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Length-Weight Relationship and Condition of the European Eel *Anguilla anguilla* in the Mediterranean Coastal Bardawil Lagoon, Egypt

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ABSTRACT

The length-weight relationship (LWR) and condition factor of the European eel *Anguilla anguilla* were investigated. A sample of 318 individuals was collected from Bardawil Lagoon, North Sinai from October to April 2020. The length ranged from 33.5 to 64.3cm for males and from 33.1 to 62.2cm for females. The results showed a negative allometric growth pattern for females (b=2.625) and an isometric growth (b=2.997) for males. The average values of Fulton's condition factor (CF) ranged from 0.178± 0.002 for the females, to 0.180± 0.002 for males. A slight decrease was observed in condition with an increase in body length for both sexes of eels. The present study provided the first reference on LWR and CF of the European eel from Bardawil Lagoon. These results contributed to the life-history parameters of the European eel which can help in the conservation and sustainability of these valuable endangered resources.

INTRODUCTION

The European eel *Anguilla anguilla* (L.) is a significant economic fisheries resource in many Atlantic and Mediterranean coastal areas **(Feunteun, 2002)**. It has a large geographic distribution from northern Europe to North Africa.The European eel inhabits fresh, brackish and coastal waters in almost all Europe and along the Mediterranean coasts of Africa and Asia.

The European eel is a catadromous fish species with unique life cycle, which involves a remarkable migration spanning thousands of kilometers. Born in the Sargasso Sea **(Tesch, 2003; Aarestrup *et al.*, 2009)**, young eel larvae embark on an incredible journey, drifting with ocean currents before reaching the European and Mediterranean waters. Upon arrival, they transform into glass eels and then elvers, adapting to freshwater environments **(Durif *et al.*, 2005)**. Eels go through a transformation known as "silvering" after the development phase (yellow phase) in freshwater. The fish go through this metamorphosis in response to physiological and morphological changes that get them ready for their oceanic migration and subsequent spawning in the Sargasso Sea **(Durif *et al.*, 2005)**. The silver eels then migrate downstream toward marine waters, and eventually return to the spawning grounds to reproduce and presumably die **(Boulenger *et al.*, 2015)**.

The European eel is known for its distinctive, elongated body and a smooth, slimy skin that can range from yellow-brown to silver. Unfortunately, the species faces numerous challenges, including habitat loss, pollution, and changes in oceanic conditions, contributing to a decline in their population **(Castonguay & Durif 2016, Aschonitis*et al*., 2017a, Drouineau*et al*., 2018)**.

In the last decades, the eel has experienced dramatic stock declines and has been listed as critically endangered by the International Union for Conservation of Nature (IUCN) through the most recent assessment **(Pike *et al*., 2020)**.

One of the most notable landform features in North Sinai is Bardawil Lagoon, a saltwater marsh that has mostly preserved its original nature. It is a coastal lagoon that has three (natural and man-made) inlets that connect to the sea. The lagoon is hyper saline, with minimal subsurface freshwater seepage, negligible precipitation, and no agricultural drainage **(Khalil & Shaltout, 2006)**.

The European eel *Anguilla anguilla* has been recorded in the landings of Bardawil lagoon with a significant catch since the late 90s.The catch increased from 2.5t in 1998 to 34.8t in 2008, then it dramatically decreased to reach 5.3t in 2021 **(LFRPDA, 2021)**. The species is targeted by the eel long line gear which operates mainly between October and December.

Indicators crucial to the management and conservation of fisheries include the length-weight relationship (LWR). According to **Moutopoulos and Stergiou (2002)**, it is highly helpful for fisheries research sinceit can be used to: (i) Convert growth-in-length equations to growth-in-weight for use in stock assessment models, (ii) Estimate biomass from length observations, (iii) Estimate fish condition, and (iv) Compare the life histories of specific species between regions. The condition factor (CF) provides crucial information when determining the period of gonad maturation, and to verify whether it is making good use of its feeding source **(Weatherley, 1972)**.

Research on the European eel in Egypt is very scarce, this study represents the first attempt to estimate the length-weight relationship and condition factor of the European eel *Anguilla anguilla* in Bardawil lagoon. Aspects of the life-history strategies of the European eel should be of great significance to fisheries management and stock sustainability.

