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SHORT COMMUNICATION

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Length–weight relationships for six elasmobranch species from the Adriatic Sea

Alessandro Colombelli | **Sara Bonanomi**

CNR IRBIM, National Research Council – Institute of Marine Biological Resources and Biotechnologies, Ancona, Italy

Correspondence
Alessandro Colombelli, CNR IRBIM, National Research Council – Institute of Marine Biological Resources and Biotechnologies, Largo Fiera della Pesca 1, 60125 Ancona, Italy.
Email: alessandro.colombelli@irbim.cnr.it

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Summary

Length–weight relationships were observed for six elasmobranch species from the Adriatic Sea. Between 2006 and 2019, data on weight and total length were collected for three shark species *Alopias vulpinus*, *Mustelus mustelus*, *Mustelus punctulatus*; and data on weight and disk width were collected for three batoid species *Aetomylaeus bovinus*, *Myliobatis aquila*, *Pteroplatytrygon violacea*. Data collection comes from monthly observations as part of a monitoring program targeting specifically bycatch on pelagic pair trawlers involved in anchovy and sardine fishing. This fishery operates using pelagic trawls with a minimum mesh size opening of 20 mm. All elasmobranchs were measured to the nearest cm using a measuring board and weighed to the nearest gram using an electronic scale or a dynamometer for the largest specimens. A linear regression analysis performed on log-transformed data was used to estimate intercept and slope, and to describe the length–weight relationship for each species.

1 | INTRODUCTION

Elasmobranchs play a major role in maintaining the balance of marine ecosystem. Knowing their biology, particularly biometric parameters, is of paramount importance for their management and conservation. Here we present length–weight relationships of six elasmobranch species from the Adriatic Sea. The observed relationships can be useful for several purposes, like obtaining growth-in-weight equations, converting lengths into biomass measurements, or estimating fish conditions. Stock assessment methods may also take advantage of LWRs, including them among the parameters considered in the construction of more complex models. Comparisons between species' life cycles in different regions are also possible (Gonçalves et al., 1997; Moutopoulos & Stergiou, 2002; Pauly, 1993; Petrakis & Stergiou, 1995), provided that all investigators used the same standardized sampling methodology.

2 | MATERIALS AND METHODS

Samples were collected between 2006 and 2019 in the northern central Adriatic Sea. The spatial distribution of the observed catches is shown in Figure 1. Data collection was carried out as part of an extensive monitoring programme conducted on midwater pair trawlers, which since 2006 records incidental catches of elasmobranchs, cetaceans and sea turtles in the Adriatic Sea, under permit issued by the Italian Ministry of Agriculture, Food and Forestry (Fishery and Aquaculture directorate), in compliance with the Italian obligations to the Council Regulation (EC) 812/2004 and the EU Data Collection Framework (Bonanomi et al., 2018; Bonanomi, Sala, et al., 2018; Fortuna et al., 2010). The monitoring programme covers about the 3%–5% of midwater pair trawlers' annual activity in the Adriatic Sea. To achieve this type of coverage, trained observers take part on several fishing trips aboard commercial fishing vessels on a monthly basis. The gear commonly used in this type of fishing is a pelagic (or midwater) pair trawl known as "*Volante*", which targets small pelagic fish such as anchovy and sardine. According to Council Regulation (1967/2006) (Mediterranean Regulation, MR), the mesh size used in this fishing technique should have a minimum opening ≥20 mm, provided that 80% of the catch, after sorting, is of sardines (*Sardina pilchardus*) and anchovies (*Engraulis encrasicolus*).

For each specimen accidentally caught, the observers collected data about the species, total length in cm (TL), disc width in cm (DW) for batoids, and weight in kg. Additional information like sex and sexual maturity were collected where possible and are often available for several (but not all) specimens. Following the *FishBase* standards,

