Lat. Am. J. Aquat. Res., 46(4): 831-836, 2018
DOI: 10.3856/vol46-issue4-fulltext-21

Short Communication

Size and relative condition index of the brown sea cucumber *Isostichopus fuscus* in the northern Gulf of California, Mexico

Héctor Reyes-Bonilla[1], Luis E. Calderón-Aguilera[2]
Juan Manuel Galaviz-López[2] & María Dinorah Herrero-Pérezrul[3]
[1]Departamento de Ciencias Marinas y Costeras, Universidad Autónoma de Baja California Sur
La Paz, B.C.S., México
[2]Laboratorio de Ecología y Pesquerías de la Zona Costera, Centro de Investigación
Científica y de Educación Superior de Ensenada, Ensenada, Baja California, México
[3]Instituto Politécnico Nacional, Centro Interdisciplinario de Ciencias Marinas, La Paz, B.C.S., México
Corresponding autor: Luis E. Calderon-Aguilera (leca@cicese.mx)

ABSTRACT. The brown sea cucumber *Isostichopus fuscus* is the most important commercial holothurian in the eastern Pacific, and its high market value caused overfishing and sharp declines of its populations and catches in several Latin American countries. In Mexico, the fishery has been intense in the northern Gulf of California since the 1990s, and it is currently under strong regulation. To evaluate the current status of the organisms, we measured the size, weight and estimated the relative condition index (Kn) of 702 specimens sampled in 86 rocky reefs of that region in 2016, at depths from 3 to 22 m. Mean length ± SD was 22.32 ± 5.23 cm, lower than average in the northern Gulf, but nevertheless, the average weight was 420.61 ± 192.48 g, among the highest recorded in the eastern Pacific; this is presumably due to the high primary production of the region that favors the presence of well-nourished organisms. The weight (W)-length (L) relationship was $W = 3.27\ L^{1.56}$, and condition index ranged from 0.045 to 2.13 (mean Kn = 0.96 ± 0.29), a figure that did not differ to that reported along the Mexican Pacific. There were differences in the value of Kn among sites, being higher in areas that are subject to the low fishing effort.

Keywords: holothurian, size, weight-length, relative condition index, marine protected area, Baja California.

The brown sea cucumber *Isostichopus fuscus* (Ludwig, 1875) is the most important commercial holothurian species in Latin America (Purcell *et al*., 2012). For that reason, there have been multiple studies of its biology and ecology, including data on abundance (Wolff *et al*., 2012; Glockner-Fagetti *et al.*, 2016), growth (Herrero-Pérezrul *et al.*, 1999; Mercier *et al.*, 2012), reproduction (Fajardo-León *et al.*, 1995; Toral-Granda & Martínez, 2007) and aquaculture (Hamel *et al.*, 2003; Mercier *et al.*, 2004). Also, good information on the status of the fisheries has been published (Ramírez-Soberón *et al.*, 2001; Herrero-Pérezrul & Chávez, 2005; Toral-Granda, 2008), and in general the findings point out that although management efforts have been steered, the stocks have decreased considerably in Ecuador and Mexico, mostly because of exceeding quotas and illegal catches due to the high market value of this resource.

Among the topics that have received less attention from the researchers are the physiology and relative condition of the specimens of *I. fuscus*. These data have ecological relevance as in holothurians they can be linked to the reproductive effort and long-term success of the populations (Watanabe *et al*., 2012), and also have been used as indicators of fishing yields of the brown sea cucumber (Herrero-Pérezrul & Reyes-Bonilla, 2005). From the commercial perspective, a stock with organisms that are heavier related to their length, it is more productive than another with a less adequate physical status (Watanabe *et al.*, 2012). Biologically, the healthier and robust individuals might have a better chance to be reproductively successful as the parents can improve the quality of the yolk, and contribute with extra energy that allows the larvae to be better armed to survive, metamorphose and eventually recruit to the adult population (Glockner-Fagetti & Benítez-Villalobos, 2017). A straightforward but efficient way to define the relative condition of a marine invertebrate is the analysis of the weight and

Corresponding editor: Amilcar Cupul

length of the individuals, and from there to calculate the relative condition index Kn (Cone, 1989; Poot-Salazar *et al*., 2014). This measure signs how heavy is an individual in relation to the expected weight at a given size, and the comparison is made in perspective with another member of the same population (Murphy *et al*., 1991).

