Baseline assessment of virgin biomass of sea cucumbers in Old Providence and Santa Catalina, Western Caribbean

Haruko Koike[1,], Paolo Usseglio[1,2] and Francisco Ramos[2]*

Abstract

In this paper we report the result of an independent baseline fishery survey conducted in the islands of Old Providence and Santa Catalina, Colombia, in 2014, with the objective of characterising spatially explicit abundance and distribution of the sea cucumber communities.

We included local artisanal fishers in the planning and data collection parts of this survey. Our results showed very limited diversity of sea cucumbers, with *Holothuria mexicana* being the most abundant. There were higher densities of *H. mexicana* in the sand and rubble habitat than in the seagrass and bioturbated areas. We found aggregation sites for sea cucumbers where density was an order of magnitude higher; this habitat was a narrow band between seagrass and sand and rubble. Total population size was considered too low to sustain a fishery, and mariculture experiments with sea cucumbers in the region should carefully consider the number of organisms taken when establishing breeding protocols.

Key words: Coral reefs, sea cucumber, artisanal fishing, beche-de-mer, ecosystem services.

Introduction

Sea cucumber fisheries in Colombia started about a decade ago, but has been mostly illegal, and to date it is still unregulated and unreported (Toral-Granda 2008; Rodriguez et al. 2013). While the main species exploited in the Colombian Caribbean include *Isostichopus badionotus*, *Stichopus herrmanni* and *Stichopus variegatus* (Rodriguez et al. 2013), reports for the wider Caribbean include up to six species (Toral-Granda 2008). Initially, the fishery was done with middlemen hiring fishers to collect as many sea cucumbers as possible but, as densities dropped, this activity shifted towards an "on-demand" activity, with fishers making about 3 USD kg^{-1} (Rodriguez et al. 2013). The unregulated nature of this fishery, coupled with the lack of knowledge of the resource, has resulted in concerns about the state of the resource. Since market demand for sea cucumber is still growing, some authors suggest mariculture of sea cucumbers instead of harvesting the wild population, as a way to establish alternative sources of income for fishers, reusing abandoned aquaculture facilities, and establishing conservation programmes (Rodriguez et al. 2013).

Inhabitants of the islands of Old Providence and Santa Catalina, located in the western Caribbean 180 miles off Central America, are closely linked to sea. Most of them are fishers either full or part time. The recent decline in landings, due to overexploitation of their marine resources, has made the local fishing community consider alternatives to fishing. With perceived high prices of sea cucumbers in Asian markets, some are looking at sea cucumber farming as one of their options. Since sea cucumbers are susceptible to overfishing (Toral-Granda 2008), the community showed an interest in mariculture. This study was conducted to assess the baseline wild stock of sea cucumbers available for mariculture around the islands of Old Providence and Santa Catalina, working in collaboration with local fishers.

Methods

Sampling area

The archipelago of San Andres, Old Providence and Santa Catalina is located in the western Caribbean between 13°17'N and 81°22'W, 190 km from

[1] Fisheries Ecology Research Lab, Department of Biology, University of Hawai'i at Mānoa, Honolulu, HI, USA
[2] Proyecto Maricultura, Fish and Farm Coop. Old Providence, Colombia
* Corresponding author: hkoike@hawaii.edu

the Middle America continental shelf, and 720 km away from the Colombian mainland (Geister 1992). Old Providence and Santa Catalina (OPSC) are located 80 km north of San Andres; Old Providence is the second largest island in the archipelago with a land area of 17 km^2, while Santa Catalina is a small satellite island located 150 m to the north of Old Providence. The two islands are joined by a floating footbridge. OPSC have 32 km of coral reef formations that run north to southeast. Within its barrier reef there are multiple patch reefs, sand flats and seagrass areas (Gómez-López et al. 2012) (Fig. 1).

