Abstract: Species composition and quantitative characteristics of the macrozoobenthos in the Kytai Lake were studied. During 2006–2012, 272 macrozoobenthic samples were collected from the littoral and sublittoral zones of the lake. A total of 66 species were identified in the collected samples. In 2006–2009, the number of species increased from the upper to the lower reaches of the lake, with all 66 species recorded in the latter. However, with increasing salinity and decreasing dissolved oxygen content, the total number of macrozoobenthic species dropped up to 12 in 2012, with the highest number observed at the lower reaches. The average annual macrozoobenthic abundance and biomass in the littoral zone (836 ± 33.08 ind. m$^{-2}$ and 19.7 ± 0.78 g m$^{-2}$, respectively) were comparable to those in the sublittoral zone (879 ± 35.16 ind. m$^{-2}$ and 9.19 ± 0.36 g m$^{-2}$, respectively). In summer 2012, during the period of maximum development, the macrozoobenthic abundance and biomass in the littoral zone were 346 ind. m$^{-2}$ and 3.26 g m$^{-2}$, respectively. The Shannon-Weaver diversity index reached 3.26 bits ind$^{-1}$ in the littoral zone in 2006–2008 and then decreased to 2.34 bits ind$^{-1}$ in 2010–2012. The Pielou evenness indices during these periods were 0.66 and 0.61, respectively. In August 2009–2012, the correlation coefficient between salinity and macrozoobenthic abundance was $-0.97$. In July 2006–2012, the correlation coefficient between dissolved oxygen content and macrozoobenthic biomass was 0.89, whereas that between dissolved oxygen content and macrozoobenthic species number was 0.95. Results of the correlation and multiple regression analyses revealed the key role of oxygen depletion in decreasing the macrozoobenthic species richness and its development. Principal component analysis indicated that the first two principal components, related to transparency, oxygen, salinity, and temperature, explained most of the total variance of the data. Transparency, oxygen, and temperature positively influenced the macrozoobenthic species composition and quantitative characteristics, whereas salinity exerted a negative influence.

Key words: lake macrozoobenthos, River Danube region, species composition, abundance, long-term changes, salinity

Introduction

The study of macrozoobenthos as a food source to fish and an indicator of the aquatic ecosystem states is important to hydrobiology and benthology (Konieczny & Daniszewsky 2013). Macroinvertebrates occupying the littoral zone of lakes may act as indicators of the anthropogenic load on aquatic ecosystems, which can disturb the ecosystem (Brodersen et al. 1998, White 2002). In addition, the commitment of some species to clean water has been observed in natural water bodies (Smit & van der Hammen 1992). Several studies have assessed the impact of eutrophication and oxygen depletion on the long-term dynamics of macrozoobenthic species composition and quantitative indicators. Most of these studies indicated that the macrozoobenthic species diversity decreases with increasing eutrophication in the lake (Gong & Xie 2011, Celik at al.
2010, Yousuf 2010) with macrozoobenthos often absent in the profundal zone (Ohtaka et al. 2006). Moreover, some studies assessed the changes in separate macrozoobenthic groups (Hirabayashi 2003, 2004). Under eutrophic conditions, the Oligochaeta was recorded as the dominant group, accounting for up to 99% of the total abundance and biomass (Szito 1997, Li et al. 2012). Comparison of the benthic communities of oligotrophic and eutrophic water bodies revealed a dominance of collector-filterers and filter-feeding bivalves in the former (Wang et al. 2007).

The Kytai Lake is located in the largest lake region of Ukraine, i.e., the Odessa region. This lake occupies an area of 60 km², with a volume of $102 \times 10^6$ m³ and a maximum depth of 5 m, as indicated by the mean long-term data (Shvebs & Igoshin 2003). The lake is connected to the Danube River by the Kofa Channel, through which approximately $17 \times 10^6$ m³ of flood water flows into the lake. In addition, the irrigation withdrawal from the lake is $47 \times 10^6$ m³. Small, highly mineralized rivers, such as the Kirghiz-Kytai and Aliyaga, flow into the upper part of the lake, albeit intermittently in summer. The salinity of these rivers can be as high as 7,600 mg L⁻¹. Of all the lakes of the Danube, the Kytai Lake exhibits the highest salinity (Denga & Medinec 2002, Dzhurtubaev et al. 2016) and the most unfavorable ecological conditions because of anthropogenic loading (Denga & Medinec 2002).

Lake pollution due to agricultural wastewater run-off from rice fields, leading to eutrophication, is of great importance. Agricultural wastewaters are one of the numerous anthropogenic factors contributing to the environmental decline of marine coastal and inland waters and collapse of fishery stocks worldwide (Galib et al. 2018). In the Kytai Lake, the annual fish capture declined from 332 tons in 2005 to 144 tons in 2009. In addition, protective dams were built along the Danube River in the second half of the 20th century, dividing the Kytai Lake into northern and southern sections corresponding to the upper and lower reaches, respectively. The construction of dams together with water withdrawal and eutrophication significantly altered the hydrological and hydrochemical regimes of the lake and consequently, its biota. A constant increase was observed in the salinity and decrease oxygen content in the lake (Dzhurtubaev et al. 2016). As a result, the number of macrozoobenthic species in the Kytai Lake was the lowest among the Danube lakes in 2006–2008 (Dzhurtubaev et al. 2012). Thus, it is important to study macrozoobenthos of the Kytai Lake to assess its ecological state.

The purpose of this study was to identify and analyze trends in the long-term dynamics of macrozoobenthic species composition and quantitative characteristics in the Kytai Lake in relation to changes in its hydrological and hydrochemical regimes.

Materials and Methods

Study site and sampling stations

Macrozoobenthos were sampled every two months at stations in the littoral and sublittoral zones of the Kytai Lake (Fig. 1) from February 2006 to December 2012. The fringe of the littoral zone was established as described by A. Tinnemann (cit. ex Timm & Timm 1986). Due to the shallow depth of the lake, the benthos beyond the littoral zone corresponded to those of the sublittoral zone with respect to their features. In the littoral zone, samples were collected from a depth of 0.5–0.7 m, whereas they were collected from up to 2.0 m in the sublittoral zone (the maximum depth of 5.0 m reported in literature was not observed). A backhoe dredge (0.02 m²), drag net, scraper, and 0.3 m-wide landing sieve (300-µm mesh size) were used for sampling. Bottom sections 1.0 m in length were trapped. Type of bottom sediments was assessed.

Sample collection, processing, and data analysis

Samples were collected and processed following the standard protocols (Romaneko 2006). Data processing and statistical analyses were performed using STAT GRIFIC 16.0 (Statgraphics Technologies, Inc.) and STATISTICA 6.0 (StatSoft) software packages. The long-term changes of species composition were assessed using Sorensen’s index.
Macrozoobenthos dynamics in the Kytai Lake

of species similarity. Cluster analysis was applied to visualize similarities in the macrozoobenthic species between years.