The objective of this paper was to examine the relative condition of populations of the brown sea cucumber *I. fuscus* resident at rocky reefs of the northwestern Gulf of California, Mexico, using three indicators: length, weight and relative condition. The region was of particular interest to conduct this study because in the 1990s was the most productive in the country in relation to the total holothurian catch (Fajardo-León & Velez-Barajas, 1996; Singh-Cabanillas & Vélez-Barajas, 1996). Unfortunately, the situation changed by the following decades because of overexploitation of the stocks (Glockner-Fagetti *et al*., 2016), and populations are still not able to recover, even when stronger management measures have been put in place (Toral-Granda, 2008).

For this study, a total of 702 specimens of *I. fuscus* were collected by scuba diving in 86 sites of the northern Gulf of California, México (from 28°17'N, 112°51'W to 29°33'N, 113°33'W in October and November 2016, and at depths of 3 to 22 m. The organisms were placed in individual bags and taken to a boat where their length from mouth to anus was recorded with a precision of ±0.1 cm, and the weight was measured with spring scales (precision ±10 g); this was done after the organisms were left untouched for about 30 min in buckets in order to avoid or at least diminish body contraction. Afterward, the animals were returned to suitable areas at the bottom and placed carefully to avoid physical damage.

We calculated the length-weight relationship by the general equation $W = a L^b$, where W = weight in g, L = body length in cm, a = the ordinate, b = the slope of the regresion (Haddon, 2011). The estimation was conducted in an iterative way using the Levenberg-Marquardt algorithm to find the best model. Afterwards, with the parameters of the equation and the weight and length data, we determined the relative condition (Kn) for each specimen by using an index which conveys the deviation from the actual weight of a given individual, from the expected value calculated for the entire field sample (Herrero-Pérezrul & Reyes-Bonilla 2005; Glocker-Fagetti & Benítez-Villalobos, 2017). The index was calculated as $Kn = W/aL^b$.

For the statistical analyses, Kn of individuals of the sampled populations was compared using one-way analyses of variance, as data were homoscedastic and normal, according to Levene and Kolmogorov-Smirnoff tests (Sokal & Rohlf, 1995).

Finally, we used kriging (Matlab, GLOBEC kriging Software Package - EasyKrig V3.0) to map the spatial distribution of the relative condition of specimens along the study region, based on the geographic position of the field survey and the condition of the specimens found there. Doing that, we prior used Matlab 7.7, the program GEODAS-NG Smart Start Center and topography and line coast from "Global Self-consistent, Hierarchical, and High-resolution Geography Database" (GSHHG, National Center for Environmental Information, NOAA).

The results indicate that the length of the specimens was 22.32 ± 5.25 cm (average ± SD), with a minimum and a maximum sizes of 5.2 and 38.2 cm, respectively (Fig. 1a). The organisms were relatively smaller than those reported for other populations of *I. fuscus* which range in average size from 23 to 25 cm in areas such as the Galapagos Islands, Ecuador (0°N; Hearn *et al*., 2005; Toral-Granda & Martínez, 2007), and Santa Rosalía (27°N), Loreto (25°N) and La Paz (24°N), in Mexico (Herrero-Pérezrul *et al*., 1999; Reyes-Bonilla & Herrero-Pérezrul, 2003; Herrero-Pérezrul & Reyes-Bonilla, 2005), but similar to the ones found in the tropical Mexican coast at Jalisco (20°N) and Huatulco (15°N), according to Glockner-Fagetti & Benítez-Villalobos (2017). At the same time, the reported sizes for Bahía de Los Ángeles (Fig. 3b) in the 1990s was 23 cm (Salgado-Castro, 1994), but for 2005-2007 was just 13.91 ± 3.47 cm, then increased to 17.78 ± 3.78 cm in 2013 (Glockner-Fagetti *et al*., 2016), and in 2016 was 22.3 cm. The slightly smaller size of the brown sea cucumber in our study, when compared with other locations in the Gulf of California, may be a consequence of the overexploitation that the stocks suffered in the last two decades, an idea suggested by Glockner-Fagetti *et al.* (2016). Nevertheless, it is also clear that the stock is recovering, as local fishers are much more aware of the need to protect the resource for the future.

