

1 **Length–weight relationships of the French pikes *Esox* spp (Teleostei,**
2 **Esocidae)**

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4 Lucas Royer¹, Fabrice Teletchea¹, Sophie Delavergne², Frédéric Lafitte², Marion Escarpit³,
5 Quentin Molina⁴, Emilie Breugnot⁵, Eddy Cosson⁶, Aurélia L’Hostis⁷, Gaël P.J. Denys^{8,9*}

6

7 1 University of Lorraine, UR AFPA, USC INRAE 340, Vandœuvre-lès-Nancy, F-
8 54506, France [lucas.royer@agrocampus-ouest.fr] [fabrice.teletchea@univ-lorraine.fr]

9 2 Fédération des Associations Agréées de Pêche et de Protection du Milieu
10 Aquatique de la Gironde, 10 ZA du Lapin, 33750 Beychac-et-Caillau, France
11 [sophie.delavergne@peche33.com] [frederic.lafitte@peche33.com]

12 3 Fédération Départementale des Landes Pêche et Protection du Milieu Aquatique,
13 102 allées Marines, 40400 Tartas, France [m.escarpit@peche-landes.com]

14 4 Fédération de Lot-et-Garonne pour la Pêche et la Protection du Milieu
15 Aquatique, 44 cours du 9ème-de-ligne BP 225 47006 Agen cedex, France
16 [qm.peche47@orange.fr]

17 5 Office Français de la Biodiversité, Direction régionale Nouvelle-Aquitaine, 207
18 cours du Médoc, 33300 Bordeaux, France [emilie.breugnot@ofb.gouv.fr]

19 6 Office français de la Biodiversité, Direction Surveillance Evaluation Données, 5
20 square Félix NADAR, 94300 Vincennes, France [eddy.cosson @ofb.gouv.fr]

21 7 Union des Fédérations pour la pêche et la protection des milieux aquatique du
22 Bassin Adour-Garonne, 5 chemin de Bramofam, 31120 Roques, France
23 [ufbag@orange.fr]

24 8 Unité Patrimoine Naturel – Centre d’expertise et de données (2006 OFB –
25 MNHN – CNRS – IRD), Muséum national d’Histoire naturelle, 36 rue Geoffroy-Saint-
26 Hilaire CP 41, 75005 Paris, France. [gael.denys@mnhn.fr]

27 9 UMR Biologie des organismes et écosystèmes aquatiques (BOREA 8067),
28 MNHN, CNRS, IRD, SU, UCN, UA, 57 rue Cuvier CP26, 75005 Paris, France.

29 * Corresponding author [gael.denys@mnhn.fr]

30

31 **Abstract** – Length–weight relationships for Pike *Esox aquitanicus* and *Esox lucius* from France
32 are provided. A total of 9,070 specimens were collected, measured and weighted from 1981 to
33 2022 throughout France by Departmental Angling Federations and the French Biodiversity
34 Agency during their survey by electrofishing. For all species, the values of b are 2.960 for *E.*
35 *aquitanicus* and 2.987 for *Esox lucius*. We hypothesize this difference by the poor environment
36 where live the Aquitanian pike with no abundant available food and small prey fish species
37 which do not contribute to good conditions for the growth. The study provides the first reference
38 of length–weight relationships for *E. aquitanicus*.

