Supplementary information

Can size spectra of European lake fish communities be predicted by community trophic position?

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Table S1 Overview of all fish species found in our lake dataset. For each species we note trophic position (according to FishBase (Froese & Pauly, 2021)), mean length (cm, from our dataset), mean weight (g, calculated from mean length with species-specific conversions), maximum length of species in our dataset (N ind.), and the species length with species

table.

| Species                | Common name       | Trophic position | Predator/ prey | Mean length | Mean weight | Max. length caught | Max. weight caught | Max. length FishBase | Max. weight FishBase | N lakes | N ind. | a       | b       |
|------------------------|-------------------|------------------|----------------|-------------|-------------|--------------------|--------------------|---------------------|---------------------|---------|--------|---------|---------|
| Abramis brama          | Common bream      | 3.15             | Prey           | 18.6        | 164         | 50                 | 1942               | 82                  | 8900                | 129     | 8228   | 0.00871 | 3.14    |
| Alburnus alburnus      | Common bleak      | 2.70             | Prey           | 12.0        | 17          | 29                 | 225                | 25                  | 135                 | 108     | 8108   | 0.00646 | 3.09    |
| Ameiurus melas         | Black bullhead    | 3.49             | Prey           | 13.3        | 39          | 28                 | 291                | 66                  | 3970                | 15      | 3886   | 0.00871 | 3.11    |
| Anguilla anguilla      | European eel      | 3.67             | Predator       | 52.5        | 365         | 93                 | 1605               | 121.5               | 3673                | 10      | 11     | 0.00095 | 3.16    |
| Ballerus ballerus      | Zope/blue bream   | 3.21             | Prey           | 27.6        | 340         | 40                 | 936                | 40                  | 900                 | 1       | 28     | 0.00871 | 3.13    |
| Barbatula barbatula    | Stone loach       | 3.45             | Prey           | 9.1         | 10          | 10                 | 13                 | 21                  | 105                 | 3       | 8      | 0.01    | 3.04    |
| Barbus barbus          | Common barbel     | 3.10             | Prey           | 46.7        | 1002        | 59                 | 1877               | 120                 | 15396               | 2       | 7      | 0.00891 | 3       |
| Barbus haasi           | Catalonian barbel | 3.35             | Prey           | 21.0        | 104         | 22                 | 104                | 30                  | 286                 | 1       | 1      | 0.00955 | 3.03    |
| Blicca bjoerna         | Silver bream      | 3.09             | Prey           | 14.4        | 57          | 50                 | 1743               | 45.5                | 1258                | 89      | 12181  | 0.00813 | 3.13    |
| Carassius auratus      | Goldfish          | 2.86             | Prey           | 23.2        | 391         | 42                 | 1036               | 48                  | 1492                | 2       | 9      | 0.01349 | 3       |
