catch data from the Santa Cruz del Sur fishing company in Camagüey related to *I. badionotus*. These data documented the period between 2003 and 2014, during the fishing season of November$_{(\text{year } x)}$ to May$_{(\text{year } x+1)}$.

Independent biological sampling of the fishery was conducted in May 2013, August 2014, and September 2015. The sites were delineated using MapInfo 8.5 with at least five outer points (see Fig. 2). At each point, a 400 m^2 area linear transect was conducted (100 × 4 m). The sum of the transect areas represented at least 0.008% of the area for the corresponding site. Coordinates were recorded by GPS for each transect. At each point, all sea cucumbers were collected within the transect area. Each specimen greater than or equal to the legal minimum size of 22 cm (LMS) was opened at

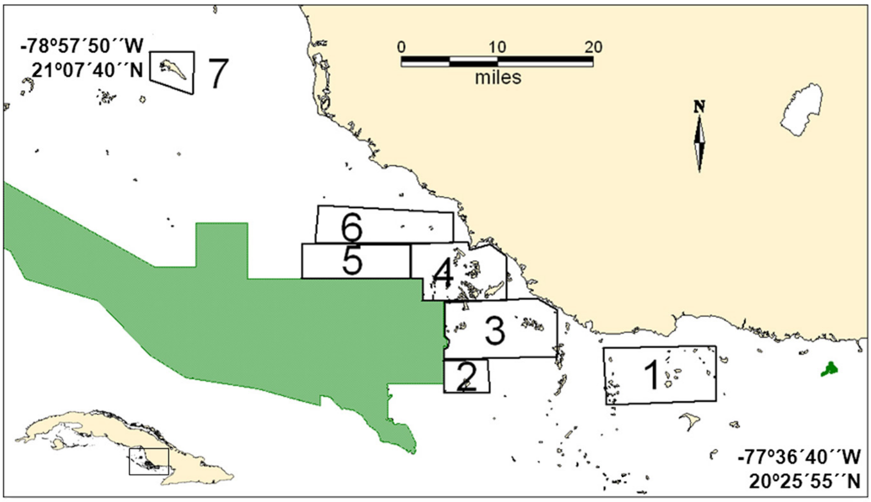

Figure 2. Seven fishing sites for sea cucumber (*Isostichopus badionotus*), south of Camagüey, Cuba. The green zone represents the protected area Jardines de la Reina.

the ventral region, and all internal organs were extracted, leaving only the integument or body wall. Wet eviscerated weights (Pe) were recorded using a 0.1 g precision analytical balance.

Density was calculated for each transect using the formula:

$$D_t = ind / A_t$$

where D_t is the transect density (individuals 100 m^{-2}), *ind* is the number of sea cucumbers in the transect that met the LMS, and A_t is the transect area (m^2). The average density per site (D_s) was estimated from D_t.

The number of sea cucumbers per site was estimated using the equation:

$$NI_s = D_s * A_{tot}$$

where NI_s is the estimated number of cucumbers at a site, D_s is the average density of adult specimens (individuals 100 m^{-2}), and A_{tot} is the total area of the site (m^2). The sum of all NI_s at each site is the number of cucumbers (*NI* total) estimated for the fishing company's region. The fishable biomass was calculated using the formula:

$$Fishable\ biomass = D_s * A_{tot} * Pe_s$$

where Pe_s is the average eviscerated weight of the sea cucumbers at the site.

The catch per unit effort (CPUE) was determined for each year as follows:

$$\text{CPUE} = ind / days\ fishing$$

where *ind* is the number of cucumbers caught, and *days fishing* is the effort equivalent to the number of days each vessel fished.

