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Length-weight relationship of four deep-sea chondrichthyans (Elasmobranchii & Holocephali) in Ecuadorian oceanic waters

Paulina Sepa [a], Dialhy Coello [a], Marco Herrera [b], René Zambrano [a,*]

[a] Departamento de Ciencias del Mar, Carrera de Biología, Facultad de Ciencias Naturales, Universidad de Guayaquil, C.P. 090601 Guayaquil, Ecuador
[b] Programa de Especies Vulnerables, Proceso de Investigación de Recursos Bioacuáticos y su Ambiente, Instituto Público de Investigación de Acuicultura y Pesca, CP. 090308 Guayaquil, Ecuador

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ABSTRACT

The present work reported the length-weight relationship of four deep-sea chondrichthyan species (i.e., *Hydrolagus* spp., *E. granulosus*, *C. owstonii* and *C. squamosus*) captured by the experimental fishery of the depth cod (*Dissostichus eleginoides*) in Ecuadorian oceanic waters, from 2018 to 2020. The fishing included 592 hauls, starting at 1,000 m depth, using between 1,000 to 1,500 N° 14/0 circle hooks. Length-weight relationship (LWR) was estimated by the power model ($y = ax^b$). The determination coefficient (r^2) value was always above 0.94. The slope (b) showed negative allometric growth ($b < 3$) for females of *C. owstonii*, *C. squamosus* and males of *E. granulosus* and *Hydrolagus* spp. Allometry was positive ($b > 3$) in females of *E. granulosus* and *Hydrolagus* spp. as well as, in males of *C. owstonii* and *C squamosus*. In addition, the allometry for the combined sexes was negative in *C. owstonii* and was positive in *C. squamosus* and *E. granulosus*.

Introduction

In Ecuador, the research on deep-sea chondrichthyans is mainly focused on records of species in the Galapagos Islands, referring to the orders Chimeriformes, Rajiformes, Squaliformes and Hexanchiformes (Acuña-Marrero et al., 2013; Buglass et al., 2020; Cerutti-Pereyra et al., 2018; McCosker & Rosenblatt, 2010). In addition, there are reports on the observed sizes and weights of the species (de Cárdenas-González & Maroto-Castaño, 2008; Martinez-Ortiz and Garcia-Dominguez, 2013), as well, there was a reported paper on the size-weight relationship of Squaliformes (González-Troncoso, 2009).

Currently, there is an experimental deep-sea cod fishery (*Dissostichus eleginoides*) in Ecuadorian oceanic waters, in which the deep-sea chondrichthyans are species caught as associated fauna. The oceanic waters of Ecuador are a place with an abundance of chondrichthyan species. Pelagic sharks are the most known as they are susceptible to fishing since some decades ago, while the fisheries in deep-water species are in an early stage of development (Bonaccorso et al., 2021; Jacquet et al., 2008; Rajan, 2018).

Furthermore, adequate management of fishery resources requires biological information on target and non-target species, e.g., length-frequency distribution, length-weight relationship, age structure and individual growth (Lteif et al., 2016; Salgado-Ugarte & Saito-Quezada, 2020). Therefore, the objective of the present work was to determine the length-weight relationship for four most representative deep-sea chondrichthyan species associated with the deep-sea cod fishery in Ecuador. The results obtained may contribute to expanding the biological information on these species, as well as to serve as input parameters in fishery evaluation and management models.

Material and methods

The present study was carried out in the *Instituto Público de Investigación de Acuicultura y Pesca* (IPIAP), corresponding to the project "Distribution, abundance and biological aspects of deep-sea cod" (*Dissostichus eleginoides*) in Ecuadorian oceanic waters (Fig. 1). Data referring to the period 2018–2020 were analyzed, in which 592 hauls were made, starting at 1,000 m depth, each with between 1,000 and 1,500 N°14/0 circle hooks. The total body length and total wet body weight data were measured onboard

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* Corresponding author at: Marine Science Department, Career in Biology, Natural Sciences Faculty, University of Guayaquil, Ecuador.
E-mail address: eddie_zam89@hotmail.com (R. Zambrano).

