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ORIGINAL ARTICLE

The invaders as natural biondicators using the example invasive amphipod *Gmelinoides fasciatus* (Stebbing, 1899) in the Moscow River Basin: the suggestion of *G. lacustris/G. fasciatus* bioindication pair

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The article presents data on the study of the diversity of crustacean communities in the Moscow-river basin. Two most common are two species of amphipods, invasive species *Gmelinodes fasciatus* and the native species *Gammarus lacustris*, were detected and studies during the study. However, the number of one of the most important bioindicator species of crustaceans, *Asellus aquaticus* found in our samples is insufficient for quantitative conclusions. At the same time, population of *G. fasciatus* can be characterized as stable at all studied stations and the species can be used as bioindicator of the natural condition of the river flowing within the Moscow City. The species seems to be significantly less sensitive to environment conditions and especially anthropogenic pollution than the native amphipod species *G. lacustris* and can successfully replace *A. aquaticus* as bioindicator species in the area where the latter species is absent. Thus, a new bioindicator pair *Gammarus lacustris / Gmelinoides fasciatus* is suggested for using in estimation water pollution In European part of the Russian Federation and adjacent areas.
Key words: invasion; amphipods; anthropogenic pollution; bioindication; river Moskva; Moscow

Introduction

Bioindication is one of the specific methods for monitoring of the environment determining the degree of pollution of natural environments with the help of living organism-bioindicators. One of the most important characteristics of bioindicator organism is the fact that such organisms should not be too sensitive and too resistant to pollution agents as well as possess a long life cycle and easily estimated population characteristics. It is also important that such organisms are widely distributed and each species should be restricted to the specific habitat (e.g. Zenkevich, 1979; Zhukova and Mastitsky, 2014).

Crustaceans, and in particular amphipods, are natural bioindicators of environment usually used as bioindicators in various aquatic systems. The abundance and diversity of benthic forms of crustaceans can be used as a bioindicator of physical parameters and suitability of the environment in fresh ecosystems (Adams 2002; Yoder and Rankin 1998; Schramm et al., 1999; Kammenga et al. 2000). It is shown that the presence of chemical oxides and even separate ions in environment may significantly affects the distribution of these crustaceans. For example, dissolved oxygen concentration and ammonium (NH4+) concentration are important abiotic factors that determine the distribution of amphipods and isopods in aquatic ecosystems (Zenkevich, 1979; Meijering, 1972, 1985, 1989). There is well known *Gammarus pulex* / *Asellus aquaticus* bioindication ratio: *A. aquaticus* usually dominates in systems influenced by anthropogenic press, whereas *G. pulex* is recording in undisturbed environments with sufficient oxygen content only. The other amphipod species *G. fasciatus* has also been used to study the distribution of metals inside the various organs and tissue of crustacean. The highest concentration of Cd and Cu was found in hepatopancreas of the species, the highest concentration of Mn and Ni - in the gut and digestive system while constant concentrations in all organs were shown for Zn in *G. fasciatus* as well as most of Pb concentration was associated with the exoskeleton. Purification almost did not change the concentrations of Cd, Cu and Zn in the body, whereas the amount of Pb greatly decreased. In addition, the intestinal contents influenced the concentrations of Cr, Fe, Mn, Ni and Pb (Amyot et al., 1999). At the same time, a series of experiments on feeding of *G. pulex* diet showed that the food diet of *Gammarus pulex* also depends on the accumulation of Mg/Fe and this effect could not be explained by the absorption of these elements separately. Moore et al. (1991) studied the relationship between food ration and the growth rates of *Orchestia*

gamarellus and it was shown that the growth and the birth rate of crustaceans significantly decreased after a reduction in the dietary intake. Thus, these population characteristics can be used as mediated parameters, easily measurable and inexpensive for bioindication of the habitats.
The Baikal amphipod *Gmelinoides fasciatus* (Stebbing, 1899) (Amphipoda: Gammaroidea: Micruropodidae) was introduced to some areas of the northwestern part of Eurasia to increase the quantity and quality of fish food reserve of natural basins (Pirozhnikov, 1955; Ioffe, 1975). The biology of this amphipod species is fully consistent with the requirements for introduced species – possibility to create high biomass and introduction into the structure of new ecosystems in a relatively short time. The average number of specimens of *G. fasciatus* on silted sands in Lake Baikal is about 125 specimens per sq.m. (Kozhov, 1947); in the remaining lakes *G. fasciatus* the number can differ from 63 specimens per sq.m. (Lake Nalim) to 630 specimens per sq.m. (Lake Chernyavoye) (Pirozhnikov, 1955). At certain periods of life (spawning migration) amphipods can form clusters of 10,000-20,000 specimens per sq.m. (Beckman, 1962). The species is regarded as omnivorous, usually an active consumer of algae and detritus. The most complete data on the distribution and ecology of *G. fasciatus* are presented in publications of Bekman (1962), Mickiewicz (1976, 1978, 1980, 1987) and Matafonov (2003, 2005). The introduction of the species into the Moscow River was first indicated in 2016 (Marin and Sinelnikov, 2016). Based on these data, population of *G. fasciatus* can be characterized as stable at all studied stations and the species can be used as bioindicator of the natural condition of the river flowing within the Moscow City.