In the fieldwork conducted for this paper, the individual weight of *I. fuscus* specimens was 420.61 ± 192.48 g (range from 8 to 960 g; Fig. 1b). This is one of the highest figures reported anywhere in the eastern Pacific (Herrero-Pérezrul *et al*., 1999; Reyes-Bonilla & Herrero-Pérezrul, 2003; Hearn *et al*., 2005; Herrero-Pérezrul & Reyes-Bonilla, 2005; Toral-Granda & Martínez, 2007; Glockner-Fagetti *et al*., 2016; Glockner-Fagetti & Benítez-Villalobos, 2017), as they ranged from 251 to 396 g in average. The only exception appears in the study by Fajardo-León *et al.* (1995), for Santa Rosalía, Mexico (27°N), where the mean weight of over 200 sampled specimens along a

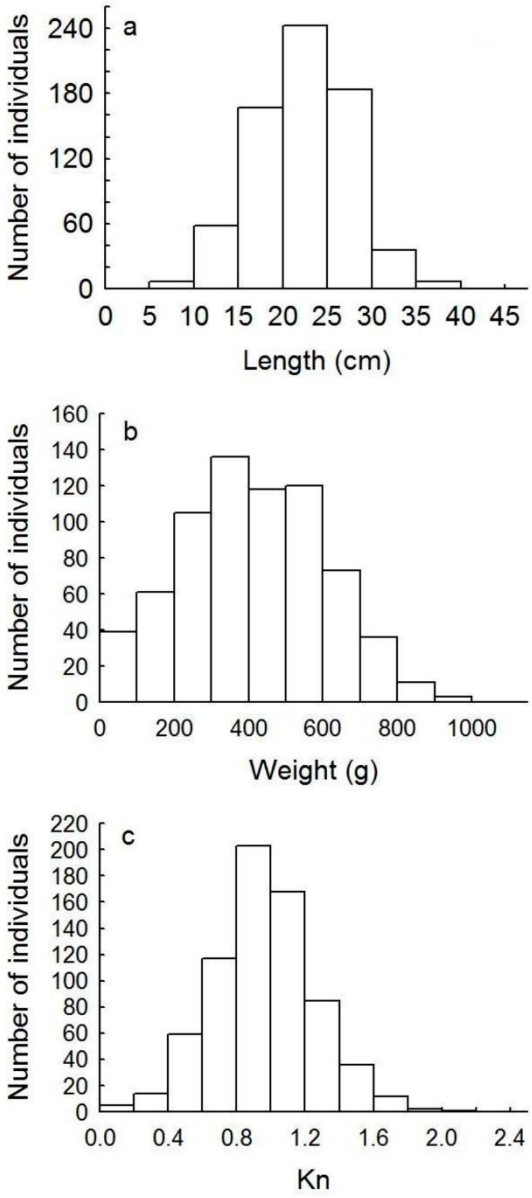

Figure 1. Frequency distribution of a) length, b) weight and c) relative condition index of analyzed specimens of the brown sea cucumber *Isostichopus fuscus* in the northwestern Gulf of California.

year was 458 g. This finding points out the excellent state of the holothurians at the study region, and is one of the reasons why the condition index reach values higher than 2.0 (Fig. 1c), the highest reported for this species (Herrero-Pérezrul & Reyes-Bonilla, 2008; Glockner-Fagetti *et al.*, 2016; Glockner-Fagetti & Benitez-Villalobos, 2017).

