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Short communication

Empirical equations for estimating maximum length from length at first maturity

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Summary

Maximum length reached by fishes is an important parameter that is highly correlated with metabolism and most other life-history traits. However, obtaining maximum length estimates for commercial fishes has become difficult due to the extirpation of large specimens by intensive fishing. Empirical equations are presented that can be used to derive maximum length of fish from length at first maturity, and vice versa.

Introduction

It is well known that most basic parameters of fish population dynamics are strongly related to maximum length (Allen, 1971; Pauly, 1980; Welcomme, 1999; Froese and Binohlan, 2000). Commercial fishing changes the size structure and reduces the mean length in a population (Beverton and Holt, 1957). Continued overfishing at the level occurring in many commercial stocks (Myers and Worm, 2003) exerts such high mortality rates that there is little chance of even a few individuals to survive long enough to reach maximum size. As a result, it has become difficult to observe maximum size in fished populations. Here we present empirical relationships for estimating maximum size from size at first maturity.

Materials and methods

Data on length at maturity (L_m) and maximum length (L_{max}) were taken from the compilations of published data in the MATURITY (Binohlan, 2000) and POPCHAR (Binohlan and Pauly, 2000) tables, respectively, in FishBase (http://www.fishbase.org). Records of L_m for a given species were matched with records of L_{max} that had the same locality, sex and type of length measurement. When the type of length measurement was not stated in the data source, we assumed fork length for groups like scombrids where fork length is usually used, standard length for records from taxonomic references where standard length is usually used, and total length for other fishes. When the L_m and L_{max} pairs were in different length types, we converted from one length type to the other using length-conversion equations from the LENGTH-LENGTH table in FishBase. Only estimates referring to mean length at maturity or the mid-point of a given range of values were selected. Data from captive populations and from semelparous fishes were excluded. Also, we verified data pairs where the L_m / L_{max} ratio fell outside the expected range of about 0.4–0.8 (Beverton and Holt, 1959).

Our screening procedure yielded 344 pairs of L_m and L_{max} comprising 230 species from 90 Families (Table 1). The linear regression routine of the NCSS software (Hintze, 2001) was used with log values of the paired estimates of L_m and L_{max}. Regression analyses were done for the whole data set and for major subgroups, namely chondrichthyans, perciforms, and ray-finned fishes (actinopterygians) in general.

Results and discussion

The results of linear regression analysis done on maximum length over length at maturity are summarized in Table 2. L_{max} and L_m were highly correlated, with the relationship accounting for 89–94% of the variance in the data. The regression slope for all fishes was similar to the chondrichthyans, as can be seen from the overlapping 95% confidence limits, and seemed to be largely influenced by this group. Note that most fishes included in the analysis with L_m approaching 100 cm and bigger were sharks and rays (elasmobranchs), with very few ray-finned fishes (Fig. 1). The chondrichthyans showed a slightly different regression slope from the ray-finned fishes; however, the 95% confidence intervals of the slopes and the intercepts overlap. The work of Frisk et al. (2001) on the relationship between average female life expectancy and age at maturity also showed a different slope for elasmobranchs from that of teleosts.

The regression slope for ray-finned fishes, though not significantly different from the sharks and rays, was significantly different from the regression slope for all fishes. We therefore present separate empirical relationships for estimating L_{max} from L_m for ray-finned fishes and elasmobranchs. Additionally, for colleagues who are interested in estimating L_m from L_{max}, we also present the corresponding relationships based on Table 3.

Table 1
Fish groups included in the L_{max}–L_m regression analysis

Fish groups	No. of Families	No. of Species
Chondrichthyans		
Sharks	9	29
Rays	4	7
Chimaeras	2	2
Actinopterygians		
Perciforms	39	117
Others	36	75
Total	90	230

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Table 2
Summary of regression statistics of maximum length on length at first maturity

Parameter	All fishes	Chondrichthyans	Actinopterygians	Perciforms
Intercept	**0.3454** (0.3089, 0.3819)	**0.2532** (0.1351, 0.3713)	**0.2602** (0.2086, 0.3119)	**0.3169** (0.245, 0.388)
Slope	**0.9194** (0.8955, 0.9433)	**0.9461** (0.8894, 1.0028)	**0.9928** (0.9541, 1.0314)	**0.9641** (0.911, 1.016)
r^2	0.943	0.939	0.904	0.890
s	0.0988	0.0517	0.1034	0.1077
t (0.025; n−2)	1.960	2.000	1.960	1.960
n	344	74	270	163

Numbers in parentheses = lower and upper 95% confidence limits for the slope and intercept; t = value of t-distribution corresponding to alpha 0.025 and n-2 degrees of freedom; s = standard deviation