Comparisons of catch (tons of eviscerated weight) and average CPUE among years were performed using Monte Carlo simulations with the Excel tool, PopTools. To assess the status of the resource, a dynamic surplus production model was applied according to Hilborn and Walters (1992), and described by Haddon (2011) with the observed catch series:

$$N_{t+1} = N_t + r * N_t * (\ln K - \ln N_t) - C_t$$

where N_t is the number of sea cucumbers in the exploitable stock at the beginning of year t, N_{t+1} is the number in the following year (t + 1), r is the intrinsic rate of population growth, K is the carrying capacity of the ecosystem that determines the maximum size of the population in the absence of exploitation, and C_t is the catch in year t.
With the model, catch estimates ($\hat{C}_t$) and the instantaneous rate of fishing mortality (F_t) for each year t were obtained according to the relationship:

$$\hat{C}_t = q * f_t * N_t F_t = -\ln\left(1 - \frac{C_t}{(N_t + N_{t+1})/2}\right)$$

where f_t is the fishing effort in year t and q is the catchability coefficient that determines the relationship between fishing mortality and effort:

$$f_t = q * F_t$$

To adjust the model, the differences between the observed and estimated catches were used, minimizing an objective function based on the least squares criterion:

$$\sum (C_t - \hat{C}_t)^2$$

The optimization model was performed by varying the parameters q, r, and K, using Microsoft Excel's Solver tool.

Quantitative reference points for fisheries management were determined according to the methodology proposed by Caddy and Mahon (1996) and Haddon (2011):

$$MSY = r * N_{MSY}, \quad N_{MSY} = \frac{K}{\exp(1)}, \quad F_{MSY} = r,$$
$$f_{MSY} = \frac{F_{MSY}}{q}, \quad D_{MSY} = N_{(t)}/A$$

MSY is the maximum sustainable yield, N_{MSY} is the population size for the MSY, F_{MSY} is the mortality rate for optimal fishing, f_{MSY} is the optimal fishing effort to obtain MSY, D_{MSY} is the density for MSY, and A is the total area of distribution estimated for the species. Reference points are technical criteria for the sustainable management of the fishery, assuming equilibrium conditions and comparison with observed values. Successful fishery management is considered to exist when the evaluated performance indicators meet the requirements of the established reference points.

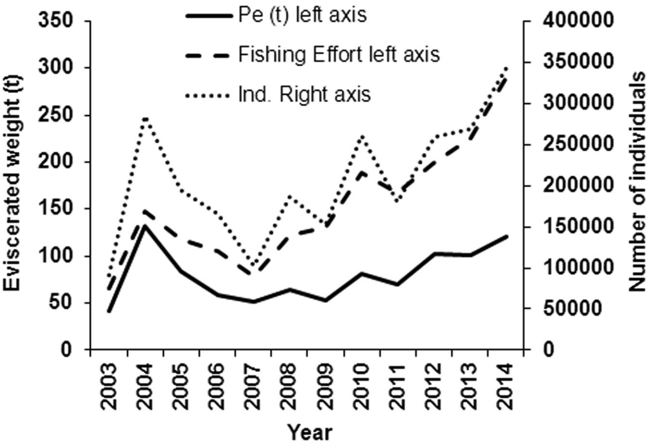

Figure 3. Sea cucumber (*Isostichopus badionotus*) catch off the southern coast of Camagüey, Cuba, between 2003 and 2014. Shown are number of individuals (small dashes), total eviscerated weight (Pe, solid line), and fishing effort (fishing days, large dashes).

Results

In total, 2,590,887 individuals were obtained between 2003 and 2014 with an annual mean of 198,591, which corresponds to 998.2 and 76.8 t, respectively (Fig. 2). The catch in metric tons of wet weight and in number of sea cucumbers both show an increasing trend over the years. The number of individuals captured in 2014 was greater than that obtained in 2004, while the tons obtained in 2014 were lower than in 2004. This may indicate a decrease in individual weight. Annual catches in weight (*Pe*) differed significantly (Monte Carlo simulations: $P < 0.001$). Fishing effort (fishing days) presents an increasing trend, with a minimum value of 65 d in 2003, and peaked in 2014 with 291 fishing days (Fig. 3). In 2004, a peak of 149 fishing days was realized, which is surpassed by the values of the past five years (2010–2014).

