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1 **Life history traits of Mediterranean brown trout (*Salmo trutta* complex) in Pyrenean**  
2 **headwater streams**

3

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25 Running head: Trout life history in Pyrenean streams

26 **Abstract**

27 The Mediterranean brown trout (*Salmo trutta* complex) is native to basins draining to the  
28 Western Mediterranean Sea, and natural populations are currently declining in abundance and  
29 distribution due to habitat degradation and introgression with stocked trout of the Atlantic  
30 lineage. Data on its life history traits is limited, although is an essential first step in  
31 developing effective conservation and management strategies. We studied age, growth and  
32 reproduction of Mediterranean brown trout from three headwater streams in northeast Iberian  
33 Peninsula. The maximum observed fork length was 382 mm in males and 322 mm in females,  
34 and six age groups (from 1+ to 6+) were identified. There was large variation in the back-  
35 calculated lengths for individual fish within ages. The von Bertalanffy growth curves were  
36 similar among streams and comparable to other European populations from small streams, but  
37 growth rate was lower when compared to larger and more productive rivers. Overall, sexual  
38 maturation began at age 1+, and the estimated  $L_{50}$  was 136 mm for males and 150 mm for  
39 females. Monthly variations in the gonadosomatic index showed that spawning occurred  
40 between late autumn and early winter, mainly in November and December. Mean fecundity  
41 and egg diameter were positively correlated with fish length, and values were within the  
42 typical range reported in other brown trout populations. Most of the differences among  
43 streams can be explained by differences in water temperature. This results constitute a  
44 contribution to better understanding of key aspects Mediterranean brown trout biology, and to  
45 develop conservation and management strategies for preserving their populations.

46

47 **Keywords:** Size at maturity · Growth rate · Fecundity · Age determination · Salmonidae

## 48 **Introduction**

49 The brown trout *Salmo trutta* L. 1758 is a polytypic species of Salmonidae family distributed  
50 over a wide geographic range, spanning Europe, Western Asia and North Africa (Jonsson and  
51 Jonsson 2011). The species is distributed as a mosaic of at least five evolutionary lineages,  
52 which evolved in geographic isolation and remained largely allopatric since the Pleistocene  
53 (Bernatchez 2001). Furthermore, the evolutionary history of brown trout is characterized by  
54 the different latitudinal impact of paleoclimatic events (e.g., glaciations) on population  
55 isolation, colonization events and secondary contacts between lineages (Bernatchez 2001;  
56 Rossi et al. 2019). Because of the complex evolutionary history of brown trout, its taxonomic  
57 status is still unclear and needs further revision (Kottelat and Freyhof 2007); in recent  
58 taxonomic revisions *Salmo trutta* is considered a species complex (e.g., Rossi et al. 2019;  
59 Splendiani et al. 2019). Originally, brown trout from the western Mediterranean basins  
60 (eastern Spain and southern France) are considered of Mediterranean lineage (Berrebi et al.  
61 2000; Sanz 2017). However, in the last century, the genetic integrity has been compromised  
62 due to massive restocking for angling, mainly with individuals of the Atlantic lineage  
63 (Araguas et al. 2017). Both Mediterranean and Atlantic lineages differ in many aspects, not  
64 only genetic but also behavioural, reproductive, and phenotypic characteristics such as  
65 ornamentation (e.g., Aparicio et al. 2005; Benhaim et al. 2013; Gil et al. 2015). Mediterranean  
66 lineage populations are strictly riverine and complete their entire life-cycle in freshwater  
67 (Doadrio et al. 2011).

68 The biology of brown trout has been largely studied because of its value as a recreational  
69 fishing resource and the diversity of life-history traits, but most research has focused on  
70 Atlantic lineage (e.g., Jonsson 1985; Jonsson and L'Abée-Lund 1993; Elliott 1994; Crisp  
71 2000; Nicola and Almodóvar 2002). Consequently, information on the life history  
72 characteristics of Mediterranean brown trout populations is still limited, and only some

73 ecological data are available (e.g., Champigneulle et al. 2003; Larios-López et al. 2015;  
74 Aparicio et al. 2018; Rocaspana et al. 2019). Mediterranean brown trout populations are  
75 currently declining mainly due to habitat degradation (Benejam et al. 2016), overfishing, and  
76 hybridization with non-native trout of the Atlantic lineage (Berrebi et al. 2000; Aparicio et al.  
77 2005). In addition, an increase in water temperature due to climate change is likely to reduce  
78 its distributional range (Almodóvar et al. 2012). Hence, a better understanding of life history  
79 traits is an essential first step in developing effective conservation and management strategies  
80 (Wootton et al. 2000). The main aim of this paper is therefore to study and provide estimates  
81 of life history characteristics of Mediterranean brown trout populations, and specific  
82 objectives are to determine growth parameters and reproductive traits (i.e., size and age at first  
83 maturity, fecundity and spawning period).

84

## 85 **Material and methods**

### 86 *Study area.*

87 The study was conducted in three headwaters tributaries (Noguera Pallaresa, Flamisell and  
88 Noguera Vallferrera) of the Segre River (NE Iberian Peninsula; Fig. 1). The Segre River is the  
89 largest catchment in the Southern Pyrenees (265 km long, 22,580 km<sup>2</sup> of basin area and ca.  
90 100 m<sup>3</sup> s<sup>-1</sup> of average water flow), and is the main tributary of the Ebro River (426 m<sup>3</sup> s<sup>-1</sup> of  
91 annual mean flow) (for more details see Rovira et al. 2012). Three different reaches were  
92 selected (Fig. 1) in the Noguera Pallaresa River (154 km long and 37.1 m<sup>3</sup> s<sup>-1</sup> of average  
93 flow); the main stream (hereafter NP) and two tributaries, the Flamisell (FLM) and the  
94 Noguera Vallferrera (NV). The three reaches were similar, channel morphology consisted  
95 primarily of pool-run-riffle sequences under a forest canopy. Physical and  
96 hydromorphological characteristics of study reaches are shown in Table 1. Streams originate  
97 in the Pyrenees, at an altitude above 2,000 m, and run through narrow valleys with steep

98 slopes. The hydrological regime is snow-fed, thus, the highest flows generally occur in spring  
99 after snowmelt (Ebro Water Authority; <http://www.chebro.es/>), and summers are relatively  
100 dry. Brown trout was the only fish species present. Headwater streams in the area support  
101 abundant trout populations of the Mediterranean lineage with high genetic integrity (Araguas  
102 et al. 2017).