39

40 **Key words**

41 *Esox aquitanicus*, *Esox lucius*, France, length, weight, endemic species

42

43 **1 Introduction**

44 Pikes *Esox* spp. (Actinopterygii, Esociformes) are emblematic fishes because of their strong
45 socioeconomic value for both recreational and commercial fishing (Raat, 1988; Mann, 1996).
46 This genus groups eight species occurring throughout North America and Eurasia (Froese &
47 Pauly, 2023). In France, two species are currently listed: the ubiquitous northern pike *Esox*
48 *lucius* Linnaeus, 1758 (Fig. 1) and the newly described Aquitanian pike *Esox aquitanicus*
49 Denys, Dettai, Persat, Hauteceœur, Keith, 2014 (Fig. 2) (Keith *et al.*, 2020). The Aquitanian pike
50 and the allochthonous northern pike co-occur from the Charente to the Adour drainages,
51 because of frequent restocking of the latest since the second part of the twentieth century (Fig.
52 3) (Denys *et al.*, 2014). Both pike species can be distinguished morphologically by their coat
53 coloration patterns, their snout length as well as lateral scales and vertebrae numbers (Denys *et*
54 *al.*, 2014; Jeanroy & Denys, 2019). However, if the northern pike is present in the main rivers
55 and lakes with aquatic vegetation, the endemic species seems to be restricted to small tributaries
56 and coastal catchments qualified as poor environment with sandy substrate and few aquatic
57 vegetation (Fig. 3) (Denys, 2017; Keith *et al.*, 2020). *E. aquitanicus* is currently listed as
58 Vulnerable according to the French IUCN Red List of Threatened Species like *E. lucius* because
59 of their risk of hybridization (UICN Comité français *et al.*, 2019; Keith *et al.*, 2020). As the
60 Aquitaine pike is then a patrimonial and threatened species, riverine managers need tools to
61 apply a good management and conservation policy (Dudgeon *et al.*, 2005; Maasri *et al.*, 2021).
62 Length–weight relationships (LWRs) constitute primary knowledges used for fish management
63 and stock assessment. They are necessary for estimating fish biomass from sampled length data,
64 as well as fish growth, and are useful for ecological modelling (Froese, 2006). For that, length
65 L and weight W are related with a mathematical formula $W = aL^b$ including two parameters: a
66 coefficient a and the allometric growth parameter b (Keys, 1928). These two parameters are
67 essential to understand the growth of each species. Each pike species has at least one LWR

68 published study (e.g., Kapuscinski *et al.*, 2007; Verreycken *et al.*, 2021; Giannetto *et al.*, 2016;
69 Huo *et al.*, 2017; Parker *et al.*, 2018), except the Aquitanian pike. Irz *et al.* (2022) published
70 also a LWR of “*Esox lucius*” from the ASPE database collecting lengths and weights data of
71 French fish species collected by the French Agency of Biodiversity (OFB) since 1980s, but
72 without distinguishing the two species. Well, working on data from badly identified taxa can
73 induce some bias on their management (Bortolus, 2008).

74 The aim of this study was to provide the first LWR for *E. aquitanicus* based on an extensive
75 sampling throughout its distribution area, to compare it with data of French *E. lucius* in order
76 to know if there are some differences between both species, and to know if misidentifications
77 in the ASPE database of Irz *et al.* (2022) have repercussions on their results.

78

79 **2 Material and methods**

80 Data for Aquitanian pike were collected from 1996 to 2022 during the monitoring of the
81 Departmental Angling Federations and the French Biodiversity Agency (OFB) which aim to
82 make the diagnosis of the physical, trophic and physico-chemical state of the environments in
83 order to best adjust the fish management measures. Specimens were caught by electrofishing
84 inventories campaigns before to be released. Populations previously characterized as hybrids
85 or introgressed by Denys *et al.* (2014, 2018) and Denys (2017) were removed from our dataset
86 as well as the locations already known to have been restocked. Thus, our dataset is composed
87 by only populations already characterized as pure Aquitanian pike according to morphological
88 (Denys *et al.*, 2014; Jeanroy & Denys, 2018) or molecular data (Denys *et al.*, 2014, 2018;
89 Denys, 2017). Total length (L in cm) was measured to the nearest millimeter and weight (W in
90 g) was determined with a digital balance to an accuracy of 0.1 g. Additional data ($n = 338$) from
91 locations already knows to shelter Aquitanian pike without any sympatry with the allochthonous

92 species were added from the ASPE database (Irz *et al.*, 2022). The list of locations and
93 measurements are available in Supplementary data 1 and 2.

94 For northern pike, data were extracted from the ASPE database excluding those from the
95 Adour-Garonne drainages (location codes beginning by “05”) in order to exclude any data
96 corresponding to the Aquitanian pike, and during the period between 1981 to 2017. Only
97 individual measurements were considered. A map synthetizing the sampling is given in Figure
98 4.

99 In both datasets, records with weights lower or equal to 1 g were removed considering weighing
100 scales used were not sufficiently accurate to have reliable data for these young offsprings.

