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Length-weight relationship of 15 species of deep-water chondrichthyans in the Canary Islands (eastern-central Atlantic)

by

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Résumé. – Relation taille-poids pour 15 espèces de chondrichtyens d'eaux profondes des îles Canaries (Atlantique Centre-Est).

Les relations taille-poids (RTP) ont été estimées pour 15 espèces de chondrichtyens d'eaux profondes provenant des pentes des îles Canaries. Les individus ont été obtenus de manière opportuniste au cours de différents projets de recherche sur les pêches. Les RTP ont été estimés pour les espèces de chondrichtyens : *Centrophorus granulosus, Centrophorus squamosus, Deania calceus, Deania hystricosa, Deania profundorum, Etmopterus pusillus, Etmopterus princeps, Centroscymnus coelolepis, Centroscymnus crepidater, Centroscymnus owstonii, Scymnodon ringens, Zameus squamulosus, Chimaera monstrosa, Hydrolagus mirabilis*, et *Rhinochimaera atlantica*. Les équations des RTP obtenues sont soutenues par des coefficients de corrélations élevés. Les données obtenues permettent d'améliorer les connaissances de base nécessaires à la poursuite de la conservation ou de la modélisation des écosystèmes.

Key words. – Deep-water – Chondrichthyes – Macaronesia – LWR – Growth.

The Canary Islands form a group of eight volcanic oceanic islands and some islets located in the eastern-central Atlantic. They consist of underwater edifices that rise abruptly from the ocean floor, at depths of more than 4000 m in some cases (*e.g*. González *et al*., 2020). The islands are situated within the Canary Current System, which is one of the Large Marine Ecosystems of the World. It forms one of the primary eastern boundary coastal upwelling systems of the world, occurring over a shelf and shelf-break (Pajuelo *et al*., 2016).

Chondrichthyan species (mainly elasmobranchs) play a fundamental role in the structure and functioning of marine ecosystem via predation (Heithaus *et al*., 2008; Espino *et al*., 2022). They control or are affected by the up-bottom and bottom-up alterations of food webs (Dulvy *et al*., 2017; Lester *et al*., 2020). However, they are highly vulnerable to anthropogenic impacts like fishing pressure, due to their life strategies such as late sexual maturity, low fecundity, and slow growth rate (Hamlett, 2005; Pajuelo *et al*., 2011). Since alterations in the abundance of these species (mainly in deep-water habitats) result in severe impacts on ecosystems, fishing for deep-sea sharks is essentially prohibited within the European Union according to the Council Regulation (EU) 2018/2025 of 17 December 2018.

Length-weight relationships (LWR) are of key importance and usefulness for fish biology, fisheries, and conservation, and increase the basic knowledge of their population ecology (Ricker, 1973; Froese *et al*., 2011). The existing information for the 15 species studied here is very limited due to the scarce number of individuals examined, or the available data refer to distant geographic locations in another ocean or hemisphere.

MATERIAL AND METHODS

Individuals were collected during eight bottom-longline fishing surveys conducted around the central islands of the archipelago (Gran Canaria and Tenerife), between 200 and 2000 m depth, from February 2005 to November 2014. Due to the abrupt underwater relief consisting of irregular volcanic rocks and escarpments, longlines were used as the ideal sampling method.

All chondrichthyan individuals were identified to species level. The taxonomical arrangement follows Froese and Pauly (2022) and WoRMS (2022). Scientific names of fish species were also verified in Eschmeyer *et al*. (2022). The name *Centrophorus granulosus* was assigned according to revisions by White *et al*. (2013, 2022). After identifying individuals (and sexing when possible), their total length (TL) was measured to the nearest cm, and total weight (TW) recorded to the nearest g for those less than 2 kg and to the nearest 10 g for heavier individuals.