MATERIALS AND METHODS

Sampling was carried out in Bardawil lagoon from October 2019 to April 2020, during the closed season from January to April. Moreover, the samples were collected from some illegal fishermen. Fish were caught by eel long lines. A total of 318 eel individuals were collected and measured to the nearest 0.1cm total length (TL), weighed on a digital scale to an accuracy of 0.1g. The length-weight relationship (LWR) was fitted for each sex of eels separately. The LWR was calculated according to the formula presented by **Ricker (1975**), as follows:$W = aL^b$, where W is total weight (in g), L is total length (TL, in cm), and *a* and *b* are the coefficients of the functional regression between W and L. The 95% confidence intervals (Cls) of the parameters and the statistical significance of the regression relationship (r^2) were estimated. The values of function parameters *a* and *b* were estimated by linear regression analysis based on the log transformed equation log W = log *a* + *b* (log L) **(Ricker, 1975)**. The determination coefficient (r^2) was used as an indicator of the quality of the linear regressions.

Fulton's condition factor (K) was calculated by applying the Fulton formula K = (weight [g] x 100) / length³ [cm] **(Fulton, 1904)**.

RESULTS

The descriptive statistics of length and weight for males, females and all collected fish are given in Table (1). The length and weight distribution of eels (N = 318) were compared monthly. For males, the longest specimen (TL = 64.3cm) was collected in December, while the shortest one (TL = 33.5cm) was recorded in April (Fig. 1). The highest male weight was recorded in February (420.3g) and the lowest was in November (86.5g) (Fig. 2). Females collected during February had a significant high total length (TL= 62.2cm) and weight (370.0g), the shortest female (TL = 23.5cm) was collected during March (Fig. 1).

Table 1. Descriptive statistics, estimated parameters of the length-weight relationship and condition factor (CF) for males, females and all individuals of European eel form Bardawil lagoon

	Length				Weight			L-W parameters			
	No.	Min	Max	Av + SD	Min	Max	Av + SD	a	b	r2	CF
Male	202	33.5	64.3	47.59 ± 0.50	51.5	420.3	193.92 ± 5.87	0.0016	3.011	0.908	0.180 + 0.003
Female	157	23.5	62.2	46.62 ± 0.51	60.0	350.1	182.64 ± 5.49	0.0028	2.874	0.909	0.178 + 0.002
All	359	23.5	64.3	46.86 ± 0.36	51.5	420.3	186.74 ± 4.24	0.0021	2.947	0.908	0.165 + 0.002

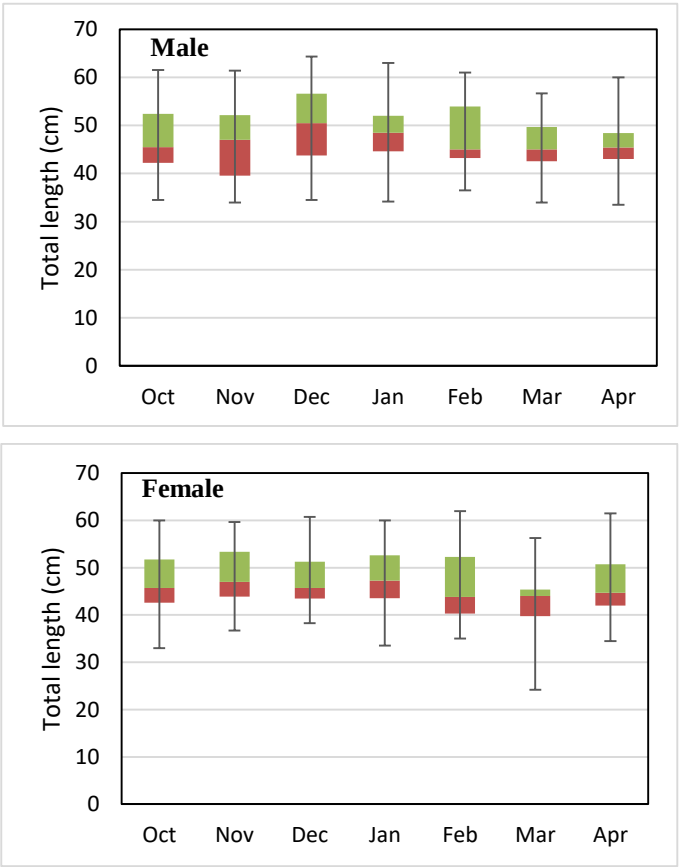

Fig. 1. Monthly length distributions of male and female European eel *Anguilla anguilla* in Bardawil lagoon. Box = 25 and 75% quartiles and median, bars = maximum and minimum values in analyzed samples