The macrozoobenthic biodiversity was evaluated using the Shannon-Weaver diversity index ($H'$) and Pielou evenness index ($J$) (Shannon & Weaver 1949, Protasov 2002). Dominant species were identified by the density index $p/b$, where $p$ and $b$ represent the frequency of species occurrence and its average biomass, respectively. This index indicates the significance of a given species in community. The water temperature was recorded, and its transparency was determined using a Secchi disk. Data on the oxygen content and salinity were provided by the Danube River Basin Water Resources Management (DRBWRM) in Izmail City.

**Results**

**Hydrological and hydrochemical parameters**

The average water transparency in spring, summer, and autumn was 0.45, 0.20, and 0.25 m, respectively, decreasing to 0.03 m during the summer bloom (Fig. 2). The average annual water temperature varied between 13.3 and 15.8°C, with the highest value of 34.0°C recorded in summer 2011–2012. In 2010, a high water temperature anomaly occurred in the nearshore seawaters of the Odessa region (Adobovskiy et al. 2012, Alexandrov et al. 2012). The lake froze in winter, and the water temperature under the surface ice ranged between 0.0 and 3.0°C.

The average annual dissolved oxygen content varied from 10.2 to 11.4 mg O$_2$ L$^{-1}$. The highest oxygen level (23.7 mg O$_2$ L$^{-1}$) was recorded in March 2012, and the lowest (6.1 mg O$_2$ L$^{-1}$) in August 2010 and July 2012 (Fig. 3). Oxygen saturation during the investigation ranged between 86% and 192%. In general, the lowest value for dissolved oxygen decreased from 6.9–7.7 mg O$_2$ L$^{-1}$ in 2006–2009 to 6.1–6.4 mg O$_2$ L$^{-1}$ in 2010–2012, indicating the deteriorating oxygen regime in the lake. Low oxygen levels were also recorded in some other water bodies of the Odessa region in 2010 (Adobovskiy et al. 2012).

The salinity of the lake presented a remarkable increase from 1,348 mg L$^{-1}$ in 1958 to 8,000–8,500 mg L$^{-1}$ in the summer and autumn of 2007 in the upper reaches of the lake (Fig. 3). The average annual salinity during our study ranged from 3.473 mg L$^{-1}$ in 2006 to 5.232 mg L$^{-1}$ in 2012. According to the DRBWRM data, the average annual salinity was 5.371 mg L$^{-1}$ in 2016. Due to the peculiar shoreline configuration, the southern part of the lake is subjected to greater freshwater influence of the Danube, whereas the northern part is affected by runoff from small rivers, namely, the Kirghiz-Kytai and Aliyaga. The salinity at the upper reaches of the lake was recorded as 6.000 and 6.360 mg L$^{-1}$ in the summers of 2011 and 2012, respectively.

Long-term dynamics of the chemical composition of wa-

![Fig. 2. Long-term dynamics of temperature and transparency in the Kytai Lake during July and August 2006–2012.](image)

![Fig. 3. Long-term dynamics of salinity and dissolved oxygen levels in the Kytai Lake during July and August 2006–2012.](image)

| Table 1. Chemical composition in the Kytai Lake (mg L$^{-1}$) in 2006–2012. |
|-----------------|-----------------|-----------------|
| Annual average values | Maximum |
|                   |          | Minimum |
| Ca$^{2+}$       | 155.9    | 191.0 (October, 2007) |
|                 | 112.6    | 83.6 (September, 2012) |
| Mg$^{2+}$       | 229.6    | 446.6 (October, 2012) |
|                 | 356.4    | 166.1 (January, 2008) |
| Na$^{+}$ + K$^+$| 677.3    | 1369.3 (October, 2012) |
|                 | 1113.7   | 559.1 (May, 2006) |
| Cl$^-$          | 563.1    | 1165.3 (October, 2012) |
|                 | 931.5    | 461.9 (January, 2008) |
| SO$_4^{2-}$     | 1661.9   | 2890.0 (September, 2012) |
|                 | 2357.5   | 1365.0 (May, 2006) |
| CO$_3^{2-}$     | 221.8    | 318.5 (December, 2012) |
|                 | 268.8    | 184.2 (January, 2008) |
ter presented an increase in the concentration of all minerals, except calcium (Table 1). The average annual concentrations of all minerals were the lowest in 2006 and the highest in 2012, except for calcium, which showed an opposite trend.

The sediment in the littoral zone was dominated by silty sand and grey mud. Small areas of silt, silty sand, and shell rock were observed in the region of Vasilevka village (site L4). Black mud was observed at sites L3 and L5. Gray and black mud dominated the sublittoral zone, whereas silted shell deposits were the most prevalent at the upper reaches of the lake.

**Macozoobenthic species composition**

A total of 66 macrozoobenthic species were identified during our study. In addition, four supraspecific taxa were identified, each of which was considered as one species (Tables 2 and A1). In the years with the highest species richness (2006–2009), all 66 species were recorded in the littoral zone, whereas only 43 species were observed in the sublittoral zone. The number of species increased from the upper to the lower reaches of the lake. During 2006–2009, 18, 36, and 66 macrozoobenthic species were recorded at the upper, middle, and lower reaches of the lake, respectively, in the littoral zone, whereas 11, 18, and 23 species, respectively, were recorded in the sublittoral zone.

The macrozoobenthic community was dominated by *Dreissena polymorpha* (Pallas, 1771), *Rhithropanopeus harrisi* tridentata (Maitland, 1879), *Unio pictorum* (L., 1758), *Cryptochironomus* gr. *defectus* (Kieffer, 1913), *Chironomus plumosus* (L., 1758), *Viviparus contectus* (Millet, 1813), and *Ischnura elegans* (V. Linden, 1823), based on the density index $\sqrt{np}$ (Table 3).

Cluster analysis of macrozoobenthic species similarity between years revealed the highest similarity among 2006–2009. The invertebrate species composition during these years formed a separate group and differed greatly from those of other years, as indicated (Fig. 4).

The numbers of the main macrozoobenthic species groups across the lakescape are presented in Table 4.

The number of macrozoobenthic species declined sharply in 2010 compared with that in 2009 (Fig. 5). For example, individuals of both the sponge *Spongilla lacustris* (L., 1758) and acarian *Acarina* sp. were absent in the samples, whereas *Bivalvia* spp. were not detected in 2011–2012 (Table 3). The decrease in the number of macrozoobenthic species may be attributed to the higher salinity in summer 2010 than in 2009. The correlation coefficient ($r$) between the average annual salinity and number of macrozoobenthic species was $r = -0.92$ during 2010–2012. However, this correlation was not significant (p-value $>0.05$) because of the limited number of samples analyzed. In addition, the sharp decline in the species richness in 2009, compared with that in 2010, may be attributed to the decrease in the dissolved oxygen level in summer 2010.

