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Simple methods to obtain preliminary growth estimates for fishes

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Summary

Explored were methods to derive preliminary information on growth from other known life history parameters such as maximum size and size and age at first maturity. Use was made of the fact that with asymptotic length known, only one point is needed to determine the general shape of a von Bertalanffy growth curve. An empirical relationship was used to predict asymptotic length from maximum observed length. We used mean size reached at age 1 or 2 or mean age and size at first maturity, as is often provided in the literature, to derive preliminary von Bertalanffy growth curves. Results of this approach were then compared with published growth estimates. We used an empirical relationship to predict length at first maturity from asymptotic length when only the age at first maturity was given in the literature. Temperate fishes usually have restricted spawning periods lasting a few months per year and maturity is typically reached in the first, second, third, or later year, i.e. in steps of 12 months, with larger species maturing later. We used data in FishBase (http://www.fishbase.org) to establish typical ranges for age at first maturity and growth performance of temperate fishes as a function of maximum size. We present an approach that uses this framework to derive preliminary growth estimates for species of which only the maximum size is known.

Introduction

Management of fish resources ultimately impacts on the biomass of species in a given ecosystem. A precondition to informed management is thus knowledge of biomass dynamics, i.e. mortality rates, recruitment, and growth, all of which are species-specific. Recruitment is highly variable in most fishes and can be stabilized to some extend only by maintaining reasonably large spawning stocks. Natural mortality rates are difficult to obtain in exploited stocks but can be inferred from other life history parameters, such as maximum age (Hoenig, 1984) or growth (Pauly, 1980). However, growth information itself is only available for about 5% of the 27 000 known species of fish (Binohlan and Pauly, 2000). In this study, we explore methods to derive preliminary information on growth from other known life history parameters, such as maximum size (L_{max}) and size (L_m) and age (t_m) at first maturity. We made use of the fact that with asymptotic length (L_∞) known, only one point is needed to determine the general shape of a von Bertalanffy growth curve. Froese and Binohlan (2000) presented an empirical relationship that explains 96% of the variance when predicting asymptotic length from maximum observed length in a large data set covering 551 populations from 27 orders, including chimaeras, sharks, rays, and ray-finned fishes. Maximum size is known for practically all fishes, and mean size reached at age 1 or 2 is often given in the literature. Similarly, mean age and size at first maturity is often provided. We used such information to derive preliminary von Bertalanffy growth curves. For some species we compared the results of this approach with published growth estimates to obtain an idea how realistic our preliminary estimates would be.

Froese and Binohlan (2000) also presented an empirical relationship to predict length at first maturity from asymptotic length, explaining 89% of the variance in their data set of 467 populations. This relationship was used to estimate length at first maturity when only the age at first maturity was given in the literature. Temperate fishes usually have restricted spawning periods lasting a few months per year. Maturity is typically reached in the first, second, third, or later year, i.e. in steps of 12 months, with larger species maturing later. We used data in FishBase (Froese and Pauly, 2000) to establish typical ranges for age at first maturity and growth performance of temperate fishes as a function of maximum size. An approach is presented here that uses this framework to derive preliminary growth estimates in species where only the maximum size is known.

We want to stress that the simple methods presented here are not meant as a substitute for more rigorous assessments of growth with traditional methods. Rather, we hope that our preliminary estimates based on existing knowledge will improve the understanding and management of species until new studies provide more data for better estimates.

Material and methods

We used three general books on the fishes of Europe (Maitland and Campbell, 1992; Muus and Dahlstrøm, 1999; Muus and Nielsen, 1999) to extract information on maximum length and length and age at first maturity or at other points in life for fishes with no growth information in FishBase (Froese and Pauly, 2000). Similarly, we used maturity information from the MATURITY table in FishBase (Binohlan, 2000). We used the empirical relationship by Froese and Binohlan (2000) to estimate asymptotic length (L_∞) from maximum length (L_{max}):

$$\log_{10} L_\infty = 0.044 + 0.9841 * \log_{10}(L_{max}) \quad (1)$$

We used the re-arranged von Bertalanffy growth function (VBGF) to estimate the parameter K from

$$K = -\ln(1 - L_m/L_\infty)/(t_m - t_0) \quad (2)$$

We used an empirical equation by Pauly (1979) to estimate the t_0 value of the VBGF:

$$\log_{10} - t_0 = -0.3922 - 0.2752 * \log_{10} L_\infty - 1.038 \log_{10} K \quad (3)$$