103

#### 104 *Sampling procedures and data analysis.*

105 Brown trout were sampled monthly (with the same sampling effort and spatial design) by  
106 electrofishing from December 1991 to November 1993. All fish collected were counted,  
107 measured (FL, fork length to the nearest mm), weighed (W, total weight to the nearest g), and  
108 a sample of scales was taken from each fish above the lateral line at the insertion of the dorsal  
109 fin. All fish were returned alive to the same location from where they were captured, except  
110 those for life history traits analysis which were euthanized *in situ* by overdose with tricaine  
111 methanesulfonate (MS-222), fixed in formaldehyde solution (4%) and transported to the  
112 laboratory.

113       The relationship between the fork length and total weight was fitted using the  
114 logarithmic form of the allometric growth equation proposed by Fuiman (1983):  $\log(W) =$   
115  $\log(a) + b \log(FL)$ , where  $a$  is the intercept, and  $b$  is the allometric growth coefficient. The  
116 parameters  $a$  and  $b$  were estimated by linear regression analysis, allometric growth is positive  
117 when  $b$  is larger than the isometric value and negative when  $b$  is lower than this threshold  
118 value. Student's  $t$  test was used to analyse divergences in the regression slope ( $b$ ) from  
119 isometric growth (i.e.,  $b = 3$ ). Differences among streams, seasons, and sexes analysed with  
120 the Package FSA (Ogle 2017) in R 3.6.3 (R Core Team 2020). Brown trout were aged from  
121 scales; scales were cleaned (5% KOH solution), rinsed in water and dry-mounted between  
122 two glass slides. Scale circuli (i.e., age) were counted and the distance between circuli were

123 measured by two independent readers using a microfilm projector. Count or measurement  
124 divergences (< 10%) were re-examined and resolved, thus a single data set was generated.  
125 Growth was back-calculated from scale readings. Back-calculated fork length at a given age  
126 was estimated by using the Fraser-Lee equation (Francis 1990; Ricker 1992):  $L_i = a + (L - a)$   
127  $(S_i/S)$ ; where  $FL_i$  is the back-calculated fork length at age  $i$ ,  $L$  is the fork length at capture,  $S_i$   
128 is the scale radius at capture,  $S$ , is the annulus radius for age  $i$ , and  $a$  is the standard intercept  
129 constant ( $a = 19.27, 19.23, 28.26$  for NP, NV, and FLM, respectively). Back-calculated fork  
130 lengths were used to estimate von Bertalanffy growth function (Ricker 1975):  $L_t = L_\infty (1 - e^{-k(t - t_0)})$   
131  $- t_0)$ ; where  $L_t$  is the mean fork length at age  $t$ ,  $L_\infty$  is the theoretical maximum fork length,  $k$  is  
132 a growth rate parameter, and  $t_0$  is the theoretical age at a fork length of 0. The growth function  
133 was fitted for each stream separately with the function “growth” in the package fishmethods  
134 (Nelson 2019) in R 3.6.3 (R Core Team 2020). Model parameters differences among streams  
135 were estimated through likelihood ratio tests with the function “vblrt” in fishmethods (Nelson  
136 2019). A total of 265 individuals ( $N = 83, 91$  and  $89$  from NP, NV, and FLM, respectively)  
137 were examined for life history analysis, fish were collected in September-October, prior to the  
138 start of the spawning period. In the laboratory, sex and maturity stage were determined by  
139 examining the gonads under a stereoscope. Males were considered mature when their testes  
140 were large and white, and immature otherwise (e.g., filiform testes restricted to the dorsal  
141 surface of the body cavity). Females were classified as mature when their ovaries contained  
142 well developed eggs occupying much of the abdominal cavity, and as immature when their  
143 ovaries were small and translucent. The gonads were weighed (GW) to the nearest 0.1 g, and  
144 ovaries were fixed in Gilson’s fluid (Bagenal and Braum 1978) to determine fecundity and  
145 egg diameter. Mature probability, for both males and females, was determined using a logistic  
146 regression models with fork length and stream as independent variables and maturity stage  
147 (juvenile/immature or mature) as response variable. Size-at-maturity ( $L_{50}$ ) of a population, is

148 the fork length at which 50% of the individuals are mature and was estimated from the fit of  
149 logistic regression. The reproductive cycle and spawning season were determined from the  
150 gonadosomatic index (GSI), calculated as the percentage of gonadal mass of total mass  $GSI =$   
151  $100 \times (GW/TW)$ . Fecundity was determined from 18 mature-rip females collected before the  
152 spawning period, only the yolky eggs were counted for fecundity estimates, and the diameter  
153 of 20 yolky eggs per female were measured with a digital micrometer. The relationship  
154 between fecundity and egg diameter with fork length was assessed through linear regression  
155 analysis (Bagenal and Braum 1978). Relative fecundity was calculated by dividing fecundity  
156 by TW. Variation in fecundity among streams were analysed with analysis of covariance  
157 (ANCOVA) using fish length as the covariate.

158

## 159 **Results**

### 160 *Mediterranean brown trout growth and age.*

161 A total of 2,859 trout were captured; the maximum recorded fork length for males and  
162 females was 382 mm and 322 mm, respectively; mean fork length was  $161.2 \pm 1.06$  mm ( $\mu \pm$   
163  $SE$ ), being similar for both adult males ( $202.0 \pm 3.60$ ) and females ( $208.9 \pm 3.13$ ). The overall  
164 length-weight relationship was:  $\log(W) = -4.774 + 2.923 \times \log(FL)$  ( $R^2 = 0.989$ ;  $F_{1, 2857} =$   
165  $125,234$ ,  $P < 0.0001$ ), and  $b$  ( $2.923 \pm 0.008$ ) was significantly different from 3 (Student's  $t$ -  
166 test,  $P < 0.0001$ ), thus indicating a slightly negative allometric relationship. The length-weight  
167 relationships did not differed significantly between sexes (ANCOVA,  $P = 0.54$ ), but varied  
168 among streams ( $F_{2, 2853} = 26.52$ ,  $P < 0.0001$ ); see equations in Fig. 2. The overall length-  
169 weight relationship also differed significantly among seasons ( $P < 0.0001$ ),  $b$  was lowest in  
170 winter (2.777) and highest in spring (3.067).

