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The ecology of freshwater bivalves in the Lake Sapanca basin, Turkey

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Abstract: Despite the ecological importance and globally threatened status of freshwater bivalves, the freshwater mussel fauna of Turkey has hitherto received little attention. The aim of this study was to describe the ecology of freshwater mussels of the Lake Sapanca basin (northwest Turkey) to provide baseline data against which to measure future trends. Five native mussel species belonging to 3 genera were encountered in surveys: *Anodonta cygnea*, *A. anatina*, *Unio pictorum*, *U. crassus*, and *Dreissena polymorpha*. In addition, an invasive species from Asia, *A. woodiana*, was recorded in the region for the first time. *A. cygnea* and *U. pictorum* were the most abundant species in the lake, while *U. crassus* was most abundant in the associated stream. Age and growth parameters were estimated for *U. pictorum* and *U. crassus*, and indicated that the latter species had a younger median age and faster growth rate than the former, possibly a function of exclusively occupying a nutrient-enriched stream. The bioecological features of the bivalve fauna of the Lake Sapanca basin, as well as the implications of the introduction of *A. woodiana*, are discussed.

Key words: Turkey, water quality, invasive species, age, growth

1. Introduction

Freshwater bivalves are a key component of the ecology of aquatic ecosystems. As sedentary suspension feeders, they have a direct impact on suspended material in the water column and potentially exert bottom-up control on phytoplankton blooms (Vaughn et al., 2008; Allen et al., 2011). Large bivalve populations can influence the calcium budget of the water bodies in which they occur (Green, 1980), and they provide an integral resource link between freshwater pelagic and benthic habitats (Howard and Cuffe, 2006; Strayer, 2008). The amount and rate of particulate matter removed from the water column by bivalves can be considerable, and freshwater mussels can function in the rehabilitation of organically polluted waters, particularly those associated with aquaculture (Ercan, 2009). In addition, freshwater mussels are preyed upon by a range of terrestrial and aquatic organisms (Öktener, 2004; Vaughn, 2010). They serve as the intermediate hosts for several parasitic species, and some species are themselves parasitic as larvae (Dillon, 2000). Globally, freshwater bivalves are threatened, primarily through habitat deterioration, and in some cases through direct exploitation (Lydeard et al., 2004).

Despite their key ecological role and threatened status, mussel faunas in many regions are poorly studied and there are few baseline data against which to measure ongoing population declines or recovery. In Turkey, freshwater bivalve communities have received little attention, though a limited number of studies have addressed their biology in Turkish freshwaters (Akyurt and Erdoğan, 1993; Kara, 2004; Yalçın, 2006; Koşal Şahin and Yıldırım, 2007; Ercan, 2009; Yılmaz, 2011). Additionally, the taxonomic status of many bivalves has yet to receive revision in light of modern molecular biology techniques. In this study, we describe the freshwater bivalve community of the Lake Sapanca basin in northwestern Turkey. Lake Sapanca is an important water body in northwestern Turkey, both from an ecological and economic perspective. An initial survey of the mollusk fauna of Lake Sapanca was performed by Koşal Şahin and Yıldırım (2007) using grab and dredge sampling. Using these techniques, they identified 4 species of bivalves, of which 2 were unionids (*Anodonta anatina* and *Unio pictorum*). Our aim was to perform more comprehensive dive surveys of the bivalve fauna, as well as estimating age and growth parameters on the most common mussel species in the lake. We also assessed the bioecological features of the native mussel fauna and considered the potential implications of an invasive bivalve species in the region.

