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Abstract
We provide a first investigation of fish species composition, sex ratios, age, length-weight relationships and growth models in Saghamo Lake located in Javakheti highland (Georgia). In total 713 specimens belonging to 8 species were collected included non-native *Coregonus albula*, *Carassius gibelio* and native *Alburnoides bipunctatus, Squalius cephalus, Capoeta capoeta, Romanogobio persus, Salmo* cf. *caspius* and *Barbus lacerta,* among which later two were recorded for the first time in the lake. In overall, relative abundances of all species is low while some species may not be presented with viable populations. Deviation from expected sex ratio, growth at age and age structure indicates severe anthropogenic pressure as a potential driver of fish community degradation in the lake.

Keywords Javakheti plateau · Fish community · Population parameters

Introduction

Javakheti plateau (South Georgia) is characterized by wealth of freshwater resources (Maruashvili 1964; Apkhazava 1975) among which lake ecosystems are of specific interest (Matcharashvili et al. 2004). The lakes of Javakheti plateau are recently recognized as a globally important wetland area (Matcharashvili et al. 2004) as well as an important bird area included in IBA system (Birdlife International 2016). Georgian government in 2011 has reflected the importance by establishing of Javakheti Protected Area system covering some wetland ecosystems within the region (http://apa.gov.ge/en/).

During the last century, lakes of Javakheti plateau were extensively used for fisheries and irrigation purposes and had a great economic importance at regional scale (Savvaitova and Petr 1999). In 1930s the vendace (*Coregonus albula* Linnaeus, 1758) was introduced into the Lakes Tabatskuri and Paravani from Ladoga Lake (Northwestern Russia) (Barach 1941) for a commercial purpose and annual catches were reaching 200 tons during the time of Soviet Union (Japoshvili 2012). Beside *C. albula*, other fish species mostly introduced had also an important economic value including common carp *Cyprinus carpio* (Linnaeus, 1758), Caspian trout *Salmo* cf. *caspius* (Kessler, 1877), khramulya *Capoeta capoeta* (Güldenstädt, 1773) and chub *Squalius cephalus* (Linnaeus, 1758) (Elanidze and Demetrashvili 1973; Elanidze 1983). After Georgian independence in 1991 there was a sharp decrease in catches as a result of overfishing and interruption of management systems (Japoshvili 2012). However, in this period the invasive *Carassius gibelio* (Bloch, 1872) was quickly spread in all freshwater systems of Georgia and is currently the dominant in regular catches (Japoshvili et al. 2013; our unpublished data).

Although there are some progresses in the protection of lake ecosystems of Javakheti plateau after establishment of protected areas, effective management including sustainable fisheries is still absent. Unregulated exploitation of all non-protected lakes with very limited knowledge of their aquatic biodiversity (Gabelashvili et al. 2016) is alarming. Lack of data regarding the lake ecosystems of Javakheti highland, impedes the proper management of this important wetland area.

Saghamo Lake is the sixth largest lake of Javakheti plateau and as non-protected area it is extensively utilized by local people for fishing, fish farming and waste disposal

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(Matcharashvili et al. 2004). Although there is information available regarding the fish composition in the lake (Barach 1941; Kasymov 1972; Apkhazava 1975; Elanidze 1983), however, this data is mostly sourced from Barach (1941), who have never sampled the lake. Instead, he assumed that species that are presented in Lake Paravani would also occur in Saghamo Lake, due to their interconnectivity. Later authors simply reiterated this information without any additional data. The only known ichthyological survey of fishes in Saghamo Lake was conducted by Pipoyan et al. (2013), who reported occurrence of five species (Table 1). However, since these authors did only time limited littoral sampling, the community composition of the Saghamo Lake would be underestimated.

The aim of our study was to investigate recent composition of fish community in Saghamo Lake. We also investigate some basic population parameters (age structure and growth, sex ratio, length-weight relationship) for each species in order to evaluate fish stocks in Saghamo Lake and build foundation for future monitoring and fisheries management.

