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Length-weight relationships and condition factors of the sand smelt *Atherina boyeri* (Risso, 1810) estimated from commercial and experimental catches in Lake Trichonis (Western Greece)

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Total length-weight relationships (LWRs) from 3583 individuals of Atherina boyeri (Risso, 1810) caught in Lake Trichonis (Western Greece), using a commercial encircled net and experimental Nordic type benthic and pelagic multi-mesh gillnets, were estimated during 2019-2020. The variation of the parameter b for all seasons combined was significantly allometric, for both encircled towed and gillnets, with a quite robust fit (R2 equals 0.925 and 0.947, respectively) and values equal to 2.254 and 2.089, respectively. The specimens were significantly lighter in summer than in the other seasons. The slopes of the LWRs significantly differ between seasons and exhibited relatively low values when compared to other ecosystems worldwide and in the same ecosystem in previous periods of time. The estimated values of the Le Cren index were significantly higher than the Allometric and the Fulton ones.

Key words: body size; encircled towed gears; gillnets, Greece

INTRODUCTION

Atherina boyeri (Risso, 1810) (class Atheriniformes, family Atherinidae) is an euryhaline teleost fish species inhabiting marine, brackish and inland waters (KOTTELAT & FREYHOF, 2007). The species is found in the eastern Atlantic, from Portugal to Mauritania, and throughout the Mediterranean and the Black Sea. It also forms isolated marine populations at the coasts of England and the Netherlands (QUIGNARD & PRAS, 1986). The most important populations of *A. boyeri* in Greek lakes are found in Lake Trichonis (Western Greece) and to a lesser extend in Lakes

Vistonis (Northern Greece) and Kourna (Crete). In Lake Trichonis, where it has been introduced naturally via the Acheloos River, becoming abundant and with a mean production of 500 tons per year it is the most important source of income for the local fishermen (DAOULAS *et al*., 1993; LEONARDOS 2001).

In this study, annual and seasonal estimates of length-weight relationships (LWRs) for *A. boyeri* were estimated from fish captured by both commercial (i.e., encircled net) and experimental fishing gears, during 2019-2020. We also present estimations of three different condition factors that can be used as indices of the fish condition and the trophodynamics of the ecosystem under study (MOUTOPOULOS *et al*., 2011), which might further reduce the uncertainty raised by the estimation of fish growth. LWRs for the species in Trichonis are available from previous studies (LEONARDOS, 2001; STOUMBOUDI *et al*., 1997; PANAGIOTOU, 2014). However, these studies are based on annual estimates (thus lacking seasonal information, related to spawning activity), deriving from samples caught during 1988-1993 by commercial small-scale and beach seine nets, which may bias the representation of the whole population in the samples. In this framework, our results could be useful in a long-term monitoring program of this commercially important species regarding the evaluation of its population stock.

MATERIAL AND METHODS

Monthly samples of *A. boyeri* were obtained on board from Lake Trichonis (Latitude: 38º33´0.59´´ N, Longitude: 21º33´8.99´ E) during 2019-2020 (10 monthly samples during May 2019 to February 2020), using a commercial encircled nets (with a maximum length of up to 150 m, a height up to 30 m and a minimum mesh size of 6 mm) complemented with the use of light (up to 3 electric lamps with maximum light intensity of 1500 lm), at depths greater than 35 m which are exclusively used in this Lake for catching *A. boyeri* (more details for that gear can be found in PETRIKI *et al*. 2021). Experimental, Nordic type benthic (30 m of length, 1.5 m of height each, with mesh size range between 5 and 55 mm) and pelagic (6 m of length, 27.5 m of height each, with mesh size range between 6.25 and 55 mm) (Comité Européen de Normalisation, CEN 2005) nets were seasonal (4 samples in March, May, August and November 2019) on board sampled. More details on the sampling scheme are presented in PETRIKI *et al.* (2021). All individuals were measured for total length to the nearest 1 mm and weight to the nearest 0.01 g.