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2. Materials and methods

Lake Sapanca is located in the Marmara region of northwestern Turkey (40°41′ to 40°30′N, 30°09′ to 30°20′E) and is one of the most important lakes in the region in terms of its fisheries and as a source of drinking water (Figure 1). Its surface area is 46.8 km^2 with a maximum depth of 55 m. It is 30 m above sea level, with 13 rivers flowing into the lake (the rivers Karaçay, Yanık, Kurtköy, Mahmudiye, İstanbul, Maşukiye, Keçi, Sarp, Balıkhane, Eşme, Liman, Maden, and Arifiye). The lake has one outflowing river (Çark). The lake is used as a source of drinking water for the city and district of Sakarya and as a recreational amenity. Although Lake Sapanca water shows evidence of enrichment with nitrates and phosphates from trout farms, of which there are more than 30 in the vicinity of the lake, it has an oligotrophic character (Albay et al., 2003). Sampling stations around the lake and in associated rivers were chosen to be representative of the major habitat types in the lake. There are 3 sampling stations in total: 1 in the Maşukiye River, 1 at the southern shore (at the mouth of the Yanık River), and 1 at the northern shore of Lake Sapanca (Figure 1). The Maşukiye River site was the most impacted, since sampling was conducted downstream of its confluence with the Balıkhane River, which has high quantities of suspended organic and inorganic material derived from anthropogenic activities. Sampling sites were concentrated on the western shore of the lake, since mussels were most abundant there (Koşal Şahin and Yıldırım, 2007).

Bivalve surveys were conducted between 2007 and 2009 by hand collection to a maximum water depth of 3 m. Hand collection was used in combination with a bathyscope to spot mussel siphons at the sediment surface. All bivalves were measured (width, height, and length) using digital calipers to the nearest 0.1 mm and their wet weight determined on an electronic balance to the nearest 0.001 g (Bilgin, 1980). Identification of mussels was performed in accordance with Killeen et al. (2004). The number of *D. polymorpha* individuals attached to the shells of *Anodonta* species and *U. pictorum* was counted. Density of *Unio* and *Anodonta* spp. at the sampling sites was calculated as the number of individuals per m^2, which was determined by transects. Mussel collection was maintained for 30 min with skin diving in each sampling occasion.

Age was determined by thin sectioning of shells (Singer and Gangloff, 2011), confirmed by length–frequency analysis (e.g., Negus, 1966). Age determination was possible only for *Unio* species; the shells of *Anodonta* spp. were too thin to section and score reliably (Neves and Moyer, 1988). Fresh dead shell material for sectioning was collected at sample site 1 (Figure 1).

Length–weight relationships of mussels were estimated using the function: W = aL^b, where W is the total (wet) weight (expressed in grams), L is the total shell length

