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Length–weight relations for 19 freshwater fish species (Actinopterygii) from the lowland Elbe River, Germany

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Abstract

Monthly and mean length–weight relations (LWRs) were calculated for 19 freshwater fish species from the middle section of the lowland Elbe River (Germany): *Abramis brama* (Linnaeus, 1758); *Alburnus alburnus* (Linnaeus, 1758); *Anguilla anguilla* (Linnaeus, 1758); *Ballerus ballerus* (Linnaeus, 1758); *Blicca bjoerkna* (Linnaeus, 1758); *Cobitis taenia* Linnaeus, 1758; *Esox lucius* Linnaeus, 1758; *Gobio gobio* (Linnaeus, 1758); *Gymnocephalus cernua* (Linnaeus, 1758); *Leuciscus aspius* (Linnaeus, 1758); *Leuciscus idus* (Linnaeus, 1758); *Leuciscus leuciscus* (Linnaeus, 1758); *Lota lota* (Linnaeus, 1758); *Perca fluviatilis* Linnaeus, 1758; *Romanogobio albipinnatus* (Lukasch, 1933); *Rutilus rutilus* (Linnaeus, 1758); *Sander lucioperca* (Linnaeus, 1758); *Scardinius erythrophthalmus* (Linnaeus, 1758); and *Squalius cephalus* (Linnaeus, 1758). The values of the exponent b in the LWR $W = a\text{TL}^b$ ranged from 2.882 (*Lota lota*) to 3.517 (*Cobitis taenia*) and the correlation coefficient (r^2) was greater than 0.96 for all species except for *Cobitis taenia* with 0.93. The relations allow for the accurate estimation of weight from length data with reduced handling times of fish in the field while enabling comparisons with other regions and future studies. The calculated LWRs together with species-specific abundance and catch data will be useful for fisheries modeling and estimating population status and related fish species protection, especially for the endangered species in the Elbe River.

Keywords

Elbe River, freshwater fish, Germany, length–weight relation, LWR

Introduction

Fish size is a key variable for several ecological and physiological processes such as sexual maturity, predation, mortality, and ontogenetic diet shifts (Erzini 1994; Wootton 1999; Froese and Binohlan 2000; Evans and Claiborne 2005; Byström et al. 2012) and has important implications for population dynamics (Erzini 1994). Length data are recorded in standard fish sampling programs and essential for studies on growth rates, age structure, and other aspects of fish population dynamics (Kolher et al. 1995). Weight data, in contrast, are collected less frequently in field studies due to the additional technical effort and time required to weigh fish in the field (Martin-Smith 1996; Koutrakis and Tsikliras 2003; Sinovčić et al. 2004). Length–weight relations (LWR) not only allow weight to be estimated from commonly collected length data (Beyer 1991), but also have various applications in fish biology, physiology, ecology, and fisheries assessment. These relations enable seasonal variations in fish growth to be identified and allow a rough assessment of the nutritional status through the calculation of condition indexes, e.g., the mean condition factor (Le Cren 1951; Ricker 1975; Bagenal and Tesch 1978; Richter et al. 2000; Froese 2006). LWRs are also useful to determine whether somatic growth is isometric (weight increases proportionally to length) or allometric (weight does not increase proportionally to length) (Le Cren 1951; Ricker 1975). Furthermore, they allow life history and morphological comparisons between different fish species, or between fish populations of the same species from different habitats and/or regions (Petrakis and Stergiou 1995; Goncalves et al. 1997; Wootton 1999). Finally, LWRs are also often used in stock assessment models to estimate stock biomass from limited sample sizes, to estimate weight-at-age (Petrakis and Stergiou 1995; Koutrakis and Tsikliras 2003), and to convert growth-in-length to growth-in-weight (Pauly 1993).

LWRs have been estimated for a large number of species. However, since the variation within a species or population is large (Froese et al. 2014), local data and LWRs are likely to be more accurate. Nevertheless, LWRs for European populations of freshwater fish species are relatively rare (Verreycken et al. 2011) and mostly available for fish from lakes (Holubová et al. 2022). To the best of our knowledge, there is no published information on LWRs of fish species in the middle part of the Elbe River in Germany. The intent of this study was therefore to describe the LWRs for freshwater fish in the middle part of a large German river.

Material and methods

The Elbe River has the 4th largest catchment area in central Europe with 148 000 km^2, a mean discharge of 861 m^3 s^{-1} at its mouth, and a surface area of about 231 000 ha (Simon et al. 2005). The sampling took place in the middle part of the Elbe River at three sampling sites (stream kilometers 337–350 (52.209314°N, 11.713875°E–52.311094°N, 11.767025°E), 418–423 (52.803450°N, 12.025439°E–52.843850°N, 12.040528°E) and 452–453 (52.974142°N, 11.772764°E). Sampling was performed annually over a four-year period (1997–2000) with fishing campaigns in spring (April–May), summer (July), and early and late autumn (September and November, respectively). Fishes were caught by a combination of DC electrofishing (FEG 5000), seine netting, drift nets, and benthic multi-mesh gillnetting (mesh sizes 6–75 mm). All caught fishes were identified to species level, and total length (TL, to the nearest 0.5 cm) and wet weight (W, measurement accuracy for individuals < 5 g ± 0.1 g and for individuals > 5 g ± 1 g) were measured individually in the field.