LWRs were estimated through the relationship $W=a \cdot TL^b$ (LE CREN, 1951), where W is the wet weight, TL the total length and a and b the intercept and the slope of the relationship respectively. To verify if b value was significantly different from the isometric growth ($b = 3$, $P < 0.05$) Student's t-test was used. LWRs were separately estimated by season and Analysis of Covariance (ANCOVA; ZAR, 1999) was used to test for differences on the LWR parameters between pairs of seasons. Three different indices of condition factors were also estimated; (a) Le Cren $K1=W/We$, where We is the predicted weight derived from the LWR (Le Cren, 1951), (b) Allometric $K2=W/TL^b \cdot 10^3$ (BOLGER & CONNOLLY, 1989) and (c) Fulton $K3=W/TL^3 \cdot 10^5$ (BAGENAL & TESCH, 1978). One and Two-way Analysis of Variance (One- and Two-way ANOVA) were also used to test for differences among seasonal and gear combinations for the estimated indices.

RESULTS AND DISCUSSION

The TL of all *A. boyeri* specimens examined (N=3583) ranged from 48 to 116 mm with a mean length of 77.2 mm (SD: 12.9) (Table 1) and the estimated LWR was highly significant ($P<0.05$) with r^2 value equal to 0.929. The TL of all the specimens caught by the encircled net ranged from 50 to 115 mm (mean length 79.58 mm, SD: 11.01) and the estimated LWR had a robust fit ($r^2 = 0.925$, $P<0.05$). The specimens caught by gillnets had a wider TL range from 48 to 116 mm (mean length 74.21 mm, SD: 14.5) and the estimated LWR had also a good fit ($r^2 = 0.947$, $P<0.05$).

The value of the exponent b estimated for all specimens (combined season and gears)

Table 1. Total length descriptive statistics and parameters of the length-weight relations (LWR) $W=a\ L^b$ [W: weight (in g) and L: length (in mm)] of Atherina boyeri estimated per fishing gear and season for specimens caught in Lake Trichonis during 2019-2020. N: number of specimens, SD: standard deviation, a and b: parameters of the LWR, SE: standard error, R^2: coefficient of determination

Fishing Gear	Season	TL (mm)					Parameters of the length-weight relations				
		N	Min	Max	Mean	SD	a-value	$SE_{(a)}$	b-value	$SE_{(b)}$	R^2
Encicled Towed	Total	2008	50	115	79.58	11.00	0.00020	0.027	2.254	0.014	0.925
	Winter	362	64	113	84.90	8.60	0.00005	0.072	2.585	0.037	0.929
	Spring	474	50	111	81.68	10.77	0.00032	0.058	2.159	0.030	0.915
	Summer	507	51	111	72.40	10.70	0.00066	0.043	1.978	0.023	0.935
	Autumn	665	56	115	80.70	9.90	0.00012	0.057	2.384	0.029	0.906
Gillnets	Total	1575	48	116	74.21	14.50	0.00045	0.023	2.089	0.012	0.947
	Winter	369	64	116	87.30	8.80	0.00013	0.075	2.359	0.038	0.910
	Spring	122	53	114	83.80	11.60	0.00014	0.113	2.336	0.059	0.928
	Summer	939	48	116	66.80	11.50	0.00046	0.035	2.087	0.019	0.923
	Autumn	145	52	114	80.30	15.10	0.00018	0.078	2.301	0.041	0.955
Both Gears	Total	3583	48	116	77.20	12.90	0.00026	0.014	2.209	0.009	0.929
	Winter	731	64	116	86.10	8.70	0.00007	0.053	2.494	0.027	0.919
	Spring	596	50	114	82.10	10.90	0.00027	0.052	2.195	0.026	0.917
	Summer	1446	48	116	68.70	11.50	0.00072	0.031	1.974	0.016	0.904
	Autumn	810	52	115	80.60	10.90	0.00014	0.049	2.344	0.025	0.911