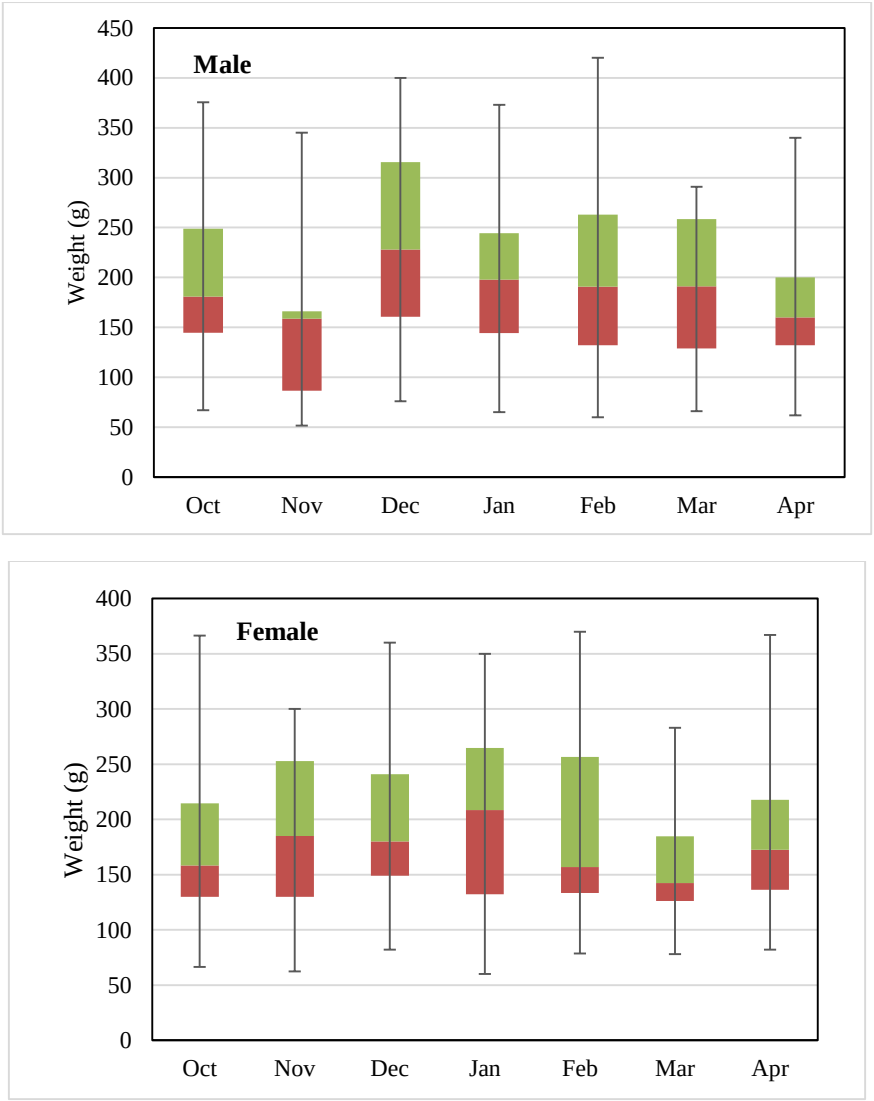

Fig. 2. Monthly weight distributions of male and female European eel *Anguilla anguilla* in Bardawil lagoon. Box = 25and 75% quartiles and median, bars = maximum and minimum values in analyzed samples

Length-weight relationship

The calculated length-weight relationships for the European eel *A. anguilla* in Bardawill lagoon (Fig. 3) are as follows:

$W = 0.0017TL^{2.997}$ for males

(r^2= 0.894, SE*a* =0.308, SE*b*= 0.080). (*b* = 2.997; 95% CI: 2.839–3.155).

$W = 0.0073\ TL^{2.625}$ for females

(r^2 = 0.829, SE*a* = 0.377, SE*b*= 0.098). (*b* = 2.625; 95% CI: 2.431–2.820).

$W = 0.0037\ TL^{2.805}$ for all samples

(r^2 = 0.853, SE*a* =0.252, SE*b*= 0.066). (b = 2.805; 95% CI: 2.675–2.934).

The growth of weight relative to length was isometric for males, and it was negative allometric for females and for all samples.