In 2006–2012, the hydrochemical parameters and macrozoobenthic quantitative indicators exhibited the highest values in summer. In addition, all identified species were recorded in July and August during these years. Thus, it is plausible to analyze the factors affecting the long-term dynamics of macrozoobenthic indicators during summer.

The factors influencing the macrozoobenthos, the most significant effect was observed for dissolved oxygen content in July 2006–2012. During this period, the correlation coefficient between the number of species and dissolved oxygen content was 0.95, whereas that between the macrozoobenthic biomass and dissolved oxygen content was 0.89 (Table 5). In addition, in August the correlation between the abundance of macrozoobenthos and salinity was also found ($R = -0.97$), but only during the period of increasing salinity in 2009–2012. All these correlations were statistically significant, with p-value $<0.05$. Thus, dissolved oxygen content and salinity were identified as the main factors influencing the macrozoobenthos during periods of their maximal values. The significant association between the macrozoobenthic biomass and dissolved oxygen content can be explained by the direct relationship between the biomass of benthic invertebrates and their oxygen consumption, whereas a similar correlation with abundance may not be evident because of their small size.

The number of annelid worm species was twice as low in 2011 compared with that in 2006–2009. In 2012, only two oligochaete species, i.e., *Potamotrix hammoniensis* (Michaelisen, 1901) and *Psammoryctides barbatus* (Grube, 1861), were recorded in the littoral and sublittoral zones of the middle and lower reaches of the lake, and the frequency of occurrence of each species was 30%. In 2006–2009, the isopod *Asellus aquaticus* (Linnaeus, 1758) was observed in the littoral zone of the middle and lower reaches of the lake, with an occurrence of 60% and 30%, respectively. All representatives of *Talitridae* gen. sp. inhabited the splash zone. The remaining amphipods were observed occupying the muddy sand in the littoral zone of the lower reaches, with the frequency of occurrence of 30–40% in spring and summer and 20% in autumn. In winter, the amphipods were observed only as individual specimens. These species were also recorded in the sublit-

| Taxa         | Number of species | 2006–2009 | 2010 | 2011 | 2012 |
|-------------|-------------------|-----------|------|------|------|
| Spongia     | 1                 | —         | —    | —    | —    |
| Annelida    | 13                | 8         | 6    | 2    |      |
| Crustacea   | 15                | 7         | 7    | 3    |      |
| Insecta     | 21                | 12        | 8    | 6    |      |
| Acarina     | 1                 | —         | —    | —    | —    |
| Gastropoda  | 10                | 8         | 2    | 1    |      |
| Bivalvia    | 5                 | 2         | —    | —    | —    |
| Total       | 66                | 37        | 23   | 12   |      |
Macrozoobenthos dynamics in the Kytai Lake

In 2012, *P. robustoides* was observed only in the lower reaches, along with the crab *R. h. tridentata* and the mysid *Paramysis intermedia*. The cumacean *Pterocuma pectinata* was recorded mainly on the silt-sandy bottom in the lower reaches of the lake (sites L4 and L5) in 2006–2011. The frequency of occurrence of *P. pectinata* decreased gradually from the initial value of 50% to 30% at the end of the study period. The total number of crustacean species was twice and five times as low in 2010–2011 and 2012, respectively, than that in 2006–2009.

In 2006–2009, all 21 insect species were observed in the littoral zone of the lower reaches of the lake, whereas 12 and 5 species were noted in the littoral zone of the middle and upper reaches, respectively. The latter five species included the larvae of the Odonata members *Platycnemis*

Table 3. The dominant species in the macrozoobenthic community in the silty sand of the littoral zone of the Kytai Lake based on the density index ($\sqrt{pb}$) during 2006–2012.

| Species                          | 2006–2009 | 2012     |
|---------------------------------|-----------|----------|
|                                 | p         | b        | $\sqrt{pb}$|
| *Dreissena polymorpha* (Pallas, 1771) | 35        | 8,06     | 16,8       |
| *Rhithropanopeus harrisi tridentata* (Maitland, 1879) | 50        | 5,23     | 16,1       |
| *Unio pictorum* (L., 1758)       | 20        | 6,15     | 11,1       |
| *Cryptochironomus gr. defectus* (Kieffer, 1913) | 90        | 0,78     | 8,4        |
| *Chironomus plumosus* (L., 1758) | 90        | 0,75     | 8,2        |
| *Viviparus contextus* (Millet, 1813) | 35        | 1,90     | 8,2        |
| *Ischnura elegans* (V. Linden, 1823) | 30        | 2,10     | 7,9        |
| *Planorbarius corneus* (L., 1758) | 35        | 1,52     | 7,3        |
| *Lymnaea stagnalis* (L., 1758)    | 35        | 1,50     | 7,2        |
| *Tanypus punctipennis* (Meigen, 1818) | 60        | 0,40     | 6,7        |
| *Paramysis intermedia* (Czern., 1882) | 60        | 0,68     | 6,4        |
| *Bithynia tentaculata* (L., 1758) | 65        | 0,13     | 5,3        |
| *Limnomysis benedeni* (Czern., 1882) | 50        | 0,50     | 5,0        |
| *Limnaea ovata* (Draparnaud, 1805) | 35        | 0,67     | 4,8        |
| *Potamotrix hammonisensis* (Michaelson, 1901) | 50        | 0,40     | 4,4        |
| *Psammorectides barbatu* (Grube, 1861) | 50        | 0,38     | 4,3        |
| *Dikerogammarus haemobaphes* (Eichw., 1841) | 70        | 0,27     | 4,3        |
| *Limnodrilus udekemianus* (Claparede, 1862) | 50        | 0,36     | 4,2        |
| *Chaetogammarus warpachowskyi* (G. Sars, 1894) | 70        | 0,26     | 4,2        |
| *Ophidionais serpentina* (O. F. Müller, 1773) | 40        | 0,30     | 3,5        |
| *Nais elinguis* (O. F. Müller, 1773) | 40        | 0,30     | 3,5        |
| *Asellus aquaticus* (L., 1758)    | 35        | 0,30     | 3,2        |
| *Dikerogammarus villosus* (Sowinsky, 1894) | 35        | 0,18     | 2,5        |
| *Pontogammarus robustoides* (G. Sars, 1894) | 35        | 0,18     | 2,5        |
| *Corophium curvispinum* (G. Sars, 1895) | 35        | 0,17     | 2,4        |
| *Aeschna grandis* (L., 1758)      | 20        | 0,21     | 1,9        |

Note: Only dominant and subdominant species are listed in the table; p is the occurrence of a species, %; b is its average biomass, g m$^{-2}$.

toral zone, except *Pontogammarus robustoides* (G. Sars, 1894). In 2012, *P. robustoides* was observed only in the lower reaches, along with the crab *R. h. tridentata* and the mysid *Paramysis intermedia*. The cumacean *Pterocuma pectinata* was recorded mainly on the silt-sandy bottom in the lower reaches of the lake (sites L4 and L5) in 2006–2011. The frequency of occurrence of *P. pectinata* decreased gradually from the initial value of 50% to 30% at the end of the study period. The total number of crustacean species was twice and five times as low in 2010–2011 and 2012, respectively, than that in 2006–2009.