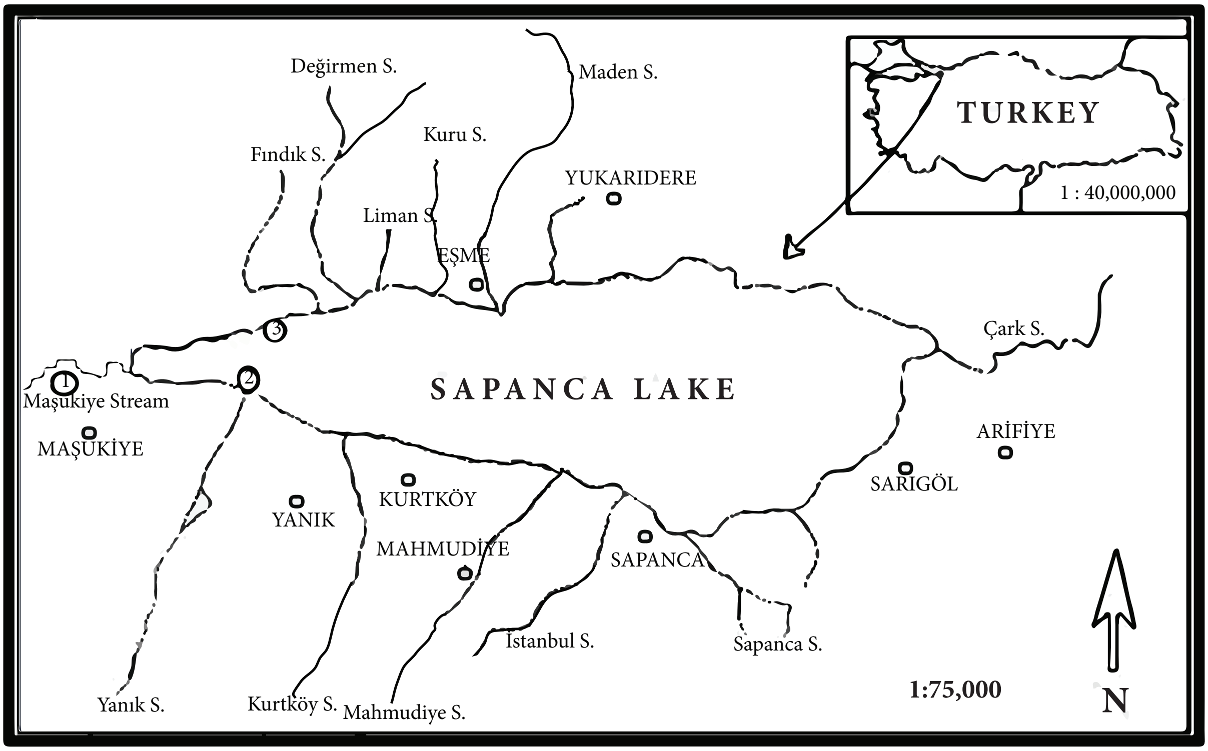

Figure 1. Sampling sites in the Lake Sapanca basin.

(expressed in millimeters), and *a* and *b* are the parameters of the equation. Regressions on log-transformed data were analyzed using analyses of covariance (ANCOVA) to examine differences in slopes between species (Zar, 1999). Total shell radius (R) and the radius of annual rings were measured as the smallest distance between the shell center and the distal edge. Lengths at previous ages were back-calculated using the Fraser–Lee equation (Francis, 1990): $L_t = c + (L_c - c)(S_t/R)$, where L_t is L when growth mark t was formed, L_c is L at the time of capture, S_t is the distance from shell center to the growth mark t, R is shell radius, and c is the intercept on the length axis of the linear regression between L and shell radius. The von Bertalanffy growth equation was fitted to lengths at age. The form of the growth curve is $L_t = L_\infty\{1 - e^{-k(t - to)}\}$ (Ricker, 1975), where L_t is the total length of mussel at time t, L_∞ is the asymptotic total length, k is the growth coefficient, and t_o is the hypothetical time at which mussel total length is zero.

Since there was no fishery for mussels in the Lake Sapanca basin, total mussel mortality comprised only natural mortality, which was estimated using the empirical formula of Pauly (1980), $\log (M) = -0.0066 - 0.279 \log (L_\infty) + 0.6543 \log (k) + 0.463 \log (T)$, where L_∞ and k are the parameters derived from the von Bertalanffy equation and T is the average water temperature in °C throughout the study period (15.2 °C in this case).

Water samples were collected at each of the sampling sites throughout the sampling period for nutrient analyses and stored at –20 °C in a freezer and in darkness until analysis. Standard Methods for the Examination of Water and Wastewater (APHA et al., 1985) were used for all analyses. Physicochemical water parameters including temperature, dissolved oxygen, conductivity, and pH were measured in the field using a multi-parameter probe (WTW 310i). For chlorophyll-*a* analysis, water samples was first filtered and then extracted through ethanol. After centrifugation, absorbance was measured before and after acidification in a spectrophotometer (Ryther and Yentsch, 1957).

3. Results

3.1. Environmental variables

Seasonally collected environmental variables showed that the Maşukiye River had a higher nutrient content than the other sample sites (Table 1). *U. crassus* occurred exclusively in the Maşukiye River (see below), and was positively correlated with chemical parameters indicating enriched waters (NO_2, NO_3, PO_4, TP) and low water temperature (Table 1, $r > 0.82$, $P < 0.01$). The abundance of the other bivalve species was not correlated with the chemical and physical variables measured in the study (Table 1).