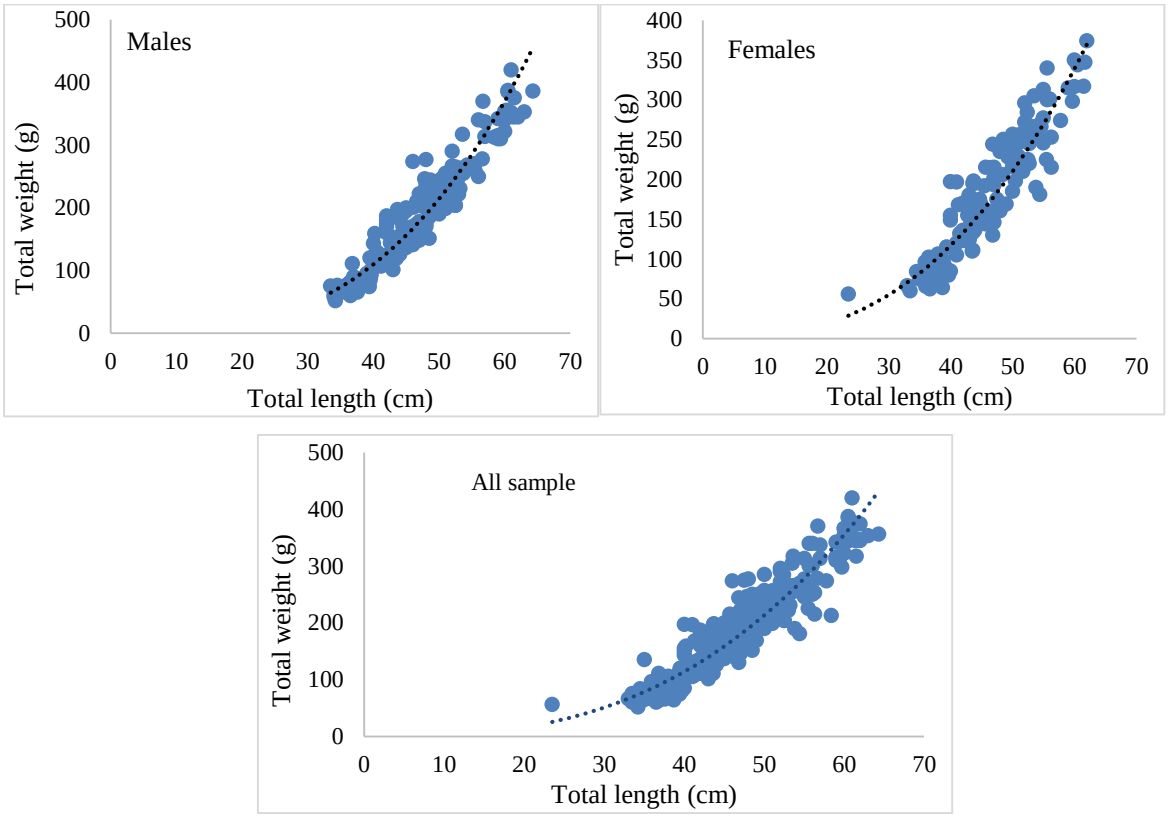

Fig. 3. Length-weight relationship of males, females and all sample of the European eel *Anguilla anguilla* in Bardawil lagoon

Condition factor (CF)

The Fulton's condition factor (CF) varied from 0.166 to 0.194 for males, with an average of 0.180± 0.003. For females, the condition factor varied from 0.169 to 0.193 with an average of 0.178± 0.002 (Table 1 & Fig. 4). The condition factor undergoes minor changes in specimens belonging to different size classes, it varied between 0.134 (for total length 62.2cm) and 0.315 (for total length 35.5cm) for females. In case of males, the condition factor (CF) varied from 0.107 (total length 58.9cm) to 0.224 (total length 51.4cm) (Fig. 5).

