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RESEARCH ARTICLE

Length-weight relationships for 24 selected fish species from a non-tidal lagoon of the southern Adriatic Sea (Italy).

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Abstract

1 - Length-weight relationships (LWR) were estimated for 24 selected fish species in a small non-tidal lagoon located on the Italian coast of the southern Adriatic Sea (central Mediterranean Sea).

2 - Samples were collected bi-weekly from June 2007 to May 2008 with fyke nets and LWR parameters were obtained by ordinary least square regression over log10-log10 transformed data.

3 - In terms of taxonomic richness, the assemblage was dominated by the family Sparidae (8 species), followed by Mugilidae (4), Gobiidae (3) and Mullidae (2). Seven families were represented by only one species.

4 - The values of the exponent b ranged from 2.891 for Sciaena umbra to 3.313 for Diplodus sargus sargus, with a mean value of 3.132. All the relationships were highly significant. Length-length equations for converting between length measurements (standard length (SL) to total length (TL)) were also computed.

5 - To the authors' best knowledge, this study reports the first reference for LWR of two gobid species in the Adriatic Sea.

Keywords: Keywords: fish; length-weight relationships; length-length relationships; non-tidal lagoon; central Mediterranean; southern Adriatic Sea; Acquatina.

Introduction

Transitional water ecosystems, such as estuaries, lagoons and coastal lakes, represent a complementary habitat in the life history of a wide range of marine species by providing them with suitable habitats, shelter from predation and abundant food resources (McLusky and Elliott, 2004). They are especially inhabited by juveniles and sub-adults stages, but are often colonized, in specific times of the year, also by group of adult individuals, with overlapping age groups and size ranges (Elliott and Hemingway, 2002; Whitfield, 1999).

In fishes, size is generally more biologically relevant than age, mainly because several ecological and physiological factors are more size-dependent than age-dependent (Santos *et al.*, 2002). Body size strongly influences the acquisition of resources and the perception of their spatio-temporal availability, the individual susceptibility to natural enemies, the home-range, the population dynamics (Basset, 1995; De Roos *et al.*, 2003; Peters, 1986).

In sampling surveys, length measurements are usually less time-consuming than weight measurements and can be obtained under a larger range of circumstances. For these reasons, the length-weight relationships (LWR) are extensively published by scientists, because of their usefulness with several applications in the domains of fisheries sciences, population dynamics, ecology and stock assessment (Erzini, 1994; King, 1995; Petrakis and Stergiou, 1995; Santos *et al.*, 2002). These relationships allow to easily estimate weight from length, to convert growth-in-length equations to growth-in-weight, to estimate growth rates and weight at age, to calculate indexes of condition, to analyze ontogenetic changes, life history and morphological comparisons of populations and species from different regions (Anderson and Gutreuter, 1983; Beyer, 1991; Borges *et al.*, 2003; Gonçalves *et al.*, 1997; King, 1995; Mendes *et al.*, 2004; Merella *et al.*, 1997; Morato *et al.*, 2001; Moutopoulus and Stergiou, 2002; Petrakis and Stergiou, 1995; Richter *et al.*, 2000; Safran, 1992; Santos *et al.*, 2002).

However, estimated length and weight can deviate substantially from true estimates of the population parameters because nearly all fishery surveys are focused on commercial or recreational species and then based on adult individuals, the juvenile or sub-adult phase often missing from the data sets.

In the Adriatic Sea (central Mediterranean Sea) some biometric relationships have been reported for Croatian marine and estuarine species (Dulčić and Glamuzina, 2006; Dulčić and Kraljević, 1996; Sinovčić *et al.*, 2004), but data for fish spending an important part of their lives in transitional water ecosystems are inadequate, especially for juveniles and sub-adult size classes. In addition, to the best of our knowledge, data regarding marine and estuarine species inhabiting coastal ecosystems of the southern Adriatic Sea are lacking, especially on the Italian side of the basin. In this study, current knowledge is supplemented by providing the parameters of the length-weight relationships for 24 selected fish species caught in a small non-tidal Mediterranean lagoon, comprising the younger age groups and the left-hand intervals of their whole size distribution.

