BULLETIN OF MARINE SCIENCE, 68(1): 59–67, 2001

ASSESSMENT OF THE SEA CUCUMBER (ECHINODERMATA: HOLOTHUROIDEA) AS POTENTIAL FISHERY RESOURCE IN BANCO CHINCHORRO, QUINTANA ROO, MEXICO

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ABSTRACT

The abundance, distribution, size, structure, nutritional quality and feasibility of exploitation of a sea cucumber population, an alternative fishery resource for Banco Chinchorro (Mexican Caribbean) were evaluated. Sampling was conduced during the three main climatic seasons: rainy (September 1998), cold front (December 1998) and dry (April 1999). Five sampling sites were chosen to cover the three major habitats: seagrass (north, central), reef patches (north, south), and shallow sandy-bottoms. Three species and a hybrid were identified: *Holothuria thomasi*, *H. mexicana*, *H. floridana*, and *H. floridana* × *H. mexicana*. *H. floridana* was the most abundant (mean density = 0.12 ind m^{-2}). Growth and natural mortality parameters, and maximum sustainable yield (MSY), were estimated using simplified protocols commonly predicated for the assessment of tropical fisheries, all assuming equilibrium conditions. Banco Chinchorro was hit by Hurricane Mitch following the first survey; estimated abundance during the second survey (after the hurricane) was only 14% of the pre-hurricane survey. Based on this study case we discuss (1) the shortcomings of methods assuming equilibrium, (2) the need for specific life-history data, and (3) the research opportunities provided by the response of populations to natural disturbances or to harvesting.

Sea cucumber fisheries have reached high levels of exploitation in China, Japan and some other Asian countries (Conand, 1990; Ferdouse, 1999; Seeto, 1999). In Mexico, the only developed holothurian fishery began 10 yrs ago with *Isostichopus fuscus* as the target species. In 1994 the species was declared endangered (Norma Oficial Mexicana, 1994), although there was no supporting information. A research project on reproductive biology and growth, as well as a brief description of the fishery in the Gulf of California, were conducted to that end. This study demonstrated that the species was not in real danger, and that it can still be exploited under controlled regimes (Reyes-Bonilla, 1997). Currently, some other species are being fished as an alternative resource in the Sea of Cortés. In the Caribbean, *Isostichopus badionotus* has been recently exploited in Venezuela (Buitrago and Boada, 1996).

Fishermen in Quintana Roo, Mexico have shown interest in sea cucumber as an alternative fishery resource because the main species currently fished, conch (*Strombus gigas*) and spiny lobster (*Panulirus argus*), have been presumably overexploited (Sosa-Cordero et al., 1993).

The main purpose of our study was to assess holothurian populations in Banco Chinchorro, off Quintana Roo (Mexico), in order to determine their abundance, the potential for the development of a fishery, and the nutritional value of the product.

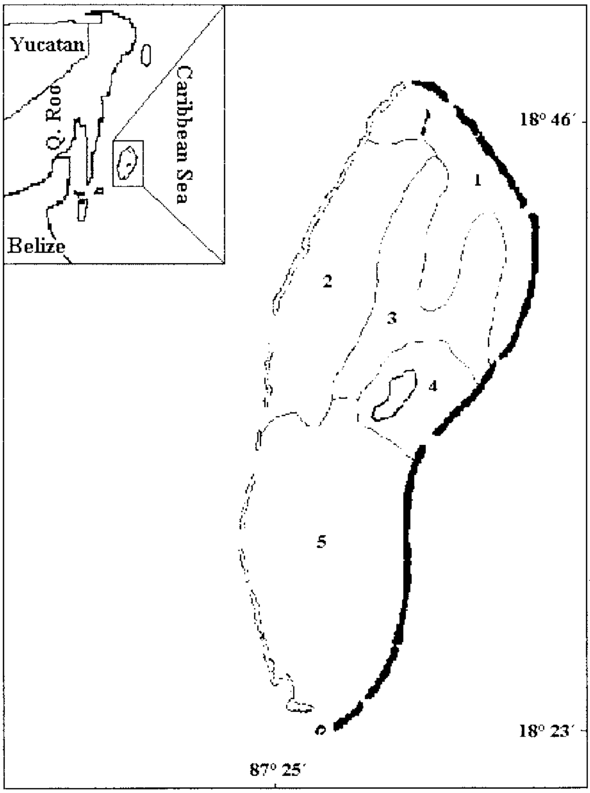

Figure. 1. Geographic location and delimited strata of Banco Chinchorro. Strata: 1. North sea grasses, 2. Shallow sand bottoms, 3. North reef patches, 4. Center sea grasses and 5. South reef patches