Materials and methods

Study area Saghamo Lake (N 41.305474; E 43.739367) is located in the eastern part of Javakheti plateau (Caspian Sea basin) at an elevation of 2000 m a.s.l. (Fig. 1). The lake is rather shallow (mean depth 2.6 m) with the surface area of 4.58 km^2. It is feeding mainly from the river Paravani that is an outflow of the Lake Paravani (located 10 km northward) and other numerous small rivulets. The surface of the lake is frozen during winter (from October–November until March–April) and the maximum temperature of water reaches 15 °C in summer (Apkhazava 1975). The lake is under pressure of artisanal fisheries and the lake surroundings are used for agricultural activities (mainly pasture). Saghamo village is situated on the eastern bank of the lake with approximately 153 inhabitants (National Statistics office of Georgia 2014). We interviewed local fishermen (10) focusing on species composition and usage of fishing methods.

Fish sampling We conducted fish sampling in spring (7 May) and summer (8 August) 2015 and in spring 2016 (13 and 14 May) using three mesh sized gillnets of 80 m long, 1.5 m depth with mesh size 15, 26 and 38 mm respectively in each sampling episode. Gillnets were exposed in the water for 9 h (from 8 pm to 5 am) to avoid fish stealing by gulls. Additionally, we also used two round cage nets (diameter 40 cm; mesh size 10 mm) in littorals at each occasion to supplement the gillnet sampling. All live-fished individuals were immediately anaesthetized by a lethal dose of tricaine methanesulfonate (MS–222, Sigma Aldrich Co.). Fishes were identified to the species level according to Kottelat and Freyhof (2007) and Ninua et al. (2013), were counted, measured and weighed. All measurements were done to the nearest millimeter and gram. To determine the sex, we dissected all fished individuals and evaluated the presence of male or female gonads.

We took three to five scales from each individual from the center of the body above the lateral line. An age of each individual was determined by the examination of three to five scales under the stereo-microscope according to Cailliet et al. (1996).

Statistical analyses We modeled length-weight relationship (LWR) using the logarithmic form of power function ($W = aL^b$) were W and L stands for length and weight respectively (Anderson and Neuman 1996). The differences in b coefficients between males and females were compared using chi-squared test (Soper 2017). Binomial test was applied to test the deviation of sex ratio from 1:1 for species with more than 10 individuals in pooled data.

We estimated growth parameters using von Bertalanffy equation - $L_t = L_\infty*(1\text{-exp}[-K(t\text{-}t_0)])$, where L_t – is length at age t; L_∞-is asymptotic length (or maximum length

Table 1 Fish species composition in Saghamo lake with historical records

Species	Barach (1941)	Elanidze (1983)	Pipoyan et al. (2013)	Current study
Squalius cephalus	?		+	+
Carassius gibelio			+	+
Alburnoides bipunctatus	?	?	+	+
Capoeta capoeta	?	?	+	+
Romanogiobio persus			+*	+
Coregonus albula	?			+
Barbus lacerta				+
Cyprinus carpio	?			
Salmo cf. *caspius*	?	?		+

Question mark indicates unconfirmed records. Asterisk indicates a record of *Gobio* cf. *gobio* after Pipoyan (2013) which is most probably misidentified *R. persus*. Note that all listed species except in bold face are also recorded from Paravani - a lake interconnceted with Saghamo (Elanidze 1983)