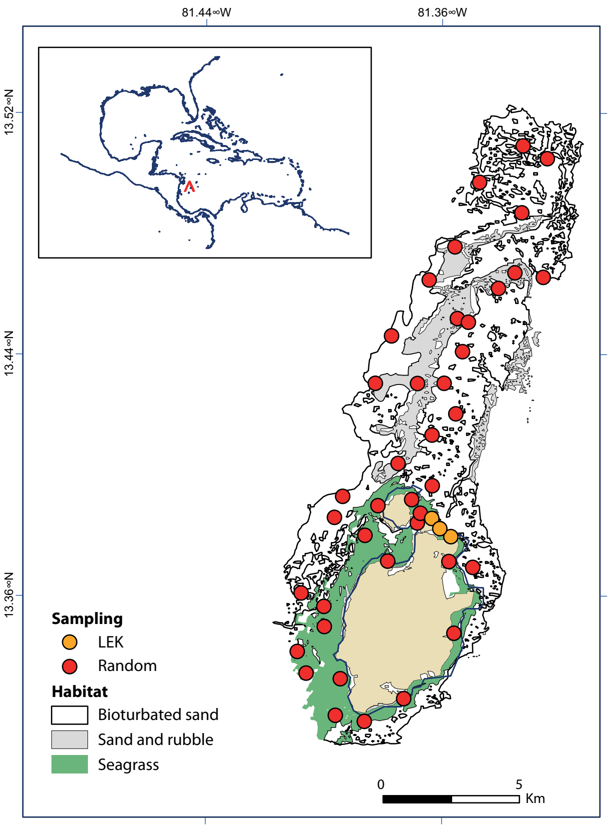

Figure 1. Location of Old Providence Island, and sampling points around the island. Inset map: World Vector Shoreline of the Gulf of Mexico and Caribbean Sea region. Source: National Imagery and Mapping Agency (formerly U.S. Defense Mapping Agency).

Survey design and community involvement

This study was a community-led effort; fishers were included in all the stages and we adopted a collaborative, rather than cooperative approach (Yochum et al. 2011).

Nine species of sea cucumbers have been recorded by Borrero-Pérez et al. (2012) in the region (Table 1). They are distributed mainly in biodisturbed sand, sand and rubble, and seagrass habitats. Using habitat maps obtained from the local environmental agency, CORALINA, we focused on surveying these habitats by means of a stratified random sampling design. The baseline stock assessment included a total of 40 sampling sites that were distributed among the identified habitat strata using the Sampling Design Tool available for the ArcGIS software (Menza and Finnen 2007). In addition, we surveyed aggregation sites, since sea cucumbers are known to aggregate in favourable habitats (Shiell and Knot 2010; Young and Chia 1982). It is important to survey these aggregation sites when estimating total population size, since a high proportion of the individuals could reside within them. However, these sites are usually a combination of multiple environmental factors and thus have a low probability of being included in randomly designed surveys. We therefore used fishers' local ecological knowledge (LEK) to identify three such high-density sampling sites, which will be referred to as LEK sites henceforth (Fig. 1).

Table 1. Sea cucumber species reported for the island of Old Providence (Borrero-Perez et al. 2012).

Species
Actinopyga agassizii
Holothuria (Cystipus) cubana
Holothuria (Halodeima) floridana
Holothuria (Halodeima) grisea
Holothuria (Halodeima) mexicana
Holothuria (Thymiosycia) thomasi
Isostichopus badionotus

Survey method

The diversity and abundance of sea cucumbers in OPSC were estimated by means of underwater visual transect surveys. At each sampling site, a pair of divers swam a twenty-minute two-metre wide belt transect in a random direction, while ensuring that they remained within the same habitat. The sampling depth was limited to 20 metres for logistics and safety reasons. For each transect, the surveyors recorded the species of sea cucumber found, and measured the total length and diameter to the nearest centimetre, using a fiberglass seamstress tape. Transect length was calculated from a towed Global Positioning System (GPS) unit, which was set to track mode and had the Wide Area Augmentation System (WASS) feature turned on to increase accuracy. Inter-observer variability was addressed by conducting training sessions where sampling methodology and species identification were explained. Since surveyors included local fishers, extra care was taken to ensure that all observers understood the limits of the sampling area and did not count cucumbers outside of the transect.