Material and Methods

In the course of research on the biological diversity of the Moscow River Basin, a number of sites (see Marin and Sinelnikov, 2016) were studied again in 2017. Additional studying sites were accomplished in the confluence of Istra and Moscow rivers (55°44'30.6"N 37°08'27.2"E) ("Istra" site) and Pahra and Moscow river (55°32'16.9"N 37°59'25.0"E) ("Pahra" site). All representatives of the macrobenthos were collected from each of sites. Samples were washed with pure water and fixed with a 70% ethanol solution. In total, 8 such sites were surveyed in three sections along the river - up to the city of Moscow, within the boundaries of the city and outside the city. One zone on the Oka River in the area of the Prioksko-Terrasniy Reserve (the most "clean" habitat) was taken as a "control". All areas were located in the coastal zone from water edge to the depth of 2 meters. The geographic coordinates of the sites were determined using a global positioning system (GPS). The investigated substrate of the majority of sites consists of sand and boulders, silt silts (within the borders of Moscow) were rarely found. During the study, standard methods of biological analysis of invasive species were used (Reznichenko, 1965; Burukovsky, 1992). Data on water quality were obtained by the Federal Service for Hydrometeorology and Environmental Monitoring of the Russian Federation (http://gidrohim.com/) and published in the annual reports on the site.
The term "bioindicator" is used in relation to the group of organisms that provide information about the current state of the environment on the basis of their presence or absence, their vital status, population characteristics/dynamics. The term "biomonitoring" is used in relation to an organism that can be used to study the geographic or temporal changes in the bioaccumulation of pollutants, by measuring the concentrations of chemicals throughout the body or in specific tissues.

Results

Among the most common species of macrobenthos of the Moscow River the invasive Baikal amphipod *Gmelinoides fasciatus* (Stebbing, 1899) (Amphipoda: Gammaroidea: Micruropodidae) was recorded in all collected samples similar to 2016 (see Marin and Sinenikov, 2016). The second most abundant species was native amphipod species *Gammarus lacustris* O.Sars, 1864 (Amphipoda: Gammaroidea: Gammaridae). Other previously recorded invasive amphipods, such as the Ponto-Caspian *Pontogammarus robustoides* (Sars, 1894) (Amphipoda: Gammaroidea: Pontogammaridae) and *Chelicorophium curvispinum* (GO Sars, 1895) (Amphipoda: Gammaroidea: Corophiidae) (Malyavin et al., 2008; etc., 2008 2010), were not found in our samples. Amphipods reached more than 70% of the biomass in all samples; other collected animals were larvae of aquatic insects, isopods and oligochaetes. The number of *Asellus aquaticus* was relatively low.
The most numerous concentrations of *G. fasciatus*, as in the previous year, were detected on sandy-stony substrates of the Oka River (control site in Prioksko-Terrasny Nature Reserve) reaching 620 specimens per sq.m. and in the Moskva River close to border of Moscow City (site 2) – 300–380 specimens per sq.m. Close to the city the abundance of the species significantly decreased, with an average density of about 100-150 specimens per sq.m. and amphipods were absent in two silty sections (sites 4,5). At the distance from the city, the density of *G. fasciatus* increases again to 230 specimens per sq.m., but the lowest values are marked on the "Pakhra" site – about 80 specimens per sq.m. It is interesting that the greatest decline in abundance and density of population of G. fasciatus is observed in the region of the confluence of the Moscow River with the Istra River ("Istra" site), whereas there was no significant decrease in the abundance of *G. lacustris* in the same region. A similar effect of the restriction of *G. fasciatus* under the influence of anthropogenic impact has already been noted in the coastal zone of Lake Onega (Sidorova, 2013, Sidorova et al., 2012) and is most likely caused by an increased concentration of ammonium ($NH4^+$).
At the same time, the population of *G. fasciatus* can be characterized as stable at all studied sites (stations), but none of the sites of the Moscow River still shows the density reaching the "control" on the Oka River. The ratio of males and females in all samples is close to 1:1. The maximum size (body length) of a male is 10.5 mm, females – 9 mm; the maximum weight of males