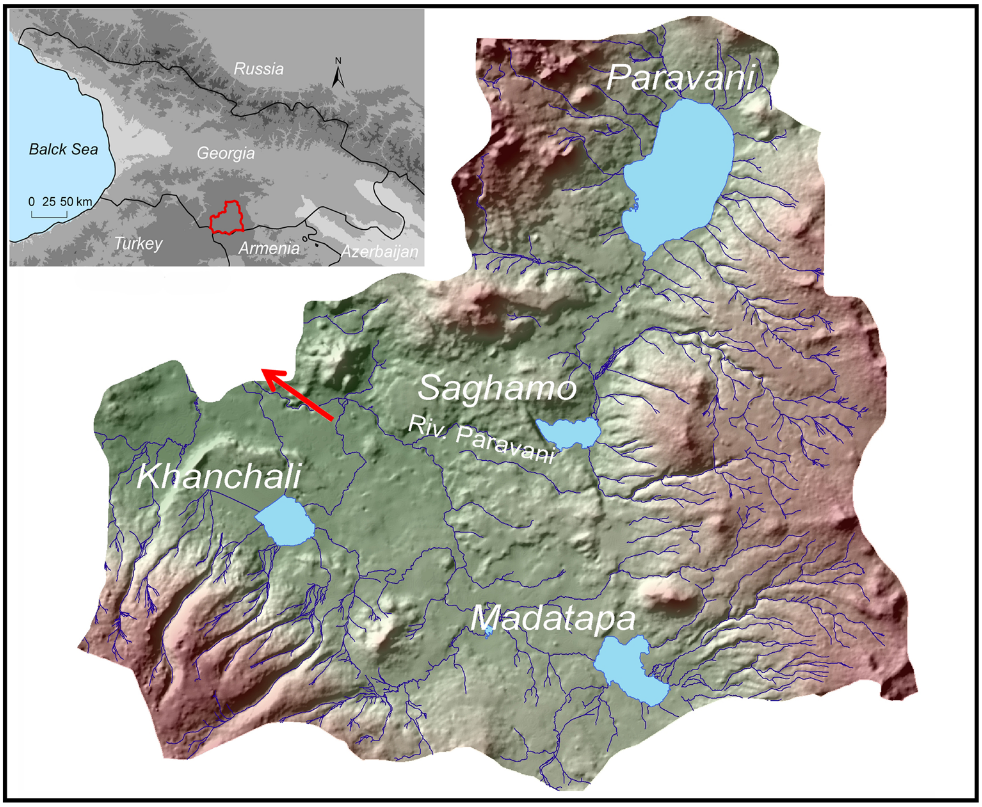

Fig. 1 A map of Javakheti highland showing the large lakes of the region and river network. All the tributaries belong to the drainage of Paravani River and the flow direction is indicated by red arrow

available from FishBase); *K*- is the growth coefficient; t_0 – is the theoretical age at zero length (In our study $t_o = 0$). Mean length for species in each age group were calculated in the statistical program R (R Development Core Team 2016), then obtained data was rearranged in spreadsheet as suggested by King (2007) to estimate best fit parameters of nonlinear least squares regressions for each species.

Estimation of catch per unit effort (CPUE) was calculated as an average number of individuals captured per single gillnet (King 2007).

Results

In total 713 individuals belonging to 8 species were collected among which 4 species were represented with more than 10 individuals (Table 2). Most of *Alburnoides bipunctatus* (Bloch, 1782) (90%) were caught by cage nets, while all others were captured by gillnets. The most abundant species (>50% of total catch) was *S. cephalus* while the *S.* cf. *caspius* and Kura barbel *Barbus lacerta* (Heckel, 1843) was represented both by one individual only.

Regarding sex of fishes, not all analyzed fish species showed balanced ratio of males and females. *S. cephalus* is strongly male biased ($p < 0.01$) ($n = 401$) while *A. bipunctatus* ($n = 79$) and *C. capoeta* ($n = 62$) are female biased ($p < 0.01$). For other species, there is no significant deviation from 1:1 sex ratio, or we did not catch a sufficient number of individuals (Table 2).

Due to low number of individuals in fishes, we analyzed age class distribution only for 6 species (Table 2). Maximum age was found to be 'V' for *A. bipunctatus, C. capoeta, Romanogobio persus* (Günther, 1899) *and S. cephalus*. The '0' age group was poorly represented in a total catch except *A. bipunctatus* presumably due to selectivity of gill nets. Only single individual of *C. albula* and 9 individuals of *C. gibelio* was represented at '0' age group.

Length- weight relationships

Data summarizing the length-weights of the species is provided in Table 3. Only *A. bipunctatus* showed positive allometric growth ($b = 3.3$) while other remaining three species had negative allometric growth ($b < 3$). There are also differences in growth parameters between males and females for some species. For instance, males of *C. capoeta* exposed lowest and females largest *b*-value among all species ($p < 0.01$). In contrast, males of *S. cephalus* showed perfect isometric growth, while females showed negative allometric growth ($p < 0.01$). For other two species, there were no significant differences in LWR models between sexes.