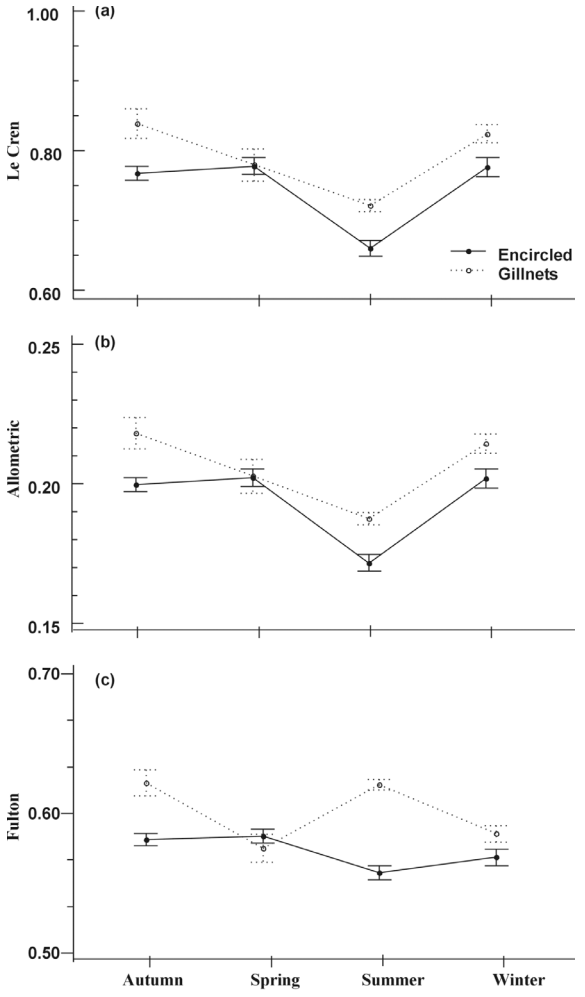

Fig. 1. Seasonal variation of (a) Le Cren, (b) Allometric and (c) Fulton condition factors of Atherina boyeri caught by encircled towed fishing gear and Nordic type benthic and pelagic multi-mesh gillnets in Lake Trichonis during 2019-2020

was significantly lower than 3 (Student's t-test; P<0.05) (Table 1). The highest value of b was 2.585 estimated for the specimens caught by the encircled net in winter, whereas the lowest value was 1.974 estimated for the specimens caught by both gears in summer. In general, the highest b values were estimated for winter samples and the lowest for the summer ones (Table 1). ANCOVA analysis also proved that the estimated LWRs exhibited significant (P<0.05) differences with season (Table 2).

All the estimated condition factors were significantly (One-Way ANOVA; F=21.35; P<0.05) the lowest during summer (Fig. 1), independent of the gear used (Two-Way ANOVA; F>21.35; P<0.05), with the Le Cren index being significantly (One-Way ANOVA; F=49.19; P<0.05) higher than the other indices (Fig. 1a). The only exception from the above pattern was the Fulton index for gillnets exhibiting high value in summer that was significantly (Two-Way ANOVA; F=42.50; P<0.05) higher than the one estimated for the encircled net (Fig. 1c). The Allometric index exhibited the lowest values, as it incorporates the value of the exponent b of the LWR, whereas, Le Cren and Fulton indices do not (KYRITSI & KOKKINAKIS, 2019).

Seasonal fluctuations in parameter b and condition factor values may be attributed either to reproductive and nutritional/ecological issues (i.e. feeding rate, maturity stage and spawning) or even to abiotic parameters i.e. the water's abiotic parameters (WOOTTON, 1999). In the present study, the seasonal b values and the condition factor indices were in general lowest during summer. This may be attributed to the energy that the species allocates for reproduction, since its reproductive period extends from March to September in Trichonis (KASPIRIS, 1998), as well as in other Balkan ecosystems, e.g. the Mala Neretva River, in Croatia (BARTULOVIĆ *et al*., 2004, 2006), in addition to the lowest food availability occurring in the summer and early autumn and the highest food resources i.e., large Copepods, were recorded during winter and spring (DOULKA *et al*., 2013).