The number of sea cucumbers (ind) was selected as a catch unit to estimate CPUE. Total eviscerated weight, *Pe*, could also be used here, as there is a high correlation between the two variables and it is statistically significant ($r = 0.8$, $P < 0.05$).

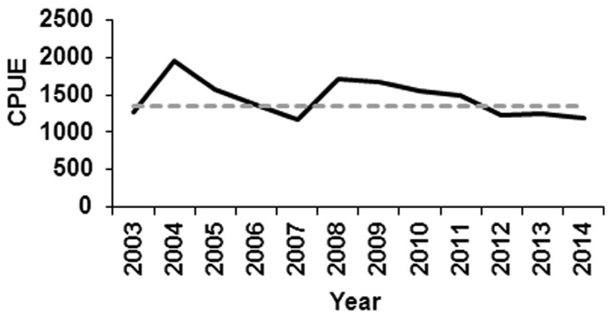

Figure 4. *Isostichopus badionotus* catch per unit effort (CPUE) expressed as the total annual number of sea cucumbers caught, divided by the total number of fishing days for the period 2003 to 2014 for the fishery off the southern coast of Camagüey, Cuba. The dashed line represents the mean value of the series.

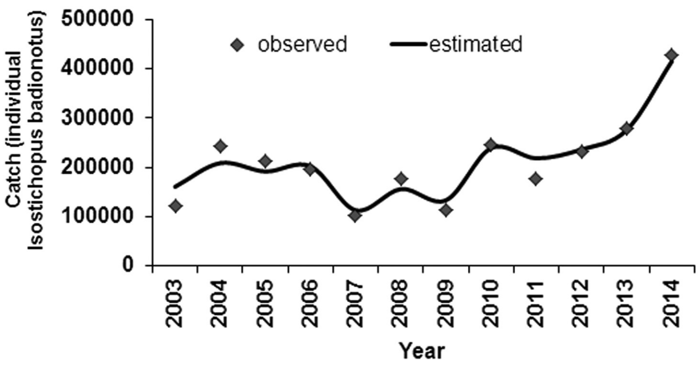

Figure 5. Observed and estimated annual catches of the sea cucumber, *Isostichopus badionotus*, from the southern coast of Camagüey, Cuba, from 2003 to 2014. Estimated annual catches were generated by a dynamic surplus production model (see text for details).

The average CPUE per year has decreased over time, with a historical average of 1353 ind per fishing day. The highest CPUE occurred in 2004 with 1953 ind per fishing day, the lowest in 2007 with 1171 ind per fishing day (Fig. 4). Three of the five values that are below the historical average have occurred in the last 3 yrs (2012–2014).

The dynamic surplus production model fit the data well, with a highly significant correlation between observed catches and model estimates (Fig. 5). The results of the model parameters and the reference points are presented in Table 1. The comparison between the variables of the fishery and its corresponding reference points reveals that the catch (Fig. 6A) has been fluctuating around values close to the MSY during the first 10 yrs of the fishery. An increasing trend began after 2009, and the catch has been above the MSY since 2012. The maximum was reached in 2014, the last year for which data are available.

Fishing effort (Fig. 6B) remained below f_{MSY} until 2013, but an upward trend since 2009 placed it above the optimal level in 2014. As expected, the size of the exploited population (Fig. 6C) has decreased from its nonexploited population size (K) in 2003, but it has remained throughout the entire period above the minimum value required by N_{MSY} to obtain a sustainable exploitation. The relationship between population size and fishing effort is linear, negative, and statistically significant ($r = -0.72$, $P = 0.008$).

Table 1. Parameters of the dynamic model for production and reference points for the management of the fishery of the sea cucumber species *Isostichopus badionotus* south of Camaguey, Cuba. K, MSY, N_{MSY} are number of cucumbers, F_{MSY} is fishing days, and D_{MSY} is individuals per 100 m^2.