Table 2 Summary table of the fish species in Saghamo lake including the binomial test (p) for sex ratio and distribution of age classes

Scientific name	Native	N[a]	M[b]	F[c]	P[*]	Age classes[d]					
						0	I	II	III	IV	V
S. cephalus	yes	403	295	106	<0.01	0	2	48	72	6	1
C. gibelio	no	133	62	69	0.7	9	42	32	25	6	0
A. bipunctatus	yes	90	23	56	<0.01	19	16	19	9	3	1
C. capoeta	yes	73	18	44	<0.01	0	1	24	25	16	2
R. persus	yes	7	2	5	0.4	0	0	1	0	3	3
C. albula	no	5	3	1	0.6	1	0	1	1	0	0
B. lacerta	yes	1	–	–	–	–	–	–	–	–	–
S. cf. *caspius*	yes	1	–	–	–	–	–	–	–	–	–

* significance value for difference in sex ratio

[a] total number of specimens

[b] male

[c] female

[d] Sex and age was not determined for all the individuals

Growth

Fitting of von-Bertalanffy growth curve was only possible for four species (Fig. 2) (*A. bipunctatus* - $L_t = 18.5*(1\text{-}\exp[-0.3*t])$; *C. capoeta* - $L_t = 41*(1\text{-}\exp[-0.3*t])$; *C. gibelio* - $L_t = 46*(1\text{-}\exp[-0.1*t])$; *S. cephalus* - $L_t = 60*(1\text{-}\exp[-0.1*t])$.

Catch per unit effort (CPUE)

The CPUE was estimated as 71 individuals per gillnet including all species combined. Among captured speceis, *S. cephalus* was dominated in total catch with CPUE of 44 individuals followed *C. gibelio* and *C. capoeta* with CPUE of 14 and 8 individuals respectively. Note that 95% of *A. bipunctatus* were captured by cage nets not a gillnet and hence did not included in CPUE calculation.

Discussion

In overall, total catch was very low. For instance, the same CPUE of *C. gibelio* in nearby Madatapa Lake resulted in 70 individuals (Japoshvili et al. 2017). This indicates a very low total abundance of fishes in the lake although we are aware that gillnets may insufficiently sample the littoral parts and hence underestimate a true population density in the lake. Nevertheless, we assume no significant deviation related to species composition, relative abundance and sex ratio. The fish community in the lake is composed by six native species *S. cephalus, A. bipunctatus, C. capoeta*, *R. persus, S.* cf.

Table 3 Length and weight distribution of fish species in Saghamo Lake; regression coefficients; significance test statistics of Length-Weight Relationships

		Standard Length		Weight		Regression parameters			Females				Males				
									Regression parameters				Regression parameters				
Species	N[a]	Min[b]	Max[c]	Min	max	b[d]	95% CI(b)[e]	r^{2*}	N	b	95% CI(b)	r^2	N	b	95% CI(b)	r^2	p[**]
Alburnoides bipunctatus	90	55	123	2.7	39	3.3	<0.01	0.9	56	3.2	<0.01	0.9	23	3.2	<0.01	0.9	0.9
Capoeta capoeta	73	148	262	58	331	2.8	<0.01	0.9	18	2.3	<0.01	0.9	44	3.4	<0.01	0.9	0.0
Carassius gibelio	133	67	203	11	313	2.9	<0.01	0.9	69	3	<0.01	0.9	63	2.8	<0.01	0.9	0.7
Squalius cephalus	403	102	229	19	214	2.9	<0.01	0.9	106	3	<0.01	0.9	295	2.7	<0.01	0.8	0.001

* coefficient of determination

** Significance of the difference between Two Slopes

[a] sample size

[b,c] minimum and maximum standard length (cm)

[d] slope; [e] confidence interval of b

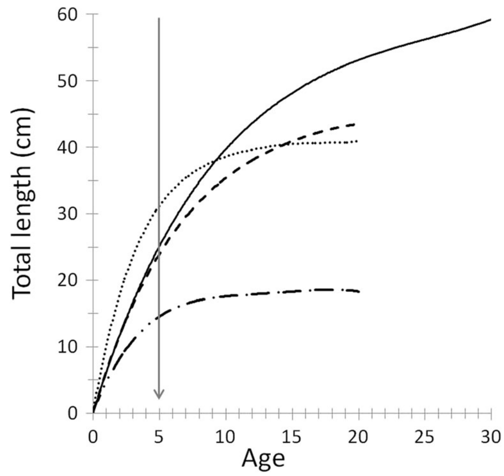

Fig. 2 Growth models for four species occurring in Saghamo Lake. Continuous line – *Squalius cephalus*; dashed line – *Carassius gibelio*; point line – *Capoeta capoeta*; dashed line with points – *Alburnoides bipunctatus*. Arrow indicates maximum age class occurring in our catch