171 A total of 1,114 trout were aged by examining scales (293, 369 and 452 from FLM, NP  
172 and NV, respectively). Age ranged from 1+ to 6+ but two large individuals could not be aged



173 because of crowded annuli on the scale margins. The majority of fish were age 1+ (39.0%) or  
174 age 2+ (33.3%), 90.5 percent of the fish aged 3+ or younger, and only 9.5% of the trout aged  
175 over 4+ (7.0, 1.8, and 0.7% of individuals in age class 4+, 5+ and 6+, respectively). Length-  
176 at-age plot showed a faster growth for younger individuals (Fig. 3). The length-at-age plots  
177 also indicated that our sample did not include the asymptote of the von Bertalanffy growth  
178 curve for either stream, thus our data probably did not include the largest (i.e., oldest) fish of  
179 the stream populations (Fig. 3). Overall, the variance in back-calculated length-at-age  
180 increased with age, but the estimated CV was highest at age 1+ (20.1%), decreasing to 9.23%  
181 by age 6+; however, it should be noted that the sample sizes for older ages were rather small.  
182 This variability is explained by differences in length and growth rates among streams.  
183 Overall, brown trout length significantly increased with age (ANOVA;  $F_{5, 1096} = 1307$ ,  $P <$   
184  $0.0001$ ), being largest in FLM stream ( $F_{2, 1096} = 74.78$ ,  $P < 0.0001$ ). However, differences in  
185 length-at-age among streams were more pronounced in the younger age groups, and reduced  
186 in older individuals (age  $\times$  stream interaction;  $F_{10, 1096} = 4.818$ ,  $P < 0.0001$ ), thus suggesting a  
187 relatively faster growth rate in the NV stream (Fig. 3). The contrast of the size-specific  
188 growth rates in the three streams is summarized by the von Bertalanffy growth curves (Fig.  
189 3). In NV, growth rate was higher and asymptotic fork length was larger; however, the von  
190 Bertalanffy growth curves were similar, and the estimated parameters did not vary among  
191 streams (likelihood ratio test,  $P = 0.91$ ,  $0.96$ , and  $0.62$  for  $L_{\infty}$ ,  $k$ , and  $t_0$ , respectively).

192

### 193 *Reproductive variables.*

194 Overall sex ratio did not deviate significantly from the expected 1:1 ( $G = 1.83$ ,  $df = 1$ ,  $P =$   
195  $0.18$ ), and was not different among the three streams ( $G = 3.95$ ,  $df = 2$ ,  $P = 0.14$ ). Overall,  
196 both sexes began to mature at age 1+, males at 119 mm fork length, and females at 145 mm  
197 fork length; the  $L_{50}$  for both sexes (estimated from the logistic models) was 136.4 mm and

198 150.1 mm for males and females respectively (Fig. 4). However, size-at-maturity differed  
199 significantly among streams in males (Wald  $\chi^2$ : stream,  $P = 0.038$ ; fork length,  $P < 0.0001$ ;  
200 Nagelkerke's  $R^2 = 0.53$ ), but not in females (Wald  $\chi^2$ : stream,  $P = 0.39$ ; fork length,  $P <$   
201  $0.0001$ ; Nagelkerke's  $R^2 = 0.83$ ). Males from NP stream matured at larger sizes (153.4 mm  
202 FL,  $P = 0.022$ ) than in FLM (129.0 mm) and NV (131.2 mm) streams (Fig. 4).

203 The gonadosomatic index (GSI) values for both male and female brown trout showed strong  
204 similarity in onset and amplitude, with minor variations among streams (Fig. 5). The timing  
205 of testis development closely coincided with that of ovary development. Three periods were  
206 identified based on the GSI variation. For both male and female brown trout, the reproduction  
207 cycle started in July, when gonads began to develop (Fig. 5). The increase in testis weight  
208 occurred sharply, the maximum monthly GSI values for males was reached in August-  
209 September, prior to the spawning period, and then decreased gradually until February.  
210 However, ovary weight and hence GSI values for females reached a peak in October-  
211 November, then reduced sharply and in January all analysed females were considered spent.  
212 In the field, spawning activity was first observed in early November, peaking in late  
213 November, and decreasing gradually until the end of December.

214 Fecundity, prior to the start of the spawning period, ranged from 148 to 561 eggs and  
215 was positively related to female fork length (Fig. 6). After accounting for fish length  
216 (ANCOVA,  $P < 0.0001$ ), females from NP stream had lower fecundity ( $F_{2, 14} = 14.83$ ,  $P <$   
217  $0.0001$ ) than females from both FLM and NV streams (Fig. 6). Overall, relative fecundity  
218 ranged from 1,822 to 4,966 ( $\mu \pm SE = 3,172 \pm 189$ ) eggs  $\text{kg}^{-1}$  of body weight. Relative  
219 fecundity was not significantly related to total weight (ANCOVA,  $F_{1, 14} = 3.138$ ,  $P = 0.098$ ),  
220 but was significantly lower (ANCOVA,  $F_{2, 14} = 13.07$ ,  $P = 0.001$ ) in NP ( $2,370 \pm 226$  eggs  $\text{kg}^{-1}$ )  
221 than in FLM ( $3,288 \pm 188$  eggs  $\text{kg}^{-1}$ ) and NV ( $3,858 \pm 232$  eggs  $\text{kg}^{-1}$ ). The mean diameter  
222 of eggs ranged from 3.2 to 5.0 mm (mean  $3.9 \pm 0.08$ ). After accounting for fish size

223 (ANCOVA,  $P < 0.0001$ ), which as expected had a positive effect (Fig. 7), there was no  
224 significant differences among streams ( $P = 0.23$ ).

225

## 226 **Discussion**

227 Overall, brown trout showed a negative isometric growth, however the allometric coefficient  
228 ( $b$ ) of the length-weight relationship varied among streams and seasons. The length-weight  
229 relationship in fish is influenced by different factors, such as age, sex, maturity, temperature,  
230 habitat, and diet (Wootton 1998; Froese 2006). The allometric coefficient ( $b$ ) was higher in  
231 spring and minimum in winter. During winter months, when water temperature is lowest,  
232 trout reduces activity and feeding activity (Cunjak and Power 1987), hence reducing growth  
233 rate. In contrast, in spring months, following an increase in water temperature, feeding  
234 activity increases (Arslan et al. 2004). Brown trout populations were characterized by medium  
235 life spans, 90.5% of the fish aged 3+ or younger and the maximum recorded age was 6+  
236 years, found in the three sampled streams. However, older fish may be present since some of  
237 the larger individuals could not be aged because of scale anomalies. It has been previously  
238 reported that harsh environmental conditions in high altitude streams reduce the growth rate  
239 of large trout, thus leading to the apparition of crowded annuli on the scale edges (Bohlin et  
240 al. 2002). Our results agree with previous studies on brown trout growth in most European  
241 waters, where trout live up to five or six years reaching a maximum length of 30–35 cm  
242 (Almodóvar and Nicola 2004; Parra et al. 2009 and references therein). However, in some  
243 Iberian populations of the Atlantic basins, observed length-at-age and growth increments were  
244 higher. For instance, in an aquifer-fed stream of central Spain trout ranged between 25.3 and  
245 27.8 cm in standard length (SL) at age 3, and 31.8–34.8 cm at age 4 (Lobón-Cerviá et al.  
246 1986). These differences can be related to stream characteristics since the growth rate of  
247 stream-resident salmonids is influenced by environmental factors, such as water temperature,