The following species were measured and weighed individually: *Abramis brama* (Linnaeus, 1758); *Alburnus alburnus* (Linnaeus, 1758); *Anguilla anguilla* (Linnaeus, 1758); *Ballerus ballerus* (Linnaeus, 1758); *Blicca bjoerkna* (Linnaeus, 1758); *Cobitis taenia* Linnaeus, 1758; *Esox lucius* Linnaeus, 1758; *Gobio gobio* (Linnaeus, 1758); *Gymnocephalus cernua* (Linnaeus, 1758); *Leuciscus aspius* (Linnaeus, 1758); *Leuciscus idus* (Linnaeus, 1758); *Leuciscus leuciscus* (Linnaeus, 1758); *Lota lota* (Linnaeus, 1758); *Perca fluviatilis* Linnaeus, 1758; *Romanogobio albipinnatus* (Lukasch, 1933); *Rutilus rutilus* (Linnaeus, 1758); *Sander lucioperca* (Linnaeus, 1758); *Scardinius erythrophthalmus* (Linnaeus, 1758); and *Squalius cephalus* (Linnaeus, 1758). Fifteen other species were collected but were excluded from the analyses as they were represented by insufficient numbers.

For sex determination, subsamples of fishes from seven species (*Ballerus ballerus*, *Gobio gobio*, *Leuciscus aspius*, *Leuciscus idus*, *Leuciscus leuciscus*, *Squalius cephalus*, and *Lota lota*) were killed, frozen, and stored under vacuum at –22°C. Sex was determined visually after thawing, a binocular microscope (WILD M32 Typ S, Fa. Heerbrugg, Germany) was used for smaller fishes.

The collected data was subjected to quality control and defined selection criteria (Froese 2006; Froese et al. 2011; Verreycken et al. 2011). In the final dataset, species-specific LWRs were calculated for every sampled month of the year and all sampled months combined. In addition, for seven species LWRs were calculated separately for each sex. The LWRs were estimated from the formula, $W = a\mathrm{TL}^b$, with W being total body weight [g], TL the total length [cm], and a and b the coefficients of the regression.

The parameters a and b of LWRs were estimated by power regression analyses on the non-transformed data, and the association degree between variables (W and TL) was calculated by the coefficient of determination (r^2). The standard errors (SE) and 95% confidence intervals (CI) of a and b estimates and the statistical significance level of r^2 were also determined.

Linear regression analyses (least-squares method) on log-transformed TL and W data were used to test for the influence of sex on the relation between TL and W. The model fits were assessed by residual diagnostics including the visual inspection of quantile-quantile plots (QQ plots) and residuals vs. fitted plots, accompanied by tests for the residual distribution (Kolmogorov–Smirnov (KS) test), dispersion, and outliers (Hartig 2021). For all statistical hypotheses testing the significance level was set at $\alpha < 0.05$.

The statistical analyses were performed with R 4.0.5 (R Core Team 2021) and the additional packages “FSA” (Ogle et al. 2021), and “nlstools” (Baty et al. 2015). The package DHARMa (Hartig 2021) was used to assess the model fits of the regression.

Results

During this study, a total of 26 434 fish representing 19 species from seven families were examined The sample size ranged from 153 for *Romanogobio albipinnatus*, to 4490 for *Abramis brama* (Table 1). Depending on the species, the smallest total lengths measured were between 3.5 and 13 cm. The maximum length values for approximately half of the species were close to the maximum lengths observed in Europe (Kottelat and Freyhof 2007; Verreycken et al. 2011; Froese and Pauly 2022).

Table 1. Descriptive statistics and estimated length–weight relation parameters for 19 freshwater fish species of the lowland Elbe River, Germany between months.