Materials and Methods

Data collection was made through 23 bi-weekly surveys in the small non-tidal lagoon of Acquatina (Lecce, Italy), between June 2007 and May 2008 (Fig. 1). The lagoon is located on the southern coast of the Adriatic Sea, has a surface area of 0.45 km^2, an average depth of 1.2 m and a maximum depth of 2 m. In each sampling time, fishes were caught with fyke nets, deployed for 24h at four stations covering the entire length of the basin and encompassing the whole habitat heterogeneity. A more detailed description of ecosystem characteristics and sampling methodologies can be found in Maci and Basset (2009).

Fishes were carried in the laboratory and identified to the species level. Identification of fishes was checked and nomenclature was updated with the international FishBase database (Froese and Pauly, 2009). All specimens were measured (Standard Length: SL) with a precision of 0.1 cm, and weighed (Wet Weight: WW) to the nearest 0.001 g, but not sexed. For the specimens whose tail was not cut or damaged, the Total Length (TL) was also measured (precision: 0.1 cm).

The relationship between the length and the weight of fish can generally be expressed by the equation: $W = a \cdot L^b$, where W = weight (WW: g), L = length (SL: cm), *a* (y: constant) is the initial growth coefficient or condition factor, and *b* (slope) is the growth coefficient. The parameters *a* and *b* were estimated by ordinary least square linear regression analysis over log10-log10 transformed data. Prior to analysis, raw and log10-log10 plots were visually inspected for outliers identification and spurious values were removed or corrected after dataset check (Froese, 2006; Gerritsen and McGrath, 2007).

The coefficient of determination (R^2) was used as an indicator of quality of the linear regression, and the 95% confidence intervals (95% CI) of the parameters *a* and *b* were also

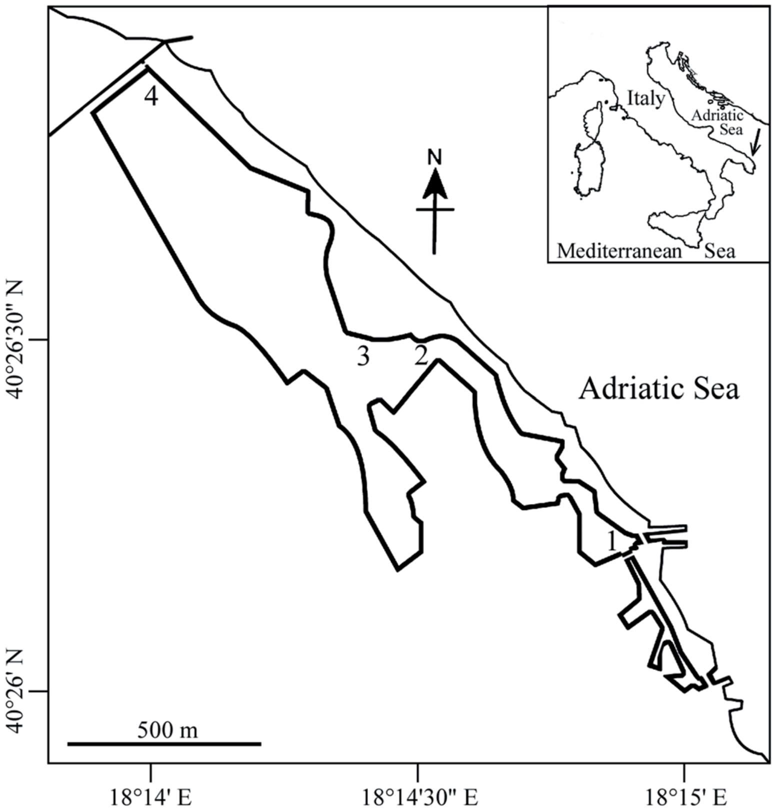

Figure 1. Map of the Acquatina lagoon showing the location of sampling stations.

estimated. In order to confirm whether the *b* values obtained in the linear regressions were significantly different from the isometric value (3), a t-test (H0: *b* = 3) was performed ($\alpha = 0.05$) using the equation $ts=(b-3)/s_b$, where t_s is th t-test value, *b* the slope and s_b the standard error of the slope (Sokal and Rohlf, 1987). According to Ricker (1973), the estimation of LWR parameters was limited to the species represented by at least 20 individuals and with a relatively wide length range, including at least juveniles and sub-adults. Since the majority of LWRs are published using Total Length as length measure (Fish Base: Froese and Pauly, 2009), for comparison purposes the SL-TL equations were also computed, assuming a linear relationship between the two units of the form TL = a + b·SL.