| Carassius carassius    | Crucian carp      | 3.11             | Prey           | 28.8        | 364         | 44                 | 1028               | 64                  | 3037                | 10      | 44     | 0.01259 | 2.98    |
| Carassius gibelio      | Prussian carp     | 2.50             | Prey           | 37.0        | 755         | 37                 | 755                | 46.6                | 1451                | 1       | 1      | 0.0138  | 3.01    |
| Chelon auratus         | Golden grey mullet| 2.84             | Prey           | 49.0        | 1014        | 49                 | 1014               | 59                  | 1705                | 1       | 1      | 0.00977 | 2.96    |
| Chelon ramada          | Thilip mullet     | 2.34             | Prey           | 47.9        | 1010        | 58                 | 1731               | 70                  | 2950                | 2       | 67     | 0.00977 | 2.97    |
| Cobitis taenia         | Spined loach      | 3.30             | Prey           | 11.0        | 10          | 11                 | 10                 | 13.5                | 16                  | 1       | 1      | 0.0049  | 3.1     |
| Coregonus albula       | Vendace           | 3.06             | Prey           | 15.3        | 40          | 29                 | 250                | 48                  | 1194                | 33      | 1377   | 0.00479 | 3.21    |
| Coregonus lavaretus    | Whitefish         | 3.15             | Prey           | 23.3        | 184         | 55                 | 1706               | 73                  | 4101                | 32      | 727    | 0.00447 | 3.2     |
| Cottus gobio           | European bullhead | 3.28             | Prey           | 8.0         | 8           | 8                  | 8                  | 8                   | 90                  | 1       | 1      | 0.00977 | 3.16    |
| Cottus poecilogus      | Alpine bullhead   | 2.98             | Prey           | 10.5        | 13          | 12                 | 19                 | 19                  | 34                  | 1       | 24     | 0.00708 | 3.13    |
| Cyprinidae hybrid      |                   | 3.00             | Prey           | 15.2        | 83          | 40                 | 991                | NA                  | NA                  | 24      | 119    | 0.01862 | 2.94    |
| Cyprinus carpio        | Common carp       | 3.05             | Prey           | 29.5        | 693         | 50                 | 1895               | 120                 | 24142               | 17      | 266    | 0.01862 | 2.94    |
| Esox lucius            | European pike     | 4.40             | Predator       | 40.3        | 540         | 66                 | 1875               | 137                 | 17496               | 150     | 440    | 0.00437 | 3.09    |
| Gasterosteus aculeatus | Three-spined      | 3.38             | Prey           | 9.0         | 11          | 9                  | 11                 | 11                  | 16                  | 1       | 1      | 0.01047 | 3.07    |
| Gobio gobio            | Gudgeon           | 3.13             | Prey           | 11.8        | 22          | 26                 | 223                | 21                  | 108                 | 19      | 766    | 0.00759 | 3.14    |
| Gobio lozanoi          | Iberian gudgeon   | 3.17             | Prey           | 9.6         | 10          | 12                 | 19                 | 13.5                | 24                  | 3       | 184    | 0.00741 | 3.11    |