caspius, *B. lacerta*, from which later two were recorded for the first time in the lake (also note that Pipoyan et al. (2013) described gudgeon in Saghamo Lake as *Gobio* cf. *gobio*, which presumably was misidentified with *R. persus*. In addition, two non-native species (*C. gibelio* and *C. albula*) are inhabiting the lake. The native fishes in the lake originated most likely from the river Paravani, which is the right tributary of the Kura River. Interestingly, Barach (1941, 1964) who never collected fishes in the lake, predicted the occurrence of most of them based on their occurrence in the lake Paravani (Table 1). In contrast to previous works about fishes of Saghamo Lake, the most common species nowadays is *S. cephalus*, not *C. Gibelio* which invaded the Georgian waters during last decades of twentieth century and spread to many lakes in Georgia (Japoshvili et al. 2013). Although this species is usually outnumbering all other species roughly of the same size (Lusk et al. 2010; Lusková et al. 2010; Japoshvili et al. 2013) this is not the case for Saghamo Lake, which could be related to high fishing pressure. Additionally, although *C. carpio* have been present in Paravani Lake (Japoshvili 2009), it is most likely not occurring in the lake Saghamo, which is supported by our survey and confirmed by local anglers. Nevertheless, fish communities in Saghamo and Paravani lakes are highly similar and richer in number of species than other large lakes in the Javakhety highland (Madatapa and Khanchali lakes) that are currently harboring a single species - *C. gibelio* (Fig. 1; Table 1). This could be attributed to either harsher environmental conditions in case of Madatapa Lake (Matcharashvili et al. 2004) or severe anthropogenic disturbance in case of Khanchali Lake (Gabelashvili et al. 2016).

The rarest species in our catch were: *R. persus* ($n = 7$), *C. albula* ($n = 5$), *B. lacerta* ($n = 1$) and *S.* cf. *caspius* (n = 1) (Table 1). The lower proportion of these species could be expected since *R. persus, B. lacerta* and *S.* cf. *caspius* are usually more common in rivers and the relative abundance of these species is not high in lakes (Elanidze 1983). The Saghamo Lake was populated by non-native *C. albula* through the river connection with nearby located Paravani Lake where it was introduced during the mid-20th centuries and since then fry was released regularly into this lake (Japoshvili 2012). According to local fishermen the last stocking of *C. albula* fry was performed in 2005. Hence, the finding of the young generation of this species indicates its naturalization in Saghamo Lake but with no commercial value due to small population size.

We found that the sex ratio was significantly male biased in *S. cephalus* population and significantly female biased in populations of *A. bipunctatus* and *C. capoeta*. In contrast, *C. gibelio* population did not show significant deviation from balanced sex ratio (1:1). The imbalanced sex ratio could be driven by different factors (Devlin and Nagahama 2002) and even the different species could have diverse response to the same factor (Ospina-Álvarez and Piferrer 2008). In this respect, *C. gibelio* is rather extensively studied. The populations of *C. gibelio* are usually female biased and sometimes the population consist of females only (Tsoumani et al. 2006). This pattern is usually attributed to the gynogenetic mode of reproduction but may exhibits great variation; however, the proportion of males seldom approaches to 50% (Vetemaa et al. 2005; Liasko et al. 2011). High proportion of males in a population of *C. gibelio* (especially in case of occurrence of other cyprinid species) indicates a dominance of sexual reproduction mode in Saghamo Lake that is hypothesized as a result of stressful environment (Smith 1978; Burt 2000; Liasko et al. 2011). Since Saghamo Lake offers milder environmental conditions than the nearby Madatapa Lake (Japoshvili et al. 2017) environmental severity cannot explain the observed sex ratio. Instead, heavy and long-term human disturbance in Saghamo Lake might be hypothesized as the structuring force of sex ratio in *C. gibelio* population. On the other hand, *C. gibelio* has very complicated genetic background (Rylková et al. 2013), and cytogenetic mechanisms, which still not have been well understood (Kalous and Knytl 2011).