According to the nonlinear adjustment, the length-weight relationship coefficients (±SE) were: a = 3.27 ± 0.50 and b = 1.56 ± 0.05; this latter constant is the slope of the curve and has been referred as the "isometry coefficient", as it represents an indication of the symmetry in body form of an organism as it grows (Haddon, 2011). The results of this study show that the studied populations of *I. fuscus* in Baja California had a negative allometric growth (Fig. 2a), a finding that is not surprising, since all published studies on this species found a similar result (Fajardo-León *et al.*, 1996; Herrero-Pérezrul *et al.*, 1999, Reyes-Bonilla & Herrero-Pérezrul, 2003; Herrero-Pérezrul & Reyes-Bonilla, 2005; Glockner-Fagetti *et al.*, 2016, Glockner-Fagetti & Benítez-Villalobos, 2017). The conclusion is that the shape of this holothurian changes ontogenetically, becoming more elongated as they grow (Herrero-Pérezrul *et al.*, 1999).

Also, here we suggest another explanation of the negative allometric growth of *I. fuscus*; it is possible that as the organisms use seawater to maintain their form, and this liquid is less dense than any biological tissue, consequently the individuals are lighter than expected.

The *b* parameter of the weight-length equation presented in this paper (1.56) is one of the highest reported for a population of *I. fuscus* in the literature as the values fluctuate from 1.20 to 1.83 (see review in Glockner-Fagetti *et al.*, 2016). As stated before, this finding suggests that the condition of the holothurians in the northwestern Gulf of California is excellent when compared with any other area of that inner sea, the tropical Mexican Pacific, and even the Galápagos Islands, and that may help explain the high biomass that characterized the fishery in the past (Fajardo-León & Vélez-Barajas, 1996; Herrero-Pérezrul & Chávez, 2005).

The average ± SD condition index Kn of the *I. fuscus* specimens collected at Baja California was 0.96 ± 0.29, with a maximum of 2.14 and a minimum of 0.046 (Fig. 2b). Glockner-Fagetti *et al.* (2016) report that the monthly average of Kn in the population of *I. fuscus* from Bahia de Los Ángeles (Fig. 3b) was 1.08 ± 0.27 in 2013 (ranging from 0.11 to 2.62) and 1.05 ± 0.32 in 2005-2007 (from 0.08 to 2.26), while Herrero-Pérezrul & Reyes-Bonilla (2008) refer monthly means of 1.040 ± 0.027 (0.12 to 2.82) for Loreto (25°N), and Glockner-Fagetti & Benítez-Villalobos (2017) mentioned 1.04 ± 0.31 (0.92 to 1.34) in Huatulco, in the southern Mexican Pacific. As observed, there seems to be no statistical difference in all estimations, evidence of stability in the relative condition of the specimens regardless of region and time in the northern Gulf. In this region, it could be expected that with the reduction of the population sizes and the interannual stability in the primary ocean productivity (Brusca *et al.*, 2017), the potential increase of available food per individual might have improved the condition of the holothurians,