As equations 2 and 3 are interdependent, we first calculated a preliminary K assuming that $t_0 = 0$, then used the preliminary K_1 to estimate a preliminary t_0, then used the preliminary t_0 to estimate a second preliminary K_2, and the second preliminary K_2 to estimate a final t_0. We then used the final t_0 to estimate a final K from equation 2.

For example, the values obtained from the literature for the gudgeon, *Gobio gobio*, were $L_{max} = 20$ cm, $L_m = 14$ cm, and $t_m = 3$ years. Equation 1 gives $L_\infty = 21.1$ cm, equation 2 with $t_0 = 0$ gives $K_1 = 0.34$, equation 3 gives $t_0 = -0.54$. Reiteration of equation 2 with $t_0 = -0.54$ gives $K_2 = 0.29$, and reiteration of equation 3 gives $t_0 = -0.6$. A second reiteration of equation 2 with $t_0 = -0.6$ results in $K = 0.28$, a value that remains stable in subsequent reiterations.

For the comparison of growth parameters we used the derived parameter Ø′ (Pauly, 1979; Munro and Pauly, 1983)

$$\varnothing' = \log_{10} K + 2 \log_{10} L_\infty \quad (4)$$

We used the empirical relationship of Froese and Binohlan (2000) to predict length at first maturity from asymptotic length:

$$\log_{10} L_m = 0.8979 * \log_{10} L_\infty - 0.0782 \quad (5)$$

Results and discussion

In Table 1, preliminary growth estimates are presented for 18 European fish species for which no growth information is contained in FishBase (Froese and Pauly, 2000), the largest compilation of growth parameters with 5529 estimates for 1396 species (Binohlan and Pauly, 2000). In the 'Information used' column, we indicate the sources and cite the information that was used. Table 2 shows a comparison between the preliminary VBGF parameters derived in this study with published estimates of similar asymptotic length. Table 3 gives preliminary estimates of growth based on maximum length

Table 1
Preliminary growth parameters for 18 European fishes estimated from maximum length and length and age at first maturity

