Plugging life-history gaps in FishBase with data on sharks and rays [1]

Tess M. McRae[a], Pui San Tong[b] and M.L.D. Palomares[c]

a) *Institute for the Oceans and Fisheries, University of British Columbia, Vancouver, B.C.,* V6T 1Z4, *Canada. Email:* t.mcrae@oceans.ubc.ca
b) *Institute for the Oceans and Fisheries, University of British Columbia, Vancouver, B.C.,* V6T 1Z4, *Canada. Email:* s.tong@oceans.ubc.ca
c) *Institute for the Oceans and Fisheries, University of British Columbia, Vancouver, B.C.,* V6T 1Z4, *Canada. Email:* m.palomares@oceans.ubc.ca

Abstract

Length-weight relationships (LWR) and parameter estimates of the von Bertalanffy growth function (VBGF) are important life history traits that are essential for fishery stock assessment and management. The aim of this study is to fill gaps in LWR and VBGF parameters of species of sharks and rays included in the *Sea Around Us* database of marine fisheries catches (www.seaaroundus.org), but which lack these key parameters in FishBase, the global online encyclopedia of fishes (www.fishbase.org). We found in the literature or estimated LWR parameters for all the 21 species of shark and rays that we selected, along with VBGF parameters. The results of the study indicate that most of these exploited species grow slowly, and thus are at risk from fisheries pressure and ocean warming.

Introduction

Although length-weight relationships (LWR) and the parameters of the von Bertalanffy growth function (VBGF) are important for fisheries management, this information is still missing for many exploited species. For instance, sharks and rays have been fished heavily for their fins and their populations are declining worldwide (Clarke *et al.* 2013). Yet, some heavily exploited sharks and rays still lack these data in FishBase (www.fishbase.org), the online encyclopedia of fishes. One such case is *Rhizoprionodon longurio* (Jordan & Gilbert 1882), considered 'Vulnerable' in IUCN's Redlist (see www.iucnredlist.org/).

LWR are important to the study of fishes and their populations (Abdurahiman *et al.* 2004; Froese 2006) as they allow for the conversion of growth in length to growth in weight, which is a basic information for fish stock assessments; also, LWR allow comparisons between the life histories of species of various shapes (Froese 2006).

Similarly, the growth of individual fish is what ensures the maintenance of a population's biomass over time, and its replenishment following declines due to environmental fluctuations of fisheries extractions (Pauly 1984). Growth thus determines an exploited population's vulnerability to overfishing (Musick *et al.* 2000).

There are three general types of data needed to find the growth parameters of the VBGF (Pauly 1984): (1) periodic markings on skeletal parts, e.g., otoliths, or other bones, (2) tagging-recapture data, and (3) size frequency data, i.e., generally the easiest type of data to collect and analyze (see Pauly 1998).

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Thus, to fill the gaps for shark and rays, especially those that occur in the catch statistics reported by fishing countries to the Food and Agriculture Organization of the United Nations (FAO), and which the *Sea Around Us* builds upon (Palomares *et al.* 2016), we assembled here the parameters of length-weight relationships (LWR) of 21 species of shark and rays. Also, published parameters of the VBGF were assembled and standardized for 20 species of shark and rays, and a set of growth parameters was estimated based on the growth parameters of morphologically similar species. The data obtained in this study will be encoded in FishBase.

Materials and Methods

Species included

The 21 shark and ray species included here are of interest to the *Sea Around Us* (www.seaaroundus.org), as they are species that are now strongly exploited, but data deficient (Table 1).

Length-weight relationships

The length-weight relationships (LWR) we use are of the form $W = a \cdot L^b$ where α is a multiplicative term, generally obtained as the antilog of the y-intercept of the log-log regression

$$log(W) = \alpha + b \cdot log(L) \qquad ...1)$$

where W and L are weight and length pairs (here in g and cm, respectively), b is the slope of the regression, equivalent to the exponent of the LWR and α the intercept, whose antilog is an estimate of a, the multiplicative term (Froese 2006).