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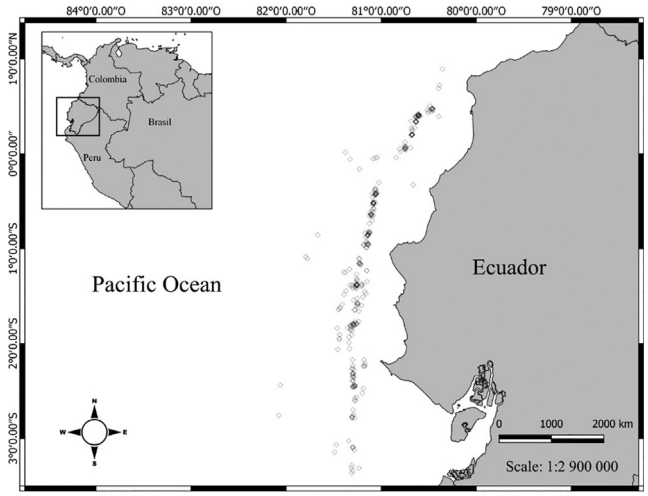

Fig. 1. Experimental fishing sites for deep-sea cod in Ecuadorian ocean waters between 2018 and 2020.

using a conventional tape measure and a 100-kg hook scale, respectively. Species were identified using the guide to deep-sea cartilaginous fishes proposed by Ebert and Mostarda (2016).

The size-weight relationships were determined using the potential model $y = ax^b$ (Le Cren, 1951), which is the classical model used in this type of analysis (for example, see Sabido-Itzá et al., 2021; Siddique et al., 2021, 2015).

The model was fitted to the raw data by least squares, using the Gauss-Newton numerical method (Salgado-Ugarte & Saito-Quezada, 2020). The type of allometry was determined by the value of the slope (b): $b > 3$ positive; if $b < 3$ negative; if $b = 3$, isometry (Froese, 2006).

Results

A total of 7,273 individuals was analyzed, comprised of the most representative species *Hydrolagus* spp. with 6,144 individuals, followed by *Etmopterus granulosus* (580 individuals), *Centroscymnus owstonii* (435 individuals) and *Centrophorus squamosus* (114 individuals). In each species, the sample was mainly represented by females. The potential model had a coefficient of determination with values higher than 0.941 (Table 1).

The slope values showed negative allometric growth ($b < 3$) for females of *C. owstonii*, *C. squamosus* and males of *E. granulosus* and *Hydrolagus* spp. Allometry was positive ($b > 3$) in females of *E. granulosus* and *Hydrolagus spp*. as well as in males of *C. owstonii* and *C. squamosus*. On the other hand, the allometry for the combined sexes was negative in *C. owstonii* and was positive in *C. squamosus* and *E. granulosus* (Table 1).

Discussion

The maximum total body length (TL) observed in *C. squamosus*, *E. granulosus* and *Hydrolagus* spp. was higher than that reported by other authors in Ecuadorian and Chilean waters (*C. squamosus*, 100 cm TL; *E. granulosus*, 60 cm TL; *Hydrolagus melanophasma*, 122.4 cm TL), and it could be related to the fishing gear used (González-Troncoso, 2009; Lamilla & Bustamante, 2005; Martinez-Ortiz & Garcia-Dominguez, 2013). Where Martinez-Ortiz and Garcia-Dominguez (2013) used a bottom trawl (< 700 m depth), while González-Troncoso (2009) used surface gillnetting. In other species as *Squalus megalops*, the size of specimens is related to the fishing gear and depth sampled (Braccini et al., 2006).

The level of allometry (b-value) was differentiated between sexes for all species, which could be related to the sample characteristics, particularly the main dominance of female individuals. Additionally, our allometry results were different to the reported in FishBase (Froese & Pauly, 2021). The females of *C. owstonii* and *C. squamosus* could be lighter (i.e., negative allometry) to offset the weight increase due to pregnancy (Motta et al., 2014; Stevens & Wiley, 1986).