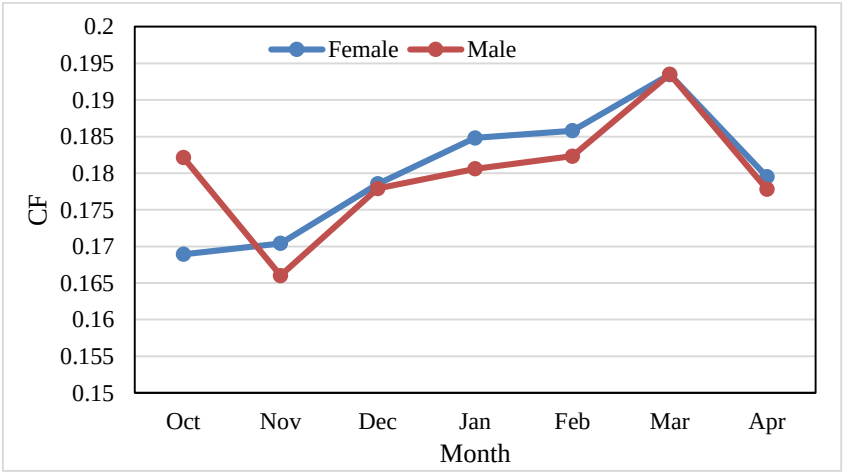

Fig. 4. Monthly variations in condition factor (CF) of the European eel *A. anguilla* from Bardawil lagoon

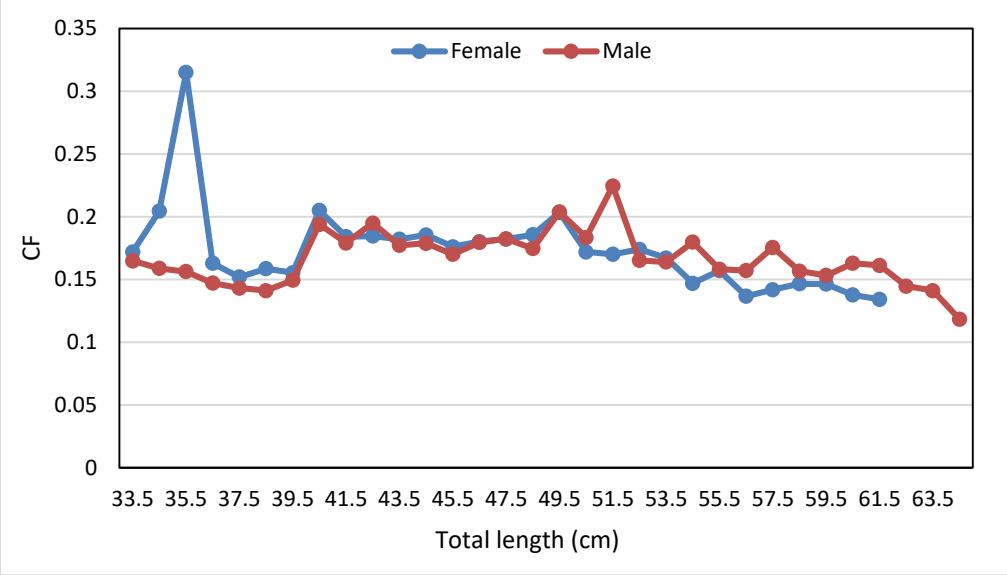

Fig. 5. Variations in condition factor (CF) for length groups of the European eel *A. anguilla* from Bardawil lagoon

DISCUSSION

Biological and biometric information is crucial in enabling a thorough and dependable analysis of global population trends. Eels collected from Bardawil lagoon ranged in length between 23.5 and 64.3cm, with a mean of 46.86± 0.36, while their weight varied from 51.5 to 420.3g, with an average of 186.74± 4.24. The highest value of body length was recorded in December, and the highest value of body weight was observed in February.These values are comparable to those of Eels in the Mediterranean rivers and lagoons which are small, short-lived, and mostly males **(Lobón-Cerviá *et al.*, 1995)**. Conversly, these values are relatively low when compared with eel biometrics in the North of Europe.

The growth of the European eel exhibits significant variability due to the differences between individuals within the same subpopulation and variations across different habitats**(Vøllestad, 1992; Panfili *et al.*, 1994; Melià *et al.*, 2006; Daverat *et al.*, 2012)**. This variability may be partially explained by differences in density, system productivity and temperature regime **(Panfili *et al.*, 1994; Aprahamian *et al.*, 2007; Daverat *et al.*, 2012)**.

The length-weight relationship and the condition of fish are useful parameters for understanding the general state, growth, survival, maturity and reproduction of fish populations **(Richter *et al.* 2000; Froese, 2006; Kharat *et al.* 2008; Milošević & Marić 2012)**. They are also needed to appreciate the suitability of the environment for fish, as well as playing an important role in fishery management, conservation and sustainability **(Richter, *et al.*, 2000)**. The current study presents the first data on the weight-length relationship and the condition of the European eel *Anguilla anguilla*in Bardawil lagoon.