The parameters of LWR were sourced through a literature search; in cases where no such parameters were found, length/weight data pairs representative of the population were fitted with Equation 1. Where suitable data were available, separate LWR for females and males were calculated. If FishBase was used to obtain the LWR, the Bayesian length-weight parameters were based on the methods of Froese *et al.* (2014).

Growth parameters

The VBGF for length has the form:

$$L_t = L_\infty(1 - e^{-K \cdot (t - t_0)}) \qquad ...2)$$

where L_t is the length at age t, L_∞ is the asymptotic length, K is a coefficient of dimension time^{-1} expressing how fast L_∞ is approached, and t_0 is a parameter setting the origin of the curve on the age-axis. The VBGF for weight has the form

$$W_t = W_\infty(1 - e^{-K \cdot (t - t_0)})^b \qquad ...3)$$

where W_∞ is the weight corresponding to L_∞, b the exponent of the LWR and the other parameters are the same as in the VBGF for length.

For comparisons of growth performance within and between different species, one can use the index

$$Ø' = \log(K) + 2 \cdot \log(L_\infty) \qquad ...4)$$

which is relatively constant within species (and higher taxa with similar shapes), as assessed by studying and relating hundreds of L_∞-K data pairs (Pauly 2019).

Length growth parameter estimates, most separated by sex, were either found in various publications or estimated using non-linear regression from published data for 20 of our 21 species. Growth parameters were inferred using *Ø'* only for scalloped bonnethead (*Sphyrna corona*), which is similar in shape and likely growth performance of other hammerhead of the genus *Sphyrna,* and for which growth parameters are available in FishBase.

Conversion of TL to DW for rays

Table 1. Summary of the length-weight relationships of 21 species of sharks and rays. For sharks, 'length' (in cm) corresponds to total length (TL); for rays, it corresponds to disk width (DW).

Species	Sex	a	b	Source
Sharks				
Callorhinchus callorynchus	Unsexed	0.00457	3.13	FishBase/Froese *et al.* (2014)
Carcharhinus amblyrhynchoides	Female	0.00933	2.923	Najmudeen *et al.* (2019)
	Male	0.0117	2.868	Najmudeen *et al.* (2019)
	Unsexed	0.0107	2.891	Najmudeen *et al.* (2019)
Carcharhinus signatus	Unsexed	0.00457	3.08	FishBase/Froese *et al.* (2014)
Etmopterus pusillus	Unsexed	0.00355	3.05	FishBase/Froese *et al.* (2014)
Hemitriakis japanica	Female	0.0197	2.595	Kamura *et al.* (2000)
	Male	0.00636	2.849	Kamura *et al.* (2000)
Mustelus griseus	Female	0.00344	2.968	Wang and Chen (1982)
	Male	0.00363	2.948	Wang and Chen (1982)
Mustelus lunulatus	Unsexed	0.005	2.92	Navia *et al.* (2006)
Nasolamia velox	Female	0.000068	3.91	Guzman *et al.* (2020)
	Male	0.000068	3.9	Guzman *et al.* (2020)
	Unsexed	0.000068	3.9	Guzman *et al.* (2020)
Pristiophorus cirratus	Unsexed	0.00389	3.12	FishBase/Froese *et al.* (2014)
Rhizoprionodon longurio	Unsexed	0.00035	3.539	Márquez-Farias *et al.* (2005)
Sphyrna corona	Unsexed	0.000015	3.75	Guzman *et al.* (2020)
Squatina australis	Unsexed	0.0162	2.908	Raoult *et al.* (2016)
Squatina guggenheim	Female	0.00492	3.13	Awruch *et al.* (2008)
	Male	0.0124	2.89	Awruch *et al.* (2008)
Squatina tergocellata	Unsexed	0.00399	3.16	Bridge *et al.* (1998)
Rhinobatos annandalei	Unsexed	0.00178	3.10	FishBase/Froese *et al.* (2014)
Rhinobatos rhinobatos	Unsexed	0.00204	3.08	FishBase/Froese *et al.* (2014)
Rays				
Amblyraja radiata	Unsexed	0.00199	3.22	FishBase/Froese *et al.* (2014) & this study
Bathyraja griseocauda	Female	0.0021	3.22	Arkhipkin *et al.* (2008)
	Male	0.0053	3.01	Arkhipkin *et al.* (2008)
Bathyraja scaphiops	Unsexed	0.0037	3.12	FishBase/Froese *et al.* (2014)
Dasyatis marmorata	Unsexed	0.048	2.94	Yeldan and Gundogdu (2018)
Myliobatis californica	Unsexed	0.013	3.00	Ehemann *et al.* (2017)