3.2. Bivalve fauna

Six species of bivalve belonging to 3 genera were collected in surveys: *A. cygnea*, *A. anatina*, *A. woodiana*, *U. pictorum*, *U. crassus*, and *D. polymorpha*. The Chinese mussel *A. woodiana*, which is an alien species, was recorded here for the first time in the Turkish mussel fauna, while *U. crassus* and *A. anatina* were new records for the Lake Sapanca basin. *U. crassus* and *A. woodiana* were collected only from the Maşukiye River (sample site 1), which discharges into Lake Sapanca, whereas the other species were found at the mouth of the Yanık River (sample site 2) and in the western part of the lake (sample site 3) (Figure 1).

U. crassus showed the highest density in the Maşukiye River (sampling site 1), while *A. cygnea* showed the highest density in the lake proper. *U. pictorum* showed the highest density at site 2, while *A. anatina* showed consistently low densities overall, though it was encountered at all sampling sites. *U. crassus* and *A. woodiana* only occurred in the Maşukiye River (Table 2). *D. polymorpha* occurred

Table 1. Mean and standard deviations (±) of physico-chemical parameters of sampling stations in the Lake Sapanca basin.

Physico-chemical parameters	Site 1	Site 2	Site 3
Total phosphorous (µg L^{-1})	80.8 (±51.0)	10.1 (±1.7)	25.0 (±5.2)
Phosphate (µg L^{-1})	38.8 (±49.9)	9.9 (± 5.1)	13.2 (±3.1)
Nitrite (µg L^{-1})	13.4 (±8.1)	1.9 (±1.6)	1.3 (±0.9)
Nitrate (µg L^{-1})	530.7 (±124.4)	157.3 (±61.0)	150.0 (±55.0)
Sulphate (mg L^{-1})	23.3 (±5.5)	55.9 (±22.5)	46.3 (±12.1)
Silicon dioxide (mg L^{-1})	3.8 (±0.9)	3.6 (±0.5)	2.4 (±0.4)
Chlorophyll *a* (mg L^{-1})	1.2 (±0.7)	0.9 (±4.9)	2.6 (±5.1)
Dissolved oxygen (ppt)	12.3 (±2.4)	7.7 (±0.9)	10.1 (±2.2)
pH	8.0 (±0.1)	8.0 (±0.1)	8.2 (±0.2)
Temperature (°C)	13.2 (±2.2)	15.5 (±2.6)	16.3 (±4.6)

Table 2. Density (individuals per m²) of *Unio* and *Anodonta* spp. at 3 sampling sites in the Lake Sapanca basin.

Species	Site 1	Site 2	Site 3
A. cygnea	30	36	73
A. anatina	13	15	8
A. woodiana	1	-	-
U. pictorum	15	48	17
U. crassus	45	-	-

at sampling sites 2 and 3, and was primarily found attached to the other bivalve species.

3.3. Age, growth, length–weight relationships, and mortality estimates

Age estimation of *U. pictorum* and *U. crassus* indicated a maximum age of collected specimens to be 13 and 7 years old, respectively. Estimates of Brody's growth constant (k) were 0.26 year^{-1} for *U. crassus* and 0.19 year^{-1} for *U. pictorum*, indicating that *U. crassus* had a faster growth rate than *U. pictorum* (Figure 2). Theoretical maximum lengths (L_∞, cm) were 96.2 mm and 89.6 mm for *U. pictorum* and *U. crassus*, respectively. *U. crassus* had a higher estimated natural instantaneous mortality rate of 0.41 year^{-1}, compared with 0.33 year^{-1} for *U. pictorum*. The slope of the length–weight relationships of the 4 unionid species collected, excluding *A. woodiana* for which there were insufficient data to estimate the parameter, varied between 2.47 for *U. crassus* and 2.97 for *U. pictorum* (Table 3). There were significant differences in the slopes of the length–weight relationships among the species (ANCOVA, $P < 0.01$). Size ranges were similar for *Unio* species and *A. anatina*; however, *A. cygnea* shell length was almost twice as long as for the other species examined (Figure 3). Plots of the length–frequency distribution showed that medium sizes were dominant with the exception of *A. anatina*, which had a relatively homogeneous length distribution (Figure 3).