Species	L_{max}	L_t	t	L_∞	t_0	K	Ø′	Information used
Acipenser sturio	500 TL	130	8	500	−2.8	0.03	3.84	Ref. 35387, p. 46: 'Males mature when 7–9 years old, at 110–150 cm. Maximum 5–6 m'
Alburnus alburnus	20 TL	11	3	21.1	−0.9	0.19	1.92	Ref. 6258, p. 206: '[ ] 10–12 cm after 3 years [ ]. [ ] in favorable habitats, 18–20 cm is attained'
Aspius aspius	120 TL	52.5	5	123	−1.1	0.10	3.17	Ref. 35387, p. 102: '50–55 cm [ ] at 4–5 years. Maximum 120 cm [ ]'
Barbatula barbatula	21 TL	12	3	22.1	−0.7	0.24	2.08	Ref. 35387, p. 140: '8–12 cm at 2–3 years'. Maximum size from FishBase
Cyclothone braueri	2.6 SL	2.2	2	2.8	−0.5	0.60	0.68	Ref. 8966: $L_{max} = 2.6$ cm SL, $L_m = 2.2$ cm, $t_m = 2$ years (cited after FishBase)
Gobio gobio	20 TL	13.5	3	21.1	−0.6	0.28	2.10	Ref. 6258, p. 193: '[ ] by their third year they are mature at 12 cm or more. [ ] fish up to 20 cm have been recorded [ ]'
Hucho hucho	150 TL	70	5	153	−1.1	0.10	3.37	Ref. 35387, p. 62: 'About 70 cm [ ] at 5 years, maximum about 150 cm [ ] at 15 years
Leucaspius delineatus	12 TL	8	2	12.7	−0.5	0.39	1.81	Ref. 35387, p. 90: '6–10 cm long at 2 years. Maximum size 12 cm'
Leuciscus idus	60 TL	18	2	62.2	−1.2	0.11	2.62	Ref. 35387, p. 96: 'After 2 years typical length is 18 cm. Rarely over 60 cm [ ]'
Misgurnus fossilis	50 TL	22.5	4	52.0	−1.1	0.12	2.52	Ref. 35387, p. 140: 'Usually 20–25 cm at 3–4 years, maximum 50 cm and over 20 years [ ]'
Pelecus cultratus	60 TL	25	4	62.2	−1.2	0.11	2.62	Ref. 35387, p. 128: 'Generally 20–30 cm at 3–4 years. Maximum 50–60 cm [ ]'
Pholis gunellus	25 TL	20	3	26.3	−0.4	0.42	2.46	Ref. 35388, p. 210: '[ ] mature with 3 years and about 20 cm length. Maximum length 25 cm'
Rhodeus amarus	9 TL	5.5	3	9.6	−0.9	0.25	1.37	Ref. 35387, p. 130: 'Generally 5–6 cm at 2–3 years. Maximum 9 cm. [ ] Lifespan is at most 5 years'
Rhodeus sericeus	9 TL	5.5	2	9.6	−0.7	0.32	1.47	Ref. 6258, p. 212: 'They mature in their second year at around 5–6 cm [ ]. [ ] occasionally grows to [ ] 9 cm'
Scardinus erythrophthalmus	45 TL	30	10	46.9	−1.7	0.09	2.28	Ref. 35387, p. 100: 'Generally 20–30 cm [ ] at 10 years. Maximum 45 cm [ ]'
Sebastes fasciatus	30 TL	22.3	6	31.4	−0.8	0.19	2.28	Ref. 12186, data from FishBase
Trachipterus arcticus	300 TL	200	14	303	−1.3	0.07	3.81	Ref. 35388, p. 113: 'Mature at about 14 years with about 2 m length. Maximum length up to 3 m'
Zoarces viviparus	50 TL	17	2	52.0	−1.0	0.13	2.55	Ref. 35388, p. 206: '[ ] reach maturity after about 2 years at a length of 16–18 cm. Maximum length about 50 cm'

TL refers to total length and SL to standard length. Reference numbers are those used in FishBase and full citations are given in the References section. Information from Ref. 35388 was translated from German into English.

Table 2
A comparison between preliminary growth estimates derived from maximum length and length and age at first maturity and published growth estimates. All examples from Muus and Dahlstrøm (1999)

Species	L_{max}	L_m	t_m	L_∞	t_0	K	Ø′	Information used	L_∞	K	Ø′	Ref.
Carassius carassius	45 TL	11.5	3.5	46.9	−3.0	0.04	1.98	p. 132: 'Maturity is normally reached in 3–4 years at a length of 8–15 cm. [ ] maximum 45 cm'	29.8 TL	0.09	1.92	719
Cyprinus carpio	100 TL	30	3.5	102.8	−1.7	0.07	2.84	p. 136: 'At 3–4 years wild carp measure 20–40 cm [ ]. Maximum rarely over 100 cm [ ] at 40 years'	85.1 TL	0.17	3.10	7029
Lota lota	152 TL	40	5	155.2	−2.6	0.04	2.97	p. 154: '40 cm [ ] at 4–6 years'. Maximum length from FishBase	104 TL	0.08	2.95	2058
Silurus glanis	350 TL	50	4	352.7	−3.9	0.02	3.38	p. 144: 'About 50 cm [ ] at 4 years. Maximum 3–4 m [ ]'	296 TL	0.04	3.57	719
Stizostedion lucioperca	120 TL	42	4	123.0	−1.5	0.08	3.06	p. 160: 'The females [ ] mature [ ] at 3–5 years, and 40–44 cm. Maximum 120 cm'	104 TL	0.13	3.14	719