Species	Endangered status		Month	*n*	TL_{min}	TL_{max}	FishBase	W_{min}	W_{max}	Length–weight relation parameters				
	FFH	RL BB/D					TL_{max}			*a*	95% CI of *a*	*b*	95% CI of *b*	r^2
Anguilla anguilla		V/3	May	399	13.0	70.5		2	571	0.001	0.001–0.001	3.285	3.23–3.34	0.979
			July	481	13.5	76.5		3	820	0.001	0.001–0.001	3.211	3.17–3.25	0.976
			September	520	13.0	72.0		3	805	0.001	0.001–0.001	3.266	3.23–3.31	0.978
			November	134	16.5	65.0		7	498	0.001	0.001–0.002	3.102	3.03–3.17	0.983
			Total year	1547	13.0	76.5	133.0	2	820	0.0007	0.001–0.001	3.209	3.18–3.24	0.975
Cobitis taenia	II	2/2	July	46	6.0	11.5		1	12	0.0007	0.001–0.001	3.926	3.65–4.21	0.950
			September	68	6.0	12.0		0.8	10	0.002	0.001–0.004	3.341	3.14–3.55	0.949
			Total year	124	6.0	12.0	13.5	0.8	12	0.002	0.001–0.003	3.517	3.33–3.70	0.927
Esox lucius		DNE/3	May	82	5.3	78.0		1	3036	0.006	0.004–0.008	3.016	2.93–3.10	0.994
			July	244	9.0	75.5		4	2725	0.008	0.007–0.010	2.931	2.88–2.98	0.994
			September	170	16.0	75.5		20	2939	0.005	0.004–0.007	3.046	2.98–3.11	0.989
			November	126	17.5	82.5		30	3851	0.007	0.005–0.009	2.987	2.93–3.05	0.992
			Total year	652	5.3	82.5	137.0	1	3851	0.006	0.006–0.007	3.001	2.97–3.03	0.991
Gobio gobio		DNE/CNE	May	114	5.0	16.5		0.5	45	0.007	0.005–0.008	3.110	3.03–3.20	0.987
			July	127	3.2	16.0		0.2	42	0.004	0.003–0.005	3.285	3.19–3.38	0.982
			September	349	3.5	17.0		0.2	38	0.006	0.005–0.007	3.129	3.08–3.18	0.987
			November	335	4.2	18.0		0.5	47	0.004	0.003–0.004	3.275	3.23–3.32	0.990
			Total year	935	3.2	18.0	21.0	0.2	47	0.005	0.005–0.006	3.189	3.16–3.22	0.985
Romanogobio albipinnatus	II	G/2	September	70	4.0	11.5		0.3	11	0.003	0.002–0.004	3.364	3.23–3.49	0.975
			November	48	5.5	12.5		1	15	0.003	0.002–0.005	3.303	3.08–3.53	0.960
			Total year	153	4.0	12.5	13.0	0.3	15	0.004	0.003–0.005	3.234	3.12–3.34	0.964
Abramis brama		DNE/CNE	May	909	4.0	55.0		0.5	1641	0.011	0.009–0.012	2.985	2.95–3.02	0.985
			July	1434	3.8	56.5		0.5	1927	0.014	0.013–0.016	2.910	2.88–2.94	0.982
			September	1312	3.8	56.5		0.5	2282	0.01	0.008–0.011	3.010	2.98–3.04	0.979
			November	591	4.0	55.5		0.5	1694	0.01	0.008–0.013	2.990	2.94–3.04	0.977
			Total year	4490	3.8	56.5	82.0	0.5	2282	0.01	0.010–0.012	2.973	2.95–2.99	0.981
Alburnus alburnus		CNE/CNE	May	339	4.3	19.5		0.5	48	0.003	0.003–0.004	3.257	3.18–3.34	0.963
			July	451	3.5	19.5		0.2	46	0.003	0.003–0.004	3.258	3.18–3.32	0.964
			September	545	3.0	19.5		0.1	58	0.003	0.002–0.003	3.307	3.24–3.37	0.973
			November	232	3.5	18.5		0.2	48	0.003	0.002–0.004	3.313	3.21–3.42	0.976
			Total year	1670	3.0	19.5	25.0	0.1	58	0.003	0.003–0.003	3.288	3.25–3.32	0.969
Ballerus ballerus		3/3	May	189	8.3	45.5		3.5	86	0.002	0.002–0.003	3.355	3.29–3.42	0.989
			July	107	6.5	49.0		1	1085	0.004	0.003–0.006	3.200	3.10–3.30	0.989
			September	62	15.0	47.0		21	960	0.003	0.002–0.004	3.294	3.18–3.41	0.990
			Total year	397	6.5	49.0	40.0	1	1085	0.003	0.002–0.003	3.294	3.25–3.34	0.989
Blicca bjoerkna		DNE/CNE	May	744	3.5	36.0		0.4	604	0.006	0.005–0.006	3.237	3.20–3.27	0.987
			July	779	5.5	34.0		1	566	0.006	0.005–0.006	3.239	3.21–3.27	0.987
			September	706	5.5	33.0		1	462	0.006	0.006–0.007	3.188	3.16–3.22	0.983
			November	413	4.3	33.5		0.7	432	0.006	0.004–0.007	3.25	3.18–3.32	0.972
			Total year	2871	3.3	39.0	45.5	0.2	660	0.006	0.006–0.006	3.227	3.21–3.25	0.982
Leuciscus aspius	II	DNE/3	May	157	6.0	67.5		1	2398	0.006	0.005–0.009	3.051	2.98–3.13	0.994
			July	252	4.0	69.5		0.3	2580	0.007	0.006–0.009	3.032	2.98–3.08	0.994
			September	351	4.9	69.0		0.5	2731	0.003	0.003–0.004	3.222	3.17–3.28	0.992
			November	173	6.5	71.5		1.5	3351	0.002	0.002–0.003	3.315	3.23–3.40	0.990
			Total year	1003	4.0	71.5	120.0	0.3	3351	0.004	0.003–0.004	3.187	3.15–3.22	0.990
Leuciscus idus		3/3	May	721	5.0	49.0		0.7	1699	0.004	0.004–0.004	3.319	3.29–3.35	0.987
			July	942	3.0	48.0		0.2	1598	0.004	0.004–0.004	3.306	3.29–3.32	0.994
			September	966	4.0	47.0		0.6	1625	0.003	0.003–0.003	3.390	3.37–3.41	0.992
			November	403	6.5	47.0		2	1496	0.002	0.002–0.003	3.492	3.43–3.56	0.987
			Total year	3134	3.0	49.0	85.0	0.2	1699	0.003	0.003–0.004	3.364	3.35–3.38	0.987
Leuciscus leuciscus		3/3	May	77	3.5	19.5		0.3	74	0.003	0.002–0.003	3.439	3.35–3.52	0.986
			July	85	5.5	17.5		1	46	0.004	0.003–0.005	3.313	3.19–3.44	0.978
			September	90	4.8	20.0		0.7	75	0.003	0.003–0.004	3.349	3.28–3.42	0.993
			November	41	7.5	20.0		2	68	0.003	0.002–0.004	3.356	3.29–3.42	0.995
			Total year	297	3.5	20.0	40.0	0.3	75	0.003	0.003–0.004	3.348	3.30–3.40	0.996
Rutilus rutilus		DNE/CNE	May	779	3.5	29.5		0.3	311	0.004	0.004–0.004	3.347	3.32–3.37	0.988
			July	1194	3.2	28.5		0.2	303	0.004	0.004–0.004	3.345	3.32–3.37	0.987
			September	1343	3.5	43.5		0.3	1141	0.004	0.004–0.004	3.339	3.33–3.35	0.994
			November	573	3.8	36.0		0.4	627	0.003	0.003–0.003	3.448	3.41–3.49	0.987
			Total year	4135	3.2	43.5	50.2	0.2	1141	0.003	0.003–0.004	3.390	3.38–3.40	0.990
Scardinius erythrophthalmus		DNE/CNE	July	61	5.0	28.0		1	259	0.008	0.007–0.009	3.129	3.09–3.17	0.998
			September	42	7.0	17.0		3	55	0.007	0.004–0.011	3.194	2.99–3.41	0.970
			Total year	144	4.8	28.0	61.7	1	259	0.007	0.006–0.008	3.173	3.14–3.21	0.995