A positive allometry for females (b = 3.425 – 3.610) and negative in males (b = 2.894 – 2.680) was reported in *C. owstonii*, while in *C. squamosus*, the allometry was positive in females and males, b = 3.382 and 3.228, respectively (Froese & Pauly, 2021). Those data are contradictory to our results for *C. owstonii* and congruent only for males *C. squamosus*.

For *Centroscymnus* species and other chondrichthyans, the depth segregation related to breeding has been reported in Australian waters and Japan; pregnant females prefer shallower waters while young and adults of both sexes inhabit deeper waters

Table 1
Minimum-maximum values of the total body length and total body weight of deep-sea chondrichthyan species present in Ecuadorian ocean waters. Intercept (a) and slope (b) values of power model with confidence intervals (CI) at 95%, as well as determinant coefficient (r^2).

Species	Sex	n	Total body length (cm)		Total body weight (g)		Regression parameters			Confidence intervals (95%)	
			min	max	min	max	a	b	r^2	CI_a	CI_b
Centroscymnus owstonii											
	F	412	31.00	106.00	362.87	5896.70	0.0092	2.8695	0.965	0.0035–0.0148	2.729–3.010
	M	23	42.50	81.00	476.27	2993.71	0.0015	3.2744	0.985	−0.0005–0.0036	2.960–3.589
	Unsexed	435	31.00	106.00	362.87	5896.70	0.0082	2.8939	0.965	0.0034–0.0130	2.759–3.028
Centrophorus squamosus											
	F	65	46.00	101.00	666.78	7484.27	0.0159	2.8039	0.982	−0,0189–0.0507	2.323–3.285
	M	49	61.00	91.00	1161.20	6350.29	0.0007	3.4940	0.968	−0.0008–0.0022	3.004–3.984
	Unsexed	114	46.00	101.00	666.78	7484.27	0.0027	3.1901	0.979	−0.0006–0.0060	2.921–3.460
Etmopterus granulosus											
	F	494	30.00	94.00	272.16	5896.70	0.0035	3.1234	0.971	0.0025–0.0044	3.059–3.188
	M	86	34.50	67.00	226.80	1678.29	0.0152	2.7461	0.978	−0.0038–0.0342	2.432–3.060
	Unsexed	580	30.00	94.00	226.80	5896.70	0.0035	3.1226	0.971	0.0026–0.0043	3.062–3.183
Hydrolagus spp.											
	F	5,136	70.00	150.00	1360.78	21772.43	0.0023	3.1809	0.942	0.0016–0.0030	3.117–3.245
	M	1,008	67.00	148.00	1360.78	15422.14	0.4356	2.0511	0.956	0.1890–0.6822	1.931–2.172
	Unsexed	6,144	67.00	150.00	1360.78	21772.43	0.0037	3.0804	0.941	0.0027–0.0047	3.022–3.138

(Braccini et al., 2006; Yano & Tanaka, 1988). The samples of the present study were mainly juvenile individuals, considering a size at sexual maturity at 100 cm TL for females and 74 cm TL for males in *C. owstonii*, and 128 cm TL for females and 102 cm TL for males in *C. squamosus* (Clarke et al., 2002; Yano & Tanaka, 1988).

For the species *E. granulosus* and *Hydrolagus* spp., the allometry was positive in females and negative in males. On the other hand, only unsexed information is reported in FishBase for 19 individuals of *E. granulosus* with values assumed as isometry (b = 2.920 and 3.060); that is incongruent with our results that shows a positive allometry in the unsexes data.

The allometry levels could be related to the degree of stomach repletion, stage of maturity, liver weight and the condition of the chondrichthyan (Kohler et al., 1995). In the genus *Centroscymnus*, the pregnant females with full-term embryos could be found in deeper water (Yano & Tanaka, 1988). In this sense, it is necessary to accomplish our work with a study of the reproductive conditions of females and their trophic ecology to determine if these factors would influence the difference in allometry between sexes.

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Ethical Clearance

The samples of this research were a part of commercial fishery harvests and no environmental harms were inflicted and all regulations, policies, and laws governing the exploitation of fish were followed to ensure and secure sustainable fishery.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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