248 which affects positively (Elliott 1994; Vøllestad et al. 2002; Réalis-Doyelle et al. 2018). Our  
249 fish sample did not include the asymptote ( $L_{\infty} = 427$  mm) of the von Bertalanffy growth curve  
250 (age 6+ mean FL =  $254.5 \pm 8.5$  mm), thus older fish (i.e., larger) may exist in the population.  
251 The results of the von Bertalanffy growth model showed similar growth rates among streams,  
252 although interpopulation differences in length-at-age, particularly by the presence of smaller  
253 fish, for a given age, in NP stream. According to Parra et al. (2009), the growth rate of 0+  
254 individuals determines the length at older ages. The size of the first year is positively related  
255 to the extent of the age 0+ (i.e., larvae and alevins stages) growing period. In colder streams,  
256 such as NP when compared to NV and FLM, the fry emergence from the stream bed occurs  
257 later, thus reducing the growing period (Ojanguren and Braña 2003), and also reducing adult  
258 fish length for a given length.

259 Overall, length at maturity of Mediterranean brown trout differed between sexes, with  
260 females reaching maturity at large sizes ( $FL_{50} = 150.1$  mm) than males (136.4 mm), but there  
261 were some differences among streams, NP males matured at larger sizes (153.4 mm) than  
262 FLM and NV (129.0 and 131.2 mm, respectively) males. Furthermore, due to differences in  
263 length-at-age and growth rate, both males and females from NP stream reached sexual  
264 maturity at older age; in colder waters, brown trout mature at older ages and larger sizes  
265 (Jonsson et al. 1991). Our results are similar to those reported in the literature, with age and  
266 length at maturity also differing between sexes, with trout males maturing at younger age and  
267 shorter length than females (Johnson 1985; Olsen and Vøllestad 2005). Previous studies have  
268 also shown great plasticity in age and length at maturity among different brown trout  
269 populations of the Atlantic lineage. For instance, in rivers of North of Spain, both males and  
270 females start to mature at lengths ranging between 10.5 and 11 cm at age 1+ (Lobón-Cerviá et  
271 al. 1997); while in Norway, resident brown trout males reach maturity at lengths between 141

272 and 187 mm at age 1+ to 3+, and females at 147–188 mm in length at age 2+ to 4+ (Olsen and  
273 Vøllestad 2005).

274 The spawning season was relatively short, beginning in late autumn-early winter, lasted  
275 for two months according to the GSI values. Brown trout spawning period usually occurs  
276 during the autumn–winter period (e.g., Klemetsen et al. 2003; Rubin et al. 2005; Riedl and  
277 Peter 2013). Several factors, such water temperature and photoperiod, have been proposed to  
278 modulate the timing and the duration of the spawning season (e.g., Jonsson and L'Abée-Lund  
279 1993; Elliott 1994; Ojanguren and Braña 2003). In colder regimes (due to latitude and/or  
280 altitude) spawning occurs earlier, because of longer incubation period (Crisp 1994; Elliott and  
281 Hurley 1998; Klemetsen et al. 2003). Despite being located in the southern range of brown  
282 trout, the high altitude of the study sites and hence water temperature regimes (Table 1)  
283 explain the relatively early spawning season. In other Iberian populations located at similar  
284 latitude but in streams with higher mean water temperature, the peak of the spawning season  
285 is between February and March (García and Braña 1988; Gortázar et al. 2007). Furthermore,  
286 the short spawning season contrasts with that of trout populations from the south of Iberian  
287 Peninsula, where the spawning season is extended from October to April, which is considered  
288 an adaptation to environmental variability of the Mediterranean climate (Gortázar et al. 2007;  
289 Larios-López et al. 2015).

290 Fork length of female trout was positively correlated with fecundity and egg diameter, as  
291 reported elsewhere (e.g., Nicola and Almodóvar 2002). Previous studies worldwide, including  
292 Central and North Europe (Maisse et al. 1987; L'Abée-Lund et al. 1989; Crisp 1994),  
293 Southern Europe (Lobón-Cerviá et al. 1986; Nicola and Almodóvar 2002; Champigneulle et  
294 al. 2003), Asia (Arslan and Aras 2007; Rasool and Jan 2013), and USA (Avery 1985), have  
295 shown that fecundity for a standard female of 200 mm FL ranges between 208 and 347 eggs.  
296 A standard female of 200 mm FL from our study populations had an estimated fecundity of

297 209, 307 and 326 for NP, NV and FLM, respectively. Therefore, both NV and FLM females  
298 are in the upper part of the range, and similar to those values reported in rivers of Central  
299 Spain (Lobón-Cerviá et al. 1986). However, NP females are in the lower part of the range,  
300 which could be explained by differences in water temperature and productivity among  
301 streams (see Lobón-Cerviá et al. 1997).

302 The results reported in this study represent a contribution to better understanding of key  
303 aspects of the biology of Mediterranean brown trout populations, for which limited  
304 information is currently available, although it is necessary to develop sound conservation and  
305 management strategies for preserving their populations.

306

### 307 **Acknowledgments**

308 This research was supported by the Biodiversity Conservation Plan of ENDESA through the  
309 project PIE 121043-00-FECSA. Carles Alcaraz also acknowledge support from CERCA  
310 Programme (Generalitat de Catalunya). We want to thank F Casals, JM Olmo and MJ Vargas  
311 for field assistance. All appropriate ethics and permissions required for the realization of this  
312 manuscript were obtained, previously, by the authors. The Departament de Medi Ambient i  
313 Habitatge de la Generalitat de Catalunya (current Departament d'Agricultura, Ramaderia,  
314 Pesca, Alimentació i Medi Natural) of the regional authorities of Catalonia provided  
315 authorization to conduct the research (SF/602).