Sea cucumber parameter/reference point	Value
Model parameters	
q	0.00043
r	0.129
K	3,989,507
Reference points	
MSY	189,399
N_{MSY}	1,467,658
F_{MSY}	301
F_{MSY}	0.129
D_{MSY}	0.45

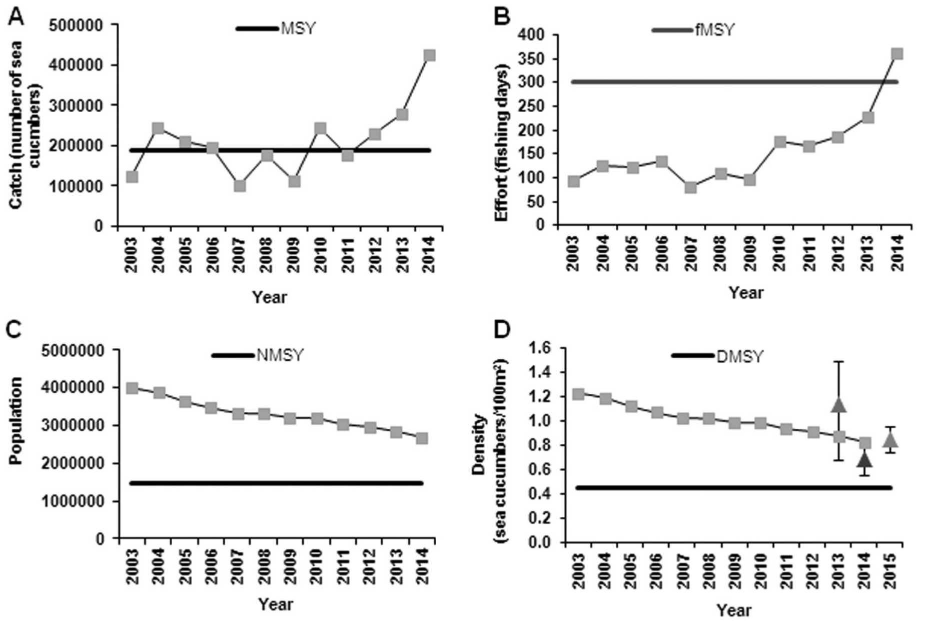

Figure 6. (A) Maximum sustainable yield (MSY), (B) fishing effort, f_{MSY}, (C) population abundance, in number of sea cucumbers N_{MSY}, and (D) density, D_{MSY} of the sea cucumber *Isostichopus badionotus* in Camagüey, Cuba. In (D), the triangular points with confidence intervals show the annual average densities of the fishery.

The density, as a limit reference point (D_{MSY}) obtained from the dynamic surplus production model, is 0.45 ind 100 m^{-2}. Figure 6D shows that density in the time series has not gone below this threshold value, although there is a decreasing trend. The densities estimated by the model for 2013 and 2014 are within, or very close to, the range of densities obtained in the fishery-independent indices for the corresponding samples. This tends to corroborate model representativeness and its use in evaluating resource status.

The fishing potential yielded values of 1,889,000 sea cucumbers and 801.8 t. Table 2 shows the catch quotas obtained by allocating 5%, 10%, 15%, 20%, and 25% of the potential yield from fishing. By applying a percentage >10%, the value of the MSY estimated by the model is exceeded by far (189,399 sea cucumbers). However, if 10% is applied, the value of the quota would be slightly below the MSY. Therefore, we propose that 10% be applied. The 10% value is considered to be the most appropriate

Table 2. Fishing potential and the fishing quotas corresponding to *Isostichopus badionotus* in 2015 for Camagüey, on the southern coast of Cuba.

Fishing potential (%)	Quota in individuals	Quota in eviscerated weight (t)
5	94,450	40.1
10	188,900	80.2
15	283,350	120.0
20	377,800	160.0
25	472,250	200.0

value because it achieves protection of the species and precautionary quota values are obtained that favor national earnings in a sustainable manner.