Results

A total of 43350 individuals belonging to 11 families and 24 species were analyzed. The best represented family in terms of taxonomic richness was Sparidae (8 species), followed by Mugilidae (4 species), Gobiidae (3 species) and Mullidae (2 species). The most abundant species was *Atherina boyeri* (39235 individual measured), followed by *Liza ramada* (1037), *Chelon labrosus* (611) and *Diplodus annularis* (393), whereas only 21 individuals of the species *Gobius niger* were measured.

For each species the taxonomic authority (FishBase: Froese and Pauly, 2009), the sample size (N), the minimum, maximum and mean length and weight (± SE), as well as the parameters *a* and *b* of the length-weight relationships, their 95% Confidence Interval and the coefficient of determination R^2 are presented in Appendix A.

The R^2 values varied from 0.948, for *Anguilla anguilla*, to 0.998, for *Diplodus puntazzo*, and all regressions were highly significant ($P < 0.001$). The lowest value of the allometric coefficient *b* was found for the species *Sciaena umbra* ($b = 2.891$), whereas the highest value for *Diplodus sargus sargus* ($b = 3.313$). The mean, standard deviation, minimum and maximum of *b* are showed in the box-whiskers plot of Fig. 2. Overall, the values of parameter *b* remained within the expected range of 2.5-3.5 (Froese, 2006).

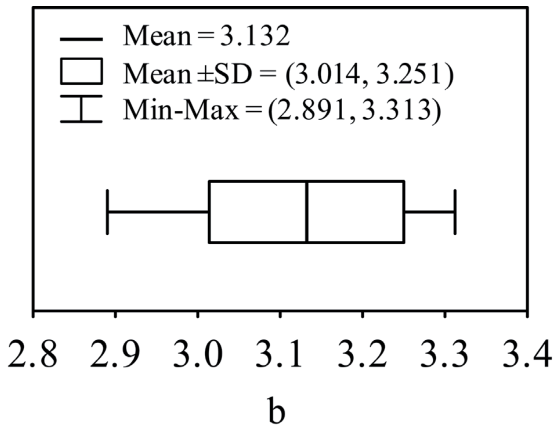

Figure 2. Box-whiskers plots of the exponent *b* of the length-weight relationships for the 24 species caught in the study area. The central vertical line represents the mean value, the box covers the mean ± standard deviation (SD) interval and the horizontal line represents the range of the values.

The growth type varied between isometric and allometric (Appendix A) and the tests revealed that 3 species (13%) showed negative allometries ($b < 3$), 8 species (33%) exhibited isometric growth ($b = 3$), and the remaining 13 species (54%) showed positive allometries ($b > 3$). The taxonomically richest family (Sparidae) showed a consistent tendency in growth type among its constituent species towards a positive allometry, except for the specie *Sparus aurata*, which growed isometrically.

In this study, fishes were collected throughout 1 year, but not every species was always present in the catches, as shown in Fig. 3. Only 6 species were constantly sampled, whereas most of the remainings exhibited specific occurrence periods, leading to a more taxonomically rich assemblage in Summer and Autumn.

Conversions between the two length measurement types are given in Table 1. All The SL-TL linear regressions were highly significant ($P < 0.001$), with no R^2 values lower than 0.935. Slope values were all greater than 1, ranging from 1.011 for *Anguilla anguilla* to 1.292 for *Diplodus sargus sargus*.

Discussion

This study is based on the fish assemblage of a small non-tidal Mediterranean lagoon, an ecosystem type whose importance in fisheries research is still poorly investigated, notwithstanding its commonness on Mediterranean coasts and, in particular, in the Adriatic Sea.