In 2006–2009, all 21 insect species were observed in the littoral zone of the lower reaches of the lake, whereas 12 and 5 species were noted in the littoral zone of the middle and upper reaches, respectively. The latter five species included the larvae of the Odonata members *Platycnemis*
pennipes and Libellula quadrimaculata (Linnaeus, 1758) and of the Chironomidae members Tanypus punctipennis (Meigen, 1818), C. plumosus, and C. gr. defectus. The only insect species recorded in the sublittoral zone were T. punctipennis, C. plumosus, and Procladius ferrugineus (Kieffer, 1919). In 2011, only the chironomids C. plumosus, C. gr. defectus, and T. punctipennis and the odonates I. elegans, Coenagrion pulchellum (V. Linden, 1823), and Aeshna grandis (L., 1758) were noted in the middle and lower reaches of the lake, whereas seven odonate species were identified in 2006–2009. Only Sigara striata (L., 1758) and Cloeon dipterum (L., 1758) were observed as representatives of the Heteroptera and Ephemeroptera, respectively, in 2011. These species, except T. punctipennis and C. dipterum, were also observed at the lower reaches in 2012, albeit with a low occurrence and as individual specimens.

All 10 Gastropoda species were observed in the littoral zone of the lower reaches in 2006–2009, whereas only Bithynia tentaculata (L., 1758) was noted in the middle reaches. Individual specimens of V. contectus, B. tentaculata, Lymnaea stagnalis (L., 1758), and Planorbarius corneus (L., 1758) were observed in the sublittoral zone. V. contectus and Physa fontinalis (L., 1758) could not be observed in 2010, whereas P. corneus and Anisus vortex (L., 1758) were detected only at the lower reaches in 2011, where their occurrence did not exceed 20%. Individual specimens of P. corneus were recorded in the littoral zone of the upper reaches in 2012.

In 2006–2009, most of the identified Bivalvia species, except the invader Sinanodonta woodiana (Lea, 1834) (Straca et al. 2015), were observed regularly in the littoral zone, whereas U. pictorum and D. polymorpha were recorded in the sublittoral zone. Of these, D. polymorpha, .

---

**Fig. 4.** Cluster analysis of the macrozoobenthic species similarity in the Kytai Lake during 2006–2012

**Table 4.** The number of species belonging to the major macrozoobenthic taxa in the Kytai Lake in 2006–2009. LT=littoral zone, SLT=sublittoral zone.

| Taxon   | Upper part | Middle part | Lower reaches | Total |
|---------|------------|-------------|---------------|-------|
| Annelids | LT         | 7           | 9             | 13    | 29    |
|         | SLT        | 3           | 3             | 7     | 13    |
| Crustaceans | LT     | 4           | 11            | 15    | 30    |
|         | SLT        | 3           | 6             | 6     | 15    |
| Insects  | LT         | 5           | 12            | 21    | 38    |
|         | SLT        | 3           | 3             | 3     | 9     |
| Gastropods | LT      | 0           | 1             | 10    | 11    |
|         | SLT        | 0           | 3             | 3     | 6     |
| Total   | LT         | 16          | 33            | 59    | 108   |
|         | SLT        | 9           | 15            | 19    | 43    |

**Fig. 5.** The number of species and quantitative indicators of the macrozoobenthos in the Kytai Lake under changing dissolved oxygen and salinity in summer 2006–2012.

**Table 5.** The correlation coefficient matrix for the main hydrochemical parameters and macrozoobenthic quantitative indicators in the Kytai Lake in July 2006–2012.

| Variables | Oxygen | Salinity | Temperature | Transparency | Abundance | Biomass | Number of species |
|-----------|--------|----------|-------------|--------------|-----------|---------|------------------|
| Oxygen    | 1      | 0.177    | 0.477       | 0.740        | 0.683     | 0.890   | 0.948            |
| Salinity  | -0.177 | 1        | -0.151      | 0.598        | 0.444     | 0.090   | -0.030           |
| Temperature | 0.477 | -0.151   | 1            | 0.368        | 0.455     | 0.684   | 0.342            |
| Transparency | 0.740 | -0.598   | 0.368        | 1            | 1         | 0.448   | 1                |
| Abundance | 0.683 | -0.444   | 0.590        | 0.455        | 1         | 0.964   | 1                |
| Biomass   | 0.890 | 0.090    | 0.342        | 0.684        | 0.448     | 0.964   | 1                |
| Number of species | 0.948 | -0.030   | 0.384        | 0.720        | 0.500     | 0.964   | 1                |

Note: Significant Values in Bold
a common fouling species, caused noticeable fouling of both stones and cane stalks in the littoral zone. In 2010, only *Anodonta cygnea* and *D. polymorpha* were observed as individual specimens in the littoral zone of the lower reaches. In addition, *S. woodiana* was recorded only at the lower reaches of the lake.

**Macrozoobenthic abundance and biomass**

The macrozoobenthic quantitative parameters increased from the upper to the lower reaches of the Kytai Lake (Tables 6, 7). The successful establishment of benthic communities in the lake depends greatly on their taxonomic diversity. In 2006–2009, the Shannon-Weaver di-

| Parts of the lake | Upper reaches | Middle part | Lower reaches | Average values in the lake |
|-------------------|---------------|-------------|---------------|---------------------------|
| **Littoral**       |               |             |               |                           |
| **Seasons**        |               |             |               |                           |
| Winter             | 347±13.9      | 387±15.5    | 416±16.6      | 383±15.3                  |
|                    | 3.6±0.1       | 3.8±0.2     | 4.04±0.2      | 3.8±0.2                   |
| Spring             | 755±30.2      | 815±32.6    | 1124±44.8     | 898±36.9                  |
|                    | 11.3±0.5      | 13.0±0.5    | 20.3±0.8      | 14.9±0.8                  |
| Summer             | 760±30.0      | 970±37.6    | 1978±74.7     | 1236±47.4                 |
|                    | 16.6±0.6      | 24.0±0.9    | 55.1±2.2      | 31.9±1.3                  |
| Autumn             | 650±26.0      | 805±32.2    | 1070±42.8     | 841±33.6                  |
|                    | 15.7±0.6      | 22.9±0.9    | 45.1±1.8      | 28.2±1.1                  |
| Average            | 628±25.0      | 740±29.5    | 1140±44.4     | 836±33.1                  |
|                    | 11.7±0.5      | 15.8±0.6    | 31.2±1.2      | 19.7±0.8                  |
| **Sublittoral**    |               |             |               |                           |
| Winter             | 541±22.8      | 688±27.5    | 760±30.4      | 673±26.9                  |
|                    | 6.5±0.3       | 6.8±0.3     | 7.9±0.3       | 7.1±0.3                   |
| Spring             | 797±25.0      | 878±30.0    | 978±33.0      | 884±30.0                  |
|                    | 9.9±0.3       | 8.5±0.3     | 11.4±0.3      | 9.9±0.3                   |
| Summer             | 816±25.0      | 901±30.0    | 1481±50.0     | 1066±32.0                 |
|                    | 7.7±0.3       | 8.3±0.3     | 13.1±2.0      | 9.7±0.3                   |
| Autumn             | 823±25.0      | 843±27.0    | 1003±31.0     | 890±30.0                  |
|                    | 9.7±0.3       | 8.2±0.3     | 12.5±0.4      | 10.1±0.3                  |
| Average            | 752±28.8      | 828±33.1    | 1056±42.2     | 879±35.2                  |
|                    | 8.4±0.3       | 7.9±0.3     | 11.2±0.4      | 9.2±0.4                   |