For several species of rays in our study (*Amblyraja radiata, Bathyraja griseocauda, Bathyraja scaphiops),* LWR parameters or VBGF parameters could only be found that involved total length (TL) instead of disc width (DW). To convert these parameters into DW for these species, conversion equations were found either through searching the literature for the equation itself or estimating a TL/DW ratio via an image of the species. For *Bathyraja griseocauda,* a conversion equation was found directly through Arkhipkin *et al.* (2008). For *Amblyraja radiata* and *Bathyraja scaphiops*, images of the species were used from FishBase with a known total length to calculate the ratio between total length and disc width. The conversion ratios were then applied to the LWR and VBGF parameters measured in TL to obtain the parameters in DW.

Validation of the estimated parameters

Plots of log(a) vs b were generated either for populations of the same species, or, in cases where FishBase did not have data for that species, the plots were created for species of the same genus or of the same family. If the newly estimated parameters followed the trend of available data points, the estimate was accepted as valid.

The VBGF parameters obtained from the literature were plotted in an auximetric plot (i.e., graphs with log(K) as Y-axis and log(L_∞) as X-axis, with each dot representing a set of growth parameters) jointly with those available in FishBase for populations of the same species. In monospecific genera and/or family, the estimated VBGF parameters were plotted for species in the same genera and/or family.

If the estimated parameters followed the trend of the ellipsoid cloud for that species group, the estimates were validated and accepted; otherwise, they will be tagged as 'doubtful' in FishBase). When growth parameters were available for females and males separately, the parameters estimated for both sexes were ignored, because L_∞ tends to be biased upward and K downward when a single growth curve is estimated in species with sexually dimorphic growth (D. Pauly, pers. comm., February 2022).

Results and Discussion

There were 21 species of sharks and rays selected for this study; we obtained LWR parameters for them either from the literature (including that covered in FishBase) or by estimating these parameters by fitting length-weight data pairs in various publication with Equation 1 (see Table 1 and Figure 1).