The b values estimated in the present study (ranged between 1.974 and 2.585 depending on the gear and the season) were lower than those reported in the Fishbase (FROESE & PAULY, 2019). Thus, in our study, specimens were assumed to be lighter of a given length, when compared with other ecosystems worldwide, as well as to the same ecosystem in the past years (Table 3). Taking into consideration the LWR studies conducted for the species in Trichonis across the last 30 years (Table 3), a significant decrease of the mean annual b value was exhibited; from 3.210 in 1988-1990 (STOUMBOUDI *et al*., 1997) and 3.180 in 1992-1993 (LEONARDOS, 2001), to 3.040 in 1997 (KASPIRIS, 1998) and 2.209 during 2019-2020 (present study). This pattern is dif-

Table 2. Results of the analysis of covariance (ANCOVA, P < 0.05) for pairs of length –weight relations (LWRs) on Atherina boyeri *specimens caught in Lake Trichonis during 2019-2020 for different gear and season combinations. a and b: parameters of the LWR; ns: non-significant difference (P > 0.05), *: significant difference (P < 0.05)*

Fishing gear	Season	Autumn		Winter		Spring	
		P of *a*	*P* of *b*	*P* of *a*	*P* of *b*	*P* of *a*	*P* of *b*
All gears combined	Winter	*	*				
	Spring	*	*	*	*		
	Summer	*	*	*	*	*	*
Nordic type benthic and pelagic multi-mesh gillnets	Winter	*	*				
	Spring	*	*	ns	*		
	Summer	*	*	*	*	*	*
Encircled towed fishing gear	Winter	*	*				
	Spring	ns	*	*	*		
	Summer	*	*	*	*	*	*

ficult to be determined and might be attributed to the effect of one or more of the following factors: (a) the fishing down effect that gradually caused a decline in the large-size specimens of the population under study, (b) intra-and interspecifc interactions that can be reflected on the decrease of the LWR parameters (especially of the mid-trophic level species) (MOUTOPOULOS *et al*., 2011) and (c) unpredictable temperature and salinity variations potentially influencing fish species recruitment, especially of the small-pelagics, such as *A. boyeri* (BARTULOVIĆ *et al*., 2006), and feeding (DOULKA *et al*., 2013).

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Table 3. Length-weight relation studies on Atherina boyeri in Greece and worldwide. C is the combined seasons, AU: autumn, SP: spring, SU: summer and WI: winter, P: purse seine, B: beach seine, L: lift-net, F: fyke-net, R: ring net, G: gillnets, T: trawls and N: nets