A number of studies are reporting the different sex ratio in populations of *S. cephalus* (Ünver 1998; Türkmen et al. 1999; Koç et al. 2007), *C. capoeta* (Abdoli et al. 2008; Patimar et al. 2009, 2011) and *A. bipunctatus* (Patimar et al. 2012). It seems that the sex ratio in these species could vary greatly, however there is no studies explicitly addressing the potential mechanism explaining those patterns. According to Nikolsky (1963) males are predominating in fish populations in early life stages while females – at later due to probable adaptive mechanisms. Although '0' and '1' age groups are purely represented in our data most probably due to selectivity of gill nets, nevertheless the distribution trends of sex ratio for any species does not support this prediction (Fig. 3). Data limitation does not allow us to

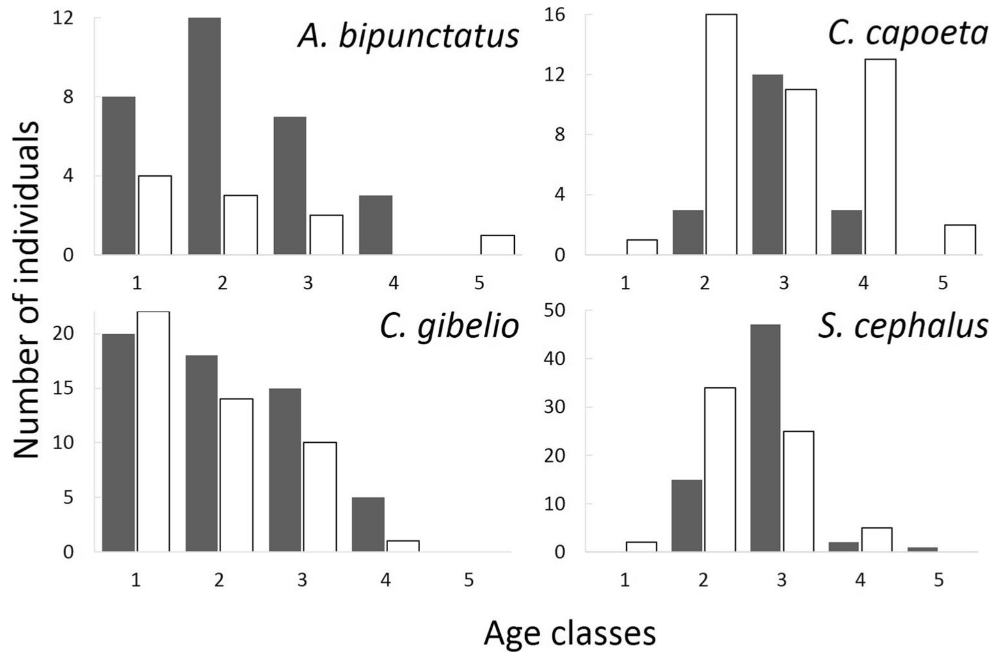

Fig. 3 Age-dependant sex distribution of four fish species in Saghamo Lake. Filled bars - males; unfilled bars – females

make any deeper analyses of the underlying mechanisms, although these inconsistencies could also be related to overfishing.

This view is supported by the low value of maximum age and sizes of species captured in the lake. In particular, *C. gibelio* attains far higher age (9 years) and large size (330 mm) in Madatapa Lake (own unpublished data), while in Saghamo Lake its maximum age does not exceed five years and the total length of 253 mm. No comparable data for all other species is available from surrounding areas although maximum sizes is far larger than ours based on data of FishBase (Froese and Pauly 2015). This clearly indicates that the species could not attain possible maximums due to fishing pressure. Furthermore, length at age distribution (Fig. 4) showed that the older individuals were not larger in any species and the maximum length is approached at 'II' – 'III' age classes. This pattern can be explained by the overfishing as the anglers are usually fishing using gill-nets with large mesh sizes (more than 30 mm). Modeled growth when asymptote length was applied from the literature showed that except *A. bipunctatus*, no other species (*C. gibelio, C. capoeta* and *S. cephalus*) can attain their maximum sizes (Riehl and Baensch 1990; Kottelat and Freyhof 2007; Verreycken et al. 2011). This in turn indicates the existence of stressful abiotic environment rather than effect of overfishing. In addition, Saghamo Lake is high mountain