316

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## Figure captions

### Figure legends

**Fig. 1** Map of the study area. **a** Location of the study streams: Noguera Pallaresa (*NP*), Flamisell (*FLM*) and Noguera Vallferrera (*NV*). Location of the sampled stream reaches is highlighted with a rectangle. The photos show representative habitats in the streams sampled

**Fig. 2** Weight-length relationship for Mediterranean brown trout per stream. *FLM* Flamisell, *NP* Noguera Pallaresa, *NV* Noguera Vallferrera

**Fig. 3** Top: von Bertalanffy growth curves for Mediterranean brown trout per stream based on back-calculated lengths-at-age. *The box* corresponds to standard deviation, *the dark line inside the box* is the mean, and *the error bars* are the range. Bottom: back-calculated lengths-at-age per stream. *Error bar* is the standard error of the mean. *FLM* Flamisell, *NP* Noguera Pallaresa, *NV* Noguera Vallferrera

**Fig. 4** Relationship between maturity stage of both male (top) and female (bottom) Mediterranean brown trout with fork length per stream (0, immature and 1, mature). *Bars* show length frequency distribution. *FLM* Flamisell, *NP* Noguera Pallaresa, *NV* Noguera Vallferrera

**Fig. 5** Mean values of gonadosomatic index (GSI) by month and stream of male (top) and female (bottom) Mediterranean brown trout. *FLM* Flamisell, *NP* Noguera Pallaresa, *NV* Noguera Vallferrera

**Fig. 6** Relationship of fecundity per stream with fork length. *FLM* Flamisell, *NP* Noguera Pallaresa, *NV* Noguera Vallferrera

**Fig. 7** Relationship of egg diameter (ED) with female body weight

**Table 1** Stream features during the study period

Variable	Stream		
	FLM	NP	NV
Latitude	42°23'40.92"N	42°44'1.68"N	42°34'3.36"N
Longitude	0°58'0.84"E	1°6'27.36"E	1°19'42.60"E
Mean elevation (m)	917	1,387	1,127
Mean slope (m km <sup>-1</sup> )	31.8	21.5	50.2
Mean base flow (m <sup>3</sup> s <sup>-1</sup> )	1.52	0.95	1.29
Mean stream width (m)	5.9	10.2	6.1
Mean water depth (cm)	15.4	21.1	22.1
Water temperature (°C)	8.8	5.8	7.9
Water temperature range (°C)	4.2–15.7	0.0–15.1	3.6–15.4
Mean pH	7.8	8.1	7.3
pH range	6.5–8.5	6.7–8.8	6.7–8.1
Conductivity (µs cm <sup>-1</sup> )	120.8	103.4	45.8
Conductivity range (µs cm <sup>-1</sup> )	78–171	46–157	17–94
Dissolved oxygen (mg l <sup>-1</sup> )	10.6	11.8	11.5
Dissolved oxygen range (mg l <sup>-1</sup> )	3.2–12.9	5.3–14.3	4.4–13.5

*FLM* Flamisell, *NP* Noguera Pallaresa, *NV* Noguera Vallferrera

Figure 1. Aparicio et al.