The LWR equation used was $TW = a\,(TL)^b$, where: TW is the total weight of the animal (g); TL the total length (cm); *a* the intercept and *b* the regression coefficient (Ricker, 1973). Parameters *a* and *b* of the LWR were estimated using linear regression, by means of the least squares algorithm applying the log-transformation $TW = \log a + b \log TL$ (Froese, 2006). The 95% confidence intervals of *a* and *b* and the standard error were also calculated. We eliminated outliers through the pcout function of the R package mvoutlier (Filzmoser *et al*., 2008; Filzmoser and Gregorich, 2020). Information available on LWR of each studied species and their maximum length were obtained from FishBase (Froese and Pauly, 2022).

RESULTS

The LWRs for 15 deep-sea chondrichthyan species from the Canaries are presented in Table I, together with sample size, length and weight ranges, 95% confidence limits and standard error

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Table I. – Length-weight relationships for 15 species of deep-water chondrichthyans from the Canary Islands (eastern-central Atlantic). N, sample size; TL, total length (cm); SE, standard error; TW, total weight (g), *a* and *b*, model parameters; SE(*b*), standard error of *b*; CI (*a*), 95% confidence interval of *a*; CI (*b*), 95% confidence interval of *b*; r^2, determination coefficient; *maximum TL or TW values observed; † upper limit used in the LWR estimation larger than reported by Froese and Pauly (2022).

Family	Species name	N	TL (cm) Min-Max	TW (g) Min-Max	a [CI (*a*)]	*b* [CI (*b*)]	SE (*b*)	r^2
Centrophoridae	*Centrophorus granulosus* (Bloch & Schneider, 1801)	192	78-148†	2460-21200*	0.00071 [0.0004-0.0014]	3.459 [3.312-3.607]	0.075	0.918
Centrophoridae	*Centrophorus squamosus* (Bonnaterre, 1788)	59	26-149†	71-16520*	0.00256 [0.0017-0.0039]	3.151 [3.059-3.243]	0.064	0.988
Centrophoridae	*Deania calceus* (Lowe, 1839)	164	38-109†	255-5020*	0.00724 [0.0047-0.0112]	2.859 [2.759-2.959]	0.051	0.952
Centrophoridae	*Deania hystricosa* (Garman, 1906)	62	80-112*†	1950-5950*	0.00049 [0.0002-0.0015]	3.473 [3.234-3.712]	0.120	0.934
Centrophoridae	*Deania profundorum* (Smith & Radcliffe, 1912)	28	59-93	710-3760*	0.00147[0.0002-0.0081]	3.219 [2.828-3.612]	0.191	0.913
Etmopteridae	*Etmopterus pusillus* (Lowe, 1839)	33	39-51*†	190-505	0.00016 [0.0001-0.0006]	3.811 [3.482-4.140]	0.161	0.947
Etmopteridae	*Etmopterus princeps* Collett, 1904	43	46-71	480-2065*	0.00027 [0.0001-0.0010]	3.714 [3.397-4.032]	0.157	0.932
Somniosidae	*Centroscymnus coelolepis* Barbosa du Bocage & de Brito Capello, 1864	268	38-116†	595-12660	0.00333 [0.0019-0.0056]	3.172 [3.053-3.292]	0.061	0.911
Somniosidae	*Centroscymnus crepidater* (Barbosa du Bocage & de Brito Capello, 1864)	106	35-96	150-4680*	0.00120 [0.0005-0.0026]	3.335 [3.150-3.520]	0.110	0.925
Somniosidae	*Centroscymnus owstonii* Garman, 1906	157	39-119	650-10620	0.03184 [0.0190-0.0535]	2.636 [2.517-2.756]	0.060	0.925
Somniosidae	*Scymnodon ringens* Barbosa du Bocage & de Brito Capello, 1864	212	41-132*†	440-12450*	0.00171 [0.0011-0.0026]	3.342 [3.241-3.443]	0.051	0.953
Somniosidae	*Zameus squamulosus* (Günther, 1877)	184†	41-95*	285-4350*	0.00174 [0.0010-0.0030]	3.197 [3.067-3.328]	0.066	0.927
Chimaeridae	*Chimaera monstrosa* Linnaeus, 1758	185	37-103	390-4310*	0.01496 [0.0010-0.0217]	2.753 [2.665-2.840]	0.044	0.955
Chimaeridae	*Hydrolagus mirabilis* (Collett, 1904)	41	33-51*†	135-570*	0.00128 [0.0005-0.0029]	3.308 [3.083-3.533]	0.111	0.958
Rhinochimaeridae	*Rhinochimaera atlantica* Holt & Byrne, 1909	54	66-159*†	1020-7910*	0.05624 [0.0395-0.0801]	2.352 [2.277-2.427]	0.038	0.987