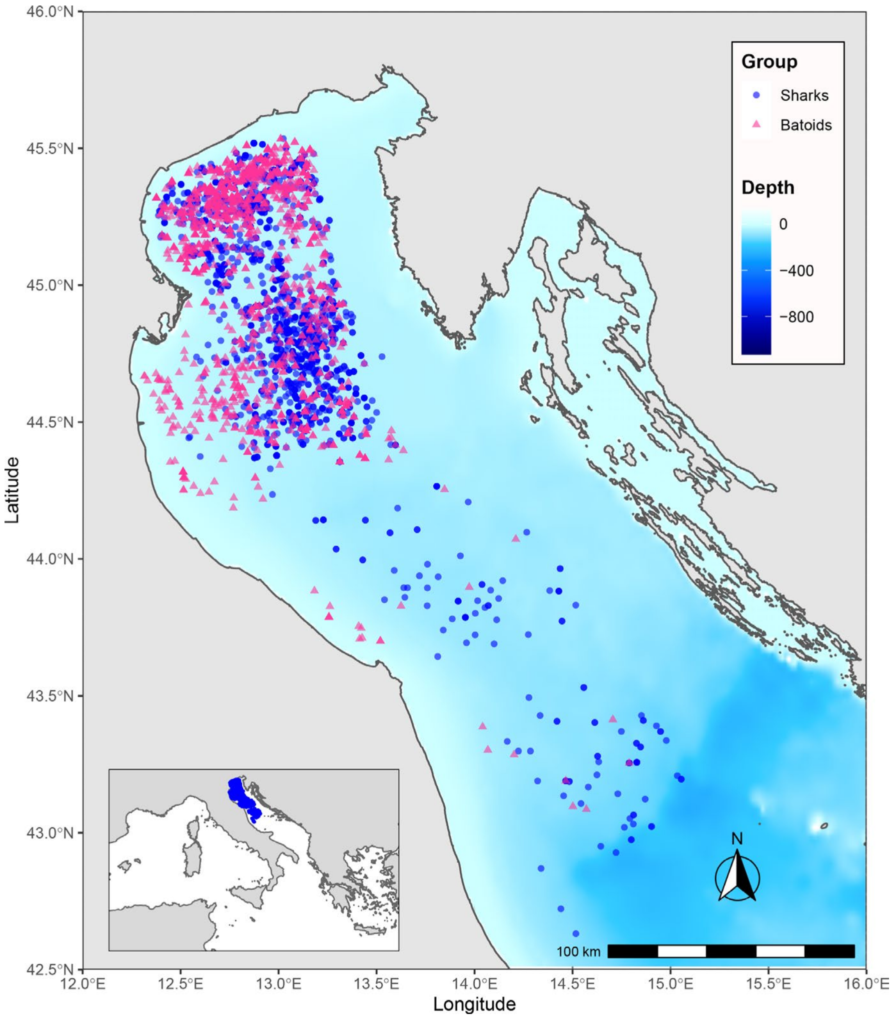

FIGURE 1 Spatial distribution of the specimens caught, categorized by taxonomic group. The recorded captures, collected between the years (2006–2019), derive from monthly observations on board of pelagic pair trawlers involved in anchovy and sardine fishing. This fishery operates using midwater pair trawls with a minimum mesh size opening of 20 mm

here the units of length and weight used are centimetres and grams respectively. All elasmobranchs were measured to the nearest cm using a measuring board and weighed to the nearest gram using an electronic scale or a dynamometer for the largest specimens. Several specimens with missing weight or length measurements were excluded from the dataset, and outliers were removed using the function *pcout* from the R package *mvoutlier* (Filzmoser & Gregorich, 2020). The *pcout* function identifies multivariate outliers in high-dimensional datasets, using the algorithm of Filzmoser, Maronna, and Werner (Filzmoser et al., 2008). The parameters of the length–weight relationships (LWRs) were calculated using the equation from (Ricker, 1973):

$$W = aL^b$$

where, W is fish weight (g), L is fish length, a = is the intercept ad b is the slope of the regression. Length weight data were $\log_{10} - \log_{10}$ transformed and length–weight relationships were calculated transforming the above equation into a linear model using the formula (Zar, 1984):

$$\log_{10} W_i = \log_{10}(\alpha) + \beta \log_{10}(L_i)$$

Here specimen length corresponds to total length in sharks and disk width in batoids. Where possible, differences among sexes were considered extending the model above with the inclusion of the quantitative variable ε gender ε and the interaction between the covariate $\beta \log_{10}(L_i)$ and the qualitative variable. The above formula is consequently modified in:

$$\log_{10} W_i = \log_{10}(\alpha) + \beta \log_{10}(L_i) + \delta \text{gender} + \gamma \text{gender} * \log_{10}(L_i)$$

with δgender as the dummy variable and γgender $* \log_{10}(L_i)$ as the interaction between the dummy variable and the covariate (Ogle, 2018). A statistical comparison of LWR between sexes was achieved using an ANCOVA test. Where differences between sexes were found significant, LWR were estimated both for males and females and in a combined model.

Elasmobranchs' growth type (isometric or not) was observed applying a Student's *t*-test (Student's *t*-test; H0: $b = 3$; $p < .05$) as described in the FishR Vignette by D. Ogle (http://derekogle.com/fishR/) using the statistical software R. 4.0.3 (R Development Core Team, 2016).

TABLE 1 Length–weight relationship parameters for the observed sharks and batoids species recorded in the northern Adriatic Sea. Captures data comes from monthly observations between the years (2006–2019). Type, measurement type; DW, disk width; TL, total length; n, sample size; Min., minimum; Max., maximum; Males, male specimens; Females, female specimens; Combined, males, females and unsexed specimens. *Alopias vulpinus**, given the low number of specimens, the length–weight relationship for this species must be considered as an attempt to estimate.