Study Area

Banco Chinchorro (BCH) is an atoll-like reef complex located off the southern coast of Quintana Roo (18°47′–18°23′ N, 87°14′–87°27′ W). It has an elliptic shape (internal area = 561 km^2), measuring 46 km long and 15 km wide; the reef-lagoon—its perimeter defined by coral reefs—ranges in depth from 1 to 12 m (Fig. 1) (Aguilar and Aguilar, 1993). Three fishery cooperatives are allowed to operate on the bank, their main fishery products being queen conch (*S. gigas*) and spiny lobster (*P. argus*). Reef-fish, contributing a lesser income, is undertaken by independent fishermen (Sosa-Cordero et al., 1993).

Materials and Methods

Sampling.—Sampling was conducted during each of the three main climatic seasons: rainy (September 1998), cold front (December 1998) and dry (April 1999). Five sampling sites were chosen attenting to the general topography: north and central sea grass meadows, north and south reef patches, and shallow sandy-bottoms (Fig. 1) each with an area of 87.11, 33.43, 91.61, 217.61 and 114.75 km^2, respectively. A sampling unit consisted of all the sea cucumbers within a large circular plot (100 m^2); sampling units were GPS-referenced. A longitudinal transect (100 m, always in the east-west direction) was staked in each sampling stratum; three sampling units (circular plots) were obtained at locations randomly selected along each transect. The number of sampling stations (transects) varied among survey dates: 29 transects (67 plots) in September 1998, 52 transects (156 plots) in December 1998, and 59 transects (165 plots) in April 1999. The specimens in each plot were measured in situ from mouth to anus with flexible tapes. Thirteen specimens were taken to the lab for further identification on the basis of calcareous ossicles (Hendler et al. 1995), and for biochemical analysis.

DATA ANALYSIS.—Size frequency data (grouped in 4 cm intervals) were analyzed to estimate the parameters of the von Bertalanffy growth model (Ricker, 1975) using the computer package FiSAT (Gayanilo et al. 1995). Asymptotic length (*L*) and the growth coefficient (*k*) were estimated using the methods of Powell-Wetheral and Shepherd. The natural mortality coefficient was calculated based on growth parameters (Pauly and Morgan, 1987; Sparre et al., 1989; Gayanilo et al., 1995; Rosenberg and Beddington, 1988; Basson et al., 1988; Galluci et al., 1996). Assuming that the population follows a 'Fox dynamics' (Garcia et al., 1989), and that fishing mortality at the maximum sustainable yield (MSY) level equals natural mortality ($FMSY=M$) (Die and Caddy, 1997), Garcia et al. (1989) expressed MSY for non-exploited resources as:

$$\mathrm{MSY} = M\, B_0\, e^{-1}$$

where M is the instantaneous per capita rate of natural mortality (usually expressed in yr^{-1}), and B_0 is virgin biomass. In non-exploited resources (this study case) total mortality rate, Z, and M are equivalent. We estimated M from the size frequency data and *Bo* through field surveys.

In order to estimate biomass we used design-based approach. It consists of a stratified random sampling scheme, where the mean biomass values calculated for each stratum of the reef lagoon are pooled according to specific rules. This approach allows estimate holothurians densities considering differences due to areas and habitat heterogeneity between stratums without overestimation of the resource (Conde and Díaz, 1985; Conquest et al., 1996).

Nutritional Value.—The specimens collected were analyzed to determine nutritional content. The phenol-sulfuric method was used in order to determine total carbohydrates (Dubois et al., 1956). Fat, moisture and ash were evaluated according to the Association of Official Analytical Chemists (AOAC, 1998). For the nitrogen and protein assessments a modified Kjeldahl method was used (Aguilar et al., 1987).