of parameters *a* and *b* of the LWR, as well as the determination coefficient (r^2). The ratios for all species were highly significant ($p < 0.01$). Except for *Rhinochimaera atlantica* with a *b*-value of 2.347, the *b*-value varied between 2.637 (*Centroscymnus owstonii*) and 3.811 (*Etmopterus pusillus*) (Fig. 1).

According to the information available in FishBase, new maximum total lengths are now recorded for *Deania hystricosa* (112 cm TL), *Etmopterus pusillus* (51 cm TL), *Scymnodon ringens* (132 cm TL), *Zameus squamulosus* (95 cm TL), *Hydrolagus mirabilis* (51 cm TL) and *Rhinochimaera atlantica* (159 cm TL), and new maximum total weight for *Centrophorus granulosus* (21200 g TW), *Centrophorus squamosus* (16520 g TW), *Deania calceus* (5020 g TW), *Deania hystricosa* (5950 g TW), *Deania profundorum* (3760 g TW), *Etmopterus princeps* (2065 g TW), *Centroscymnus crepidater* (4680 g TW), *Scymnodon ringens* (12450 g TW), *Zameus squamulosus* (4350 g TW), *Chimaera monstrosa* (4310 g TW), *Hydrolagus mirabilis* (570 g TW) and *Rhinochimaera atlantica* (7910 g TW) (Table I).

DISCUSSION

The *b*-values of the LWR obtained for all chondrichthyan species fell within the expected range indicated by Froese (2006) except for *Rhinochimaera atlantica*. Estimated *a*-values of the LWRs varied among species, due to factors known to affect LWR, such as maturity, stomach fullness (owing mainly to bait used with longlines) and/or season (González *et al.*, 2020), which have not been considered. In viviparous sharks, LWR is affected by the gestation period which can strongly affect somatic weight (Tsikliras and Dimarchopoulou, 2021). Differences in growth (*b*-value) for the same species in the available information may be due to factors related to sampling, such as the low number of specimens recorded, or the ranges of lengths and weights sampled (Colombelli and Bonanomi, 2022).

The length-weight relationships calculated in the present study are based on very different sample sizes, ranging from 28 individuals of *Deania profundorum* to 268 of *Centroscymnus coelolepis*. The low number of individuals analysed also precludes estimating the LRWs for each sex separately. However, our survey constitutes a significant baseline of LWRs for the chondrichthyan species studied, which should be refined in future. These LWRs can enrich the available information on length-weight relationships and maximum lengths recorded. Although the fish data analysed were collected some years ago, the LWR parameters obtained can be taken as valid.

The LWR obtained for *Centrophorus granulosus* in the present study is based on fuller length/weight data than those used by Pereira *et al.* (2012, 107 cm TL, Cape Verde) but not as extensive as