The length weight relationship for males *A. anguilla* in Bardawil lagoon showed an isometric growth pattern, while females attained negative allometric growth. Several authors investigated the length-weight relationship of *A. anguilla* in the Mediterranean and European countries and they got variable results (Table 2). In contrary of our results, **Boulenger *et al.***

(2015) reported mainly negative allometry for males and positive for females in eels from six countries (13 basins) in Europe. **Piria *et al*.(2014)** studied the length–weight relationships of eels from six rivers in Croatia; they found that the value b is within the range between 2.5957 and 2.8155, which indicates a negative allometric growth. However, the variations in the estimated values of *b* are possibly due to factors related to the methods of sampling or to variations in the environmental conditions.

Studying the condition factor is required for knowing the wellbeing of fish and the suitability of the environment to the fish species. The condition factor value depends on the relationship between length and weight, and its value changed from season to another, and it varied with variation of the fish gonad maturation state. Moreover, its value also varied due to suitability of the environment with regard to the feeding conditions and food abundance **(Lagler, 1956)**.

The condition factors for eels in Bardawil Lagoon (0.16– 0.18) are higher than those for eels in Dutch coastal waters, (0.08– 0.12) **(Tesch, 1928)**, for yellow eels Lesina Lagoon **(Rossi & Villani, 1980)**, for eels of the western part of Baltic Sea (0.13– 0.17) **(Thurow, 1959)**, and for yellow eels of the upper River Havel (0.149– 0.212) **(Jörgensen, 1988a)**. The relatively high mean condition factors in Bardawill lagoon indicated a better diet status and wellbeing of the eels. The condition factor (K) of the European eel *A. anguilla* showed the highest value during March, whereas the lowest value was recorded during November.

The results of the relationship between the condition factor and the total body length showed a slight decrease in condition with the increase in body length, this is in agreement with the results of **Milosevic *et al*. (2022)** for silver males in small estuaries of Montenegro. On the other hand, **Piria*et al*.(2016)** recorded an increasing of condition with lengthon European eels from Lake Skadar, River Bojana and River Sutorina, proving that the investigated areas are good habitats for the European eels.

Table 2. Length weight relationship parameters of the European eel *A. Anguilla* in different localities

Country/locality	Length range	a	b	No	Reference
England/UK Engld Wal	10.0-60.0	0.00056	3.313	957	**Mann *et al*.(1991)**
Turkey/Hatay region	45.1-61.8	0.005	2.767	212	**Özcan (2008)**
Belgium/Flanders	6.8-121.5	0.0011	3.13	17586	**Verreycke *et al*.(2011)**
Turkey/Homa lagoon	27.0-60.3	0.0006	3.266	103	**Acarli *et al*. (2014)**
Italy/Comacchio lagoon	40.5-105.0	0.006	2.78	360	**Klassen *et al*. (2014)**
Asi River (Turkey)	6.5-92.0	0.0007	3.270	315	**Yalçın-Özdilek *et al*.(2006)**
Denmark/Gudenna River	48.6-78.7	0.0026	2.917	39	**Boulenger *et al*. (2015)**
Averio Lagoon (Portugal)	5.0-59.0	0.0006	3.281	1170	**Gordo and Jorge (1991)**
Donana Marshlands (Southwest Spain	5.3-67.0	0.0010	3.280	512	**Moreno-Valcárcel *et al*. (2012)**
France/Bages-Sigean	35.4-44.2	0.002	2.942	39	**Boulenger *et al*. (2015)**
Jadro River (Croatia)	18.0-70.0	0.0066	2.724	151	**Piria *et al*., (2014)**

Spain/EsvaRiver	28.8-51.2	0.0013	3.071	49	**Boulenger*et al*. (2015)**
France/Loire River	33.4-100.5	0.0005	3.326	179	**Boulenger *et al*. (2015)**
Ireland/Corrib River and Lake systems	33.6-97.0	0.0012	3.087	50	**Boulenger *et al*. (2015)**
France/FremurRiver	30.3-79.6	0.0014	3.053	99	**Boulenger *et al*. (2015)**
Arade Estuary (Southern Portugal)	17.0-68.6	0.0010	3.160	107	**Veiga *et al.* (2009)**

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