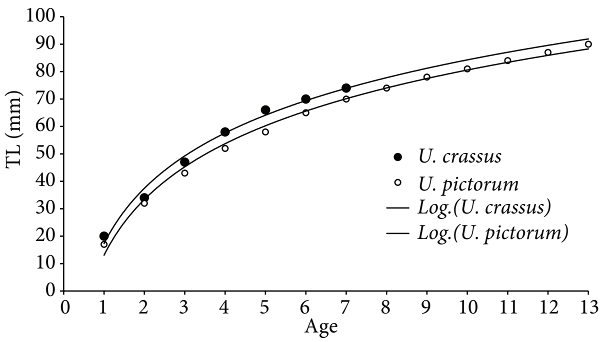

Figure 2. Growth curves of *Unio crassus* and *U. pictorum* from the Lake Sapanca basin.

4. Discussion

The aim of this study was to describe the ecology of freshwater mussels of the Lake Sapanca basin (northwestern Turkey) to provide baseline data against which to measure future trends. Six species of bivalve were collected, 1 of which was a nonnative species. A previous survey on the mollusk fauna of Lake Sapanca reported only 2 unionid species, namely *U. pictorum* and *A. cygnea* (Koşal Şahin and Yıldırım, 2007). These species were also identified in the present study. In addition, 2 further native species (*U. crassus* and *A. anatina*) and 1 nonnative species (*A. woodiana*) were recorded, which were not recorded in the survey by Koşal Şahin and Yıldırım (2007). Given the relatively high abundance of *U. crassus* and *A. anatina* in the lake, the failure to identify them in the previous survey may have been through misidentification of samples, or as a consequence of selectivity in the sampling methods used, which were with an Ekman grab and hand dredge. Koşal Şahin and Yıldırım (2007) also sampled only from the main body of the lake, not from streams flowing into the lake, which could be another reason why they did not encounter *U. crassus*; this species was encountered exclusively in one stream (Table 2). It is notable that Koşal Şahin and Yıldırım (2007) encountered one bivalve species, *Sphaerium lacustre*, which was not recorded in the present study. Our failure to collect *S. lacustre*, which is a

Table 3. Mean values (±standard deviation) of length, width, height, weight, and parameters of the length–weight relationship of freshwater bivalve species in the Lake Sapanca basin.

Species	Length (mm)	Width (mm)	Height (mm)	Weight (g)	a	b
U. pictorum	69.57 (±7.12)	32.54 (±3.33)	22.39 (±2.71)	31.84 (±9.99)	0.0001	2.97
U. crassus	61.44 (±4.81)	33.01 (±1.91)	23.10 (±1.75)	31.05 (±6.33)	0.0012	2.47
A. anatina	68.18 (±8.05)	40.25 (±4.46)	19.15 (±2.60)	25.34 (±8.62)	0.0002	2.78
A. cygnea	106.83 (±1.31)	51.30 (±0.60)	33.53 (±2.59)	87.78 (±30.20)	0.0001	2.87
D. polymorpha	15.34 (±5.24)	8.31 (±2.98)	7.72 (±3.20)	0.84 (±1.10)	0.0004	3.21
A. woodiana	71.20	35.07	45.03	64.30	-	-