| Gymnocephalus cernua   | Eurasian ruffe    | 3.26             | Prey           | 10.2        | 12          | 21                 | 94                 | 25                  | 148                 | 126     | 7920   | 0.00977 | 2.99    |
| Lepomis gibbosus       | Pumpkinseed       | 3.27             | Prey           | 10.2        | 20          | 19                 | 117                | 40                  | 1087                | 23      | 401    | 0.01175 | 3.1     |
| Leuciscus aspius | Asp     | 4.47 | Predator | 32.8 | 591 | 47 | 1489 | 120 | 24002 | 4 | 5 | 0.01389 | 3 |
|-----------------|---------|------|----------|------|-----|----|------|-----|-------|--|--|---------|--|
| Leuciscus idus  | Ide     | 3.79 | Predator  | 20.0 | 210 | 44 | 1055 | 85  | 7944  | 3 | 7 | 0.00759 | 3.12 |
| Leuciscus leuciscus | Common dace | 2.93 | Prey     | 21.4 | 156 | 31 | 375  | 40  | 791   | 4 | 21| 0.00794 | 3.12 |
| Leuciscus lucioperca | Common roach | 2.80 | Prey     | 10.2 | 16  | 16 | 57   | 26  | 242   | 3 | 411| 0.0081 | 3.16 |
| Lota lota       | Burbot  | 4.05 | Predator  | 30.0 | 270 | 65 | 1961 | 152 | 26438 | 23| 123| 0.00479 | 3.09 |
| Luciobarbus graellisi | Common rudd | 2.76 | Prey     | 27.3 | 310 | 55 | 1917 | 80  | 5910  | 7 | 283| 0.00813 | 3.08 |
| Micropterus salmoides | Brown trout | 4.42 | Predator  | 18.5 | 110 | 32 | 459  | 97  | 13162 | 7 | 63| 0.01047 | 3.07 |
| Oncorhynchus mykiss | Rainbow trout | 3.53 | Predator  | 31.2 | 372 | 47 | 1149 | 122 | 20030 | 6 | 24 | 0.00955 | 3.03 |
| Osmerus eperlanus | European smelt | 3.46 | Prey     | 11.9 | 13  | 21 | 71   | 45  | 743   | 16| 477| 0.00427 | 3.17 |
| Parachondrostoma migii | Common dace | 3.00 | Prey     | 14.0 | 32  | 30 | 270  | 25  | 146   | 9 | 2213| 0.00724 | 3.08 |
| Perca fluviatilis | European perch | 3.78/4.35 | Predator  | 10.7/20.1 | 18/139 | 50 | 1763 | 60  | 2997  | 213| 68834| 0.01 | 3.06 |
| Phoxinus phoxinus | Eurasian minnow | 3.27 | Prey     | 9.5  | 11  | 11 | 16   | 14  | 30    | 5 | 16 | 0.00794 | 3.12 |
| Rhodeus amarus  | European bitterling | 2.95 | Prey     | 8.0  | 8   | 8  | 8    | 11.2| 19    | 1 | 1 | 0.01023 | 3.12 |
| Rutilus rutilus | Common dace | 2.87 | Prey     | 13.7 | 46  | 43 | 1108 | 50.2| 1738  | 206| 65768| 0.00794 | 3.14 |
| Salmo trutta    | Brown trout | 3.80 | Predator  | 26.0 | 263 | 59 | 1991 | 140 | 26383 | 24| 587 | 0.00871 | 3.02 |
| Salvelinus umbla | Lake char | 3.90 | Predator  | 18.0 | 158 | 56 | 1989 | 75  | 4692  | 10| 1601| 0.00977 | 3.03 |
| Sander lucioperca | Zander/pike perch | 4.04 | Predator  | 23.5 | 271 | 58 | 1988 | 100 | 10476 | 74| 2227| 0.00661 | 3.1 |
| Scardinus erythrophthalmus | Common dace | 2.89 | Prey     | 17.1 | 113 | 43 | 1206 | 61.7| 3627  | 102| 3222| 0.00832 | 3.15 |
| Silurus glanis  | Wels catfish | 4.12 | Predator  | 39.4 | 441 | 55 | 1025 | 273 | 109088 | 8 | 19| 0.00794 | 2.93 |
| Squalius cephalus | Common chub | 3.61 | Predator  | 26.2 | 421 | 53 | 1916 | NA  | NA    | 15| 273 | 0.00776 | 3.12 |
| Telestes soufflia | Soufflia | 3.37 | Prey     | 13.9 | 29  | 20 | 76   | 26  | 208   | 2 | 105| 0.00692 | 3.09 |
| Tinca tinca     | Tench   | 3.27 | Prey     | 32.6 | 697 | 54 | 1967 | 70  | 4190  | 57| 169| 0.01122 | 3.02 |
Table S2 Pearson correlations between all variables in the original model. All values were below 0.6, suggesting no strong correlations between explanatory variables. N = 235.