1

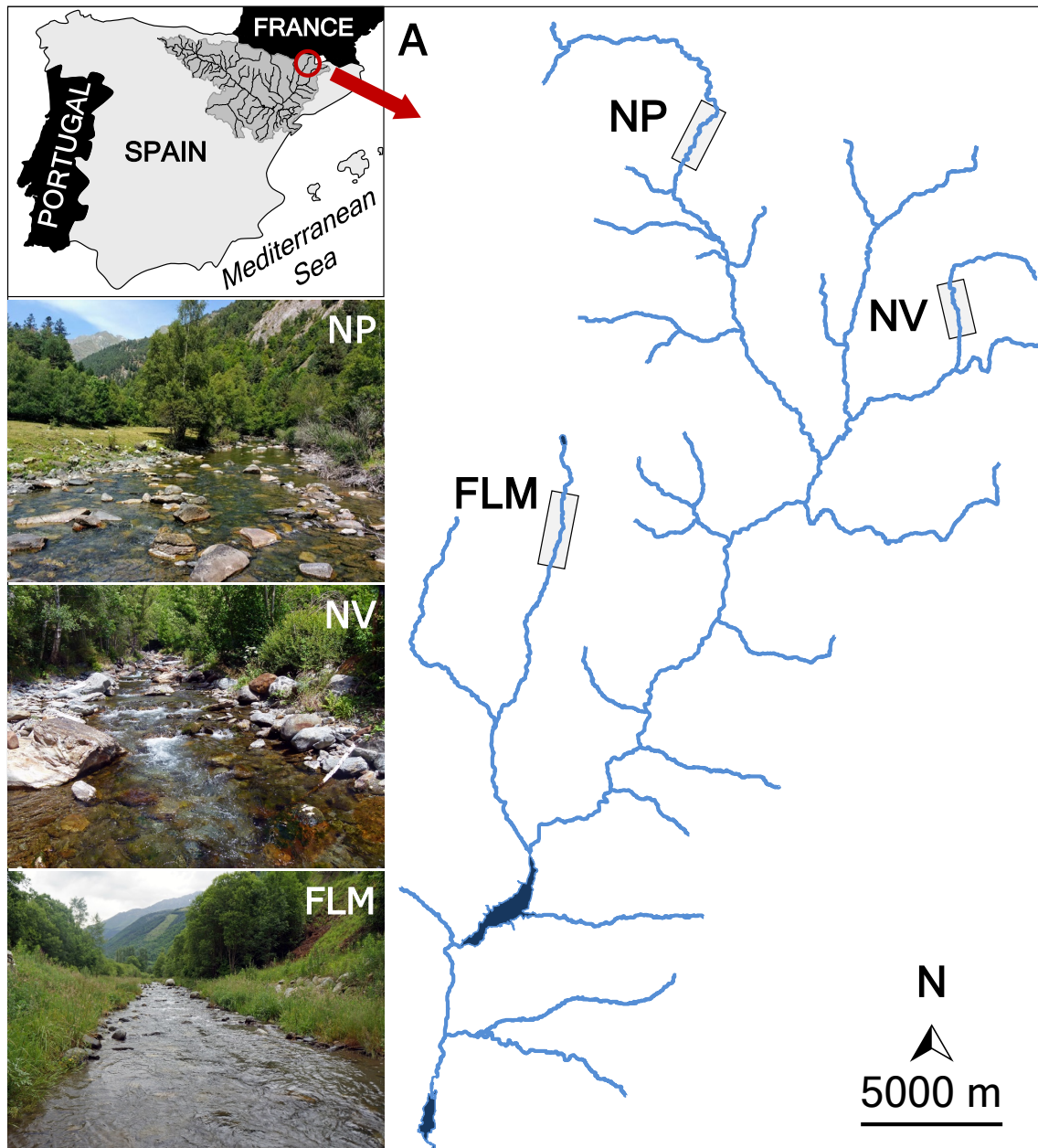


Figure 2. Aparicio *et al.*

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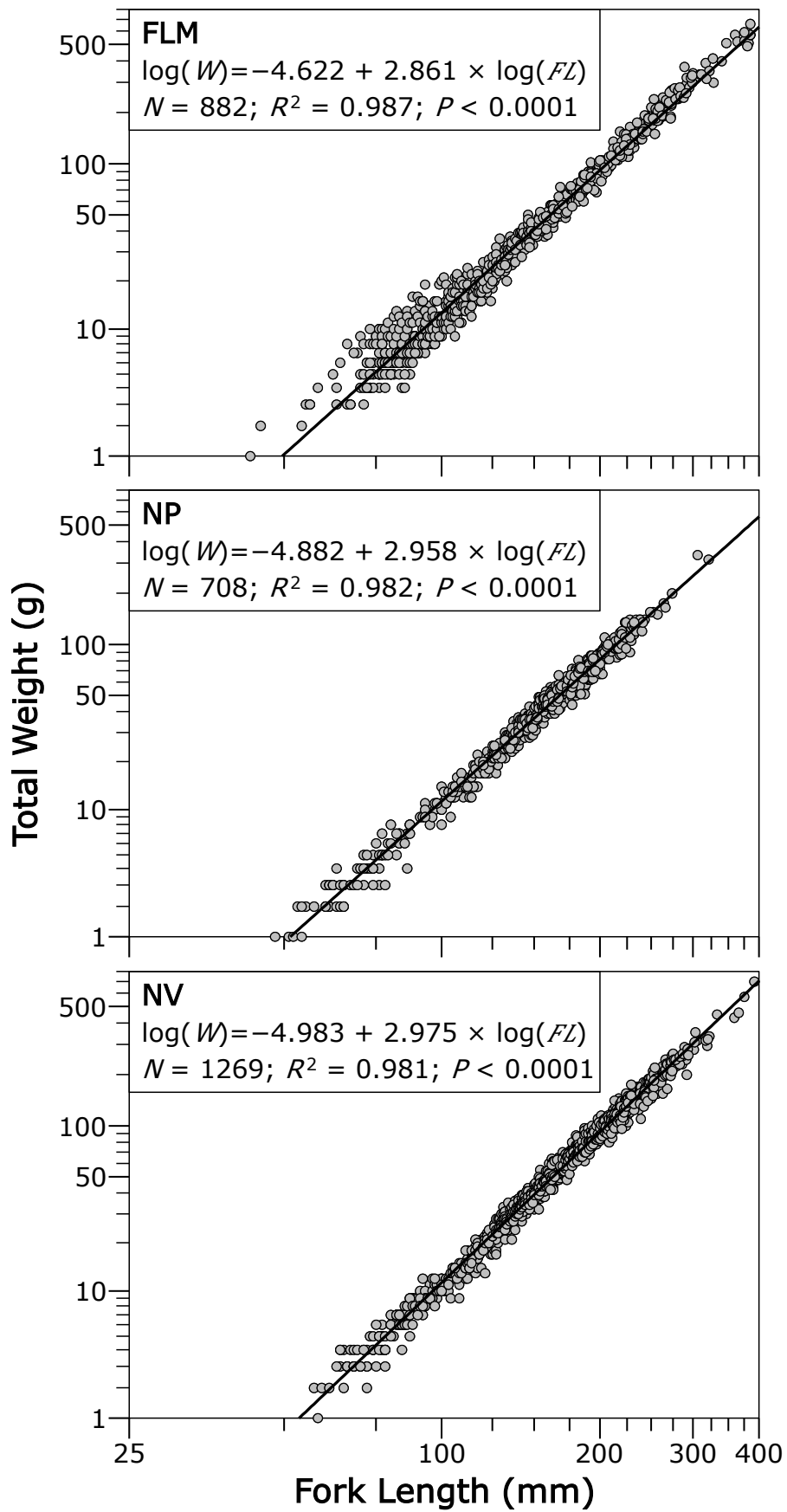