Of the 24 species caught, 15 were in common with the study of Dulčić and Kraljević (1996) and 17 appeared in the species list of Dulčić and Glamuzina (2006), which, respectively, analyzed the coastal and estuarine ichthyofauna of the central Adriatic Sea. Some other papers dealing with the life history of single species in Croatian waters gave as well information about length-weight relationships comparable with our data (Kraljević *et al*., 1996; Pallaoro and Jardas, 2003; Sinovčić, 2004). All the species in common (except for *Anguilla anguilla*, *Sparus aurata* and *Zosterisessor ophiocephalus*) had maximum lengths lower than those reported in these papers. Furthermore, for *Dentex dentex*, *Diplodus*

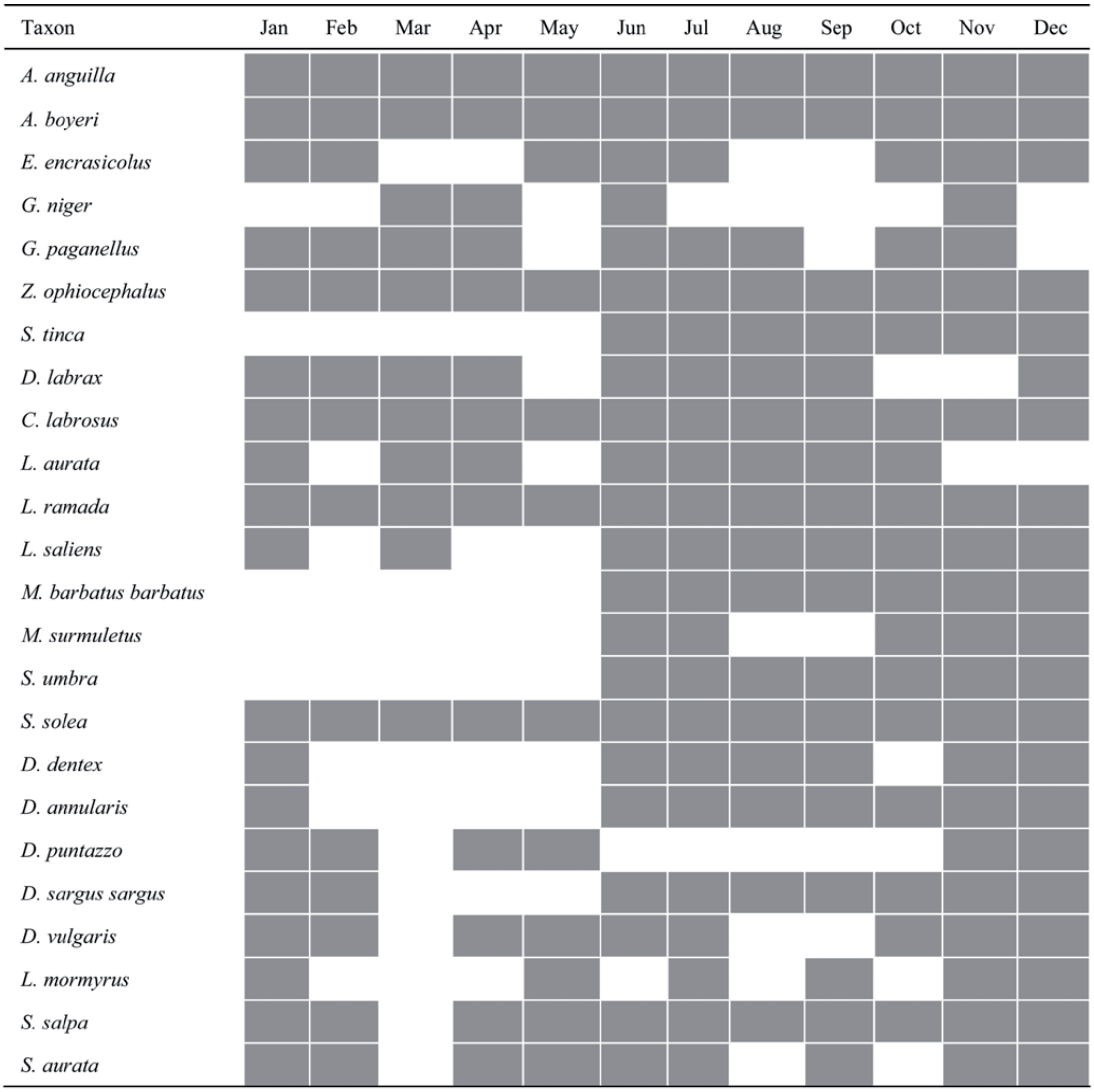

Figure 3. Monthly occurrence of the 24 fish species in the catches of fyke nets in the Acquatina lagoon.

sargus sargus, *Lithognathus mormyrus*, *Mullus barbatus barbatus* and *Liza saliens* the size ranges overlapped only marginally, with the largest Italian individuals having approximately the same size of the smallest Croatian fishes.