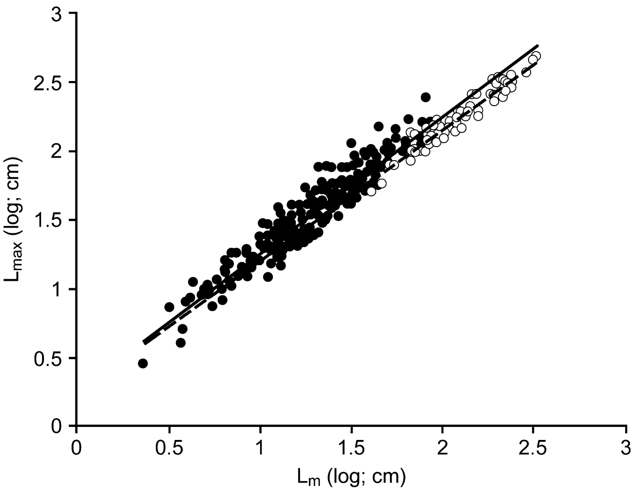

Fig. 1. Relationship between maximum length and length at first maturity for 230 species (344 records) of fish. The regression lines are for ray-finned fishes (solid line, black dots) and chondrichthyans (broken line, white dots)

a) Ray-finned fishes

$$\log L_{\max} = 0.2602 + 0.9928 * \log(L_{\mathrm{m}}) \tag{1}$$

$$\log L_{\mathrm{m}} = -0.1189 + 0.9157 * \log(L_{\max}) \tag{2}$$

b) Elasmobranchs

$$\log L_{\max} = 0.2532 + 0.9461 * \log(L_{\mathrm{m}}) \tag{3}$$

$$\log L_{\mathrm{m}} = -0.1246 + 0.9924 * \log(L_{\max}) \tag{4}$$

The 95% confidence limits for mean log $L_{\max}$ or mean log L_{m} from the above equations are given by

$$\log L_{\max}\,\text{lower} = \log L_{\max} - t * s * \sqrt{1/\mathrm{n}} \tag{5}$$

$$\log L_{\max}\,\text{upper} = \log L_{\max} + t * s * \sqrt{1/\mathrm{n}} \tag{6}$$

and the 95% prediction limits can be obtained from

$$\log L_{\max}\,\text{lower} = \log L_{\max} - t * s * \sqrt{1 + 1/\mathrm{n}} \tag{7}$$

$$\log L_{\max}\,\text{upper} = \log L_{\max} + t * s * \sqrt{1 + 1/\mathrm{n}} \tag{8}$$

where $L_{\max}$ can be replaced by L_{m}; t is the value of the t-distribution corresponding to alpha 0.025 and n-2 degrees of freedom, s is the standard deviation and n is the sample for the fish group. Values for t, s and n are given in Tables 2 and 3.

Applying equation (1) to a bony fish that matures at 10 cm would predict an $L_{\max}$ of 18 cm with 95% prediction limits (PL) for the estimate of 11–29 cm; a fish that matures at 100 cm would give an $L_{\max}$ of 176 cm with 95% PL of 110–281 cm. Equation (2) for elasmobranchs would predict, for a maturity length of 100 cm, an $L_{\max}$ of 140 cm with 95% PL of 110–178 cm. The 95% prediction intervals for $L_{\max}$ values are wide, especially for very small and very large bony fishes, which are underrepresented as can be seen from Fig. 1.

Beverton and Holt (1959) pointed out that the ratio between L_{m} and asymptotic length – which is closely related with $L_{\max}$ (Froese and Binohlan, 2000) – is about constant among different populations of the same species and similar between closely related species, with values for most fishes falling between 0.4 and 0.8 (see also Charnov and Berrigan, 1991). Thus, another option to obtain recent estimates of maximum length for species where previous data for L_{m} and $L_{\max}$ are available is to obtain the geometric mean of the $L_{\mathrm{m}} / L_{\max}$ ratio and apply it to currently observed L_{m} data. For example, from different populations of *Oreochromis mossambicus* we have the following (7) pairs of L_{m} and $L_{\max}$: 12.8, 23.8; 10, 24; 12, 24; 17, 31; 15, 34; 12.8, 38; 19, 39. The geometric mean of the

Table 3
Summary of regression statistics of length at first maturity vs maximum length

Parameter	All fishes	Chondrichthyans	Actinopterygians	Perciforms
Intercept	**−0.2713** (−0.3177, −0.2248)	**−0.1246** (−0.2569, 0.0076)	**−0.1189** (−0.1693, −0.0569)	**−0.1475** (−0.2293, −0.0656)
Slope	**1.0260** (0.9993, 1.0526)	**0.9924** (0.9329, 1.0518)	**0.9157** (0.8757, 0.9466)	**0.9232** (0.8727, 0.9737)
r^2	0.943	0.939	0.9045	0.890
s	0.1043	0.0529	0.0991	0.1053
t (0.025; n−2)	1.960	2.000	1.960	1.960
n	344	74	270	163

Numbers in parentheses = lower and upper 95% confidence limits for the slope and intercept; t = value of t-distribution corresponding to alpha 0.025 and n−2 degrees of freedom; s = standard deviation

L_m / L_{max} ratios is 0.461 with 95% confidence limits 0.384 – 0.588. Thus for a population of *O. mossambicus* with L_m = 10 cm, we would obtain, using the ratio of the given L_m to the geometric mean (10 cm / 0.461), a corresponding L_{max} of 21.7 cm. This estimate compared to 18 cm predicted from equation (1) is much closer to the corresponding observed L_{max} of 24 cm in the given data set. Thus, estimating maximum length from L_m / L_{max} ratios, whenever data is available, is to be preferred over the empirical equations. We hope the above equations will prove useful to fisheries managers and fish biologists.

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