Size comparison

Significant differences in the mean length and width of sea cucumbers found in random and LEK sites were assessed by means of ANOVA, followed by Tukey's HSD test.

Density calculation and population size estimate

We used the model selection method to estimate the density of sea cucumbers because it allowed us to account for the cucumbers' clumped distribution (Campagna and Hand 1999). We created a set of generalised linear models assuming four distributions: normal, Poisson, negative binomial, and zero-inflated. Additionally, we tested for the influence of sampling habitat strata on density. This resulted in a total of eight models (Table 2).

Model selection was based on the Akaike information criterion (AIC), which calculates the log likelihood of the model, while penalising for the number of parameters (Akaike 1973). The best explaining model was chosen, based on the fewest parameters within two units of the lowest AIC score (Burnham and Anderson 2002). Additionally, we used the likelihood ratio test for the competing best-fit models to test for significant differences. We used this approach for the randomly located and LEK sites.

Total population size was calculated by multiplying the resulting estimated density for each habitat with the area size of said habitat. These were obtained from the benthic habitat maps for LEK sites. The total area was calculated by delineating the habitat area from a geo-referenced digitised aerial photograph using ArcGIS 10.2.

All of the statistical analyses were done using the open source software R (R Development Core Team 2009); plotting was done with the package ggplot2 (Wickham 2009); data manipulation was done with the package reshape2 (Wickham 2007); the generalised linear model in the negative binomial distribution was fitted, using package pscl (Jackman et al. 2012); and the likelihood ratio test was conducted using the package lmtest (Hothorn et al. 2010).

Results

Although nine species of sea cucumbers have been described for OPSC (Borrero-Pérez et al. 2012; Table 1), we found only two in our baseline survey. *Holothuria mexicana* was the most common species, followed by occasional sighting of *Holothuria thomasi*. Overall density was low, as we counted a total of 82 sea cucumbers. For randomly placed transects (n = 40), we counted 43 sea cucumbers (41 *H. mexicana* and 2 *H. thomasi*), and 39 *H. mexicana* in LEK transects (n = 3). Due to the low abundance of *H. thomasi*, we focused all further analyses on *H. mexicana*.

Size distribution

The length of *H. mexicana* in OPSC ranged between 15.0 and 46.5 cm, with a mean of 29.66 cm ±0.75 SE, while the width ranged between 2 and 15 cm, with a mean of 8.25 cm ±0.23 SE. There were significant differences in the length of sea cucumbers between habitats ($P < 0.01$), where sand and rubble habitat and bioturbated sand habitat had significantly larger individuals than LEK and seagrass habitat ($P < 0.05$ under Tukey HSD test) (Fig. 2).

Baseline stock assessment

Model selection showed model 7 (negative binomial distribution accounting for habitat) to be the most parsimonious model, with the lowest AIC score (Table 2). The density for each habitat strata, estimated using model 7, is as listed: sand and rubble had the highest density with 6.38 ind. hr^{-1} ±3.01 SE, followed by seagrass with 1.56 ind. hr^{-1} ±0.66 SE, and bioturbated sand with 1.47 ind. hr^{-1} ±0.63

Table 2. Model types testing for habitat effects and distributions. df = degree of freedom; AIC = Akaike information criterion.

Model	Habitat Effect	Distribution	df	AIC score
1	No	Normal	2	245.94
2	No	Poisson	1	274.86
3	No	Negative Binomial	2	151.55
4	No	Zero-Inflated Normal	2	210.52
5	Yes	Normal	5	210.91
6	Yes	Poisson	4	153.86
7	Yes	Negative Binomial	5	136.96
8	Yes	Zero-Inflated Normal	8	137.54

SE (Table 3). The sand and rubble habitat showed higher density (but not significant) compared to the other two habitats (Table 3).

Aggregation site assessment

Aggregation sites — so-called "good sites" by fishers — were consistently found between seagrass and sand and rubble, close to the shore on the eastern side of Old Providence Island (Fig. 1). The width of this specific habitat was narrow, ranging from three to six metres, and consisted of only 0.3% of the area of OPSC (Table 3).