|               | \(\log_{10}(\text{PPMR})\) | \(\log_{10}(\text{CPUE})\) | Species richness | Max T | \(\log_{10}(\text{Total P})\) | \(\log_{10}(\text{Max Depth})\) | \(\log_{10}(\text{Area})\) |
|---------------|------------------------------|-----------------------------|------------------|-------|-----------------------------|------------------------------|------------------|
| Trophic position | -0.12                        | -0.38                       | -0.45            | -0.53 | -0.48                       | 0.10                        | -0.16            |
| \(\log_{10}(\text{PPMR})\) | 0.12                         | -0.09                       | -0.13            | -0.07 | -0.08                       | 0.01                        |                  |
| \(\log_{10}(\text{CPUE})\)   | 0.31                         | 0.39                        | 0.53             | -0.49 | 0.12                        |                             |                  |
| Species richness |                             | 0.50                        | 0.58             | 0.15  | 0.45                        |                             |                  |
| Max T          |                              |                             | 0.52             | 0.02  | 0.29                        |                             |                  |
| \(\log_{10}(\text{Total P})\) |                              |                             |                  | -0.27 | 0.17                        |                             |                  |
| \(\log_{10}(\text{Max Depth})\) |                              |                             |                  |       | 0.41                        |                             |                  |

Figure S1 Comparison between the slopes based on maximum likelihood (MLE, as used in the study) and the ordinary least squares (OLS) approach. OLS slopes were based on binning of size classes and calculated with linear regressions. Both for good fit lakes (\(r(233) = 0.81, p < 0.001\)) and ill fit lakes (\(r(127) = 0.84, p < 0.001\)) there was a positive correlation between the slopes based on the two different methods.
Figure S2 Here we show examples of two lakes with a relatively good MLE fit (a and b), and two lakes with a relatively ill MLE fit (c and d). In these plots we show the individual size distribution and MLE (bins) fit (red solid line), with 95% CI intervals (red dashed line). The horizontal green line shows the range of body sizes for each bin, with its value on the y-axis corresponding to the total number of individuals in bins whose minima are ≥ the bin’s minimum. The vertical span of each grey bar shows the possible range of the number of individuals with body mass ≥ the body mass of individuals in that bin (its horizontal span is the same as for the green lines) (according to Edwards et al. (2020)). In the “ill-fitting” graphs one can see that there is an underestimation of individuals in the “small fish” (before the intersect of the red MLE curve with the data), and an overestimation of “large fish” (after the intersect of the red MLE curve with the data). Note that both y and x axes are displayed on a log scale, which is a similar depiction of how traditional SS slopes are displayed.
Figure S3 Map showing the distribution of lakes in our study, including lakes with a “good fit” (black circles) as well as lakes with a “bad fit” which were excluded from analyses (red triangles).
Figure S4 Correlation plots of the biotic variables (trophic position, $\log_{10}(\text{PPMR})$, $\log_{10}(\text{CPUE})$ and species richness). N=235 lakes.
Figure S5 Marginal effect plots between the exponent b of the size spectrum and a) the species richness, b) the maximum temperature, c) total Phosphorus (log10), d) maximum depth (log10) and e) area (log10). The lines are significant regression lines with 95% CI intervals. Model outputs are shown in Table 3. N=235 lakes
Sensitivity analyses with fish mass 8-1000g (instead of 8-2000 g)

Figure S6 Comparison of exponent b calculated with fish with weight 8-2000 g (main analyses) and with weight 8-1000 g.

Table S3 Fish size 8-1000 g. Output of the model (linear mixed model with a structure to account for potential spatial autocorrelation) relating the exponent b of the size spectrum to the mean trophic position of the community, PPMR, CPUE, the species richness and four environmental covariates (maximum temperature, total phosphorus, maximum depth and lake area). In the last two columns standardized values and errors are noted. R² of the model is 0.40. N = 235 lakes. Significance codes: *** p < 0.001; ** p < 0.01; * p < 0.05; + p<0.1.

|            | Value    | Std. error | DF  | t-value | p-value  | Std. value | Std. error |
|------------|----------|------------|-----|---------|----------|------------|------------|
| (Intercept)| -0.745   | 0.324      | 226 | -2.300  | 0.022*   | 0.223      | 0.216      |
| Trophic position | 0.075 | 0.064      | 226 | 1.162   | 0.247    | 0.072      | 0.062      |
| log₁₀(PPMR) | -0.429  | 0.051      | 226 | -8.394  | <0.001***| -0.404     | 0.048      |
| log₁₀(CPUE) | -0.300  | 0.047      | 226 | -6.437  | <0.001***| -0.453     | 0.070      |
| Species richness | -0.008 | 0.007      | 226 | -1.176  | 0.241    | -0.088     | 0.075      |
| Max T       | -0.012   | 0.010      | 226 | -1.275  | 0.204    | -0.103     | 0.081      |
| log₁₀(Total P) | -0.007 | 0.048      | 226 | -0.149  | 0.882    | -0.012     | 0.077      |
| log₁₀(Max depth) | -0.061 | 0.052      | 226 | -1.177  | 0.241    | -0.084     | 0.071      |
| log₁₀(Area)  | 0.050    | 0.028      | 226 | 1.781   | 0.076+   | 0.110      | 0.062      |