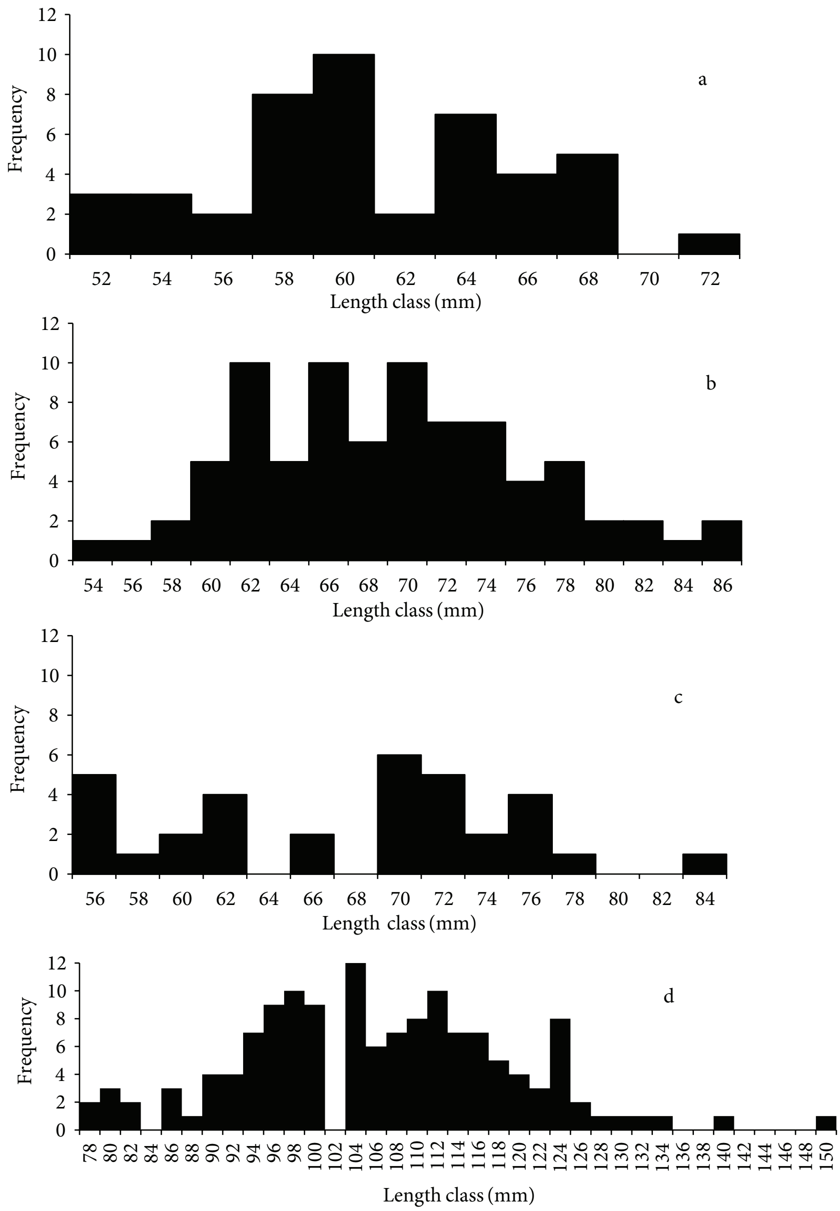

Figure 3. Length–frequency distribution of (a) *Unio crassus*, (b) *Unio pictorum*, (c) *Anodonta anatina*, (d) *Anodonta cygnea* in the Lake Sapanca basin.

small species (typically <10 mm maximum length), may also have been a result of the hand-searching sampling method used, which is inefficient for small specimens.

The relative abundance of native unionid species from the Lake Sapanca basin suggests that of the 2 *Unio* species *U. pictorum* was the most abundant species in the lake proper, while *U. crassus* was dominant in the Maşukiye River, which discharges into the lake. *U. crassus* has previously been reported as the dominant unionid species in lotic waters elsewhere (Kiss, 1994; İlhan et al., 2004). Overall, *A. cygnea* was the most abundant unionid throughout the entire lake basin, while *A. anatina* occurred at lower densities, but was encountered at all 3 sampling sites.