RESULTS

IDENTIFICATION.—Examination of the ossicles indicated that three species were represented in the collections: *Holothuria* (*Halodeima*) *mexicana* Ludwig, *H.* (*Thymiosycia*) *thomasi*, and *H.* (*Halodeima*) *floridana* Pourtalès. A hybrid, *H. floridana* × *H. mexicana*, was also present; it showed spicules characteristic of both *H. mexicana* and *H. floridana*.

SIZE STRUCTURE.—Only two specimens of *H. thomasi* were observed (both in September 1998) but were not measured. Few specimens of *H. mexicana* (n = 7) were observed during the three surveys, their total length (TL) varying from 17 to 51 cm. Hybrids were also scarce (n = 4), with total length ranging from 20 to 51 cm. Through the rest of the text results pertain to *H. floridana* only, as the other species were poorly represented. In September 1998, TL for 83 individuals of *H. floridana* varied from 9 to 51 cm. In December 1998, TL of 29 individuals varied from 16 to 35 cm, and in April 1999, 54 individuals ranged from 9 to 51 cm (Fig. 2). Considering the size structure of *H. floridana* we assumed that the size of full recruitment is TL = 31 cm.

DENSITY.—In September 1998, observed density varied in the range 0–12 individuals per plot, which corresponds to 0–0.12 ind m^{-2} (Fig. 3A). Density ranged from 0 to 0.02 ind m^{-2} during the cold front season (December 1998) and from 0 to 0.03 ind m^{-2} during

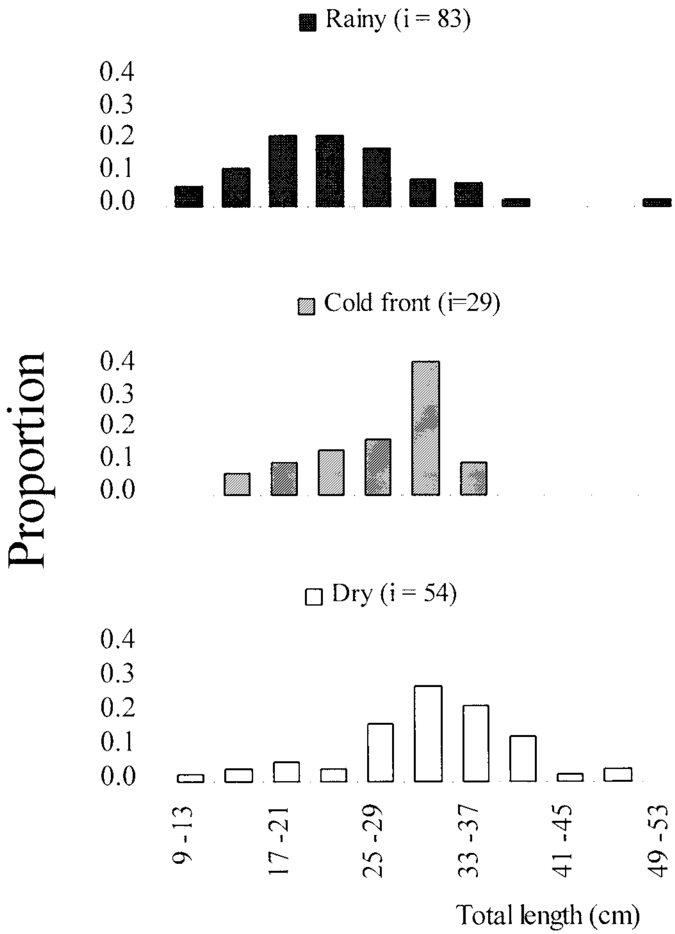

Figure. 2. Total length size classes for *H. floridana*. Frequency sizes in Y-axis are in relative terms; i is the quantity of specimens measured.

the dry season (April 1999). Abundance was highest in the central sea grass stratum, in September 1998 (before Hurricane Mitch hit BCH). The difference in density between each season has a dramatic repercussion on the concentration profiles (Fig. 3B).