Note: The numerator presents abundance, ind. m$^{-2}$, and the denominator presents biomass, g m$^{-2}$

| Parts of the lake | Years              | 2006–2009 | 2010     | 2011     | 2012     |
|-------------------|--------------------|-----------|----------|----------|----------|
| Upper reaches     | 760±30.0           | 1085±43.4 | 435±37.4 | 0        |          |
|                    | 16.6±0.6           | 3±0.1     | 3.9±0.2  | 0        |          |
| Middle part       | 970±37.6           | 1445±57.8 | 1190±47.6| 495±19.4 |          |
|                    | 24±0.9             | 9.2±0.4   | 6.1±0.2  | 2.8±0.1  |          |
| Lower reaches     | 1978±74.7          | 2439±97.6 | 1414±56.6| 561±22.3 |          |
|                    | 55.1±2.2           | 27.1±1.1  | 10.4±0.1 | 6.9±0.3  |          |
| Average in the lake| 1236±47.4         | 1656±66.2 | 1180±47.2| 352±13.8 |          |
|                    | 31.9±1.3           | 13.1±0.5  | 6.8±13.8 | 3.3±0.1  |          |

Note: The numerator presents abundance, ind. m$^{-2}$, and the denominator presents biomass, g m$^{-2}$
Fig. 6. Correlation biplot diagram based on the principal component analysis (PCA) of the physicochemical variables and macrozoobenthic biomass of the Kytai Lake.

The ecological condition of the water catchment area is of great importance, without which the ecological state of the lake cannot be estimated or predicted (EP (European Parliament) & CEU (Council of European Union 2000)).

The results of previous investigations conducted in the Danube lakes, including the Kytai Lake, suggest that the macrozoobenthic species occurring here are widespread in the Danube region, both in the Danube River and the Danube Delta, lakes, and branches (Mood et al. 1994, Vadineanu et al. 2000, Popescu-Marinescu 2004, 2005, Humpesch & Fels 2005, Grabowski & Pešić 2007, Martinović-Vitanović 2007, Arslan et al. 2016, Mimier et al. 2017, Tarrats et al. 2017). For example, 52 species of oligochaetes have been identified during faunal surveys in the Danube River, of which 30% are commonly occurring species in this river, its lakes and tributaries (Adamek et al. 2013, Atanacković et al. 2013). The distribution of the invader bivalve S. woodiana extends up to Serbia.

The macrozoobenthic species composition of the Kytai Lake did not differ significantly among the seasons. In contrast, the abundance and biomass of the macrozoobenthos varied significantly among the seasons, yielding the highest values in summer. Of the macrozoobenthic species, the oligochaetes (up to 68.0% of the total abundance in the littoral zone in winter), chironomids (up to 44.2% in the sublittoral zone in summer), amphipods, and the crab R. h. tridentata were the most abundant. In terms of biomass, bivalve mollusks (D. polymorpha), chironomids (larvae), oligochaetes, and crabs dominated in different years, accounting for up to 37.5%, 34.0%, 20.0%, and 41.6%, of the total biomass, respectively.

A decrease in the macrozoobenthic biomass did not always coincide with decreased macrozoobenthic abundance. The average macrozoobenthic biomass declined by 2.4 times, whereas the average macrozoobenthic abundance increased by 1.3 times in 2010 compared with those in 2006–2009. The increase in macrozoobenthic abundance occurred due to an increase in the number of small-sized oligochaetes and several other species, whereas the decrease in macrozoobenthic biomass could be attributed to a reduction in the abundance of mollusks with relatively high individual masses. In 2012, under the highest salinity level, the average abundance and biomass of benthic invertebrates in summer were about 350 ind. m⁻² and 3.26 g·m⁻², respectively. No living benthic organisms were detected at the upper reaches during this period.

In 2006–2009, the mollusks D. polymorpha, U. pictorum, V. contectus, P. corneus, and L. stagnalis; larvae of
the chironomids *C. gr. defectus* and *C. plumosus*; mysids *P. intermedia* and *L. benedeni* (Czern., 1882); and dragonfly *I. elegans* dominated the zoobenthos on the silty sand in the littoral zone, as indicated by the density index $\sqrt{PB}$. In 2012, the density index declined sharply due to the decrease in the biomass and reduced frequency of species occurrence. In addition, the dominant species exhibited a shift from the species *D. polymorpha*, *U. pictorum*, *C. gr. defectus*, *C. plumosus* to the species *Rh. harrisi tridentata*, *I. elegans*, *C. pulchellum*, *A. grandis*. Notably, the highest density index value of 16.8 corresponded to *D. tridentata* in 2006–2009; it was not recorded among the dominant species in 2012. The crab *R. h. tridentata*, which was in 2006–2009 the second most-dominant species with a density index of 16.1, was the most dominant in 2012; however, its density index was as low as 5.0 during this period due to a decrease in its abundance and biomass.

The most remarkable transformations of the Kytai Lake macrozoobenthos took place from 2009 to 2012. Extreme values of dissolved oxygen and salinity fixed in summer caused significant high correlation between above-mentioned hydrochemical parameters and some indicators of macrozoobenthos, which were recorded in this period. Similar relationships between species richness and dissolved oxygen caused by eutrophication were observed earlier (Gong & Xie 2011). The negative influence of oxygen depletion on the macrozoobenthos in summer was also observed by Szito (1997). In July 2006–2012, the correlation coefficient between the macrozoobenthic biomass and dissolved oxygen concentration was 0.89 (Table 5). The higher species diversity observed in the littoral zone than in the sublittoral zone may be attributed to the larger area occupied by silty sand sediments in the littoral zone, whereas the predominance of mud promoted oxygen depletion in the sublittoral zone, leading to a decrease in species richness. The upper reaches are characterized by greater mud accumulation compared with the lower reaches, which results in lower species diversity. A sharp increase was observed in salinity during the summers of 2009–2012; therefore, the impact of salinity on the macrozoobenthos should be analyzed during the period of changing salinity. The correlation coefficient between the macrozoobenthic abundance and salinity was the highest during the period of the sharp increase in salinity, in August 2009–2012 ($r = -0.97$, $p \leq 0.05$). Similar main factors affecting macrozoobenthos abundance in Lake Qarun (Egypt) were noted before (Shadrin et al. 2016). Discussing the combined effect of oxygen and salinity on aquatic ecosystems, it is important to remember that salinity not only reduces the solubility of oxygen but as usually leads to an increase of temperature (Shadrin & Anufrieva 2018; Shadrin et al. 2019).