101 Lengths and weights averages were compared using a *u* test of Mann-Whitney after having
102 checked a non-normal distribution with a Shapiro-Wilk test ($p\text{-value} < 2.2 e^{-16}$). Length–weight
103 relationships were calculated following the method of Kuriakose (2014) using the equation
104 $\log_{10}W = \log_{10}a + b \log_{10}L$, where *a* is the intercept on the *Y*-axis of the regression curve and
105 *b* is the regression coefficient (Ricker, 1975). LWRs were calculated for unsexed individuals,
106 as the sex determination is not done by the angling federations nor the French Agency of
107 Biodiversity, because it is not included in their protocol of surveys. The 95% confidence limits
108 of *a* and *b* (CL 95%) were also computed (Froese, 2006) for both equations.

109 Linear regressions and all statistic tests were performed using the R package (R core team,
110 2022) using *lmtest*, *stats* and *dplyr* packages following Irz (2022). In order to validate the
111 regression model for each dataset, a Rainbow-test was done in order to verify if the residuals
112 mean was equal to 0 (Utts, 1982). Their *p*-value = 1 and 0.147 for respectively *E. aquitanicus*
113 and *E. lucius* indicated a leverage effect. So, the Cook’s D distances were then calculated and
114 data exceeding $4/N$ (*N* being the number of observations) were removed from the dataset
115 (Bollen & Jackman, 1990).

116

117 **3 Results**

118 Data on lengths and weights are provided for a total of 3,657 Aquitanian pikes and 5,413
119 northern pikes. The average sizes and weights are respectively 10.7 cm for 20.2 g and 30.2 cm
120 for 339.8 g. Both u-tests of Mann-Whitney on lengths and weights indicates that the average
121 data for *E. aquitanicus* is lower than those of *E. lucius* ($W_{\text{lengths}} = 1341292$; $W_{\text{weights}} = 1413738$;
122 $p\text{-value} < 2.2 \times 10^{-16}$ for both datasets). The number of specimens, TL range, parameters a and b
123 with their 95% CL and the correlation coefficient (R^2) are reported in Table 1.

124 The R^2 values are respectively equal to 0.982 and 0.988 demonstrating a strong correlation
125 between lengths and weights for both species (Fig. 5).

126 *E. aquitanicus* has a lower b parameter than *E. lucius* (2.960 vs. 2.987) as their range do not
127 overlap (Table 1).

128

129 **4 Discussion**

130 LWR of *E. aquitanicus* and French *E. lucius* were established from the analysis of 9,070 fish.
131 Aquitanian pike are smaller than northern pike with a maximum size conserved in our dataset
132 of 72 cm for 2.5 kg. Fish sizes are positively correlated with the surface area of habitat and
133 negatively with the temperature (Denys *et al.*, 2016; Kennedy & Rennie, 2023). But Aquitanian
134 pike lives in small tributaries and little coastal basins (Keith *et al.*, 2020), and in southwestern
135 France which is one of the warmer regions in the country (e.g., Parey *et al.*, 2007). However,
136 anglers accounts and data from bibliographical archives described larger specimens: 85 cm for
137 5 kg (Lagardère, 2020), 107 cm for 9 kg (Glize, 1993) and large fish from 12 to 15 kg (Cahuzac,
138 2001). So, when the environmental conditions are favourable, Aquitanian pike can reach
139 comparable sizes than northern pike.

140 The a parameter for the Aquitanian pike is significantly smaller than the one of *E. lucius* (Table
141 1). Whereas the b parameters are respectively 2.960 and 2.987 in accordance with Carlander

142 (1969) assuming that b normally falls between 2.5 and 3.5. Values of b lower than 3, meaning
143 a “negative” growth, so both pike species become slimmer with increasing length. Comparing
144 both b values, the one *E. aquitanicus* is lower than *E. lucius* (Table 1). The hypothesis that *E.*
145 *aquitanicus* would be more elongated than *E. lucius* would be false because of its shorter snout
146 and the fewer number of vertebrae (Denys *et al.*, 2014). So, the northern pike would be heavier
147 than the Aquitanian pike for the same given size. Differences between a and b values may be
148 explained by the poor environments where it lives (sandy substrates, few aquatic vegetation,
149 low biomass) conferring a lower primary productivity (Tales *et al.*, 2004). The specific richness
150 is also low (about 5 to 8 co-occurring fish species) (see CGA hydroregion from Santoul *et al.*
151 (2004) and assemblage type 1 from Park *et al.* (2006)), and closed to the historical native
152 ichthyofauna community in the Adour-Garonne basin (Keith *et al.*, 2020) with little sized
153 species such as minnows *Phoxinus* spp, stone loaches *Barbatula* spp and gudgeons *Gobio* spp
154 which are not in elevated densities considering the particular habitat (Tales *et al.*, 2004).
155 However within pikes, the growth rate is correlated with the size of the eaten preys (Hart &
156 Connellan, 1984) and the quantity of available food (Kozłowski *et al.*, 2012; Kennedy &
157 Rennie, 2023). A study on ecological traits of the Aquitanian pike is sorely needed to support
158 this hypothesis.