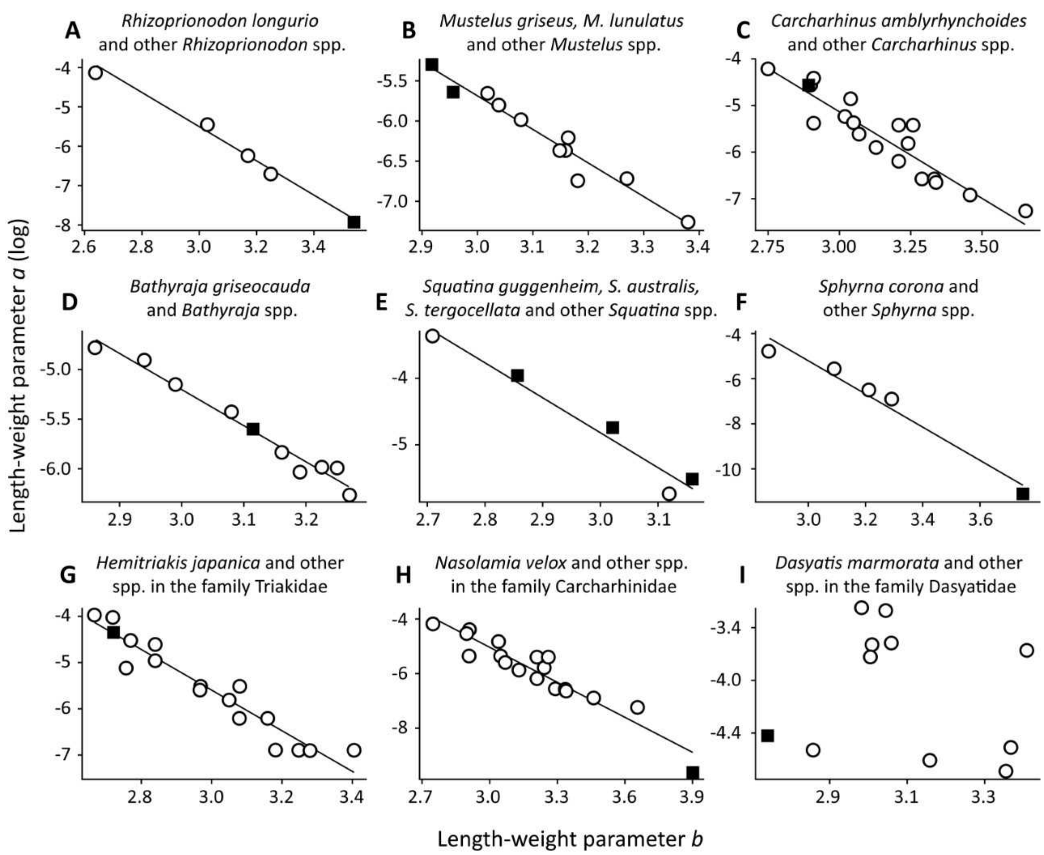

Figure 1. Plot of length-weight parameters (log(a) vs b in shark and ray taxa in FishBase as of the end of December 2021 (dots) and those newly estimated (black squares). The lengths for sharks are total length in cm, and disk width for rays.

The plots in Figure 1 do not imply vast differences in the length-to-weight relationships of the taxa in question, despite the wide ranges of the a and b values that they cover, because high values of a

compensates for low values of *b*, and vice-versa. What such plots reflect, rather (particularly when they refer to a single species, as do such plots in FishBase), are cyclical variations of the parameters of LWR due to different patterns of seasonal oscillations in length (whose increase slows down, but hardly reverses in winter) and weight growth (which usually becomes negative in winter). Indeed, these oscillations, as shown by simulations performed by one of the authors (M.L.D. Palomares) documented on p. 53-54 of Pauly (2019), cause LWR parameters to oscillate seasonally from the upper right corner of the graphs in summer to its lower right corner in winter, in a fashion similar to the plots in Figures 1A to H.

This implies that, ideally, LWR should be computed from L-W data pair samples covering all seasons equally, and/or that care must be taken, when using LWR, to account for their seasonal oscillations. Table 2 presents the VBGF parameters for our 21 species of sharks and rays, while Figure 2 shows that most of the L_∞ and *K* values obtained fit within an ellipsoid encompassing most of the data for a family. One exception is *Bathyraja griseocauda* whose *K* value is similar to those in other species within the family, while its asymptotic length is much higher than other species. Also, the species of interest in the genus *Squatina*, i.e., *S. guggenheim*, *S. tergocellata* and *S. australis*, do not have much family data available, and it is difficult to judge how well these data fit into that family.