Multiple regression analysis of the macrobenthic indices and water quality parameters during July and August 2006–2012 revealed a significant cumulative effect of salinity and oxygen on macrozoobenthic abundance (p-value=0.16) and biomass (p-value=0.17). The oxygen level exerted a significant stimulatory effect (p-value=0.05) on both abundance and biomass of the macrozoobenthos. Thus, salinity decreased the combined effect of oxygen and salinity, which could be attributed to the delayed effect of salinity on the quantitative indicators of the macrozoobenthos compared with the influence of oxygen, which determines the level of metabolism. Oxygen content plays a leading role in the determination of macrozoobenthos species diversity and quantitative development, especially in conditions of the sublittoral zone and upper reaches of the Kytai Lake.

PCA was used to assess the most important factors explaining the variation in the environmental data set. PCA is an indirect ordination technique for obtaining a low-dimensional representation of multivariate data, such that the data can be presented visually in a two-dimensional PCA correlation biplot. PCA confirmed the stimulatory role of oxygen and the inhibitory effect of salinity on both species composition and quantitative characteristics of the macrozoobenthos. In addition, salinity was the main parameter (with a loading of 0.8) in the second principal component and explained 23.7% of the total variance in the data. Thus, PCA showed that of the physiochemical parameters, only salinity was negatively correlated with the species composition and quantitative characteristics of the macrozoobenthos.

Thus, the environmental condition prevalent in the Kytai Lake may serve as a model for macrozoobenthic dynamics in water bodies subjected to the combined effect of decreasing dissolved oxygen content and increasing water salinity. A significant reduction was observed in the macrozoobenthic species composition and quantitative characteristics of the Kytai Lake in 2009–2012. However, based on the Shannon-Weiner and Pielou indices, the existing species indicate the relative diversity and stability of the benthic communities in the lake.

### Acknowledgements

Data analysis and manuscript writing was partly supported (N. Shadrin and V. Yakovenko) by of the state assignment of A.O. Kovalevsky Institute of Biology of the Southern Seas of RAS (No. AAAA-A19-119100790153-3). The authors are grateful to Ms. T. Urbanskaya (DRB-WRM) for providing the hydrochemical data for the Kytai Lake and to Dr. V. Makovskiy and Dr. Yu. Sonzhak (Institute of Hydrobiology NAS of Ukraine) for their help in identifying the oligochaetes and chironomid larvae. The authors thank Dr. M. Krivega (USA) for improving the language of the manuscript.

### References

Adamek Z, Zahradkova S, Jurajda P, Barnardova J, Juraidova Z, Janač MD, Nemejcova D (2013) The response of benthic mac-
rionvertebrate and fish assemblages to human impact along the lower stretch of the rivers Marava and Dyje (Danube basin, Czech Republic). Croatian Jour Fish 71: 93–115.

Alexandrov BG, Terenko LM, Nesterova BA (2012) The first case of a bloom of *Nodularia spumigena* Mertens ex Bornet et Flahault in the Black sea. Algologia 22: 152–165.

Adobovskiy VV, Alexandrov BG, Bogatova YuI, Bolshakov VN, Dotsenko SA, Govorin IA, Zotov AB, Minicheva GG, Terenko YaM, Khomova YeS, Shatsilillo YeL (2012) Ecological consequences of hydrometeorological anomalies in nearshore zone of the Odessa region (2009–2011). Black Sea Ecol Bull 43: 112–126.

Atanacković AD, Šporka F, Csányi B, Vasiljević BM, Tomović JM, Paunović MM (2013) Oligochaeta of the Danube River—a faunistical review. Biologia Sect Zool 68: 269–277.

Arslan N, Kökçü CA, Mercan D (2016) Aquatic Oligochaetes Biodiversity in Turkey: example of Lake Sapanca with Application of the Biotic Indices. Int Jour Adv Chem Eng Biol Sci 3: 27–31.

Brodersen KP, Dall PC, Lindegaard C (1998) The fauna in the upper stony littoral of Danish lakes: macroinvertebrates as trophic indicators. Freshw Biol 39: 577-592.

Celik K, Akbulut N, Akbulut A, Ozatli D (2010) Macrozoobenthos of Lake Uluabat, Turkey, related to some physical and chemical parameters. Pan-Am Jour Aquat Sci 5: 520–529.

Denga YuM, Medinets VI (2002) Hydrochemical regime and quality of the Danube lakes. Odessa National University Herald Ser Ecolog 7(2): 17–25. (in Russian with English abstract)

Dzhurtubaev MM, Zamorov VV, Dzhurtubaev YuM (2012) Modern state of the Danube lakes of the Odessa region. Hydrobiol Jour 48(6): 36–42. (in Russian with English abstract)

Dzhurtubaev MM, Urbanskaya TV, Dzhurtubaev YuM (2016) Long-term dynamics of hydrological and hydrochemical indicators of the Kytai Lake (Odessa region, Ukraine). Dniprope-etrovsk National University Herald 24(2): 184–191. (in Russian with English abstract)

EP (European Parliament) & CEU (Council of European Union) (2000) Directive 2000/60/EC of the European Parliament and of the Council of 23 October, 2000 establishing a framework for Community action in the field of water policy. Official Jour Eur Communities 43(327): 1–73.

Galib SM, Mohsin ABM, Parvez MT, Lucas MC, Chaki N, Arnob SS, Hossain MI, Islam MN (2018) Municipal wastewater can result in a dramatic decline in freshwater fishes: a lesson from a developing country. Knowl Manag Aquat Ecosyst 419(37): 1–12.

Gong Z, Xie P (2001) Impact of eutrophication on biodiversity of the macrozoobenthos community in a Chinese shallow lake Jour Freshw Ecol 16: 171–178.

Grabowski M, Pešič V (2007) New data on the distribution and checklist of fresh—and brackish water Gammaridae, Ponto-gammaridae and Behningiellidae (Amphipoda) in Bulgaria. Lauterbornia 59: 53–62.

Hirabayashi K, Hanazato T, Nakamoto N (2003) Population dynamics of *Propodiobdella akamusi* and *Chironomus plumosus* (Diptera: Chironomidae) in Lake Suwa in relation to changes in the lake's environment. Hydrobiologia 506–509: 381–388

Hirabayashi et al. 2004 Progress of eutrophication and change of chironomid fauna in Lake Yamanakako, Japan. Limnology 5: 47–53.