Best-fit model showed that data from LEK sites were in negative binomial distribution. The estimated density was significantly higher by an order of magnitude than in the randomly selected sites, with a mean density of 32.99 ind. ha^{-1} ±10.22 SE (Fig. 3).

Total population size in OPSC

The total estimated density for each habitat was calculated as the estimated density per habitat strata multiplied by the area. The population size for each habitat is as follows: 7,550 ±3,558 SE individuals for

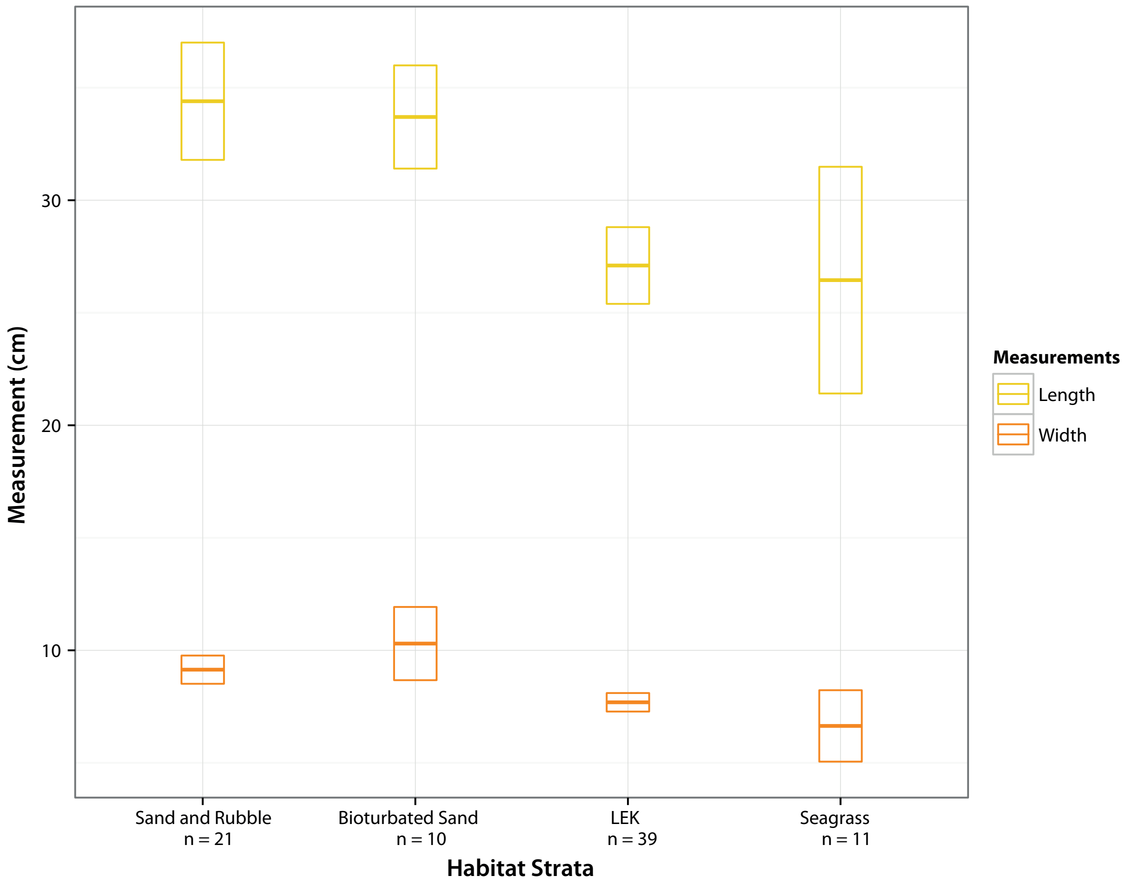

Figure 2. Length and width (in cm) of *Holothuria mexicana* for each habitat strata. Box outline marks the boundary of 95% confidence interval. Sample sizes for each habitat strata are noted at the bottom.