Species	Endangered status		Month	n	TL_{min}	TL_{max}	FishBase TL_{max}	W_{min}	W_{max}	Length–weight relation parameters				
	FFH	RL BB/D								a	95% CI of a	b	95% CI of b	r^2
Squalius cephalus		CNE/CNE	May	295	4.3	42.5		0.6	755	0.012	0.011–0.012	2.962	2.94–2.98	0.995
			July	351	5.5	28.5		1	274	0.004	0.005–0.006	3.246	3.22–3.28	0.992
			September	385	4.2	39.5		0.5	699	0.005	0.004–0.005	3.263	3.24–3.29	0.991
			November	293	4.2	43.0		0.4	1056	0.003	0.003–0.003	3.408	3.39–3.43	0.998
			Total year	1350	4.2	43.0	60.0	0.4	1056	0.005	0.005–0.005	3.240	3.22–3.26	0.990
Lota lota		2/2	May	54	3.0	33.0		0.2	282	0.006	0.004–0.014	2.993	2.80–3.19	0.967
			July	162	5.7	41.0		1	545	0.007	0.005–0.009	3.024	2.95–3.10	0.975
			September	171	8.0	41.5		3	367	0.017	0.013–0.022	2.711	2.63–2.80	0.969
			November	107	9.5	38.5		5	381	0.005	0.003–0.007	3.111	3.00–3.22	0.977
			Total year	498	3.0	41.5	152.0	0.2	545	0.010	0.008–0.012	2.882	2.83–2.94	0.965
Gymnocephalus cernua		DNE/CNE	May	74	6.2	16.0		2	52	0.008	0.006–0.011	3.111	2.99–3.23	0.980
			July	96	3.7	17.0		0.5	53	0.012	0.009–0.015	2.969	2.86–3.07	0.978
			September	194	6.0	18.0		2	87	0.004	0.003–0.004	3.462	3.38–3.54	0.980
			November	176	5.5	16.0		1.5	57	0.006	0.005–0.007	3.269	3.18–3.36	0.976
			Total year	562	3.7	18.0	25.0	0.5	87	0.006	0.005–0.007	3.272	3.22–3.32	0.974
Perca fluviatilis		DNE/CNE	May	626	3.3	40.5		0.3	868	0.006	0.005–0.007	3.234	3.20–3.27	0.985
			July	933	3.8	43.5		0.4	1230	0.005	0.005–0.005	3.280	3.27–3.29	0.995
			September	1279	5.0	43.5		1	1438	0.004	0.003–0.004	3.392	3.37–3.41	0.987
			November	564	5.0	40.5		1	970	0.005	0.004–0.005	3.327	3.30–3.35	0.993
			Total year	3438	3.3	43.5	60.0	0.3	1438	0.004	0.004–0.004	3.342	3.33–3.35	0.987
Sander lucioperca		V/CNE	July	50	4.5	71.5		0.5	3313	0.002	0.002–0.003	3.331	3.23–3.43	0.998
			September	59	7.5	76.5		2	4184	0.003	0.002–0.004	3.300	3.19–3.42	0.996
			November	52	9.0	76.0		4	4551	0.002	0.001–0.002	3.416	3.32–3.52	0.996
			Total year	198	4.5	76.5	100.0	0.5	4551	0.002	0.002–0.003	3.316	3.24–3.39	0.993