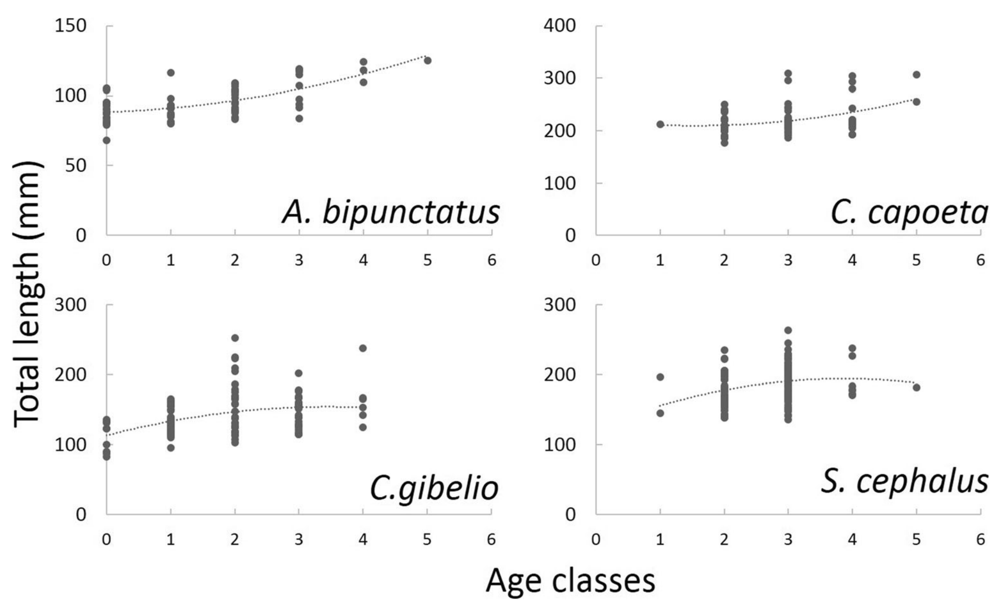

Fig. 4 Length at age relationship of four species from Saghamo Lake

oligotrophic lake that may be related to slow growth rate of fish stock.

We found all species (except *A. bipunctatus*) exhibiting very low growth rate up to asymptote (Fig. 2). In particular, *C. gibelio* for which the maximum age is thought to be 10 years (Kottelat and Freyhof 2007) needs almost 20 years to reach maximum length reported in FishBase (Froese and Pauly 2015). Similarly, the *S. cephalus* that can grow as large as 60 cm in length and live up to 22 years (Kottelat and Freyhof 2007; Froese and Pauly 2015), needs to live for 30 years to gain reported maximum size according to our growth model. No such data are available for *C. capoeta* and we cannot confidently judge the parameters of its growth model.

In summary, the fish community of Saghamo Lake consists currently of eight fishes among which *S. cephalus, C. gibelio, C. capoeta* and *A. bipunctatus* are relatively abundant, while others (*C. albula, B. lacerta, R. persus* and *S.* cf. *caspius*) are very rare. Especially the dominance of non-native *C. gibelio* is alarming since it is classified as the invasive species with potentially severe impact on ecosystem (Copp et al. 2009). However, the populations of even those relatively abundant species seems to be much diminished and probably in a critical condition. Strong overfishing is evident in Saghamo Lake that is supposedly a main contributor in fish community degradation although there are signs of poor abiotic conditions as well. Overall, fish species diversity and distribution of Georgia and South Caucasus in general is purely documented (for instance, the area was not thoroughly considered in the last compendium by Kottelat and Freyhof (2007) due to lack of information). Hence, the studies similar to ours can greatly contribute in the understanding of fish diversity and distribution of the region. In addition, provided information regarding the fish species of Saghamo Lake could be effectively used to better understand the lake ecosystem as well as for a sustainable fisheries management and monitoring purposes.

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