Discussion

The sea cucumber fishery in Cuba began in 1999 and has been active in Camagüey Province since 2001. Catch and effort have increased during the past decade. Although more individuals have been captured in recent years than at the start of the fishery, the total eviscerated weight has not increased as quickly and was lower than in 2004, which suggests that harvested individuals are smaller than a decade ago. It is possible that larger individuals remain at greater depths, with smaller ones more common in the fishing grounds. Use of an air-supply hose for the extraction of sea cucumbers prohibits the diver from reaching greater depths (>15 m), so that only relatively shallow areas are exploited. Individuals in deeper areas remain intact, so their size increases to optimal levels (>22 cm length). Three years after the fishery for *I. badionotus*, *H. floridana,* and *Astichopus multifidus* (Sluiter, 1910) began in Yucatán, Mexico, harvests were made at depths >15 m. This expansion was considered indicative of the decline of sea cucumbers associated with the shallow coastal zone (Espinoza et al. 2012). In addition, economic interest in sea cucumbers led to an increase in illegal fishing in Yucatán and decompression health problems among divers. Off the south coast of Camagüey, illegal fishing can essentially be ruled out because of the remote locations of the fishing zones, which make them difficult to reach. However, there is undocumented evidence of illegal fishing in other regions of Cuba, such as north of Pinar del Río (the northwestern region), where catches are marketed to Chinatown in the Province of Havana (personal communication from anonymous fishers). Buitrago and Boada (1996) found a significant correlation between the mean minimum size of *I. badionotus* and depth (larger sizes at greater depths), indicating that is it important to analyze catches by number of individuals rather than by weight.

The initial abundance (K) of *I. badionotus* obtained by the model is interpreted as the maximum carrying capacity that the system can support (Haddon 2011). For the fishing region south of Camagüey, K was estimated to be 3,989,507 sea cucumbers. In comparison to values in Yucatán, Mexico, this figure is considered high (López-Rocha et al. 2013). In the Mexico study, these authors obtained an initial biomass of 328,040 individuals for an area of 860 km^2. The fishing area in Camagüey (900 km2) is comparable in size to that of Yucatan, but there is a marked difference in density between the two sites. In southern Camagüey, there were more than 0.45 ind 100 m^{-2}, in Yucatan fewer than 0.005 ind 100 m^{-2}. The differences in abundance and population density are likely an artifact of habitat. The fishing sites south of Camagüey are associated with or surrounded by cays, which could provide protection for this species. There are many shallow areas with no boat access, allowing juveniles to develop free of fishing pressure. The fishing area in the Yucatan has no such natural refuges.

The output parameter r represents the intrinsic rate of growth and is a constant assumed to be independent of population size (N) (Haddon 2011). Only one estimate of r was found for sea cucumbers: Cisneros-Mata (2016) assumes an r of 0.5 for *Isostichopus fuscus* (Ludwig, 1875) in the Gulf of California. Our estimate for *I. badionotus* (r = 0.129) was considerably lower, perhaps because the two species differ in size: *I. fuscus* is generally smaller than *I. badionotus*—it reaches approximately 24 cm in length—while *I. badionotus*, grows to 45 cm (Borrero-Pérez et al. 2012, Purcell et al. 2012).

The levels of abundance in catches of this species at the national level correspond to the effort exerted, just as they do in the region off the southern coast of Camagüey, where it is evident that the their abundance is affected by increased fishing activity. Since 2011, there has been an increase in catches as a result of this growing effort, which in turn has had an impact on the abundance of the resource. This is reflected in the CPUE, a measure of abundance of the exploited population, so a decrease in CPUE over a period of time is likely to indicate that populations are declining (Purcell et al. 2010). In the last 3 yrs (2012–2014), a lower CPUE was realized than at the start of the fishery; this is additional evidence of decline, and corresponds to the greater effort exerted in recent years.