Figure 3. Aparicio *et al.*

3

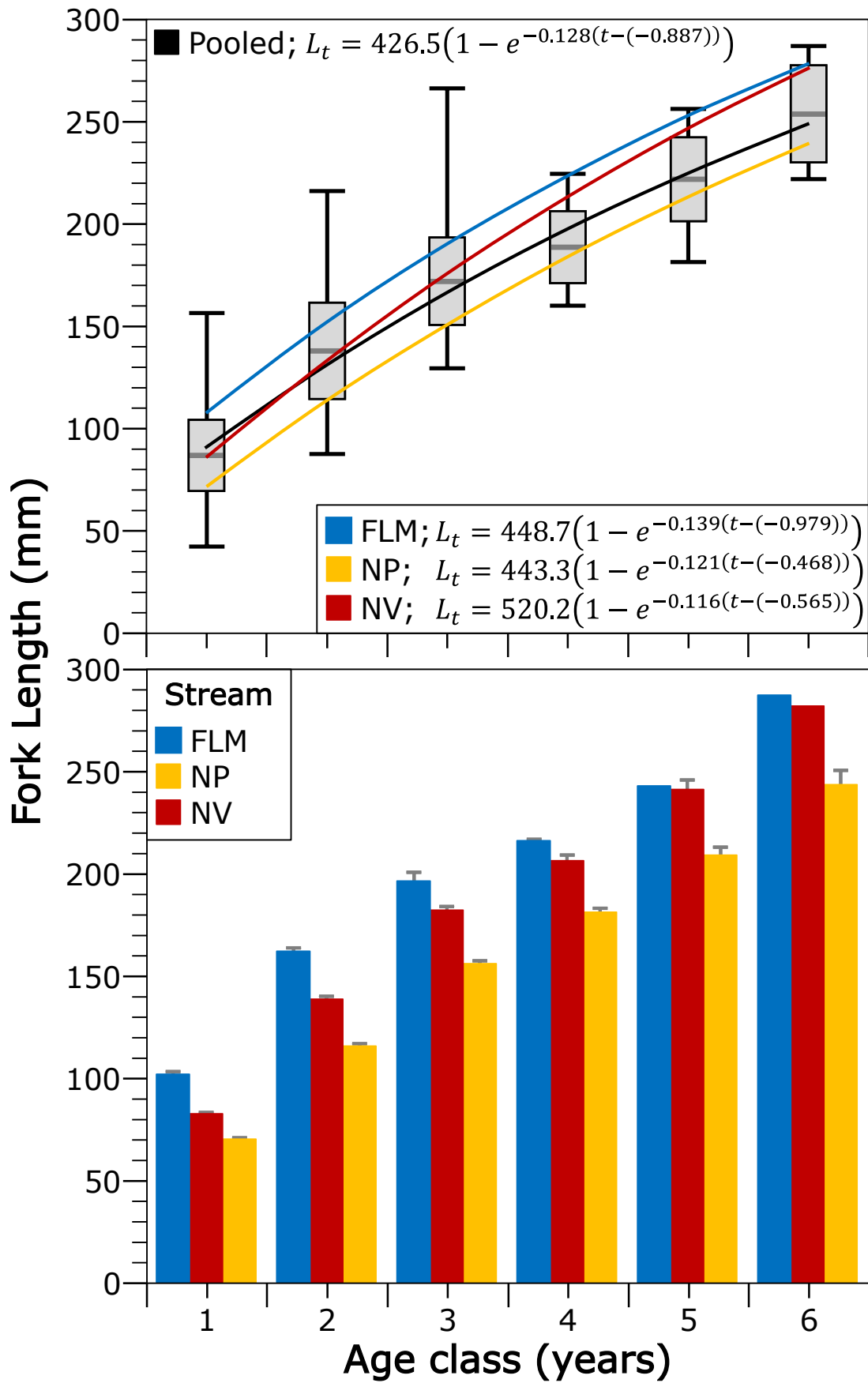


Figure 4. Aparicio et al.

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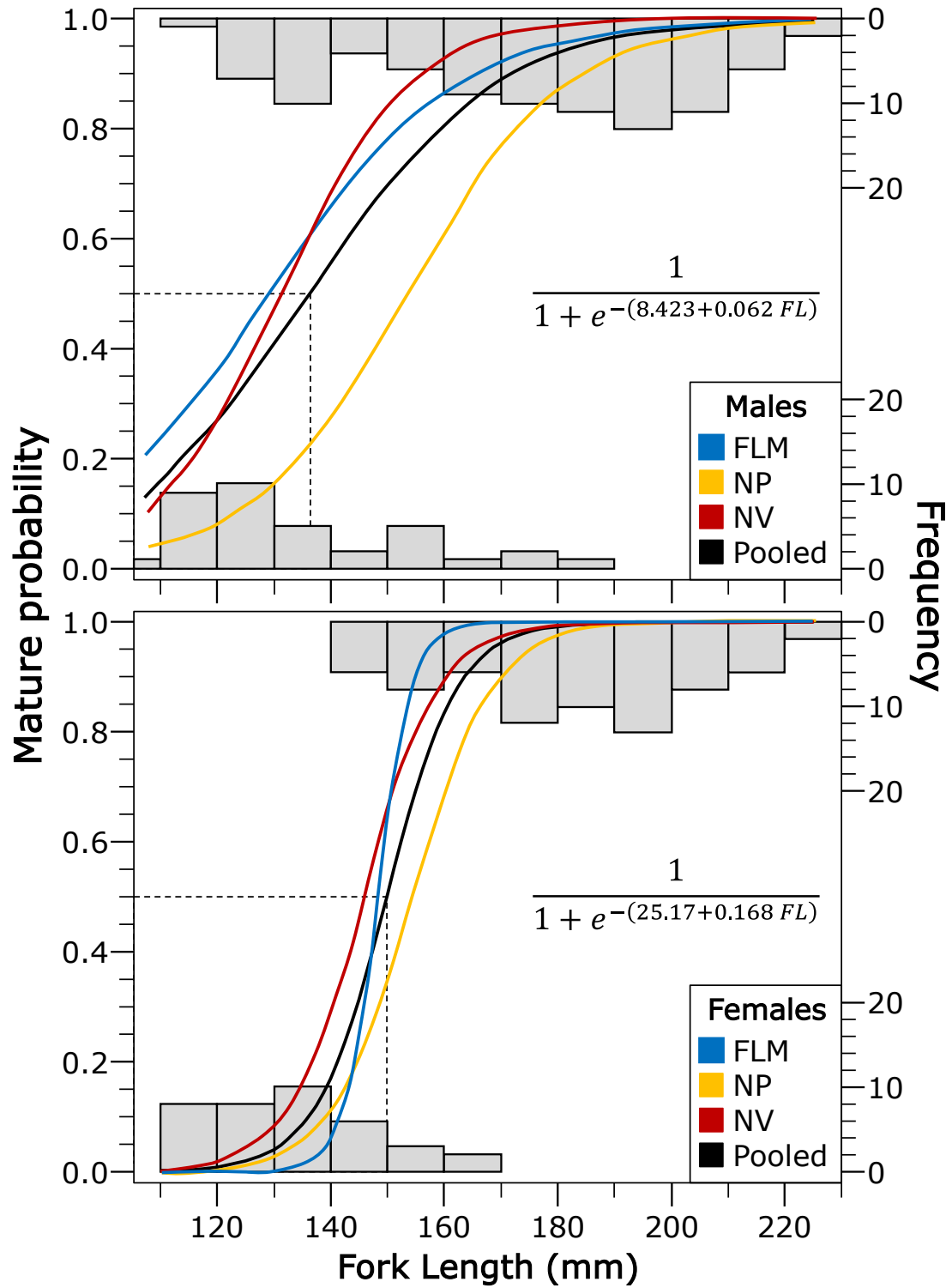