is 24 mg, females – 12 mg. These dimensions are much larger than the size of animals from the native population (Matafonov, 2003, 2005)
The population of the native species *G. lacustris*, similar to the previous year, is less abundant, on sandy-stony substrates of the "control" site of the Oka River – about 140 specimens per sq.m., close to borders of Moscow City – 80 specimens per sq.m., and about 30–35 specimens per sq.m. within the city, including on silted stations. The ratio of males and females is close to 1:1. In the shallow water areas of the Moskva River, mainly young species of the species were found, while mature individuals and large number of different age groups of animals were found in the middle river current.
Pollution value (values of the IKIP) of the river varied within the limits of III and V pollution classes. By the data, the most “clean” region is the “Istra site”, while the most polluted is “Pakhra site”, where the quality of water belongs to V class and cab ne characterized as "extremely dirty" water. The number of critical indicators of water pollution, including ammonium and nitrite nitrogen, less often - easily and hardly oxidizable organic substances (BOD5 and COD respectively) varied in separate sites. More than 100 cases of “high water pollution” have been registered in the above areas in 2017, of which more than 50 refer to pollution with nitrite nitrogen (N-NO3) with a concentration of more than 40 times than maximum accepted concentrations (MAC), ammonium nitrogen (N-NH3 +, N -NH4) with a concentration of more than 40 MAC times, Cu compounds up to 5–18 MAC times, while at the site close to Yauza River a higher water pollution with oil products with a concentration of more than 20 MPC times has been detected. There have also been cases of a decrease in the concentration of oxygen dissolved in water at “Pakhra” site (2.55 mg. per l.). For exact data see official site of the Federal Service for Hydrometeorology and Environmental Monitoring of the Russian Federation (http://gidrohim.com/) publishing annual reports.

Discussions

It was previously shown that *Gammarus pulex* and *Asellus aquaticus* can be useful for assessing the water quality (Meijering, 1972, 1985, 1989; Sidorova, A.I. 2013). These species are widely distributed in the European part, but especially in Europe (see Takhteev et al., 2015). Having similar trophic niches, they occupy different parts of the river. Isopod *A. aquaticus* occurs mainly in the lower layers of water while amphipod *G. pulex* in the upper layers (Steel, 1961). Due to its resistance to pollution and hypoxic conditions, *A. aquaticus* dominates systems under anthropogenic press, while *Gammarus* species live in uncontaminated systems with sufficient oxygen content. Nevertheless, there are coexisting populations of both species. For such populations, there were no interspecies differences in micro distribution, but intraspecific differences in the distribution of juveniles and adults were detected. Juveniles preferred algal mats while adult individuals preferred hard substrates close to bottom. Data on the dynamics of the abundance of the two species did not give quite clear results as to whether competition is really an important factor in determining their distribution (Meijering, 1972, 1985, 1989; Schramm et al., 1999; Sidorova, A.I. 2013).
The concentration of dissolved oxygen and ammonium are important abiotic factors determining the distribution of amphipods and isopods in aquatic ecosystems. *Asellus aquaticus*, for example, is for 5 times more resistant to hypoxia and twice - to ammonium than *G. pulex* (Graça et al., 1993, 1994). It is believed that the different susceptibility of these two species the low limits of the oxygen can be caused by differences in the respiratory and circulatory systems. With ammonium, the situation is not entirely clear. The different resistance of the two species to pollution and lack of oxygen is usually used as a simple tool for determining water quality. In this method, the *Gammarus/Asellus* ratio is calculated. Studies have shown that changes in this ratio in different rivers have been associated with changes in water quality. The disadvantage of the method is that the *Gammarus/Asellus* ratio is somewhat dependent is depended on sampling method and even the region of sampling (Meijering, 1972, 1985, 1989; Sidorova, A.I. 2013).
While the ratio *Gammarus/Asellus* is rather a specialized biological indicator, some crustaceans are also included in various biotic indices that cover a wider range of taxa. In Germany and some other European countries, a system based on the concept of saprobity is used to assess water quality. The mortality of *G. pulex* was influenced by the concentration of ammonium, copper and zinc, and the mortality of *A. aquaticus* was also the concentration of cadmium. Maltby (1991) с с соавторами (Maltby and Calow, 1986a,b; Maltby and Booth, 1991; Malby et al., 1987a, b)) showed that *A. aquaticus* not only directly reacts to pollution by increasing the tolerance, but also changes the life strategy, producing fewer but a larger offsprings. This system can be criticized from an environmental point of view. It allows assessing only almost exclusively organic pollution and does not solve the problem of comparing different flow systems.
According to our data on the species composition and the indicative values for the category of water cleanliness, the Moscow river in the frames of Moscow city belongs to oligo- and β-saprobial zone. At the same time, native representatives of bottom fauna sensitive to pollution were not found in the number eligible for any quantitative water quality expertise. Most of native crustacean species are resistant to pollution while an invasive species, *G. fasciatus*, is seems to be more sensitive to any pollution agents being native from clean waters of Baikal and surrounding area. Thus, herewith, we are suggesting a new bioindicator pair *Gammarus lacustris / Gmelinoides fasciatus* which is more useful in study of water pollution In European part of the Russian Federation and adjacent areas. At the same time, obtained data suggest that the introduced species is significantly less sensitive to environment conditions and especially anthropogenic pollution than the native amphipod species *G. lacustris* and can successfully replace *A. aquaticus* in the area where the latter species is absent.

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