n = sample size, TL = total length [cm], W = weight [g], min = minimum, max = maximum, a = regression intercept, b = slope of regression line, CI = confidence interval, r^2 = coefficient of correlation. FFH = FFH Fauna-Flora-Habitat Directive (EU 1992): Annex II Animal and plant species of community interest whose conservation requires the designation of special areas of conservation; RL BB/D =RL-BB Red List of the Federal State of Brandenburg (Knuth et al. 1998); RL-D Red List of Germany (Bless et al. 1998): 2 = critically endangered, 3 = endangered, G = endangered status is assumed, V = declining, Pre-warning list, CNE = currently not considered endangered, DNE = definitely not endangered. Note: Total year can include additional data from other months with fewer individuals than 30 per species that were not separately shown in the table.

At the time of data collection, three of the 19 species were classified as critically endangered and six as endangered in the Red List of Fishes in Germany (Bless et al. 1998, Table 1). Furthermore, two species were classified as critically endangered and three species as endangered in the Red List of Fishes of the Federal State of Brandenburg (Knuth et al. 1998). Three of the 19 species are listed in Annex II of the Fauna-Flora-Habitat Directive (EU 1992, Table 1).

The linear regression analyses indicated that there were no significant differences in slopes between males and females in the seven species where this effect could be tested (Table 2).

The power regressions were significant for all species ($P < 0.001$). The r^2 was ≥ 0.99 for seven of the species and was greater than 0.96 for all other species except for *Cobitis taenia* with 0.93 (Table 1). The regression parameters a (intercept) and b (slope) differed between species. The parameters a and b ranged from 0.0005 ± 0.0001 (mean ± SE) (*Anguilla anguilla*, May) to 0.017 ± 0.003 (*Lota lota*, September) and from 2.711 ± 0.044 (*Lota lota*, September) to 3.926 ± 0.138 (*Cobitis taenia*, July), respectively. Both parameters varied also between the sampling months with comparably small standard errors in the estimates for a (Table 1). With *Rutilus rutilus*, for example, the parameter a ranged from 0.003 in November to 0.004 in the other sampling months. The parameter b ranged from 3.339 ± 0.005 in September to 3.448 ± 0.02 in November. The estimates of a for *Perca fluviatilis*, in contrast, varied between 0.004 in September to 0.006 in May. The b values were lowest in May (3.234 ± 0.017) and highest in September (3.392 ± 0.011). With *Esox lucius*, the estimates for a were higher and ranged from 0.005 in September to 0.008 in July. The b estimates were slightly lower than those of *Rutilus rutilus* and *Perca fluviatilis* and ranged from 2.931 ± 0.025 in July to 3.046 ± 0.034 in September (Table 1).

Discussion

Although various studies investigated the fish populations from the Elbe River, LWRs are only available for ten species (Hölker and Hammer 1994; Holubová et al. 2022). To the authors' best knowledge, this study provides the first references on LWRs for the *Romanogobio albipinnatus* worldwide, for 15 species in German waters and nine species from the Elbe River (Froese and Pauly 2022; Holubová et al. 2022). Finally, this study shows LWRs of seven fish species whose LWRs exist in fewer than five literature sources in Europe.

Due to the size selectivity of the fishing gear, the majority of samples did not include juveniles or very small individuals. According to Petrakis and Stergiou (1995), the respective LWR should only be used for the size range for which data were available when estimating the linear regression parameters. For this reason, the extrapolating of the relations to fish larvae (Pepin 1995), juveniles (Safran 1992), or immature stages (Bagenal and Tesch 1978) can lead to inaccurate results and is not recommended.