Humpesch U, Fesl Ch (2005) Biodiversity of macrozoobenthos in a large river, the Austrian Danube, including quantitative studies in a free–flowing stretch below Vienna: a short review. Freshw Forum 24: 3–23.

Konieczny R, Daniszewski P (2013) Using macrozoobenthos to assess the ecological condition of the Starzyc Lake (North-West Poland). Jour Ecol Eng 14(4): 1–8.

Martinović-Vitanovic V, Djikanovic V, Odradovic S, Kalafatic V (2007) Composition and structure of the Oligochaeta (Annelida) in benthic assemblages of the Danube River in the Belgrad region during May and October of 2004. Ecologia (Bratislava). 26: 174–186.

Mimier D, Godzich M, Zbikowski J (2017) Macrozoobenthos structure in a temperate acid oligotrophic lake. Ecol Questions 27: 97–107.

Moog O, Ronar M, Humpesch UH (1994) The macrozoobenthos of the River Danube in Austria. Lauterbornia 15: 25–51.

Li L, Xiong J, Xiao B, Song L, Xie Z (2012) Dynamics of macrozoobenthos assemblages in the Fubao Bay of Lake Dianchi and their relation to organic pollutants. Afr Jour Biotech 11: 11830–11837.

Ohtaka et al. (2006) Disappearance of deep profundal zoobenthos in Lake Ikeda, southern Kyushu, Japan, with relation to recent environmental changes in the lake. Limnology, 7: 237–242.

Popescu-Maresincu V. (2004) Taxonomic composition and numerical density and biomass of the zoobenthos in the Dam lake Iron gates I (Romanian section) in 2002. Rom Jour Biol-Zool 49: 59–72.

Popescu-Maresincu V. (2005) Taxonomic composition, numerical density and biomass of the zoobenthos in the Dam lake Iron gates II (Romanian section) in 2002. Rom Jour Biol-Zool 50: 16–23.

Protasov AA (2002) Biodiversity and its Estimation. Conceptualizing Diversicology. Akademperiodika, Kyiv, 105 pp. (in Russian with English abstract)

Romanenko VD (ed.) (2006) Methods of Hydroecological Studies of Surface Waters. Logos, Kyiv 408 pp. (in Ukrainian with English abstract)

Shadrin N, Anufriieva E (2018) Ecosystems of hypersaline waters: structure and trophic relations. Zhurnal Obschei Biol 79: 418–427 (in Russian)

Shadrin NV, EL-Shabrawy GM, Anufriieva EV, Goher ME, Ragab E (2016) Long-term changes of physicochemical parameters and benthos in Lake Qarun (Egypt): Can we make a correct forecast of ecosystem future? Knowl Manag Aquat Ecosyst 417(18): 1–11.

Shadrin N, Kolesnikova E, Revkova T, Latushkin A, Chepyzhenko A, Dyakov N, Anufriieva E (2019) Macrostructure of benthos along a salinity gradient: the case of Sivash Bay (the Sea of Azov), the largest hypersaline lagoon worldwide. Jour Sea Res 154: 101811.

Shannon CE, Weaver W (1949) The Mathematical Theory of Communication. The University of Illinois Press, Illinois, 117 pp.

Shvebs GI, Igoshin MI (2003) Catalog of Rivers and Water Bod-
ies of Ukraine. Astroprint, Odessa, 389 pp. (in Ukrainian with English abstract)

Straca M, Špaček J., Pařil P. (2015) First record of the invasive polychaete *Hypania invalida* (Grube, 1960) in the Czech Republic. Bioinv Rec 4: 87–90.

Szito A. (1997) Macrozoobenthos biomass in the backwaters with different water supply. In: The Cris/Körös Rivers and Valleys. Tiscia Monograph Series 2, Szolnok–Szeged–Târgu Mureş, Hungary–Romania (eds. Sárkány-Kiss E, Bács S, Markó B). Ecology University of Szeged, Szeged, pp. 221–229.

Smit H, van der Hammen H (1992) Water mites as indicators of natural aquatic ecosystems of the coastal dunes of the Netherlands and northeastern France. Hydrobiologia 231: 51–64.

Tarrats P, Cañedo-Argüelles M, Rieradevall M, Prat N (2017) Chironomid communities as indicators of local and global changes in an oligotrophic high mountain lake (Enol Lake, Northwestern Spain). Jour Limnol 76: 355–365.

Timm VYa, Timm TE (1986) On the terminology of lake benthal. Hydrobiol Jour 22(6): 40–45. (in Russian with English abstract)

Vadineanu A, Cristofor S, Ignat Gh, Ciubuc C, Rîşnoveanu G, Bodescu F, Botnariuc N. (2000) Structural and functional changes within the benthic communities of Danube Delta lakes. Verh Internat Verein Limnol 27: 2571–2576.

Yousuf AR, Bhat FA. (2010) The ecology of macrozoobenthos in Shallabugh wetland of Kashmir Himalaya, Indian Jour Ecol Nat Environ 2(5): 84–91.

Wang et al. (2007) Macrozoobenthic community of Poyang Lake, the largest freshwater lake of China, in the Yangtze floodplain. Limnology 8: 65–71.

White J. (2002) The potential use of littoral macroinvertebrates in the assessment of lake water quality. Verh Internat Ver Limnol 27: 3527–3532.

Table A1. List of collected species in Kytai Lake.