GROWTH PARAMETERS.—Parameters of the von Bertalanffy growth model, estimated for *H. floridana* with the Powell-Wetherall and SLCA methods, were L = 57.9 cm (TL), and k = 0.21 yr^{-1}, the lineal regression achieved a r = 0.83 score. Natural mortality rate (M) estimated by the censored version of the Beverton-Holt equation (Ault and Ehrhardt, 1992) was 0.72 yr^{-1}.

BIOMASS ESTIMATION AND MSY.—Mean stock density of *H. floridana* estimated was 21 ind ha^{-1}. Considering the fully recruited individuals (41.7%), each strata area and the mean weight (876 g), the stock global size during this asses is 438 mt. Whereas in September 1998 was 560 mt. It diminished drastically after the hurricane to 170 mt (December 1998) and recovered to 491 mt for April 1999. Applying the García et al. (1989) equation to the global biomass, the MSY is a 116-mt catch per year.

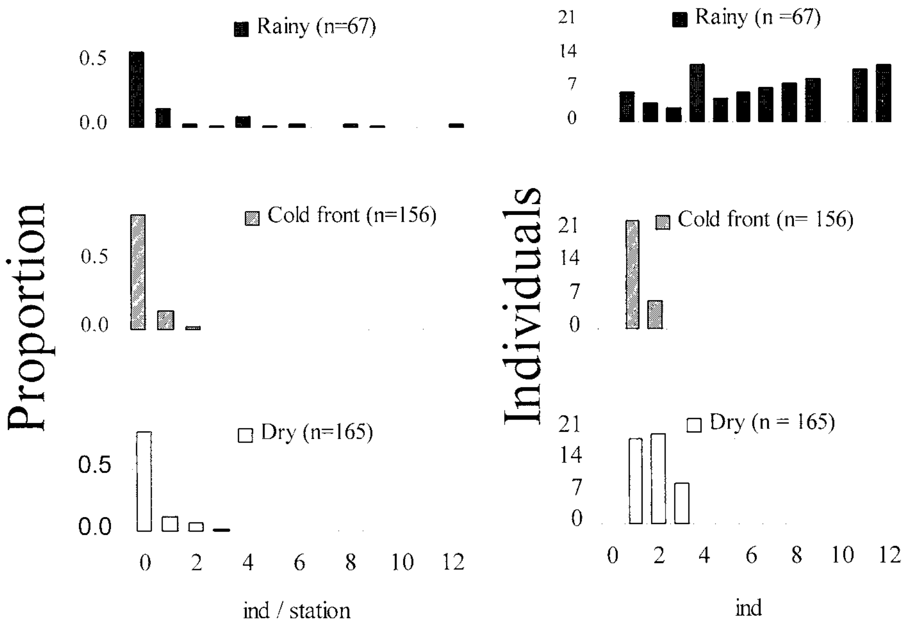

Figure. 3. (A) Number of specimens of *H. floridana* per station. Station frequency in relative terms. (B) Concentration profiles.

Applying to the same equation the partial biomass data, the MSY is 148, 45 and 130 mt respectively for each season.

NUTRITIONAL CONTENT.—Values of carbohydrate, nitrogen, moisture, fat and ash content for all the four species are shown in Table 1, which also presents the nutritional composition of the dried product reported by Sachthananthan (1979). The nutritional values found in this study refer to the raw product; percentages of protein, fat and carbohydrates are given for dehydrated samples.

Table 1. Nutritional content of sea cucumber in Banco Chinchorro and Beche de mer (reported).

Species	Nutritional Parameter (%)					
	Protein	Moisture	Fat	Ash		Carbohydrates
				Minerals	Insoluble	
H. mexicana (n = 4)	74.17 ± 6.65	73.4 ± 4.9	0.91 ± 0.25	9.6 ± 2.8		0.080 ± 0.0040
H. floridana (n = 5)	68.17 ± 3.15	76.3 ± 3.4	1.11 ± 0.26	13.0 ± 5.39		0.080 ± 0.0006
Hybrid (n = 3)	70.47 ± 7.55	75.1 ± 3.5	0.84 ± 0.05	12.6 ± 4.7		0.008 ± 0.0006
H. thomasi (n = 1)	46.36	90.00	1.70	18.3		0.08
Beche de mer (Sachthananthan, 1979)	43	27	2	21	7	–