Table 3. Information of each habitat type surveyed. Information includes: number of transects, estimated density with 95% confidence interval (CI), area size of each habitat strata, and estimated population size. Information on aggregation site (marked as LEK) is also included.

Habitat	n	Density (ind. ha^{-1})	95% CI	Area (ha)	Population size
LEK	3	32.99	17.97–60.56	29.59	976
Sand and rubble	8	6.38	2.53–16.07	1,183.14	7,550
Seagrass	16	1.56	0.68–3.59	1,563.78	2,444
Bioturbated sand	16	1.47	0.63–3.43	5,405.30	7,928

the sand and rubble habitat; 2,444 ±1,037 SE individuals for seagrass habitat; 7,928 ±3,431 SE individuals for the bioturbated sand habitat; and 976 ±302 SE for the LEK (aggregation) sites (Table 3). Therefore, total estimated number of sea cucumbers for OPSC was 18,898, with a 95% confidence interval of 7,994–44,959. The confidence interval was calculated by accounting for the standard error of each habitat strata.

Discussion

Distribution of *H. mexicana* in OPSC was very patchy, with clear aggregation sites located on the northern side of the island of Old Providence on a very narrow fringe habitat between seagrass, and sand and rubble. The density of *H. mexicana* was low, even when accounting for its negative binomial distribution, compared to other sites in the Caribbean (Table 4). From the density and size difference between habitat strata (Figs 2 and 3), we can infer that younger *H. mexicana* likely occur in seagrass areas (hence the significantly smaller sized individuals in LEK and seagrass strata), but no actual juveniles were found during the survey.

The total estimated abundance of sea cucumbers in OPSC (both in species richness and stock size) indicates that commercial wild fishery activities are not feasible. In fisheries, as a rule of thumb, 20% virgin biomass is often used as a reference point to ensure sustainable exploitation (Restrepo et al. 1998). Furthermore, for sea cucumbers there is evidence that exploitation values as low as 5% virgin biomass have resulted in over-exploitation (Uthicke 2004). If we apply this to our estimated current population size, only 944 sea cucumbers should be harvested each year for a fishery to be sustainable. This low number would not ensure the economic sustainability of a wild fishery.

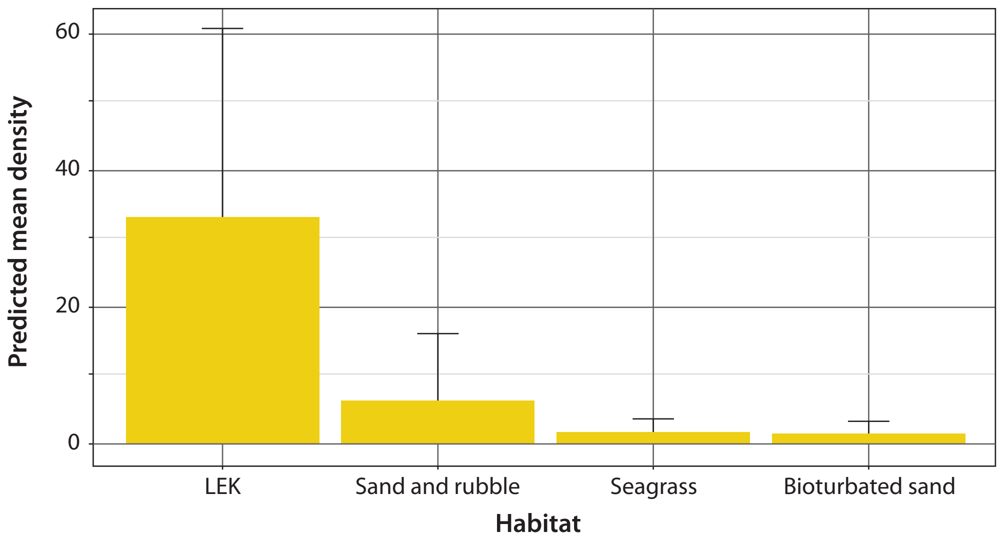

Figure 3. Estimated density of *Holothuria mexicana* for each survey strata in the islands of Old Providencia and Santa Catalina.