159 Our a and b parameters for *Esox lucius* are exactly the same as given by Irz *et al.* (2022), as
160 well as the R^2 (0.987). Their huge dataset ($n = 9,535$) in the ASPE database and removing data
161 after the Cook’s D distances calculations has certainly drowned the signal of *E. aquitanicus* in
162 the dataset. The addition of data from angling federations allowed as well as working on
163 populations correctly identified has allowed to bring new knowledges on the endemic species.
164 Angling federations have useful data and naturalist observations which deserve to be known
165 and used in monitoring, ecological studies and conservations programs (Maasri *et al.*, 2021).

166 Their datasets are then complementary with the database ASPE. However, the data
167 centralization from each departmental angling federation and the access is still a huge challenge.
168 Managers are encouraged to integrate in their protocol the sex determination. This kind of data
169 would allow to highlight a potential sexual size dimorphism already known within pike species
170 (e.g., Craig, 1996) with female growing faster than males. Nevertheless, these cases are
171 correlated with the availability of food resources and cool temperatures (Kennedy & Rennie,
172 2023). But the geographical context does not fulfil these conditions.
173 Finally, our study provides then the first data of LWR for Aquitanian pike which could be
174 implemented in FishBase (Froese & Pauly, 2023). This LWR could be useful for managers for
175 estimating weights from measurements and to know if the environment of a location brings
176 ideal conditions for growth, as well as for other disciplines in biology.

177

178 **Acknowledgements**

179 This work was supported by the Muséum national d'Histoire naturelle (MNHN), the Unit
180 PatriNat 2006, the UMR BOREA 8067, the Lorraine University, the French Biodiversity
181 Agency and the Union of Angling Federations of the Adour-Garonne Basin (UFBAG). This
182 study is included within a global project about the Aquitanian pike BIOESOX funded by the
183 UFBAG and the French Federation of Angling in France (FNPF). We thank all people from the
184 Angling departmental federations and the OFB for providing data.

185

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- 284

285 **Table legend**

286

287 Table 1. Descriptive statistics and parameters of total length (TL, in cm) – weight (W, in g)

288 regression for the Aquitanian pike (South West of France) and northern pike from France;

289 SD means standard deviation.

290

Species	Sex	n	TL range (SD)	W range (SD)	a	Range a (95% CL)	b	Range b (95% CL)	R ²
<i>Esox aquitanicus</i>	All	3,657	5.0 – 72.0 (5.834)	1.2 – 2,500 (85.060)	0.008	0.007–0.008	2.960	2.947–2.973	0.982
<i>Esox lucius</i>	All	5,413	5.9 – 125.0 (15.355)	2.0 – 12,450 (708.559)	0.007	0.006–0.007	2.987	2.978–2.995	0.988

291

292

293 **Figure legends**

294



295

296 Figure 1. The northern pike *Esox lucius*: 92 mm from the Vie river at Poiré-sur-Vie (A), 278

297 mm from the Yser river (B), 770 mm from the Oise river (C); credit photos: Hydrosphere,

298 Fishpass, OFB.

299



300

301 Figure 2. The Aquitanian pike *Esox aquitanicus*: 111 mm for 9 g from the Ciron stream (A),

302 480 mm for 816g from the Courant mort brook (B); 747 mm for 3,200 g from the Jalle du Sud

303 stream (C); credit photos: FDAAPPMA47, FDAAPPMA40, FDAAPPMA33.