The present study provides an important additional contribution to the available length-weight relationships in the Adriatic Sea, and represents the first reference for two species from this geographical area: *Gobius niger* and *Gobius paganellus*.

Due to the lagoonal habitat sampled, in the Acquatina lagoon most samples were dominated by juvenile and sub-adult individuals of the marine species, even though a consistent number of adults allowed the results to be adequately representative of the whole size ranges reported. For the few resident species, such as *Atherina boyeri* and *Zosterisessor ophiocephalus*, capable to complete their entire biological cycle within

Table 1 - Estimated parameters for the conversion between the length measurements (Standard Length (SL) to Total Length (TL) in cm) for 24 selected species caught in the Acquatina lagoon: CI = Confidence Interval; *b* = Slope; *a* = Intercept; R^2 = Determination Coefficient. All regressions were highly significant ($P < 0.001$).

Taxon	SL-TL (cm) Relationship Parameters		R^2
	Intercept *a* (95% CI)	Slope *b* (95% CI)	
Anguillidae			
Anguilla anguilla	0.2777 (-0.2151 / 0.7705)	1.011 (0.999 / 1.023)	0.996
Atherinidae			
Atherina boyeri	0.0800 (0.0722 / 0.0878)	1.150 (1.149 / 1.152)	0.985
Engraulidae			
Engraulis encrasicolus	0.1541 (0.0502 / 0.2579)	1.147 (1.131 / 1.164)	0.983
Gobiidae			
Gobius niger	-0.3559 (-0.8933 / 0.1815)	1.245 (1.190 / 1.301)	0.991
Gobius paganellus	-0.0104 (-0.2400 / 0.2191)	1.206 (1.178 / 1.234)	0.993
Zosterisessor ophiocephalus	-0.2694 (-0.3784 / -0.1605)	1.260 (1.249 / 1.272)	0.997
Labridae			
Symphodus tinca	-0.0061 (-0.3307 / 0.3186)	1.183 (1.148 / 1.219)	0.986
Moronidae			
Dicentrarchus labrax	1.2774 (0.8155 / 1.7392)	1.113 (1.085 / 1.142)	0.974
Mugilidae			
Chelon labrosus	-0.0539 (-0.0859 / -0.0219)	1.239 (1.234 / 1.244)	0.998
Liza aurata	0.7026 (-0.1102 / 1.5155)	1.152 (1.103 / 1.201)	0.994
Liza ramada	-0.1524 (-0.1766 / -0.1281)	1.256 (1.252 / 1.260)	0.998
Liza saliens	-0.0873 (-0.1581/ -0.0166)	1.240 (1.226 / 1.255)	0.991
Mullidae			
Mullus barbatus barbatus	-0.0221 (-0.2779 / 0.2337)	1.221 (1.198 / 1.244)	0.986
Mullus surmuletus	-0.3061 (-0.7508 / 0.1385)	1.235 (1.192 / 1.278)	0.993
Sciaenidae			
Sciaena umbra	1.2700 (0.6563 / 1.8837)	1.153 (1.111 / 1.196)	0.935
Soleidae			
Solea solea	-0.1826 (-0.5553 / 0.1900)	1.154 (1.134 / 1.174)	0.994
Sparidae			
Dentex dentex	-0.4010 (-0.8774 / 0.0753)	1.262 (1.219 / 1.305)	0.993
Diplodus annularis	-0.0164 (-0.1316 / 0.0989)	1.247 (1.232 / 1.261)	0.988
Diplodus puntazzo	0.1791 (-0.0134 / 0.3717)	1.224 (1.194 / 1.254)	0.995
Diplodus sargus sargus	-0.1373 (-0.1974 / -0.0772)	1.292 (1.280 / 1.305)	0.997
Diplodus vulgaris	-0.1229 (-0.2068 / -0.0389)	1.286 (1.274 / 1.297)	0.997
Lithognathus mormyrus	0.0752 (-0.1190 / 0.2694)	1.203 (1.173 / 1.233)	0.996
Sarpa salpa	0.0028 (-0.0556 / 0.0612)	1.214 (1.206 / 1.222)	0.998
Sparus aurata	0.3771 (0.0187 / 0.7354)	1.231 (1.208 / 1.254)	0.994