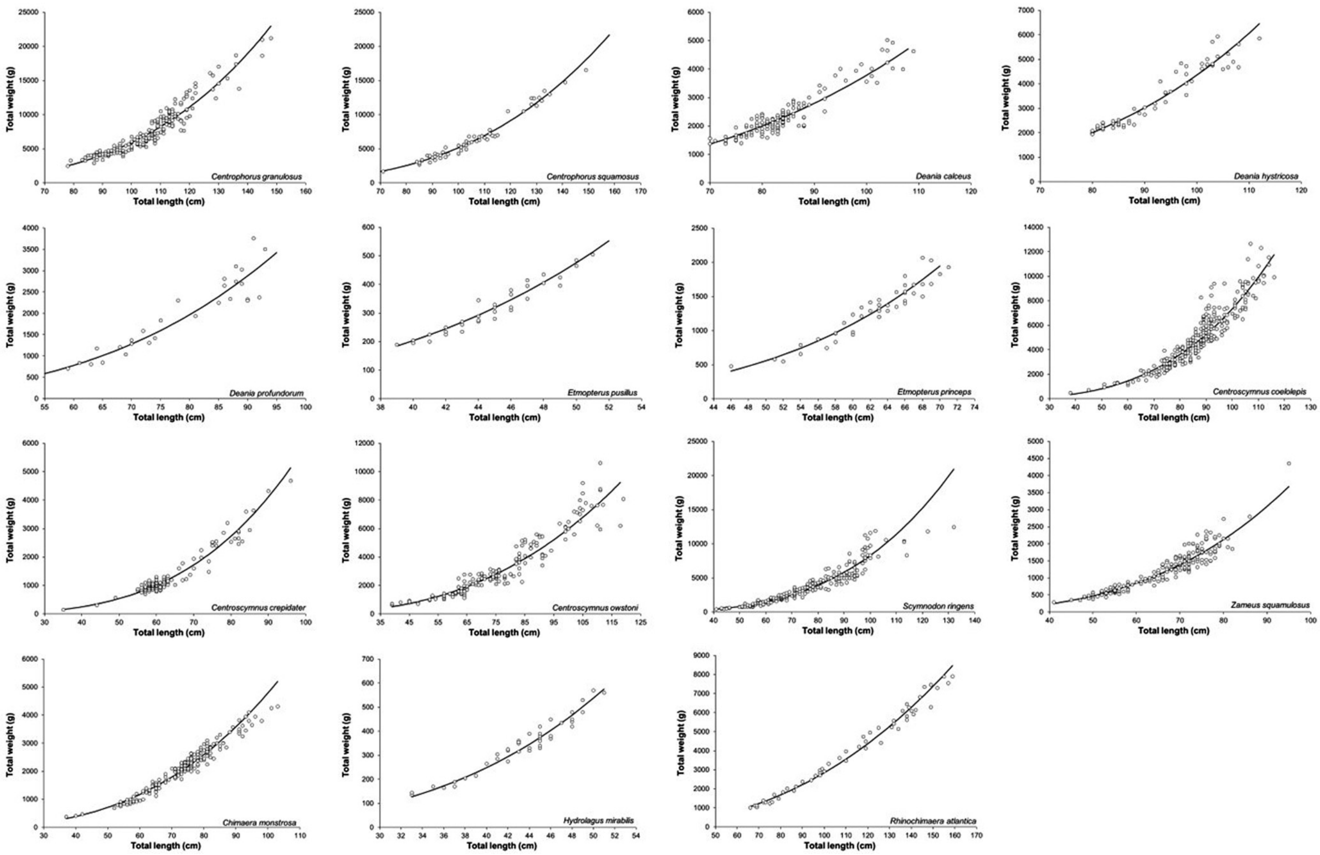

Figure 1. – Length-weight relationships estimated for 15 deep-water chondrichthyan species from the slopes of the Canary Islands.

those of Freitas *et al*. (2022, 154 cm TL and 24050 g TW, Madeira), which are not yet recorded in FishBase. For *Centrophorus squamosus*, the LWR is based on more numerous data than those used by Parker and Francis (2012, 145 cm TL, New Zealand) and by Freitas *et al*. (2022, 136 cm TL and 17159 g TW, Madeira). The maximum sizes for both species were measured by White *et al*. (2006, 170 cm TL and 164 cm TL, respectively).