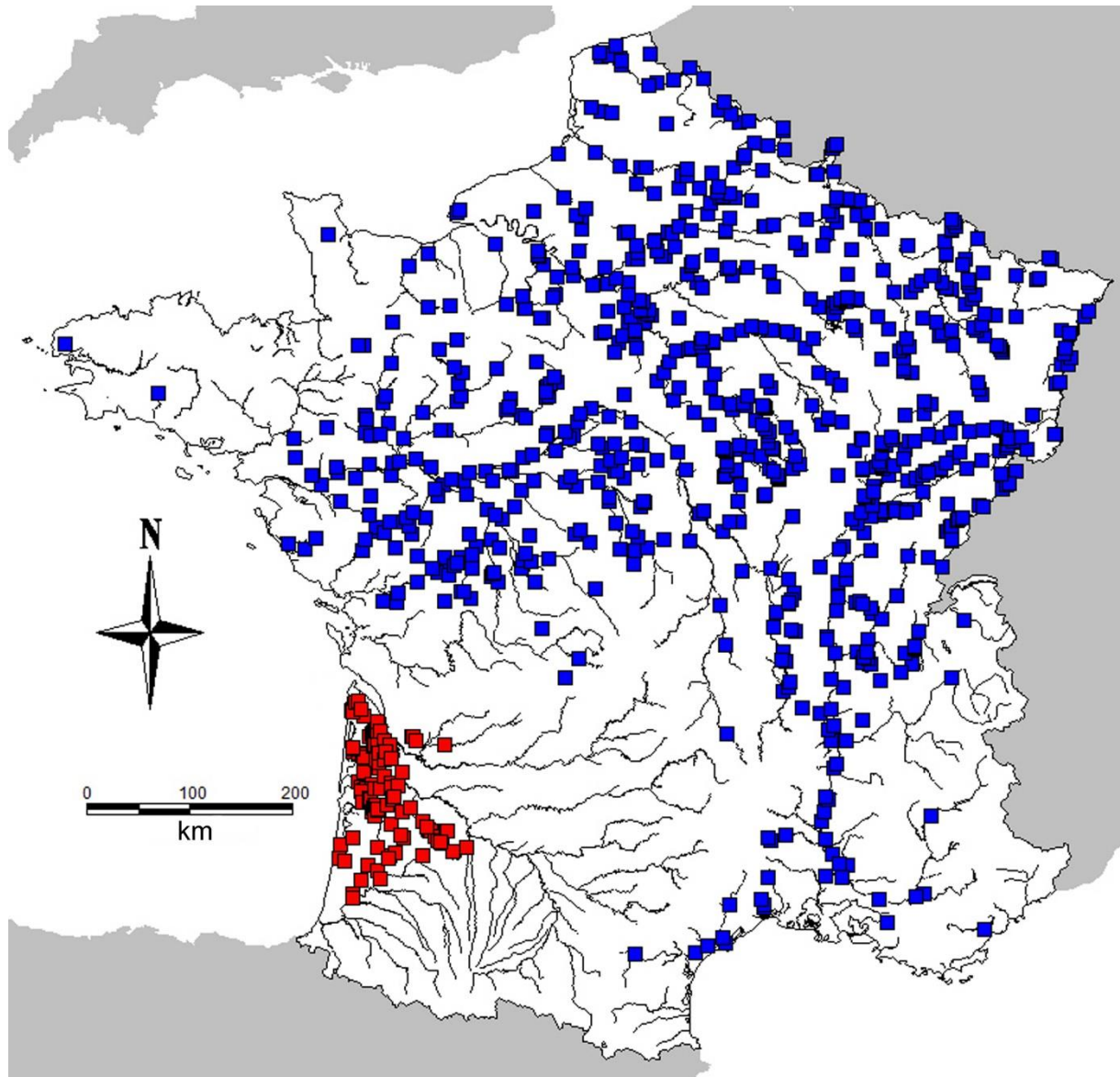
304



305

306 Figure 3. Distribution area of the two pike species in France (*Esox aquitanicus* in red, *Esox*
307 *lucius* in its native area in blue and introduced in green) (modified and adapted from Keith *et*
308 *al.*, 2020 and Denys, 2017), with examples of typical habitats of both species: the Sèvre nantaise
309 (A) as a large river with many aquatic vegetation and the Ciron stream (B) as watershed with a
310 poor environment (sandy substrate and no aquatic vegetation except stumps); credit photos: G.
311 Denys.