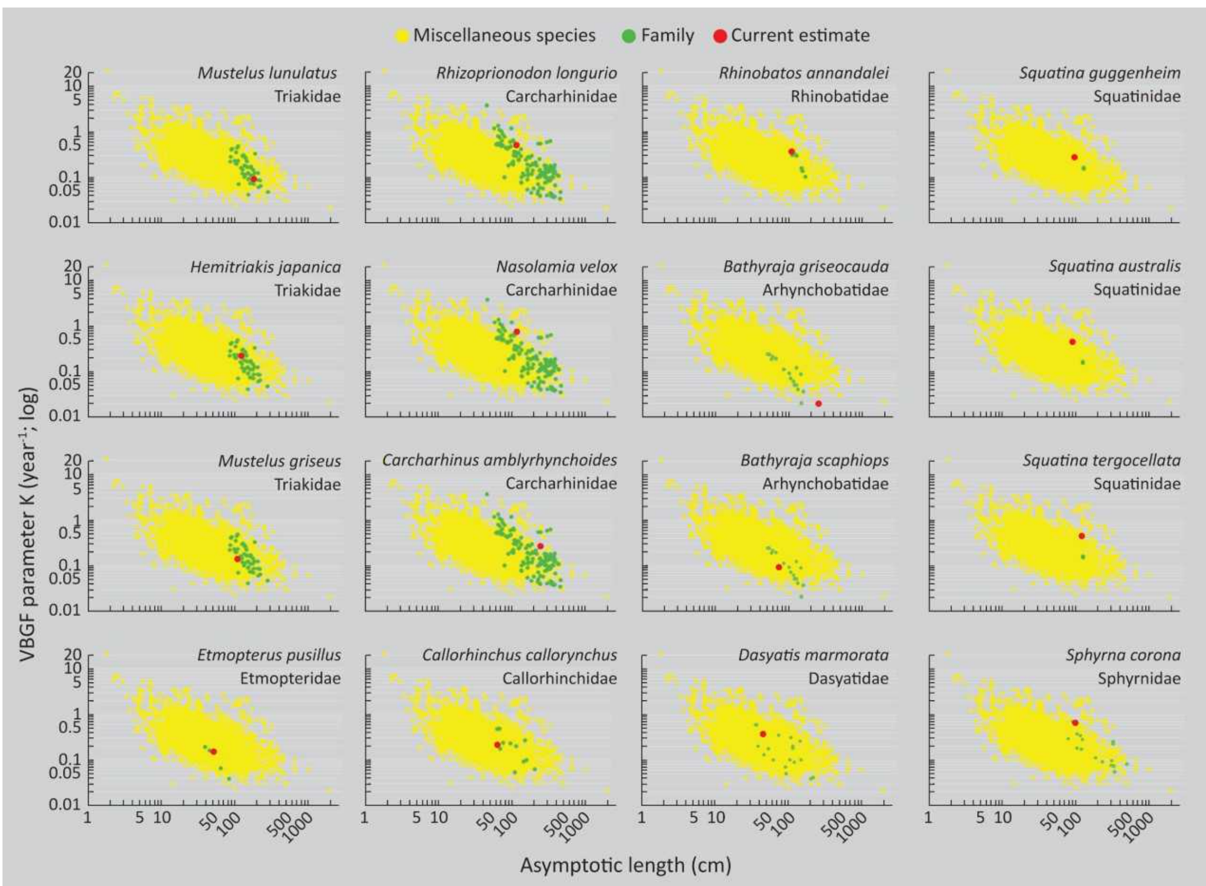

Figure 2. Auximetric plots (log(K) vs. log(L_∞)) for sharks and ray taxa (see text).

While some of the data in Figure 2 suggest that the growth performance of shark and rays is not lower than that of bony fish of similar sizes, it is also the case that sharks and rays have low absolute values of *K*, implying that they require a long time to approach the adult sizes (Smith *et al.* 1998). Thus, populations cannot quickly replace themselves, and cannot resist a strong fishing pressure (Pauly 1984). Indeed, sharks and rays are known to be susceptible to over-exploitation (Stevens *et al*. 2000) also due to their low fecundity (Stevens *et al*. 2000).

Although the importance of obtaining length-weight relationships and growth parameters of exploited species is known to be vital for fisheries management, there are still many exploited species for which this information is lacking. This study, which helps fill this knowledge gap for different exploited species of sharks and rays, may serve to illustrate how such gaps can and should be filled, to assist in fisheries management and conservation efforts.