the lagoon, nearly the entire size spectrum has likely been included in the analysis.

Length-weight relationship parameters may vary significantly under the influence of the following factors: (i) differences in the number of specimens examined; (ii) area/ season effect; (iii) habitat; (iv) degree of stomach fullness; (v) gonad maturity; (vi) sex; (vii) health and general fish condition; (viii) preservation techniques; and (ix) differences in the observed length ranges of the specimens caught (Tesch, 1971; Wootton, 1998), none of which were accounted for in the present study.

Although we consider our results to be an adequate estimation of length-weight relationships, the resulting allometric coefficients could diverge substantially from true estimates of the population parameters and the equations should be used with caution outside of the observed size range and the investigated geographical context (Bagenal and Tesch, 1978; Petrakis and Stergiou, 1995).

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Appendix A - Descriptive statistics and estimated parameters of the length-weight relationships. N = sample size; SL = Standard Length (cm); WW = Wet Weight (g); Min = Minimum; Max = Maximum; SE = Standard Error; CI = Confidence Interval; b = Slope; a = Intercept; R^2 = Determination Coefficient; i = Isometric Growth; a+ = Positive Allometry; a- = Negative Allometry.

Taxon	Sample	SL (cm)		WW (g)		LWR Parameters		Growth	R^2
	size N	Mean (± SE)	Min–Max	Mean (± SE)	Min–Max	Intercept *a* (95% CI)	Slope *b* (95% CI)	type	
Anguillidae									
Anguilla anguilla (L., 1758)	142	39.72 (±0.88)	19.9-80.9	148.229 (±13.175)	11.715-1039.390	0.0016 (0.0010 - 0.0024)	3.043 (2.925 - 3.161)	i	0.948
Atherinidae									
Atherina boyeri (Risso, 1810)	39235	5.36 (±0.005)	2.1-9.0	1.505 (±0.004)	0.066-8.839	0.0096 (0.0095 – 0.0097)	2.956 (2.949 - 2.963)	a -	0.985
Engraulidae									
Engraulis encrasicolus (L., 1758)	26	7.34 (±0.29)	4.1-9.7	3.445 (±0.364)	0.459-7.205	0.0057 (0.0042 - 0.0078)	3.155 (2.995 - 3.315)	i	0.985
Gobiidae									
Gobius niger (L., 1758)	21	9.60 (±0.35)	5.0-12.5	8.994 (±1.963)	1.829-39.905	0.0109 (0.0064 - 0.0183)	3.286 (3.055 - 3.516)	a +	0.978
Gobius paganellus (L., 1758)	54	7.69 (±0.35)	4.0-16.0	12.966 (±2.239)	1.154-84.469	0.0137 (0.0106 - 0.0176)	3.195 (3.070 - 3.319)	a +	0.980
Zosterisessor ophiocephalus (Pallas, 1814)	152	8.81 (±0.29)	3.8-19.0	19.300 (±1.906)	0.691-109.244	0.0111 (0.0102 - 0.0121)	3.203 (3.161 - 3.244)	a +	0.994
Labridae									
Symphodus tinca (L., 1758)	64	8.90 (±0.26)	4.3-14.5	19.828 (±1.766)	1.646-74.203	0.0192 (0.0138 - 0.0268)	3.100 (2.948 - 3.252)	i	0.963