The CPUE peak in 2004 may indicate that fishers gained experience in the identification of fishing sites and in visualizing the organisms themselves underwater. This is followed by a decrease in catch and CPUE in the following years, as a result of the fishing pressure exerted on these fishing grounds. Singh and Vélez (1996) report this same behavior in the *I. fuscus* fishery in Baja California, Mexico, obtaining a peak twice as high in 1991 with respect to the average of the previous and following years. In this same region of Mexico, Salgado-Rogel et al. (2009) reported the decrease of the CPUE of the Parastichopus parvimensis (Clark 1913) due to fishing.

When analyzing the status of a resource in a way similar to that of the United States (NOAA 2014), the evaluation can conclude that the sea cucumber fishery off the southern coast of Camagüey is not overfished, because the effort there has only exceeded the reference point of f_{MSY} during the 2014 season. In addition, the resource has not collapsed, since the size of the population has not decreased below the reference point of N_{MSY}. Given the recent increase in both effort and catch, management of this fishery should maintain a precautionary approach to assure that sustainable levels are not exceeded.

At the global level, sea cucumber fisheries show an alarmingly high incidence of overexploitation and depletion of their populations (Purcell et al. 2013). In our analysis, it was evident that 20% of the fisheries are exhausted, 38% are overexploited, and 14% are fully exploited. Only 27% of global fisheries are underexploited or moderately fished. Most of these occur in temperate waters at greater depths, or are under development or moratorium.

Another factor that influences resource abundance is the catch quota. This is a limit set for a particular sea cucumber fishery, usually for a year or a fishing season (Purcell et al. 2010). Historically, Cuba has allocated 25% of the potential yield as the quota. Starting in 2013, the country allocated between 15% and 25% of the potential yield to determine the quota, based on different densities in various regions of the country (Ortega 2009, Informe-CIP 2012, 2013a,b,c,d). Other countries, such as Mexico, have set more conservative quotas of <12% of the fishing potential, quotas that are independent of the density values (Rodriguez 2007, Salgado-Rogel 2009).

In regions where higher percentages have been applied, dramatic decreases of the resource have followed (Chávez et al. 2011, DOF 2004 cited in Espinosa et al. 2012, Wolff et al. 2012). In 1996, on the east coast of Baja California Sur, fishing quotas of 30% biomass were proposed for the species, *I. fuscus* (Singh and Vélez 1996); however, in 2007 a new proposal of 10% was suggested (Avendaño 2007). Following this example, we propose that 10% of the fishing potential be used to establish quotas in

Cuba, based mainly on comparisons of results obtained from our model, regardless of densities obtained in the samples (as done in previous years). In addition, we propose the establishment of catch quotas for individual fishing sites to avoid overfishing them.

The reduced abundance of *I. badionotus* in the study region is almost certainly attributed to the fishing pressure on this resource. During the study period, there were no major meteorological phenomena, such as hurricanes, that might have affected the fishing zone (Reyes et al. 2016). Whereas the shrimp fleet also operates in this region with the use of trawls, it does not affect the abundance of sea cucumbers, which constitute <3% of the bycatch and are returned to the sea alive (Pérez 2016).

Based on our evidence, the populations of *I. badionotus* off southern Camagüey can be evaluated as moderately exploited. Still, there is strong evidence of a decline in biomass, and it is essential to implement new management measures to counteract this loss. We must take into account the ecological and socio-economic importance of this species and understand that if it were to collapse, it might take decades to recover.

The combination of the analysis based on sampling data, such as fishing potential and density, together with the results of the dynamic surplus production model based on catch and effort, resulted in reference points, which are useful tools for the management, administration, and protection of sea cucumber species. Using these results, an ideal percentage of the fishing potential to determine the catch quota, and the applicable density limit to the areas being regulated can be recommended. These assessments should be performed annually, should incorporate catch and effort data of the concluding fishing season, as well as data from surveys conducted during the closed season, to issue new regulations that define catch quota and fishing area for the next season.

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