Table 2. Summary of the von Bertalanffy growth parameters of 20 species of sharks and rays; lengths or width are in cm, weight in g and K are in year^{-1}. The method (Meth.) used are analysis of length-frequency data (L/F), or marking on skeletal parts (SP).

Species	Meth.	Sex	L_∞	L-type	W_∞	K	Ø'	Source
Sharks								
Callorhinchus calloryнchus	L/F	F M	71 563	TL TL	2815 1363	0.17 0.26	2.93 2.91	Bernasconi *et al*. (2015) Bernasconi *et al*. (2015)
Carcharhinus amblyrhynchoides	L/F	F M	255 237	TL TL	100652 74538	0.29 0.23	4.27 4.11	Najmudeen *et al*. (2019) Najmudeen *et al*. (2019)
Carcharhinus signatus	SP	U	270	TL	140772	0.11	3.91	Santana and Lessa (2004)
Etmopterus pusillus	SP	F M	54 49	TL TL	684 508	0.13 0.17	2.58 2.61	Coelho and Erzini (2007) Coelho and Erzini (2007)
Hemitriakis japanica	SP	F M	132 111	TL TL	6276 4280	0.20 0.24	3.54 3.48	Tanaka *et al*. (1978) Tanaka *et al*. (1978)
Mustelus griseus	SP	F M	125 94	TL TL	5721 2346	0.11 0.18	3.23 3.201	Wang and Chen (1982) Wang and Chen (1982)
Mustelus lunulatus	L/F	U	176	TL	18024	0.09	3.46	Olvera (2006)
Nasolamia velox	L/F	F M	121 111	TL TL	9470 6564	0.66 0.79	3.98 3.99	Bizarro *et al*. (2009) Bizarro *et al*. (2009)
Pristiophorus cirratus	SP	F M	TL TL	TL TL	24052 10886	0.15 0.31	3.53 3.62	Walker and Hudson (2005) Walker and Hudson (2005)
Rhizoprionodon longurio	SP	F M	124 110	TL TL	9104 5983	0.46 0.58	3.85 3.85	Espinosa (2011) Espinosa (2011)
Sphyrna corona	Ø'[a)]	U	97	TL	423	0.64	3.78	This study
Squatina australis	L/F	F M	97 86	TL TL	9548 6759	0.45 0.42	3.62 3.49	Jones *et al*. (2010) Jones *et al*. (2010)
Squatina guggenheim	L/F	U	95	TL	6980	0.27	3.39	Vooren and Klippel (2005)
Squatina tergocellata	L/F	F M	138 103	TL TL	22925 9195	0.27 0.77	3.71 3.91	Bridge *et al*. (1998) Bridge *et al*. (1998)
Rhinobatos annandalei	L/F	F M	91 99	TL TL	2169 2817	0.57 0.43	3.67 3.62	Purushottama *et al*. (2020) Purushottama *et al*. (2020)
Rhinobatos rhinobatos	SP	U	150	TL	10404	0.2	3.54	Başusta *et al*. (2008)
Rays								
Amblyraja radiata	SP	F	60	DW	1058	0.10	2.56	McPhie and Campana (2009) & this study
Bathyraja griseocauda	SP	F M	270 266	DW DW	141648 105479	0.02 0.02	3.16 3.15	Arkhipkin *et al*. (2008) Arkhipkin *et al*. (2008)
Bathyraja scaphiops	SP	F M	88 59	DW DW	4315 1239	0.06 0.13	2.69 2.68	Bücker (2006) Bücker (2006)
Dasyatis marmorata	L/F	U	46	DW	3713	0.36	2.88	Yeldan and Gundogdu (2018)

Myliobatis californica	SP	F M	157 152	DW DW	50309 45653	0.10 0.08	3.39 3.27	Martin and Caillet (1988) Martin and Caillet (1988)

a) The growth parameter L_∞ was inferred from the maximum length for this species and *K* via the mean *Ø'* of the genus *Sphyrna*, whose species have very similar shapes.

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