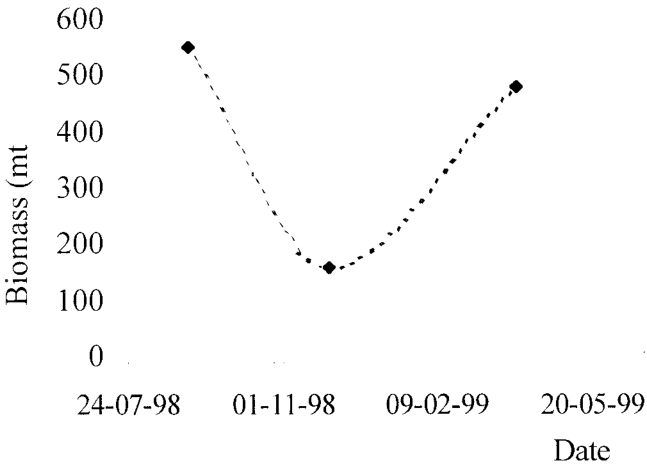

Figure 4. *H. floridana* biomass within the reef lagoon for each season. Arrow indicates hurricane Mitch.

Discussion

Size of commercial sea-cucumber species varies from 20 to 70 cm (total length, TL), with a body-wall thickness of 8–20 mm and a maximum live weight of 6 kg (Sachthananthan, 1979; Conand, 1990). In Banco Chinchorro the maximum size (TL) measured was 51 cm, and the maximum weight 1.87 kg. *H. floridana* is well within the marketable size range for sea cucumbers. Hydrodynamics plays a primarily role in holothurian distribution. Sea cucumbers, in general, prefer low energy waters that favor organic sediment accumulation (Kerr et al., 1993; Barkai, 1991; Conde, 1997; Mosher, 1980). Consistently, in our study we found that they were most abundant in seagrass meadows. The stratified random sampling approach allowed the estimation of density attending to differences due to spatial and habitat-related heterogeneity, without overestimating population size (Conde and Díaz, 1985; Conquest et al., 1996). Density of *H. floridana* in Banco Chinchorro (all sampling dates combined in the analysis) was 20 ind ha^{-1}. This figure may appear low, but falls within range of some commercial species. Density of *I. fuscus* in Baja California ranges from 13 to 23 ind ha^{-1} (Reyes-Bonilla, 1997). Conand (1990) reported average densities of commercial species of 50, 80 and 1000 ind ha^{-1} for reefs in (respectively) New Caledonia, Papua New Guinea and Australia. Thus, the density of *H. floridana* in Banco Chinchorro is towards the lower end to those reported for other commercial sea cucumbers fishing grounds. This comparison, however, should be taken cautiously, as definition and bounding of fishing grounds must certainly vary among studies.

Harvesting sea cucumbers could be a complementary item for the commercial diving fishery, which currently targets queen conch and spiny lobster. High protein content (higher than reported by Sachthananthan (1979)), and low fat and ash content (few calcareous ossicles), contribute to a high quality product (Conand, 1990).

Obviously, the holothurian stock diminished drastically after the first survey was conducted, most likely due to the effect of hurricane Mitch. Then, the calculated MSY could be under-estimated for a stock in equilibrium and over-estimated under conditions of recovering after hurricane. The estimated MSY must be considered as a limit, not as a target. If a fishery were authorized, we suggest that a quota of only ~50% of the MSY should be allowed, and suspend after a catastrophic event (e.g., a hurricane).

In addition to this 'low abundance' one must consider the concentration profile (Fig. 2B), because the reproductive success depends on it (Lawrence, 1987; Sewell and Levitan, 1992; Orensanz et al., 1998; Prince and Hilborn, 1998).

Notwithstanding, more precise studies on reproduction and population dynamics are needed in order to determine whether the species can be exploited or not and to determine the most adequate regimes of exploitation. Other studies are required on its characteristics (appearance, color, flavor, odor, and taste) of the processed product.

Annual surveys of this holothurian stock are needed and would provide much information on the aggregated dynamics (incorporating growth, mortality and recruitment). Stock logistic-type models could then be fitted to the recovery trajectory.