Our samples were always collected in the same four months in four consecutive years. For comparisons with, for example, other ecological regions or future studies, the calculated mean annual values can be considered (Petrakis

Table 2. Descriptive statistics and estimated length–weight- relation parameters by sex for seven freshwater fish species of the lowland Elbe River, Germany.

Species	Sex	n	TL_{min}	TL_{max}	W_{min}	W_{max}	Length–weight relation parameters					
							a	95% CI of a	b	95% CI of b	r^2
Gobio gobio	Male	40	9.5	16.5	6	37	0.009	0.005–0.016	2.972	2.77–3.17	0.964
	Female	37	9.5	17.0	7	45	0.005	0.003–0.010	3.183	2.94–3.43	0.964
	Both	77	9.5	17.0	6	45	0.007	0.004–0.010	3.094	2.94–3.25	0.963
Ballerus ballerus	Male	29	23.0	43.5	88	660	0.005	0.003–0.008	3.149	3.01–3.29	0.991
	Female	23	16.5	47.0	27	980	0.004	0.001–0.008	3.236	3.00–3.48	0.988
	Both	52	16.5	47.0	27	980	0.004	0.002–0.006	3.209	3.08–3.34	0.989
Leuciscus aspius	Male	45	12.5	64.5	13	2175	0.009	0.004–0.018	2.972	2.80–3.15	0.983
	Female	49	14.5	66.5	22	2639	0.002	0.001–0.003	3.402	3.26–3.55	0.991
	Both	94	12.5	66.5	13	2639	0.004	0.002–0.006	3.216	3.09–3.35	0.984
Leuciscus idus	Male	64	11.5	43.5	15	1089	0.005	0.003–0.007	3.258	3.15–3.37	0.991
	Female	62	12.5	48.0	15	1699	0.003	0.001–0.006	3.404	3.21–3.61	0.976
	Both	126	11.5	48.0	15	1699	0.002	0.001–0.004	3.450	3.31–3.59	0.976
Leuciscus leuciscus	Male	24	10.0	19.5	6	74	0.002	0.001–0.003	3.620	3.44–3.80	0.984
	Female	30	10.0	20.0	7	75	0.003	0.002–0.005	3.358	3.19–3.53	0.985
	Both	54	10.0	20.0	6	75	0.003	0.002–0.004	3.439	3.32–3.56	0.983
Squalius cephalus	Male	44	11.0	38.0	12	650	0.004	0.003–0.006	3.312	3.12–3.42	0.994
	Female	63	10.5	43.0	9	1056	0.003	0.003–0.004	3.383	3.33–3.44	0.997
	Both	107	10.5	43.0	9	1056	0.003	0.003–0.004	3.366	3.32–3.41	0.996
Lota lota	Male	26	11.0	38.5	9	381	0.007	0.003–0.017	3.000	2.73–3.27	0.959
	Female	37	11.0	37.0	9	404	0.008	0.002–0.028	2.946	2.59–3.31	0.917
	Both	63	11.0	38.5	9	404	0.008	0.004–0.016	2.967	2.74–3.20	0.933

n = sample size, TL = total length [cm], W = weight [g], min = minimum, max = maximum, a = regression intercept, b = slope of regression line, CI = confidence interval, r^2 = coefficient of correlation.

and Stergiou 1995; Goncalves et al. 1997). The observed b values of the LWRs in our study were within the limits reported for all fish species (2–4 by Bagenal and Tesch (1978) and 2.5–3.5 by Froese (2006)). Despite the many different body shapes between the fish species, [illegible]n the majority of fish species larger than 3.0 indicating positive allometric growth (increase in relative body thickness) (Froese 2006; Verreycken et al. 2011). In this study, two species (*Abramis brama* and *Esox lucius*) showed isometric growth ($b = 3$), one species (*Lota lota*) showed slightly negative allometric growth ($b < 3$), and the remaining species showed slightly positive to positive allometric growth ($b > 3$).

Additionally, we have also calculated month-specific LWRs that represent specific seasons of the year. LWRs are not constant throughout the year and can vary depending on factors such as food availability, gonad development, and spawning period (Le Cren 1951; Bagenal and Tesch 1978; Froese 2006; DeWeber et al. 2021). Parameter b is characteristic of the species (Mayrat 1970) and generally does not vary distinctly throughout the year (Le Cren 1951; Bagenal and Tesch 1978; Froese 2006). The small differences in b-values between sampling months within a species found in our study can be attributed to the following factors:

- Differences in the number and size range of specimens examined,
- effect of the year or season and
- health and general fish condition (Le Cren 1951; Froese 2006).

The parameter a, however, can vary substantially in days, seasons, and/or habitats (Le Cren 1951; Bagenal and Tesch 1978; Froese 2006). The differences in the parameters between months and years found in our study highlight the importance of considering season and sampling year when calculating and applying LWRs.