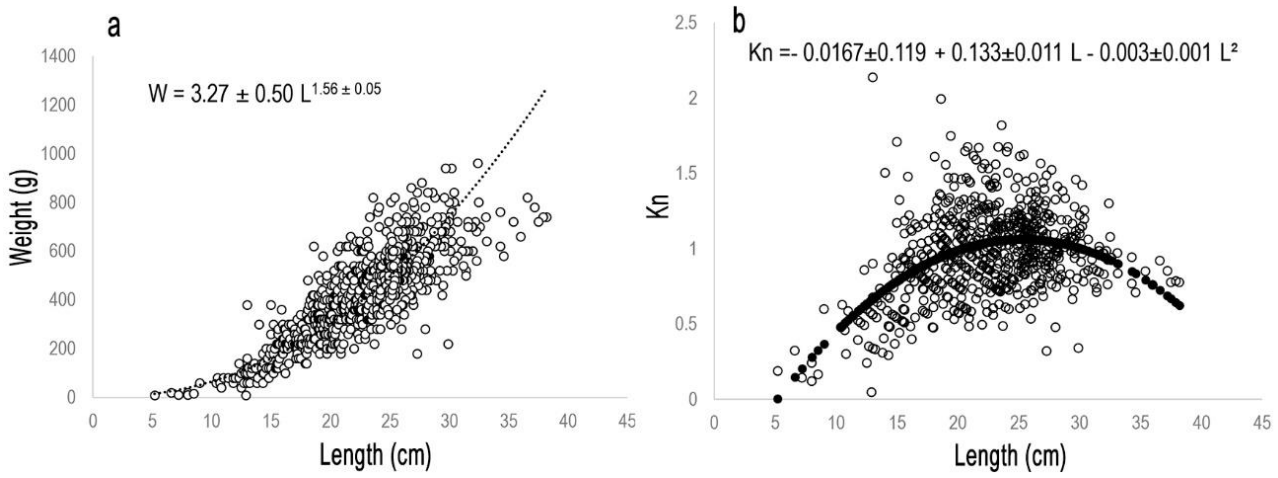

Figure 2. a) Length-weight relationship and b) relative condition index of the brown sea cucumber *Isostichopus fuscus* in the study area. The regression models that describe the data are presented.

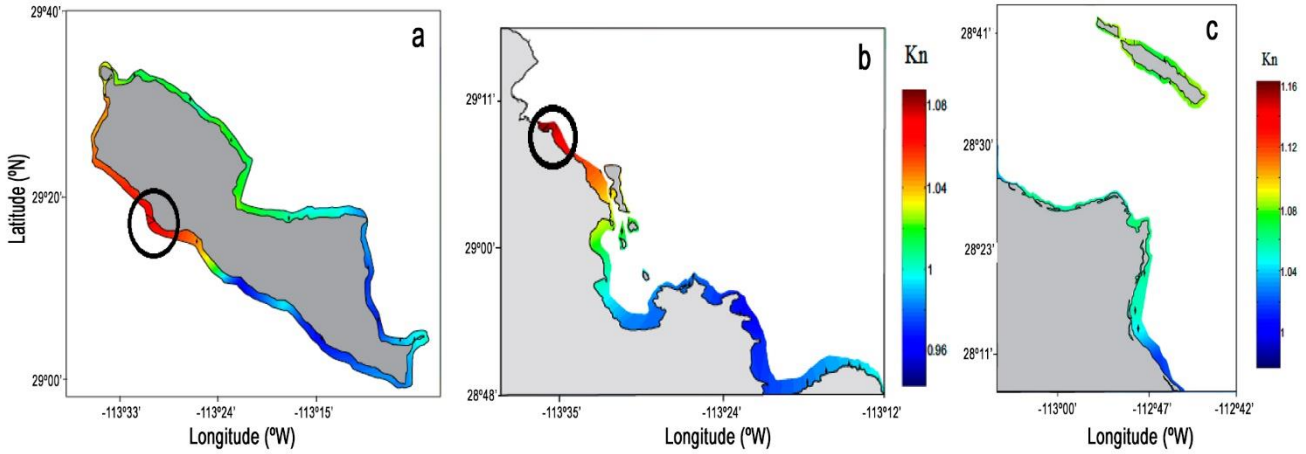

Figure 3. Interpolation maps of the relative condition index (Kn) of *I. fuscus*, along the study region. a) Angel de la Guarda Island, b) Bahía de los Ángeles, c) San Lorenzo Archipelago. The areas inside the black circles include the locations with significantly higher Kn than the rest (five sample sites in Fig. 3a and four in Fig. 3b; from a total of 85 sites).

but that was not the case. We suggest that as environmental factors seem to play minor roles, the constancy in the relative condition of *I. fuscus* may represent a physiological limit in the weight of the animals in relation to its length.

Moreover, the analysis of variance showed that specimens from different sites differ in their Kn ($F_{(87, 614)} = 3.5$, $P < 0.01$): organisms in the outer coast of Angel de la Guarda Island (Fig. 3a) and north of Bahia de los Ángeles (Fig. 3b) had higher Kn, as shown in the interpolated maps of relative condition. The possible explanation hinges on the way the fishery is conducted. Many fishermen travel from Sonora (at the eastern coast of the gulf) to the east, but they usually work at San Lorenzo Island (Fig. 3c) and west of Angel de la Guarda Island. While on the other hand, local fishermen conduct their work mostly on the peninsular coast; this way, the northwest coast of Angel de la Guarda Island may receive less fishing effort than others. The case for north Bahía de los Ángeles is explained here by the management efforts conducted by authorities of the biosphere reserve.