Acknowledgments

The authors express their gratitude to the following persons: the Artisanal Fisheries Group (J. Oliva, N. Quintero, T. Valtierra and V. Valencia) for their collaboration in field work. To the fishermen 'Chandez', 'Vidal' and 'Sami' for their help during fieldwork, and to A. Zavala for laboratory assistance. Special thanks to L. Orenzans, Y. García-Baello and B. Schmook for their comments on this manuscript. This project was financed by ECOSUR (Fishery Ecology Project), and by PATM (Programa de Apoyo a Tesis de Maestría). Special thanks to ECOSUR for two years of scholarship support for MGFB.

Literature Cited

Aguilar A. and W. Aguilar. 1993. Banco Chinchorro. Último refugio en el Caribe mexicano. Cuaderno de divulgación no. 5. CIQRO. México. 35 p.

Aguilar, S. A., B. J. D. Etchevers and R. J. Z. Castellanos. 1987. Análisis químico para evaluar la fertilidad del suelo. Sociedad Floridana de la Ciencia del Suelo. Publicación especial no. 1: 70–72.

Anónimo. 1994. NOM-059-ECOL-1994. Que determina las especies y subespecies de fauna y flora silvestres, terrestres y acuáticas en peligro de extinción, amenazadas, raras y las sujetas a protección especial, y que establece especificaciones para su protección. Diario Oficial de la Federación. Mayo 16.

AOAC. 1998. Official methods of analysis of AOAC International, 16th ed., 4th rev., vols I and II; by Dr. Patricia A. Cunniff, ed.

Ault, J. S. and N. M. Ehrhardt. 1992. Correction to the Beverton and Holt Z-estimator for truncated catch length-frequency distributions. ICLARM Fishbyte 9: 37–39.

Barkai, A. 1991. The effect of water movement on the distribution and interaction of three holothurians species on the South African West Coast. J. Exp. Mar. Biol. Ecol. 153: 241–254.

Basson, M., A. A. Rosenberg and J. R. Beddington. 1988. The accuracy and reliability of two new methods for estimating growth parameters from length frequency data. J. Con. Int. Exp. Mer 44: 277–285.

Beverton, R. J. H. and S. J. Holt. 1956. A review of methods for estimating mortality rates in exploited fish populations, with special reference to sources of bias in catch sampling. Rapp. P.-V. Réun. CIEM 140: 67–83.

Buitrago, J. and J. Boada. 1996. La pesca de la holoturia *Isostichopus badionatus* en el oriente de Venezuela. Memoria. Sociedad de Ciencias Naturales la Salle. Tomo LVI, no. 146, Contribución no. 242: 33–40.

Conand, C. 1990. The fishery resources of Pacific Island Countries, part 2, Holothurians. FAO Fish. Tech. Pap., Rome. 143 p.

Conde, J. E. 1997. Una historia de sushi, sedimentos y codicia: Holoturias o pepinos de mar. Ciencia Hoy 7(39): 5–15.

__________ and H. Díaz. 1985. Diseño de muestreo aleatorio estratificado aplicado al estudio de poblaciones del género Uca (Brachyura, Ocypodidae). Inv. Pesq. 49(4): 567–579.

Conquest, L., R. Burr, R. Donnelly, J. Chavarría and V. Galluci. 1996. Sampling methods for small-scale fisheries in developing countries. Pages 179–225 *in* V. F. Galluci, S. B. Saila, D. J. Gustafson and B. Rothschild, eds. Stock assessment quantitative methods and applications for small-scale fisheries.

Die, D. J. and J. F. Caddy. 1997. Sustainable yield indicators from biomass: are the appropriate reference points for use in tropical fisheries? Fish. Res. 32: 69–79.

Dubois, M., K. A. Gills, J. K. Hamilton, P. A. Rebers and F. Smith. 1956. Colorimetric method for determination of sugar and related substances. Anal. Chem. 28: 350–356.

Ferdouse, F. 1999. Bêche-de-mer markets and utilisation. Secretariat of the Pacific Community. Bêche-de-mer Info. Bull. 11: 3–9.