Table 3
Preliminary growth parameters for 12 European fishes estimated from maximum length and age at first maturity

Species	L_{max}	t_m	L_m	L_∞	t_0	K	Ø′	Information used
Acipenser baeri	140 TL	17	72.0	143.1	−3.3	0.03	2.85	Ref. 2059, cited from FishBase
Aphanius iberus	5 TL	0.5	3.8	5.4	−0.1	1.95	1.75	Ref. 35387, p. 152: 'Maturity may be reached in 6 months. Size 4–5 cm'
Chondrostoma nasus	50 TL	3	29.0	52.0	−0.6	0.23	2.78	Ref. 35387, p. 108: '[ ] becomes mature at 2–4 years. [ ] rarely 50 cm'
Coregonus pidschian	46 TL	4	26.9	47.9	−0.9	0.17	2.59	Ref. 27368, cited from FishBase
Crystallogobius linearis	5 TL	1	3.8	5.4	−0.3	0.97	1.45	Ref. 35388, p. 230: '[ ] matures after 1 year. Maximum length 4–5 cm'
Gobiusculus flavescens	6 TL	1	4.5	6.5	−0.2	0.94	1.59	Ref. 35388, p. 228: '[ ] matures at the end of 1 year. Maximum length 6 cm'
Notoscopelus kroyeri	14 SL	4	9.4	14.9	−1.0	0.20	1.65	Ref. 35388, p. 111: '[ ] becomes mature with 4 years. Maximum length 14 cm'
Pomatoschistus lozanoi	8 TL	1	5.7	8.6	−0.2	0.89	1.82	Ref. 35388, p. 229: 'Mature with 1 year. Maximum length 8 cm'
Thorogobius ephippiatus	13 TL	3.5	8.8	13.8	−0.9	0.23	1.65	Ref. 35388, p. 227: 'Mature with 3–4 years. Maximum length 13 cm'
Triglops quadricornis	60 TL	4	34.1	62.2	−0.8	0.16	2.80	Ref. 27547, cited from FishBase
Umbra krameri	17 TL	1	11.2	18.0	−0.2	0.79	2.41	Ref. 26183, cited from FishBase
Vimba vimba	50 TL	3.5	29.0	52.0	−0.7	0.19	2.72	Ref. 35387, p. 128: 'It becomes mature at 3–4 years. [ ] maximum 50 cm [ ]'

TL = total length and SL = standard length.

and age at first maturity for 12 species. Table 4 shows, for different size classes of temperate fish, typical ranges of age at first maturity and of the VBGF parameter K.

Tables 1 and 3 provide preliminary growth estimates for 30 European fishes, many of which are well known, such as the bleak, *Alburnus alburnus*, which is often used as bait, or the game fish huchen, *Hucho hucho*, but which are apparently not well studied as no growth information was found in FishBase (http://www.fishbase.org) in October 2001.

To obtain an idea on how realistic our preliminary growth estimates are, we applied our methodology to five species for which growth studies were available. As can be seen in Table 2, the maximum sizes used by us are larger and the K values are lower than those found in the literature, which is not surprising as our maximum size was meant to be the largest reported for these species, and in a given species a larger L_∞ usually is associated with a lower K value. For the same reason, most of the K values in Tables 1 and 3 are close to or slightly below the typical ranges for K given in Table 4.

Pauly (1979) has shown in a double-logarithmic plot of K over L_∞ that the various growth estimates for a given species will roughly form an ellipse with the long axis having a slope of 2, and Ø′ (equation 4) being the value where this axis intersects the ordinate. Ø′ values derived from different growth studies for the same species should vary less than the values of L_∞ or K, and thus Ø′ is well suited to compare growth estimates (Munro and Pauly, 1983). In the five cases in Table 2, the difference of $Ø'_{(\text{this study})}$ minus $Ø'_{(\text{literature})}$ is not significantly different from zero (paired t-test; $t_{4;\ 0.05}$).