Table 4. Density estimates of *Holothuria mexicana* for several locations in the Caribbean.

Country	Year	Abundance (ind. ha^{-1})	Reference
Panama, Bocas del Toro	2000	161.8	Guzman and Guevara (2002)
Venezuela, Isla de Cubagua	2008	7.7	Trigliafico et al. (2011)
Jamaica	1981	70	Hammond (1981)
Venezuela	1998	110–210	Rodríguez-Milliet and Pauls (1998)
Venezuela	1999	13,500	Bitter (1999)
Venezuela, Isla de Cubagua	1987	7,000–9,400	Sambrano (1987)
Venezuela	1988	1,400–19,700	Bitter (1988)
Venezuela	1997	9,400	Conde (1997)
Cuba	2006	0–17,000	Alfonso-Hernandez (2006)

This low population could, however, sustain capture of individuals to be used as parent stock in mariculture. In this activity, adult wild sea cucumbers are harvested and conditioned in tanks to collect viable eggs, which is determinant (Morgan 2000). However, the survival rate of a sea cucumber's planktonic larvae is very low, with estimates of as little of one individual from its cohort surviving to the juvenile stage (Purcell et al. 2012). This results in a negative relationship between larvae stocking density and survival to settlement (Battaglene and Bell 2004). Furthermore, this low larval survivorship is followed by a high predation rate among juveniles by carnivorous fish, birds, turtles, sea stars, crabs, gastropods and other invertebrates (Dance et al. 2003; Francour 1997). This is a problem when a pen is built in open water, where it is difficult to avoid these predators (Purcell et al. 2012). Consequently, obtaining a large enough brood stock to ensure adequate supply of larvae for mariculture could result in a reduction of larvae for the wild population. Therefore, decisions on the number of adult individuals taken from the field should be made with great care. Additionally, aggregation sites with much larger densities (Fig. 3) have a higher risk of being targeted, once market demand is present, due to ease of catch compared to searching time. Nonetheless, depleting these high density sites can have detrimental effects on the overall sea cucumber population of OPSC, possibly causing an Allee effect (Uthicke 2004), and this should be taken into special consideration when opening a fishery.

With an ever-increasing market demand for beche-de-mer, it is inevitable for a sea cucumber fishery to be considered an alternative source of income. However, it is important to understand the local stock status when considering this option. Based on our results, we propose the recommendations listed below.

- A wild fishery of *H. mexicana* in the islands of OPSC should not be considered.
- Mariculture activities that capture *H. mexicana* from the field should limit their annual harvest to no more than 944 individuals.
- Should mariculture be considered, mechanisms are needed to prevent poaching of wild stock and selling them as farmed.
- Aggregation areas could be a source of broodstock, but they should not be depleted. Instead, collection could be done in low-density areas, while protecting these aggregation sites in order to ensure adequate larval supply.

Acknowledgements

We would like to show our great appreciation to the local fishermen of Old Providence and Santa Catalina who participated in all aspects of this project and greatly improved it by sharing their knowledge with us. We also thank the staff at the Fish and Farm Coop and the Sony dive shop, especially Rosana Torres and June Marie Mow. We thank CORALINA for providing logistic support. We thank Julio Andrade for field help, and Laura Rodriguez for help in the surveys and literature review. This project is the result of the government-run initiative Plan San Andres, and was funded through the program Fase I de un Proyecto de Ciencia, Tecnología e Innovación para el desarrollo de técnicas de cultivo de especies marinas a escala de laboratorio y de planta piloto con fines comerciales, cooperation agreement No. 9677-20-822-2013 between Fish and Farm Cooperative Enterprise and Unidad nacional para la gestion del riesgo de desastres — Fondo nacional de gestion del riesgo de desastres, Presidencia de la Republica.