The present LWR estimated for *Deania calceus* is new in the Atlantic, being obtained from more abundant length/weight values than those of Freitas *et al*. (2022, 104 cm TL and 5004 g TW, Madeira). The maximum size of this species was recorded by Finucci (2017, 127 cm TL, New Zealand). For *Deania hystricosa*, the LWR we obtained is the first in the literature, and in the eastern-central Atlantic its maximum size was higher than that recorded by Compagno (1984, 109 cm TL). The maximum weight of *Deania profundorum* was higher than reported by Ferreira *et al*. (2008).

For *Etmopterus pusillus*, the LWR was based on more data than those in Ferreira *et al*. (2008, 45 cm TL, 9 individuals, Madeira) and Pereira *et al*. (2012, 47 cm TL, 12 individuals, Cape Verde), but similar to Freitas *et al*. (2022, 51 cm TL and 684 g TW, Madeira). In the eastern-central Atlantic the maximum size was higher than reported by Bianchi *et al*. (1999, 50 cm TL). For *Etmopterus princeps* from the same Atlantic zone, the LWR calculated is similar than those in Freitas *et al*. (2022, 71 cm TL and 2003 g TW), as yet not recorded in Fishbase. The maximum size (TL) of the species was reported by Weigmann (2016).

The LWR of *Centroscymnus owstonii* in the Atlantic was based on a wider sample than that taken by Freitas *et al*. (2022, 109 cm TL and 7518 g TW, Madeira). The maximum sizes of this species were recorded by Finucci (2017, 148 cm TL and 21300 g TW, New Zealand).

The Atlantic LWR for *Centroscymnus coelolepis* was based on wider data than those used by Barría *et al*. (2015, 83 cm TL, Mediterranean) and by Freitas *et al*. (2022, 114 cm TL and 12528 g TW, Madeira). Maximum weights recorded were higher than in Finucci (2017, 10100 g TW, New Zealand). The LWRs for *Centroscymnus coelolepis* and *Deania calceus* were very similar to those available in adjacent geographical areas (ICES, 1997). Therefore, no new scientific advance on these species-specific LWRs is produced here, except that the current data confirm existing knowledge. However, since the above LWRs only generate *a* and *b* parameters, they can be considered a complement to previous estimates (González *et al*., 2021). In the case of *Centroscymnus crepidater* in the Atlantic, the LWR obtained was calculated from more length/weight data than those used by Freitas *et al*. (2022, 83.3 cm TL and 2676 g TW, Madeira). Its maximum size was recorded by Bass *et al*. (1986, 130 cm TL).

For *Scymnodon ringens* and *Zameus squamulosus*, the LWRs presently calculated are the first in the literature, and in the eastern-central Atlantic the maximum lengths (110 cm TL and 84 cm TL, respectively) recorded for these species by the authors are higher than those recorded by Compagno (1984), Gordon and Hunter (1994) and Last and Stevens (1994). For *Chimaera monstrosa*, the LWR estimated in this work was based on more length/weight data than Borges *et al*. (2003, 93.3 cm TL, Atlantic), and in the eastern-central Atlantic the maximum weight of the species was higher than that reported by Muus and Dahlström (1978, 2500 g TW). Lastly, *Hydrolagus mirabilis* and *Rhinochimaera atlantica* showed maximum sizes (41 cm TL and 140 cm TL, respectively), greater than those observed by Krefft (1990).

Somatic growth (allometric or isometric) was not addressed in this study because the samples did not include seasonal cycles or inter-annual variations, which should be considered when discussing growth patterns. In addition, as the sampling method was longline (a very selective fishing gear according to its hook size) there are no small sizes in the samples and, therefore it would be misleading to describing growth patterns (Jurado-Ruzafa and Martín-Sosa, 2022).

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Online supplementary data

TL (cm) and TW (g) values recorded for the 15 species of Canary Islands deep-water chondrichthyans studied.

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