Moronidae									
Dicentrarchus labrax (L., 1758)	161	15.43 (±0.36)	3.7-50.0	78.501 (±12.891)	0.777-1873.160	0.0165 (0.0138 - 0.0196)	2.984 (2.919 - 3.048)	i	0.981
Mugilidae									
Chelon labrosus (Risso, 1827)	611	5.27 (±0.14)	2.6-28.8	9.172 (±1.766)	0.246-447.426	0.0139 (0.0134 - 0.0144)	3.064 (3.040 - 3.087)	a +	0.991
Liza aurata (Risso, 1810)	30	13.84 (±1.06)	7.3-31.0	57.508 (±18.481)	4.667-441.380	0.0100 (0.0069 - 0.0144)	3.087 (2.946 - 3.228)	i	0.986
Liza ramada (Risso, 1810)	1037	5.38 (±0.11)	2.3-32.0	6.390 (±0.733)	0.128-486.537	0.0140 (0.0138 - 0.0142)	2.985 (2.974 - 2.996)	a -	0.996
Liza saliens (Risso, 1810)	273	4.74 (±0.06)	3.2-10.2	1.561 (±0.106)	0.383-15.508	0.0112 (0.0100 - 0.0126)	3.056 (2.982 - 3.130)	i	0.961
Mullidae									
Mullus barbatus barbatus (L., 1758)	159	10.85 (±0.25)	3.8-16.0	33.470 (±1.831)	0.680-101.572	0.0118 (0.0103 - 0.0135)	3.230 (3.172 - 3.287)	a +	0.987
Mullus surmuletus (L., 1758)	26	10.00 (±0.69)	4.2-18.2	31.613 (±6.508)	0.941-132.037	0.0106 (0.0084 - 0.0134)	3.290 (3.189 - 3.392)	a +	0.994
Sciaenidae									
Sciaena umbra (L., 1758)	203	14.36 (±0.12)	5.0-20.8	78.518 (±1.710)	2.677-225.324	0.0343 (0.0270 - 0.0435)	2.891 (2.801 - 2.980)	a -	0.952
Soleidae									
Solea solea (L., 1758)	82	18.44 (±0.39)	6.5-25.0	88.427 (±4.693)	2.970-202.696	0.0106 (0.0081 - 0.0139)	3.062 (2.969 - 3.155)	i	0.981
Sparidae									
Dentex dentex (L., 1758)	27	10.59 (±0.80)	4.2-17.0	45.624 (±8.813)	1.564-124.896	0.0183 (0.0144 - 0.0233)	3.140 (3.036 - 3.244)	a +	0.993
Diplodus annularis (L., 1758)	393	8.06 (±0.06)	2.8-12.1	17.697 (±0.338)	0.499-53.622	0.0166 (0.0153 - 0.0179)	3.304 (3.266 - 3.342)	a +	0.987
Diplodus puntazzo (Cetti, 1777)	36	5.71 (±0.63)	2.0-16.1	18.847 (±7.234)	0.193-198.058	0.0227 (0.0209 - 0.0246)	3.184 (3.134 - 3.233)	a +	0.998
Diplodus sargus sargus (L., 1758)	150	4.44 (±0.20)	2.1-13.3	6.701 (±1.177)	0.219-88.878	0.0185 (0.0167 - 0.0204)	3.313 (3.245 - 3.381)	a +	0.984
Diplodus vulgaris (Geoffroy Saint-Hilaire, 1817)	147	6.89 (±0.27)	2.3-14.3	18.287 (±1.709)	0.277-106.072	0.0204 (0.0193 - 0.0214)	3.221 (3.193 - 3.248)	a +	0.997
Lithognathus mormyrus (L., 1758)	29	5.97 (±0.41)	3.5-13.2	5.575 (±1.868)	0.759-54.968	0.0154 (0.0130 - 0.0182)	3.141 (3.045 - 3.238)	a +	0.994
Sarpa salpa (L., 1758)	219	5.82 (±0.29)	2.3-23.1	15.541 (±2.868)	0.158-327.604	0.0126 (0.0121 - 0.0132)	3.246 (3.220 - 3.272)	a +	0.996
Sparus aurata (L., 1758)	73	14.57 (±0.69)	3.3-31.0	121.322 (±17.223)	0.703-842.0	0.0232 (0.0205 - 0.0262)	3.042 (2.996 - 3.089)	i	0.996