Within a fish species, LWRs can significantly differ depending on sex, life stage (larvae, ages 0 and 1 and for sexually mature males and females), and stage of gonadal development (Le Cren 1951; Froese 2006; DeWeber et al. 2021). In the presently reported study, no significant differences between males and females were observed in the seven species that had been caught in sufficient numbers for comparisons (Table 2). This suggests a lack of pronounced sexual dimorphism concerning the LWR for these species, which is similar to the results of (Morato et al. 2001) who found significant differences between males and females for only two of 15 coastal fish species of the Azores.

A limitation of the study is that the data and LWRs represent conditions from over 20 years ago which may not longer be representative of the Elbe River. Since conditions including productivity and temperature might have changed in the meantime, the data can be only used as examples for potentially typical LWRs for the studied species in the same ecoregion. These data nevertheless provide the first LWRs for many species of the study region, and future studies can investigate whether the LWRs have changed substantially over time.

Conclusions

The calculated LWRs allow us to dispense with weighing fish in the field during data collection and still get accurate weight estimates for fishes of the middle Elbe River. This allows less and shorter handling, less skin contact with objects, less damage to the mucosa, and minimizes stress, which is especially important for rare and protected fish species and leads to lower costs due to the time saved.

For the Elbe River, data regarding the abundances and biomass composition of catches as well as densities of the individual species in the shore zone and an open water area of groin fields, training walls, and mainstream exists (Fladung 2002a, 2002b). Thus, the additionally calculated LWRs will be useful for fisheries management and the protection of especially the endangered fish species in the Elbe River.

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References

Bagenal TB, Tesch FW (1978) Age and growth. Pp. 101–136. In: Bagenal TB (Ed.) Methods for assessment of fish production in fresh waters. 3rd Edition. IBP Handbook No. 3. Blackwell Scientific Publications, Oxford, UK.

Baty F, Ritz C, Charles S, Brutsche M, Flandrois JP, Delignette-Muller ML (2015) A toolbox for nonlinear regression in R: The package nlstools. Journal of Statistical Software 66(5): 1–21. https://doi.org/10.18637/jss.v066.i05

Beyer JE (1991) On length–weight relationships. 2. Computing mean weights from length statistics. Fishbyte 9(2): 50–54.

Bless R, Lelek A, Waterstraat A (1998) Rote Liste der in Binnengewässern lebenden Rundmäuler und Fische (Cyclostomata & Pisces). Schriftenreihe für Landschaftspflege und Naturschutz 55: 53–59.

Byström P, Huss M, Persson L (2012) Ontogenetic constraints and diet shifts in Perch (*Perca fluviatilis*): Mechanisms and consequences for intra-cohort cannibalism. Freshwater Biology 57(4): 847–857. https://doi.org/10.1111/j.1365-2427.2012.02752.x

DeWeber JT, Rösch R, Baer J, Brinker A (2021) Long-term changes in body condition and gillnet selectivity in Lake Constance pelagic spawning whitefish (*Coregonus wartmanni*). Canadian Journal of Fisheries and Aquatic Sciences 78(7): 841–851. https://doi.org/10.1139/cjfas-2020-0231

Erzini K (1994) An empirical study of variability in length-at-age of marine fishes. Journal of Applied Ichthyology 10(1): 17–41. https://doi.org/10.1111/j.1439-0426.1994.tb00140.x

EU (1992) Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora. Official Journal of the European Union L 206: 22.7.1992, 7–50.

Evans DH, Claiborne JB (2005) The physiology of fishes. 3rd edn. CRC Press, 616 pp. https://doi.org/10.1201/9781420058093

Fladung E (2002a) Untersuchungen zum adulten Fischbestand im Hauptstrom (Fahrrinne) der Mittelelbe. Zeitschrift für Fischkunde. Supplementband 1: 121–131.

Fladung E (2002b) Der präadulte/adulte Fischbestand in Buhnenfeldern und Leitwerken der Mittelelbe. Zeitschrift für Fischkunde. Supplementband 1: 101–120.

Froese R (2006) Cube law, condition factor and weight–length relationships: History, meta-analysis and recommendations. Journal of Applied Ichthyology 22(2): 241–253. https://doi.org/10.1111/j.1439-0426.2006.00805.x

Froese R, Binohlan C (2000) Empirical relationships to estimate asymptotic length, length at first maturity and length at maximum yield per recruit in fishes, with a simple method to evaluate length frequency data. Journal of Fish Biology 56(4): 758–773. https://doi.org/10.1111/j.1095-8649.2000.tb00870.x

Froese R, Pauly D (2022) FishBase. [Version 10/2022] http://www.fishbase.org

Froese R, Tsikliras AC, Stergiou KI (2011) Editorial note on weight–length relations of fishes. Acta Ichthyologica et Piscatoria 41(4): 261–263. https://doi.org/10.3750/AIP2011.41.4.01

Froese R, Thorson JT, Reyes Jr RB (2014) A Bayesian approach for estimating length–weight relationships in fishes. Journal of Applied Ichthyology 30(1): 78–85. https://doi.org/10.1111/jai.12299