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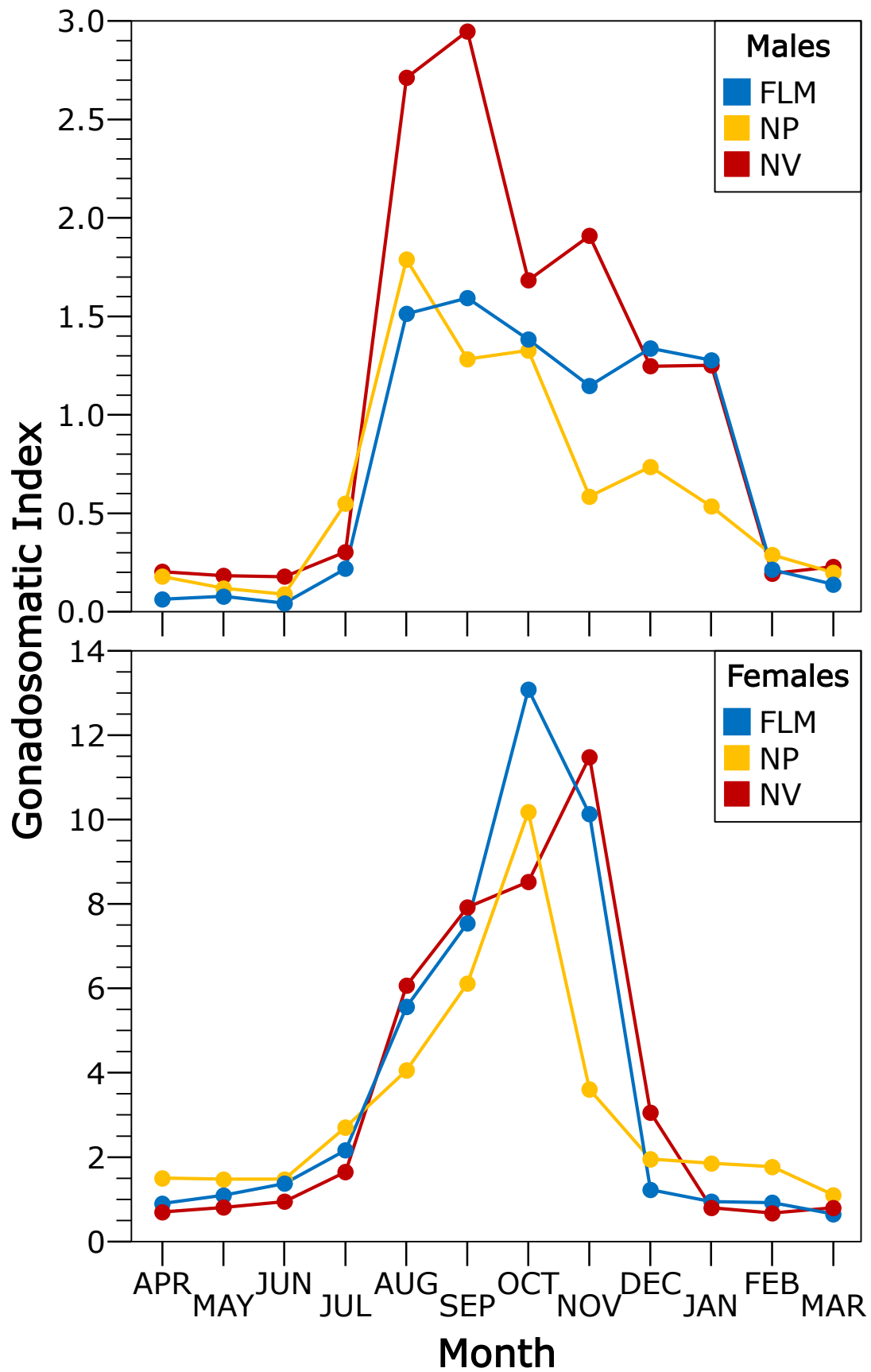


Figure 7. Aparicio *et al.*

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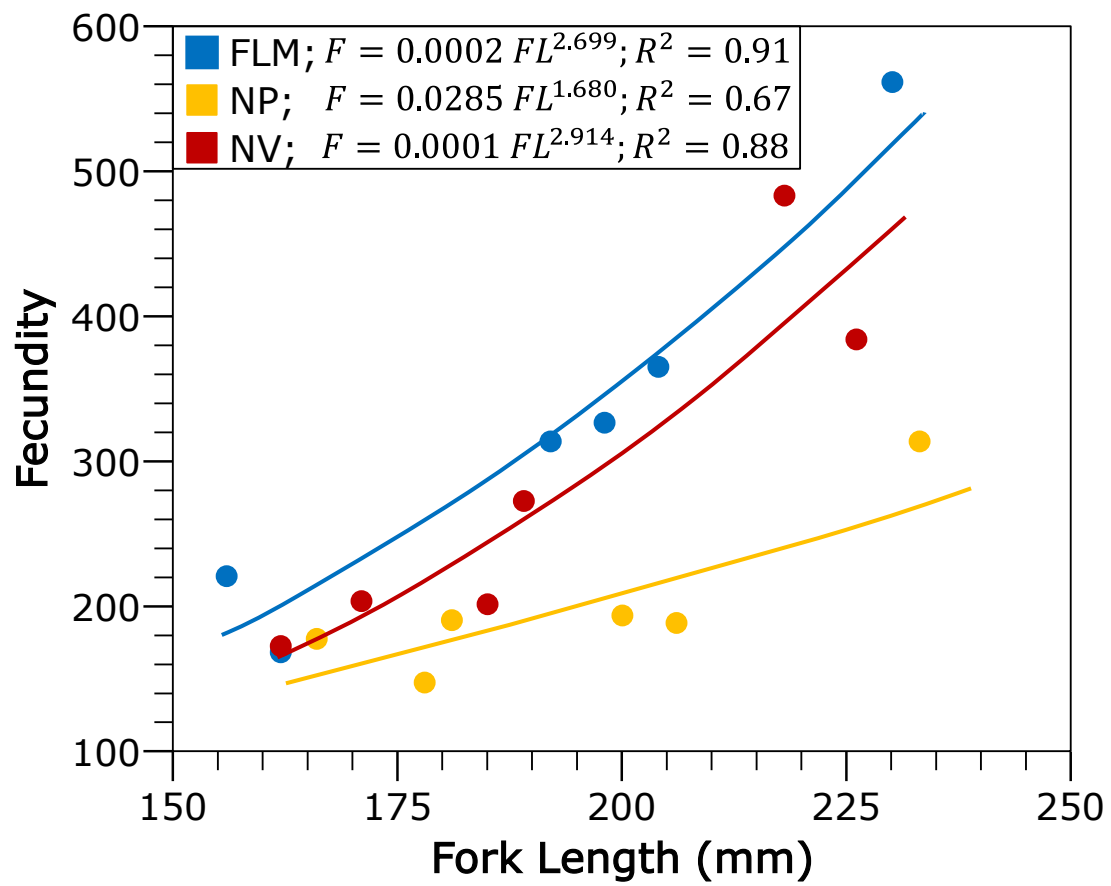


Figure 7. Aparicio et al.