312

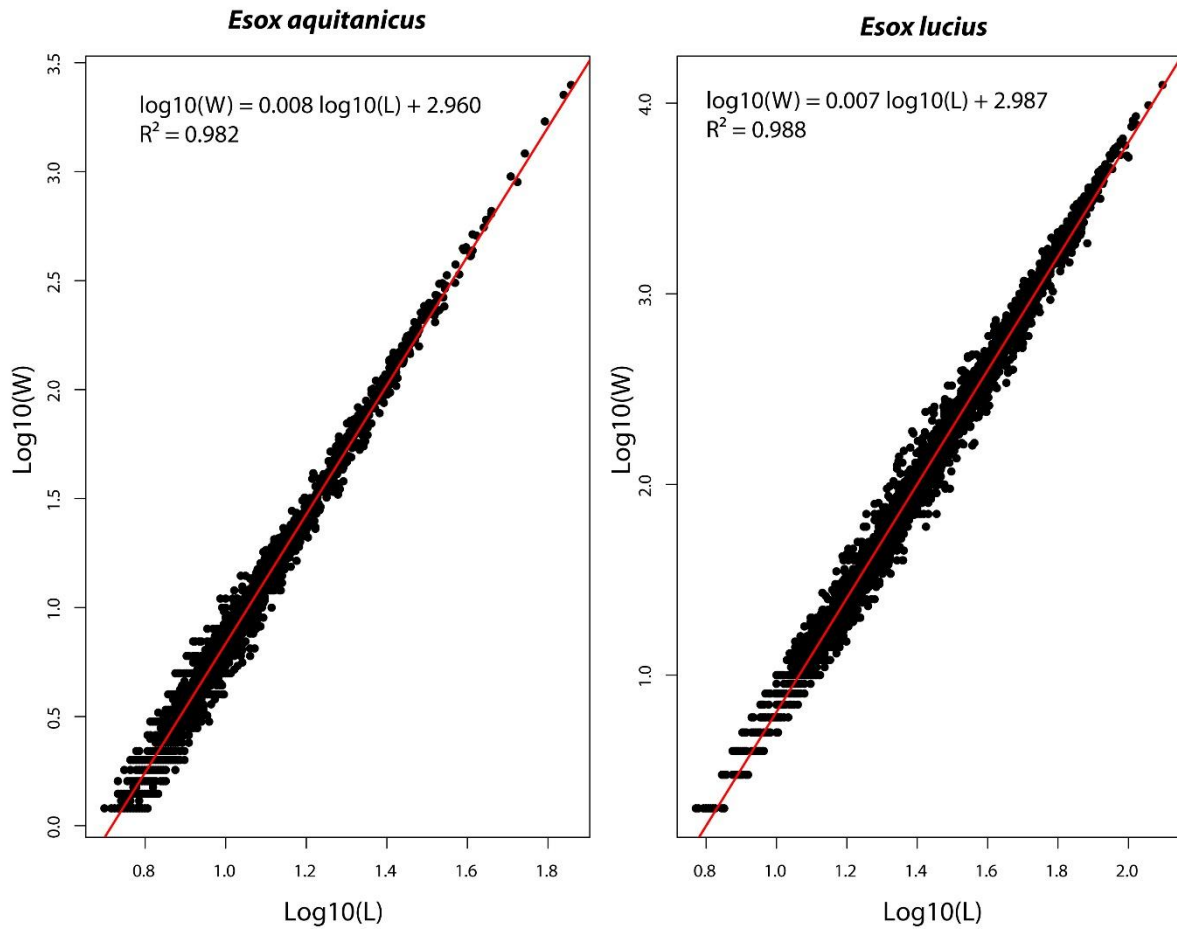


313

314 Figure 4. Locations of both pike species (*Esox aquitanicus* in red and *Esox lucius* in blue) from

315 where lengths and weights data came.

316



317

318 Figure 5. Lengths (L) - weights (W) regressions of *Esox aquitanicus* and *Esox lucius*. Data were

319 log₁₀ transformed.

320

- 321 Supplementary data 1. List of locations of *Esox aquitanicus* used in this study.
- 322 Supplementary data 2. Measurements of *Esox aquitanicus* used in this study.