| Taxa          | Years  | First Identified in the Lake | The Ponto-Caspian complex species |
|---------------|--------|------------------------------|----------------------------------|
|               | 2006–2009 | 2010 | 2011 | 2012 | 6 | 7                       |
| **Spongia**   |        |      |      |      |   |                         |
| Spongillidae  | +      | −    | −    | −    | − | +                       |
| *Spongilla lacustris* (Linnaeus. 1758) | | | | | | |
| **Polychaeta**|        |      |      |      |   |                         |
| Ampharetidae  | +      | −    | −    | −    | + |                         |
| *Hypania invalida* (Grube, 1860) | | | | | | |
| *Hypaniola kowalewskii* (Grimm, 1887) | | | | | | |
| **Oligochaeta**|        |      |      |      |   |                         |
| Naididae      | +      | −    | −    | −    | + |                         |
| *Dero digitata* (O. F. Müller, 1773) | | | | | | |
| *Ophidonais serpentina* (O. F. Müller, 1773) | | | | | | |
| *Nais elinguis* (O. F. Müller, 1773) | + | + | + | − | + |                         |
| Tubificidae   | +      | +    | +    | +    | + |                         |
| *Potamotrix hammoniesis* (Michaelsen, 1901) | | | | | | |
| *Psammoryctides albicola* (Michaelsen, 1901) | | | | | | |
| *P. barbatus* (Grube, 1861) | + | + | + | + | + |                         |
| *Limnodrilus udekenianus* (Claparede, 1862) | | | | | | |
| *Tubifex tubifex* (O. F. Müller, 1773) | + | − | − | − | + |                         |
| Hirudinea     | +      | −    | −    | −    | + |                         |
| Piscicolidae  | +      | −    | −    | −    | + |                         |
| *Piscicola geometra* (Linnaeus, 1761) | | | | | | |
| Glossiphoniidae | + | + | ? | − | − |                         |
| *Glossiphonia complanata* (Linnaeus, 1758) | | | | | | |
| Erpobdellidae | +      | +    | +    | −    | + |                         |
| *Erpobdella octoculata* (Linnaeus, 1758) | | | | | | |
| Isopoda       | +      | +    | −    | −    | − |                         |
| Asellidae     | +      | −    | −    | −    | − |                         |
| *Asellus aquaticus* (Linnaeus, 1758) | | | | | | |
| Amphipoda     | +      | −    | −    | −    | − |                         |
| Gammaridae    | +      | −    | −    | −    | − |                         |
| *Dikerogammarus haemobaphes* (Eichw., 1841) | | | | | | |
| Taxa | Years | 2006–2009 | 2010 | 2011 | 2012 | First Identified in the Lake | The Ponto-Caspian complex species |
|------|-------|-----------|------|------|------|-------------------------------|---------------------------------|
| D. villosus (Sowinskyi, 1894) | + | + | + | − | + | + |
| Pontogammarus robustoides (G. Sars, 1894) | + | + | + | + | + | + |
| Chaetogammarus warpachowskyi (G. Sars, 1894) | + | + | + | − | + | + |
| Corophiidae | + | + | + | − | + | + |
| Corophium curvispinum (G. Sars, 1895) | + | − | − | − | + | + |
| Talitridae | + | − | − | − | + | + |
| Talitridae gen. sp. | + | − | − | − | + | + |
| Tanaidacea (Anisopoda) gen. sp. | + | − | − | − | + | + |
| Mysidacea | + | − | − | − | + | + |
| Cumacea | + | − | − | − | + | + |
| Pseudocumidae | + | − | − | − | + | + |
| Pterocuma pectinata (Sowinskyi, 1893) | + | + | + | + | + | + |
| Decapoda | + | + | + | + | + | + |
| Xanthidae | + | + | + | + | + | + |
| Rhithropanopeus harrisi tridentata (Maitland, 1879) | + | + | + | + | + | + |
| Odonata | + | + | + | + | + | + |
| Coenagrionidae | + | + | + | + | + | + |
| Ischnura elegans (V. Linden, 1823) | + | − | − | − | + | + |
| L. pumilio (Charpentier, 1825) | + | + | + | + | + | + |
| Cenagrion pulchellum (V. Linden, 1823) | + | − | − | − | + | + |
| C. scitulum (Rambur, 1842) | + | − | − | − | + | + |
| Platycnemidae | + | + | − | − | + | + |
| Platycnemis pennipes (Pallas, 1771) | + | + | + | + | + | + |
| Aeschnidae | + | + | + | + | + | + |
| Aeschna grandis (Linnaeus, 1758) | + | + | + | + | + | + |
| Libellulidae | + | + | − | − | + | + |
| Libellula quadrimaculata (Linnaeus, 1758) | + | + | + | + | + | + |
| Ephemeroptera | + | + | + | + | + | + |
| Baetidae | + | + | − | − | + | + |
| Cloeon dipterum (Linnaeus, 1758) | + | + | − | − | + | + |
| Heptageniidae | + | + | − | − | + | + |
| Heptagenia sp. | + | + | − | − | + | + |
| Heteroptera | + | + | − | − | + | + |
| Nepidae | + | + | − | − | + | + |
| Ranatra linearis (Linnaeus, 1758) | + | + | + | + | + | + |
| Corixidae | + | + | + | + | + | + |
| Sigara striata (Linnaeus, 1758) | + | + | − | − | + | + |
| Pleidae | + | + | − | − | + | + |
| Plea minutissima (Leach, 1817) | + | + | − | − | + | + |
| Coleoptera | + | + | − | − | + | + |
| Dytiscidae | + | + | − | − | + | + |
| Dytiscus marginalis (Linnaeus, 1758) | + | + | − | − | + | + |
Table A1. Continued.

| Taxa | Years | First Identified in the Lake | The Ponto-Caspian complex species |
|------|-------|-----------------------------|----------------------------------|
|      | 2006–2009 | 2010 | 2011 | 2012 | 6 | 7 |
| Diptera | | + | + | + | − | |
| Chironomidae | | | | | | |
| Tanypus punctipennis (Meigen, 1818) | | + | − | − | − | |
| Procladius ferrugineus (Kieffer, 1919) | | + | − | − | − | |
| Cricotopus gr. silvestris (Fabricius, 1794) | | + | − | − | − | |
| Cryptochironomus gr. defectus (Kieffer, 1821) | | + | + | + | + | |
| Chironomus plumosus (Linnaeus, 1758) | | + | + | + | + | |
| Polyplecton gr. nubeculosum (Meigen, 1818) | | + | − | − | − | |
| Trichoptera | | + | − | − | − | + |
| Hydroptilidae | | | | | | |
| Tricholeiochiton fagesii (Guinard, 1879) | | + | − | − | − | + |
| Phryganeidae | | | | | | |
| Phryganea bipunctata (Retzius, 1783) | | + | − | − | − | + |
| Acrina (Hydracarina) | | + | − | − | − | + |
| Acrina gen. sp. | | + | − | − | − | + |
| Gastropoda | | + | − | − | − | + |
| Viviparidae | | | | | | |
| Viviparus contectus (Millet, 1813) | | + | + | − | − | |
| Bithyniidae | | | | | | |
| Bithynia tentaculata (Linnaeus, 1758) | | + | + | − | − | |
| B. leachi (Sheppard, 1823) | | + | + | − | − | |
| Lymnaeidae | | + | + | − | − | |
| Lymnaea stagnalis (Linnaeus, 1758) | | + | + | − | − | |
| L. auricularia (Linnaeus, 1758) | | + | + | − | − | |
| L. palustris (O. F. Müller, 1774) | | + | + | − | − | |
| L. ovata (Draparnaud, 1805) | | + | + | − | − | |
| Physidae | | + | + | − | − | |
| Physa fontinalis (Linnaeus, 1758) | | + | + | − | − | + |
| Planorbidae | | + | + | − | − | + |
| Unio pictorum (Linnaeus, 1758) | | + | + | − | − | |
| Anodonta cygnea (Linnaeus, 1758) | | + | + | − | − | |
| Sinanodonta woodiana (Lea, 1834) | | + | + | − | − | + |
| Carididae | | + | − | − | − | + |
| Hypanis pontica (Eichw., 1835) | | + | + | − | − | + |
| Dreissenidae | | + | + | − | − | + |
| Dreissena polymorpha (Pallas, 1771) | | + | + | − | − | |

Total 66 37 23 12 8 14