In conclusion, this study demonstrated that average length in the populations of the brown sea cucumber *I. fuscus* in the northeastern Gulf of California is lower than that reported for other areas of the same region, but size has been improving from the lowest point in 2005-2007 when the fishery was at its apex. On the other hand, the average weight of the specimens was among the highest reported in the eastern Pacific, probably reflecting on the high local primary productivity of the study region (Brusca *et al.*, 2017). Finally, the average

relative condition of the animals did not differ to that recorded in the Mexican Pacific coast, and in the study region, the value of the index has not changed in a decade; something that can be explained as a genetic limitation on the condition of the specimens.

ACKNOWLEDGMENT

The study was conducted with funds from project 225235 SAGARPA-CONACYT and OSC1 PROCODES to LECA. The authors acknowledge the collaboration of Buzos de Bahía SCPR in the fieldwork.

REFERENCES

Brusca, R.C., S. Álvarez-Borrego, P.A. Hastings & L.T. Findley. 2017. Colorado River flow and biological productivity in the northern Gulf of California, Mexico. Earth-Sci. Rev., 164: 1-30.

Cone, R.S. The need to reconsider the use of condition indices in fishery science. 1989. Trans. Am. Fish. Soc., 118: 510-514.

Fajardo-León, M.C. & A. Vélez-Barajas. 1996. Pesquería del pepino de mar. In: M.C. Casas-Valdéz & G. Ponce-Díaz (eds.). Estudio del potencial pesquero y acuícola de Baja California Sur, SEMARNAP/ CICIMAR, La Paz, pp. 151-165.

Fajardo-León, M.C., E. Michel-Guerrero, J. Singh-Cabanillas, J.A. Vélez-Barajas & A. Massó-Rojas. 1995. Estructura poblacional y ciclo reproductor del pepino de mar *Isostichopus fuscus* en Santa Rosalía, B.C.S., México. Cienc. Pesq., 11: 45-53.

Glockner-Fagetti, A. & F. Benítez-Villalobos. 2017. Spatio-temporal variation in density and size structure of the endangered sea cucumber *Isostichopus fuscus* in Huatulco National Park, Mexico. Mar. Ecol., 38(1): e12386. doi:10.1111/maec.12386.

Glockner-Fagetti, A., L.E. Calderón-Aguilera & M.D. Herrero-Pérezrul. 2016. Density decrease in an exploited population of brown sea cucumber *Isostichopus fuscus* in a biosphere reserve from the Baja California Peninsula, Mexico. Ocean Coast. Manage., 121: 49-59.

Haddon, M. 2011. Modeling and quantitative methods in fisheries. Chapman and Hall/CRC, Boca Raton, 465 pp.

Hamel, J.F., R. Ycaza-Hidalgo & A. Mercier. 2003. Larval development and juvenile growth of the Galapagos sea cucumber *Isostichopus fuscus*. SPC Bêche de Mer Inf. Bull., 18: 3-8.

Hearn, A., P. Martínez, M.V. Toral-Granda, J.C. Murillo & J. Polovina. 2005. Population dynamics of the exploited sea cucumber *Isostichopus fuscus* in the western Galápagos Islands, Ecuador. Fish. Oceanogr., 14: 377-385.

Herrero-Pérezrul, M.D. & E.A. Chávez. 2005. Optimum fishing strategies for *Isostichopus fuscus* (Echinodermata: Holothuroidea) in the Gulf of California, México. Rev. Biol. Trop., 53: 357-366.

Herrero-Pérezrul, M.D. & H. Reyes-Bonilla. 2008. Weight-length relationship and relative condition of the holothurian *Isostichopus fuscus* at Espiritu Santo Island, Gulf of California, México. Rev. Biol. Trop., 56: 273-280.

Herrero-Pérezrul, M.D. & H. Reyes-Bonilla. 2005. Weight-length relationship and relative condition of the holothurian *Isostichopus fuscus* at Espíritu Santo Island, Gulf of California, México. Rev. Biol. Trop., 56 (Suppl. 3): 273-280.