References

Akaike H. 1973. Information theory as an extension of the maximum likelihood principle. p. 267–281. In: Petrov B.N. and Csaki F. (eds). Second International Symposium on Information Theory. Budapest, Hungary: Akademiai Kiado.

Alfonso-Hernandez I. 2006. National Report Cuba. p. 141–144. In: Bruckner A.W. (ed.). Proceedings of the CITES workshop on the conservation of sea cucumbers in the families Holothuriidae and Stichopodidae. 1–3 March 2004. Silver Spring, United States of America: NOAA Technical Memorandum NMFS-OPR 34. 244 p.

Battaglene S.C. and Bell J.D. 2004. The restocking of sea cucumbers in the pacific islands. p. 109–132. In: Bartley D.M. and Leber K.L. (eds). Case Studies in Marine Ranching. FAO Fisheries Technical Paper No. 429. Rome, Italy: Food and Agriculture Organization from the United Nations. 213 p.

Bitter R.S. 1988. Análisis multivariado de la comunidad asociada a *Thalassia testudinum* en el Parque Nacional Morrocoy. PhD. Thesis. Caracas, Venezuela: Universidad Central de Venezuela. 153 p.

Bitter R.S. 1999. Benthic communities associated to *Thalassia testudinum* (Hydrocharitaceae) at three localities of Morrocoy Nacional Park, Venezuela. Revista de Biologia Tropical 47:443–452.

Borrero-Pérez G.H., Benavides-Serrato M. and Diaz-Sanches C.M. 2012. Equinodermos del Caribe colombiano II: Echinoidea y Holothuroidea. Santa Marta, Colombia: Instituto de Investigaciones Marinas y Costeras. 252 p.

Burnham K.P. and Anderson D.R. 2002. Model selection and multimodel inference: A practical information-theoretic approach. 2nd Edition. New York, United States of America: Springer-Verlag. 488 p.

Campagna S. and Hand C.M. 1999. Density estimates of giant red sea cucumber (*Parastichopus Californicus*) populations, by dive survey, in the Gulf Islands and Jervis Inlet Areas, British Columbia, Canada, in November 1997 and January 1998. Nanaimo, Canada: Fisheries and Oceans Canada, Science Branch, Pacific Region, Pacific Biological Station. 53 p.

Conde J.E. 1997. Après les bébés phoques, les concombres de mer. La Recherche 304:61–64.

Dance S.K., Lane I. and Bell J.D. 2003. Variation in short-term survival of cultured sandfish (*Holothuria scabra*) released in mangrove-seagrass and coral reef flat habitats in Solomon Islands. Aquaculture 220:495–505.

Francour P. 1997. Predation on holothurians: A literature review. Invertebrate Biology 116:52–60.

Geister B.J. 1992. Modern reef development and Cenozoic evolution of an oceanic island / ref. complex: Isla de Providencia (western Caribbean Sea, Colombia). Erlangen 27:1–70.

Gómez-López D.I., Segura-Quintero C., Sierra-Correa P.C. and Garay-Tinoco J. 2012. Atlas de la Reserva de Biósfera Seaflower. Archipiélago de San Andrés, Providencia y Santa Catalina. Instituto de Investigaciones Marinas y Costeras "José Benito Vives De Andréis" -INVEMAR- y Corporación para el Desarrollo Sostenible del Archipiélago de San Andrés, Providencia y Santa Catalina -CORALINA-, Santa Marta, Colombia. 180 p.

Guzman H.M. and Guevara C.A. 2002. Population structure, distribution, and abundance of three commercial species of sea cucumber (Echinodermata) in Panama. Caribbean Journal of Science 38(3–4):230–238.

Hammond L.S. 1981. An analysis of grain size modification in biogenic carbonate sediments by deposit-feeding holothurians and echinoids (Echinodermata). Limnology and Oceanography 26(5):898–906.

Hothorn T., Zeileis A., Millo G. and Mitchell D. 2010. Package 'lmtest'. Testing Linear Regression Models.