Goncalves JMS, Bentes L, Lino PG, Ribeiro J, Canário AVM, Erzini K (1997) Weight–length relationships for selected fish species of the small-scale demersal fisheries of the south and south-west coast of Portugal. Fisheries Research 30(3): 253–256. https://doi.org/10.1016/S0165-7836(96)00569-3

Hartig F (2021) DHARMa: Residual diagnostics for hierarchical (multi-level/mixed) regression models. R package version 0.4.4. https://CRAN.R-project.org/package=DHARMa

Hölker F, Hammer C (1994) Growth and food of ruffe *Gymnocephalus cernuus* (L.) in the Elbe Estuary. Archiv für Fischerei- und Meeresforschung 42(1): 47–62.

Holubová K, Musilová Z, Horká P (2022) Regression analysis of the length–weight relationships for 17 common European fish in rivers in the Czech Republic. European Journal of Environmental Sciences 12(2): 90–92. https://doi.org/10.14712/23361964.2022.11

Knuth D, Rothe U, Zerning M (1998) Rote Liste und Artenliste der Rundmäuler und Fische des Landes Brandenburg (Cyclostomata u. Pisces). Naturschutz und Landschaftspflege Brandenburg, no. 7, Beilage, 19 pp.

Kolher N, Casey J, Turner P (1995) Length–weight relationships for 13 species of sharks from the western North Atlantic. Fish Bulletin 93(2): 412–418.

Kottelat M, Freyhof J (2007) Handbook of European freshwater fishes. Kottelat, Cornol, Switzerland and Freyhof, Berlin, Germany, 646 pp.

Koutrakis ET, Tsikliras AC (2003) Length–weight relationships of fishes from three northern Aegean estuarine systems (Greece). Journal of Applied Ichthyology 19(4): 258–260. https://doi.org/10.1046/j.1439-0426.2003.00456.x

Le Cren ED (1951) The length–weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). Journal of Animal Ecology 20(2): 201–219. https://doi.org/10.2307/1540

Martin-Smith KH (1996) Length/weight relationships of fishes in a diverse tropical freshwater community, Sabah, Malaysia. Journal of Fish Biology 49(4): 731–734. https://doi.org/10.1111/j.1095-8649.1996.tb00069.x

Mayrat A (1970) Allometric et taxinomie. Revue de Statistique Appliquee 18(4): 47–58.

Morato T, Afonso P, Lourinho P, Barreiros JP, Santos RS, Nash RDM (2001) Length–weight relationships for 21 coastal fish species of the Azores, North eastern Atlantic. Fisheries Research 50(3): 297–302. https://doi.org/10.1016/S0165-7836(00)00215-0

Ogle DH, Doll JC, Wheeler P, Dinno A (2021) FSA: Fisheries Stock Analysis. R package version 0.9.1. https://github.com/droglenc/FSA

Pauly D (1993) FishByte section editorial. Naga, ICLARM Quarterly 16, 26 pp.

Pepin P (1995) An analysis of the length–weight relationship of larval fish: Limitations of the general allometric model. Fish Bulletin 93(2): 419–426.

Petrakis G, Stergiou KI (1995) Weight–length relationships for 33 fish species in Greek waters. Fisheries Research 21(3–4): 465–469. https://doi.org/10.1016/0165-7836(94)00294-7

R Core Team (2021) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. https://www.R-project.org/

Richter HC, Luckstadt C, Focken U, Becker K (2000) An improved procedure to assess fish condition on the basis of length–weight relationships. Archiv für Fischerei- und Meeresforschung 48(3): 255–264.

Ricker WE (1975) Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada 191: 1–382.

Safran P (1992) Theoretical analysis of the weight–length relationship in fish juveniles. Marine Biology 112(4): 545–551. https://doi.org/10.1007/BF00346171

Simon M, Bekele V, Kulasová B, Maul C, Oppermann R, Řehák P (2005) Die Elbe und ihr Einzugsgebiet – Ein geographisch-hydrologischer und wasserwirtschaftlicher Überblick. Internationale Kommission zum Schutz der Elbe, Magdeburg, 258 pp.

Sinovčić G, Franičević M, Zorica B, Čikeš-Keč V (2004) Length–weight and length–length relationships for 10 pelagic fish species from the Adriatic Sea (Croatia). Journal of Applied Ichthyology 20(2): 156–158. https://doi.org/10.1046/j.1439-0426.2003.00519.x

Verreycken H, Van Thuyne G, Belpaire C (2011) Length–weight relationships of 40 freshwater fish species from two decades of monitoring in Flanders (Belgium). Journal of Applied Ichthyology 27(6): 1416–1421. https://doi.org/10.1111/j.1439-0426.2011.01815.x

Wootton RJ (1999) Ecology of teleost fishes. 2nd edn. Fish and Fisheries Series No. 24, Springer Netherlands, 400 pp.