Another property of Ø′ is that it can be used to estimate the corresponding K for a given L_∞. Thus, colleagues are likely to find that a population in which they are interested does not

Table 4
Typical values (25 and 75 percentile) for age at first maturity and the von Bertalanffy growth function (VBGF) parameter K for temperate fishes

Maximum length range (cm)	Maturity range (year)	K range (1 per year)
5–10	1–2	0.52–1.4
11–20	1–3	0.30–0.79
21–30	1–3	0.26–0.48
31–40	2–4	0.23–0.50
41–50	2–4	0.17–0.35
51–70	2–6	0.13–0.29
71–100	2–7	0.11–0.22
101–150	2–7	0.10–0.19
> 150	3–15	0.05–0.12

attain as large a size as used here. They can rearrange equation 4 to obtain the corresponding K for their observed L_∞ from $\log_{10} K = Ø' - 2 \log_{10} L_\infty$. For example, for *Carassius carassius* we estimated $L_\infty = 46.9$ cm, $K = 0.04$ and $Ø' = 1.98$. For a population with $L_\infty = 30$ cm we calculate $\log_{10} K = 1.98 - 2 * 1.48 = 0.11$, which is very close to the observed $K = 0.09$ for $L_\infty = 29.8$ cm (Nikolsky, 1957; see first row of Table 2).

Even after applying the techniques described above, there will still be no growth information for the majority of European fishes. We therefore present here an approach that will result in one or two 'possible' growth curves for a given species, using only maximum length as input. We again estimate asymptotic length from equation 1 and mean size at first maturity from equation 5. We then make use of the fact that age at first spawning in temperate fishes is not a continuous variable, but rather takes integer values between 1 and 20, depending on the size of the species. In Table 4 we present the 25 and 75 percentile values of age at first spawning of temperate fishes, as derived from the MATURITY table of FishBase (Binohlan, 2000). We also present the corresponding 25 and 75 percentile values for K. As expected, typical age at first maturity changes from 1–2 years in small fishes to 3–15 years in large fishes. Similarly, typical K values decrease from 0.5–1.4 in small fishes to 0.05–0.12 in large fishes. We suggest using this table as a framework for temperate fishes to identify likely age at first maturity and likely growth performance. We stress that Table 4 may be used only with temperate fishes, as e.g. tropical fishes can be expected to mature earlier and grow faster, and e.g. polar and deep-sea fishes can be expected to mature later and grow more slowly.

For example, no maturity or growth information is available for the schneider, *Alburnoides bipunctatus*; its size is given as '…rarely over 16 cm' (Muus and Dahlstrøm, 1999; p. 120). Applying equations 1 and 5 results in $L_\infty = 16.9$ and $L_m = 10.6$ cm, respectively. For this size, Table 4 suggests an age at first maturity of 1, 2 or 3 years. Applying equations 2 and 3 results in $K = 0.80$ for $t_m = 1$, $K = 0.40$ for $t_m = 2$, and $K = 0.26$ for $t_m = 3$. Of these three K values, two fall outside the 25 and 75 percentile values given in Table 4 and are thus less likely. An age at first maturity of 2 years and a K value of 0.40 fall within the expected range and may be used as preliminary estimates until better data become available.

In another example, no growth information is available for the rough pomfret, *Taractes asper*, which reaches 50 cm maximum size. Table 4 suggests an age at first maturity of 2–4 years, resulting in $K = 0.34$ for $t_m = 2$, $K = 0.23$ for $t_m = 3$, and $K = 0.17$ for $t_m = 4$. Since all values for K fall within the range given in Table 4, three scenarios of maturity and growth are possible for this species. However, a precautionary approach would assume late maturity ($t_m = 4$) and slow growth ($K = 0.17$) until better data become available.

As the above example shows, selecting the appropriate K becomes more problematic with increasing possible ages at first maturity and thus this method may not be suitable without additional information for fishes beyond 50 cm maximum length.

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