Despite occupying a distinct ecological niche in comparison with the unionid species, *D. polymorpha* was abundant in the lake. *D. polymorpha* is widely distributed throughout the Black Sea region (Son, 2007), and tends to be abundant where it is found (Gaygusuz et al., 2007; Vrtílek and Reichard, 2012). It has well-described negative impacts, such as obstructing pipelines (DSI, 2005) and fouling unionid mussels (Lewandowski, 1976; Schloesser et al., 1996). Although native to Turkey (e.g., May et al., 2006; Son, 2007), *D. polymorpha* also has negative effects in the Lake Sapanca basin. Most *D. polymorpha* collected during the present study were only found attached to the shells of unionids. *D. polymorpha* is known to compete with unionids for food particles (Baker and Hornbach, 2000) and to deform their shells by fouling (Schloesser et al., 1996). There has been a marked increase in the abundance of *D. polymorpha* between the time at which Koşal Şahin and Yıldırım (2007) conducted their sampling in 2000 and 2001 and the present study in 2007 and 2009. Further monitoring of the *D. polymorpha* population of the Lake Sapanca basin is needed to chart the increase of this species, and to intervene to protect the unionid populations if necessary.

U. crassus is considered an endangered species in Europe (Cuttelod et al., 2011), and is typically associated with clear water conditions (Zettler and Jueg, 2007). Indeed, occurrence of *U. crassus* was reported to be characterized by high chemical oxygen demand and high dissolved oxygen content (Bauer, 1988; Douda, 2010). This was supported by the fact that *U. crassus* is not present in lentic waters, where the oxygen content is more limited. The present study showed a strong association of this species with the nutrient-enriched Maşukiye River (Table 1). The distribution of *U. crassus* appears to be associated with lotic waters rather than with water with high nutrient loads (Kiss, 1994; İlhan et al., 2004), though our findings indicate that this species is at least tolerant of relatively low water quality. Köhler (2006) linked low survival of juvenile *U. crassus* to nitrate concentrations below 2 mg L^{-1}, and nitrate concentrations between 2 and 10 mg L^{-1} have been associated with limited or failed recruitment (Zettler and Jueg, 2007). This is in agreement with the situation in the Lake Sapanca basin, as *U. crassus* had a healthy population at nitrate concentrations between 0.4 and 0.6 mg L^{-1} in the Maşukiye River (Table 1). Thus, while high nitrate concentrations may be partially responsible for declines in *U. crassus*, it would appear not to be the only factor limiting this species.

The growth and size parameters of the bivalve species collected in the present study differ somewhat from those of other studies from this region (Akyurt and Erdoğan, 1993; Kara, 2004; Yalçın, 2006) and elsewhere in Europe (Negus, 1966) (Table 4). Both *Unio* species exhibited different growth rates, as might be anticipated from the different systems and habitats they occupy (Table 4). *U. pictorum* was found primarily in the lake, though it did occur in low densities in the river at site 1. *U. crassus* appeared to be more specialized in its habitat requirements and was exclusively encountered in the river habitat. The older age profile of *U. pictorum* relative to *U. crassus* fits the predicted negative relationship between growth coefficient (*k*) and lifespan (Metcalfe and Monaghan, 2003). A similar pattern was recorded for the Tisza River in Hungary, indicating that *U. crassus* has a faster growth rate but a shorter lifespan (Kiss, 1994). The slopes of the length–weight relationships indicated that *U. pictorum* had a greater weight gain per unit length in comparison with *U. crassus*. There are some comparable estimates of *b* for *U. pictorum* (Kiss, 1994; Yalçın, 2006) and *U. crassus* (Kiss, 1994) that report higher estimates than ours for these species, with the exception of Kiss (1994), who estimated a lower value of *b* for *U. pictorum* (Table 4). A previous study from England (Negus, 1966) on the age and growth of *U. pictorum* from the River Thames yielded a similar pattern of growth and lifespan. However, comparable works from

Table 4. Comparison of length at age (mm), maximum age and length, and slope (b) of the length–weight relationship for *U. pictorum*, *U. crassus*, and *A. cyngnea*.