Area	Sex	Year	Season	FM*	L	a	b	r^2	n	Lmin (cm)	Lmax (cm)	Source
Vstonis-Porto Lagos Lagoon, Greece	C	1989-90	C	P	TL	2×10^6	3.220	0.980	1056	13	105	KOUTRAKIS *et al.* (2004)
Mesolongi lagoon, Greece	F	1989-90	C	B	TL	0.0040	3.160	0.980	265	19	103	LEONARDOS & SINIS (2000)
Mesolongi lagoon, Greece	M	1989-90	C	B	TL	0.0040	3.110	0.950	161	13	83	LEONARDOS & SINIS (2000)
Trichonis lake, Greece	C	1992-93	C	P	TL	0.0030	3.180	0.740	503	44	109	LEONARDOS (2001)
Trichonis lake, Greece	C	1988-90	C	-	TL	0.0040	3.210	0.980	2543	-	-	STOUMBOUDI *et al.* (1997)
Trichonis lake, Greece	F	1988-90	C	G-T	TL	0.0050	3.210	0.972	1237	36	119	PANAGIOTOU (2014)
Trichonis lake, Greece	M	1988-90	C	G-T	TL	0.0050	3.160	0.957	1267	3	123	PANAGIOTOU (2014)
Trichonis lake, Greece	C	1997	C	N	SL	0.0110	3.040	0.980	-	-	135	KASPIRIS (1998)
Kourna Lake, Greece	C	1999-00	AU	R	SL	0.0003	2.238	0.550	98			TIGILIS (2001)
Kourna Lake, Greece	C	1999-00	SP	R	SL	0.0004	2.166	0.650	107			TIGILIS (2001)
Kourna Lake, Greece	C	1999-00	SU	R	SL	0.0004	2.136	0.730	110			TIGILIS (2001)
Kourna Lake, Greece	C	1999-00	WI	R	SL	$3*10^{-6}$	3.316	0.985	150			TIGILIS (2001)
Ria de Aveiro, Portugal	C	1998-99	C	B	TL	-	3.350	-	2503	16	116	POMBO *et al.* (2005)
Mellah Lagoon, Algeria	F	2010-11	C	B	TL	0.0040	3.170	0.935	770	26	85	BOUDINAR *et al.* (2016)
Mellah Lagoon, Algeria	M	2010-11	C	B	TL	0.0040	3.070	0.935	523	25	85	BOUDINAR *et al.* (2016)
Gomishan wetland, Caspian Sea	F	2007	C	B	TL	0.0050	3.060	0.960	1278	44	128	PATIMAR *et al.* (2009)
Gomishan wetland, Caspian Sea	M	2007	C	B	TL	0.0050	3.010	0.960	980	37	12	PATIMAR *et al.* (2009)
Mala Neretva River, Croatia	F	2001-02	C	L	TL	0.0030	3.270	0.973	606	45	116	BARTULOVIC *et al.* (2004)
Mala Neretva River, Croatia	M	2001-03	C	L	TL	0.0040	3.100	0.929	462	45	98	BARTULOVIC *et al.* (2004)
Mar Menor lagoon, Spain	F	1997-98	C	F	FL	0.0030	3.250	0.960	598	42	94	ANDREU-SOLER (2003)
Mar Menor lagoon, Spain	M	1997-98	C	F	FL	0.0030	3.220	0.970	519	39	87	ANDREU-SOLER (2003)
Maramara Lake, Turkey	C	2015	SP	T	TL	0.0060	3.110	0.920	185	56	82	İLHAN & İLHAN (2018)
Homa Lagoon, Turkey	C	2015	SP	T	TL	0.0080	2.930	0.929	172	37	99	İLHAN & İLHAN (2018)
Izmir Bay, Turkey	C	2002-03	C	N	TL	$3*10^6$	3.190	0.932	596	43	97	TAŞKAVAK *et al.* (2012)
Lake Trasimeno, Italy	F	2012-13	C	F-G-N	TL	0.0040	3.160	0.956	583	-	-	LORENZONI *et al.* (2015)
Lake Trasimeno, Italy	M	2012-14	C	F-G -N	TL	0.0040	3.130	0.984	411	-	-	LORENZONI *et al.* (2015)

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SAŽETAK

Dužinsko-maseni odnosi (LWR_s) su izračunati za 3583 jedinke gavuna veleljuskaša *Atherina boyeri* (Risso, 1810) ulovljenih u jezeru Trichonis (Zapadna Grčka), tijekom razdoblja 2019-2020, Jedinke su ulovljene komercijalnim mrežama i eksperimentalnim mrežama nordijskog tipa bentoskih i pelagičnih mreža različitih oka. Varijacija parametra b za sva godišnja doba bila je značajno alometrijska, i za zaokružne povlačne mreže i za mreže stajačice, s prilično robusnim vrijednostima koeficijenta korelacije (r^2 je 0,925 odnosno 0,947) i vrijednostima jednakim 2,254 odnosno 2,089. Primjerci su ljeti bili znatno lakši nego u ostalim godišnjim dobima. Nagibi LWR-a značajno se razlikuju između godišnjih doba i pokazali su relativno niske vrijednosti u usporedbi s drugim ekosustavima diljem svijeta i u istom ekosustavu u prethodnim vremenskim razdobljima. Procijenjene vrijednosti Le Crenovog indeksa bile su znatno veće od alometrijskih i Fultonovih.

Ključne riječi: veličina tijela; zaokružne povlačne mreže, mreže stajačice; Grčka