Galluci, V. F., B. Amjoun, J. B. Hedgepeth and H. Lai. 1996. Sized-based methods of stock assessment of small-scale fisheries. Pages 9–81 *in* V. F. Galluci, S. B. Saila, D. J. Gustafson and B. Rothschild, eds. Stock assessment quantitative methods and applications for small-scale fisheries.

García, S. M., P. Sparre and J. Csirke. 1989. Estimating surplus production and maximum sustainable yield from biomass data when catch and effort time series are not available. Fish. Res. 8: 13–23

Gayanilo, F.C., P. Sparre and D. Pauly. 1995. The FAO-ICLARM stock assessment tools (FiSAT). FAO Computerized Information Series (Fisheries), no. 8. FAO, Rome.

Hendler G., J. E. Miller, D. L Pawson and P. M. Kier. 1995. Sea stars, sea urchins, and allies. Echinoderms of Florida and the Caribbean. Smithson. Inst. Press. Hong Kong. 390 p.

Kerr, A. M., E. M. Stoffel and R. L. Yoon. 1993. Abundance distribution of holothuroids (Echinodermata: Holothuroidea) on a windward and leeward fringing coral reef, Guam, Mariana Islands. Bull. Mar. Sci. 52: 780–791.

Lawrence, J. M. 1987. A functional biology of echinoderms. Croom Helm, London. 340 p.

Mosher, C. 1980. Distribution of *Holothuria arenicola* semper in the Bahamas with observations on habitat, behavior, and feeding activity (Echinodermata: Holothuroidea). Bull. Mar. Sci. 30: 1–12.

Orensanz, J. M., A. M. Parma and M. A. Hall. 1998. The analysis of concentration and crowding in shellfish research. *In* G. S. Jamieson and A. Campbell, eds. Proc. North Pacific Symp. Invertebrate Stock Assesment and Management. Can. Spec. Publ. Fish Aquat. Sci. 125.

Pauly, D. and G. R. Morgan, eds. 1987. Length-based methods in fisheries research. ICLARM-Kuwait Institute for Scientific Research, Sicily. 468 p.

Prince, J. and R. Hilborn. 1998. Concentration profiles and invertebrate fisheries management. *In* G. S. Jamieson and A. Campbell, eds. Proc. North Pacific Symp. Invertebrate Stock Assesment and Management. Can. Spec. Publ. Fish Aquat. Sci. 125.

Reyes-Bonilla, H. 1997. Biología poblacional de *Isistichopus fuscus* (Ludwig, 1875) (Echinodermata: Holothuroidea) en el sur del Golfo de California. Informe final proyecto H216 Convenio Conabio-UABCS FB315/H216/96.

Ricker, W. C. 1975. Computation and interpretation of biological statistics of fish population. Bull. Fish. Res. Bd. Can. 191: 1–382.

Rosenberg, A. A. and J. R. Beddington. 1988. Length-based methods of fish stock assessment. Pages 83–103 *in* J. A. Gulland, ed. Fish population dynamics, 2nd ed. John Wiley and Sons Ltd.

Sachthananthan, K. 1979. Bêche-de-mer of the tropical pacific. A handbook for fishermen. South Pacific Commission Noumea, New Caledonia. 29 p.

Seeto, J. 1999. Bêche-de-mer processing - A little more effort to get much more money while saving precious resources. SPC Bêche-de-mer Info. Bull. 11: 2–3.

Sewell, M. A. and D. R. Levitan. 1992. Fertilization success in a natural spawningof the dendrochirote sea cucumber *Cucumaria miniata*. Bull. Mar. Sci. 51: 161–166.

Sosa-Cordero, E., A. Medina-Quej, A. Ramírez-González, M. Domínguez-Viveros and W. Aguilar-Dávila. 1993. Invertebrados marinos explotados en Quintana Roo. *In* S. Salazar-Vallejo and E. González, eds. Biodiversidad marina y costera de México. Com. Nal. Biodiversidad y CIQRO, México. 865 p.

Sparre, P., E. Ursin and S. C. Venema. 1989. Introduction to tropical fish stock assessment Part I - Manual. FAO Fish. Tech. Pap. no. 306.1. FAO, Rome. 376 p.

DATE SUBMITTED: December 1, 1999. DATE ACCEPTED: July 24, 2000.

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