Herrero-Pérezrul, M.D., H. Reyes-Bonilla, F. García-Domínguez & C.E. Cintra-Buenrostro. 1999. Reproduction and growth of *Isostichopus fuscus* (Ludwig, 1875) (Echinodermata: Holothuroidea) in the southern Gulf of California, México. Mar. Biol., 135: 521-532.

Mercier, A., R. Ycaza-Hidalgo & J.F. Hamel. 2004. Aquaculture of the Galapagos sea cucumber, *Isostichopus fuscus*. In: A. Lovatelli, C. Conand, S. Purcell, S. Uthicke, J.F. Hamel & A. Mercier (eds.). Advances in sea cucumber aquaculture and management. FAO, Rome, pp. 347-358.

Mercier, A., R. Ycaza-Hidalgo, R. Espinoza, V.M. Arriaga-Haro & J.F. Hamel. 2012. Hatchery experience and useful lessons from *Isostichopus fuscus* in Ecuador and Mexico. Asia-Pacific tropical sea cucumber aquaculture. ACIAR Proceedings, 136: 79-90.

Murphy, B.R., D.W. Willis & T.A. Springer. 1991. The relative weight index in fisheries management: status and needs. Fisheries, 16: 30-38.

Poot-Salazar, A., A. Hernández-Flores & P.L. Ardisson. 2014. Use of the SLW index to calculate growth function in the sea cucumber *Isostichopus badionotus*. Sci. Rep., 4(5151): doi: 10.1038/srep05151.

Purcell, S.W., Y. Samyn & C. Conand. 2012. Commercially important sea cucumbers of the World. FAO Species Catalogue for Fishery Purposes, 6: 1-124.

Ramírez-Soberón, G., M.C. Fajardo-León, J.A. Massó-Rojas, A. Aguilar-Ibarra & A. Gutiérrez-García. 2001. Pepino de mar. Sustentabilidad y pesca responsable en México. Evaluación y manejo. Instituto Nacional de la Pesca/SAGARPA, México, pp. 851-874.

Reyes-Bonilla, H. & M.D. Herrero-Pérezrul. 2003. Population parameters of an exploited population of *Isostichopus fuscus* (Holothuroidea) in the southern Gulf of California, Mexico. Fish. Res., 59: 423-430.

Salgado-Castro, L.R. 1994. The fishery of the sea cucumbers *Isostichopus fuscus* and *Parastichopus parvimensis* in Baja California, México. In: B. David & M. Guille (eds.). Echinoderms through time. Balkema, Rotterdam, 504 pp.

Singh-Cabanillas, J. & A. Vélez-Barajas. 1996. La pesquería de pepino de mar *Isostichopus fuscus* en la costa oriental de Baja California Sur, y propuestas de regulación. Cienc. Pesq., 12: 13-18.

Sokal, R.R. & F.J. Rohlf. 1995 Biometry. W.H.H. Freeman and Company, New York, 915 pp.

Toral-Granda, M.V. 2008. Population status, fisheries, and trade of sea cucumbers in Latin America and the Caribbean. In: V. Toral-Granda, A. Lovatelli & M. Vasconcellos (eds.). Sea cucumbers. A global review of fisheries and trade. FAO Fisheries and Aquaculture Technical Paper 516, Rome, pp. 213-230.

Received: 3 March 2017; Accepted: 5 December 2017

Toral-Granda, M. V. & P.C. Martínez. 2007. Reproductive biology and population structure of the sea cucumber *Isostichopus fuscus* (Ludwig, 1875) (Holothuroidea) in Caamaño, Galápagos Islands, Ecuador. Mar. Biol., 151: 2091-2098.

Watanabe, S., J.M. Zarate, J.G. Sumbing, M. Lebata-Ramos & M.F. Nievales. 2012. Size measurement and nutritional condition evaluation methods in sandfish (*Holothuria scabra,* Jaeger). Aquacult. Res., 43: 940-948.

Wolff, M., A. Schuhbauer & M. Castrejón. 2012. A revised strategy for the monitoring and management of the Galapagos sea cucumber *Isostichopus fuscus* (Aspidochirotida: Stichopodidae). Rev. Biol. Trop., 60: 539-551.