	Length at age (mm)																
	1	2	3	4	5	6	7	8	9	10	11	12	13	Lifespan (years)	Max. length (mm)	b	Reference
U. pictorum	17	32	43	52	58	65	70	74	78	81	84	87	90	13	90	2.97	Present study
U. pictorum	-	38	53	64	72	72	78	80	81	-	-	-	-	9	81	-	Kara (2004)
U. pictorum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	3.16	Yalçın (2006)
U. pictorum	-	-	-	-	-	-	-	-	-	-	-	-	-	13	75	-	Negus (1966)
U. pictorum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.66	Kiss (1994)
U. crassus	20	34	47	58	66	70	74	-	-	-	-	-	-	7	74	2.47	Present study
U. crassus	19	29	42	52	53	58	61	-	-	-	-	-	-	7	61	-	Akyurt and Erdoğan (1993)
U. crassus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.82	Kiss (1994)
A. cygnea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	150	2.87	Present study
A. cygnea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	145	2.89	Başçınar (2003)

Turkey (Akyurt and Erdoğan, 1993; Kara, 2004) recorded contrasting growth rates (both slower and faster) with shorter lifespans (Table 4). The fact that these studies made estimates of age based on counting external growth bands on the shells, which has been considered an unreliable method for ageing due to underestimation of older specimens (Neves and Moyer, 1988), may explain some of these growth variations among studies. Notwithstanding the limitations of this method, it would appear that the growth and lifespan of *Unio* species are variable in Turkey, perhaps related to variation in temperature and water quality. Although *Anodonta* species were not aged in the present study because of their thin shells, our estimates of *b* for *A. cygnea* corresponded closely with those of Lake Çıldır in eastern Turkey (Başçınar 2003), though there were differences in maximum shell length (Table 4).

The occurrence of *A. woodiana* in the Lake Sapanca basin represents the first record for Turkish waters. This species may grow to a large size and is native to east and Southeast Asia (Watters, 1997). The rapid dispersal of this species has recently been recognized, with reports of its occurrence in Serbia (Paunovic et al., 2006), Poland (Kraszewski, 2007), the Czech Republic (Vrtílek and Reichard, 2012), and Romania (Popa et al., 2007) in the Danube basin. The initial introduction and spread of *A. woodiana* is thought to have occurred via the export of fish species such as *Carassius auratus*, *C. gibelio*, *Ctenopharyngodon idella*, and *Hypophthalmichthys molitrix* from eastern Asia for ornamental or biological control purposes (Watters, 1997). *Carassius* species in particular have spread extensively in Turkish waters (Tarkan et al., 2012) and *C. gibelio* is known to occur in Lake Sapanca (A.S. Tarkan, unpublished data), and is also distributed throughout the country, raising the possibility that *A. woodiana* may be more widespread in the region than this single case might suggest. A recent study on the invasion success of *A. woodiana* demonstrated that it is a successful invasive species tolerant of a wide range of environmental conditions (Douda et al., 2012). Monitoring of freshwaters in the vicinity of Lake Sapanca and elsewhere in western Turkey is warranted to measure the potential spread of this species.

In conclusion, the present study provides baseline data for future work on some ecologically important and common freshwater bivalves, some of which have not been previously studied in this respect in Turkey. These data facilitate more effective conservation measures for native mussel species, which are under threat of pollution, habitat degradation, and nonnative species introductions. All of these threats were apparent in the present study of Lake Sapanca and it is likely that bivalve populations face similar challenges elsewhere in Turkey, as well as in other areas of the Black Sea region in which these mussels are native. Further comprehensive studies focusing particularly on the ecology and habitat requirements of native and nonnative mussel species are warranted to better understand the conservation status of native mussels, not only in the Lake Sapanca basin, but also elsewhere in Turkey.

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