Jackman S., Zeileis C.M., Fearon J., Jackman M.S. and MCMCpack S. 2012. Package 'pscl'. Standford University, United States of America: Political Science Computational Laboratory.

Menza C. and Finnen E. 2007. Manual for the sampling design tool for ArcGIS. NOAA Center for Coastal Marine Monitoring.

Morgan A.D. 2000. Induction of spawning in the sea cucumber *Holothuria scabra* (Echinodermata: Holothuroidea). Journal of the World Aquaculture Society 31:186–194.

Purcell S.W., Hair C.A. and Mills D.J. 2012. Sea cucumber culture, farming and sea ranching in the tropics: Progress, problems and opportunities. Aquaculture 368–369:68–81.

R Development Core Team. 2009. R: A language and environment for statistical computing. Vienna, Austria: The R Foundation for Statistical Computing. 409 p.

Restrepo V.R., Thompson G.G., Mace P.M., Gabriel W.L., Low L.L., MacCall A.D., Methot R.D., Powers J.E., Taylor B.L., Wade P.R. and Witzig J.F. 1998. Technical guidance on the use of precautionary approaches to implementing national standard 1 of the Magnuson-Stevens fishery conservation and management act. NOAA Technical Memorandum NMFS-F/SPO 31. United States of America: National Oceanic and Atmospheric Administration. 54 p.

Rodriguez F.A., Vergara W. and Agudelo-Martinez V. 2013. First insight into Colombian Caribbean sea cucumbers and sea cucumber fishery. SPC Beche-de-mer Information Bulletin 33:9–13.

Rodríguez-Milliet E. and Pauls S.M. 1998. Sea cucumbers fisheries in Venezuela. p. 513–516. In: Mooi R. and Telford M. (eds). Echinoderms. Proceedings of the Ninth International Echinoderm Conference, San Francisco, August 1996. San Fransisco, United States of America: Balkema. 923 p.

Sambrano A. 1987. Actividad sedimentivora de *Isostichopus badionotus* e *Holothuria mexicana* (Echinodermata: Holothuroidea) en bajos de Thalassia. Trabajo Especial de Grado. Caracas, Venezuela: Universidad Simon Bolívar. 131 p.

Shiell G.R. and Knott B. 2010. Aggregations and temporal changes in the activity and bioturbation contribution of the sea cucumber *Holothuria whitmaei* (Echinodermata: Holothuroidea). Marine Ecology Progress Series 415:127–139.

Toral-Granda V. 2008. Population status, fisheries and trade of sea cucumbers in Latin America and the Caribbean. p. 213–229. In: Toral-Granda V., Lovatelli A. and Vasconcellos M. (eds). Sea cucumbers: A global review of fisheries and trade. FAO Fisheries and Aquaculture Technical Paper No. 516. Rome, Italy: Food and Agriculture Organization from the United Nations. 317 p.

Tagliafico A., Rangel M.S. and Rago N. 2011. Distribución y densidad de dos especies de holoturoideos en la isla de Cubagua, Venezuela. Revista de Biología Tropical 59(2):843–852.

Uthicke S. 2004. Overfishing of holothurians: Lessons from the Great Barrier Reef. p. 163–172. In: Lovatelli A., Conand C, Purcell S., Uthicke S., Hamel J.-F. and Mercier A. (eds). Advances in Sea Cucumber Aquaculture and Management. FAO Fisheries Technical Paper No. 463. Rome, Italy: Food and Agriculture Organization from the United Nations. 425 p.

Wickham H. 2007. Reshaping data with the reshape package. Journal of Statistical Software: 21(12):1–20.
Wickham H. 2009. ggplot2: Elegant graphics for data analysis. New York, United States of America: Springer-Verlag. 213 p.
Yochum N., Starr R.M. and Wendt D.E. 2011. Utilizing fishermen knowledge and expertise: Keys to success for collaborative fisheries research. Fisheries 36:593–605.
Young C.M. and Chia F.S. 1982. Factors controlling spatial distribution of the sea cucumber *Psolus chitonoides*: Settling and post settling behaviour. Marine Biology 69:195–205.