				Size (cm)		Weight (g)								
Species	Sex	n	Type	Min	Max	Min	Max	*a*	log10(*a*)	*b*	95% CI of *a*	95% CI of *b*	R^2	Pearson's *r*
Aetomylaeus bovinus (Geoffroy Saint-Hilaire, 1817)	Combined	101	DW	28	171	450	70,000	0.023	−1.628	2.919	−2.012; −1.243	2.706; 3.133	.880	.939
Myliobatis aquila (Linnaeus, 1758)	Combined	1421	DW	15	130	100	30,000	0.031	−1.504	2.84	−1.623; −1.385	2.770; 2.910	.815	.903
Myliobatis aquila (Linnaeus, 1758)	Females	242	DW	18	102	100	15,000	0.088	−1.055	2.554	−1.287; −0.822	2.418; 2.690	.805	.905
Myliobatis aquila (Linnaeus, 1758)	Males	105	DW	24	120	200	20,000	0.076	−1.117	2.554	−1.399; −0.835	2.418; 2.690	.805	.859
Pteroplatytrygon violacea (Bonaparte, 1832)	Combined	316	DW	37	90	1300	18,000	0.525	−0.279	2.273	−0.593; 0.033	2.096; 2.449	.670	.819
Pteroplatytrygon violacea (Bonaparte, 1832)	Females	105	DW	45	88	3000	18.000	0.691	−0.161	2.246	−0.578; 0.257	2.016; 2.476	.870	.874
Pteroplatytrygon violacea (Bonaparte, 1832)	Males	29	DW	38	62	1300	6000	0.492	−0.308	2.246	−0.772; 0.357	2.016; 2.476	.870	.806
Alopias vulpinus * (Bonnaterre, 1788)	Combined	21	TL	142	415	5000	130,000	0.006	−2.161	2.824	−3.758; −0.564	2.166; 3.482	.799	.899
Mustelus mustelus (Bonnaterre, 1788)	Combined	685	TL	20	180	80	18,000	0.035	−1.455	2.471	−1.567; −1.343	2.414; 2.528	.914	.956
Mustelus mustelus (Bonnaterre, 1788)	Females	150	TL	40	165	400	16,100	0.009	−2.008	2.763	−2.197; −1.818	2.665; 2.860	.916	.972
Mustelus mustelus (Bonnaterre, 1788)	Males	446	TL	32	180	200	18,000	0.035	−1.446	2.46	−1.888; −1.004	2.234; 2.686	.916	.944
Mustelus punctulatus (Risso, 1827)	Combined	188	TL	44	141	250	8150	0.003	−2.453	2.963	−2.691; −2.215	2.842; 3.084	.925	.962
Mustelus punctulatus (Risso, 1827)	Females	50	TL	54	132	400	8000	0.001	−2.915	3.216	−3.302; −2.527	3.017; 3.414	.934	.968
Mustelus punctulatus (Risso, 1827)	Males	138	TL	44	141	250	8150	0.005	−2.277	2.868	−3.140; −1.415	2.427; 3.309	.934	.967

3 | RESULTS

In this study, more than 4000 elasmobranchs specimens from 5 families were analysed. The number of specimens considered for each species, length and weight ranges, LWRs parameters (*a* and *b*), their 95% confidence interval and coefficient of determination R^2 are reported in Table 1. Both combined model and a model with separated sexes are reported in Table 1 for *M. aquila*, *M. mustelus*, *M. punctulatus and P.violacea*. Statistical comparison of LWR between sexes using the ANCOVA test reported non-significant differences among sexes for the species *A. bovinus*, *and A. vulpinus*. All elasmobranch species exhibited isometric growth since Student's *t*-test results reported a value of *b* non-significantly different from the value of 3.

4 | DISCUSSION

The length–weight relationships observed in this work are based on very different sample sizes, variable for each species, ranging from a few individuals for *A. vulpinus* to over 1400 specimens recorded for *M. aquila*. The reliability of the relationships described must therefore take account of these differences. In fact, the small number of individuals registered for *A. vulpinus* allows only an attempt to estimate. Furthermore, due to an incomplete gender classification, LWRs estimated considering both sexes combined should be considered more reliable, as they were obtained using a larger sample size, including individuals whose sex was not recorded during the sampling phase.

The observed growth type seems to confirm that small-bodied sharks allegedly undergo isometric morphological growth and don't change their body shape during their life, as already observed in previous studies (Ahnelt et al., 2020; Fu et al., 2016; Irschick et al., 2017; Irschick & Hammerschlag, 2015). Other studies provided different *b* values for the species considered, sometimes suggesting an allometric growth type. Observed differences in growth type within the same species may be due to several factors including the number of specimens recorded, length ranges considered, sampling areas and environmental conditions (Ismen et al., 2009). Additionally, each basin of the Mediterranean has its habitat peculiarities and marine resources can be exploited differently according to bordering countries. If standard sampling protocols are adopted, the existence of these differences underline the importance of LWRs as a useful tool for documenting the variability in terms of life cycles, size and growth type within the same species, whose populations live in similar habitats but are scattered in different and distant geographic areas.

CONFLICT OF INTEREST

None.

DATA AVAILABILITY STATEMENT

Data subject to third party restrictions.

ORCID

Alessandro Colombelli https://orcid.org/0000-0003-3855-161X

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